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Adaptive Harvest Management for Eastern Mallards

Progress Report

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Introduction

The biology of eastern mallards appears to differ from that of midcontinent mallards (Fig. 1) in several important ways. The size of the midcontinent population has been fairly stable over time, and numerically is much larger than the eastern population. However, the eastern population appears to be more productive than the midcontinent population, and apparently has been growing in size at least since the mid-1960's. These biological differences suggest possible differences in allowable harvest pressure. Based on recent analyses, the optimal regulatory strategy for eastern mallards is more liberal than that for the midcontinent population, even in the face of regulation-specific harvest rates that are higher in eastern North America.

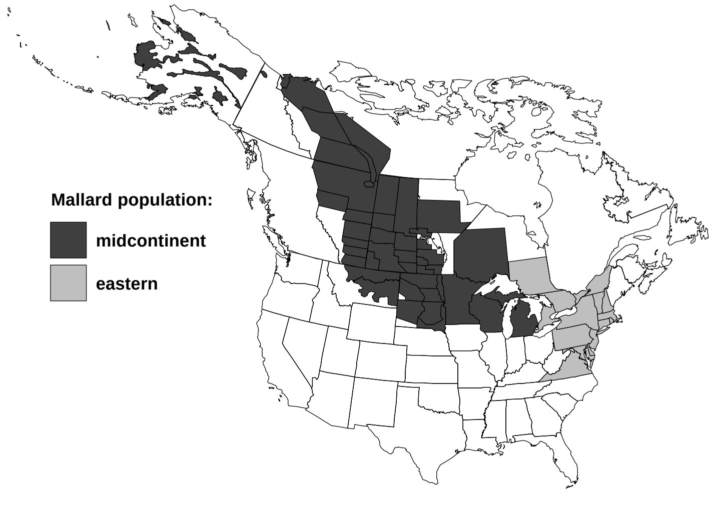

Fig. 1. Survey areas currently assigned to the midcontinent and eastern populations of mallards for purposes of harvest management.

Because of these biological differences and their management implications, there has been considerable interest in modifying the current AHM protocol to account for the status and dynamics of eastern mallards. This modification involves:

(1) revision of the objective function to account for harvest-management goals for eastern mallards;
(2) augmentation of the decision criteria to include population and environmental variables relevant to eastern mallards; and
(3) modification of the decision rules to allow Flyway-specific regulatory choices.

This report summarizes our efforts since August 1999 to address these issues. This report is intended primarily as a synopsis of major findings and policy implications and, therefore, *we have omitted a great deal of technical detail*. We hope to have a more comprehensive report available prior to the Flyway Council technical meetings in February.

Modification of Decision Rules

The current AHM protocol permits one regulatory decision for all four Flyways based on the predicted fall-flight of midcontinent mallards. Our goal is to allow Flyway-specific regulatory choices, which are determined by each Flyway's unique derivation of mallards (assuming, of course, that there is sufficient differences in derivation among Flyways). This modification of the decision rules greatly complicates the optimization procedure, however. Instead of five possible regulatory decisions (C, VR, R, M, and L), we have to evaluate $5^4 = 625$ decisions for every possible combination of each breeding population's size and associated environmental condition(s). In our effort to include eastern mallards in the AHM protocol, we investigated the expected gain in management performance associated with moving from one nationwide regulatory decision to Flyway-specific decisions for the Atlantic, Mississippi, and Central/Pacific Flyways. Our intent was to determine the number of regulatory decisions that provided a reasonable balance between management performance and regulatory complexity.

This exercise was based on an objective to maximize the harvest of eastern mallards, the "working model" of eastern mallard population dynamics, and current models and management objective for midcontinent mallards (U.S. Fish and Wildlife Service, 1999, Adaptive Harvest Management: 1999 Duck Hunting Season, Dept. Inter., Washington, D.C., 37pp.). We evaluated a full range of possible harvest rates, rather than discrete regulatory alternatives, and assumed perfect controllability of harvest. We derived optimal harvest strategies using dynamic programming, and then simulated application of the strategies to derive three measures of expected performance: (1) average population size of midcontinent mallards (Nm); (2) average population size of eastern mallards (Ne); and (3) average aggregate harvest (H). We also calculated the mean harvest rate (h) for each harvest area (i.e., each Flyway or combination of Flyways).

There were moderate gains in performance when comparing a 2-dimensional decision (i.e., Atlantic Flyway vs. the remainder of the country) with a nationwide decision (Table 1). The 2-dimensional decision resulted in an average midcontinent population size closer to the NAWMP goal, higher aggregate harvest, and optimal harvest rates that were higher for the Atlantic Flyway. The additional gain in performance with a 3-dimensional decision was negligible.

Table 1. Expected performance of optimal harvest strategies, conditioned on the number of harvest areas for which regulatory decisions are made. (Definitions of metrics are provided in the report narrative.)

	Performance metric					
Decision space	**N_m***	**N_e***	**H***	**h_{AF}**	**h_{MF}**	**$h_{remainder}$**
(1) nationwide	7.85	1.36	1.55	0.14	0.14	0.14
(2) AF, remainder	8.21	0.88	1.66	0.29	0.12	0.12
(3) AF, MF, remainder	8.14	0.86	1.67	0.29	0.14	0.09

* in millions.

Based on this exercise, we used current harvest models (U.S. Fish and Wildlife Service, 1999:28-31, Adaptive Harvest Management: 1999 Duck Hunting Season, Dept. Inter., Washington, D.C., 37pp.) to predict population-specific harvest rates for the 25 combinations of regulatory alternatives in the Atlantic Flyway and the remainder of the country. Harvest rates of midcontinent mallards are affected little by the regulatory choice in the Atlantic Flyway because of the small proportion (2%) of midcontinent mallards migrating to that Flyway (Table 2). However, harvest rates of eastern mallards are affected to a fair degree by regulations in the western three Flyways because of the relatively high proportion (13%) of eastern mallards that migrate there (Table 3).

Table 2. Predicted harvest rates of midcontinent mallards for current regulatory alternatives, allowing for different regulatory choices between the Atlantic Flyway and the remaining Flyways.

Proposed Regulatory Alternative for MF, CF, and PF	**Proposed Regulatory Alternative for AF**	**Predicted MC Mallard Harvest Rate (%)**	**Standard Error**
Closed	Closed	0.0	0.0
Closed	Very Restrictive	1.9343	0.52116
Closed	Restrictive	1.9722	0.52222
Closed	Moderate	2.0326	0.52414
Closed	Liberal	2.0681	0.52598
Very Restrictive	Closed	5.2087	1.02560
Very Restrictive	Very Restrictive	5.2644	1.06198
Very Restrictive	Restrictive	5.3046	1.06890
Very Restrictive	Moderate	5.3602	1.08056
Very Restrictive	Liberal	5.4029	1.08706
Restrictive	Closed	6.5760	1.36330
Restrictive	Very Restrictive	6.6222	1.41532
Restrictive	Restrictive	6.6530	1.42327
Restrictive	Moderate	6.7240	1.43431
Restrictive	Liberal	6.7595	1.44138
Moderate	Closed	10.9442	2.50067
Moderate	Very Restrictive	11.0389	2.63703
Moderate	Restrictive	11.0792	2.64459
Moderate	Moderate	11.1407	2.65685
Moderate	Liberal	11.1774	2.66372
Liberal	Closed	12.8217	3.04241
Liberal	Very Restrictive	12.9129	3.20371
Liberal	Restrictive	12.9520	3.21152
Liberal	Moderate	13.0147	3.22356
Liberal	Liberal	13.0514	3.23040

Table 3. Predicted harvest rates of eastern mallards for current regulatory alternatives, allowing for different regulatory choices between the Atlantic Flyway and the remaining Flyways.

Proposed Regulatory Alternative for AF	**Proposed Regulatory Alternative for MF, CF and PF**	**Predicted Eastern Mallard Harvest Rate (%)**	**Standard Error**
Closed	Closed	0.0	0.0
Closed	Very Restrictive	9.2678	1.41717
Closed	Restrictive	9.5930	1.38131
Closed	Moderate	10.6237	1.31170
Closed	Liberal	11.0953	1.30447
Very Restrictive	Closed	11.2990	2.10816
Very Restrictive	Very Restrictive	12.1225	2.04704
Very Restrictive	Restrictive	12.4476	2.03105
Very Restrictive	Moderate	13.4784	2.01257
Very Restrictive	Liberal	13.9482	2.02033
Restrictive	Closed	12.3726	2.24807
Restrictive	Very Restrictive	13.1961	2.19813
Restrictive	Restrictive	13.5213	2.18646
Restrictive	Moderate	14.5520	2.17861
Restrictive	Liberal	15.0236	2.19051
Moderate	Closed	14.0733	2.56853
Moderate	Very Restrictive	14.7289	2.52117
Moderate	Restrictive	15.2219	2.52950
Moderate	Moderate	16.2527	2.53612
Moderate	Liberal	16.7243	2.55214
Liberal	Closed	15.0611	2.81626
Liberal	Very Restrictive	15.8847	2.79176
Liberal	Restrictive	16.2098	2.78818
Liberal	Moderate	17.2405	2.80076
Liberal	Liberal	17.7104	2.81849

Harvest Management Objectives

The preliminary objective for eastern mallards is to maximize long-term cumulative harvest. This objective is subject to change once the implications for average population size, variability in annual regulations, and other performance characteristics are better understood. The objective for midcontinent mallards is to maximize long-term cumulative harvest, subject to a population goal of 8.7 million breeding birds. One of the difficulties in modifying the current AHM protocol involves combining the population-specific objectives into one objective function so that an aggregate harvest strategy can be derived. We initially explored three possible forms for the aggregate objective function:

OF1: $\alpha H_m + H_e$, which uses the actual harvest of eastern mallards (H_e) added to the harvest utility of midcontinent mallards (αH_m, i.e., actual harvest [H_m] devalued [α] when populations are expected to be lower than NAWMP goal). In this case, the value of the objective function is influenced heavily by the harvest of midcontinent mallards because of the difference in size of the two populations.

OF2: $\alpha(H_m + H_e)$, which uses the actual harvest of eastern mallards added to the actual harvest of midcontinent mallards, and then the sum is devalued when midcontinent mallard populations are expected to be lower than NAWMP goal. For this objective function, a primary management concern would be the NAWMP goal for midcontinent mallards. This objective likely would reduce harvest opportunity in the Atlantic Flyway when midcontinent mallards were below the NAWMP goal.

OF3: weighting the actual harvest of eastern mallards and the harvest utility of midcontinent mallards to account for the discrepancy in magnitude of the two populations:

> **OF3A:** $0.2\alpha H_m + 0.8H_e$, which uses population-specific weights based on the relative magnitude of each population's predicted mean harvest. These are model-based weights, conditional on the "working model" for eastern mallards and current models for midcontinent mallards.
>
> **OF3B:** $\alpha H_m + 8.9H_e$, which uses weights based on the difference in size of the two breeding populations. We used the average ratio of breeding population estimates of midcontinent to eastern mallards during 1992-99.

The expected performance of optimal harvest strategies was not sensitive to the form of the objective function (Table 4), principally because there is a high degree of spatial separation of the two populations during the hunting season.

Table 4. Expected performance of optimal harvest strategies, conditioned on alternative objective functions. N_m = average midcontinent population size, N_e = average eastern population size, H = average annual harvest utility, h_{AF} = average annual harvest rate in the Atlantic Flyway, $H_{remainder}$ = average annual harvest rate in the remainder of the country.

	Performance metric				
Objective	N_m	N_e	**H**	h_{AF}	$h_{remainder}$
OF1: $\alpha H_m + H_e$	8.21e6	0.88e6	1.66e6	0.289	0.121
OF2: $\alpha(H_m + H_e)$	8.35e6	0.89e6	1.64e6	0.288	0.117
OF3A: $0.2\alpha H_m + 0.8H_e$	8.21e6	0.88e6	1.66e6	0.289	0.121
OF3B: $\alpha H_m + 8.9H_e$	8.13e6	0.89e6	1.66e6	0.286	0.123

Models of Eastern Mallard Population Dynamics

The population dynamics of eastern mallards were studied extensively by Sheaffer and Malecki (1996, Quantitative Models for Adaptive Harvest Management of Mallards in Eastern North America, New York Coop. Fish and Wildl. Res. Unit, Ithaca, N.Y., 116pp.), but managers have not yet established a set of alternative models that characterize key uncertainties about the mortality and reproductive processes. In the interim, a “working model” has been used to help managers understand the potential biological impacts of the current AHM process on eastern mallards (U.S. Fish and Wildlife Service, 1999:21-24, Adaptive Harvest Management: 1999 Duck Hunting Season, Dept. Inter., Washington, D.C., 37pp.).

We examined all structural components of the “working model,” updated relevant databases, tested various hypotheses, and identified what we believed to be key sources of uncertainty in the population dynamics of eastern mallards. We developed a set of eight alternative models based on differences in the functional form of the relationship between dependent and independent variables of interest. This differs from our previous approach to construction of alternative models that was based on parametric uncertainty after specifying a unique functional form. Through extensive investigations, we have discovered that the functional forms used to express population processes can have profound effects on optimal harvest strategies, even when alternative forms fit existing data equally well (M.C. Runge, F. A. Johnson, J. D. Nichols, and W. L. Kendall, The importance of functional form in optimal control solutions of population dynamics, unpubl. ms.).

Reproductive models: We made the decision to use fall age ratios of males rather than females to index production of young. Using male-based age-ratios has two important advantages. First, there is evidence for eastern mallards that natural mortality of females is high and variable, relative to males. Because we do not fully understand the nature of the temporal variability, it is difficult to interpret female age ratios (e.g., high age ratios could mean good production of young, poor summer survival of adults, or both). Although we recognize that males do not lay eggs, we do believe that male age ratios should be a better index of production because natural mortality of males is lower and less variable than that of females. Secondly, we found that the best predictor of male age-ratios is simply breeding population size (i.e., the BBS index). Both spring precipitation and breeding population size are needed in a model predicting female age-ratios, resulting in a model that is more complex, but that has no greater explanatory power than the single-variable model for males. Our goal is model parsimony because model complexity carries a high cost in terms of computing optimal harvest strategies.

We expressed fall age ratios of males as a function of a Breeding Bird Survey (BBS) index, which represented a weighted average of stratum-specific indices in the northeastern U.S. (Fig. 2). We considered three functional forms for this relationship: (1) negative exponential; (2) logistic; and (3) linear. The logistic model expresses a dampening of density-dependent effects at small densities, while the negative exponential model does not. These two models also differ in the degree which density dependence is operative at high population levels. The linear model expresses the same degree of density dependence at all population sizes. All three models fit the data equally well. From a biological perspective, we believed the negative exponential and logistic to be most plausible and, therefore, retained them in the final model set.

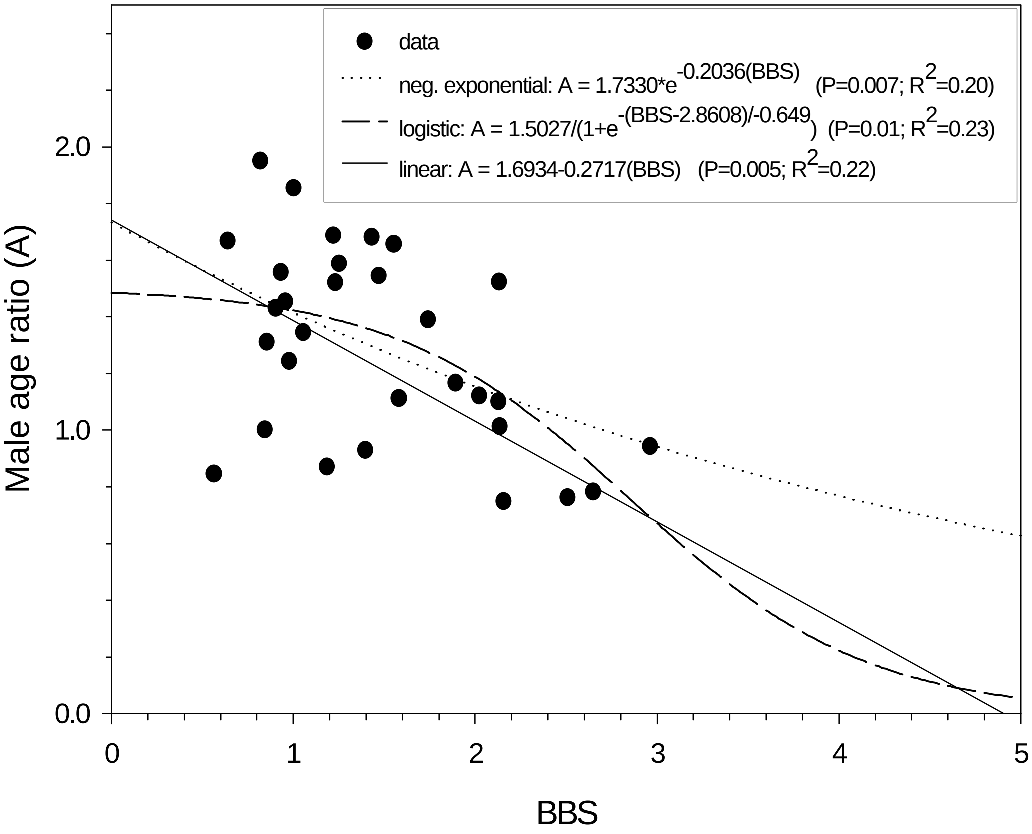

Fig. 2. Models relating the fall age ratio of eastern mallard males to a Breeding Bird Survey index in the northeastern U.S.

We expressed the BBS index as a function of the combined population size of mallards in fixed-wing strata (51-54, 56) and northeastern plot surveys (Fig. 3). This was necessary to enable managers to use current estimates of population size, rather than the BBS index, as the criterion for regulatory decisions. We considered three forms of the relationship: (1) logarithmic; (2) linear; and (3) exponential rise to a maximum. All models fit the data equally well. We retained the logarithmic and exponential forms to characterize possible extremes in the relationship. The logarithmic model tends to predict large changes in the BBS index with small changes in population size. This might be the case if populations in areas surveyed by the BBS were growing at a faster rate than in the population as a whole. The model specifying an exponential rise to a maximum suggests that only small changes in the BBS index associated with large changes in population size, which might be the case where BBS routes had become "saturated" with mallards.

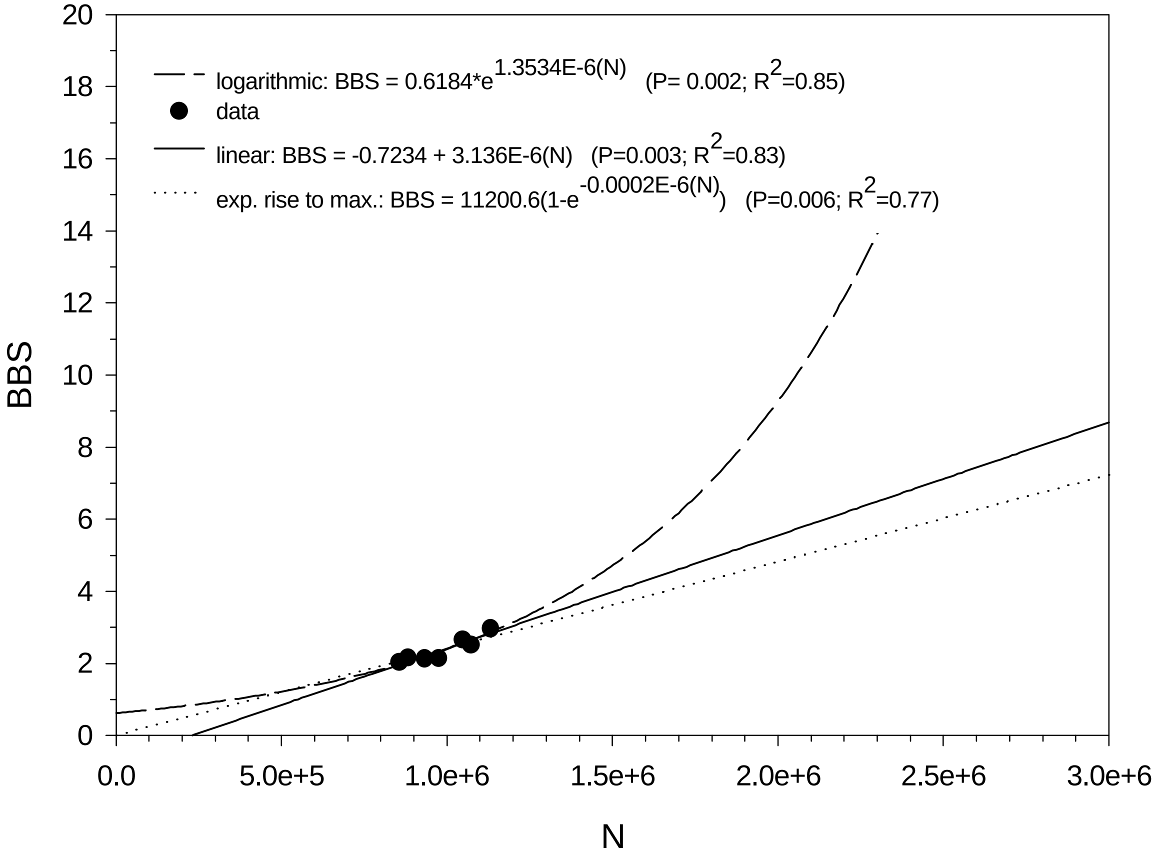

Fig. 3. The relationship between population size of eastern mallards (N) and the Breeding Bird Survey index in the northeastern U.S.

Survival models: We compiled preseason banding and recovery records of mallards banded in reference areas 8 (eastern Ontario, western Quebec), 15 and 16 (northeastern U.S.) for the period 1979-95. We adjusted hunter recoveries for non-reporting of bands (Nichols et al., 1995, Geographic variation in band reporting rates for mallards based on reward banding., J. Wildl. Manage. 59:697-708, and C. Moore, J. Dubovsky and W. Kendall, unpubl. data) and for crippling loss, and then investigated spatial, temporal, and demographic sources of variability in harvest and natural mortality rates. The most general model took the form:

$$S_{asry} = \theta_{asry} \, (1 - K_{asry}),$$

where S = annual survival, θ = survival from natural causes, K = rate of hunter kill, a = adult or young, s = male or female, r = reference area, and y = year. Likelihood-ratio tests confirmed that all four sources of variation were significant ($P = 0.00$), but even the most general model fit the data poorly (variance inflation factor = 9.1). Although specification of adequate survival models has always been a problem for eastern mallards, our models (general model above, as well as its reduced forms) nonetheless provide relatively unbiased estimates of survival (although the estimated variances are biased low).

In all subsequent investigations, we used reduced models which ignored reference-area effects. While the reference-area effects were substantial in some cases (particularly for kill rates), we did not have a sufficient time-series of population estimates with which to weight reference-area specific estimates. Therefore, our survival estimates reflect pooling of banding and recovery data across the three reference areas. We also assumed no age effects in survival after the hunting season (i.e., differences in annual survival of young and adults are attributable to differences in harvest pressure), and that sex-specific differences in natural mortality are confined to the breeding season. Finally, we assumed that survival during February-April was a constant 90%, and then calculated summer survival rates for males and females (Fig. 4).

For females, we considered two alternative models for summer survival: (1) a mean model, with random variation in summer survival; and (2) a logistic model in which variation in summer survival was a function of the BBS index. The latter model reflects density-dependence in the mortality process, and provides a mechanism to partially compensate for harvest during the previous hunting season. Summer survival of males was higher on average than that for females, and was not related to the BBS index. Therefore, we combined a single mean model with randomly varying summer survival for males with the two alternative models for female survival.

Optimal Harvest Strategies

We first examined model behavior and optimal harvest strategies associated with the eight alternative models (2 reproduction models × 2 BBS models × 2 survival models) of eastern mallard population dynamics. In deriving optimal harvest strategies, we used an objective to maximize long-term cumulative harvest, and assumed perfect controllability of harvest rates. Population sizes expected in the absence of harvest, and when exposed to optimal harvest rates, varied among models (Table 5). However, there were minimal differences among models in average optimal harvest rates. Optimal harvest rates tend to increase with increasing population size, although the increase is not monotonic for all models (Fig. 5). For recent population sizes (i.e., >1 million), seven of the eight models prescribe optimal harvest rates that are higher than those attained with the current liberal regulatory alternative.

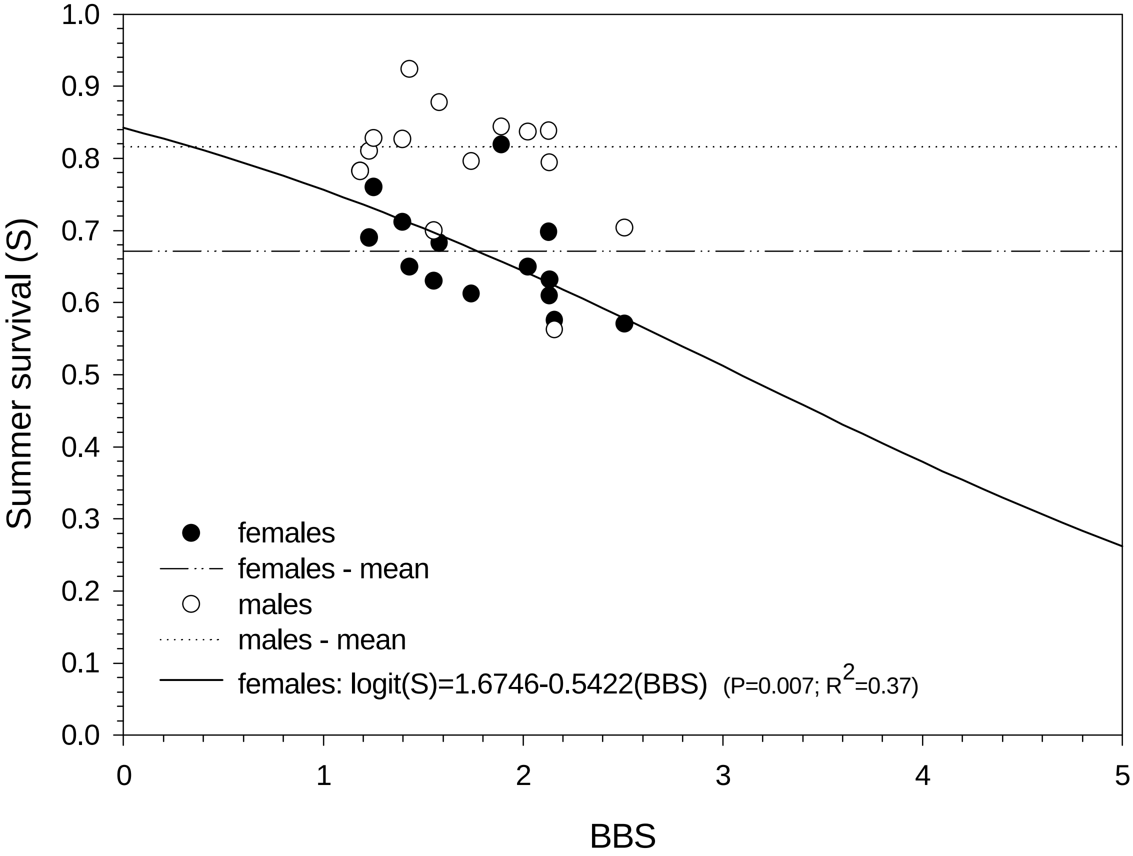

Fig. 4. Estimated summer survival rates of male and female eastern mallards in relation to the Breeding Bird Survey index in the northeastern U.S.

Table 5. Expected population sizes of mallards in the absence of harvest and when exposed to optimal harvest rates, for eight alternative models of population dynamics. $P_{h=0}$ = average population size expected in the absence of harvest, P* = average population size expected under an optimal harvest regime, and h* = average optimal harvest rate of adult males.

Model						
Reproduction	BBS	Summer survival	Designation	$P_{h=0}$	P*	h*
negative exponential	logarithmic	constant	r1b1s1	1.95e6	0.91e6	0.20
negative exponential	logarithmic	f(BBS)	r1b1s2	1.49e6	0.82e6	0.21
negative exponential	exp_{max}	constant	r1b2s1	3.49e6	1.20e6	0.18
negative exponential	exp_{max}	f(BBS)	r1b2s2	2.20e6	0.96e6	0.20
logistic	logarithmic	constant	r2b1s1	1.41e6	0.77e6	0.22
logistic	logarithmic	f(BBS)	r2b1s2	1.23e6	0.74e6	0.23
logistic	exp_{max}	constant	r2b2s1	1.68e6	0.83e6	0.22
logistic	exp_{max}	f(BBS)	r2b2s2	1.48e6	0.79e6	0.22

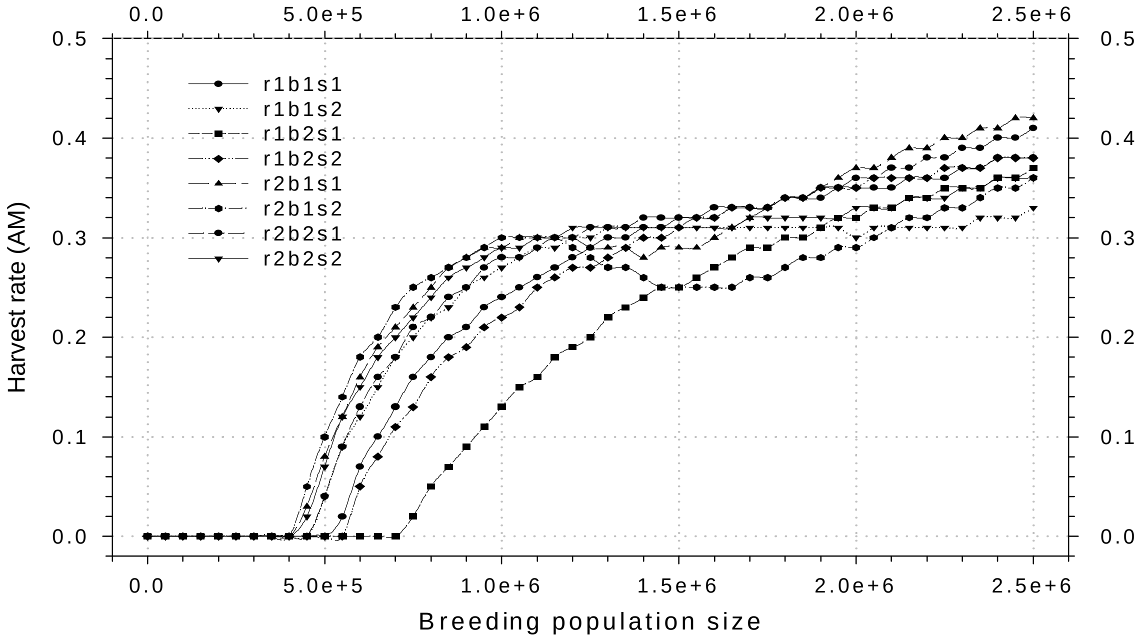

Fig. 5. Optimal harvest rates (adult males) for eight alternative models of eastern mallard population dynamics. Model designations refer to models described in Table 4.

We next examined optimal harvest strategies in which we integrated eastern and midcontinent mallards. We specified the following conditions to derive an optimal strategy:

(1) an objective function that maximizes the long-term cumulative sum of eastern mallard harvest and midcontinent mallard harvest utility (OF1: $\alpha H_m + H_e$);

(2) all possible combinations of current regulatory alternatives in the Atlantic Flyway and the remainder of the country (Tables 2 and 3), and an assumption of perfect controllability (i.e., deterministic harvest rates); and

(3) current population models and associated weights for midcontinent mallards, and eight models of eastern mallards, equally weighted.

The optimal regulatory choice for the Atlantic Flyway rarely diverges from the liberal alternative, even when the status of midcontinent mallards is poor (Table 6). The status of eastern mallards has somewhat more effect on the optimal regulatory choice in the remainder of the country, but the effect is minimal and observed only under extreme conditions. These results are consistent with the high degree of spatial discrimination between the two populations during the hunting season. We recognize that it is most appropriate to develop the optimal strategy using: (1) smaller increments for population sizes and ponds than we used here; and (2) harvest rates that incorporate stochastic variation. However, such a solution likely will take approximately over three weeks on a dual-300mhz Pentium II processor. While we do not expect any major changes in the patterns of optimal regulations presented here, we intend to make the more comprehensive solution available prior to the winter Flyway meetings.

Table 6. Optimal regulatory choices for midcontinent and eastern mallards. The objective function, models of population dynamics, and harvest rates associated with each regulatory alternative are provided in text.

Midcontinent Mallard Breeding Pop. (millions)	Prairie Ponds (millions)	Eastern Mallard Breeding Pop. (millions)	PF/CF/MF Regulation	AF Regulation
3	1-5	0.5-1.5	C	L
3	6	0.5	C	M
3	6	0.6-1.5	C	L
3	7	0.5	C	M
3	7	0.6-1.5	C	L
4	1-6	0.5-1.5	C	L
4	7	0.5	C	M
4	7	0.6-1.5	C	L
5	1-5	0.5-1.5	C	L
5	6	0.5	C	L
5	6	0.6-1.5	VR	L

5	7	0.5-0.6	VR	L
5	7	0.7-1.5	R	L
6	1-2	0.5-1.5	C	L
6	3	0.5-1.5	VR	L
6	4	0.5-0.6	VR	L
6	4	0.7-1.5	R	L
6	5	0.5-0.9	R	L
6	5	1.0-1.5	R	L
6	6	0.5	M	M
6	6	0.6-1.5	M	L
6	7	0.5	M	M
6	7	0.6-1.5	M	L
7	1	0.5-0.7	VR	L
7	1	0.8-1.5	R	L
7	2	0.5-1.5	R	L
7	3	0.5-0.7	R	L
7	3	0.8-1.5	M	L
7	4	0.5	M	M
7	4	0.6-1.5	M	L
7	5	0.5	L	M
7	5	0.6-1.5	L	L
7	6-7	0.5-1.5	L	L
8	1	0.5-1.5	M	L
8	2	0.5-1.0	M	L
8	2	1.1-1.3	L	L
8	2	1.4-1.5	M	L
8	3	0.5	M	L
8	3	0.6-1.5	L	L
8	4-7	0.5-1.5	L	L
9	1	0.5	L	M

9	1	0.6-1.5	L	L
9	2	0.5	L	M
9	2	0.6-1.5	L	L
9	3-7	0.5-1.5	L	L
10	1	0.5	L	M
10	1	0.6-1.5	L	L
10	2-7	0.5-1.5	L	L
11-12	1-7	0.5-1.5	L	L

Conclusions

Modifying the AHM protocol to account for multiple duck populations is perhaps the most challenging technical issue facing harvest managers. Never before have we tried to consider the status of multiple populations in such a formal way, nor have we attempted to give Flyways the ability to choose regulations that are predicated on their particular derivation of birds. We expect the effort with eastern mallards to be precedent setting and, thus, must be done carefully and in a way that provides a sound conceptual framework for considering additional populations in the future. In that regard, the approach described herein provides an objective basis for determining the additional benefit derived from stratifying breeding populations and harvest areas into more homogeneous units. However, the utility of this approach could be greatly enhanced by incorporating the additional monitoring and assessment costs, and possibly administrative costs, associated with these higher-level stratifications. Only then can we make sound and effective decisions regarding the extent to which our harvest management protocol should account for sources of spatial, temporal, and bio-organizational variation in the biological systems of interest.

With respect to our effort to account for both midcontinent and eastern mallards, we make the following observations:

(1) Based on our investigation of the potential levels of stratification for harvest areas (i.e., the number of Flyway-specific regulatory choices), we believe there is sufficient justification for allowing a regulatory choice in the Atlantic Flyway that can differ from that in the remainder of the country. However, there seems to be little additional benefit (in terms of harvest) from allowing different rates of harvest in the Atlantic Flyway, Mississippi Flyway, and the remainder of the country, in spite of the considerable difference in the proportion of eastern mallards migrating to the Mississippi Flyway and the western two Flyways (13% vs. 0.05%, respectively). Moreover, when we permitted different harvest rates in the Mississippi and Central/Pacific Flyways, the pattern of differences in Flyway-specific harvest rates was not always intuitive and, consequently, raised questions regarding the most appropriate allocation of harvest opportunity between the Mississippi Flyway and the remainder of the country. The allocation of sustainable harvests (within that allowed by biological constraints) is a value judgement, and would require considerable inter-Flyway dialogue before a broadly accepted harvest strategy could be derived.

(2) The patterns in predicted harvest rates associated with the 25 combinations of regulations in the Atlantic Flyway and the remainder of the country are consistent with what we know about the wintering distributions of midcontinent and eastern mallards. However, we emphasize that these predictions

represent extrapolation beyond our range of experience. Moreover, the estimation procedure relies heavily on statistical and conceptual models that must meet certain assumptions. We have no way to verify these assumptions, nor can we gauge their effects should they not be met. Therefore, the use of this procedure for predicting mallard harvest rates warrants considerable caution and underscores the need to accumulate experience with a stable set of regulatory alternatives.

(3) Initially, we were surprised that management performance (in terms of expected population sizes and harvest) was not sensitive to the form of the aggregate objective function. However, the result seems to follow from the high degree of spatial segregation of the two mallard populations during the hunting season. Therefore, an unweighted sum of population-specific harvest utilities seems to us a reasonable choice. However, we emphasize that in many, if not most, cases of managing multiple stocks the form of the aggregate objective function will be critical. Difficult value judgements will be necessary where populations vary markedly in abundance and capacity to support harvest, and where there is limited ability to regulate population-specific harvest rates.

(4) We constructed alternative population models based on plausible functional forms of biological relationships, rather than on the variance of parameter estimates from a given functional form. This decision was influenced heavily by recent theoretical work, which suggests that the choice of functional form can greatly influence optimal harvest strategies, and that this influence can exceed that associated with alternative parameter values for a given statistical model. Our approach also has the advantage of providing alternative models that fit the data equally well, which is not the case with models based on alternative parameter values. Finally, we believe that our approach forces managers and researchers to think more critically about the nature of biological relationships, particularly those system responses that might be observed beyond the range of experience.

(5) Our technical efforts to account for eastern mallards in the current AHM protocol appear to have substantial policy implications. In particular, there seems to be no influence of midcontinent mallard status on Atlantic Flyway regulatory prescriptions, nor does there seem to be any significant impact of eastern mallard status on regulations in the remainder of the country (at least within the range of population sizes we examined). Therefore, the additional benefit (in terms of harvest opportunity and the NAWMP goal for midcontinent mallards) of integration appears to be negligible. However, the computational costs associated with derivation of the optimal harvest strategy for midcontinent and eastern mallards is considerable. We experienced severe limitations in our ability to fully explore the implications of all sources of uncertainty, for all possible system states, even when using state-of-the-art Pentium workstations. We also are concerned about the implications of the integrated harvest strategy for the Atlantic Flyway, which suggests liberal regulations under almost all conditions. Clearly, the absence of any formal consideration for other key species in the Flyway (e.g., wood ducks, scaup) limits the utility of this management strategy. Therefore, we suggest that it may be more productive to integrate the harvests of eastern mallards with those of other key species in the Atlantic Flyway, rather than with midcontinent mallards. In effect, we suggest that the management community consider allowing the regulatory decision in the western three Flyways to be determined solely by the status of midcontinent mallards. For the Atlantic Flyway, we suggest that managers may want to moderate the regulatory strategy designed to maximize the harvest of eastern mallards by: (1) explicitly modeling the impacts of regulations on other species of concern; (2) decreasing the season length and bag limits associated with the liberal regulatory alternative; or (3) using a population goal for eastern mallards that was sufficiently high to introduce regulatory conservatism. The latter alternative would be the most practical in the short term if a constraint were deemed necessary, but we believe a long-term solution involves explicit consideration of the dynamics of other duck populations breeding in the Atlantic Flyway.

******************************** REPORT ERRATA **************************************

Tables 2 (page 5) and 3 (page 6) indicate 0.0% harvest rates for closed seasons in the United Sates. These predictions are probably not correct, in that they do not account for the possibility that seasons in Canada would remain open. While we don't believe correction of this error will markedly change the results in this report, we currently are attempting to derive more reliable predictions under the closed-season scenario.

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