A proposed assessment and decision making framework to inform harvest management of wood ducks in the Atlantic and Mississippi Flyways

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1. Introduction

Harvest management for wood ducks has generally been quite conservative in the latter 20th and early 21st century, largely due to a history of over-exploitation. Wood duck seasons were closed entirely from 1918 to 1940. Bag limits of one were generally the rule in the Atlantic and Mississippi Flyways from 1941 through 1961, and, with the exception of a few special seasons, the daily bag limit has remained at 2 since 1962 (Bellrose and Holm 1994).

Conservative wood duck harvest regulations can also be attributed to limitations in population monitoring programs. While breeding population estimates and midwinter indices are available for most duck species, wood ducks cannot be accurately surveyed from the air due to their preference for heavily wooded habitats.

The lack of a range-wide population estimate for wood ducks has frustrated attempts to develop a harvest strategy for them. Over the past 3 years, I have worked with US Fish and Wildlife Service, US Geological Service, and state personnel to update and improve available monitoring data for wood ducks. These include: current band reporting rates, estimated historic reporting rates, band recovery, annual survival, non-hunting survival, and harvest rates, harvest and preseason age ratios (which are annual indices of reproduction), and population indices derived from hierarchical modeling of Christmas Bird Count (CBC) and Breeding Bird Survey (BBS) data.

Here I formally propose an assessment framework based on an adaptation of the technique of Potential Biological Removal (Wade 1998, Runge et al. 2004) for use in a game species, discuss the management objectives that may be chosen as a result, propose a monitoring system and test criteria for making regulatory decisions, and describe possible regulatory alternatives. The USFWS and the states within the Atlantic and Mississippi Flyways have provided feedback and discussion of these points, and consensus has not yet been reached on all of them. The intent of this document is to identify areas of consensus, areas where further discussion is needed, as well as provide suggestions for compromise, all with the ultimate goal of developing a decision-making framework for implementation, perhaps as early as the 2008 regulations cycle. In addition, I present some technical work done in response to feedback that may assist in resolving some areas of disagreement.

2. Assessment Framework

A major motivation for choosing the Potential Biological Removal (PBR) framework is its use of data that is readily available for wood ducks. In particular, if one is willing to manage based on an allowable take rate (rather than the total number to be taken), it can be calculated as:

$$h = \frac{PBR}{N_{\min}} = \frac{1}{2} r_{\max} F_R$$

where

$$0 < F_R \le 2$$

Simply put, the maximum intrinsic growth rate (λ) is calculated, for a population at low density, in the absence of harvest, under the assumption of average environmental conditions. Subtracting 1 from this growth rate gives the annual expected surplus production (r_{max}) for this population under ideal conditions. ½ r_{max} is the allowable take rate, which can be expressed as maximum sustainable yield (MSY), the top of the yield curve. The method has intuitive appeal, and has been done by biologists in an ad hoc way to estimate annual production, and the portion that can be allocated to harvest, in geese (M. Vrtiska, personal communication). *Fr* is a recovery factor that was originally designed to introduce additional conservatism into management based on PBR, since it was originally applied to species of conservation concern. An Fr between 0 and 1 effectively corresponds to the now familiar class of right shoulder strategies, while an Fr between 1 and 2 might be appropriate for over-abundant species where the management goal is to reduce population size (Runge et al., in review).

To estimate the maximum intrinsic growth rate (λ), two pieces of information are needed: estimates of survival in the absence of harvest, and reproduction at low density. There are many ways to approach it, depending on the quality and availability of data. Fortunately, for wood ducks, good information is available to estimate both.

Nathan Zimpfer and I estimated non-hunting survival rates for all wood duck age-sex cohorts using banding and recovery data, current and historic estimates of band reporting probabilities, and assuming a crippling loss of 0.2. Details for this and all technical work are in Appendix 1. If one assumes that mortality from harvest is completely additive, non-hunting survival is equivalent to survival in the absence of harvest (W Kendall, personal communication).

I estimated reproduction at low density by regressing pre-season (adjusted for differential vulnerability) juvenile/adult age ratios against range-wide wood duck population indices (derived from Christmas Bird Count (CBC) and Breeding Bird Survey (BBS) data). The intercept of this relationship is an estimate of reproduction at low density.

Once I obtained estimates of survival and reproduction, I calculated the maximum intrinsic growth rate (λ) by plugging those vital rates into the appropriate projection matrix (Leslie 1945, 1948). Thus the estimate of population growth reflected the survival rates of all age-sex cohorts. Accounting for uncertainty in monitoring data and model-based projections is generally important for developing realistic harvest management strategies. Therefore, I estimated variances as well as point estimates for all data input into the PBR formula, as well as for estimates of allowable take (Appendix 1).

The possibility that non-hunting survival and reproduction estimates, and thus estimates of allowable take, could vary by geographic region was a very important consideration for wood duck management in Eastern North America. Researchers had repeatedly found lower annual survival (Bowers and Martin 1975, Nichols and Johnson 1988, Kelley 1997, Wilkins 2000, Garrettson 2006), and higher band recovery (Bowers and Martin 1975, Nichols and Johnson 1988, Kelley 1997, Wilkins 2000) and harvest (Garrettson 2006) rates for birds banded in northern portions of their breeding range relative to those banded further south. Wood ducks breeding in the south have a longer breeding season, and can sometimes rear two broods a season, so many have speculated that their reproductive rates should be higher than northern-breeding birds, However, evidence on a broad geographic scale suitable for management had not been found.

Therefore, I attempted to calculate region specific estimates of allowable take, as well. Moreover, calculating region-specific survival in the absence of harvest allowed me to distinguish between harvest pressure, the degree to which a population experiences harvest-related mortality and harvest potential, its ability to tolerate it. Band recovery and harvest rates are indicators of harvest pressure, and northern-banded birds experience more of it. Northern birds also experience lower annual survival rates, but this does not necessarily mean they have lower harvest potential than southern birds. Annual survival rates are a product of hunting and non-hunting season survival, are a measure in which harvest pressure and potential are confounded. Using the PBR framework, unbiased estimates of harvest potential are used to set limits on allowable take, and unbiased estimates of harvest pressure (kill rates) are the monitoring tool used to ensure allowable take rates are not exceeded.

Although the allowable take rates I calculated are based on survival rates of all four age-sex cohorts, it may be desirable to use kill rates (calculated annually, or as multi-year averages) from one cohort for monitoring purposes, due to data quality or stability of harvest rates. As long as kill rates of the three other cohorts increase at the same rate relative to the kill rates of the cohort used for monitoring, cohort-specific allowable take can be calculated algebraically (M. Runge, personal communication).

3. Assessment results

Non-hunting survival rates of wood ducks in eastern North America followed expected patterns, similar to those seen in annual survival rates, higher for males than for females, and lower for juveniles than adults (Table 1).

Table 1. Non-hunting survival rates for wood ducks in Eastern North America.

Cohort	S_0 (95% confidence interval)
Adult Male	0.6523 (0.6488-0.6557)
Juvenile Male	0.5835 (0.5717-0.5953)
Adult Female	0.5647 (0.5592-0.5701)
Juvenile Female	0.5349 (0.5194-0.5504)

Region-specific heterogeneity was detected, principally for juveniles (Table 2). Juvenile non-hunting survival rates were 10-12 percentage points lower for birds of northern origin than those of southern origin. Interestingly, although northern adult wood ducks have higher harvest rates and lower annual survival rates than southern wood ducks, their non-hunting survival rates are similar to those of southern birds. Furthermore, there was a greater difference between the non-hunting survival of juveniles and adults banded in the north than for those banded in the south; in fact, for southern banded birds, point estimates for juveniles were slightly higher than those of adults. These patterns suggest that northern banded wood ducks suffer non-hunting related migration costs as juveniles but not as adults.

Table 2. Region-specific non-hunting survival rates for wood ducks in Eastern North America.

	S_0 (95% confidence interval)	
Cohort	North	South
Adult Male	0.6500 (0.6457-0.6543)	0.6561 (0.6560-0.6620)
Juvenile Male	0.5452 (0.5316-0.5588)	0.6678 (0.6442-0.6913)
Adult Female	0.5587 (0.5518-0.5655)	0.5759 (0.5670-0.5848)
Juvenile Female	0.5055 (0.4875-0.5235)	0.5978 (0.5684-0.6272)

I calculated reproduction at low density a number of different ways (Appendix 1). I ran a series of analyses based on age ratios derived from either direct or all recoveries, constant or year-specific differential vulnerability, and at different regional scales. I regressed these age ratios against indices from either Breeding Bird Survey (BBS) or Christmas Bird Count Data (CBC), except that region-specific estimates could only be calculated using BBS data.

For Eastern North America as a whole, the use of a constant differential vulnerability and age ratios based on direct and indirect recoveries consistently produced point estimates of 1.21-1.22 juveniles per adult, regardless of whether male or female age ratios were used, or what population index they were regressed against. However, variances around estimates for females were higher than those for males. Use of year-specific differential vulnerability also increased variances. Region-specific estimates for males were higher than those for the population as a whole, but their variances were also high, which did not offer compelling evidence for geographic heterogeneity in reproduction. Therefore, I used an estimate of 1.22 (1.17-1.26, 95% CI) to calculate all estimates of allowable take, including region-specific ones. Estimation of region-specific reproduction in wood ducks at a relatively large scale remains a question of interest to managers and biologists.

The estimate of the allowable kill rate for birds of southern origin is higher than that of northern birds, or for the two flyways as a whole. Considering the entire region gives a slightly higher estimate of allowable kill rate than for northern birds, but the confidence intervals for these overlap, so they are statistically similar.

Table 3. Wood duck allowable kill rates calculated at different regional scales in Eastern North America.

Region	Allowable Kill Rate (95% CI)
All	0.1817 (0.1657-0.1978)
North	0.1572 (0.1416-0.1731)
South	0.2351 (0.2137-0.2573)

4. Setting Management Objectives

Allowable kill rates calculated within the PBR framework can be modified by an Fr to set management objectives at points other than maximum sustained yield. These objectives express how risk aversive harvest management should be. Another way to illustrate them is to mathematically convert Fr into a “shoulder point” on the yield curve. Table 4 lists some shoulder points calculated (after Runge et al., in review) based on the maximum allowable kill rate for the Atlantic and Mississippi Flyways combined.

Table 4. Allowable kill rate shoulder points for the Atlantic and Mississippi Flyways combined.

Shoulder	Allowable Kill Rate
99%	0.1635
97%	0.1502
95%	0.1411
85%	0.1242
80%	0.1004
75%	0.0908

Feedback was solicited from members of the Atlantic and Mississippi Flyway wood duck committees on this and other policy questions. Eight of 13 Atlantic Flyway (AF) states favored a shoulder strategy approach to setting management objectives. Of those favoring a shoulder point strategy, 1 suggested a 95% shoulder, 2 suggested somewhere in the range of 90-95% shoulder, and five were unsure. One of 6 Mississippi Flyway (MF) respondents favored a shoulder strategy, and one was unsure. Two AF respondents favored using ½ r_{max} as the management objective, provided it was combined with provisions in the test criteria (see next section) that introduced additional conservatism, which is also the objective favored by the Division of Migratory Bird Management. Five MF states preferred a management objective of ½ r_{max} , but only one specified that it be accompanied by test criteria provisions. The remaining MF respondent favored a 95-98% shoulder point. If a shoulder point is used, the variance, or the degree of uncertainty, in the estimate of the allowable kill rate could be a consideration in choosing it. For example, the lower 95% CI on the allowable kill rate estimate for the entire population (Table 3) roughly corresponds to the 99% shoulder point (Table 5).

5. Monitoring Program and Test Criteria

Choosing a monitoring program and an associated test criteria really involves asking the question: "How certain do we want to be that we are not exceeding allowable kill rates?" Comparison of actual to allowable kill rates will be the basis for monitoring. But decisions are needed about three aspects of such a monitoring program are needed to proceed with the development of a harvest strategy:

1) Should observed kill rates be calculated on an annual basis, or on the basis of 2 or 3-year averages?

The Division of Migratory Bird Management (DMBM) took no position on this question, except to state that anything greater than a 3-year average would be unacceptable, and to note the tradeoff between the greater precision and robustness to annual variation that a 3-year average would provide and the greater flexibility in evaluating the effects of regulations under a 2-year average. DMBM also proposed that the wood duck bag limit would be set conditional on a liberal season length in each flyway. Under this proposal, the bag limit for wood ducks would remain unchanged during periods of restricted season length in either flyway, and the years of restricted season length would not be included in the calculation of realized mean kill rate.

All respondents in both Flyways (except one who was not sure) favored the use of a 3-year average, so there appears to be clear consensus on this question.

2) Observed kill rates should be based on what cohort?
   --adult males or adult females?
   --northern birds or a flyway wide average?

The monitoring of adult male kill rates of either northern birds or the two flyways combined have been the most frequently discussed options for determining whether actual kill rates are exceeding allowable kill rates. Estimates of adult male kill rates are more precise and stable than those of other cohorts. Converting allowable kill rates based on entire population to cohort-specific kill rates (Appendix 1) produces the following rates for adult males and adult females (Table 5).

Table 5. Allowable kill rates for adult male and female wood ducks, calculated at different regional scales in Eastern North America.

Region	Adult Male Allowable Kill Rate (95% CI)	Adult Female Allowable Kill Rate (95% CI)
All	0.1657 (0.1511-0.1803)	0.1282 (0.1169-0.1396)
North	0.1433 (0.1291-0.1578)	0.1109 (0.0999-0.1222)
South	0.2143 (0.1949-0.2346)	0.1659 (0.1508-0.1816)

The use of adult male kill rates for monitoring was agreed upon by all but one respondent, who favored monitoring adult females instead, because "they drive production." While this is true, the data suggest that monitoring the adult male cohort would not affect the conservatism of the strategy. Kill rates of juvenile males and females increase at rates that are constant and proportional to those of adult males, so managing based on adult males should not impose a risk of over-harvest on juveniles. Managing based on adult males may be even more conservative for adult females, as they are the cohort that is least vulnerable to harvest (0.78) relative to adult males. Furthermore, if one considers direct recoveries only, adult female kill rates increase less relative to those of juveniles of both sexes as adult male kill rates increase (Appendix 1).

The choice to monitor northern birds rather than a flyway-wide average is a more conservative strategy. Nonetheless, DMBM proposed monitoring based on a flyway-wide average, due to the relatively small difference between allowable kill rates, as well as their overlapping confidence intervals, and our imperfect ability to control harvest through regulations. Mississippi Flyway respondents were split evenly on the question, while the Atlantic Flyway overwhelmingly favored monitoring northern birds.

However, the lone dissenter in the Atlantic Flyway raised interesting questions about the presumed lack of philopatry of males and its potential effects on harvest.

> *"…we aren't talking about dramatically different levels of harvest pressure in the range of harvest alternatives. Females (because of their philopatry) are the only "northern" wood ducks in the population. Males could easily be northern one year and southern the next (because they pair on the wintering grounds, where northern and southern birds are mixed, and follow the female to her natal area in spring). If you buy this argument, then by far most of the harvest pressure is exerted on birds that are not necessarily "northern" (in other words, all males plus all southern females)."*

Data from telemetry studies and return rates of marked ducklings indicate that natal philopatry of females is very high, and that of males much less so (See Bellrose 1980, and Fredrickson 1988 for reviews). But I could not find information on the probability that a male banded in a given area would breed in that or another area in subsequent years, so I analyzed early-season indirect and direct recoveries of wood ducks banded from 1997-2003. Of birds banded in each of the five Kelley (1997) banding regions and subsequently recovered, I calculated the proportions that were subsequently recovered in either the north or the south. Proportions of indirect recoveries should provide a rough estimate of the probability of birds breeding in an area other than where they were banded, and the proportion of direct recoveries gives a "baseline" figure for comparison, as these should represent very early-season or molt migrants (Full table and details in Appendix 1). I subtracted the proportion of direct recoveries in the area "opposite" of banding from those of indirect recoveries to calculate the minimum probability that a southern male would breed in the north, and vice versa.

The probability that a bird banded in the south would subsequently breed in the north was much higher than the reverse situation (Table 6). Probability of breeding in the north was 20% for adult males banded in the southern Mississippi Flyway, and 36% for those from the southern Atlantic Flyway. Not surprisingly, the area "switching" probability was higher for juvenile males, at 48% for the southern Mississippi Flyway, and 58% for the southern Atlantic Flyway. By contrast, the probability that males switched areas was less than 10% for either age cohort in any northern banding region.

Table 6. Estimated area switching probabilities based on early season[1] recoveries of male wood ducks banded in the Atlantic and Mississippi Flyways 1997-2003.

BAREA	Age	RecovType	N	S	ProbN	ProbS	Prob N/S Switch
LakeSt	A	dir	75	8	0.904	0.096	
LakeSt	A	ind	68	12	0.850	0.150	0.054
LakeSt	J	dir	248	48	0.838	0.162	
LakeSt	J	ind	120	25	0.828	0.172	0.010
NAtl	A	dir	117	22	0.842	0.158	
NAtl	A	ind	125	21	0.856	0.144	0.000
NAtl	J	dir	323	22	0.936	0.064	
NAtl	J	ind	135	26	0.839	0.161	0.098
NCMi	A	dir	455	38	0.923	0.077	
NCMi	A	ind	312	39	0.889	0.111	0.034
NCMi	J	dir	1427	75	0.950	0.050	
NCMi	J	ind	499	60	0.893	0.107	0.057
SAtl	A	dir	5	23	0.179	0.821	
SAtl	A	ind	24	20	0.545	0.455	0.367
SAtl	J	dir	2	80	0.024	0.976	
SAtl	J	ind	51	34	0.600	0.400	0.576
SMs	A	dir	64	405	0.136	0.864	
SMs	A	ind	147	297	0.331	0.669	0.195
SMs	J	dir	54	702	0.071	0.929	
SMs	J	ind	301	242	0.554	0.446	0.483

[1]Prior to Nov 1 in the Atlantic Flyway, and Nov 19 in the Mississippi Flyway. Prior to these dates, less than 5% of direct recoveries in southern regions consist of northern banded birds (Wilkins 2000).

Why the difference? Region-specific survival and recovery probabilities (which this analysis did not account for) may play some role, but alone cannot account for this substantial difference. The surprising result is not so much that southern banded males breed in the north, but that so few northern banded birds eventually breed in the south. Although wood ducks may begin pairing prior to and during migration (Dugger and Fredrickson 1992), early pair bonds are tenuous, and are tested throughout the winter (Fredrickson 1988). Perhaps northern males are less successful at maintaining existing pair bonds, or competing for females on the wintering ground relative to southern males, which have the advantages of site dominance and a shorter or non-existent migration. Furthermore, the early pair bonds of northern birds are more likely to be broken by the death of one of them due to the higher harvest rates they experience. Lastly, there is speculation that unpaired males tend to return to their natal areas (Bellrose 1980). These factors, or a combination thereof, could explain these surprising results.

Although a more rigorous analysis is warranted, southern banded males appear to breed in the north with considerable frequency. Perhaps they function as a "source" that compensates for the higher harvest pressure on northern males. These results would seem to support management of wood ducks in the aggregate, perhaps with supplemental monitoring or special attention to the status of northern females. Alternatively, if northern adult males were the monitored cohort, then use of direct recoveries to calculate observed kill rates might be most appropriate. These results are new to DMBM staff as well as to the flyways, and they will likely generate considerable discussion at the winter meetings. I welcome critical review of the technical work, especially alternative interpretations and critiques of the method.

3) Test criteria should be based on either:

1) The negative presumption, that is, the requirement that the upper confidence bound of the observed kill rate be below the allowable kill rate. This approach accounts for uncertainty in the measurement of observed kill rates, at the expense of possibly forgoing some harvest unnecessarily.

2) A point estimate. The point estimate of the observed kill rate must remain below the allowable kill rate. This approach ignores uncertainty in the estimation of observed kill rates, is inconsistent with SEIS 88, which places the burden of proof on those seeking higher exploitation levels, and provides no incentive to maintain banding efforts sufficient to calculated reasonably precise estimates of harvest rate.

The Division of Migratory Bird Management favors the first approach due to its responsibility to "consider and acknowledge uncertainty in decision making" whenever possible (USFWS Scientific Code of Professional Conduct), and because this uncertainty can be readily measured. Several states expressed reservations about this approach, concerned that it could make a strategy too conservative, or that harvest opportunities might be unnecessarily restricted, and favored the point estimate approach instead.

To avoid making the negative presumption approach too conservative, DMBM recommended it be used along with a management objective of MSY (½ r_{max}, in this case). Other possibilities for compromise could include the use of smaller (perhaps 80%) confidence intervals in a negative presumption strategy, or the use of a point estimate along with a shoulder strategy, with banding goals set according to a level designed to meet adequate stewardship requirements.

Setting Regulatory Alternatives

An increase from a two to a three bird bag limit would be the most likely regulations change. In a December letter to the flyways, DMBM stated that it would not support within flyway or within season differences in regulations. To consider increasing the bag limit from 2 to 3, it was necessary to predict how much the harvest rate on wood ducks would increase, and whether that predicted harvest rate would exceed the allowable harvest rate.

Greg Balkcom from Georgia DNR modeled expected increases in harvest rate using parts collection survey data (Appendix 2), from the Canadian Wildlife Service (where the bag limit is 6), data from early-season wood duck bag liberalizations in a few Atlantic Flyway states during the mid-1980s, as well as regular-season data from the Atlantic and Mississippi Flyways, and found that an additional 14-15% increase in harvest rate would be expected if the wood duck bag limit were increased to 3. He then modeled the effects of season length and hunter numbers on harvest rate, and calculated expected wood duck harvest rates under various season lengths and bag limits. I converted these to kill rates (Table 7). These are for birds banded in northern regions, but could be calculated for flyway averages as well.

Table 7. Predicted kill rates of adult male and female wood ducks banded in the northern Atlantic and Mississippi Flyways combined. From Balkcom (Appendix 2), harvest rates converted to kill rates.

	Northern Adult Male			Northern Adult Female		
Season	Bag Limit			Bag Limit		
Length	1-Bird	2-Bird	3-Bird	1-Bird	2-Bird	3-Bird
30	0.055	0.079	0.090	0.049	0.070	0.080
45	0.069	0.100	0.115	0.059	0.084	0.098
50	0.074	0.106	0.123	0.061	0.089	0.103
60	0.084	0.121	0.139	0.069	0.099	0.114

A 60-day season with a 3-bird bag would produce an expected kill rate that is slightly below allowable take for the northern adult male cohort, and slightly above that for the northern adult female cohort (Table 5). In essence, the choice to raise the wood duck bag limit to 3 rests upon the choice of a management objective, and a test criteria.

Predicted kill rates never exceed allowable kill rates under season lengths that are 50 days or less. This presented the question of whether wood duck bag limits should be allowed to differ between flyways, particularly since season lengths are set by the status of mid-continent mallards in the Mississippi Flyway, and the status of eastern mallards in the Atlantic Flyway. A moderate (45-day) season in the Mississippi Flyway could occur while the Atlantic Flyway had a liberal (60-day) season. And although the Atlantic Flyway is projected to be under a liberal season nearly 100% of the time, they have recently discussed shortening liberal seasons to 50-days due to concerns about other species. Either scenario could produce a situation where season lengths in the two flyways differed.

Two respondents in the Mississippi Flyway favored bag limits that would not differ among flyways, citing concerns that the overall harvest rate could fall if the season length in the Mississippi Flyway were reduced, which would lead to a bag liberalization even though harvest rates in the Atlantic Flyway had not dropped. It is not clear if the respondent was concerned about over harvest of birds from the Atlantic Flyway, that the Atlantic flyway would be gaining a larger share of overall wood duck harvest under such a scenario, or that regulations could toggle back and forth in response to apparent over and under harvest. Three Mississippi Flyway and 12 Atlantic Flyway states (one was uncertain) favored a strategy under which bag limits could differ between the two flyways, since there is "little overlap in harvest distribution." Several cited a Heusmann and McDonald (2002) paper that suggested that a low (3.8 and 8.5) percentage of birds crossed flyway boundaries.

However, this paper considered northern birds only, and only the northernmost portions of the Kelley (1997) banding regions upon which my work has been based. Furthermore, they considered only direct recoveries of males, and pooled direct and indirect recoveries of females. I did a broader, but similar analysis of wood duck recovery data, both in response to feedback from the flyways, and because most of the work I have done with wood duck banding data has included direct and indirect recoveries. In particular, I was curious about the extent to which males' lack of philopatry would influence the location of indirect recoveries.

My approach was similar to the work I did to estimate the probability of that a bird would breed in an area other than where it was banded, except that I used all recoveries, and similar to that of Huesmann and McDonald (2002), except for the differences noted above. Again, I analyzed recoveries of birds banded from 1997-2003, when band reporting rates and regulations were relatively stable.

Up to 26% of female (Appendix 1) and 39% of male recoveries of birds banded in the lake states region occurred in the Atlantic Flyway. Cross-flyway recovery of adults banded in the lake states is nearly as common for direct as for indirect recoveries, which suggests that much of this pattern is due to cross-flyway migration. Approximately 38% of both direct and indirect recoveries of adult males banded in the southern Mississippi Flyway occurred in the Atlantic Flyway. Much of this may be due to lateral post-molting movements (Dugger and Fredrickson 1992), as 58% early-season direct and indirect recoveries of southern Mississippi Flyway adult males occurred in the Atlantic Flyway, largely in the southern Atlantic Flyway (Appendix 1).

Approximately 20% of the indirect recoveries of juvenile males banded in both the southern and northern Atlantic Flyway regions occurred in the Mississippi Flyway, and approximately 20% of indirect recoveries of juvenile males banded in the southern Mississippi Flyway occurred in the Atlantic Flyway. By examining early-season recoveries and using the same criteria as I used for estimating the probability of north-south switching, I estimated that the probability that juvenile males would subsequently breed in a flyway different than where they were banded was 20%, 23%, and 28% for lake states, northern Atlantic Flyway, and southern Atlantic Flyway birds, respectively.

By contrast, cross-flyway recovery proportions rarely exceeded 10% for females, except for those from the lake states, and birds from the north-central region of the Mississippi Flyway were rarely recovered in the Atlantic Flyway.

Table 8. Proportions of male wood duck recoveries in the Atlantic and Mississippi Flyways that did not occur in the flyway where they were banded. From birds banded 1997-2003.

AGE	BAREA	RecovType	AT	MS	Prop Recov Opposite Flyway
A	LakeSt	dir	57	123	0.317
A	LakeSt	ind	77	118	0.395
J	LakeSt	dir	90	418	0.177
J	LakeSt	ind	131	205	0.390
A	NAtl	dir	337	31	0.084
A	NAtl	ind	420	43	0.093
J	NAtl	dir	671	76	0.102
J	NAtl	ind	398	114	0.223
A	NCMi	dir	32	814	0.038
A	NCMi	ind	50	667	0.070
J	NCMi	dir	46	2225	0.020
J	NCMi	ind	91	1091	0.077
A	SAtl	dir	185	16	0.080
A	SAtl	ind	197	28	0.124
J	SAtl	dir	340	37	0.098
J	SAtl	ind	261	63	0.194
A	SMs	dir	294	476	0.382
A	SMs	ind	284	451	0.386
J	SMs	dir	152	1475	0.093
J	SMs	ind	234	927	0.202

This evidence for greater interchange between flyways is new to DMBM staff, as it will be to the states. Again, this appears to suggest that it may be reasonable to manage for wood ducks in the aggregate. Allowing wood duck bag limits to differ between flyways could present some additional technical challenges, namely, producing a formal harvest derivation for wood ducks in the absence of region-specific population estimates. We expect this will be an area for further discussion at the winter Flyway meetings.

Policy Decisions

Considerable technical progress has been made on estimating the harvest potential of wood ducks in Eastern North America, and flyway feedback on the general approach and work was positive. Continued feedback and discussion will be needed on the following policy questions to move forward in developing a wood duck harvest strategy:

1. Determination of cohort for monitoring purposes (i.e., northern adult males, or a range-wide average of adult males, and what, if any, consideration should be given to northern females?)

2. Management objective (how much, and how should any additional conservatism be incorporated into the strategy?)

3. Test criteria (negative presumption, or point estimate, areas for possible compromise?)

4. Should wood duck bag limits be allowed to differ by Flyway?

Feedback from the flyways has been helpful in illustrating issues that will need to be addressed to apply the technical work to wood duck management. This feedback also prompted questions that I have attempted to address by doing additional work, which may be relevant to continued discussion of policy questions 1 and 4. DMBM looks forward to discussions at the winter Flyway meetings and continued collaboration on the development of a wood duck harvest strategy.

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Appendix 1. Technical Details for Estimating Harvest Potential of Wood Ducks in Eastern North America, and its Application to a Harvest Strategy

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Introduction

Harvest management for wood ducks has generally been quite conservative in the latter 20th and early 21st century, largely due to a history of over-exploitation. Wood duck seasons were closed entirely from 1918 to 1940. Bag limits of one were generally the rule in the Atlantic and Mississippi Flyways from 1941 through 1961, and, with the exception of a few special seasons, the daily bag limit has remained at 2 since 1962 (Bellrose and Holm 1994).

Conservative wood duck harvest regulations can also be attributed to limitations in population monitoring programs. While breeding population estimates and midwinter indices are available for most duck species, wood ducks cannot be accurately surveyed from the air due to their preference for heavily wooded habitats.

As part of the wood duck population monitoring initiative, Kelley (1997) presented wood duck survival and recovery rates, an evaluation of wood duck nest box monitoring as a means for measuring production, and results from attempts to model wood duck age ratios relative to weather variables. Major results were that banding efforts were insufficient to produce survival rates with coefficients of variation <15% on a sub-flyway scale, and that nest box monitoring data was insufficient for use as a widespread measure of wood duck production. Preseason age ratios (PAR), an index of productivity, were positively correlated with some weather variables.

As a follow-up, and as groundwork for a wood duck population model upon which to base a harvest strategy for the Atlantic and Mississippi Flyways, Wilkins (2000) updated survival and recovery rates, and corrected age ratios for juvenile vulnerability. Both of these metrics were scaled to wood duck banding regions produced by MRPP analyses (Kelley 1997). In particular, for age ratios, a date cutoff for harvest parts collection data was established for southern regions to avoid “contamination” by birds migrating from northern regions. However, recovery rates after 1993 were not comparable to those prior to 1993, nor to each other, in all likelihood, due to changes in band inscription and band reporting rate.

From 2001-2004, Garrettson and Smith attempted to construct population models based on breeding bird survey (BBS) data as a surrogate for population size. However, they encountered difficultly with the use of breeding bird survey data as a surrogate for N, and with obtaining realistic estimates of kill and survival in the absence of harvest.

Meanwhile, data from a band reporting rate study that included wood ducks had become available, so, in consultation with Dan Holm and Greg Balkcom, the wood duck committee chairs from the Mississippi and Atlantic Flyways, DMBM proposed the following approach:

1) Analyze mallard and wood duck reward band data to determine whether reporting rates differed by species, sex, or geographic region in Eastern North America

2) Use the relationship between mallard and wood duck reporting rates, coupled with information from previous reward band studies on mallards, as well as information on band types and how bands were reported to construct a time-series of wood duck reporting rates, which includes "composite" estimates for the years when reporting rates were changing due to changes in band inscription.

3) Perform a standard Brownie analysis on wood duck data to obtain region, sex, and age-specific time series of annual survival and band recovery rates. These would be directly comparable to previous work, and would avoid the complication of uncertain crippling loss rates.

4) Use the reporting rate time series to convert recovery rates to harvest rates. Graphically illustrate these relative to season length. Over the time-frame in question, wood duck bag limits have remained constant, aside from limited special seasons, so even a qualitative view of these data should be informative.

5) Present additional information from other data sources, such as age ratios, Christmas bird counts, Eastern Plot Survey Data, population estimates based on harvest parts collection and harvest rates from banding data.

6) Based on the new data time series, consider new options for developing a wood duck harvest strategy

Steps 1-4 were presented at the Atlantic/Mississippi Flyways Joint Technical meeting in February 2006, and in greater detail in an interim report (Garrettson 2006). In November 2006 at the Adaptive Harvest Mangagement Working Group Meeting, I presented a proposal for applying Potential Biological Removal (PBR, Wade 1998), a technique originally developed for marine mammals, to a game species, the wood duck (Steps 5-6). Over the past year, I worked with the wood duck committees in the Atlantic and Mississippi Flyways and with USFWS and USGS biologists to refine and improve this work, and to develop a harvest strategy for wood ducks based on the results.

Potential Biological Removal

Potential Biological Removal (PBR) was developed for assessing allowable take of marine mammals (Wade 1998), and its use extended to birds (Runge et al. 2004). With modification, it should be applicable to game species, and particularly well suited to the management of wood ducks. Under the PBR formulation, allowable take is expressed as a function of the growth rate of the population at low density and in the absence of harvest (λ_{max}), under average environmental conditions, assuming discrete logistic growth. Under these conditions, a population should be growing as fast as its life history characteristics allow. The maximum allowable take is then $\frac{1}{2} r_{max}$, where $r_{max} = \lambda_{max} - 1$, which is

½ the incremental growth of such a population. It can be expressed either as allowable absolute harvest (H, Eq. 1), or as an allowable harvest rate (h, Eq. 2).

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Eq. 1 $$H = PBR = \frac{1}{2} r_{\max} N_{\min} F_R$$

Eq. 2 $$h = \frac{PBR}{N_{\min}} = \frac{1}{2} r_{\max} F_R$$

. Eq. 3 $$0 < F_R \leq 1$$

In this formulation, F_R represents a recovery factor that introduces additional conservatism into the estimate of allowable take. F_R can be chosen closer to one for a population for which there is little concern, and closer to zero with increasing concern about its conservation status. F_R can also be expressed as a shoulder point on a sustainable yield curve (M. Runge, personal communication), where $\frac{1}{2} r_{max}$ corresponds to maximum sustainable yield (MSY). N_{min} is an estimate of minimum population size. For populations for which good monitoring data are available the lower 95% confidence interval of the population estimate is often used.

Wood duck population indices show an overall positive trend over the past 40 years (Sauer and Droege 1998, J. Sauer, unpublished data), but a true population estimate is unavailable. Therefore I used the harvest rate PBR formulation (Eq. 2) to calculate allowable take. For a game species such as wood ducks for which there is little concern about current population status, an F_R that is close to one might be chosen. However, the choice of F_R, or a shoulder point is somewhat arbitrary, so I have proposed using the lower 95% CI of the allowable harvest rate to guide the choice of or even specify the selection of F_R. Thus, limits on allowable take would become less conservative as monitoring data improves, more conservative if it is poor. Linking allowable take limits to data quality also allows one to evaluate the feasibility of managing harvest at different scales.

Issues of Scale

Wood ducks in eastern North America can be roughly split into two stocks: a migratory and non-migratory stock. Birds breeding in northern states are harvested on their breeding grounds and wintering grounds, and during migration. Birds breeding in southern states are sedentary, or migrate relatively short distances, and thus may be subject to harvest over a shorter time frame than their northern counterparts. Furthermore, they may be less vulnerable to harvest than northern birds, since they do not have to negotiate unfamiliar territory while subject to harvest pressure (Bowers and Martin 1975).

Indeed, greater harvest pressure on birds of northern origin has been well documented. Band recovery rates (Bowers and Martin 1975, Nichols and Johnson 1988, Kelley 1997, Wilkins 2000), and harvest rates (Garrettson 2006) are higher, and annual survival rates lower (Bowers and Martin 1975, Nichols and Johnson 1988, Kelley 1997, Wilkins 2000, Garrettson 2006) for birds of northern origin.

Wood ducks breeding in southern states may also be more productive, so their harvest potential could be greater that that of northern wood ducks. Long breeding seasons and the presence, if not prevalence, of double-brooding have been advanced as reasons why southern wood ducks should be more productive than their northern counterparts. But evidence for this is harder to come by, at least on a large scale. A major hurdle is obtaining age ratio estimates for southern birds that are uncontaminated by northern migrants, yet of sufficient sample size. Kelley (1997) used data from special seasons in Kentucky, Tennesse, and Florida, and early October seasons in North and South Carolina as surrogates for all southern breeding birds. Although he found that fall female WODU age ratios were higher in the southern Mississippi Flyway than in the northern Mississippi Flyway, the confidence intervals on these estimates are very wide. Point estimates for the northern and southern Atlantic Flyway were similar, and also had a high variance.

It is important to make the distinction between harvest pressure and harvest potential. Band recovery rates and harvest rates measure harvest pressure only, but annual survival rates can be decomposed into hunting and non-hunting season survival rates that reflect harvest pressure and harvest potential, respectively. One should not simply assume that northern birds have lower harvest potential because they have lower annual survival rates. It is reasonable to ask, however, if some of the difference in annual survival is due to factors other than hunting, perhaps associated with the costs of migration (Nichols and Johnson 1988). Estimating survival in the absence of harvest (S_0) addresses that question.

I addressed issues of scale by attempting to estimate allowable harvest rates and the vital rates needed to calculate them, on two scales: the Atlantic and Mississippi Flyways combined, and the northern and southern regions, based on aggregations of the Kelley (1997) banding regions (Figure1).

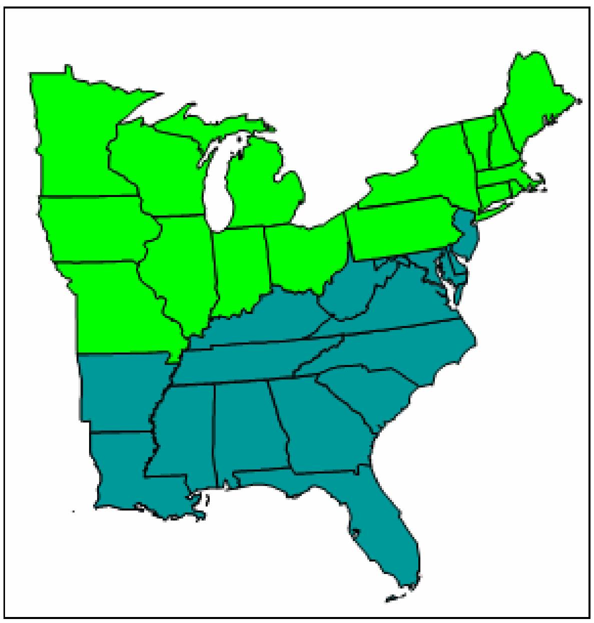

Figure 1. Delineation of north-south wood duck stocks for investigating heterogeneity in harvest potential.

Estimating Survival in the Absence of Harvest (S_0)

Nathan Zimpfer and I adapted the band recovery model of Smith and Reynolds (1992) which partitions annual survival into hunting and non-hunting components (Anderson et al. 1982, Barker et al. 1991). The model is

Eq. 4

$$S = So(1-\beta K)$$
$$and$$
$$S' = S'o(1-\beta K')$$

where S and S' are the annual survival rates, and So and S'o are non-hunting survival rates for adults and juveniles respectively, and K and K' are adult and juvenile annual kill rates, respectively, and β is the slope of the linear relationship between annual survival and kill rates.

Then

Eq. 5

$$K = \frac{f}{(1-c)\lambda}$$

and

$$K' = \frac{f'}{(1-c)\lambda}$$

where *f* and *f'* are the annual band recovery rates for juveniles and adults, *c* is the crippling loss rate, and λ is the band reporting rate.

We assumed that hunting mortality is additive, thus $\beta = 1$. Under this assumption, S_0 and S_0' are estimates of survival in the absence of hunting. The assumption of additive mortality should cause no controversy, since any assumption of compensatory mortality makes S_0 smaller (Anderson and Burnham 1976). Under the PBR framework, this would make estimates of allowable take more conservative. We assumed a constant crippling loss rate of 0.20 (P. Padding, personal communication), and used annual composite reporting rates (Garrettson 2006) based on known reporting probabilities and actual recoveries of various band types and the means by which they were reported . They also incorporate recoveries of solicited bands, with the assumption that their reporting probability is one.

We expected that S_0 and *K* would vary by sex, so we ran models separately for males and females. We ran a set of models in which S_0 and *K* were allowed to vary by, or were constrained by age, region (north vs. south) and time (constant, year-specific, or constrained across periods of similar hunting regulations), and used information theoretic methods (Burnham and Anderson 1998) to evaluate models. Models in which kill was allowed to vary by age, region and time received the most support. Estimates of allowable take using PBR assume average environmental conditions, so I wanted to incorporate all the data in the time series in its estimation. Therefore, S_0 estimates were from models with kill rates that were age, region and year specific, and S_0 rates that were age-specific, held constant across the entire time series. Based on regional differences, two sets of estimates were calculated, one for the entire two-flyway region, and one with the north-south split.

S_0 estimates were generally higher for males than for females, and lower for juveniles than adults (Table 1). Region-specific heterogeneity was detected, principally for juveniles (Table 2). Juvenile non-hunting survival rates were 10-12 percentage points lower for birds of northern origin than those of southern origin. Interestingly, although northern adult wood ducks have higher harvest rates and lower annual survival rates than southern wood ducks, their non-hunting survival rates are similar to those of southern birds. Furthermore, there was a greater difference between the non-hunting survival of juveniles and adults banded in the north than for those banded in the south; in fact, for southern banded birds, point estimates for juveniles were slightly higher than those of adults. These patterns suggest that northern banded wood ducks suffer non-hunting related migration costs as juveniles but not as adults.

Table 1. Non-hunting survival rates for wood ducks in Eastern North America.

Cohort	S_0 (95% confidence interval)
Adult Male	0.6523 (0.6488-0.6557)
Juvenile Male	0.5835 (0.5717-0.5953)
Adult Female	0.5647 (0.5592-0.5701)
Juvenile Female	0.5349 (0.5194-0.5504)

Table 2. Region-specific non-hunting survival rates for wood ducks in Eastern North America.

	S_0 (95% confidence interval)	
Cohort	North	South
Adult Male	0.6500 (0.6457-0.6543)	0.6561 (0.6560-0.6620)
Juvenile Male	0.5452 (0.5316-0.5588)	0.6678 (0.6442-0.6913)
Adult Female	0.5587 (0.5518-0.5655)	0.5759 (0.5670-0.5848)
Juvenile Female	0.5055 (0.4875-0.5235)	0.5978 (0.5684-0.6272)

Estimating Wood Duck Recruitment at Low Density

The general approach I used for estimating recruitment at low density was to regress juvenile/adult age ratios against indices of population, such as the Breeding Bird Survey (BBS) and the Christmas Bird Count (CBC). If a negative linear relationship exists, which would suggest linear density dependence in reproduction, the intercept of this equation should be an estimate of recruitment at low density (M. Runge, personal communication).

In all analyses, I converted harvest age ratios (HAR) for differential vulnerability to produce preseason age ratios (PAR), using the following equation:

Eq.6

$$PARm = \frac{HARm}{Vdifm}$$

$$where$$

$$Vdif = \frac{fjm}{fam}$$

and f_{jm} and f_{am} are the band recovery rates of juvenile and adult males, respectively. Pre-season female age ratios (PAR_f) were calculated similarly.

BBS and CBC indices were calculated for 1966-2004 (J. Sauer, unpublished data). BBS indices were the median number of birds/route, adjusted for observer and startup effects (Link and Sauer 2002). CBC indices were the median count/circle, scaled to the average effort in the circle, adjusted for observer effort (Link et al. 2006). To ensure that counts are of the same post-harvest pre-breeding population CBC indices are those for the year t-1 due to the difference in the timing of CBC and BBS. Using indices from these hierarchical models allows for adjustments for effects that are not of interest, and represent technical improvements in the estimation process (J. Sauer, personal communication). In particular, these BBS indices are an improvement over those calculated using the estimating equations method (Link and Sauer 1994) because annual indices are not influenced by the trend in the entire time series. Using the median rather than the mean of the replicates from the Markov Chain

Monte Carlo process produces indices that are less likely to be influenced by extreme values (J. Sauer, personal communication).

BBS indices were calculated for the Atlantic and Mississippi Flyways combined, and for northern and southern regions separately. CBC indices were calculated only for the two flyways combined. In the past, I used CBC wood ducks/party hour for the entire US. Calculation of CBC indices at the proper scale, along with the use of indices from hierarchical models, addresses concerns expressed by myself, as well as other biologists over the appropriate use of these data for this analysis. When standardized to their mean counts for the time series at the appropriate scale, BBS and CBC data show similar trends (Figure 1).

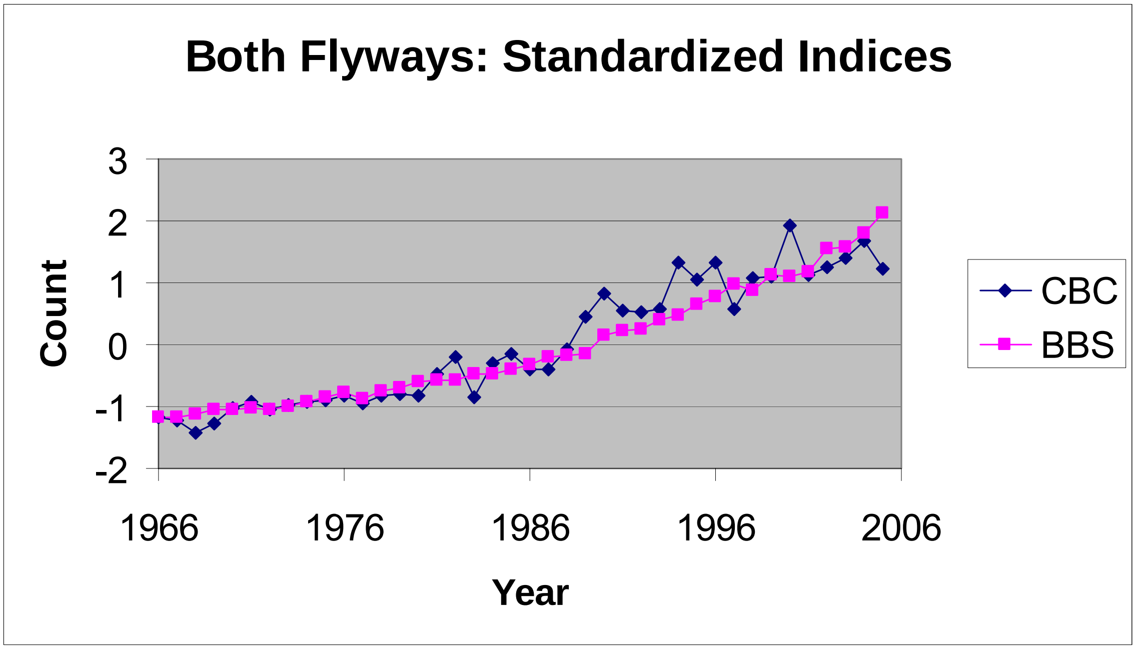

Figure 1. Wood duck BBS and CBC indices for the Atlantic and Mississippi Flyways combined, standardized relative to their mean counts for the time series.

When regressed against CBC data (Figure 2), PAR_m age ratios declined with increasing WODU CBC ($P < 0.001$). By contrast, the slope of PAR_f, did not differ from 0 ($P = 0.747$). The intercept is greater for PAR_m than for PAR_f, so the choice between them has important management implications. Using the PAR_m regression would give a more liberal estimate of allowable take.

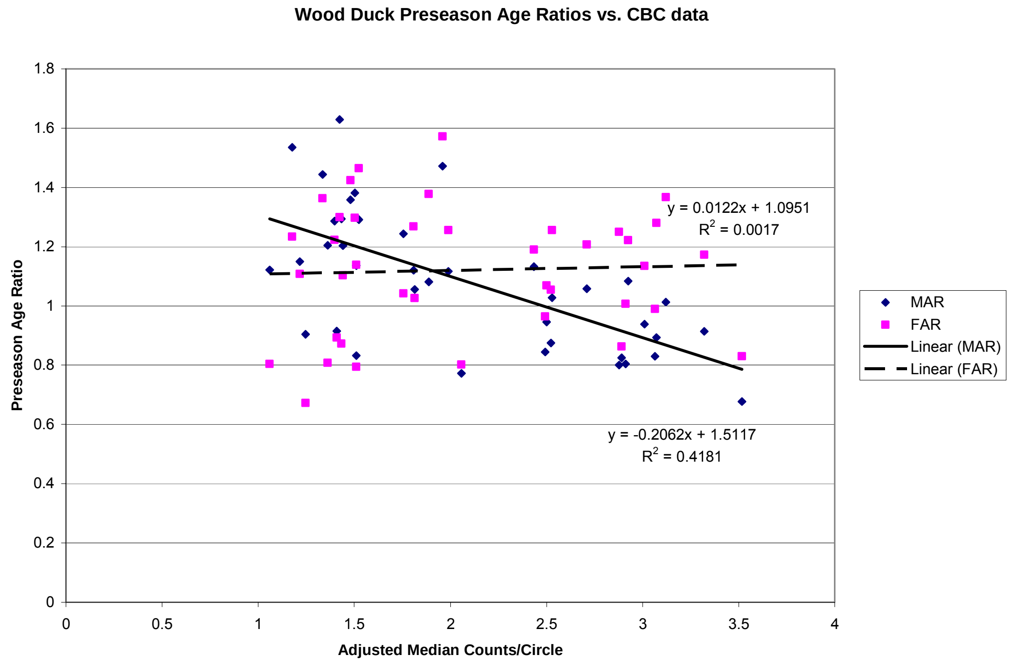

Figure 2. Linear regression of male and female juvenile/adult preseason age ratios against median wood duck counts/circle for the Atlantic and Mississippi Flyways combined.

Results of analyses using BBS data are similar (Figure 3). There is no relationship between BBS indices and PAR_f (P = 0.708). Moreover, the relationship between BBS and PAR_m is even stronger (P < 0.001) and the intercept higher, than when regressed against CBC data.

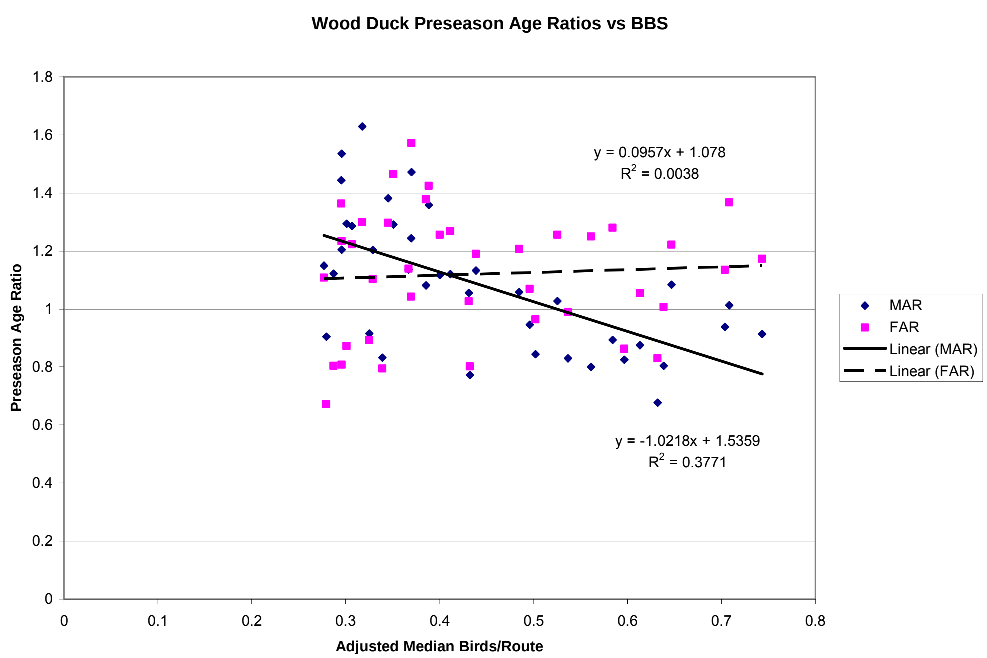

Figure 3. Wood duck preseason male and female age ratios, regressed against median WODU BBS birds/route for the Atlantic and Mississippi Flyways, combined.

The difference between the patterns exhibited by male and female age ratios and the management implications of the choice were a concern. Paul Padding (personal communication) suggested that patterns of age ratios may reflect changes in the proportion of adult cohorts and not simply changes in recruitment, over the course of a time series. In particular, he wondered whether declining male age ratios reflected an increasingly male biased population. So I adjusted cohort specific harvest estimates (H) from harvest survey data for relative vulnerability using year and cohort-specific band recovery rates, and scaled them to those of adult males (Johnson, et al. 2002) to produce estimates of the proportion of each cohort in the pre-hunting season population (PrAM, PrJM, etc).

For example, if $H'af = \dfrac{Haf}{Vdif(af : am)}$ = female harvest adjusted for vulnerability relative to adult males (Eq. 8)

then $$\Pr AF = \frac{H'AF}{HAM + H'AF + H'JM + H'JF}$$

Eq. 9

I then regressed these estimates of the proportion of each cohort in the preseason population against year for the entire time series of the survey (Figure 4).

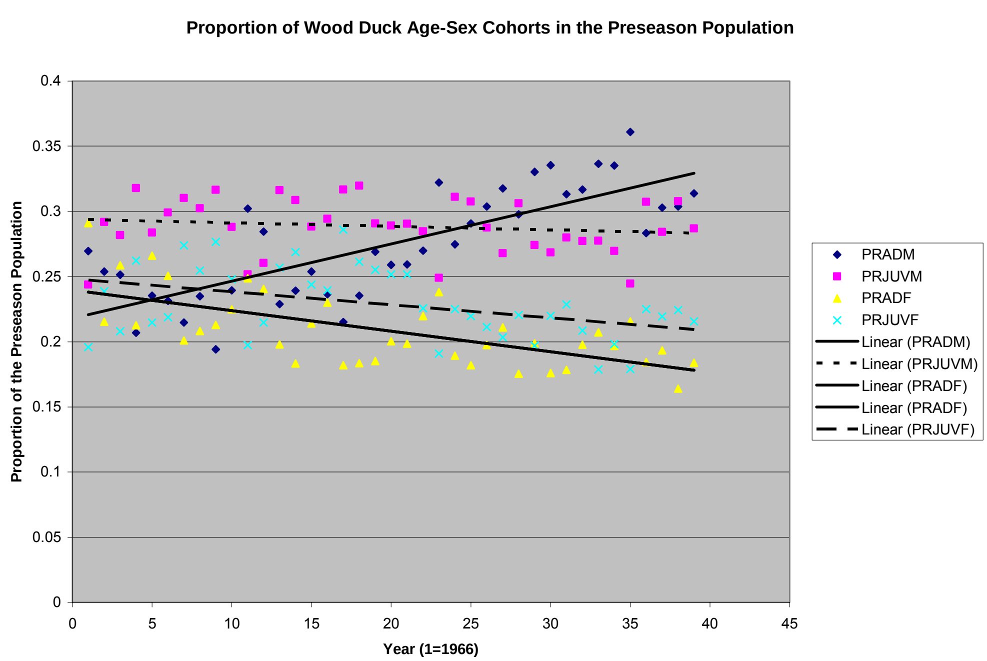

Figure 4. Estimated proportion of wood duck age sex cohorts in the pre-hunting season population in eastern North America, calculated by adjusting cohort-specific harvest for differential vulnerability relative to adult males. Data are from the USFWS parts collection survey, 1966-2004.

Indeed, the estimated proportion of adult males in the preseason population has increased (R^2 = 0.5609, P <0.001), and the proportion of adult females has decreased (R^2 = 0.222, P =0.002) over time.[1] By contrast, the proportion of juvenile males (R^2 = 0.093, P = 0.059) and females declined slightly (R^2 = 0.072, P = 0.099) but did not dffer from each other (P = 0.127). This suggested that the relationships between sex-specific preseason age ratios and population indices were confounded by the increasingly adult-male biased preseason population.

[1] As a side note, I found that the preseason sex ratio (adjusted for differential vulnerability) of adults has increased over time (from a little over 1 to close to 1.4:1—the Illinois Natural History Survey reports 1.31:1—not sure where their data are from), while the sex ratio of juveniles, though male-biased, has remained constant over time. In the sample of banded birds, the sex ratio of adults is heavily male-biased, that of juveniles is as well, but less so. The sex ratio of birds banded as locals is 50:50, as expected, which suggests that the sex bias in the wood duck banding data is likely not due to bander error

To obtain estimates of wood duck reproduction at low density unbiased by changes in the proportion of adults in the preseason population, I ran multiple regressions that included both the population index values and the proportion of the preseason population that the adult cohort in question comprises.

Eq. 10 $$PAR = \mathrm{B}_0 + \mathrm{B}_1(popindex) + B_2(proportionadultcohort) + \varepsilon$$

I ran a total of four multiple regressions: PAR_m, and proportion of adult males in the preseason population against BBS and CBC data, and PAR_f and proportion of adult females in the preseason population against BBS and CBC data.

For the preseason female age ratio models, the regression equations were:

Eq. 11 PAR_f, = 3.35982 - 0.18481 (CBC) - 8.91277 ($PrAF$)

and

Eq. 12 $PAR_{f,}$ = 3.35560 - 0.91813 (BBS) – 8.78337 ($PrAF$)

Both models fit well ($F \geq$ 130.64, P < 0.001), and after adjusting for proportion of adult females in the harvest, PAR_f, decreased with decreasing CBC (P < 0.001) and BBS (P < 0.001).

For the preseason male age ratio models, the regression equations were:

Eq. 13 PAR_m, = 2.73619 + 0.12108 (CBC) - 6.93183 ($PrAM$)

and

Eq. 14 PAR_m, = 2.65175 + 0.50377 (BBS) – 6.52099 ($PrAM$)

Both models fit well ($F \geq$ 337.35, P < 0.001), but after adjusting for proportion of adult males in the harvest, PAR_m, actually increased with increasing CBC (P < 0.001) and BBS (P < 0.001).

To obtain estimate of age ratios at low population density that are unbiased by the increase in the proportion of adult males in the preseason population over time (at least over the time frame for which we have reliable survey data), I inserted the intercept from the regression of the proportion of adult males or females in the preseason population vs. year, where year 0 = 1966, the first year of the BBS (Figure 4). I substituted 0 in place of the CBC or the BBS index, since we are interested in estimating the age ratio at a very low density. The adjustment uses data from the same source, but the adjustment is for the increasing proportion of adult males (and decreasing proportion of adult females) over time, which should be an appropriate use of such data.

So then,

Eq. 15 PAR_{f}, = 3.35982 - 0 (CBC) - 8.91277 (0.23968) = 1.224 (0.899-1.549, 95% CI)

and

Eq. 16 $PAR_{f,}$ = 3.35560 - 0 (BBS) – 8.78337 (.23968) = 1.219 (0.930-1.508, 95% CI)

based on female age ratios, and

Eq. 17 PAR_{m}, = 2.73619 + 0 (CBC) - 6.93183 (0.21970) = 1.210 (1.094-1.326, 95% CI)

and

Eq. 18 PAR_{m}, = 2.65175 + 0 (BBS) – 6.52099 (0.21970) = 1.219 (1.171-1.267, 95% CI)

based on male age ratios.

The standard error around the intercept of this regression equation was converted to a 95% CI, as shown, and was used to create a random normal distribution of age ratios for use in simulations to generate a variance for the estimate of r_{max} (Part VI of this document).

The adjusted regression gives a consistent answer about reproduction at low density, regardless of the population index used, or whether male or female data are used. Use of female age ratios and CBC data produced estimates that were more variable, so the estimate derived from the regression of male age ratios against BBS were used in subsequent calculations of r_{max}. The slight increase in male adjusted preseason age ratios regressed against population indices, a pattern opposite that for females, is somewhat puzzling. Using male age ratios (as has been customary for modeling recruitment of several other duck species) allows the use of data that is less variable due to larger sample sizes and perhaps, less variability in summer survival (F. Johnson, personal communication). The adjustment for an increasing proportion of adult males removes the influence of an effect that is not of interest.

The point estimates are consistent with the average preseason ratio of wood duck young/adult of 1.2 reported by Bellrose (1980) for the period 1960-1971. This suggests that a similar answer might be obtained in a simpler fashion by regressing young/adult ratios (from harvest estimates adjusted for differential vulnerability). However, documentation of changes in the proportion of wood duck adult cohorts in the preseason population over time was a worthwhile outcome, nonetheless.

The age ratios shown above are based on data from the entire Atlantic and Mississippi Flyways combined, and utilize band recovery rates from models (Brownie et al. 1985) based on all (direct and indirect) recoveries, adjusted using a constant differential vulnerability correction factors. However, I ran a series of analyses based on age ratios derived from either direct or all recoveries, constant or year-specific differential vulnerability, and at different regional scales. I was only able to use a constant differential vulnerability correction with age ratios based on all recoveries; as vulnerability of adult females increased at a higher rate than those of other age-sex cohorts when direct recoveries were used in the calculations. Complete results are summarized in Table 3. Due to good precision and the similarity of the point estimate regardless of the method used, I used the figure for adjusted male age ratios based on the entire two flyways, all recoveries, corrected using constant differential vulnerability (shown in yellow) in subsequent estimations of r_{max}.

Table 3. Estimates of wood duck preseason age ratios at low density, adjusted for changes in proportion of adults in the preseason population over time.

Region	DVT	DVR	Type	Sex	AR	SE	LCI	UCI
A	C	I	CBC	F	1.22	0.16594	0.898758	1.549242
A	C	I	BBS	F	1.22	0.14724	0.93041	1.50759
A	C	I	CBC	M	1.21	0.05916	1.094046	1.325954
A	C	I	BBS	M	1.22	0.0247	1.170588	1.267412
A	Y	I	CBC	F	1.09	0.15908	0.778203	1.401797
A	Y	I	BBS	F	1.1	0.169	0.76456	1.42704
A	Y	I	CBC	M	1.21	0.09917	1.015627	1.404373
A	Y	I	BBS	M	1.22	0.09375	1.03565	1.40315
A	Y	D	CBC	F	0.91	0.16594	0.584758	1.235242
A	Y	D	BBS	F	0.91	0.18229	0.549712	1.264288
A	Y	D	CBC	M	1.31	0.08726	1.13897	1.48103
A	Y	D	BBS	M	1.31	0.08464	1.141106	1.472894
N	Y	D	BBS	F	1.01	0.23048	0.559259	1.462741
N	Y	D	BBS	M	1.38	0.10862	1.165105	1.590895
S	Y	D	BBS	F	1.24	0.31318	0.621167	1.848833
S	Y	D	BBS	M	1.32	0.19384	0.941074	1.700926

Key:
DVT: C = constant dif vuln, Y = year-specific dif vuln
DVR: I = includes all recoveries, D = includes only direct recoveries
Region: A = all wodu areas, N = North, S = South

Estimating r_{max}, allowable harvest rates, and variances

I used a Leslie projection matrix (Eq.19) to calculate estimates of r_{max}.

Eq. 19

$$\begin{bmatrix} S^{AM} + R^{M} S^{JM} & 0 \\ R^{M} S^{JF} & S^{AF} \end{bmatrix} \cdot \begin{bmatrix} M_t \\ F_t \end{bmatrix}$$

This form uses male age ratios, and assumes sex and age-specific non-hunting survival, and a fledgling sex ratio of 50:50 (F. Johnson, personal communication). The dominant eigenvector is λ_{max}. Then allowable take is ½ r_{max}, where $r_{max} = \lambda_{max} - 1$. Proportion of males and females at equilibrium can be calculated from the dominant eigenvalues. I assumed that estimates of age ratio at low density (AR) and non-hunting survival (S_0) were normally distributed. Using program R (Ihaka and Gentleman 1996), I generated 10,000 replicates of r_{max} by drawing from random normal distributions of AR and S_0, and used bootstrapping techniques to estimate means and 95% confidence intervals (Manly 1991). These were converted to estimates of allowable harvest rate (Table 4). In the PBR framework these harvest rates really represent kill rates, as they are meant to encompass all human-caused mortality. I ran simulations, based on S_0 rates calculated at different scales (Table 4).

Table 4. Wood duck allowable kill rates calculated at different regional scales.

Region	Allowable Kill Rate (95% CI)
All	0.1817 (0.1657-0.1978)
North	0.1572 (0.1416-0.1731)
South	0.2351 (0.2137-0.2573)

Results are not shown here, but I also calculated allowable kill rates using one of the higher age ratio estimates (1.31) shown in Table 3. Not surprisingly, the point estimates were higher, but the higher variance around the age ratio estimate produced a larger confidence interval around the estimate of allowable harvest rate. If one uses a lower confidence bound as guidance for setting allowable take, use of the higher age ratio estimate would actually produce a smaller allowable harvest rate.

Calculating cohort-specific allowable harvest (kill) rates

One issue that our staff and the flyway wood duck committees have wrestled with is how to utilize an allowable kill rate based on all cohorts in a management strategy. One method could be to set an allowable kill rate for one cohort, provided that the kill rates of other cohorts increase at the same rate with increasing kill rate of the cohort being monitored. For wood ducks this is generally true. Then the overall harvest rate on a population can be expressed as

Eq. 20

$$h = \frac{(hAM)(\Pr AM) + (hAF)(\Pr AF) + (hJM)(\Pr JM) + (hJF)(\Pr JF)}{\Pr AM + \Pr AF + \Pr JM + \Pr JF}$$

Where hAM etc, are the cohort specific harvest rates, and $\Pr AM$ etc, are the proportion of each cohort in the preseason population, from Equations.8 and 9, above. Then the adult male harvest rate can pulled out of the right side of the equation and the other cohort specific rates expressed as the product of their proportions in the preseason population and their vulnerability to harvest relative to adult males, $Vdif$, as calculated in equation 8, above.

Eq. 21

$$h = (hAM)[(\Pr AM) + (VdifAF)(\Pr AF) + (VdifJM)(\Pr JM) + (VdifJF)(\Pr JF)]$$

solving for hAM gives:

$$hAM = \frac{h}{(\Pr AM) + (VdifAF)(\Pr AF) + (VdifJM)(\Pr JM) + (VdifJF)(\Pr JF)}$$

Then substituting the allowable kill rate (from Table 4), calculated for the entire population, for h and the appropriate values into the equation gives:

$$hAM = \frac{0.1817}{(0.31) + (0.78)(0.18) + (1.47)(0.29) + (1.03)(0.22)}$$

= 0.1657

Estimating the probability that wood ducks banded in northern or southern regions will switch areas in subsequent years

Estimating the proportions of wood ducks banded in one flyway and recovered in another

My approach for these two tasks was generally the same:

1) Compile area and age-sex cohort specific direct and indirect recoveries for birds banded in each of the Kelley (1997) wood duck banding areas from 1997-2003. Those years were chosen because reporting and recovery rates do not vary dramatically during this time frame (Garrettson 2006). Only status 300 and 304 (normal wild, control birds in reward band study) bandings were used.

2) Sum these recoveries across years, and across regions to produce the total number recovered north vs. south, Atlantic vs. Mississippi Flyway, for each banding area-age-sex cohort.

3) Conditional on being recovered and reported, calculate the proportion of recoveries of birds banded in each Kelley region that are recovered in the north or the south, in the Atlantic or Mississippi Flyway. This is **not** the same thing as asking what the probability that a bird banded in a given region will be recovered in a given region.

4) Assuming there is not a large year by region interaction in survival and recovery rates, these proportions should indicate the degree to which birds move among areas.

To fully address the first question, I wanted to limit the analysis to recoveries of birds that had likely bred in the area where they were recovered. Therefore I only included recoveries that occurred prior to a date cutoff set so that no more than 5% of direct recoveries in southern region included birds banded in northern regions. This is November 1 in the Atlantic Flyway, and November 19 in the Mississippi Flyway.

I knew that any direct, early-season recoveries of birds outside the region where they were banded likely represented either birds that migrated before the cutoff date, or dispersal of post-breeding adults or juveniles. I assumed that the rate of such movement was constant across years, and that subtracting the proportion of cross-area direct recoveries from the proportion of cross-area indirect recoveries, I could estimate the probability that birds banded in a given area (especially males) would move into new areas, presumably to breed, or attempt to breed, most likely because they had paired with females from those areas.

To use a real example, 9% of the direct recoveries and 20% of the indirect recoveries of adult males banded in the southern Mississippi Flyway occur in northern regions, but for juvenile males the figures are 4% and 27%, respectively. So then,

20-9 = 11% = probability that adult males banded in the southern Mississippi Flyway will move north, presumably as a result of breeding behavior

27-4% =23% = probability that juvenile males banded in the southern Mississippi Flyway will move north, presumably as a result of breeding behavior

So we would conclude that juvenile males from this area are more likely to move north than birds banded as adults. You can probably see one problem with this analysis, though, that birds banded as juveniles are perpetually treated as juveniles, because all indirect recoveries are treated alike, whether they occur one or 10 years after banding. However, treating them separately would likely lead to small sample sizes for most regions. The full tables (5 and 6) for early-season and all recoveries, all regions and age-sex cohorts can be found after the acknowledgments and literature cited.

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Table 5. Proportions of early-season (prior to Nov. 1 in the Atlantic Flyway, prior to Nov.19 in the Mississippi Flyway) recoveries, by area, of wood ducks banded in the Atlantic and Mississippi Flyways 1997-2003.

Banded Cohort					Number Recovered in Area									Proportion Recovered in Area			
Sex	Age	AREA	#band	Type	LSMi	NAtl	NCMi	SAtl	SMis	AT	MS	N	S	PrAT	PrMS	PrN	PrS
F	A	LSMi	2049	dir	56	1	1	2	4	3	61	58	6	0.047	0.953	0.906	0.094
F	A	LSMi	2049	ind	38	0	3	2	1	2	42	41	3	0.045	0.955	0.932	0.068
F	J	LSMi	5572	dir	201	1	6	3	26	4	233	208	29	0.017	0.983	0.878	0.122
F	J	LSMi	5572	ind	79	4	9	1	9	5	97	92	10	0.049	0.951	0.902	0.098
F	A	NAtl	2515	dir	3	73	0	3	1	76	4	76	4	0.950	0.050	0.950	0.050
F	A	NAtl	2515	ind	2	35	0	4	0	39	2	37	4	0.951	0.049	0.902	0.098
F	J	NAtl	6469	dir	7	277	0	14	1	291	8	284	15	0.973	0.027	0.950	0.050
F	J	NAtl	6469	ind	1	131	2	6	0	137	3	134	6	0.979	0.021	0.957	0.043
F	A	NCMi	4890	dir	1	0	215	0	12	0	228	216	12	0.000	1.000	0.947	0.053
F	A	NCMi	4890	ind	1	1	124	0	6	1	131	126	6	0.008	0.992	0.955	0.045
F	J	NCMi	16686	dir	7	0	1103	0	38	0	1148	1110	38	0.000	1.000	0.967	0.033
F	J	NCMi	16686	ind	5	1	419	1	15	2	439	425	16	0.005	0.995	0.964	0.036
F	A	SAtl	3340	dir	0	0	0	23	0	23	0	0	23	1.000	0.000	0.000	1.000
F	A	SAtl	3340	ind	0	2	0	10	0	12	0	2	10	1.000	0.000	0.167	0.833
F	J	SAtl	4441	dir	0	0	0	53	2	53	2	0	55	0.964	0.036	0.000	1.000
F	J	SAtl	4441	ind	1	4	1	25	1	29	3	6	26	0.906	0.094	0.188	0.813
F	A	SMis	8296	dir	2	5	5	16	125	21	132	12	141	0.137	0.863	0.078	0.922
F	A	SMis	8296	ind	5	3	9	13	65	16	79	17	78	0.168	0.832	0.179	0.821
F	J	SMis	17439	dir	17	17	14	39	537	56	568	48	576	0.090	0.910	0.077	0.923
F	J	SMis	17439	ind	6	11	20	24	147	35	173	37	171	0.168	0.832	0.178	0.822
M	A	LSMi	3229	dir	71	3	1	5	3	8	75	75	8	0.096	0.904	0.904	0.096
M	A	LSMi	3229	ind	54	4	10	10	2	14	66	68	12	0.175	0.825	0.850	0.150
M	J	LSMi	5996	dir	239	1	8	7	41	8	288	248	48	0.027	0.973	0.838	0.162
M	J	LSMi	5996	ind	55	20	45	14	11	34	111	120	25	0.234	0.766	0.828	0.172
M	A	NAtl	5448	dir	5	111	1	21	1	132	7	117	22	0.950	0.050	0.842	0.158
M	A	NAtl	5448	ind	5	116	4	20	1	136	10	125	21	0.932	0.068	0.856	0.144
M	J	NAtl	7263	dir	8	314	1	22	0	336	9	323	22	0.974	0.026	0.936	0.064
M	J	NAtl	7263	ind	17	96	22	24	2	120	41	135	26	0.745	0.255	0.839	0.161
M	A	NCMi	10659	dir	8	0	447	1	37	1	492	455	38	0.002	0.998	0.923	0.077
M	A	NCMi	10659	ind	15	3	294	1	38	4	347	312	39	0.011	0.989	0.889	0.111
M	J	NCMi	20396	dir	12	0	1415	2	73	2	1500	1427	75	0.001	0.999	0.950	0.050
M	J	NCMi	20396	ind	42	7	450	9	51	16	543	499	60	0.029	0.971	0.893	0.107
M	A	SAtl	3585	dir	1	3	1	23	0	26	2	5	23	0.929	0.071	0.179	0.821
M	A	SAtl	3585	ind	3	16	5	19	1	35	9	24	20	0.795	0.205	0.545	0.455
M	J	SAtl	5261	dir	0	2	0	77	3	79	3	2	80	0.963	0.037	0.024	0.976
M	J	SAtl	5261	ind	11	26	14	32	2	58	27	51	34	0.682	0.318	0.600	0.400
M	A	SMis	12927	dir	9	46	9	226	179	272	197	64	405	0.580	0.420	0.136	0.864
M	A	SMis	12927	ind	26	51	70	205	92	256	188	147	297	0.577	0.423	0.331	0.669
M	J	SMis	20240	dir	9	24	21	83	619	107	649	54	702	0.142	0.858	0.071	0.929
M	J	SMis	20240	ind	48	37	216	88	154	125	418	301	242	0.230	0.770	0.554	0.446

Table 6. Proportions of all recoveries, by area, of wood ducks banded in the Atlantic and Mississippi Flyways 1997-2003.

Banded Cohort					Number Recovered in Area									Proportion Recovered in Area			
Sex	Age	AREA	#band	Type	LSMi	NAtl	NCMi	SAtl	SMis	AT	MS	N	S	PrAT	PrMS	PrN	PrS
F	A	LSMi	2049	dir	59	1	3	22	20	23	82	63	42	0.219	0.781	0.600	0.400
F	A	LSMi	2049	ind	40	0	3	20	13	20	56	43	33	0.263	0.737	0.566	0.434
F	J	LSMi	5572	dir	212	1	12	43	96	44	320	225	139	0.121	0.879	0.618	0.382
F	J	LSMi	5572	ind	85	4	11	35	44	39	140	100	79	0.218	0.782	0.559	0.441
F	A	NAtl	2515	dir	4	77	1	82	9	159	14	82	91	0.919	0.081	0.474	0.526
F	A	NAtl	2515	ind	2	39	0	42	8	81	10	41	50	0.890	0.110	0.451	0.549
F	J	NAtl	6469	dir	10	304	2	195	36	499	48	316	231	0.912	0.088	0.578	0.422
F	J	NAtl	6469	ind	4	145	2	99	17	244	23	151	116	0.914	0.086	0.566	0.434
F	A	NCMi	4890	dir	1	0	226	7	123	7	350	227	130	0.020	0.980	0.636	0.364
F	A	NCMi	4890	ind	1	1	133	2	74	3	208	135	76	0.014	0.986	0.640	0.360
F	J	NCMi	16686	dir	12	0	1155	18	379	18	1546	1167	397	0.012	0.988	0.746	0.254
F	J	NCMi	16686	ind	5	2	437	14	211	16	653	444	225	0.024	0.976	0.664	0.336
F	A	SAtl	3340	dir	0	0	0	104	10	104	10	0	114	0.912	0.088	0.000	1.000
F	A	SAtl	3340	ind	0	2	0	93	5	95	5	2	98	0.950	0.050	0.020	0.980
F	J	SAtl	4441	dir	0	0	0	220	22	220	22	0	242	0.909	0.091	0.000	1.000
F	J	SAtl	4441	ind	1	5	1	152	5	157	7	7	157	0.957	0.043	0.043	0.957
F	A	SMis	8296	dir	3	5	8	33	318	38	329	16	351	0.104	0.896	0.044	0.956
F	A	SMis	8296	ind	6	3	9	23	218	26	233	18	241	0.100	0.900	0.069	0.931
F	J	SMis	17439	dir	17	17	22	86	1023	103	1062	56	1109	0.088	0.912	0.048	0.952
F	J	SMis	17439	ind	7	11	22	55	410	66	439	40	465	0.131	0.869	0.079	0.921
M	A	LSMi	3229	dir	73	3	1	54	49	57	123	77	103	0.317	0.683	0.428	0.572
M	A	LSMi	3229	ind	55	4	10	73	53	77	118	69	126	0.395	0.605	0.354	0.646
M	J	LSMi	5996	dir	250	1	12	89	156	90	418	263	245	0.177	0.823	0.518	0.482
M	J	LSMi	5996	ind	57	20	45	111	103	131	205	122	214	0.390	0.610	0.363	0.637
M	A	NAtl	5448	dir	6	120	1	217	24	337	31	127	241	0.916	0.084	0.345	0.655
M	A	NAtl	5448	ind	5	125	4	295	34	420	43	134	329	0.907	0.093	0.289	0.711
M	J	NAtl	7263	dir	9	342	2	329	65	671	76	353	394	0.898	0.102	0.473	0.527
M	J	NAtl	7263	ind	19	104	24	294	71	398	114	147	365	0.777	0.223	0.287	0.713
M	A	NCMi	10659	dir	9	1	462	31	343	32	814	472	374	0.038	0.962	0.558	0.442
M	A	NCMi	10659	ind	17	3	307	47	343	50	667	327	390	0.070	0.930	0.456	0.544
M	J	NCMi	20396	dir	17	0	1479	46	729	46	2225	1496	775	0.020	0.980	0.659	0.341
M	J	NCMi	20396	ind	44	7	468	84	579	91	1091	519	663	0.077	0.923	0.439	0.561
M	A	SAtl	3585	dir	1	3	2	182	13	185	16	6	195	0.920	0.080	0.030	0.970
M	A	SAtl	3585	ind	4	16	6	181	18	197	28	26	199	0.876	0.124	0.116	0.884
M	J	SAtl	5261	dir	0	2	0	338	37	340	37	2	375	0.902	0.098	0.005	0.995
M	J	SAtl	5261	ind	12	26	16	235	35	261	63	54	270	0.806	0.194	0.167	0.833
M	A	SMis	12927	dir	10	46	12	248	454	294	476	68	702	0.382	0.618	0.088	0.912
M	A	SMis	12927	ind	26	51	72	233	353	284	451	149	586	0.386	0.614	0.203	0.797
M	J	SMis	20240	dir	12	24	33	128	1430	152	1475	69	1558	0.093	0.907	0.042	0.958
M	J	SMis	20240	ind	52	37	224	197	651	234	927	313	848	0.202	0.798	0.270	0.730

Appendix II

Evaluating Impacts of Regulatory Options on Wood Duck
Harvest Rates in Eastern North America
Greg Balkcom, Ga. DNR
DRAFT

The historic relationship between season length, hunter number, and wood duck harvest rate has been explored using multiple regression based on existing data gathered from the DMBM (See Table at end). Results for northern[1] adult female wood ducks indicate that modeling harvest rate by season length and duck stamp sales (which were used as a surrogate for hunter number) provided a better fit ($r^2 = 0.746$, $p < 0.001$) than using season length ($r^2 = 0.391$) or duck stamp sales ($r^2 = 0.657$) alone. Results were similar when modeling harvest rates for northern adult males ($r^2 = 0.701$, $p < 0.001$). The resulting regression equation to predict harvest rate for northern adult females is as follows:

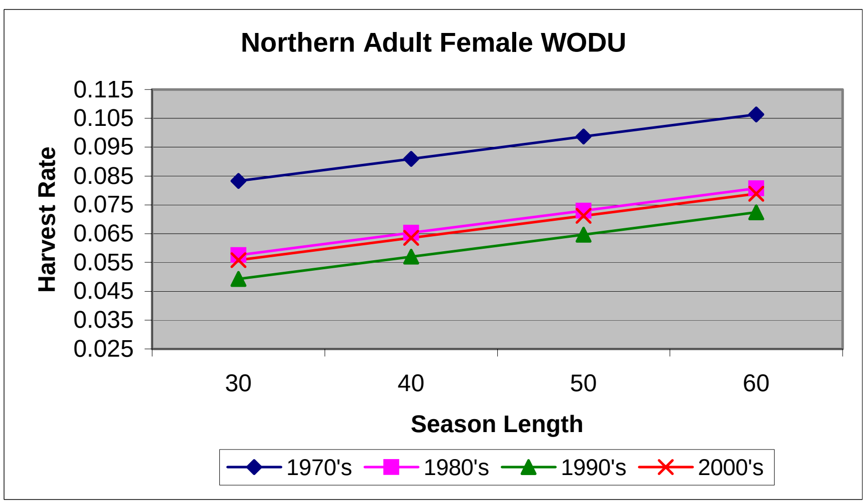
Harvest rate = 0.000769204 (season length) + 0.0000000911 (duck stamps sold) – 0.06045

The regression equation to predict harvest rate for northern adult males is as follows:

Harvest rate = 0.001122461 (season length) + 0.0000000728 (duck stamps sold) – 0.4516

Because hunter number and season length both play a strong role in the harvest rate of wood ducks, it is necessary to make future predictions of harvest rate based on season length and contemporary estimates of hunter numbers. As shown in Figure 1, the resulting harvest rate estimates for any given season length are noticeably higher when modeled using the average number of hunters in the 1970's as compared to the average number of hunters in the 1980's, 1990's, or 2000's.

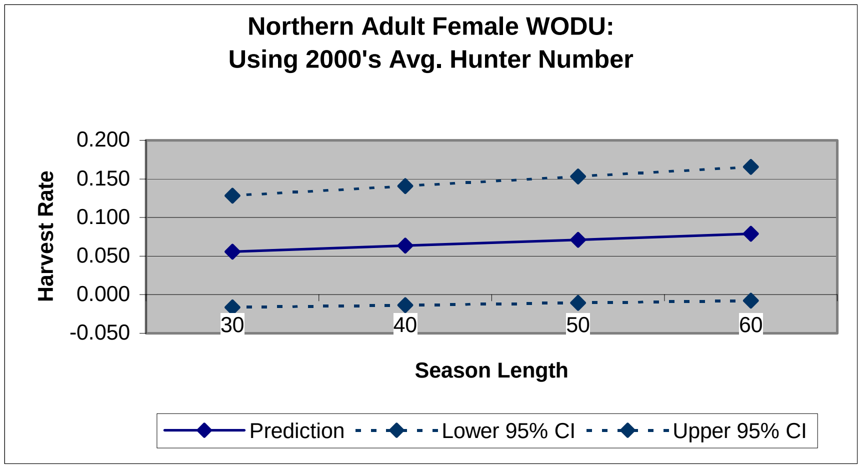
Figure 1. Predicted harvest rate of northern adult female wood ducks based on season length and average number of duck stamps sold in each decade.



The regression equation contains 95% confidence intervals around the estimates for intercept, season length coefficient, and hunter number coefficient. When the upper and lower confidence intervals are used in the equation, the predicted harvest rates vary by $\pm$ 110% (Figure 2).

[1] Based on Jim Kelley's 1997 analysis. The term "northern" includes the northeastern Atlantic Flyway, the Great Lakes States, and the northern Mississippi Flyway.

Figure 2. 95% confidence intervals of harvest rate predictions when using upper and lower bounds for intercept, season length coefficient, and hunter number coefficient from the regression equation.



Once the relationship between harvest rate, season length, and hunter number was determined, it was necessary to find ways to estimate the potential impacts of increased bag limits. Four options were explored: using bag check data from other species as a surrogate for wood ducks, using bag check data from the liberalizations that occurred in the southern Atlantic Flyway in the 1980's, using contemporary data from the Atlantic and Mississippi Flyways, and using contemporary data from Canada. In Canada, there is no species restriction on wood ducks; therefore, the number of wood ducks harvested can equal the total bag limit of 6.

<u>Other Species</u>: DMBM data from mallards and green-winged teal indicate an 8% increase in harvest when the bag limit is increased from 2 to 3, and data from scaup indicate a 13% increase (*source*: P. Padding and P. Garrettson, DMBM, pers. comm.).

<u>October Liberalizations</u>: Bag check data from the 1980's (n = 3,034) indicates a 63.1% increase in wood duck harvest when the bag limit increases from 1 to 2, a 22.2% increase in harvest when bag limit increases from 2 to 3, and a 10.4% increase when bag limit increases from 3 to 4 (*source*: P. Padding, DMBM, pers. comm.). These liberalizations occurred in the southeastern Atlantic Flyway for a limited time in October, when few other species of waterfowl were present to "buffer" the harvest of wood ducks.

<u>Canadian Wildlife Service (CWS) Bag Check Data</u>: Bag check data from the CWS indicates a 39.8% increase in harvest when the bag limit increases from 1 to 2, and an 11.9% increase in harvest when the bag limit changes from 2 to 3 (Table 1). These data are from 12,479 bags taken in Ontario and eastward containing wood ducks between 1990 and 2006 (*source*: raw data received from M. Gendron, CWS). In Canada there is no species restriction on wood ducks; therefore, the wood duck limit can equal the total bag limit of 6.

Table 1. Differences in harvest when changing bag limits based on CWS bag check data.

Current	Bag Limit Changed To:					
Bag Limit	1	2	3	4	5	6
1		39.82%	56.44%	63.73%	66.60%	67.43%
2	-28.48%		11.89%	17.10%	19.15%	19.75%
3	-36.08%	-10.62%		4.66%	6.50%	7.03%
4	-38.92%	-14.60%	-4.45%		1.75%	2.26%

5	-39.98%	-16.08%	-6.10%	-1.72%		0.50%
6	-40.27%	-16.49%	-6.57%	-2.21%	-0.50%	

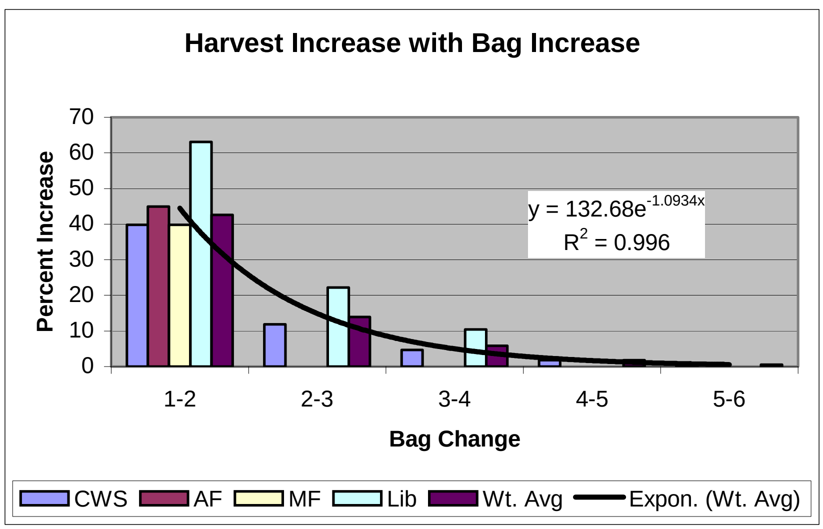
<u>Atlantic and Mississippi Flyway Data</u>: Bag check data from the Atlantic Flyway between 1990 and 2006 indicate a 44.9% increase in harvest when going from a 1-bird to a 2-bird bag (*source*: P. Garrettson DMBM, pers. comm.). Bag check data from the Mississippi Flyway between 1990 and 2006 indicate a 39.8% increase in harvest when going from a 1-bird to a 2-bird bag (*source*: raw data received from K. Richkus, DMBM).

<u>Weighted Average of all Wood Duck Data</u>: Another option for examining bag check data is to generate a weighted average, based on sample size, for the expected increase in harvest as bag limits increase. Table 2 shows the sample size, data source, and harvest increase as bag increases from each of the data sets, and Figure 2 shows the exponential trendline (r^2 = 0.996) and predictive equation to estimate harvest increase as bag increases.

Table 2. Sample size, source, and expected harvest increase as bag limit increases.

Sample Size:	12,479	33,623	38,333	3,034	
Source:	CWS	AF	MF	AF Lib.	Wt. Avg
<u>Bag Change</u>					
1-2	39.8%	44.9%	39.8%	63.1%	42.6%
2-3	11.9%			22.2%	13.9%
3-4	4.7%			10.4%	5.8%
4-5	1.8%				1.8%
5-6	0.5%				0.5%

Figure 2. Data source and expected harvest increase as bag limit increases, and exponential trendline showing predictive equation.



The predicted harvest rates for northern adult female wood ducks from the regression equation (using average number of stamps sold during the 2000's) and the exponential trendline equation based on the weighted average bag data are shown in Table 3. The trendline equation predicts a a 14.9% increase in harvest when increasing the bag limit from 2 to 3, and a 30.8% decrease when reducing the bag limit from 2 to 1.

Table 3. Predicted harvest rate of northern adult female wood ducks at 1, 2, and 3-bird bag limits based on regression equation using 2000's average number of hunters and exponential trendline equation based on the weighted average bag check data.

Northern Adult Female			
Season Length	Bag Limit		
	1-Bird	2-Bird	3-Bird
30	0.039	0.056	0.064
45	0.047	0.067	0.078
50	0.049	0.071	0.082
60	0.055	0.079	0.091

Similar predictions can be made for other cohorts of wood ducks including northern adult males as well as adult males and adult females in eastern North America.

Table 4. Predicted harvest rate of northern adult male wood ducks at 1, 2, and 3-bird bag limits based on regression equation using 2000's average number of hunters and exponential trendline equation based on the weighted average bag check data.

Northern Adult Male			
Season Length	Bag Limit		
	1-Bird	2-Bird	3-Bird
30	0.044	0.063	0.072
45	0.055	0.080	0.092
50	0.059	0.085	0.098
60	0.067	0.097	0.111

DMBM data used to model harvest rate, season length, and hunter number for two cohorts of wood ducks. (*Source*: data from P. Garrettson, DMBM).

Wood Duck Harvest Rates

Northern Adult Male Harv Rate	Northern Adult Female Harv Rate	Season Length	Stamps Sold	Year
0.124	0.109	50	1504507	1971
0.093	0.080	50	1331038	1972
0.084	0.078	45	1261762	1973
0.088	0.089	50	1340866	1974
0.123	0.128	50	1358572	1975
0.111	0.104	50	1290857	1976
0.101	0.077	50	1306622	1977
0.093	0.106	50	1300177	1978
0.118	0.091	50	1224625	1979
0.111	0.107	50	1196517	1980
0.121	0.094	50	1132239	1981
0.093	0.079	50	1112850	1982
0.112	0.091	50	1076910	1983
0.121	0.093	50	1116024	1984
0.060	0.056	40	1033738	1985
0.066	0.059	40	1061606	1986
0.077	0.068	40	988713	1987
0.053	0.039	30	850725	1988
0.055	0.042	30	859877	1989
0.051	0.045	30	883953	1990
0.058	0.048	30	867156	1991
0.041	0.039	30	854728	1992
0.050	0.040	30	863085	1993
0.068	0.049	40	932169	1994
0.073	0.053	50	960304	1995
0.074	0.063	50	993223	1996
0.072	0.057	60	1065498	1997
0.094	0.072	60	1040909	1998
0.109	0.095	60	1055888	1999
0.100	0.095	60	1053834	2000
0.088	0.075	60	1049479	2001
0.089	0.074	60	1024931	2002
0.108	0.088	60	1010035	2003
0.093	0.073	60	977490	2004