U. S. Fish & Wildlife Service

Adaptive Harvest Management

2003 Duck Hunting Season

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 2003 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 information presented in this report will differ from that in previous reports.

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ACKNOWLEDGMENTS

A working group comprised of representatives from the USFWS, the Canadian Wildlife Service, 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. A. Johnson (USFWS) was the principal author, but many of the supporting assessments were conducted by S. G. Boomer (USFWS) J. A. Dubovsky (USFWS), W. L. Kendall (U.S. Geological Survey [USGS]), M. T. Moore (USFWS), and J. A. Royle (USFWS). Individuals that provided essential information or otherwise assisted with report preparation were D. J. Case (D.J. Case & Assoc.), M. J. Conroy (USGS), R. V. Raftovich (USFWS), and K. A. Wilkins (USFWS). Finally, we are especially grateful to M. C. Runge (USGS) for assistance with this report and for his substantial technical contributions to the AHM effort. 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: Ron Louque's painting of snow geese (*Chen caerulescens*) that was selected for the 2003 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 USFWS adopted the concept of adaptive resource management for regulating duck harvests in the United States. The adaptive 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.

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 2003 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.

The mallard population models that are the basis for prescribing hunting regulations were revised extensively prior to last year's regulations process. 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 strongly 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 (70%). To date, there is only weak evidence for bias in the estimates of survival and reproductive rates (55%) for eastern mallards.

For the 2003 hunting season, the USFWS has made two significant changes to the set of regulatory alternatives. Based on recommendations from the Flyway Councils, the USFWS: (1) has eliminated the very-restrictive alternative; and (2) has placed a constraint on closed seasons in the western three Flyways whenever the midcontinent mallard breeding-population size (traditional survey area plus MN, MI, and WI) is equal to or greater than 5.5 million. The USFWS also continues to offer extended framework dates in the moderate and liberal regulatory alternatives.

Bayesian statistical methods are used for generating and updating predictions of harvest rates associated with the set of regulatory alternatives. 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 midcontinent mallards under the regulatory alternatives have been updated based on band-reporting rate studies conducted since 1998. Results from the 2002 hunting season suggest that use of the extended framework dates was responsible for a marginal increase in harvest rates of midcontinent mallards of 0.016, which is similar to what was expected. It is not feasible to update estimates of eastern-mallard harvest rates until additional band-reporting rate studies can be conducted.

Optimal regulatory strategies for the 2003 hunting season were calculated using: (1) stock-specific harvest-management objectives; (2) the revised regulatory alternatives for 2003; and (3) current population models and associated weights for midcontinent and eastern mallards. Based on this year's survey results of 8.80 million midcontinent mallards (traditional surveys area plus MN, WI, and MI), 3.52 million ponds in Prairie Canada, and 1.04 million eastern mallards, the optimal regulatory choice for all four Flyways is the liberal alternative.

The USFWS is continuing discussions with the AHM Working Group, Flyway Councils, States, and others about future development and application of AHM. The International Association of Fish and Wildlife Agencies has convened an AHM task force, comprised of recognized leaders in waterfowl management, to help provide policy guidance regarding the nature of harvest-management objectives and regulatory alternatives. Moreover, it is apparent that the future success of AHM will depend on how managers account for variation in the ability of different duck species to support harvest. An effective means to account for these differences in the face of a common duck-hunting season is a high priority for the AHM Task Force and Working Group.

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. The adaptive 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 existing 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 (Johnson et al. 1993, Williams and Johnson 1995) include:

(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 alternative 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 abundance of the managed population. 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

Significant numbers of breeding mallards occur from the northern U.S. through Canada and into Alaska. Geographic differences in the reproduction, mortality, and migrations of these mallards suggest that there are 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 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 is 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 don't 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 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 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 midcontinent population so defined are available only since 1992 (Table 1).

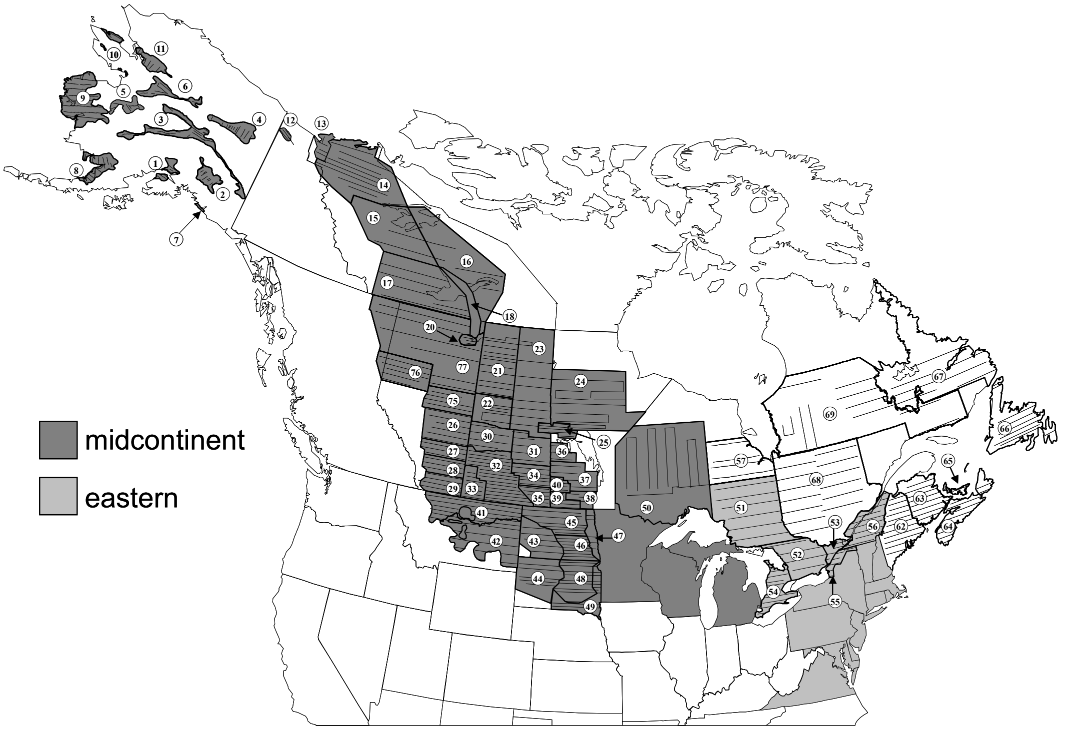

Fig. 1. Survey areas currently assigned to the midcontinent and eastern stocks of mallards for the purposes of AHM. Delineation of the western-mallard stock is pending a review of population monitoring programs.

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.

	Traditional surveys		State surveys		Total	
Year	N	SE	N	SE	N	SE
1992	5.9761	0.2410	1.0268	0.1607	7.0029	0.2897
1993	5.7083	0.2089	0.9487	0.1462	6.6570	0.2550
1994	6.9801	0.2828	1.1717	0.1193	8.1518	0.3069
1995	8.2694	0.2875	1.1187	0.1967	9.3881	0.3483
1996	7.9413	0.2629	1.0322	0.1447	8.9735	0.3001
1997	9.9397	0.3085	1.0959	0.1451	11.0356	0.3410
1998	9.6404	0.3016	1.1113	0.1791	10.7516	0.3507
1999	10.8057	0.3445	1.0529	0.2125	11.8586	0.4048
2000	9.4702	0.2902	1.1962	0.1772	10.6664	0.3400
2001	7.9040	0.2269	0.8410	0.1082	8.7450	0.2514
2002	7.5037	0.2465	1.0758	0.1154	8.5795	0.2722
2003	7.9497	0.2673	0.8511	0.0749	8.8008	0.2777

Population models.--Last year 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).

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 on information provided by Blohm et al. (1987), that 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:

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

where γ denotes the bias-correction factors for survival (S) or 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):

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

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%). 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 more appropriately express 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:

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

and a strongly density-dependent model:

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

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

$$P_t = 2.2127 + 0.3420P_t + \varepsilon_t$$

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 submodels 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:

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

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

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

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 submodels, 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 1996-2003, 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 or compensatory mortality models. For the last several years, model weights favor the weakly density-dependent reproductive model over the strongly density-dependent one. The reader is warned, 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 are not available from those 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 up to reflect inclusion of mallards in the Great Lakes region. From 1992 through 2003, 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 0.1157 (SD = 0.0202). 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. Weights for the models of 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.

					Model				Observed bpop(t+1)[a]
Year	Bpop(t)[a]	Ponds(t)[b]	Rate(t)[c]		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	0.2483	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	0.1191	predicted bpop(t+1):	9.0964	9.9258	9.1482	9.9376	9.6404
				weight(t+1):	0.2236	0.2723	0.2306	0.2735	
1998	9.6404	2.5217	0.1109	predicted bpop(t+1):	7.4334	8.4655	7.6398	8.6388	10.8057
				weight(t+1):	0.0598	0.3816	0.0927	0.4659	
1999	10.8057	3.8620	0.1004	predicted bpop(t+1):	8.5916	9.9905	8.9479	10.3310	9.4702
				weight(t+1):	0.0550	0.4022	0.0970	0.4457	
2000	9.4702	2.4222	0.1271	predicted bpop(t+1):	7.3262	8.2969	7.3545	8.2630	7.9040
				weight(t+1):	0.0516	0.4046	0.0920	0.4518	
2001	7.9040	2.7472	0.1081	predicted bpop(t+1):	6.9153	7.2626	7.0877	7.4258	7.5037
				weight(t+1):	0.0460	0.4048	0.0880	0.4611	
2002	7.5037	1.4390	0.1136	predicted bpop(t+1):	6.1036	6.4607	6.2295	6.5733	7.9497
				weight(t+1):	0.0258	0.3949	0.0612	0.5181	

[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. Rates for 1995 and 1998-2002 are empirical estimates. Rates for 1996 and 1997 are predictions based on models describing the historical relationship between regulations and harvest rate.

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; Heusmann and Sauer 2000) (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).

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

Population models.--Last year we extensively revised the population models for eastern mallards (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 summer survival against female summer survival, 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:

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

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

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

(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 a 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:

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

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:

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

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

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

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 all 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 alternative can be precipitated by only small changes in breeding-population size. This result is largely 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.--We calculated weights for the alternative models of eastern mallard population dynamics based on an assumption of equal model weights in 1996 (the last year data was used to develop most model components) and on predictions of year-specific harvest rates. The model best predicting observed population size has varied among years; accordingly, there is no single model that is clearly favored over the others at the end of the time frame (Table 4). However, we note that the three models with strongly density-dependent reproduction currently account for 70% of the total model weight.

Table 4. Weights for the models of 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.

				Model						Observed bpop(t+1)[a]
Year	Bpop(t)[a]	Rate(t)[b]		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	0.1771	predicted bpop(t+1):	1.0853	1.0832	0.9070	0.9053	0.9148	0.9133	1.0389
			weight(t+1):	0.0793	0.1551	0.1840	0.1881	0.1902	0.2032	
1998	1.0389	0.1771	predicted bpop(t+1):	1.1126	1.0923	0.9298	0.9128	0.9388	0.9245	1.0922
			weight(t+1):	0.1308	0.2580	0.1516	0.1307	0.1699	0.1591	
1999	1.0922	0.1771	predicted bpop(t+1):	1.1576	1.1066	0.9674	0.9248	0.9785	0.9427	0.8900
			weight(t+1):	0.0323	0.1146	0.2021	0.2023	0.2144	0.2343	
2000	0.8900	0.1771	predicted bpop(t+1):	0.9815	1.0450	0.8203	0.8733	0.8241	0.8686	1.0077
			weight(t+1):	0.0606	0.2116	0.1226	0.2220	0.1369	0.2463	
2001	1.0077	0.1771	predicted bpop(t+1):	1.0857	1.0833	0.9074	0.9054	0.9152	0.9135	1.0054
			weight(t+1):	0.0653	0.2302	0.1166	0.2086	0.1363	0.2430	
2002	1.0054	0.1871	predicted bpop(t+1):	1.0601	1.0590	0.8860	0.8851	0.8942	0.8934	1.0401
			weight(t+1):	0.0985	0.3474	0.0883	0.1566	0.1116	0.1976	

[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. Rates are predictions based on models describing the historical relationship between regulations and harvest rate.

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 fact is making 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 (USFWS 2001). Another complicating factor is that federal survey strata 1-12 in Alaska and the Yukon are within the current geographic bounds of midcontinent mallards. Therefore, the AHM Working Group is continuing its investigations of western mallards and is not prepared to recommend an AHM protocol at this time.

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.

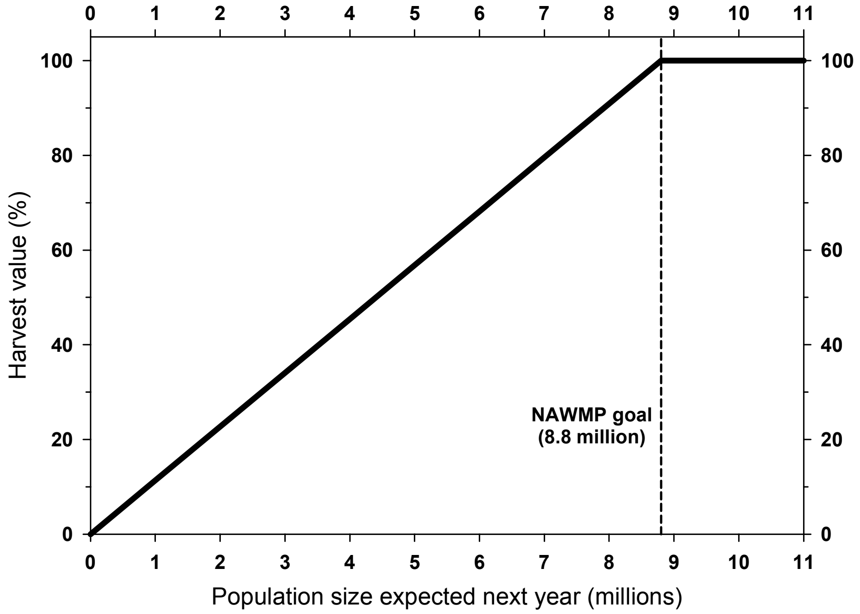

Fig. 2. The relative value of midcontinent mallard harvest, expressed as a function of breeding-population size expected in the subsequent year.

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.

For the 2003 hunting season, the very-restrictive alternative has been 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 will only consider closed duck-hunting seasons when the breeding-population size of midcontinent mallards is <5.5 million (traditional survey area plus the Great Lakes region). Based on our assessments, 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 provided by Johnson (2003). However, closed seasons targeted at particular species or populations could still be necessary in some situations regardless of the status of midcontinent mallards.

Table 5. Regulatory alternatives considered for the 2003 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 1 - Sunday nearest Jan 20		
Moderate and Liberal	Saturday nearest Sep 24 - last Sunday in Jan			
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 very restrictive, restrictive, moderate, and liberal alternatives, respectively.
[c] The Columbia Basin Mallard Management Unit is allowed seven extra days in the very restrictive, 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 contemporary specifications of season lengths, bag limits, and for hunter numbers. 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.

Last year 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 now have empirical estimates of harvest rate from the recent period of liberal hunting regulations (1998-2002). 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 midcontinent 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 (2000*b*) 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 hunting season, the updated ("posterior") estimate of the marginal change in harvest rate attributable to the framework-date extension is 0.0157 (SD = 0.0091). This estimate is similar to our prior belief in large part because so far we have only one year of experience with the framework-date extensions. The reader also is strongly cautioned that reliable inference about the effect of framework-date extensions ultimately depends on a rigorous study design (including experimental controls and random application of treatments), which to date has not been deemed politically feasible.

The 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 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*a*). 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.

For eastern mallards, predictions of regulation-specific harvest rates continue to depend exclusively on historical ("prior") information because no contemporary estimates of harvest rate are available. Updated predictions of harvest rates await additional band-reporting rate studies in eastern Canada and the Atlantic Flyway. In contrast to the case with midcontinent mallards, harvest rates of eastern mallards appear to depend significantly on regulations beyond the principal Flyway of harvest (USFWS 2000*a*), so predictions of harvest rates cannot be based solely on the regulation in the Atlantic Flyway. To avoid making the regulatory choice in the Atlantic Flyway conditional on regulations elsewhere, we inflated the variance of predicted harvest rates of eastern mallards to account for "uncontrolled" changes in regulations in the three western Flyways (Johnson et al. 2002*a*). 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. Predicted harvest rates of adult male midcontinent mallards based on regulations in the three western Flyways. The parameter μ is the mean harvest rate expected in the absence of framework-date extensions and δ is the marginal change in mean harvest rate expected with extended framework dates. Standard errors are in parentheses.

Regulatory alternative	μ	δ	$\mu + \delta$
Closed (U.S.)	0.0088 (0.0018)	-------------N/A------------	
Restrictive	0.0607 (0.0133)	-------------N/A------------	
Moderate	0.1012 (0.0223)	0.0157 (0.0091)	0.1169 (0.0241)
Liberal	0.1191 (0.0231)	0.0157 (0.0091)	0.1348 (0.0248)

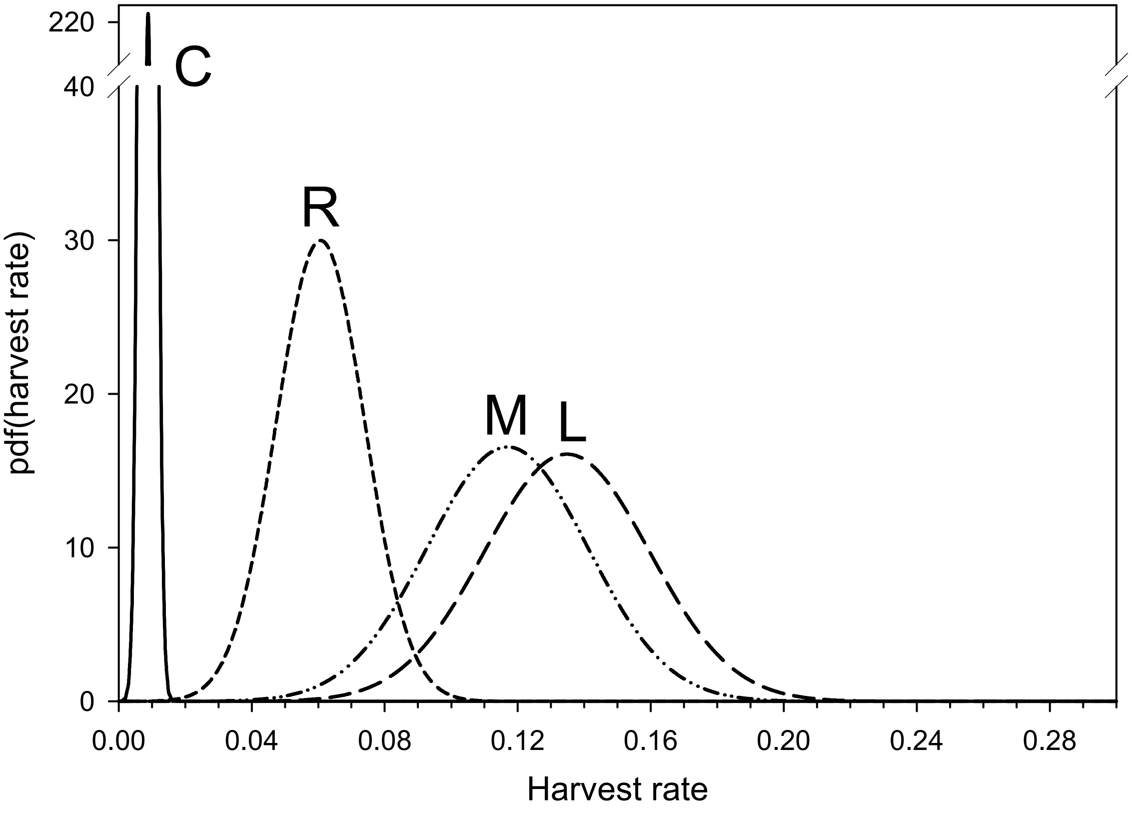

Fig. 3. Probability density functions (pdf) of harvest rates of adult male midcontinent mallards under current regulatory alternatives in the three western Flyways (C = closed, R =restrictive, M = moderate, L = liberal).

Table 7. Predicted harvest rates of adult male eastern mallards based on regulations in the Atlantic Flyway. The parameter μ is the mean harvest rate expected in the absence of framework-date extensions and δ is the marginal change in mean harvest rate expected with extended framework dates. Standard errors are in parentheses.

Regulatory alternative	μ	δ	$\mu + \delta$
Closed (U.S.)	0.0800 (0.0240)	-------------N/A------------	
Restrictive	0.1352 (0.0406)	-------------N/A------------	
Moderate	0.1625 (0.0488)	0.01 (0.01)	0.1725 (0.0498)
Liberal	0.1771 (0.0531)	0.01 (0.01)	0.1871 (0.0540)

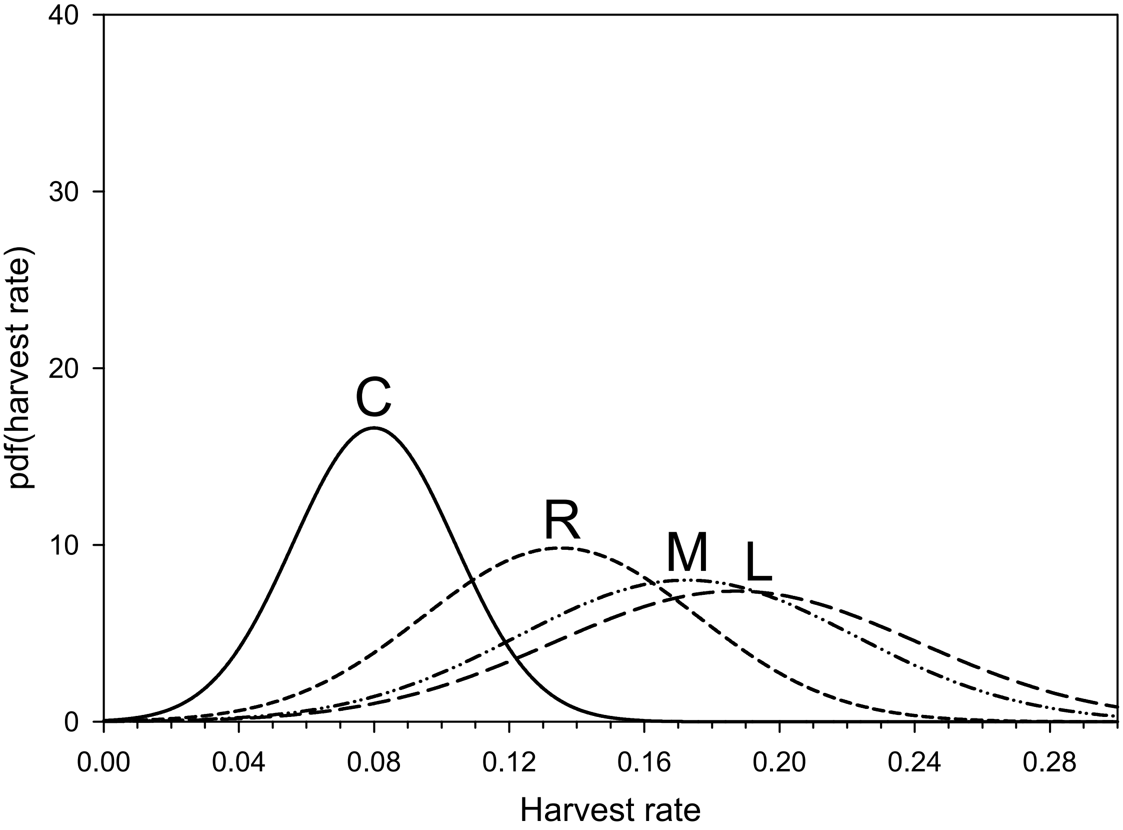

Fig. 4. Probability density functions (pdf) of harvest rates of adult male eastern mallards under current regulatory alternatives in the Atlantic Flyway (C = closed, R = restrictive, M = moderate, L = liberal).

OPTIMAL REGULATORY STRATEGIES

The optimal regulatory strategy for the three western Flyways was calculated using stochastic dynamic programming (Lubow 1995, Johnson and Williams 1999) and based on: (1) the 2003 regulatory alternatives, including the closed-season constraint; (2) current population models and associated weights for midcontinent mallards; and (3) the dual objectives to maximize long-term cumulative harvest and achieve a population goal of 8.8 million midcontinent mallards. The resulting regulatory strategy (Table 8) is similar to that used last year except for the absence of prescriptions for very-restrictive regulations and closed seasons for mallard population sizes above 5.5 million.

Assuming that regulatory choices adhered to this strategy (and that current model weights accurately reflect population dynamics), breeding-population size and harvest value (i.e., annual harvest, devalued where subsequent population size <8.8 million) would be expected to average 7.06 million (SD = 1.64) and 0.97 million (SD = 0.76), respectively. 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 current regulatory alternatives.

Based on a population size of 8.80 million midcontinent mallards (traditional surveys plus MN, MI, and WI) and 3.52 million ponds in Prairie Canada, the optimal regulatory choice for the Pacific, Central, and Mississippi Flyways in 2003 is the liberal alternative.

Table 8. Optimal regulatory strategy[a] for the three western Flyways for the 2003 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 represents the optimal regulatory choice for 2003.

	Ponds[c]									
Bpop[b]	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
5.50-6.50	R	R	R	R	R	R	R	R	R	R
6.75	R	R	R	R	R	R	R	R	M	M
7.00	R	R	R	R	R	R	M	M	M	L
7.25	R	R	R	R	M	M	L	L	L	L
7.50	R	R	R	M	L	L	L	L	L	L
7.75	R	M	M	L	L	L	L	L	L	L
8.00	M	M	M	L	L	L	L	L	L	L
8.25	M	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 2003 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 largely because of the small differences in harvest rate among regulatory alternatives (Fig. 4).

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 harvest and breeding population size would be expected to average 508 thousand (SD = 135) and 947 thousand (SD = 172), respectively.

Based on a breeding population size of 1.04 million mallards, the optimal regulatory choice for the Atlantic Flyway in 2003 is the liberal alternative.

Table 9. Optimal regulatory strategy[a] for the Atlantic Flyway for the 2003 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 represents the optimal regulatory choice for 2003.

Mallards[b]	Regulation
≤200	C
225	R
250	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.

Current Issues in AHM

Policy Questions

A special session was held at the 2000 North American Wildlife and Natural Resources Conference (Humburg et al. 2000, Johnson and Case 2000, Nichols 2000) to offer a retrospective on the development and implementation of AHM, and to describe a number of policy issues affecting future progress. Relevant questions included:

(a) Should AHM account explicitly for hunter "satisfaction" and, if so, how would it be measured and monitored? What constitutes a "fair" distribution of harvest or hunting opportunity, and should regulations be used to achieve this fairness?

(b) To what extent should the population goals of the North American Waterfowl Management Plan influence hunting opportunity?

(c) To date, AHM has been based on midcontinent and eastern mallards. To what extent should we try to account for differences in the harvest potential of various duck stocks in setting hunting regulations? How do we distinguish what is desirable from what is practical?

(d) How many regulatory alternatives should there be? Among the alternatives, what are desirable or acceptable ranges of season lengths, bag limits, and framework dates? How often should the set of regulatory alternatives be reviewed?

The International Association of Fish and Wildlife Agencies has convened a task force comprised of recognized leaders in waterfowl management to help address these and other policy questions related to future application of AHM. This task force is working closely with the USFWS, the Flyway Councils, and the AHM Working Group. Also, the Wildlife Management Institute has received a federal grant to help explore the relationship between waterfowl hunting regulations and hunter satisfaction and participation, and to recommend how such information might be used in the AHM process.

Multiple-Stock AHM

One of the most difficult scale issues confronting AHM concerns that of multiple duck stocks. The problem is characterized by the following features:

(1) duck stocks vary in their potential to support sport harvest;
(2) multiple stocks generally are exposed to a common hunting season (although stock-specific harvests can be regulated somewhat by stratifying hunting regulations on spatial, temporal, and organizational scales);
(3) stock-specific harvest returns and population trajectories are subject to considerable uncertainty, whose sources include uncontrolled environmental variation, random effects of regulations (i.e., partial controllability), uncertainties in population dynamics, and errors and biases in data-collection programs (i.e., partial observability); and
(4) management objectives are complex, in that they must account for stock-specific values (i.e., not all stocks will be equally valued by hunters) and for the legal mandate to prevent over-exploitation of any particular stock.

It is increasingly apparent that the future development and success of AHM will depend heavily on how we address the multiple-stock problem. There are several challenges, however, that will not be overcome easily. First, although AHM provides a coherent framework for exploring the effects of various approaches to multiple-stock harvesting, those explorations can be conducted only to the extent that information on the dynamics of various stocks is available. And while AHM provides an effective means for coping with uncertainty, high levels of uncertainty in management outcomes will severely reduce the benefits expected from an explicit recognition of variation in harvest potential. Second, more objective decisions about the appropriate multiple-stock approach will require a better accounting of monitoring and assessment costs. There also may be social costs to consider as regulations become increasingly complex to account for variation in harvest potential. Third, there will be difficult decisions about harvest-management objectives, including the importance of population goals, the relative value of stocks among hunters, and about what constitutes fair allocations of hunting opportunity.

Western mallards.--Efforts to understand the population dynamics of western mallards have been underway for several years. In support of this effort, the Pacific Flyway States and the USFWS have worked cooperatively to improve survey and banding programs throughout the breeding range of western mallards. In addition, two assessment projects have been cooperatively funded:

(1) In 1998 funding was provided to the New York Cooperative Fish and Wildlife Research Unit to compile survey, banding, and harvest data, and to develop models describing the population dynamics of western mallards. A final report, which was issued in 1999, provided estimates of mortality and reproductive rates for western mallards, as well as a preliminary assessment of how these rates might vary as a function of environmental conditions and harvest. This project was cooperatively funded by the USFWS ($15,000), Ducks Unlimited ($15,000), the Pacific Flyway Council ($10,000), the California Dept. of Fish and Game ($10,000), and California Waterfowl Association ($10,000) (total = $60,000). (An additional $60,000 also was provided concurrently by these same partners to advance AHM for pintails.)

(2) After completion of the first cooperative assessment project, the AHM Working Group identified a number of technical concerns with the original effort to model population dynamics. In January of this year, the University of Nevada - Reno hired a post-doctoral fellow to pursue the outstanding technical issues. The project budget is $57,000 and is being cooperatively funded by the Pacific Flyway Council ($20,000), the State of Oregon ($20,000), and the USFWS ($17,000).

The assessment work being conducted at the University of Nevada is focused on understanding the potential of the western mallard population to support sport harvests. We expect this project to be completed by January 2004. Upon completion of this project, there will be additional work required: (1) to assess the relationship between hunting regulations and the harvest rates of western mallards; (2) to explore and agree on appropriate harvest-management objectives for western mallards; and (3) to integrate western and midcontinent mallard AHM in a way that appropriately recognizes the mixing of these two stocks during the hunting season. Therefore, a reasonable expectation for implementation of AHM for western mallards might be the 2005 hunting season.

Pintails.--The development of an AHM strategy for northern pintails has been challenging on both technical and political levels. As we move beyond mallards to develop more quantitative harvest strategies for other species, we face two fundamental difficulties: greater uncertainty about the biology, because the monitoring data are sparser; and the political challenge of identifying management objectives for multiple stocks.

For pintails, there are three technical issues that are impeding development of an AHM strategy:

(1) There is evidence of a temporal trend in reproductive rates, presumably due to habitat changes in the western Canadian prairies. In the past, reproduction was strongly influenced by the latitude of the breeding population. In years when the prairies were wet and pintails settled in the southern part of their breeding range, reproductive success was high; in years when pintails overflew the prairies, reproduction was low. This effect appears to have disappeared over time, so that now even when the prairies are wet and pintails settle in the south, reproductive success is not very high. From a decision-making perspective, this trend presents some conceptual problems because of uncertainty about whether (and to what extent) a temporal trajectory in the reproductive process will continue in the future.

(2) There are several apparent biases in the monitoring programs for pintails, but we do not yet know their cause or how to compensate for them. When combined into a "balance equation," estimates of survival and reproductive rates over-predict the growth rate of the population. Worse, the magnitude of the over-prediction is related to where the birds settle. That is, when pintail overfly the prairies, we appear to undercount them. The first type of bias (balance-equation bias) is also seen in midcontinent and eastern mallards, and we have successfully developed remedial measures. But we do not yet have an acceptable means to correct for the over-flight bias.

(3) It will be difficult to develop a predictive model for harvest rate as a function of regulations. This is a key component in AHM because it is the link between the management action and the effect on the population. Estimates for pintail harvest rates have wide confidence intervals because of the small number of birds that are banded and recovered each year. Because of the attendant large sampling errors, it will be difficult to discern the extent to which changes in regulations affect changes in harvest rate.

Assuming these technical problems can be overcome, there are three remaining impediments, each of which is a human-dimensions question that needs to be answered in the political arena:

(1) How will decisions about pintail harvest interact with decisions about mallard harvest? What regulatory structure is desired: independent regulations for each species, a common season length but separate bag limits, or the same regulations? If a common season length is desired, should the season be set by mallard status and the pintail bag set conditionally, or should the regulations for the two species be jointly optimized?

(2) What are the objectives for pintail management? There are many possible objectives, including to maximize harvest, to provide incentive for winter habitat conservation, to provide consistent hunting opportunity, and to avoid closed seasons. How are these objectives to be balanced against one another, and how are they to be balanced against the management objectives for mallards and other species?

(3) How much do we want to forego harvest opportunity to promote recovery of the pintail population? There is strong consensus that the decline in the pintail population is due to habitat degradation, not harvest. Nevertheless, harvest could delay population recovery. Should time to recovery be a consideration in setting harvest regulations?

Black ducks.--An international working group was formed in 2000 to pursue a coordinated AHM strategy for black ducks. AHM is viewed as a means of dealing with (not resolving) uncertainties in population dynamics, particularly those concerning the role of mallard competition and sport harvest in the long-term decline in black duck abundance. The Cooperative Fish and Wildlife Research Unit in Georgia, under contract to the Black Duck Joint Venture, has developed a one-population model that recognizes four alternative biological hypotheses (presence or absence of a mallard effect on reproduction, additive or compensatory hunting mortality) (Conroy et al. 2002) and two adjustment factors that are needed because of a bias in estimates of survival or reproductive rates. The developing AHM framework also includes: (a) breeding-population goals; (b) parity in U.S. and Canadian harvests; and (c) possible regulatory alternatives. An extension of this framework to three breeding stocks and six harvest areas (three in eastern Canada, two in the Atlantic Flyway, and the Mississippi Flyway) also is being pursued. For more information about black duck AHM visit http://coopunit.forestry.uga.edu/blackduck/.

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APPENDIX A: AHM Working Group

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APPENDIX B: Modeling Midcontinent Mallard Harvest Rates

We modeled midcontinent mallard harvest rates within a Bayesian statistical framework similar to the approach used last year (Johnson et al. 2002*c*, USFWS 2002). Because estimates of harvest rates since the inception of AHM are available only under the liberal regulatory alternative, 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, and of 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 a new 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. 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 our 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 regulations 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.

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:

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

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

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 regulatory 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 of the harvest rates observed under the liberal regulatory alternative. We further specified that the standard error of the normal distribution 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 under the restrictive and moderate regulation alternatives, respectively.

Liberal:

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

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

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

The parameters specified for the harvest rate distribution under the liberal alternative and the effect of the framework-date extensions are identical to the prior values used to evaluate harvest-rate predictions last year (USFWS 2002).

The prior distributions were then multiplied by the likelihood functions based on the five years of data (under liberal regulations) and the resulting posterior distributions were evaluated with Markov Chain Monte Carlo simulation using a Metropolis-Hastings algorithm (J. A. Royle, pers. comm.).

This analysis resulted in the following posterior estimates of midcontinent mallard harvest rates and model parameters (only parameter estimates that could be updated at this time are provided):

Parameter	Estimate	SD
h_{1998}	0.1109	0.0113
h_{1999}	0.1004	0.0076
h_{2000}	0.1271	0.0103
h_{2001}	0.1081	0.0113
h_{2002}	0.1136	0.0058
μ_L	0.1191	0.0082
v_L	0.0231	0.0055
δ_f	0.0157	0.0091

NOTES


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