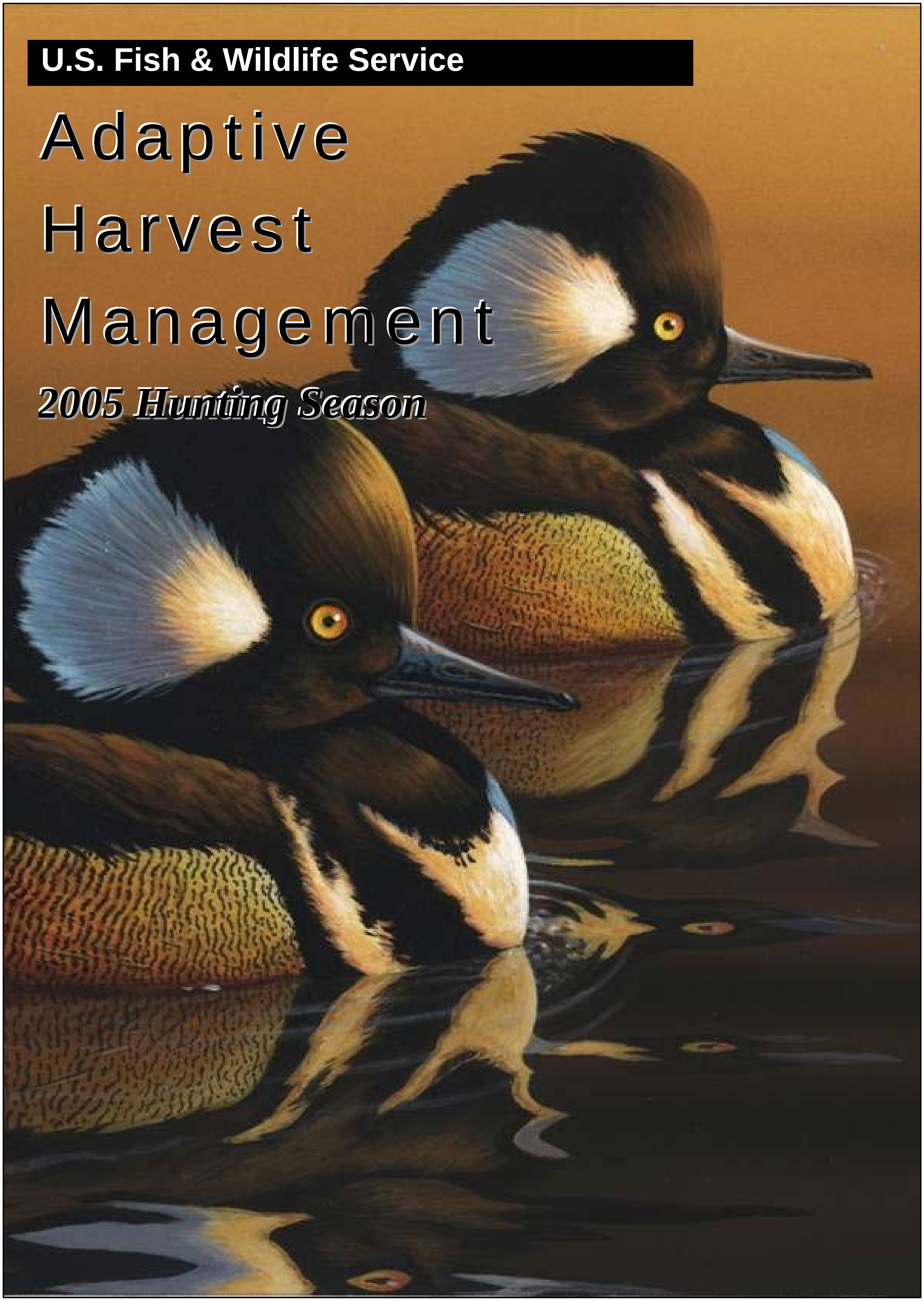
U.S. Fish & Wildlife Service

Adaptive Harvest Management

2005 Hunting Season



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PREFACE

The process of setting waterfowl hunting regulations is conducted annually in the United States (Blohm 1989). This process involves a number of meetings where the status of waterfowl is reviewed by the agencies responsible for setting hunting regulations. In addition, the U.S. Fish and Wildlife Service (USFWS) publishes proposed regulations in the *Federal Register* to allow public comment. This document is part of a series of reports intended to support development of harvest regulations for the 2005 hunting season. Specifically, this report is intended to provide waterfowl managers and the public with information about the use of adaptive harvest management (AHM) for setting duck-hunting regulations in the United States. This report provides the most current data, analyses, and decision-making protocols. However, adaptive management is a dynamic process and some information presented in this report will differ from that in previous reports.

Citation: U.S. Fish and Wildlife Service. 2005. Adaptive Harvest Management: 2005 Hunting Season. U.S. Dept. Interior, Washington, D.C. 43pp.

ACKNOWLEDGMENTS

A working group comprised of representatives from the USFWS, the Canadian Wildlife Service (CWS), and the four Flyway Councils (Appendix A) was established in 1992 to review the scientific basis for managing waterfowl harvests. The working group, supported by technical experts from the waterfowl management and research community, subsequently proposed a framework for adaptive harvest management, which was first implemented in 1995. The USFWS expresses its gratitude to the AHM Working Group and to the many other individuals, organizations, and agencies that have contributed to the development and implementation of AHM.

This report was prepared by the USFWS Division of Migratory Bird Management. F. Johnson and G. Boomer were the principal authors. Individuals that provided essential information or otherwise assisted with report preparation were D. Case (D.J. Case & Assoc.), M. Conroy (U.S. Geological Survey [USGS]), E. Cooch (Cornell University), P. Garrettson (USFWS), W. Harvey (Maryland Dept. of Natural Resources), R. Raftovich (USFWS), E. Reed (Canadian Wildlife Service), K. Richkus (USFWS), J. Royle (USGS), M. Runge (USGS), J. Serie, (USFWS), S. Sheaffer (Cornell University), and K. Wilkins (USFWS). Comments regarding this document should be sent to the Chief, Division of Migratory Bird Management - USFWS, 4401 North Fairfax Drive, MS MSP-4107, Arlington, VA 22203.

Cover art: A portion of Mark Anderson's painting of hooded mergansers (*Lophodytes cucullatus*), which was chosen for the 2005 federal "duck stamp."

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This report and others regarding Adaptive Harvest Management are available online at http://migratorybirds.fws.gov.

EXECUTIVE SUMMARY

In 1995 the U.S. Fish and Wildlife Service (USFWS) implemented the Adaptive Harvest Management (AHM) program for setting duck hunting regulations in the United States. The AHM approach provides a framework for making objective decisions in the face of incomplete knowledge concerning waterfowl population dynamics and regulatory impacts.

The original AHM protocol was based solely on the dynamics of midcontinent mallards, but efforts are being made to account for mallards breeding eastward and westward of the midcontinent region. The challenge for managers is to vary hunting regulations among Flyways in a manner that recognizes each Flyway's unique breeding-ground derivation of mallards. For the 2005 hunting season, the USFWS will continue to consider a regulatory choice for the Atlantic Flyway that depends exclusively on the status of eastern mallards. This arrangement continues to be considered provisional, however, until the implications of this approach are better understood. The prescribed regulatory choice for the Mississippi, Central, and Pacific Flyways continues to depend exclusively on the status of midcontinent mallards. Investigations of the dynamics of western mallards (and their potential effect on regulations in the West) are continuing and the USFWS is not yet prepared to recommend an AHM protocol for this mallard stock.

The mallard population models that are the basis for prescribing hunting regulations were revised extensively in 2002. These revised models account for an apparent positive bias in estimates of survival and reproductive rates, and also allow for alternative hypotheses concerning the effects of harvest and the environment in regulating population size. Model-specific weights reflect the relative confidence in alternative hypotheses, and are updated annually using comparisons of predicted and observed population sizes. For midcontinent mallards, current model weights favor the weakly density-dependent reproductive hypothesis (91%). Evidence for the additive-mortality hypothesis remains equivocal (58%). For eastern mallards, current model weights favor the strongly density-dependent reproductive hypothesis (64%). By consensus, hunting mortality is assumed to be additive in eastern mallards.

For the 2004 hunting season, the USFWS is continuing to consider the same regulatory alternatives as last year. The nature of the restrictive, moderate, and liberal alternatives has remained essentially unchanged since 1997, except that extended framework dates have been offered in the moderate and liberal alternatives since 2002. Also, at the request of the Flyway Councils in 2003 the USFWS agreed to exclude closed duck-hunting seasons from the AHM protocol when the breeding-population size of midcontinent mallards is $\geq$5.5 million (traditional survey area plus the Great Lakes region).

Harvest rates associated with the each of the regulatory alternatives are predicted using Bayesian statistical methods. Essentially, the idea is to use historical information to develop initial harvest-rate predictions, to make regulatory decisions based on those predictions, and then to observe realized harvest rates. Those observed harvest rates, in turn, are used to update the predictions. Using this approach, predictions of harvest rates of mallards under the regulatory alternatives have been updated based on band-reporting rate studies conducted since 1998. Estimated harvest rates from the 2002-2004 liberal hunting seasons have averaged 0.12 and 0.15 for adult male midcontinent and eastern mallards, respectively. The estimated marginal effect of framework-date extensions has been about 11% and 4% on mid-continent and eastern mallards, respectively.

Optimal regulatory strategies for the 2005 hunting season were calculated using: (1) harvest-management objectives specific to each mallard stock; (2) the 2004 regulatory alternatives; and (3) current population models and associated weights for midcontinent and eastern mallards. Based on this year's survey results of 7.54 million midcontinent mallards (traditional survey area plus MN, WI, and MI), 3.92 million ponds in Prairie Canada, and 1.05 million eastern mallards, the optimal regulatory choice for all four Flyways is the liberal alternative.

BACKGROUND

The annual process of setting duck-hunting regulations in the United States is based on a system of resource monitoring, data analyses, and rule-making (Blohm 1989). Each year, monitoring activities such as aerial surveys and hunter questionnaires provide information on population size, habitat conditions, and harvest levels. Data collected from this monitoring program are analyzed each year, and proposals for duck-hunting regulations are developed by the Flyway Councils, States, and USFWS. After extensive public review, the USFWS announces regulatory guidelines within which States can set their hunting seasons.

In 1995, the USFWS adopted the concept of adaptive resource management (Walters 1986) for regulating duck harvests in the United States. This approach explicitly recognizes that the consequences of hunting regulations cannot be predicted with certainty, and provides a framework for making objective decisions in the face of that uncertainty (Williams and Johnson 1995). Inherent in the adaptive approach is an awareness that management performance can be maximized only if regulatory effects can be predicted reliably. Thus, adaptive management relies on an iterative cycle of monitoring, assessment, and decision-making to clarify the relationships among hunting regulations, harvests, and waterfowl abundance.

In regulating waterfowl harvests, managers face four fundamental sources of uncertainty (Nichols et al. 1995, Johnson et al. 1996, Williams et al. 1996):

(1) environmental variation - the temporal and spatial variation in weather conditions and other key features of waterfowl habitat; an example is the annual change in the number of ponds in the Prairie Pothole Region, where water conditions influence duck reproductive success;
(2) partial controllability - the ability of managers to control harvest only within limits; the harvest resulting from a particular set of hunting regulations cannot be predicted with certainty because of variation in weather conditions, timing of migration, hunter effort, and other factors;
(3) partial observability - the ability to estimate key population attributes (e.g., population size, reproductive rate, harvest) only within the precision afforded by extant monitoring programs; and
(4) structural uncertainty - an incomplete understanding of biological processes; a familiar example is the long-standing debate about whether harvest is additive to other sources of mortality or whether populations compensate for hunting losses through reduced natural mortality. Structural uncertainty increases contentiousness in the decision-making process and decreases the extent to which managers can meet long-term conservation goals.

AHM was developed as a systematic process for dealing objectively with these uncertainties. The key components of AHM include (Johnson et al. 1993, Williams and Johnson 1995):

(1) a limited number of regulatory alternatives, which describe Flyway-specific season lengths, bag limits, and framework dates;
(2) a set of population models describing various hypotheses about the effects of harvest and environmental factors on waterfowl abundance;
(3) a measure of reliability (probability or "weight") for each population model; and
(4) a mathematical description of the objective(s) of harvest management (i.e., an "objective function"), by which alternative regulatory strategies can be compared.

These components are used in a stochastic optimization procedure to derive a regulatory strategy. A regulatory strategy specifies the optimal regulatory choice, with respect to the stated management objectives, for each possible combination of breeding population size, environmental conditions, and model weights (Johnson et al. 1997). The setting of annual hunting regulations then involves an iterative process:

(1) each year, an optimal regulatory choice is identified based on resource and environmental conditions, and on current model weights;

(2) after the regulatory decision is made, model-specific predictions for subsequent breeding population size are determined;
(3) when monitoring data become available, model weights are increased to the extent that observations of population size agree with predictions, and decreased to the extent that they disagree; and
(4) the new model weights are used to start another iteration of the process.

By iteratively updating model weights and optimizing regulatory choices, the process should eventually identify which model is the best overall predictor of changes in population abundance. The process is optimal in the sense that it provides the regulatory choice each year necessary to maximize management performance. It is adaptive in the sense that the harvest strategy “evolves” to account for new knowledge generated by a comparison of predicted and observed population sizes.

MALLARD STOCKS AND FLYWAY MANAGEMENT

Since its inception, AHM has focused on the population dynamics and harvest potential of mallards, especially those breeding in midcontinent North America. Mallards constitute a large portion of the total U.S. duck harvest, and traditionally have been a reliable indicator of the status of many other species. As management capabilities have grown, there has been increasing interest in the ecology and management of breeding mallards that occur outside the midcontinent region. Geographic differences in the reproduction, mortality, and migrations of mallard stocks suggest that there may be corresponding differences in optimal levels of sport harvest. The ability to regulate harvests of mallards originating from various breeding areas is complicated, however, by the fact that a large degree of mixing occurs during the hunting season. The challenge for managers, then, is to vary hunting regulations among Flyways in a manner that recognizes each Flyway’s unique breeding-ground derivation of mallards. Of course, no Flyway receives mallards exclusively from one breeding area, and so Flyway-specific harvest strategies ideally must account for multiple breeding stocks that are exposed to a common harvest.

The optimization procedures used in AHM can account for breeding populations of mallards beyond the midcontinent region, and for the manner in which these ducks distribute themselves among the Flyways during the hunting season. An optimal approach would allow for Flyway-specific regulatory strategies, which in a sense represent for each Flyway an average of the optimal harvest strategies for each contributing breeding stock, weighted by the relative size of each stock in the fall flight. This “joint optimization” of multiple mallard stocks requires:

(1) models of population dynamics for all recognized stocks of mallards;
(2) an objective function that accounts for harvest-management goals for all mallard stocks in the aggregate; and
(3) decision rules allowing Flyway-specific regulatory choices.

Joint optimization of multiple stocks presents many challenges in terms of population modeling, parameter estimation, and computation of regulatory strategies. These challenges cannot always be overcome due to limitations in monitoring and assessment programs, and in access to sufficient computing resources. In some cases, it may be possible to impose constraints or assumptions that simplify the problem. Although sub-optimal by design, these constrained regulatory strategies may perform nearly as well as those that are optimal, particularly in cases where breeding stocks differ little in their ability to support harvest, where Flyways do not receive significant numbers of birds from more than one breeding stock, or where management outcomes are highly uncertain.

Currently, two stocks of mallards are officially recognized for the purposes of AHM (Fig. 1). We continue to use a constrained approach to the optimization of these stocks’ harvest, whereby the Atlantic Flyway regulatory strategy is based exclusively on the status of eastern mallards, and the regulatory strategy for the remaining Flyways is based exclusively on the status of midcontinent mallards. This approach has been determined to perform nearly as well as a joint-optimization approach because mixing of the two stocks during the hunting

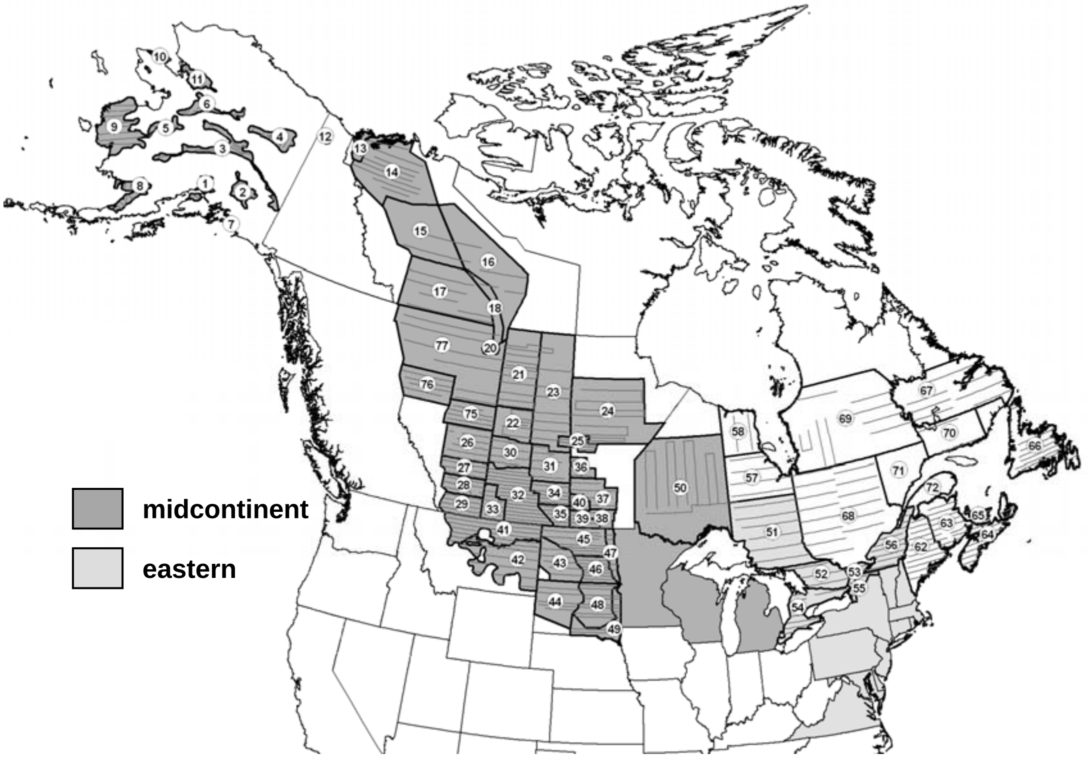


Fig 1. Survey areas currently assigned to the midcontinent and eastern stocks of mallards for the purposes of AHM. Delineation of the western-mallard stock is pending further review of population monitoring programs.

season is limited. However, the approach continues to be considered provisional until its implications are better understood.

MALLARD POPULATION DYNAMICS

Midcontinent Mallards

Population size.--For the purposes of AHM, midcontinent mallards currently are defined as those breeding in federal survey strata 1-18, 20-50, and 75-77 (i.e., the “traditional” survey area), and in Minnesota, Wisconsin, and Michigan. Estimates of the abundance of this midcontinent population are available only since 1992 (Table 1).

Population models.-In 2002 we extensively revised the set of alternative models describing the population dynamics of midcontinent mallards (Runge et al. 2002, USFWS 2002). Collectively, the models express uncertainty (or disagreement) about whether harvest is an additive or compensatory form of mortality (Burnham et al. 1984), and whether the reproductive process is weakly or strongly density-dependent (i.e., the degree to which reproductive rates decline with increasing population size).

Table 1. Estimates (N) and standard errors (SE) of mallards (in millions) in spring in the traditional survey area (strata 1-18, 20-50, and 75-77) and the states of Minnesota, Wisconsin, and Michigan.

Year	**Traditional surveys**		**State surveys**		**Total**	
	N	**SE**	**N**	**SE**	**N**	**SE**
1992	5.9761	0.2410	0.9946	0.1597	6.9706	0.2891
1993	5.7083	0.2089	0.9347	0.1457	6.6430	0.2547
1994	6.9801	0.2828	1.1505	0.1163	8.1306	0.3058
1995	8.2694	0.2875	1.1214	0.1965	9.3908	0.3482
1996	7.9413	0.2629	1.0251	0.1443	8.9664	0.2999
1997	9.9397	0.3085	1.0777	0.1445	11.0174	0.3407
1998	9.6404	0.3016	1.1224	0.1792	10.7628	0.3508
1999	10.8057	0.3445	1.0591	0.2122	11.8648	0.4046
2000	9.4702	0.2902	1.2350	0.1761	10.7052	0.3395
2001	7.9040	0.2269	0.8622	0.1086	8.7662	0.2516
2002	7.5037	0.2465	1.0820	0.1152	8.5857	0.2721
2003	7.9497	0.2673	0.8360	0.0734	8.7857	0.2772
2004	7.4253	0.2820	0.9333	0.0748	8.3586	0.2917
2005	6.7553	0.2808	0.7862	0.06503	7.5415	0.2883

All population models for midcontinent mallards share a common “balance equation” to predict changes in breeding-population size as a function of annual survival and reproductive rates:

$$N_{t+1} = N_t \left(mS_{t,AM} + (1-m)\left(S_{t,AF} + R_t \left(S_{t,JF} + S_{t,JM}\, \phi_F^{sum} / \phi_M^{sum} \right)\right)\right)$$

where:
N = breeding population size,
m = proportion of males in the breeding population,
S_{AM}, S_{AF}, S_{JF}, and S_{JM} = survival rates of adult males, adult females, young females, and young males, respectively,
R = reproductive rate, defined as the fall age ratio of females,
$\phi_F^{sum} / \phi_M^{sum}$ = the ratio of female (F) to male (M) summer survival, and
t = year.

We assumed that m and $\phi_F^{sum} / \phi_M^{sum}$ are fixed and known. We also assumed, based in part on information provided by Blohm et al. (1987), the ratio of female to male summer survival was equivalent to the ratio of annual survival rates in the absence of harvest. Based on this assumption, we estimated $\phi_F^{sum} / \phi_M^{sum}$ = 0.897. To estimate m we expressed the balance equation in matrix form:

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

and substituted the constant ratio of summer survival and mean values of estimated annual survival and reproductive rates. The right eigenvector of the transition matrix is the stable sex structure that the breeding population eventually would attain with these constant demographic rates. This eigenvector yielded an estimate of $m = 0.5246$.

Using estimates of annual survival and reproductive rates, the balance equation for midcontinent mallards over-predicted observed population sizes by 10.8% on average. The source of the bias is unknown, so we modified the balance equation to eliminate the bias by adjusting both survival and reproductive rates:

$$N_{t+1} = \gamma_S N_t \left(m S_{t,AM} + (1-m)\left(S_{t,AF} + \gamma_R R_t \left(S_{t,JF} + S_{t,JM} \ \phi_F^{sum} / \phi_M^{sum} \right)\right)\right)$$

where γ denotes the bias-correction factors for survival (S) and reproduction (R). We used a least squares approach to estimate $\gamma_S = 0.9479$ and $\gamma_R = 0.8620$.

***Survival process.*–**We considered two alternative hypotheses for the relationship between annual survival and harvest rates. For both models, we assumed that survival in the absence of harvest was the same for adults and young of the same sex. In the model where harvest mortality is additive to natural mortality:

$$S_{t,sex,age} = s_{0,sex}^{A} \left(1 - K_{t,sex,age}\right)$$

and in the model where changes in natural mortality compensate for harvest losses (up to some threshold):

$$S_{t,sex,age} = \begin{cases} s_{0,sex}^{C} & if \ K_{t,sex,age} \le 1 - s_{0,sex}^{C} \\ 1 - K_{t,sex,age} & if \ K_{t,sex,age} > 1 - s_{0,sex}^{C} \end{cases}$$

where s_0 = survival in the absence of harvest under the additive (A) or compensatory (C) model, and K = harvest rate adjusted for crippling loss (20%, Anderson and Burnham 1976). We averaged estimates of s_0 across banding reference areas by weighting by breeding-population size. For the additive model, $s_0 = 0.7896$ and 0.6886 for males and females, respectively. For the compensatory model, $s_0 = 0.6467$ and 0.5965 for males and females, respectively. These estimates may seem counterintuitive because survival in the absence of harvest should be the same for both models. However, estimating a common (but still sex-specific) s_0 for both models leads to alternative models that do not fit available band-recovery data equally well. More importantly, it suggests that the greatest uncertainty about survival rates is when harvest rate is within the realm of experience. By allowing s_0 to differ between additive and compensatory models, we acknowledge that the greatest uncertainty about survival rate is its value in the absence of harvest (i.e., where we have no experience).

***Reproductive process.*–**Annual reproductive rates were estimated from age ratios in the harvest of females, corrected using a constant estimate of differential vulnerability. Predictor variables were the number of ponds in May in Prairie Canada (P, in millions) and the size of the breeding population (N, in millions). We estimated the best-fitting linear model, and then calculated the 80% confidence ellipsoid for all model parameters. We chose the two points on this ellipsoid with the largest and smallest values for the effect of breeding-population size, and generated a weakly density-dependent model:

$$R_t = 0.7166 + 0.1083 P_t - 0.0373 N_t$$

and a strongly density-dependent model:

$$R_t = 1.1390 + 0.1376 P_t - 0.1131 N_t$$

Pond dynamics.–We modeled annual variation in Canadian pond numbers as a first-order autoregressive process. The estimated model was:

$$P_{t+1} = 2.2127 + 0.3420 P_t + \varepsilon_t$$

where ponds are in millions and ε_t is normally distributed with mean = 0 and variance = 1.2567.

Variance of prediction errors.–Using the balance equation and sub-models described above, predictions of breeding-population size in year *t+1* depend only on specification of population size, pond numbers, and harvest rate in year *t*. For the period in which comparisons were possible, we compared these predictions with observed population sizes.

We estimated the prediction-error variance by setting:

$$e_t = \ln\left(N_t^{obs}\right) - \ln\left(N_t^{pre}\right)$$

then assuming $e_t \sim N\left(0, \sigma^2\right)$

and estimating $\hat{\sigma}^{\mathbf{2}} = \sum_t \left[\ln\left(N_t^{obs}\right) - \ln\left(N_t^{pre}\right)\right]^{\mathbf{2}} \Big/ \left(n-1\right)$

where *obs* and *pre* are observed and predicted population sizes (in millions), respectively, and *n* = the number of years being compared. We were concerned about a variance estimate that was too small, either by chance or because the number of years in which comparisons were possible was small. Therefore, we calculated the upper 80% confidence limit for σ^2 based on a Chi-squared distribution for each combination of the alternative survival and reproductive sub-models, and then averaged them. The final estimate of σ^2 was 0.0243, equivalent to a coefficient of variation of about 17%.

Model implications.–The set of alternative population models suggests that carrying capacity (average population size in the absence of harvest) for an average number of Canadian ponds is somewhere between about 6 and 16 million mallards. The population model with additive hunting mortality and weakly density-dependent recruitment (SaRw) leads to the most conservative harvest strategy, whereas the model with compensatory hunting mortality and strongly density-dependent recruitment (ScRs) leads to the most liberal strategy. The other two models (SaRs and ScRw) lead to strategies that are intermediate between these extremes. Under the models with compensatory hunting mortality (ScRs and ScRw), the optimal strategy is to have a liberal regulation regardless of population size or number of ponds because at harvest rates achieved under the liberal alternative, harvest has no effect on population size. Under the strongly density-dependent model (ScRs), the density-dependence regulates the population and keeps it within narrow bounds. Under the weakly density-dependent model (ScRw), the density-dependence does not exert as strong a regulatory effect, and the population size fluctuates more.

Model weights.--Model weights are calculated as Bayesian probabilities, reflecting the relative ability of the individual alternative models to predict observed changes in population size. The Bayesian probability for each model is a function of the model's previous (or prior) weight and the likelihood of the observed population size under that model. We used Bayes' theorem to calculate model weights from a comparison of predicted and observed population sizes for the years 1996-2004, starting with equal model weights in 1995. For the purposes of updating, we predicted breeding-population size in the traditional survey area in year *t* + 1, from breeding-population size, Canadian ponds, and harvest rates in year *t*.

Model weights changed little until all models under-predicted the change in population size from 1998 to 1999, perhaps indicating there is a significant factor affecting population dynamics that is absent from all four models (Table 2). Throughout the period of updating model weights, there has been no clear preference for either the additive (58%) or compensatory (42%) mortality models. For most of the time frame, model weights favor the weakly density-dependent (91%) reproductive model over the strongly density-dependent (9%) one. The reader is cautioned, however, that models can sometimes make reliable predictions of population size for reasons having little to do with the biological hypotheses expressed therein (Johnson et al. 2002*b*).

Inclusion of mallards in the Great Lakes region.--Model development originally did not include mallards breeding in the states of Wisconsin, Minnesota, and Michigan, primarily because full data sets were not available from these areas to allow appropriate analysis. However, mallards in the Great Lakes region have been included in the midcontinent mallard AHM protocol since 1997 by assuming that population dynamics for these mallards are similar to those in the traditional survey area. Based on that assumption, predictions of breeding population size are scaled to reflect inclusion of mallards in the Great Lakes region. From 1992 through 2005, when population estimates were available for all three states, the average proportion of the total midcontinent mallard population that was in the Great Lakes region was 0.1143 (SD = 0.0178). We assumed a normal distribution with these parameter values to make the conversion between the traditional survey area and total breeding-population size.

Table 2. Model-specific predictions and weights for midcontinent mallards (ScRs = compensatory mortality and strongly density-dependent reproduction, ScRw = compensatory mortality and weakly density-dependent reproduction, SaRs = additive mortality and strongly density-dependent reproduction, and SaRw = additive mortality and weakly density-dependent reproduction). Model weights were assumed to be equal in 1995.

Year	**Bpop(t)**[a]	**Ponds(t)**[b]	**Harvest rate(t)**[c]		**Model**				**Observed bpop(t+1)**[a]
					ScRs	**ScRw**	**SaRs**	**SaRw**	
1995	8.2694	3.8925	0.1198	predicted Bpop(t+1):	7.6740	8.0153	7.7037	8.0280	7.9413
				weight(t+1):	0.2469	0.2525	0.2482	0.2524	
1996	7.9413	5.0026	0.1184	predicted Bpop(t+1):	8.0580	8.1776	8.0702	8.1841	9.9397
				weight(t+1):	0.2305	0.2666	0.2348	0.2681	
1997	9.9397	5.0610	0.1166	predicted bpop(t+1):	9.0964	9.9258	9.1833	9.9768	9.6404
				weight(t+1):	0.2235	0.2722	0.2324	0.2719	
1998	9.6404	2.5217	0.1102	predicted bpop(t+1):	7.4334	8.4655	7.6471	8.6474	10.8057
				weight(t+1):	0.0596	0.3801	0.0944	0.4659	
1999	10.8057	3.8620	0.1004	predicted bpop(t+1):	8.5916	9.9905	8.9478	10.3308	9.4702
				weight(t+1):	0.0548	0.4007	0.0987	0.4458	
2000	9.4702	2.4222	0.1264	predicted bpop(t+1):	7.3262	8.2969	7.3621	8.2718	7.9040
				weight(t+1):	0.0514	0.4033	0.0940	0.4513	
2001	7.9040	2.7472	0.1077	predicted bpop(t+1):	6.9153	7.2626	7.0917	7.4301	7.5040
				weight(t+1):	0.0459	0.4035	0.0900	0.4607	
2002	7.5040	1.4390	0.1133	predicted bpop(t+1):	6.1036	6.4607	6.2325	6.5766	7.9497
				weight(t+1):	0.0257	0.3928	0.0628	0.5187	
2003	7.9497	3.5223	0.1132	predicted bpop(t+1):	7.3237	7.6031	7.4291	7.6983	7.4253
				weight(t+1):	0.0261	0.3956	0.0639	0.5144	
2004	7.4253	2.5126	0.1245	predicted bpop(t+1):	6.5706	6.7972	6.5662	6.7794	6.7553
				weight(t+1):	0.0257	0.3960	0.0630	0.5152	

[a] Breeding population size (in millions) in the traditional survey area only (i.e., does not include Minnesota, Michigan, and Wisconsin) in year t.

[b] Ponds (in millions) in May in Prairie Canada.

[c] Harvest rate of adult-male midcontinent mallards. Harvest rates for 1995 and 1996 were based on recovery rates of standard bands, corrected for band-reporting rates. For 1997, we used the most recent estimate of the posterior mean of the harvest rate under the 1997 liberal regulatory alternative. For 1998-2004, we used the most recent posterior estimates of the actual harvest rates in those years.

Eastern Mallards

Population size.--For purposes of AHM, eastern mallards are defined as those breeding in southern Ontario and Quebec (federal survey strata 51-54 and 56) and in the northeastern U.S. (state plot surveys; Heusman and Sauer 2000) (see Fig. 1). Estimates of population size have varied from 856 thousand to 1.1 million since 1990, with the majority of the population accounted for in the northeastern U.S. (Table 3). The reader is cautioned that these estimates differ from those reported in the USFWS annual waterfowl trend and status reports, which include composite estimates based on more fixed-wing strata in eastern Canada and helicopter surveys conducted by the Canadian Wildlife Service.

Table 3. Estimates (N) and associated standard errors (SE) of mallards (in thousands) in spring in the northeastern U.S. (state plot surveys) and eastern Canada (federal survey strata 51-54 and 56).

	State surveys		**Federal surveys**		**Total**	
Year	**N**	**SE**	**N**	**SE**	**N**	**SE**
1990	665.1	78.3	190.7	47.2	855.8	91.4
1991	779.2	88.3	152.8	33.7	932.0	94.5
1992	562.2	47.9	320.3	53.0	882.5	71.5
1993	683.1	49.7	292.1	48.2	975.2	69.3
1994	853.1	62.7	219.5	28.2	1072.5	68.7
1995	862.8	70.2	184.4	40.0	1047.2	80.9
1996	848.4	61.1	283.1	55.7	1131.5	82.6
1997	795.1	49.6	212.1	39.6	1007.2	63.4
1998	775.1	49.7	263.8	67.2	1038.9	83.6
1999	879.7	60.2	212.5	36.9	1092.2	70.6
2000	757.8	48.5	132.3	26.4	890.0	55.2
2001	807.5	51.4	200.2	35.6	1007.7	62.5
2002	834.1	56.2	171.3	30.0	1005.4	63.8
2003	731.8	47.0	308.3	55.4	1040.1	72.6
2004	809.1	51.8	301.5	53.3	1110.7	74.3
2005	753.6	53.6	293.4	53.1	1047.0	75.5

Population models.–We also revised the population models for eastern mallards in 2002 (Johnson et al. 2002*a*, USFWS 2002). The current set of six models: (1) relies solely on federal and state waterfowl surveys (rather than the Breeding Bird Survey) to predict reproductive rates; (2) allows for the possibility of a positive bias in estimates of survival or reproductive rates; (3) incorporates competing hypotheses of strongly and weakly density-dependent reproduction; and (4) assumes that hunting mortality is additive to other sources of mortality.

As with midcontinent mallards, all population models for eastern mallards share a common balance equation to predict changes in breeding-population size as a function of annual survival and reproductive rates:

$$N_{t+1} = N_t \cdot \left(\left(p \cdot S_t^{am} \right) + \left((1-p) \cdot S_t^{af} \right) + \left(p \cdot \left(A_t^m / d \right) \cdot S_t^{ym} \right) + \left(p \cdot \left(A_t^m / d \right) \cdot \psi \cdot S_t^{yf} \right) \right)$$

where:
N = breeding-population size,
p = proportion of males in the breeding population,
S^{am}, S^{af}, S^{ym}, and S^{yf} = survival rates of adult males, adult females, young males, and young females, respectively,
A^m = ratio of young males to adult males in the harvest,
d = ratio of young male to adult male direct recovery rates,
ψ = the ratio of male to female summer survival, and
t = year.

In this balance equation, we assume that p, d, and ψ are fixed and known. The parameter ψ is necessary to account for the difference in anniversary date between the breeding-population survey (May) and the survival and reproductive rate estimates (August). This model also assumes that the sex ratio of fledged young is 1:1; hence A^m/d appears twice in the balance equation. We estimated $d = 1.043$ as the median ratio of young:adult male band-recovery rates in those states from which wing receipts were obtained. We estimated $\psi = 1.216$ by regressing through the origin estimates of male survival against female survival in the absence of harvest, assuming that differences in natural mortality between males and females occur principally in summer. To estimate p, we used a population projection matrix of the form:

$$\begin{bmatrix} M_{t+1} \\ F_{t+1} \end{bmatrix} = \begin{bmatrix} S^{am} + \left(A^m / d \right) \cdot S^{ym} & 0 \\ \left(A^m / d \right) \cdot \psi \cdot S^{yf} & S^{af} \end{bmatrix} \begin{bmatrix} M_{t+1} \\ F_{t+1} \end{bmatrix}$$

where M and F are the relative number of males and females in the breeding populations, respectively. To parameterize the projection matrix we used average annual survival rate and age ratio estimates, and the estimates of d and ψ provided above. The right eigenvector of the projection matrix is the stable proportion of males and females the breeding population eventually would attain in the face of constant demographic rates. This eigenvector yielded an estimate of $p = 0.544$.

We also attempted to determine whether estimates of survival and reproductive rates were unbiased. We relied on the balance equation provided above, except that we included additional parameters to correct for any bias that might exist. Because we were unsure of the source(s) of potential bias, we alternatively assumed that any bias resided solely in survival rates:

$$N_{t+1} = N_t \cdot \Omega \cdot \left(\left(p \cdot S_t^{am} \right) + \left((1-p) \cdot S_t^{af} \right) + \left(p \cdot \left(A_t^m / d \right) \cdot S_t^{ym} \right) + \left(p \cdot \left(A_t^m / d \right) \cdot \psi \cdot S_t^{yf} \right) \right)$$

(where Ω is the bias-correction factor for survival rates), or solely in reproductive rates:

$$N_{t+1} = N_t \cdot \left(\left(p \cdot S_t^{am} \right) + \left((1-p) \cdot S_t^{af} \right) + \left(p \cdot \alpha \cdot \left(A_t^m / d \right) \cdot S_t^{ym} \right) + \left(p \cdot \alpha \cdot \left(A_t^m / d \right) \cdot \psi \cdot S_t^{yf} \right) \right)$$

(where α is the bias-correction factor for reproductive rates). We estimated Ω and α by determining the values of these parameters that minimized the sum of squared differences between observed and predicted population sizes. Based on this analysis, $\Omega = 0.836$ and $\alpha = 0.701$, suggesting a positive bias in survival or reproductive rates. However, because of the limited number of years available for comparing observed and predicted population sizes, we also retained the balance equation that assumes estimates of survival and reproductive rates are unbiased.

***Survival process.*–**For purposes of AHM, annual survival rates must be predicted based on the specification of regulation-specific harvest rates (and perhaps on other uncontrolled factors). Annual survival for each age (*i*) and sex (*j*) class under a given regulatory alternative is:

$$S_t^{i,j} = \bar{\theta}^{\,j} \cdot \left(1 - \frac{\left(h_t^{am} \cdot v^{i,j}\right)}{\left(1 - c\right)}\right)$$

where:

S = annual survival,

$\bar{\theta}^{\,j}$ = mean survival from natural causes,

h^{am} = harvest rate of adult males, and

v = harvest vulnerability relative to adult males,

c = rate of crippling (unretrieved harvest).

This model assumes that annual variation in survival is due solely to variation in harvest rates, that relative harvest vulnerability of the different age-sex classes is fixed and known, and that survival from natural causes is fixed at its sample mean. We estimated $\bar{\theta}^{\,j}$ = 0.7307 and 0.5950 for males and females, respectively.

***Reproductive process.*–**As with survival, annual reproductive rates must be predicted in advance of setting regulations. We relied on the apparent relationship between breeding-population size and reproductive rates:

$$R_t = a \cdot \exp\left(b \cdot N_t\right)$$

where R_t is the reproductive rate (i.e., A_t^m / d), N_t is breeding-population size in millions, and a and b are model parameters. The least-squares parameter estimates were a = 2.508 and b = -0.875. Because of both the importance and uncertainty of the relationship between population size and reproduction, we specified two alternative models in which the slope (b) was fixed at the least-squares estimate ± one standard error, and in which the intercepts (a) were subsequently re-estimated. This provided alternative hypotheses of strongly density-dependent (a = 4.154, b = -1.377) and weakly density-dependent reproduction (a = 1.518, b = -0.373).

***Variance of prediction errors.*--**Using the balance equations and sub-models provided above, predictions of breeding-population size in year $t+1$ depend only on the specification of a regulatory alternative and on an estimate of population size in year t. For the period in which comparisons were possible (1991-96), we were interested in how well these predictions corresponded with observed population sizes. In making these comparisons, we were primarily concerned with how well the bias-corrected balance equations and reproductive and survival sub-models performed. Therefore, we relied on estimates of harvest rates rather than regulations as model inputs.

We estimated the prediction-error variance by setting:

$$e_t = \ln\left(N_t^{obs}\right) - \ln\left(N_t^{pre}\right)$$

then assuming $e_t \sim N\left(0, \sigma^2\right)$

and estimating $\hat{\sigma}^2 = \sum_t \left[\ln\left(N_t^{obs}\right) - \ln\left(N_t^{pre}\right)\right]^2 \Big/ n$

where *obs* and *pre* are observed and predicted population sizes (in millions), respectively, and $n = 6$.

Variance estimates were similar regardless of whether we assumed that the bias was in reproductive rates or in survival, or whether we assumed that reproduction was strongly or weakly density-dependent. Thus, we averaged variance estimates to provide a final estimate of $\sigma^2 = 0.006$, which is equivalent to a coefficient of variation (*CV*) of 8.0%. We were concerned, however, about the small number of years available for estimating this variance. Therefore, we estimated an 80% confidence interval for σ^2 based on a Chi-squared distribution and used the upper limit for $\sigma^2 = 0.018$ (i.e., $CV = 14.5\%$) to express the additional uncertainty about the magnitude of prediction errors attributable to potentially important environmental effects not expressed by the models.

Model implications.--Model-specific regulatory strategies based on the hypothesis of weakly density-dependent reproduction are considerably more conservative than those based on the hypothesis of strongly density-dependent reproduction. The three models with weakly density-dependent reproduction suggest a carrying capacity (i.e., average population size in the absence of harvest) >2.0 million mallards, and prescribe extremely restrictive regulations for population size <1.0 million. The three models with strongly density-dependent reproduction suggest a carrying capacity of about 1.5 million mallards, and prescribe liberal regulations for population sizes >300 thousand. Optimal regulatory strategies are relatively insensitive to whether models include a bias correction or not. All model-specific regulatory strategies are “knife-edged,” meaning that large differences in the optimal regulatory choice can be precipitated by only small changes in breeding-population size. This result is at least partially due to the small differences in predicted harvest rates among the current regulatory alternatives (see the section on Regulatory Alternatives later in this report).

Model weights.**—**Beginning this year, we used Bayes’ theorem to calculate model weights from a comparison of predicted and observed population sizes for the years 1996-2004. We calculated weights for the alternative models based on an assumption of equal model weights in 1996 (the last year data was used to develop most model components) and on estimates of year-specific harvest rates (Appendix B). There is no single model that is clearly favored over the others at the end of the time frame, although collectively the models with strongly density-dependent reproduction are better predictors of changes in population size as those with weak density dependence. In addition, the change this year from the use of predicted to estimated harvest rates in the updating of model weights led to substantial evidence of bias in extant estimates of survival and/or reproductive rates (93%).

Table 4. Model-specific predictions and weights for eastern mallards (BnRw = no bias-correction and weakly density-dependent reproduction, BnRs = no bias-correction and strongly density-dependent reproduction, BsRw = bias-corrected survival rates and weakly density-dependent reproduction, BsRs = bias-corrected survival rates and strongly density-dependent reproduction, BrRw = bias-corrected reproductive rates and weakly density-dependent reproduction, and BrRs = bias-corrected reproductive rates and strongly density-dependent reproduction). Model weights were assumed to be equal in 1996.

Year	**Bpop(t)**[a]	**Harvest rate(t)**[b]		**Model**						**Observed bpop(t+1)**[a]
				BnRw	**BnRs**	**BsRw**	**BsRs**	**BrRw**	**BrRs**	
1996	1.1315	0.1510	predicted bpop(t+1):	1.2577	1.1791	1.0511	0.9854	1.0625	1.0074	1.0072
			weight(t+1):	0.0565	0.1100	0.2053	0.2129	0.1996	0.2157	
1997	1.0072	0.1626	predicted bpop(t+1):	1.1197	1.1175	0.9357	0.9339	0.9428	0.9412	1.0389
			weight(t+1):	0.0628	0.1232	0.1974	0.2024	0.2000	0.2142	
1998	1.0389	0.1626	predicted bpop(t+1):	1.1477	1.1267	0.9592	0.9416	0.9674	0.9527	1.0922
			weight(t+1):	0.0866	0.1769	0.1842	0.1643	0.1977	0.1902	
1999	1.0922	0.1626	predicted bpop(t+1):	1.1941	1.1412	0.9980	0.9538	1.0083	0.9712	0.8900
			weight(t+1):	0.0139	0.0552	0.2155	0.2409	0.2164	0.2583	
2000	0.8900	0.1626	predicted bpop(t+1):	1.0127	1.0786	0.8464	0.9014	0.8494	0.8956	1.0077
			weight(t+1):	0.0229	0.0806	0.1562	0.2847	0.1623	0.2932	
2001	1.0077	0.1626	predicted bpop(t+1):	1.1201	1.1176	0.9361	0.9340	0.9432	0.9414	1.0054
			weight(t+1):	0.0193	0.0689	0.1574	0.2844	0.1681	0.3018	
2002	1.0054	0.1626	predicted bpop(t+1):	1.1181	1.1169	0.9344	0.9335	0.9414	0.9406	1.0401
			weight(t+1):	0.0222	0.0793	0.1523	0.2736	0.1696	0.3031	
2003	1.0401	0.1471	predicted bpop(t+1):	1.1864	1.1638	0.9915	0.9726	0.9990	0.9832	1.1107
			weight(t+1):	0.0282	0.1069	0.1537	0.2427	0.1789	0.2896	
2004	1.1107	0.1342	predicted bpop(t+1):	1.2825	1.2139	1.0718	1.0145	1.0815	1.0335	1.0470
			weight(t+1):	0.0101	0.0643	0.1649	0.2573	0.1894	0.3140	

[a] Breeding population size (in millions) in the northeastern U.S. (state plot surveys) and eastern Canada (federal survey strata 51-54 and 56) in year t.

[b] Harvest rate of adult-male eastern mallards. The harvest rate for 1996 was based on the recovery rates of standard bands, corrected for band-reporting rates. For 1997-2001, we used the most recent estimate of the posterior mean of the harvest rate under the liberal regulatory alternatives for those years. For 2002-2004, we used the most recent posterior estimates of the actual harvest rates in those years.

Western Mallards

Substantial numbers of mallards occur in the states of the Pacific Flyway (including Alaska), British Columbia, and the Yukon Territory during the breeding season. The distribution of these mallards during fall and winter is centered in the Pacific Flyway (Munro and Kimball 1982). Unfortunately, data-collection programs for understanding and monitoring the dynamics of this mallard stock are highly fragmented in both time and space. This makes it difficult to aggregate monitoring instruments in a way that can be used to reliably model this stock's dynamics and, thus, to establish criteria for regulatory decision-making under AHM. Another complicating factor is that federal survey strata 1-12 in Alaska and the Yukon are within the current geographic bounds of midcontinent mallards. The AHM Working Group is continuing its investigations of western mallards and while it is not prepared to recommend an AHM protocol at this time, progress is being made on a number of issues:

1) *Population modeling* – In August 2004, Drs. Herzog and Sedinger circulated a report entitled "Western Mallard Population Model: Report to the Wildlife Management Institute and the Pacific Flyway Study Committee." The report represents an extensive body of work designed to help define the spatial bounds of a western mallard stock, to estimate breeding population size, survival and recruitment rates, and to synthesize population models that could be used for management purposes.

2) *Breeding populations surveys* – The development of AHM for western mallards continues to present technical challenges that make implementation much more difficult than with either midcontinent or eastern mallards. In particular, we remain concerned about our ability to reliably determine changes in the population size of western mallards based on a collection of surveys conducted independently by Pacific Flyway States and the Province of British Columbia. These surveys tend to vary in design and intensity, and in some cases lack measures of precision (i.e., sampling error). For example, we still consider the methods for estimating mallard abundance in British Columbia to be in the development and evaluation phase, and there are as yet unanswered questions about how mallard abundance will be determined there on an operational basis. Toward that end, experimental fixed-wing surveys were conducted in British Columbia this spring in a collaborative effort by the USFWS and the Canadian Wildlife Service. Unfortunately, the terrain required aircraft speeds and altitudes that were not conducive for surveying waterfowl, and fixed-wing surveys were deemed an unsatisfactory (and unsafe) approach for a long-term, operational monitoring program. Plans have now been made to evaluate the use of helicopters next spring for developing surveys that eventually could cover the majority of key waterfowl habitats in British Columbia.

   We also appreciate the cooperation of Pacific Flyway States in helping us better understand the sampling design of their breeding-population surveys. During the past year, we were able to help the State of California evaluate their use of helicopters to derive visibility-correction factors for their fixed-wing surveys. Data suggested helicopter counts provided reasonable adjustments for visibility bias in fixed-wing counts, and that the bias varied by year and survey strata. In the coming year, we hope to work collaboratively with other Pacific Flyway States to review their mallard survey programs.

3) *Harvest rates* – We have been able to estimate harvest rates of adult male mallards in western breeding areas directly from recoveries of reward bands placed on mallards prior to the hunting seasons in 2002-2004. Generally, these rates were similar to those for mid-continent mallards, although it is not known how representative they are of western mallards as a whole (Table 5).

Table 5. Harvest rates (h, and standard errors, se) of adult male mallards banded in states and provinces of the Pacific Flyway as based on reward banding.

Year	**Region**									
	AK		**BC**		**WA**		**OR**		**CA**	
	h	**se**	**h**	**se**	**h**	**se**	**h**	**se**	**h**	**se**
2002	0.1121	0.0306	0.1504	0.0228	0.2308	0.0683	0.1173	0.0241	0.1013	0.0122
2003	0.1000	0.0391	0.1382	0.0281	0.1304	0.0502	0.1324	0.0292	0.0858	0.0135
2004	0.0968	0.0379			0.2727	0.0679	0.0853	0.0247	0.1460	0.0235
mean	0.1030	0.0057	0.1443	0.0087	0.2113	0.0517	0.1116	0.0170	0.1111	0.0221

HARVEST-MANAGEMENT OBJECTIVES

The basic harvest-management objective for midcontinent mallards is to maximize cumulative harvest over the long term, which inherently requires perpetuation of a viable population. Moreover, this objective is constrained to avoid regulations that could be expected to result in a subsequent population size below the goal of the North American Waterfowl Management Plan (NAWMP) (Fig. 2). According to this constraint, the value of harvest decreases proportionally as the difference between the goal and expected population size increases. This balance of harvest and population objectives results in a regulatory strategy that is more conservative than that for maximizing long-term harvest, but more liberal than a strategy to attain the NAWMP goal (regardless of effects on hunting opportunity). The current objective uses a population goal of 8.8 million mallards, which is based on 8.2 million mallards in the traditional survey area (from the 1998 update of the NAWMP) and a goal of 0.6 million for the combined states of Minnesota, Wisconsin, and Michigan.

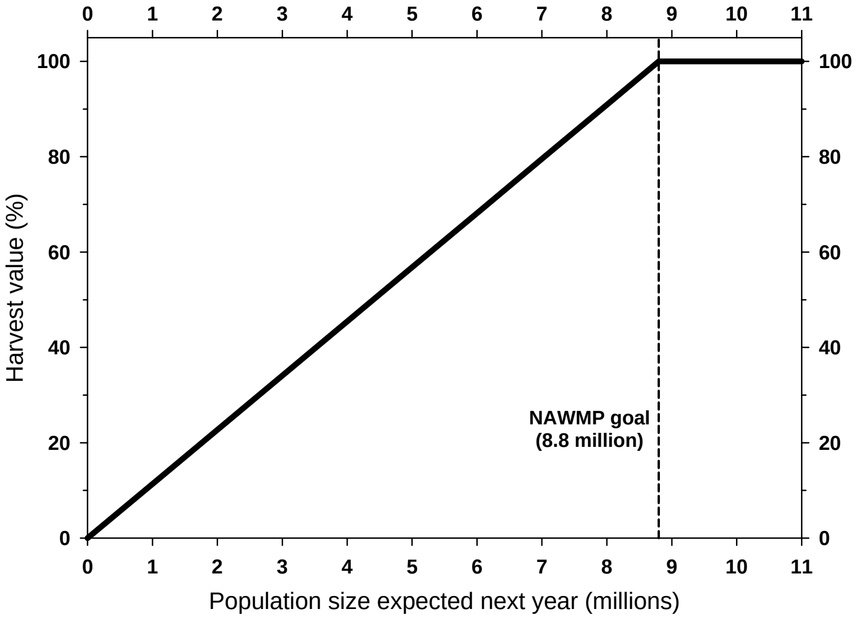


Fig. 2. The relative value of midcontinent mallard harvest, expressed as a function of breeding-population size expected in the subsequent year.

For eastern mallards, there is no NAWMP goal or other established target for desired population size. Accordingly, the management objective for eastern mallards is simply to maximize long-term cumulative (i.e., sustainable) harvest.

REGULATORY ALTERNATIVES

Evolution of Alternatives

When AHM was first implemented in 1995, three regulatory alternatives characterized as liberal, moderate, and restrictive were defined based on regulations used during 1979-84, 1985-87, and 1988-93, respectively. These regulatory alternatives also were considered for the 1996 hunting season. In 1997, the regulatory alternatives were modified to include: (1) the addition of a very-restrictive alternative; (2) additional days and a higher duck bag limit in the moderate and liberal alternatives; and (3) an increase in the bag limit of hen mallards in the moderate and liberal alternatives. In 2002 the USFWS further modified the moderate and liberal alternatives to include extensions of approximately one week in both the opening and closing framework dates.

In 2003 the very-restrictive alternative was eliminated at the request of the Flyway Councils. Expected harvest rates under the very-restrictive alternative did not differ significantly from those under the restrictive alternative, and the very-restrictive alternative was expected to be prescribed for ≤5% of all hunting seasons. Also, at the request of the Flyway Councils the USFWS agreed to exclude closed duck-hunting seasons from the AHM protocol when the breeding-population size of midcontinent mallards is ≥5.5 million (traditional survey area plus the Great Lakes region). Based on our assessment, closed hunting seasons do not appear to be necessary from the perspective of sustainable harvesting when the midcontinent mallard population exceeds this level. The impact of maintaining open seasons above this level also appears to be negligible for other midcontinent duck species (scaup, gadwall, wigeon, green-winged teal, blue-winged teal, shoveler, pintail, redhead, and canvasbacks), as based on population models developed by Johnson (2003). However, complete or partial season-closures for particular species or populations could still be deemed necessary in some situations regardless of the status of midcontinent mallards. Details of the regulatory alternatives for each Flyway are provided in Table 5.

Table 5. Regulatory alternatives for the 2005 duck-hunting season.

	Flyway			
Regulation	**Atlantic**[a]	**Mississippi**	**Central**[b]	**Pacific**[c]
Shooting hours	one-half hour before sunrise to sunset			
Framework dates				
Restrictive	Oct 1 - Jan 20	Saturday nearest Oct 1to the Sunday nearest Jan 20		
Moderate and Liberal	Saturday nearest September 24 to the last Sunday in January			
Season length (days)				
Restrictive	30	30	39	60
Moderate	45	45	60	86
Liberal	60	60	74	107
Bag limit (total / mallard / female mallard)				
Restrictive	3 / 3 / 1	3 / 2 / 1	3 / 3 / 1	4 / 3 / 1
Moderate	6 / 4 / 2	6 / 4 / 1	6 / 5 / 1	7 / 5 / 2
Liberal	6 / 4 / 2	6 / 4 / 2	6 / 5 / 2	7 / 7 / 2

[a] The states of Maine, Massachusetts, Connecticut, Pennsylvania, New Jersey, Maryland, Delaware, West Virginia, Virginia, and North Carolina are permitted to exclude Sundays, which are closed to hunting, from their total allotment of season days.
[b] The High Plains Mallard Management Unit is allowed 8, 12, 23, and 23 extra days in the restrictive, moderate, and liberal alternatives, respectively.
[c] The Columbia Basin Mallard Management Unit is allowed seven extra days in the restrictive, and moderate alternatives.

Regulation-Specific Harvest Rates

Initially, harvest rates of mallards associated with each of the open-season regulatory alternatives were predicted using harvest-rate estimates from 1979-84, which were adjusted to reflect current hunter numbers and contemporary specifications of season lengths and bag limits. In the case of closed seasons in the U.S., we assumed rates of harvest would be similar to those observed in Canada during 1988-93, which was a period of restrictive regulations both in Canada and the U.S. All harvest-rate predictions were based only in part on band-recovery data, and relied heavily on models of hunting effort and success derived from hunter surveys (USFWS

2002: Appendix C). As such, these predictions had large sampling variances and their accuracy was uncertain.

In 2002 we began relying on Bayesian statistical methods for improving regulation-specific predictions of harvest rates, including predictions of the effects of framework-date extensions. Essentially, the idea is to use existing ("prior") information to develop initial harvest-rate predictions (as above), to make regulatory decisions based on those predictions, and then to observe realized harvest rates. Those observed harvest rates, in turn, are treated as new sources of information for calculating updated ("posterior") predictions. Bayesian methods are attractive because they provide a quantitative and formal, yet intuitive, approach to adaptive management.

For midcontinent mallards, we have empirical estimates of harvest rate from the recent period of liberal hunting regulations (1998-2004). The Bayesian methods thus allow us to combine these estimates with our prior predictions to provide updated estimates of harvest rates expected under the liberal regulatory alternative. Moreover, in the absence of experience (so far) with the restrictive and moderate regulatory alternatives, we reasoned that our initial predictions of harvest rates associated with those alternatives should be re-scaled based on a comparison of predicted and observed harvest rates under the liberal regulatory alternative. In other words, if observed harvest rates under the liberal alternative were 10% less than predicted, then we might also expect that the mean harvest rate under the moderate alternative would be 10% less than predicted. The appropriate scaling factors currently are based exclusively on prior beliefs about differences in mean harvest rate among regulatory alternatives, but they will be updated once we have experience with something other than the liberal alternative. A detailed description of the analytical framework for modeling mallard harvest rates is provided in Appendix B.

Our models of regulation-specific harvest rates also allow for the marginal effect of framework-date extensions in the moderate and liberal alternatives. A previous analysis by the USFWS (2001*a*) suggested that implementation of framework-date extensions might be expected to increase the harvest rate of midcontinent mallards by about 15%, or in absolute terms by about 0.02 (SD = 0.01) (i.e., our "prior" belief). Based on the observed harvest rate during the 2002-2004 hunting seasons, the updated ("posterior") estimate of the marginal change in harvest rate attributable to the framework-date extension is 0.012 (SD = 0.008). Therefore, the estimated effect of the framework-date extension has been to increase harvest rate of midcontinent mallards by about 11% over what would otherwise be expected in the liberal alternative. However, the reader is strongly cautioned that reliable inference about the marginal effect of framework-date extensions ultimately depends on a rigorous experimental design (including controls and random application of treatments).

Current predictions of harvest rates of adult-male midcontinent mallards associated with each of the regulatory alternatives are provided in Table 6 and Fig. 3. Predictions of harvest rates for the other age-sex cohorts are based on the historical ratios of cohort-specific harvest rates to adult-male rates (Runge et al. 2002). These ratios are considered fixed at their long-term averages and are 1.5407, 0.7191, and 1.1175 for young males, adult females, and young females, respectively. We continued to make the simplifying assumption that the harvest rates of midcontinent mallards depend solely on the regulatory choice in the western three Flyways. This appears to be a reasonable assumption given the small proportion of midcontinent mallards wintering in the Atlantic Flyway (Munro and Kimball 1982), and harvest-rate predictions that suggest a minimal effect of Atlantic Flyway regulations (USFWS 2000). Under this assumption, the optimal regulatory strategy for the western three Flyways can be derived by ignoring the harvest regulations imposed in the Atlantic Flyway.

Until this year, predictions of harvest rates for eastern mallards have depended exclusively on historical ("prior") information because more contemporary estimates of harvest rate were unavailable. However, we have now begun updating the predictions of eastern-mallard harvest rates in the same fashion as that for midcontinent mallards based on reward banding conducted in eastern Canada and the northeastern U.S. (Appendix B). Like midcontinent mallards, harvest rates of age and sex cohorts other than adult male mallards are based on constant rates of differential vulnerability as derived from band-recovery data. For eastern mallards, these constants are 1.153, 1.331, and 1.509 for adult females, young males, and young females, respectively (Johnson et al. 2002*a*). Regulation-specific predictions of harvest rates of adult-male eastern mallards are provided in Table 7 and Fig. 4.

Table 6. Predictions of harvest rates of adult-male midcontinent mallards expected with application of the 2005 regulatory alternatives in the three western Flyways.

Regulatory alternative	Mean	SD
Closed (U.S.)	0.0088	0.0019
Restrictive	0.0601	0.0129
Moderate	0.1121	0.0217
Liberal	0.1290	0.0219

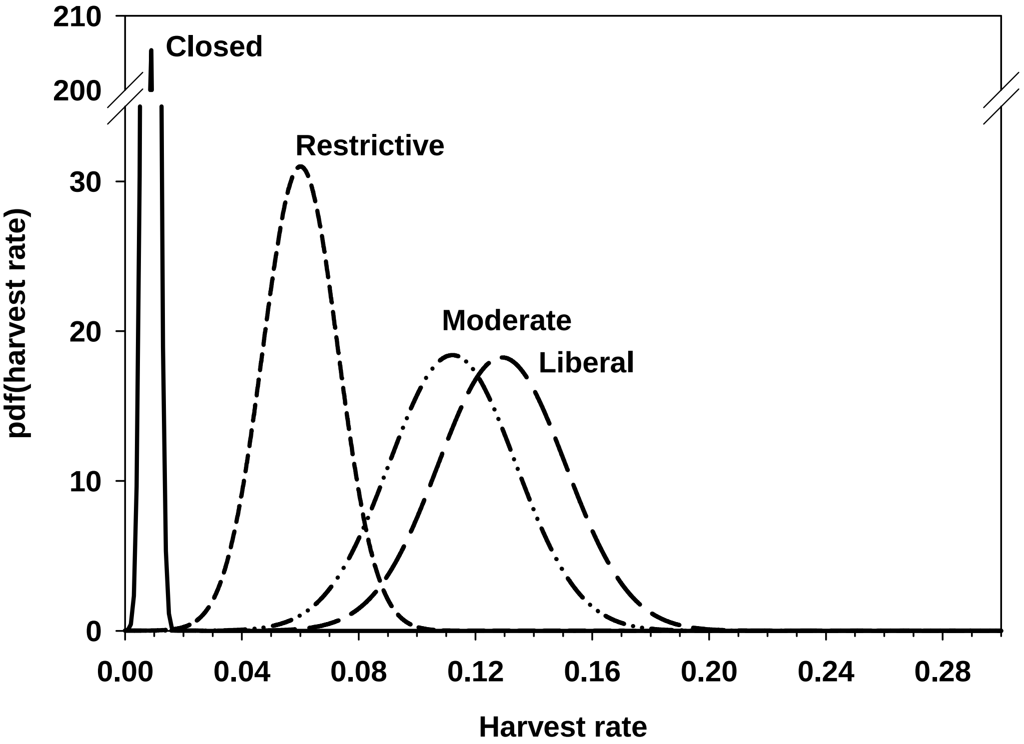


Fig. 3. Probability distributions of harvest rates of adult male mid-continent mallards expected with application of the 2005 regulatory alternatives in the three western Flyways.

In contrast to midcontinent mallards, framework-date extensions were expected to increase the harvest rate of eastern mallards by only about 5% (USFWS 2001), or in absolute terms by about 0.01 (SD = 0.01) (i.e., our “prior” belief). Based on the observed harvest rate during the 2002-2004 hunting seasons, the updated (“posterior”) estimate of the marginal change in harvest rate attributable to the framework-date extension is 0.007 (SD = 0.010). Therefore, the estimated effect of the framework-date extension has been to increase harvest rate of eastern mallards by about 4% over what would otherwise be expected in the liberal alternative.

Table 7. Predictions of harvest rates of adult-male eastern mallards expected with application of the 2005 regulatory alternatives in the Atlantic Flyway.

Regulatory alternative	Mean	SD
Closed (U.S.)	0.0801	0.0233
Restrictive	0.1233	0.0392
Moderate	0.1593	0.0473
Liberal	0.1700	0.0472

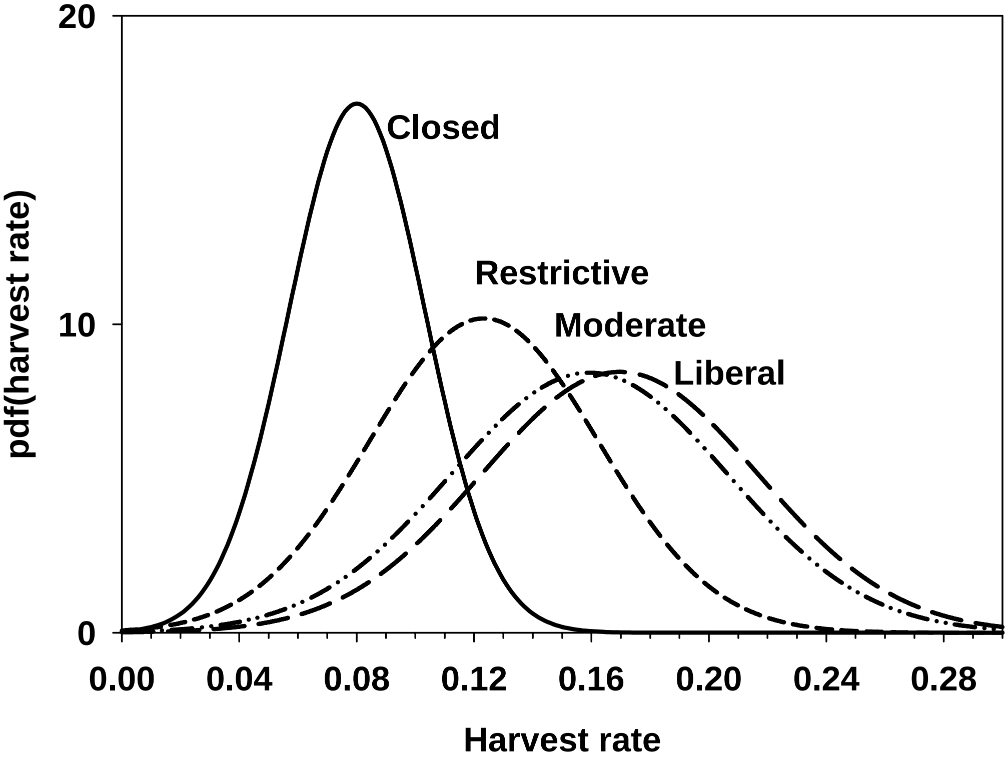


Fig. 4. Probability distributions of harvest rates of adult male eastern mallards expected with application of the 2005 regulatory alternatives in the Atlantic Flyway.

OPTIMAL REGULATORY STRATEGIES

We calculated optimal regulatory strategies using stochastic dynamic programming (Lubow 1995, Johnson and Williams 1999). For the three western Flyways, we based this optimization on: (1) the 2005 regulatory alternatives, including the closed-season constraint; (2) current population models and associated weights for midcontinent mallards; and (3) the dual objectives of maximizing long-term cumulative harvest and achieving a population goal of 8.8 million midcontinent mallards. The resulting regulatory strategy (Table 8) is similar to that used last year.

Assuming that regulatory choices adhered to this strategy (and that current model weights accurately reflect population dynamics), breeding-population size would be expected to average 7.34 million (SD = 1.76). Note that prescriptions for closed seasons in this strategy represent resource conditions that are insufficient to support one of the current regulatory alternatives, given current harvest-management objectives and constraints. However, closed seasons under all of these conditions are not necessarily required for long-term resource protection, and simply reflect the NAWMP population goal and the nature of the current regulatory alternatives.

Based on an observed population size of 7.54 million midcontinent mallards (traditional surveys plus MN, MI, and WI) and 3.92 million ponds in Prairie Canada, the optimal regulatory choice for the Pacific, Central, and Mississippi Flyways in 2005 is the liberal alternative.

Table 8. Optimal regulatory strategy[a] for the three western Flyways for the 2005 hunting season. This strategy is based on current regulatory alternatives (including the closed-season constraint), on current midcontinent mallard models and weights, and on the dual objectives of maximizing long-term cumulative harvest and achieving a population goal of 8.8 million mallards. The shaded cell indicates the regulatory prescription for 2005.

Bpop[b]	**Ponds[c]**									
	1.5	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**
≤5.25	C	C	C	C	C	C	C	C	C	C
5.50-6.25	R	R	R	R	R	R	R	R	R	R
6.50	R	R	R	R	R	R	R	R	R	M
6.75	R	R	R	R	R	R	M	M	M	L
7.00	R	R	R	R	R	M	M	L	L	L
7.25	R	R	R	M	M	M	L	L	L	L
7.50	R	M	M	M	L	L	L	L	L	L
7.75	M	M	M	L	L	L	L	L	L	L
8.00	M	M	L	L	L	L	L	L	L	L
8.25	L	L	L	L	L	L	L	L	L	L
≥8.5	L	L	L	L	L	L	L	L	L	L

[a] C = closed season, R = restrictive, M = moderate, L = liberal.
[b] Mallard breeding population size (in millions) in the traditional survey area (survey strata 1-18, 20-50, 75-77) and Michigan, Minnesota, and Wisconsin.
[c] Ponds (in millions) in Prairie Canada in May.

We calculated an optimal regulatory strategy for the Atlantic Flyway based on: (1) the 2004 regulatory alternatives; (2) current population models and associated weights for eastern mallards; and (3) an objective to maximize long-term cumulative harvest. The resulting strategy suggests liberal regulations for all population sizes of record, and is characterized by a lack of intermediate regulations (Table 9). The strategy exhibits this behavior in part because of the small differences in harvest rate among regulatory alternatives (Fig. 4).

Table 9. Optimal regulatory strategy[a] for the Atlantic Flyway for the 2005 hunting season. This strategy is based on current regulatory alternatives, on current eastern mallard models and weights, and on an objective to maximize long-term cumulative harvest. The shaded cell indicates the regulatory prescription for 2005.

Mallards[b]	Regulation
<225	C
225	R
250	R
275	M
>275	L

[a] C = closed season, R = restrictive, M = moderate, and L = liberal.
[b] Estimated number of mallards in eastern Canada (survey strata 51-54, 56) and the northeastern U.S. (state plot surveys), in thousands.

We simulated the use of the regulatory strategy in Table 9 to determine expected performance characteristics. Assuming that harvest management adhered to this strategy (and that current model weights accurately reflect population dynamics), the annual breeding-population size would be expected to average 0.86 million (SD = 0.16). Based on a breeding population size of 1.05 million mallards, the optimal regulatory choice for the Atlantic Flyway in 2005 is the liberal alternative.

Application of AHM Concepts to Species of Concern

The USFWS is striving to apply the principles and tools of AHM to improve decision-making for several species of special concern. We here report on three such efforts in which significant progress has been made since last year.

Pintails

We examined the harvest potential of northern pintails using a revision of the current population model in conjunction with the “interim” harvest strategy. The revised population model accounts for overflight-bias, a new understanding of the recruitment relationship, and recent harvest data (details of this modeling effort are available at http://migratorybirds.fws.gov/mgmt/ahm/special-topics.htm). This model appears to be an unbiased predictor of pintail population change, and explains a large fraction of the observed variation in annual pintail population size. We used this model to examine harvest potential and to simulate the performance of the current harvest strategy.

Much of the temporal variation in pintail dynamics is driven by habitat conditions on the breeding grounds, and the average latitude of the breeding population appears to be a useful metric to capture habitat conditions. Recruitment decreases with increasing latitude. There is evidence that the pintail population is settling, on average, about 2.4° of latitude farther north now than it did prior to 1975, possibly as a result of changes in habitat (Fig. A). This more northern distribution has resulted in lower reproduction, and a substantial shift in the yield curve: a 30-45% decrease in carrying capacity, and a 40-65% decrease in sustainable harvest potential (Fig. B).

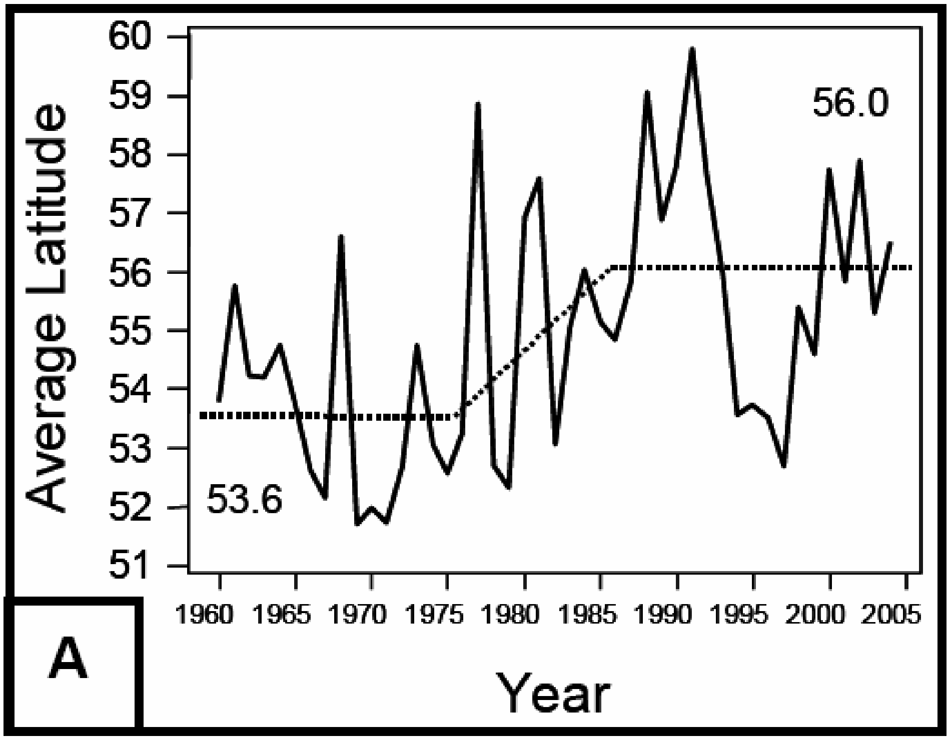


Fig. A. Average latitude of the center of the pintail breeding population, 1960-2004.

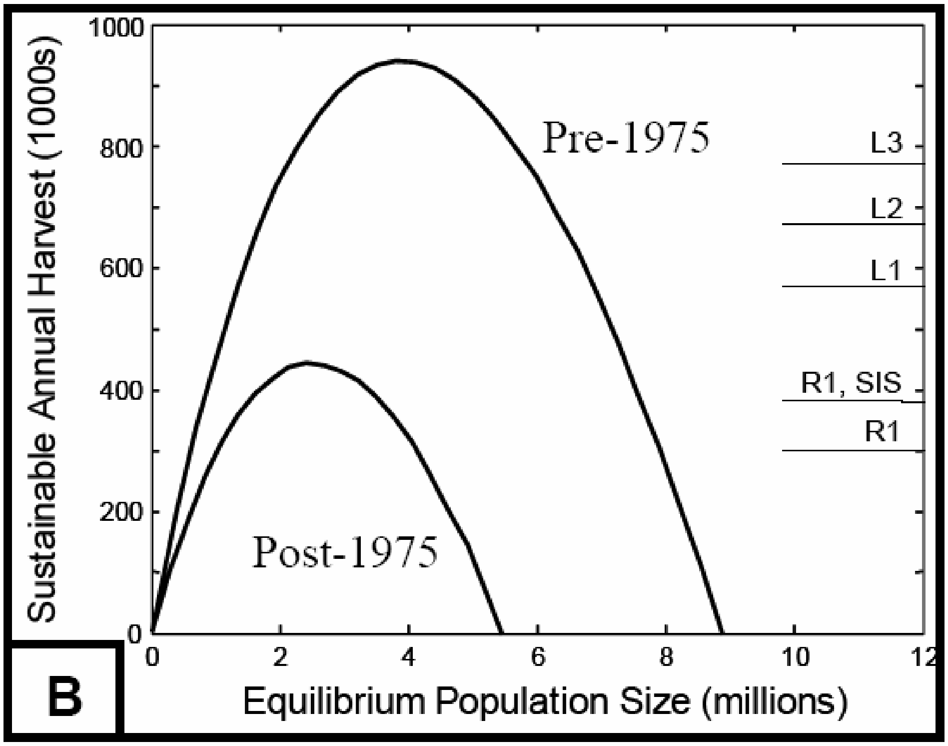


Fig. B. Sustainable annual harvests of pintails as a function of equilibrium population sizes. The top curve represents harvest potential under environmental conditions observed prior to 1975, while the bottom curve represents harvest potential after changes in environmental conditions observed since 1975. The five horizontal reference lines show the expected continental harvest under a series of regulatory alternatives with AHM season lengths (letter) and pintail bag limits (number); SIS represents a restrictive pintail season within a liberal AHM season.

Does the “interim” harvest strategy have the ability to respond to temporal variation in pintail dynamics? If the “latitude” variable captures the important habitat conditions, then we have the ability to respond to annual variation. But, the long-term shift in the latitude is more challenging, because it implies there has been a substantial loss of harvest potential; responding to this means reducing the expectations for pintail harvest. If this was a one-time shift in system dynamics, then we probably have suitable monitoring and regulatory control to deal with it; if, on the other hand, the system is in a state of perpetual change, then we would need to have a better understanding of the processes driving that change to respond properly.

If we use this model to simulate the current pintail harvest strategy, and take account of the post-1975 environmental conditions, we expect pintail season length to deviate from the AHM season length 13% of the time, the average observed pintail breeding population to be around 3.7 million, and the average annual continental harvest to be around 380 thousand.

Table 10. Expected performance characteristics of the “interim” pintail harvest strategy using technical revisions of the pintail population model.

Performance metric	AHM regulation	Pintail regulations	
		Pre-1975	Post-1975
Closed seasons	12%	12%	19%
Restrictive seasons	39%	39%	36%
Restrictive partial seasons	N/A	0.1%	6%
Moderate seasons	8%	8%	6%
Liberal seasons	41%	41%	33%
Mean population size (sd), millions		6.9 (1.7)	3.7 (1.9)
Mean harvest (sd), millions		0.43 (0.19)	0.38 (0.22)

The “interim” pintail harvest strategy (without the technical revisions mentioned above) does not have good predictive power and cannot be easily assessed. Using the revised population model for assessment, the current pintail harvest strategy appears to be sustainable and can actually accommodate a significant amount of system change without jeopardizing that sustainability. The tight tie to the midcontinent mallard AHM season lengths drives a lot of the expected variation in pintail regulations. The current strategy was prescribed, however, not derived; articulation of the underlying objectives would allow more focused assessment and improvements

Black Ducks

We examined the harvest potential of black ducks using models of population dynamics described by Conroy et al. (2002). Our full report is available at http://migratorybirds.fws.gov/mgmt/ahm/special-topics.htm. These models incorporate the most controversial hypotheses about reproductive and survival processes in black ducks, and also allow for the possibility that extant estimates of reproductive and survival rates are positively biased. Using empirically based model weights (from 1962-93) in conjunction with deterministic dynamic programming, we derived combinations of equilibrium population size and harvest for a range of adult harvest rates. These combinations of equilibrium population sizes and harvests can be depicted as a “yield curve,” whose shape depends on the abundance of sympatric mallards (Fig. 5).

Because of evidence that the reproductive rate of black ducks declines with increasing numbers of mallards, the carrying capacity (i.e., the point on the graph corresponding to 0 harvest and maximum population size) and harvestable surplus of black ducks are smaller with higher numbers of sympatric mallards. We can account for annual changes in both the number of black ducks and mallards with a state-dependent harvest strategy, assuming that an unambiguous management objective can be specified. We examined the optimal harvest rates associated

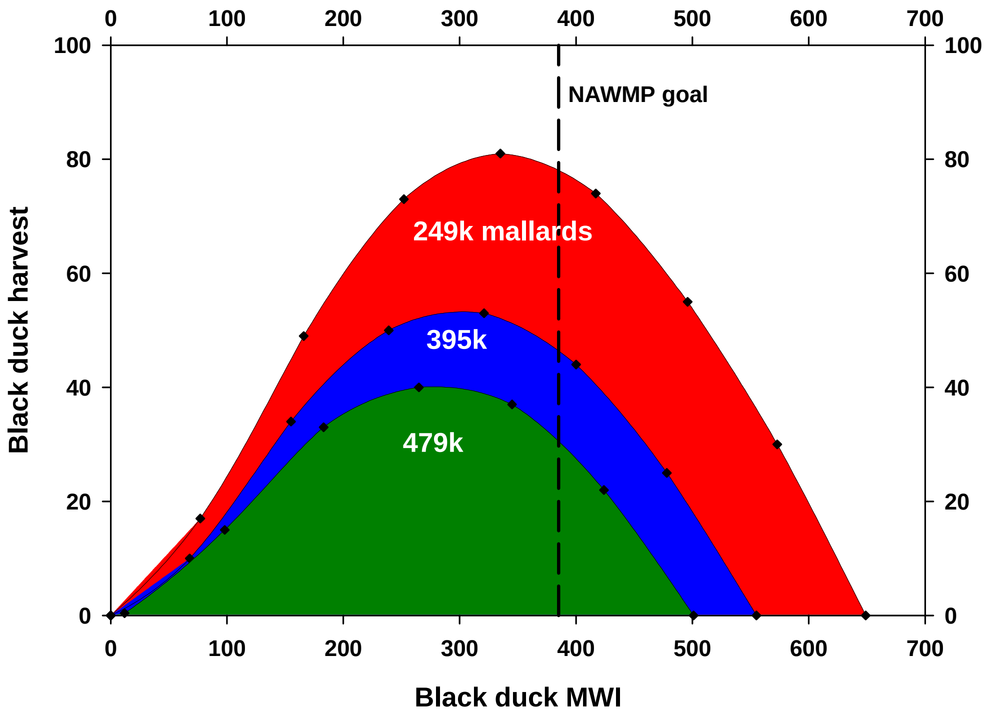


Fig. 5. Equilibrium population sizes and harvests for black ducks for three levels of mallards (both black ducks and mallards are in expressed in thousands in the Midwinter Index, MWI). The three levels of mallards, in increasing order of abundance, represent the 5th percentile from 1961-2003, the mean from 1994-2003, and the 95th percentile from 1961-2003. The North American Waterfowl Population Management (NAWMP) is 385 thousand. These yield curves were derived from population models provided by Conroy et al. (2002).

with three such management objectives using stochastic dynamic programming and compared them to those estimated from reward band recoveries during 2002-2004 (Table 11).

Table 11. Observed harvest rates (h) of black ducks based on reward banding compared to those that would be optimal under state-dependent strategies (MWI = Midwinter Index) with three different management objectives.

Year	**Black duck MWI**	**Mallard MWI**	**Observed**	**Optimal harvest rate**		
			h (se)	**Maximize long-term cumulative harvest**	**Maximize harvest and a population goal of 289k**	**Maximize harvest and a population goal of 385k**
2002	300k	550k	0.075 (0.010)	0.13	0.12	0.04
2003	250k	300k	0.087 (0.012)	0.04	0.02	0.00
2004	250k	350k	0.080 (0.011)	0.04	0.02	0.00

The foregoing analyses do not account for an apparent temporal decline in the reproductive rate of black ducks that cannot explained by changes in black duck and mallard abundance. The cause is unknown but may be related to declines in the quantity and/or quality of breeding or wintering habitat or both. Whatever the cause, the implications are profound, suggesting that carrying capacity and maximum sustainable harvest of black ducks have decreased by 35% and 60%, respectively, in the past two decades (Fig. 6).

Since 1983, the U.S. Fish and Wildlife Service has been operating under guidance provided in an Environmental Assessment that specified states harvesting significant numbers of black ducks achieve at least a 25% reduction in harvest from 1977- 81 levels. Although this level has been achieved, black duck harvest rates have increased recently with the return of 50-60 day duck hunting seasons associated with implementation of AHM. Development of the recent assessment framework allows managers to account for both expected and unexpected changes in black duck and mallard abundance, and for uncertainty in black duck population dynamics. In addition, there is an ongoing joint effort with Canada to develop a fully adaptive framework with internationally agreed-upon harvest management objectives and joint regulatory decision making.

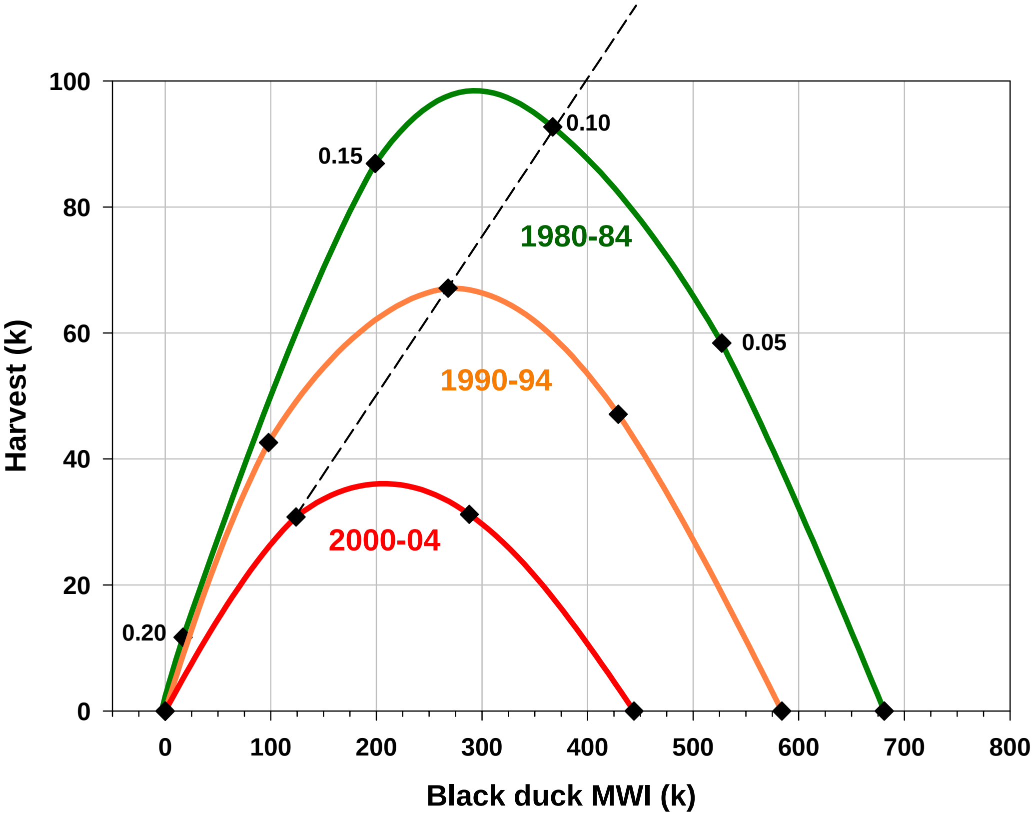


Fig 6. Collapsing yield curves of black ducks as result of declining productivity. Yield curves were based on population models provided by Conroy et al. (2002). For each period, we used the median year to represent black duck productivity and fixed the number of mallards at their average midwinter count. The diagonal line intersects the 10% adult harvest rate on each yield curve.

Scaup

We evaluated the harvest potential of the continental scaup (greater *Aythya marila* and lesser *Aythya affinis* combined) population using a discrete, logistic population model and the available monitoring information describing scaup population and harvest dynamics. Our full report is available at http://migratorybirds.fws.gov/mgmt/ahm/special-topics.htm. We used a fully Bayesian approach to estimate scaup population parameters and to characterize the uncertainty related to scaup harvest potential. We plotted mean scaup equilibrium population sizes and corresponding sustainable harvests (Fig. 7) along with 95% credibility intervals (gray shading). When observed harvests and breeding population sizes from 1994 – 2003 were added to this plot, the results suggest that harvest levels in 1997 and 1998 were significantly larger than a maximum sustainable yield (MSY) value equal to 0.382 million. We used this estimation framework to perform a retrospective analysis to discern changes in scaup harvest potential that may have resulted from possible large scale system changes thought to be a factor in the scaup population decline. To perform this analysis, we conducted two assessments using monitoring data from two different time periods: from 1961 – 1981, and from 1961 – 2001. We chose these time periods to compare population parameters based on data observed when scaup populations were historically high (i.e., the decade of the 70’s) to population parameters based on information collected over the time period when larges-scale system changes may have occurred (i.e., 1961 –2001). The

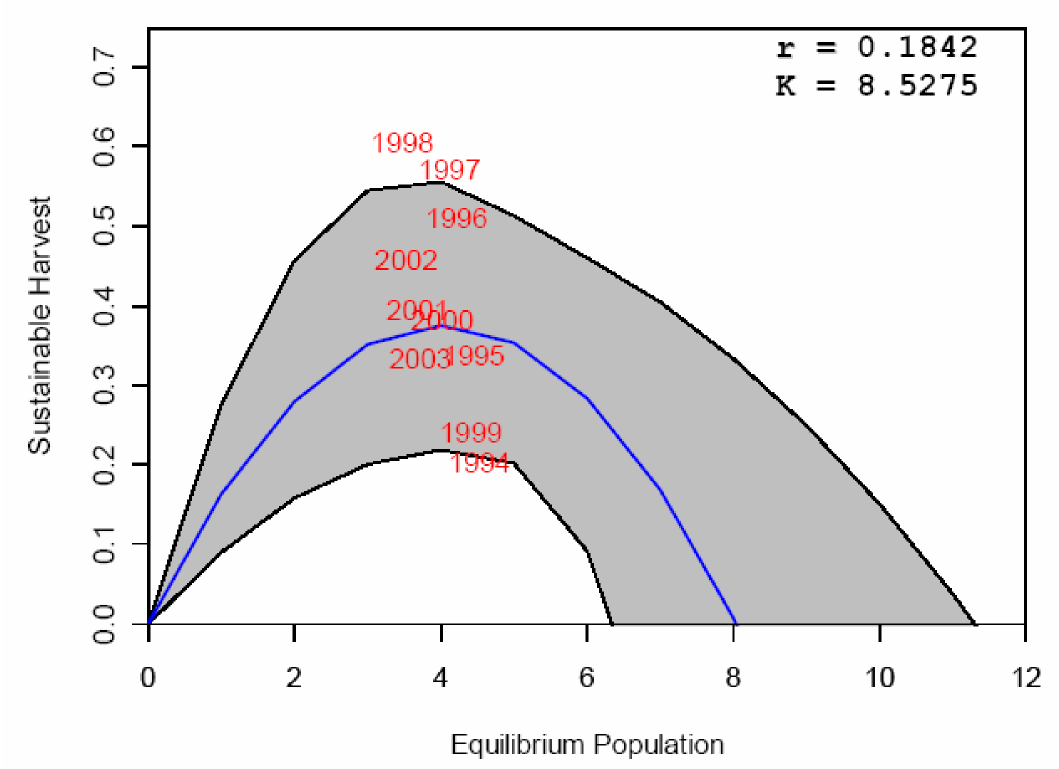


Fig. 7. Equilibrium population sizes and harvests (and 95% credibility intervals (shading) estimated for continental scaup populations from a logistic model using a Bayesian hierarchical approach. The years represent combinations of population sizes and harvest observed in the last decade.

retrospective analysis shows how scaup harvest potential based on an assessment conducted in 1981 is substantially higher than the harvest potential based on an assessment conducted in 2001, indicating a decrease in MSY from 0.600 to 0.394 million birds (Table 12).

Table 12. Estimates of model and management parameters derived from fitting a logistic population model to continental scaup populations using a Bayesian hierarchical approach.

Parameter	**1961-1981**			**1961-2001**		
	mean	**2.50%**	**97.50%**	**mean**	**2.50%**	**97.50%**
r	0.303	0.127	0.619	0.192	0.096	0.344
K	8.266	6.358	11.185	8.505	6.322	11.420
MSY	0.600	0.294	1.039	0.394	0.225	0.608
Harvest rate at MSY	0.151	0.063	0.310	0.096	0.048	0.172
Effort at MSY	25.062	10.729	51.842	15.494	7.952	28.206

Plotting the observed harvest and population sizes on the corresponding yield curves (Fig. 8) suggests that not only has the sustainable harvest shifted downward since 1981, but that observed scaup harvest and population sizes have moved from the right hand shoulder to the top of the yield curve, suggesting that some of these harvests may not be sustainable. Because scaup harvest management is predicated on the status of mallard populations and the AHM protocol, we do not have an ability to manage the scaup harvest in relation to population status and harvest potential. Ultimately, a state dependent harvest policy will be required to make an informed harvest management decision in response to population changes and variation in scaup harvest potential.

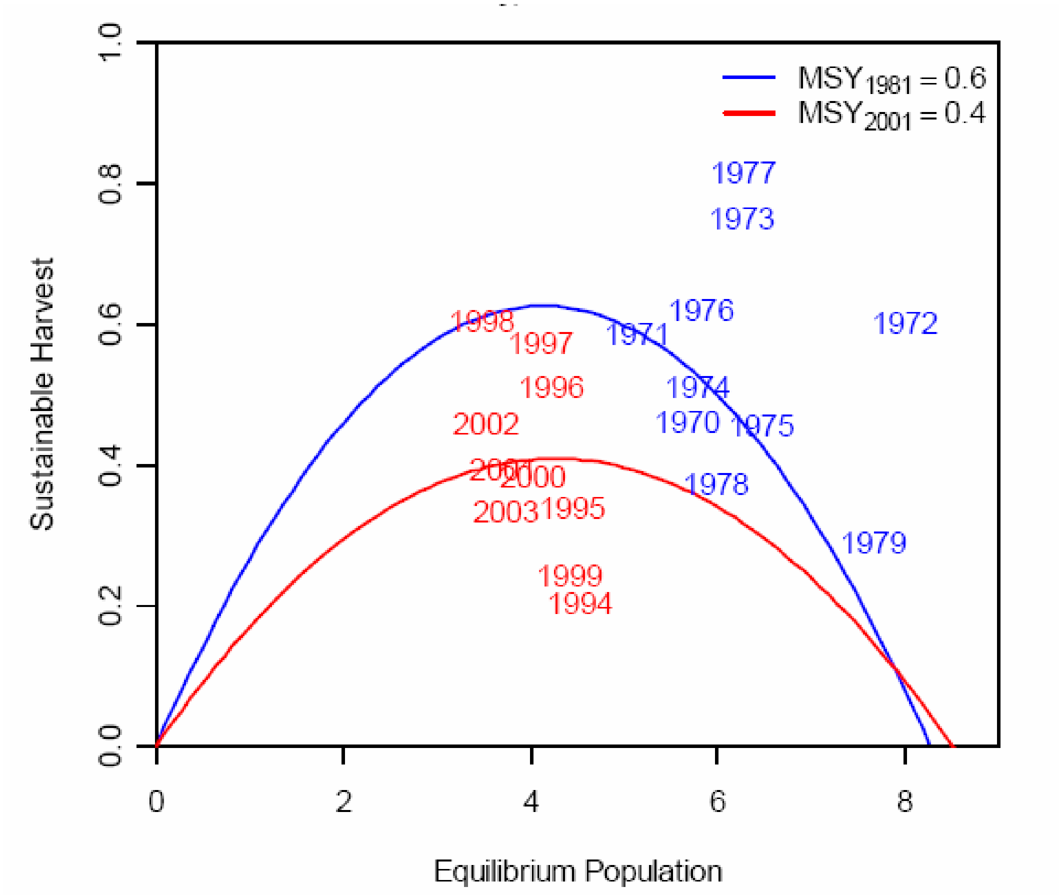


Fig. 8. Equilibrium population sizes and harvests of scaup based on a retrospective analysis using data from 1961-1981 and from 1961-2001 and a logistic population model. The years represent combinations of population levels and harvest observed during the 1970s and from 1994-2003.

Atlantic Population of Canada Geese

The need to identify optimal harvest policies is apparent for many waterfowl populations, and particularly for the Atlantic Population of Canada geese (APCG) whose numbers declined significantly in the 1980's and early 1990's. Sport-hunting seasons for this population were closed in the U.S. from the fall of 1995 to the winter of 1999. Hunting seasons have been reinstated, but are currently at restrictive to moderate levels in the U.S. Continuation of sport harvest for APCG and maintenance of the population within desired bounds is contingent upon effective harvest management and monitoring programs. Effective management will need to incorporate multiple objectives and must be accomplished with incomplete knowledge of the system and in the presence of various types of uncertainty including environmental variation, partial system control, model uncertainty, and partial system observability.

Adaptive management provides a useful framework for making sequential decisions in the presence of uncertainty. AHM is currently used to set regulations for mallard harvest management, but we are not aware of any attempts to use these decision-making techniques for any species or population of geese. Developing an AHM protocol for APCG will require extending approaches currently used for other waterfowl to account for fundamental differences in the demography and management of ducks and geese. To date, most applications of adaptive management to waterfowl harvesting have relied on simple scalar population models. Such scalar models assume all individuals in the population have the same responses to environmental stressors. By contrast, goose populations have significant age structure as a result of relatively high survival rates and age-dependent productivity. Previous investigations have shown that optimal harvest management of age-structured populations is conditional on the age-structure of the population and on age-specific differences in vulnerability of harvest.

Adequate description of the population dynamics of geese will therefore require age-structured models; derivation of goose harvest strategies from existing scalar models may significantly hinder management performance by failing to take advantage of increased harvest potential and to accommodate decreased harvest potential driven by intrinsic and extrinsic changes in the age structure.

The overall goal of this project will be to develop an AHM protocol for the U.S. sport harvest of APCG . The specific objectives are:

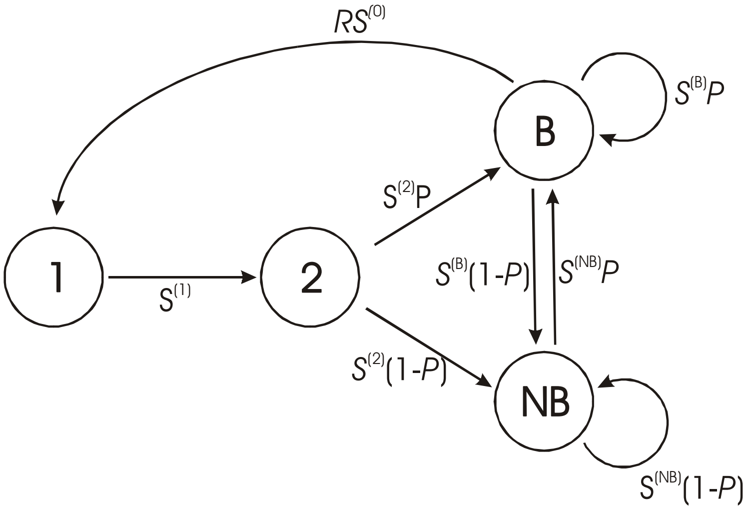
1. to explore the general implications of age structure, non-equilibrium population dynamics, and population ‘momentum’ for managing the sport harvest of geese;
2. to develop a set of models describing population and harvest dynamics for geese and parameterize these models using data specific to APCG, or to other populations comprised principally of *B. canadensis interior*;
3. to identify key uncertainties in population or harvest dynamics (i.e., those to which optimal harvest policies are sensitive); and
4. to derive adaptive policies specifying optimal state-specific harvest rates, and demonstrate the expected performance of these policies.

For the purposes of development of this AHM application, the APCG is defined as those geese breeding on the Ungava Peninsula. By this delineation, we assume that geese in the Atlantic population outside this area are either few in number, similar in population dynamics to the Ungava birds, or both.

To account for heterogeneity among individuals, we developed a base model consisting of a truncated time-invariant age-based projection model to describe the dynamics of the APCG population,

$\mathbf{n}(t+1)=\mathbf{A}\mathbf{n}(t)$,

where $\mathbf{n}(t)$ is a vector of the abundances of the ages in the population at time t, and $\mathbf{A}$ is the population projection matrix, whose ijth entry a_{ij} gives the contribution of an individual in stage j to stage i over 1 time step. The projection interval (from t to t+1) is one year, with the census being taken in mid-June (i.e., this model has a pre-breeding census). The life cycle diagram reflecting the transition sequence, and the corresponding projection matrix **A** are shown below:



,

$$\mathbf{A} = \begin{bmatrix} 0 & 0 & RS^{(0)} & 0 \\ S^{(1)} & 0 & 0 & 0 \\ 0 & S^{(2)}P & S^{(\mathrm{B})}P & S^{(\mathrm{NB})}P \\ 0 & S^{(2)}(1-P) & S^{(\mathrm{B})}(1-P) & S^{(\mathrm{NB})}(1-P) \end{bmatrix}, \ \mathbf{n}_t = \begin{bmatrix} N_t^{(1)} \\ N_t^{(2)} \\ N_t^{(\mathrm{B})} \\ N_t^{(\mathrm{NB})} \end{bmatrix}$$

where node 1 refers to one-year-old birds, node 2 refers to two-year-old birds, node B refers to adult breeders, and node NB refers to adult non-breeders. One immediate extension of the base model is to remove the assumption of time-invariance, and express the parameters as time-dependent quanitites:

P_t = proportion of adult birds in population in year *t* which breed;

R_t = basic breeding productivity in year *t* (per capita);

$S_t^{(0)}$ = annual survival rate of young from fledging in year *t* to the census point the next year;

$S_t^{(1)}$ = annual survival rate of one-year-old birds in year *t*; etc.

The projection matrix, so extended, is equivalent to the following recursive balance equations:

$$N_{t+1}^{(1)} = N_t^{(\mathrm{B})} R_t S_t^{(0)}$$

$$N_{t+1}^{(2)} = N_t^{(1)} S_t^{(1)}$$

$$N_{t+1}^{(\mathrm{B})} = P_t\left[N_t^{(2)} S_t^{(2)} + N_t^{(\mathrm{B})} S_t^{(\mathrm{B})} + N_t^{(\mathrm{NB})} S_t^{(\mathrm{NB})}\right]$$

$$N_{t+1}^{(\mathrm{NB})} = \left(1-P_t\right)\left[N_t^{(2)} S_t^{(2)} + N_t^{(\mathrm{B})} S_t^{(\mathrm{B})} + N_t^{(\mathrm{NB})} S_t^{(\mathrm{NB})}\right].$$

Note that we can write the number of young produced in year *t* as

$$N_t^{(0)} = N_t^{(\mathrm{B})} R_t$$

but strictly speaking, that is an intermediate variable in the model, not a state variable, because those young do not exist on the anniversary date of the model (mid-June census point).

In our base model, we make several simplifying assumptions. First, we assume that breeding begins at age 3 in APCG. However, while evidence from other goose populations is that breeding propensity increases with age, in the absence of age-specific estimates for APCG, we assume that breeding propensity (*P*) is constant over all breeding ages in a given year (note: in the future, we may consider relaxing this assumption, making use of estimates from closely related species nesting at similar latitudes). Second, we assume that breeding individuals have the same per capita breeding success (*R*), independent of age; while we know this is unlikely to be true, since geese typically show age-specific differences in reproductive output until at least age 5 yr, age-specific estimates of per capita breeding success are not available for APCG (note: in the future, we may consider relaxing this assumption making use of estimates from closely related species nesting at similar latitudes). Third, since goose species exhibit a monogamous breeding system, with evidence of a 50:50 sex-ratio throughout the life cycle, we do not recognize sex structure in the model dynamics (thus, $N_t^{(\mathrm{B})}$ is the number of adult breeders, male and female, at time *t*). Fourth, we assume that the probability of a state transition (i.e., between breeder and nonbreeder) is random, and not Markovian, that is, that the probability of breeding, P_t in year t is not a function of breeding state (B or NB) in year t–1. Recent evidence from snow geese and brant suggests that such transitions are, in fact, likely to be at least first-order Markovian, but there are no data available at present for APCG, or other populations of Canada geese.

Our objective is to make annual state-based harvest decisions, given the population objectives noted previously. To do this requires assessment of state on a yearly basis, in time for the annual cycle by which harvest decisions are made (note: we assume for the moment that such decisions are made annually; one area for investigation is whether or not annual updating is optimal for goose populations).

For the APCG population, only $N^{(\mathrm{B})}$, R and z are observable annually, where $N^{(\mathrm{B})}$ is the number of breeding adults, R is the per capita reproductive output (ratio of fledged young to breeding adults), and z is an extrinsic variable (a function of timing of snow melt on the breeding grounds).

Note that at the time of the management decision in the United States (July), estimates for only the breeding population size and the environmental variable(s) are available; the age-ratio isn't estimated until later in the summer. Thus, in year t, the directly measurable state variables are $N_t^{(\mathrm{B})}$, z_t, and R_{t-1}.

There are several other state variables of interest, however, namely, $N^{(1)}$, $N^{(2)}$, and $N^{(\mathrm{NB})}$. Since annual harvest decisions need to be made based on the total population size (N^{tot}), which is the sum of contributions from various non-breeding age classes as well as the number of breeding individuals, annual variation in abundance of non-breeding individuals ($N^{(\mathrm{NB})}$, $N^{(1)}$, and $N^{(2)}$) will need to be derived using population reconstruction techniques. Population reconstruction involves estimation of unseen parameter values given a time series of observed population vectors. In most cases, population reconstruction involves estimating the most likely projection matrix, given a time series of population vectors (where number of individuals in each age class at each time is known). However, in our case, estimates of N^B, R and z only are available (not the complete population vector); in effect, we seek to estimate some parameter values given the dynamics of other parameters in the model. Recent extensions of Bayesian statistical methods to population reconstruction may provide an adequate solution.

Management of the APCG has, in recent years, been focused on achieving the minimum population needed to sustain some level of sport harvest. However, there is growing concern over the potential problems caused by overabundant goose species, and management objectives for goose species are increasingly considering population control as an important objective.

Specification of an explicit, mathematical objective function for the APCG population will require careful deliberation among the appropriate stakeholders. Since formal AHM is an exercise in optimization, the objective often not only drives the outcome, but also strongly influences the development of the other components of the decision framework (e.g., the decision variables, the projection model, etc.). As a starting point for our work in developing an AHM application for APCG, and as a starting point for discussions about the management objectives for this resource, we developed a candidate objective function. We propose that the management objective needs to reflect the simultaneous problem of maximizing opportunity for harvest, while minimizing the risk that the population will become either too large (i.e., beyond human tolerance in terms of impacts on habitat or other species), or too small (i.e., requiring season closure for political reasons).

We believe that the critical components governing the dynamics of APCG, unlike those governing ducks, are generally density-independent over the range of population sizes that likely characterize management objectives; as such, harvest represents an imposed regulatory mechanism on the dynamics of the population. This requires specification of a desired range for the population size. Let N^{MTP} represent the maximum tolerable population size that stakeholders would accept, given the potential for negative impacts of overabundant APCG on stakeholder interests. Let N^{Min} be the minimum tolerable population size, below which season closure is the only politically viable management option. The management objective is to maintain the population in the range between the maximum and minimum values, while simultaneously maximizing opportunity for sport harvest.

There is another implicit dynamic that may interact with this objective: there may be a limit to the amount of harvest that could be induced with traditional harvest regulations. Let N^{MCP} represent the maximum controllable population level that could be regulated by harvest (a function of a finite number of goose hunters or hunting effort; this is currently an unknown quantity for APCG). We think it's most likely that $N^{\mathrm{MTP}} < N^{\mathrm{MCP}}$, although this assumption won't affect the development of any other aspect of the AHM protocol. N^{MCP} might strongly affect the optimal policy, however, as the policy should avoid letting the population reach an uncontrollable level, especially if that level is also intolerable. Thus, the objective should implicitly minimize the risk of losing the ability to control that population. Note that N^{MCP} should be calculated from biological considerations in conjunction with information about the limits to harvest. N^{MTP}, however, is a purely sociological constraint.

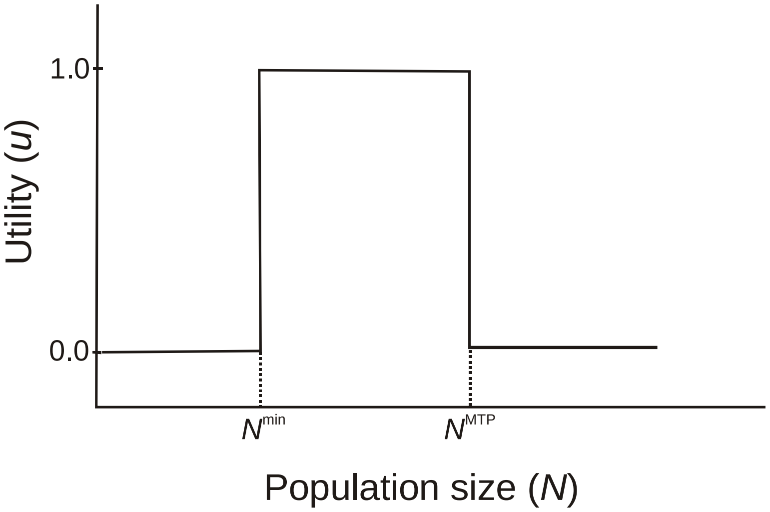
We think this objective will hold the population as close to the maximum tolerable population size as possible (thus, allowing the greatest harvest), while guarding against the risk of the population getting out of control.

Mathematically, these objectives can be expressed as

$$\max \sum_{t=0}^{\infty} u(N_t) H_t ,$$

that is, maximizing the long-term cumulative harvest utility, where the value (utility) of harvest is decremented relative to the bounds of the constraint (i.e., the maximum and minimum bounds). One possible form of the utility function *u* is a 'square-wave', where utility of the harvest is 0 when the population size is above and below N^{MTP} and N^{Min}, respectively. This function is shown below.

It would be valuable if the Atlantic Flyway, and other stakeholders identified by the USFWS or the Atlantic Flyway, would begin deliberations about the specific objectives for management of the Atlantic Population of Canada Geese. Specifically, (1) is one component of the objective to maximize long-term harvest; (2) what is the upper tolerable level for the population size; and (3) what is the lower tolerable level for the population size? At this point, we are defining the population size as the total population size in mid-June, during the pair surveys, including both breeders and non-breeders; N^{MTP} and N^{Min} should be expressed on this scale.



LITERATURE CITED

Anderson, D. R., and K. P. Burnham. 1976. Population ecology of the mallard. VI. The effect of exploitation on survival. U.S. Fish and Wildlife Service Resource Publication No. 128. 66pp.

Blohm, R. J. 1989. Introduction to harvest - understanding surveys and season setting. Proceedings of the International Waterfowl Symposium 6:118-133.

Blohm, R. J., R. E. Reynolds, J. P. Bladen, J. D. Nichols, J. E. Hines, K. P. Pollock, and R. T. Eberhardt. 1987. Mallard mortality rates on key breeding and wintering areas. Transactions of the North American Wildlife and Natural Resources Conference 52:246-263.

Burnham, K. P., G. C. White, and D. R. Anderson. 1984. Estimating the effect of hunting on annual survival rates of adult mallards. Journal of Wildlife Management 48:350-361.

Conroy, M. J., M. W. Miller, and J. E. Hines. 2002. Identification and synthetic modeling of factors affecting American black duck populations. Wildlife Monographs 150. 64pp.

Heusman, H W, and J. R. Sauer. 2000. The northeastern states' waterfowl breeding population survey. Wildlife Society Bulletin 28:355-364.

Johnson, F. A. 2003. Population dynamics of ducks other than mallards in midcontinent North America. Draft. Fish and Wildlife Service, U.S. Dept. Interior, Washington, D.C. 15pp.

Johnson, F. A., J. A. Dubovsky, M. C. Runge, and D. R. Eggeman. 2002*a*. A revised protocol for the adaptive harvest management of eastern mallards. Fish and Wildlife Service, U.S. Dept. Interior, Washington, D.C. 13pp. [online] URL: http://migratorybirds.fws.gov/reports/ahm02/emal-ahm-2002.pdf.

Johnson, F. A., W. L. Kendall, and J. A. Dubovsky. 2002*b*. Conditions and limitations on learning in the adaptive management of mallard harvests. Wildlife Society Bulletin 30:176-185.

Johnson, F. A., C. T. Moore, W. L. Kendall, J. A. Dubovsky, D. F. Caithamer, J. R. Kelley, Jr., and B. K. Williams. 1997. Uncertainty and the management of mallard harvests. Journal of Wildlife Management 61:202-216.

Johnson, F. A., and B. K. Williams. 1999. Protocol and practice in the adaptive management of waterfowl harvests. Conservation Ecology 3(1): 8. [online] URL: http://www.consecol.org/vol3/iss1/art8.

Johnson, F. A., B. K. Williams, J. D. Nichols, J. E. Hines, W. L. Kendall, G. W. Smith, and D. F. Caithamer. 1993. Developing an adaptive management strategy for harvesting waterfowl in North America. Transactions of the North American Wildlife and Natural Resources Conference 58:565-583.

Johnson, F. A., B. K. Williams, and P. R. Schmidt. 1996. Adaptive decision-making in waterfowl harvest and habitat management. Proceedings of the International Waterfowl Symposium 7:26-33.

Lubow, B. C. 1995. SDP: Generalized software for solving stochastic dynamic optimization problems. Wildlife Society Bulletin 23:738-742.

Munro, R. E., and C. F. Kimball. 1982. Population ecology of the mallard. VII. Distribution and derivation of the harvest. U.S. Fish and Wildlife Service Resource Publication 147. 127pp.

Nichols, J. D., F. A. Johnson, and B. K. Williams. 1995. Managing North American waterfowl in the face of uncertainty. Annual Review of Ecology and Systematics 26:177-199.

Runge, M. C., F. A. Johnson, J. A. Dubovsky, W. L. Kendall, J. Lawrence, and J. Gammonley. 2002. A revised protocol for the adaptive harvest management of midcontinent mallards. Fish and Wildlife Service, U.S. Dept. Interior, Washington, D.C. 28pp. [online] URL: http://migratorybirds.fws.gov/reports/ahm02/MCMrevise2002.pdf.

U.S. Fish and Wildlife Service. 2000. Adaptive harvest management: 2000 duck hunting season. U.S. Dept. Interior, Washington. D.C. 43pp. [online] URL: http://migratorybirds.fws.gov/reports/ahm00/ahm2000.pdf.

U.S. Fish and Wildlife Service. 2001. Framework-date extensions for duck hunting in the United States: projected impacts & coping with uncertainty, U.S. Dept. Interior, Washington, D.C. 8pp. [online] URL: http://migratorybirds.fws.gov/reports/ahm01/fwassess.pdf.

U.S. Fish and Wildlife Service. 2002. Adaptive harvest management: 2002 duck hunting season. U.S. Dept. Interior, Washington. D.C. 34pp. [online] URL: http://migratorybirds.fws.gov/reports/ahm02/2002-AHM-report.pdf.

Walters, C. J. 1986. Adaptive management of renewable resources. MacMillan Publ. Co., New York, N.Y. 374pp.

Williams, B. K., and F. A. Johnson. 1995. Adaptive management and the regulation of waterfowl harvests. Wildlife Society Bulletin 23:430-436.

Williams, B. K., F. A. Johnson, and K. Wilkins. 1996. Uncertainty and the adaptive management of waterfowl harvests. Journal of Wildlife Management 60:223-232.

APPENDIX A: AHM Working Group

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APPENDIX B: Modeling Mallard Harvest Rates

We modeled harvest rates of midcontinent mallards within a Bayesian statistical framework (USFWS 2003). We developed a set of models to predict harvest rates under each regulatory alternative as a function of the harvest rates observed under the liberal alternative, using historical information relating harvest rates to various regulatory alternatives. We modeled the probability of regulation-specific harvest rates (*h*) based on normal distributions with the following parameterizations:

Closed: $p(h_C) \sim N(\mu_C, \nu_C^2)$

Restrictive: $p(h_R) \sim N(\gamma_R \mu_L, \nu_R^2)$

Moderate: $p(h_M) \sim N(\gamma_M \mu_L + \delta_f, \nu_M^2)$

Liberal: $p(h_L) \sim N(\mu_L + \delta_f, \nu_L^2)$

For the restrictive and moderate alternatives we introduced the parameter γ to represent the relative difference between the harvest rate observed under the liberal alternative and the moderate or restrictive alternatives. Based on this parameterization, we are making use of the information that has been gained (under the liberal alternative) and are modeling harvest rates for the restrictive and moderate alternatives as a function of the mean harvest rate observed under the liberal alternative. For the harvest-rate distributions assumed under the restrictive and moderate regulatory packages, we specified that γ_R and γ_M are equal to the prior estimates of the predicted mean harvest rates under the restrictive and moderate alternatives divided by the prior estimates of the predicted mean harvest rates observed under the liberal alternative. Thus, these parameters act to scale the mean of the restrictive and moderate distributions in relation to the mean harvest rate observed under the liberal regulatory alternative. We also considered the marginal effect of framework-date extensions under the moderate and liberal alternatives by including the parameter δ_f.

In order to update the probability distributions of harvest rates realized under each regulatory alternative, we first needed to specify a prior probability distribution for each of the model parameters. These distributions represent prior beliefs regarding the relationship between each regulatory alternative and the expected harvest rates. We used a normal distribution to represent the mean and a scaled inverse-chi-square distribution to represent the variance of the normal distribution of the likelihood. For the mean (μ) of each harvest-rate distribution associated with each regulatory alternative, we use the predicted mean harvest rates provided in USFWS (2000*a*:13-14), assuming uniformity of regulatory prescriptions across flyways. We set prior values of each standard deviation (ν) equal to 20% of the mean (CV = 0.2) based on an analysis by Johnson et al. (1997). We then specified the following prior distributions and parameter values under each regulatory package:

Closed (in U.S. only):

$$p(\mu_C) \sim N(0.0088, \frac{0.0018^2}{6})$$

$$p(\nu_C^2) \sim Scaled\ Inv - \chi^2(6, 0.0018^2)$$

These closed-season parameter values are based on observed harvest rates in Canada during the 1988-93 seasons, which was a period of restrictive regulations in both Canada and the United States.

For the restrictive and moderate alternatives, we specified that the standard error of the normal distribution of the scaling parameter is based on a coefficient of variation for the mean equal to 0.3. The scale parameter of the inverse-chi-square distribution was set equal to the standard deviation of the harvest rate mean under the restrictive and moderate regulation alternatives (i.e., CV = 0.2).

Restrictive:

$$p(\gamma_R) \sim N(0.51, \frac{0.15^2}{6})$$

$$p(\nu_R^2) \sim Scaled\ Inv - \chi^2(6, 0.0133^2)$$

Moderate:

$$p(\gamma_M) \sim N(0.85, \frac{0.26^2}{6})$$

$$p(\nu_M^2) \sim Scaled\ Inv - \chi^2(6, 0.0223^2)$$

Liberal:

$$p(\mu_L) \sim N(0.1305, \frac{0.0261^2}{6})$$

$$p(\nu_L^2) \sim Scaled\ Inv - \chi^2(6, 0.0261^2)$$

The prior distribution for the marginal effect of the framework-date extension was specified as:

$$p\left(\delta_f\right) \sim N\left(0.02, 0.01^2\right)$$

The prior distributions were multiplied by the likelihood functions based on the seven years of data (under liberal regulations), and the resulting posterior distributions were evaluated with Markov Chain Monte Carlo simulation. Posterior estimates of model parameters and of annual harvest rates are provided in the following table:

Parameter	Estimate	SD	Parameter	Estimate	SD
μ_C	0.0088	0.0007	h_{1998}	0.1102	0.0112
ν_C	0.0019	0.0005	h_{1999}	0.1004	0.0076
γ_R	0.5116	0.0613	h_{2000}	0.1264	0.0099
ν_R	0.0129	0.0033	h_{2001}	0.1077	0.0112
γ_M	0.8493	0.1057	h_{2002}	0.1133	0.0059
ν_M	0.0217	0.0055	h_{2003}	0.1132	0.0085
μ_L	0.1166	0.0075	h_{2004}	0.1245	0.0111
ν_L	0.0219	0.0044			
δ_f	0.0124	0.0085			

We modeled harvest rates of eastern mallards using the same parameterizations as those for midcontinent mallards:

Closed: $p(h_C) \sim N(\mu_C, \nu_C^2)$

Restrictive: $p(h_R) \sim N(\gamma_R \mu_L, \nu_R^2)$

Moderate: $p(h_M) \sim N(\gamma_M \mu_L + \delta_f, \nu_M^2)$

Liberal: $p(h_L) \sim N(\mu_L + \delta_f, \nu_L^2)$

We set prior values of each standard deviation (ν) equal to 30% of the mean (CV = 0.3) to account for additional variation due to changes in regulations in the other Flyways and their unpredictable effects on the harvest rates of eastern mallards. We then specified the following prior distribution and parameter values for the liberal regulatory alternative:

Liberal:

$$p(\mu_L) \sim N(0.1771, \frac{0.0531^2}{6})$$

$$p(\nu_L^2) \sim Scaled\ Inv - \chi^2(6, 0.0531^2)$$

Moderate:

$$p(\gamma_M) \sim N(0.92, \frac{0.28^2}{6})$$

$$p(\nu_M^2) \sim Scaled\ Inv - \chi^2(6, 0.0488^2)$$

Restrictive:

$$p(\gamma_R) \sim N(0.76, \frac{0.28^2}{6})$$

$$p(\nu_R^2) \sim Scaled\ Inv - \chi^2(6, 0.0406^2)$$

Closed (in U.S. only):

$$p(\mu_C) \sim N(0.0800, \frac{0.0240^2}{6})$$

$$p(\nu_C^2) \sim Scaled\ Inv - \chi^2(6, 0.0240^2)$$

A previous analysis suggested that the effect of the framework-date extension on eastern mallards would be of lower magnitude and more variable than on mid-continent mallards (USFWS 2000). Therefore, we specified the following prior distribution for the marginal effect of the framework-date extension for eastern mallards as:

$$p\left(\delta_f\right) \sim N\left(0.01, 0.01^2\right)$$

The prior distributions were multiplied by the likelihood functions based on the three years of data (under liberal regulations), and the resulting posterior distributions were evaluated with Markov Chain Monte Carlo simulation. Data-based harvest rate estimates were 0.1620 (SE = 0.0133), 0.1459 (SE = 0.0108) and 0.1322 (SE = 0.0108) for 2002, 2003, and 2004, respectively. Posterior estimates of model parameters and of annual harvest rates are provided in the following table:

Parameter	Estimate	SD	Parameter	Estimate	SD
μ_C	0.0800	0.0100	μ_L	0.1626	0.0178
ν_C	0.0233	0.0059	ν_L	0.0472	0.0105
γ_R	0.7608	0.1137	δ_f	0.0070	0.0096
ν_R	0.0392	0.0100	h_{2002}	0.1626	0.0128
γ_M	0.9242	0.1134	h_{2003}	0.1471	0.0104
ν_M	0.0473	0.1200	h_{2004}	0.1342	0.0105