U. S. Fish & Wildlife Service

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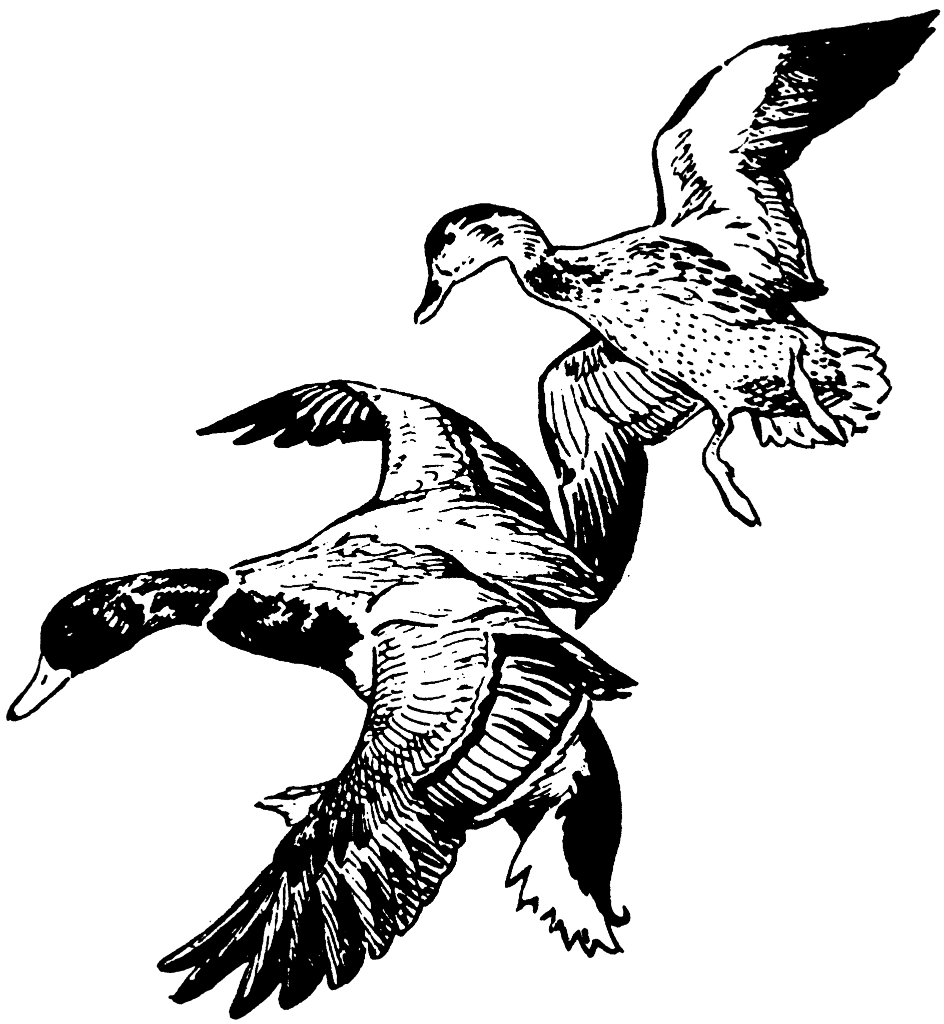

Adaptive Harvest Management for Eastern Mallards
1999 Progress Report

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Mallards breeding east of the midcontinent survey area (Fig. 1) winter in the Atlantic and Mississippi Flyways, where they contribute significantly to the sport harvest. Since the 1980's, there has been an ongoing effort to understand the ecology of these mallards, and to develop a procedure for recognizing this mallard population in the development of annual hunting regulations. This report provides information regarding the effort to modify the adaptive harvest management (AHM) protocol to account for mallards breeding in eastern Canada and the northeastern U.S.[1] For purposes of this report, eastern mallards are defined as those breeding in survey strata 51-54 and 56, and in New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, Pennsylvania, New Jersey, Delaware, Maryland, and Virginia.

In this report I address five questions concerning this effort:

I. Is it important to account for eastern mallards in the AHM process?
II. How will the AHM protocol be modified to account for eastern mallards?
III. What is the status of efforts to predict (model) responses of eastern mallards to harvest and uncontrolled environmental factors?
IV. What is the status of necessary modifications to the decision-making process?
V. Are there any concerns about this effort?

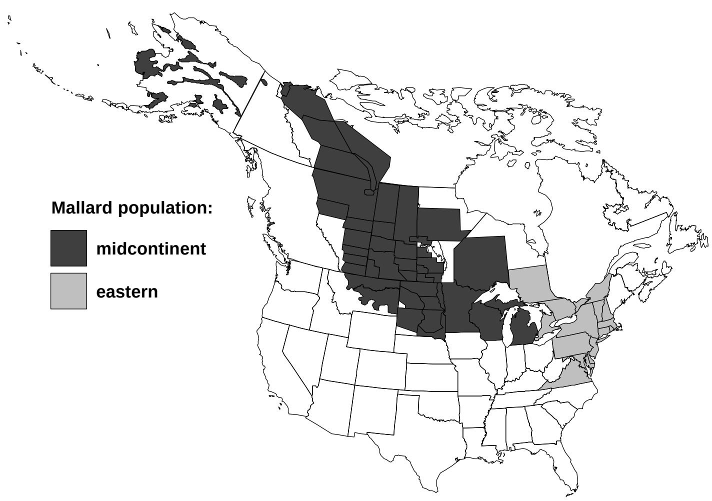

Fig. 1. Survey areas currently assigned to the midcontinent and eastern populations of mallards for purposes of harvest management.

[1] All analyses in this report are based on current information; results are subject to change as new information becomes available.

I. Is it important to account for eastern mallards in the AHM process?

The current AHM protocol explicitly recognizes only a midcontinent population of mallards, which is defined as those birds breeding in the traditional survey area and in the states of Minnesota, Wisconsin, and Michigan. Based on population surveys, band-recovery data, hunter surveys, and other information, the biology of eastern mallards appears to differ from that of midcontinent mallards in several important ways (Table 1). The midcontinent population is much larger than the eastern population, and population size has been fairly stable over time. 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 differences in allowable harvest pressure. Based on current population models, the optimal regulatory strategy for eastern mallards tends to be more liberal than that for the midcontinent population, even in the face of regulation-specific harvest rates that are higher in eastern North America (U.S. Fish and Wildlife Service. 1998. Adaptive harvest management: Considerations for the 1998 duck hunting season. U.S. Dep. Inter., Washington, D.C. 29pp.). This difference in optimal regulatory strategies could lead to situations where status of the two populations warranted different regulations. This presents a fundamental problem because the current AHM protocol permits only one regulatory alternative to be applied nationwide based on the status of midcontinent mallards.

Table 1. Some differences in the biology of midcontinent and eastern mallards. Standard errors are in parentheses.

Parameter	Midcontinent mallards	Eastern mallards
abundance (1998)	9.64 (0.30) million	1.04 (0.08) million
annual growth rate	-0.010 (0.003)	0.079 (0.002)
natural survival (adult females)	0.638 (0.010)	0.647 (0.009)
natural survival (adult males)	0.814 (0.015)	0.821 (0.006)
young/adult in fall population	0.865 (0.043)	1.711 (0.119)
proportion wintering in Atlantic Flyway	0.025 (0.003)	0.737 (0.072)
proportion wintering in Mississippi Flyway	0.705 (0.050)	0.262 (0.060)
proportion wintering in Central & Pacific Flyways	0.270 (0.021)	0.001 (0.001)
annual precipitation in core breeding range (cm)	41.8 (5.6)	106.4 (14.7)

I examined the potential for conflicting regulatory prescriptions between midcontinent and eastern mallards using current models of population dynamics. I generated independent optimal strategies for midcontinent and eastern mallards, assuming that all Flyways would use the same regulatory option. I used the current set of regulatory alternatives, the current objective for midcontinent mallards, and an objective to maximize the long-term cumulative harvest of eastern mallards. Upon simulating the two population-specific strategies, I found that the midcontinent population would be managed primarily by the moderate (22% of years) and liberal (64% of years) options. The eastern population would be managed almost entirely with the liberal option (98% of years). I assumed that the two populations are independent (no exchange, no correlation in relevant environmental conditions), and estimated the percentage of years in which there would be conflicting regulatory prescriptions for the two populations (Table 2). The down diagonal in the table (shaded) represents the percentage of years in which there would be no conflict in regulatory prescriptions (about 63%). Above the diagonal represents years in which the eastern population would be harvested at a rate less than optimal if all Flyways were driven by a midcontinent strategy (about 35%). Below the diagonal represents years when eastern mallards would be harvested at a rate higher than optimal (2%).

Based on this analysis, the Atlantic Flyway might expect overly restrictive regulations in about three out of ten years, if the Flyway's regulations continued to be determined solely on the basis of midcontinent mallards. In virtually all of those years, the Atlantic Flyway would experience regulations that were only one level more restrictive than would be optimal based on the status of eastern mallards (e.g., moderate instead of liberal).

Table 2. The expected frequency (%) of years with population-specific regulatory choices. VR=very restrictive, R=restrictive, M=moderate, and L=liberal regulations.

	Eastern population			
Midcontinent population	VR	R	M	L
VR	0.0	0.0	0.0	2.1
R	0.0	0.1	0.2	12.2
M	0.0	0.2	0.3	21.0
L	0.0	0.5	1.0	62.4

II. How will the AHM protocol be modified to account for eastern mallards?

Modification of the current AHM protocol to account for the status of eastern mallards 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.

Once these modifications are made, there no longer will be a need for two population-specific regulatory strategies. Essentially, the strategies would be melded into one, where regulatory-decision criteria would include both population size of midcontinent and eastern mallards, as well as environmental indicators appropriate for each population (e.g., ponds in southern Canada and spring precipitation in the northeastern U.S.). Moreover, instead of one regulatory prescription for all Flyways, optimal regulatory choices would be Flyway-specific based on the relative contribution of the two populations to the respective Flyways.

To demonstrate this framework, I derived an optimal harvest strategy using simplified versions of the current models of mallard population dynamics (e.g., I assumed all cohorts were equally vulnerable to harvest). I also assumed that managers have direct and perfect control over harvest rates. I permitted the Central and Pacific Flyways to share the same harvest rate because their harvests are derived almost entirely from the midcontinent population. Finally, I used a harvest-management objective to maximize the long-term cumulative harvest of mallards (regardless of their origin), conditional on maintaining the midcontinent population above the goal of the North American Waterfowl Management Plan. Table 3 contains excerpts from the full optimal harvest strategy, which is too large to reproduce in its entirety. Although I emphasize that this table is for demonstration purposes, it does reveal some interesting patterns of harvest rates. As expected, the optimal harvest rate for the Atlantic Flyway is highly dependent on the status of eastern mallards (first portion of the table). Also, as expected, optimal harvest rates are positively related to the status of midcontinent mallards. However, the relationship between Flyway-specific harvest rates and the status of midcontinent mallards occasionally is counter-intuitive. Although these patterns could be the result of over-simplifying the mallard models, they may suggest that managers ultimately will need to specify how the available harvest (and, thus, hunting opportunity) is to be shared (allocated) among Flyways.

Table 3. A portion of an optimal harvest strategy for mallards. See text for information regarding its derivation.

				Optimal harvest rate		
Midcontinent population	Ponds	Eastern population	Spring precip.	Cen. & Pac. Flyways	Miss. Flyway	Atl. Flyway
4.0e+6	4.0e+6	0.50e+6	11	0.00	0.00	0.00
4.0e+6	4.0e+6	0.75e+6	11	0.00	0.00	0.05
4.0e+6	4.0e+6	1.00e+6	11	0.00	0.00	0.25
4.0e+6	4.0e+6	1.25e+6	11	0.00	0.00	0.35
4.0e+6	4.0e+6	1.50e+6	11	0.00	0.00	0.40
…	…	…	…	…	…	…
8.0e+6	1.0e+6	1.00e+6	11	0.30	0.00	0.45
8.0e+6	2.5e+6	1.00e+6	11	0.35	0.00	0.45
8.0e+6	4.0e+6	1.00e+6	11	0.35	0.00	0.45
8.0e+6	5.5e+6	1.00e+6	11	0.10	0.15	0.40
8.0e+6	7.0e+6	1.00e+6	11	0.15	0.15	0.40
…	…	…	…	…	…	…
4.0e+6	5.5e+6	1.00e+6	11	0.00	0.00	0.25
6.0e+6	5.5e+6	1.00e+6	11	0.10	0.00	0.45
8.0e+6	5.5e+6	1.00e+6	11	0.10	0.15	0.40
10.0e+6	5.5e+6	1.00e+6	11	0.30	0.15	0.40
12.0e+6	5.5e+6	1.00e+6	11	0.00	0.35	0.35

III. What is the status of efforts to predict (model) responses of eastern mallards to harvest and uncontrolled environmental factors?

We have made important advances in understanding the dynamics of waterfowl populations and the impacts of hunting regulations by investigating patterns in abundance data, monitoring harvests, and estimating key parameters such as survivorship and reproduction. This information is folded into models of population size and distribution, as influenced by harvest regulations and uncontrolled environmental factors. By building on the databases they are designed to represent, these population models provide a predictive tool for management and, thus, represent a critical component of the regulations-setting process.

The formal effort to model population dynamics of eastern mallards began in 1988. Dr. David Gordon (Ducks Unlimited) was contracted to assemble and summarize relevant monitoring data, and to determine patterns of mallard derivation within the Flyway. That contract was completed in 1994. In 1995, Dr. Sue Sheaffer (New York Cooperative Fish & Wildlife Research Unit) was contracted to develop quantitative models describing the population dynamics of eastern mallards. In 1996, Dr. Sheaffer completed a comprehensive assessment of reproductive and mortality processes, and suggested a set of alternative models for use in the AHM framework. In 1997, I relied on Dr. Sheaffer's work and other anlayses to develop a *single* "working model," because key sources of uncertainty had not been agreed upon, and because of concern that some of the models had been over-parameterized (i.e., more parameters than necessary were used to describe population dynamics). This "working model" currently is being used to assess optimal regulations for eastern mallards, *although the status of midcontinent mallards continues to drive a nationwide regulatory decision*.

The working model for eastern mallards predicts population size (N) as measured in the combined federal and state waterfowl surveys in eastern Canada and the northeastern U.S. However, these surveys have not been operational long enough to permit estimation of the relationship between abundance and reproductive rate. Therefore, the model relies on a Breeding Bird Survey (BBS) index, and its empirical relationship to N, to predict annual reproduction (A_t) using a logit transformation:

$$\ln \frac{\acute{A}_t}{1 - \acute{A}_t} = a - b(BBS_t) + c(PPT_t)$$

where

$$\acute{A}_t = \frac{A_t}{A_{\max}}$$

and

$$A_t = A_{\max} \frac{e^{a - b(BBS_t) + c(PPT_t)}}{1 + e^{a - b(BBS_t) + c(PPT_t)}}$$

and where A_t = fall age ratio of females in year t,
a = -0.483415, b = -0.284774, c = 0.121664,
A_{max} = maximum age ratio = 3.0,
BBS = 0.000004656 * N_t, and
PPT = cumulative precipitation in northeastern states during March to May, which is distributed Normal(10.7, 4.0).

The model assumes complete additivity of hunting mortality, and predicts changes in population size using:

$$N_{t+1} = N_t * f_t ,$$

where

$$f_t = ((1 - sex) * ssf * (SHAF_t + A_t * (SHYF_t + SHYM_t) + sex * ssm * SHAM_t) * sw ,$$

and where sex = 0.55 = mean proportion of males in the breeding population,
ssf = 0.71 = summer survival of females,
ssm = 0.90 = summer survival of males,
sw = 0.90 = winter survival,
$SHAF_t$ = hunting-season survival of adult females,
$SHYF_t$ = hunting-season survival of young females,
$SHYM_t$ = hunting-season survival of young males, and
$SHAM_t$ = hunting-season survival of adult males.

Hunting-season survival rates are calculated using harvest rates predicted for each regulatory alternative. Harvest rates are cohort-specific, based on constant vulnerabilities relative to adult males (0.98 for adult females, 1.45 for young males, and 1.32 for young females). Hunting-season survival rates also account for a crippling loss of 20 percent.

I examined the validity of this “working model” by comparing its predictions of annual change in population size with observed changes from the monitoring program (eastern aerial and plot surveys) (Fig. 2). For both monitoring observations and model predictions, I calculated the annual growth rate as the ratio of successive population estimates. I estimated the variance of the observed growth rate using the Taylor-series approximation for the variance of a ratio. I estimated the variance of the predicted growth rate using simulation, by assuming that observed population size and harvest rate were normally distributed about their point estimates.

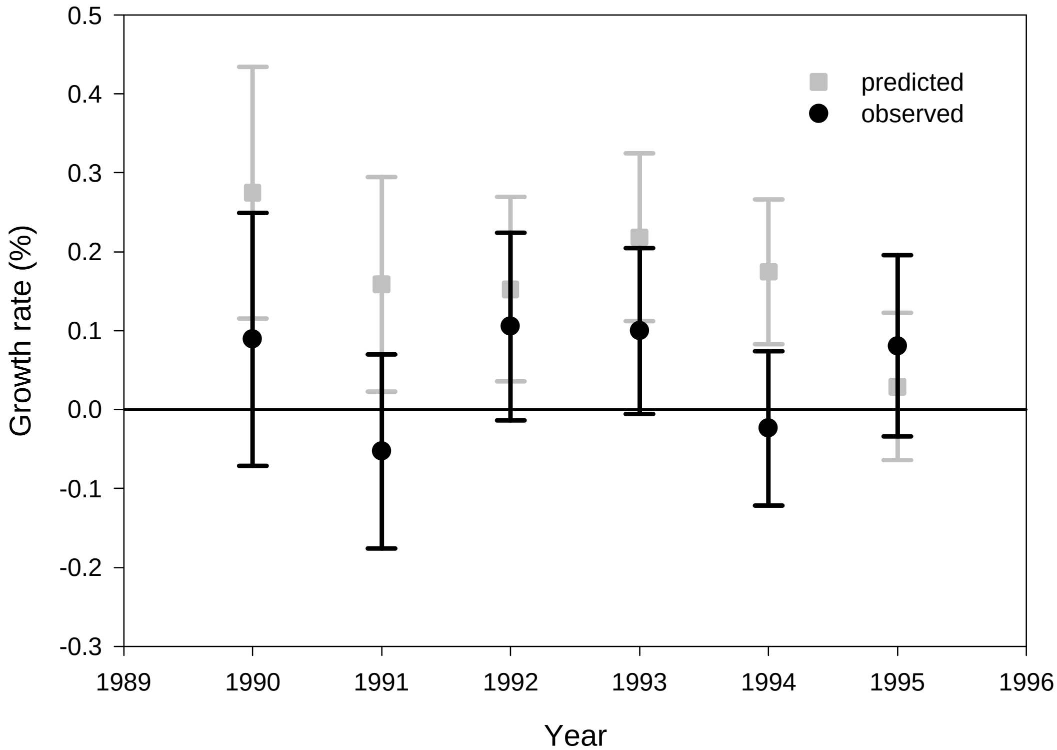

Fig. 2. Estimated growth rates and standard error bars as estimated from the monitoring program (observed) and from the "working model" (predicted) of population dynamics.

Although the confidence limits for the observed and predicted growth rates overlap in all cases, the point estimates of the model predictions are usually higher than those observed from the monitoring program. It is unclear whether the source of this bias is in the "working model's" survival or reproductive process.

This model validation effort demonstrates the importance of considering a set of alternative models that capture key uncertainties about population dynamics. Future modeling efforts should focus on the following issues:

Reproduction.--Among eastern mallards, there is a strong negative relationship between fall age ratios and indices of breeding-population size, suggesting a high degree of density dependence in reproduction. The nature of this relationship is important because the presence of strong density-dependence in population growth can lead to very liberal harvest strategies. Therefore, further investigations are needed to help understand whether the observed relationship actually represents cause and effect. Also, questions remain about the influence of environmental conditions on reproduction. To date, no weather variables have explained much of the variation in fall age ratios, and it is unclear whether these results reflect an insensitivity to weather conditions or a failure to identify the appropriate weather variable(s).

The "working model" relies on the empirical relationship between population size and the BBS index to predict reproductive success. This relationship currently is based on only seven data points, one for each year in which both the BBS index and N are available. Although the BBS index and N are positively correlated ($P < 0.01$), there is considerable uncertainty regarding the slope, intercept, and shape of this relationship (Fig. 3). By using a combination of optimization and simulation procedures, I determined that optimal regulations for eastern mallards are very sensitive to the predicted relationship between N and the BBS index, particularly at low and high population levels. It is therefore essential that this relationship be monitored and updated as often as possible.

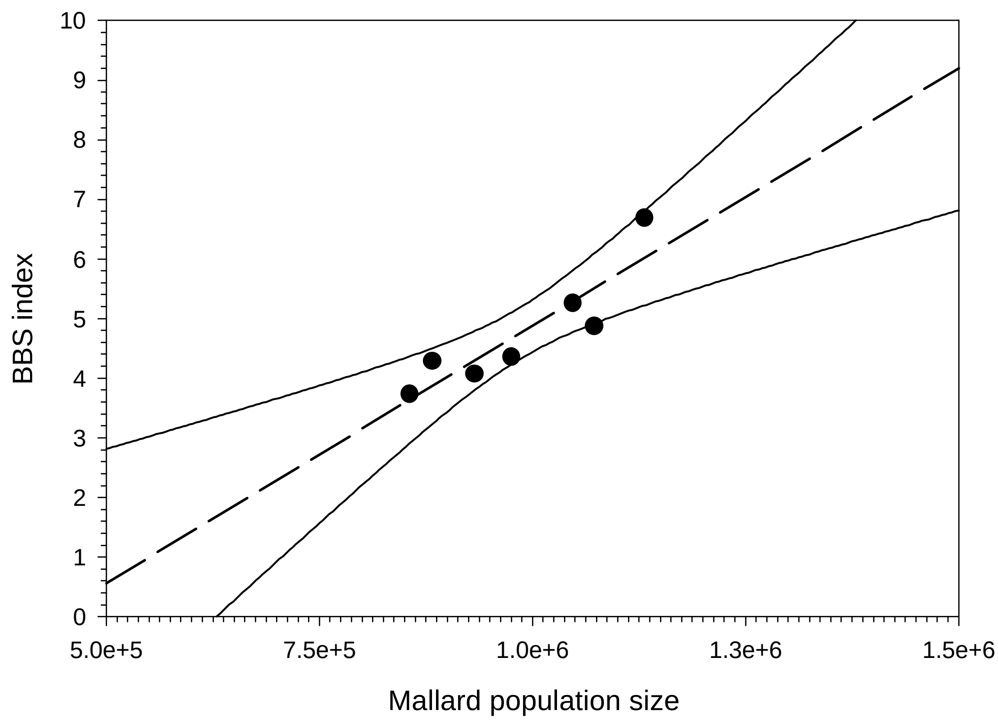

Fig. 3. The relationship between mallard population size and the Breeding Bird Survey (BBS) index. The dotted line is the least-square regression and the solid lines are 95% confidence intervals for the mean.

Survival.--There is some evidence that female mallards in the eastern population are more vulnerable to harvest than their midcontinent counterparts. However, it has been difficult to understand the spatial and temporal patterns (if any) of harvest vulnerability because band-reporting rates for female mallards in eastern North America are unknown. Until estimates of band-reporting rate are available, managers perhaps should consider sex-specific harvest vulnerability as a key source of uncertainty in population models for eastern mallards.

IV. What is the status of necessary modifications to the decision-making process?

Harvest-management objective(s).--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 framework involves combining the population-specific objectives into one objective function so that an aggregate harvest strategy can be derived.

I currently am using an objective function which maximizes the aggregate harvest of both populations, but devalues *all* regulatory decisions that result in the midcontinent population falling below goal. This objective function helps ensure that the midcontinent population goal is not sacrificed for the sake of more eastern mallard harvest. Much work remains, however, to understand the implications of various objective functions, particularly on Flyway-specific regulations.

Augmentation of the decision criteria.--I have made considerable progress in augmenting the decision criteria to include population and environmental variables relevant to eastern mallards. A recent investigation involves the following scenario:

(1) population models which include the "working model" for eastern mallards, and current models and associated likelihood weights for midcontinent mallards;
(2) explicit consideration of the eastern population when making a regulatory decision (i.e., decision criteria to include population sizes of both midcontinent & eastern mallards, Canadian ponds, and spring precipitation in the northeastern U.S.);
(3) one regulatory decision to apply to all Flyways;
(4) the current set of regulatory alternatives;
(5) deterministic harvest rates (i.e., expected mean harvest rates for both populations under the current regulatory alternatives); and
(6) an objective function that maximizes the combined harvests of midcontinent and eastern mallards, subject to the population constraint on midcontinent mallards.

The two "decision matrices" for midcontinent and eastern mallards were "blended" into one via an optimization algorithm developed for this problem. Because the number of decision criteria has been increased, the optimal strategy can no longer be displayed as a matrix, but must take the form of a table (Table 4). Although comprehensive patterns of optimal regulations are hard to discern from the small portion of the strategy reproduced in Table 4, it does appear that population size of eastern mallards and spring precipitation in the Northeast can modify the nationwide regulatory decision for a given status of midcontinent mallards. However, the effect is very small, presumably because the midcontinent population is so numerically dominant.

Table 4. Optimal regulations (C = closed, VR = very restrictive, R = restrictive, M = moderate, and L = liberal) for mallards breeding in central and eastern North America. Only a small portion of the strategy is contained in the table.

Midcontinent population (millions)	Ponds (millions)	Eastern population (millions)	Northeast spring precipitation (inches)	Optimal regulation
5.0	2.5	0.75	7	C
5.0	2.5	0.75	15	C
5.0	2.5	1.25	7	C
5.0	2.5	1.25	15	C
5.0	4..5	0.75	7	C
5.0	4.5	0.75	15	C
5.0	4.5	1.25	7	C
5.0	4.5	1.25	15	VR
6.5	2.5	0.75	7	VR
6.5	2.5	0.75	15	VR
6.5	2.5	1.25	7	VR
6.5	2.5	1.25	15	VR
6.5	4..5	0.75	7	R
6.5	4.5	0.75	15	R
6.5	4.5	1.25	7	R
6.5	4.5	1.25	15	M
8.0	2.5	0.75	7	M
8.0	2.5	0.75	15	M
8.0	2.5	1.25	7	M
8.0	2.5	1.25	15	M
8.0	4..5	0.75	7	L
8.0	4.5	0.75	15	L
8.0	4.5	1.25	7	L
8.0	4.5	1.25	15	L

I compared this policy with the midcontinent policy from last year by taking the mean regulation over all ponds, eastern mallard population sizes, and Northeast spring precipitation amounts for each level of midcontinent population size (Fig. 4). For population sizes of midcontinent mallards >8.5 million, there is little difference in regulations, suggesting that the status of eastern mallards has little effect on the nationwide decision. At those levels, the midcontinent population simply dwarfs the eastern population and, thus, dominates the choice of regulations. For midcontinent population sizes <6 million, explicit consideration of eastern mallards will tend to produce more liberal regulations than would be the case with a strategy focused solely on midcontinent mallards. In fact, for very low midcontinent mallard sizes, consideration of eastern mallards can prevent a closed season from being the optimal choice. For midcontinent population sizes between 6 and 8.5 million, the aggregate strategy actually appears to be slightly more conservative than the strategy based on midcontinent mallards. I am not sure of the reason for this result, but I suspect the conservative regulations permit more growth in the midcontinent population, while substituting harvest from the eastern population. Thus, this example demonstrates the importance of investigating the implications of various combinations of harvest management objectives for midcontinent and eastern mallards.

Modification of the decision rules.--Modification of the decision rules to allow for Flyway-specific regulatory choices greatly complicates the optimization procedures. 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 midcontinent population size, ponds, eastern population size, and spring precipitation in the Northeast. If we assume that the Central and Pacific Flyways could share a regulatory decision, the number of decisions could be reduced to $5^3 = 125$. Although this simplification would be acceptable for now, the Central and Pacific Flyways will require separate decisions if and when a western population of mallards is adopted. The additional complexity arising from the expanded decision space will severely strain our computational abilities. Investigations into computer hardware and software that can handle these large-dimension problems are ongoing.

Although season length, bag limits, and other regulatory specifications always have been Flyway-specific, liberalization or restriction of regulations usually has occurred concurrently in all Flyways. Because of this tradition, our ability to predict harvest rates resulting from various combinations of Flyway-specific regulatory alternatives is extremely limited. Therefore, it is imperative that we adopt a stable set of regulatory alternatives, and then use those alternatives long enough to validate harvest rate predictions.

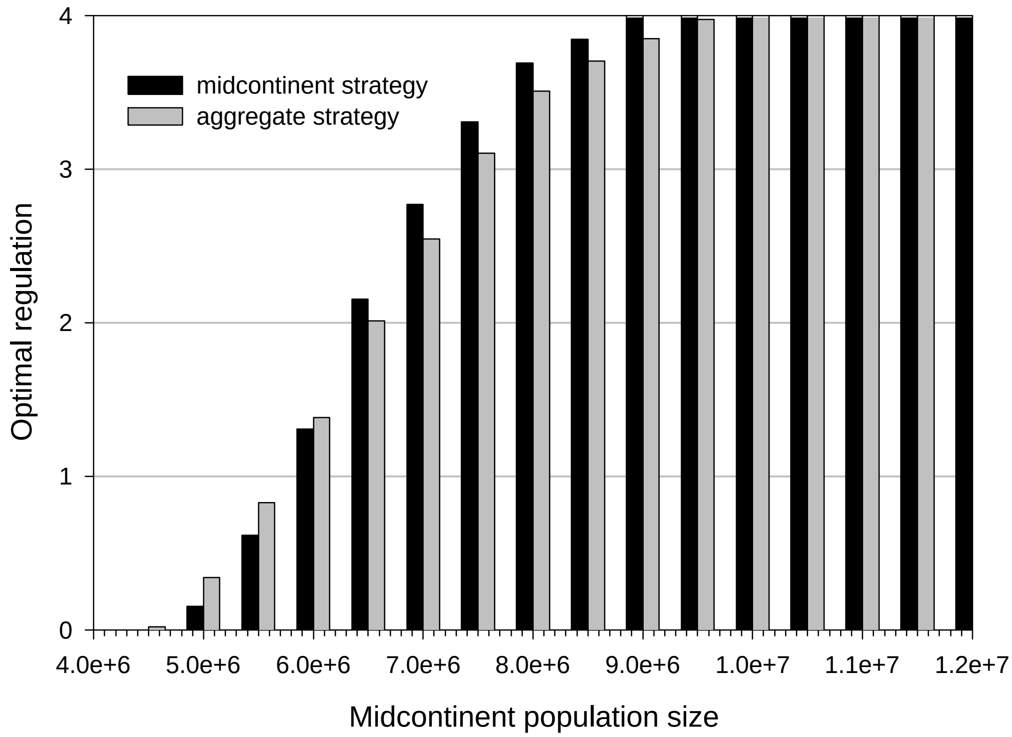

Fig. 4. Mean regulatory choices (0 = Closed, 1 = Very restrictive, 2 = Restrictive, 3 = Moderate, and 4 = Liberal) for various levels of midcontinent population size, as based on the 1998 midcontinent mallard strategy and on an aggregate strategy that also considers that status of eastern mallards.

V. Are there any concerns about this effort?

The role of Flyway biologists.--There is a critical need for Flyway biologists to be involved in modeling the population dynamics of eastern mallards, and in investigating the management implications of various models and harvest-management objectives. The Office of Migratory Bird Management (MBMO) does not have the necessary field experience to formulate hypotheses of eastern mallard ecology, nor does it have adequate staff resources to sustain a unilateral modeling effort. I encourage the Atlantic Flyway Technical Section to join in a working partnership, similar to the collaboration between MBMO and the Technical Section's Canada Goose Committee. In that partnership, MBMO staff provide analytical tools and assistance, but most investigations are conducted by the Canada Goose Committee.

Intermediate steps.--While we are making considerable progress, it is not yet clear when we will be ready to move from a nationwide harvest strategy based on midcontinent mallards to a Flyway-specific approach based on both midcontinent and eastern mallards. In the interim, two alternatives have been suggested. The first involves augmenting the decision criteria to explicitly include population and environmental variables relevant to eastern mallards, but continuing to permit only one regulatory decision for all Flyways. The other alternative involves an Atlantic Flyway regulation based solely on eastern mallards, and a regulatory choice for the other three Flyways based solely on midcontinent mallards. The first alternative explicitly recognizes that there is a sharing of mallard populations among the Mississippi and Atlantic Flyways. The second alternative assumes that there is little or no sharing of populations. Although we know this assumption to be false, I believe this alternative likely poses little biological risk in terms of mallard populations.

In the end, however, the problem comes down to predicting the harvest rates realized on each population *when Flyways select different regulatory alternatives*. Otherwise, we have no basis to develop an optimal strategy for either population (unless we assume eastern mallards don't go to the Mississippi Flyway, and midcontinent mallards don't go to the Atlantic). Since there is a sharing of populations among the Flyways, we must be able to predict these population-specific harvest rates, even if we were to let the Atlantic be guided solely by the eastern population, and the rest of the country by the midcontinent population. If we knew the harvest rates for various combinations of Flyway-specific regulations, then we could develop the full-featured harvest strategy. Thus, we come full circle, and I believe that the first alternative described above is the only possible intermediate step. However, the management community must judge whether this intermediate step is necessary or desirable, given that the interim strategy appears to be only marginally different from that for the midcontinent population.

Other species.--I am concerned that the “working model,” which tends to over-predict population size, suggests a very liberal harvest strategy. I don't believe it would be prudent to formally adopt this model, or its associated Flyway-specific strategies, without an explicit consideration of key sources of model uncertainty, or without considering how the associated harvest strategy may impact the status of species like black ducks, scaup, or wood ducks.