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Report to the International Whooping Crane Recovery Team

September 22, 2008

Steve Baynes, Florida FWCC

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ABSTRACT

We used a structured decision-making approach to inform the decision of whether the Florida Fish and Wildlife Conservation Commission should request of the International Whooping Crane Recovery Team that additional whooping crane chicks be released into the Florida Non-Migratory Population (FNMP). Structured decision-making is an application of decision science that strives to produce transparent, replicable, and defensible decisions that recognize the appropriate roles of management policy and science in decision-making. We present a multi-objective decision framework, where management objectives include successful establishment of a whooping crane population in Florida, minimization of costs, positive public relations, information gain, and providing a supply of captive-reared birds to alternative crane release projects, such as the Eastern Migratory Population. We developed models to predict the outcome relative to each of these objectives under 29 different scenarios of the release methodology used from 1993 to 2004, including options of no further releases and variable numbers of releases per year over the next 5-30 years. In particular, we developed a detailed set of population projection models, which make substantially different predictions about the probability of successful establishment of the FNMP. We used expert elicitation to develop prior model weights (measures of confidence in population model predictions); the results of the population model weighting and model-averaging exercise indicated that the probability of successful establishment of the FNMP ranged from 9% if no additional releases are made, to as high as 41% with additional releases. We also used expert elicitation to develop weights (relative values) on the set of identified objectives, and we then used a formal optimization technique for identifying the optimal decision, which considers the tradeoffs between objectives. The optimal decision was identified as release of 3 cohorts (24 birds) per year over the next 10 years. However, any decision that involved release of 1-3 cohorts (8-24 birds) per year over the next 5 to 20 years, as well as decisions that involve skipping releases in every other year, performed better in our analysis than the alternative of no further releases. These results were driven by the relatively high objective weights that experts placed on the population objective (i.e., successful establishment of the FNMP) and the information gain objective (where releases are expected to accelerate learning on what was identified as a primary uncertainty: the demographic performance of wild-hatched birds). Additional considerations that were not formally integrated into the analysis are also discussed.

INTRODUCTION

A goal of the Whooping Crane Recovery Plan (Canadian Wildlife Service and U.S. Fish and Wildlife Service 2005) is the establishment of 1-2 additional population(s) of whooping cranes in North America, and this goal has been pursued through the release of captive-reared (CR) chicks each year from 1993-2004 to create the Florida nonmigratory whooping crane population (FNMP). In 2003, research scientists at USGS Patuxent Wildlife Research Center (USGS) and the Florida Fish and Wildlife Conservation Commission (FWC) began a collaborative effort to address the problem of choosing the number of releases annually to most efficiently reach the goal of a self-sustaining population of nonmigratory whooping cranes in Florida.

The initial purpose of the project was to develop models to predict the impact of different release scenarios on the FNMP into the future. However, releases ceased in 2004 due to concerns about the performance of the reintroduced flock. During the subsequent years, the Whooping Crane Eastern Partnership ("Eastern Partnership") increased the numbers of CR birds that it was releasing to the Eastern Migratory Population (EMP) in Wisconsin; since 2004, all CR production has been allocated to the Eastern Partnership effort. However, there remains interest within the FWC in considering additional releases to the FNMP. Thus, the FWC faced a decision of whether to request additional CR birds, allocated by the International Whooping Crane Recovery Team ("Recovery Team"), to be released to the FNMP. This decision may well be time-sensitive, as the number of birds in the FNMP is declining, and the lack of releases over the last several years means that there are no young CR birds that will be entering the breeder classes in the near future (Table 1). Fewer birds in the FNMP result in a greater chance of loss of the flock due to demographic stochasticity. Furthermore, if Allee effects are operating in the population, a smaller population will be much more likely to accelerate toward extinction (Allee 1931).

In February 2008, during a meeting in Gainesville, Florida, members of the USGS and FWC collaboration recognized that additional management objectives, beyond the objective to secure a viable FNMP, would inform the decision of whether to pursue additional releases. The FWC requested that USGS collaborators develop a structured decision-making framework to inform the decision of whether to recommend to the Recovery Team additional releases to the FNMP. During conference calls and by email in the spring and summer of 2008, and culminating in a workshop in late August 2008, this decision framework was completed. Herein, we describe the framework and communicate the recommendation of the report's authors to the Recovery Team. We thank M. C. Runge and M. J. Ratnaswamy for helpful reviews of this report.

THE STRUCTURED DECISION-MAKING PROCESS

Structured decision-making is a decision-support process that emphasizes deconstruction, analysis, and synthesis of the components of a decision in order to identify an optimal action. Those components include objectives (the management goals), alternative actions (the different management actions available to decision-makers), predictive models (predictions of the impacts of the different actions on the objective(s)), and optimization (a methodology for identifying the optimal action). Structured decision-making focuses on recognizing the appropriate functions of policy (i.e., objective setting) versus science (i.e., model development and optimization) in decision-making, and on making decisions that are transparent and replicable.

In a multi-objective decision, like the decision faced by FWC, the structured decision-making process proceeds generally as follows: 1) Develop a comprehensive set of objectives that capture all of the fundamental values of the decision-makers relevant to the decision, and determine the relative importance of each objective; 2) Develop a set of alternative actions that the decision-makers will choose from; 3) Develop a method (predictive models) for predicting the outcome for each objective, under each alternative; i.e., determine how each alternative will perform with respect to each objective; 4) Develop a method (optimization) for making tradeoffs among the objectives; and 5) Conduct the optimization exercise and consider the results; revisit the framework to determine whether additional considerations should be included.

FWC chose to include partners from the major breeding centers (the International Crane Foundation (ICF) and USGS Patuxent Wildlife Research Center ("Patuxent")), the U.S. Fish and Wildlife Service (USFWS), and University of Florida in the decision-making process. All partners informed and shaped the decision framework. In addition, two expert elicitation exercises, conducted at the workshop in August 2008, included formal input by these partners on the development of the objective function, through objective weighting, and on the weight placed on predictions from multiple differing population models. The first 2 authors of this report did not participate as decision-making partners. Instead, they acted as consultants in leading the team through development of the framework.

MANAGEMENT OBJECTIVES AND MEASURABLE CRITERIA

During discussions beginning in February 2008 and extending through the spring and summer of 2008, the members of the decision-making team identified 5 objectives that would be considered when making decisions about the release of CR whooping cranes to Florida: population establishment, cost, alternative restoration project needs, public relations, and information. Since the beginning of the FNMP restoration effort, the population objective had been identified as one, and perhaps the primary, fundamental objective. The latter four objectives had not been previously formally specified.

One management objective, cost, was subsequently broken down into 2 subobjectives, the costs incurred by the FWC and the costs incurred by project partners. This allowed for the possibility of different weights placed on these 2 components of the objective. Therefore, essentially 6 separate objectives were identified.

During discussions with the USGS consultants, the team members also identified "measurable criteria" which define the specific metrics that would be used to measure progress toward achieving a particular objective. Measurement of these objectives will be explained in greater detail in the "Predictive Models" section, below.

1. Cost Objective
   Direction of criterion: Minimize costs to FWC and Partners.
   a. Cost Subobjective A – FWC costs

Measurable criterion: Dollars ($) spent by FWC over the next 30 years on the FNMP effort.

   b. Cost Subobjective B – Partner costs
      Measurable criterion: Dollars ($) spent by project partners over the next 30 years to produce chicks and ship chicks to Florida.

2. Alternative Restoration Project Needs Objective
   Direction of criterion: Maximize captive-reared chicks available for the Eastern Partnership or other whooping crane restoration efforts.
   Measurable criterion: The number of cohorts (1 cohort = 8 birds) available for alternative restoration efforts over the next 20 years, assuming captive production of 3 cohorts (24 individuals) per year.
3. Public Relations Objective
   Direction of criterion: Maximize positive public relations.
   Measurable criterion: A constructed scale of positive public relations, from 0-1.
4. Population Objective
   Direction of criterion: Maximize probability of developing a self-sustaining non-migratory whooping crane population in Florida.
   Measurable criterion: The probability that, between 111 and 131 years from present, the FNMP exhibits positive population growth.
5. Information Objective
   Direction of criterion: Maximize learning about whooping cranes.
   Measurable criterion: The probability that, in 20 years, the weight on Model 1 (the pessimistic model of population performance, described below), assuming it is correct, is ≥ 95%.

Alternative Actions

The team considered 29 alternative fixed schedules of releasing birds (actions), varying by the number of cohorts to be released in each year and the number and pattern of years over which birds would be released (a cohort is composed of 8 cranes, a release size that is logistically feasible for the FWC release team and, in the opinion of FWC biologists, is most conducive to formation of social bonds in the released birds).

Alternative 1. No additional releases.

Alternatives 2-13. Combinations of 1, 2, or 3 cohorts per year for 5, 10, 15, or 20 years, with releases beginning in the winter of 2009-2010 from 2009 captive production.

The first 13 alternatives were developed early in the USGS/FWC collaboration, to take into account a variety of different release strategies that would include no releases, or that would use relatively little (i.e., 1 cohort per year) or basically all (i.e., 3 cohorts per year) of the captive production each year, and for various numbers of years, representing different institutional commitments to the reintroduction effort. With these alternatives, it was assumed that releases would start as soon as possible; at present, this implies releases to the FNMP from 2009 captive production.

> *Alternatives 14-25*. Combinations of 1, 2, or 3 cohorts per year for 5, 10, 15, or 20 years, with releases beginning in the winter of 2019-2020 from 2019 captive production (i.e., a 10-year delay on releases).

The alternatives that allowed for a 10-year delay were developed later in the USGS/FWC collaboration. They were designed to evaluate the relative costs and benefits of delaying releases until after 10 more years of releases into the EMP. That is, these alternatives were initially developed, at least implicitly, to balance FNMP and EMP objectives.

> *Alternatives 26-29*. Combinations of 1 or 2 cohorts per year for 10 or 20 years, with releases occurring only *every other year*, beginning in the winter of 2009-2010 from 2009 captive production.

The last 4 alternatives were developed after the February 2008 meeting. These alternatives also attempted to strike a balance with the Eastern Partnership project, but rather than waiting 10 years, over which time much of the institutional commitment to the FNMP releases in FWC may have eroded, these alternatives would allow some releases to the FNMP beginning immediately, and occurring every other year. These alternatives would claim less than half of the captive production over the next 20 years, thus allowing the Eastern Partnership, or an alternative restoration project, to continue to operate in every year.

Reintroduction solely through means of releasing captive-reared chicks (the approach used from 1993 to 2004) was the operational scope of the primary decision maker, the FWC; therefore the decision context was framed around this specific release methodology. Some of the decision partners invited by the FWC offered alternative options at one or more of the meetings in 2008, including egg releases (replacement of eggs in the nest to assure that the incubated egg is fertile), release of chicks reared in captivity in Florida, and direct autumn releases (release of captive-reared chicks into associations of older birds). However, FWC participants indicated that such alternatives would be considered by the agency only in the context of a separate experimental effort and not in the operational setting explored through this work.

PREDICTIVE MODELS

Predictive models were developed for each of the different objectives, so that outcomes for each objective could be assessed under each alternative.

For the population objective, 3 different models were developed; these models attempt to capture uncertainty in the future dynamics of the FNMP. To develop one set of predictions from these 3 models, we estimated prior model weights through expert elicitation (explained below).

Cost Objective

Cost Subobjective A: *Florida Fish and Wildlife Conservation Commission Costs*.—The first cost subobjective was the portion of costs that were incurred by the FWC, including the annual grant to FWC from the USFWS. Costs were estimated over a 30-year period (i.e., over a period including the latest possible release, which would occur under the alternatives with a 10-year delay and 20 years of release). Annual fixed costs were estimated at $300,000/year, including $150,000/year contributed by the USFWS grant and another $150,000/year contributed by FWC. Fixed costs are assumed to be incurred even in the case of no further releases, as activities in support of bird monitoring and recovery will nevertheless continue for the existing population. Annual release-specific costs were estimated at $75,000 for 1 cohort, $85,000 for 2 cohorts, and $95,000 for 3 cohorts. In addition, the model assumes 2 additional years of fixed costs ($600,000) would be associated with any alternative involving a 10-year delay, due to the expected decrease in efficacy with a loss of institutional experience after 10 years without releases.

For example, under the alternative with 2 cohorts released per year over 10 years, beginning in 2019-2020 (i.e., 10 year delay), costs would equal: $300,000 × 30 (fixed costs) + $85,000 × 10 (release-specific costs) + $600,000 (costs due to delay) = $10,450,000.

Cost Subobjective B: *Partner Costs*.—The second cost subobjective was the portion of costs that were incurred by partners for the breeding, rearing, and shipping of chicks for release in Florida. Per-bird costs were estimated at $15,000 at the Patuxent breeding facility and $18,000 at the ICF breeding facility. It was assumed that Patuxent would supply two-thirds of the birds for release, while ICF would supply the remaining third, given the greater flock size at Patuxent. In addition, shipping costs were estimated at $15,000 per cohort.

As an example, under the alternative with 2 cohorts released per year over 10 years, beginning in 2009-2010, total costs would be

	$15,000/bird × 8 birds/cohort × 2 cohorts/yr × 10 yrs × (2/3) +	(Patuxent Costs)
	$18,000/bird × 8 birds/cohort × 2 cohorts/yr × 10 yrs × (1/3) +	(ICF Costs)
	$15,000/bird × 2 cohorts/yr × 10 yrs	(Shipping Costs)
=	$2,860,000	

Alternative Restoration Projects Objective

The numbers of birds shipped in late summer from Patuxent and ICF to Necedah National Wildlife Refuge for the Eastern Partnership project have equaled 26, 25, and 29 from 2005 to 2007, respectively. Typically, one or more mortalities occur between the time birds are shipped and when they are released. Therefore, it is reasonable to assume that 3 cohorts (24 birds) would represent virtually the entire captive production available for release to the FNMP in the coming years, barring a major improvement in captive productivity and survival. The model for this objective calculated the number of cohorts available to alternative whooping crane restoration projects (Eastern Partnership and/or others) over the next 20 years (out of 60 produced over that time frame), which seemed to be a reasonable planning horizon given the expected length of Eastern Partnership releases and the ability to make predictions about the production at captive breeding facilities in the future.

As an example, under the alternative with 2 cohorts released per year over 10 years, beginning in 2009-2010, the number of cohorts available for alternative restoration projects would equal 60 – 10 × 2 = 40.

Population Objective

The development of a predictive model for the population objective was substantially more involved than for the preceding objectives, and is described here in some detail. Three different types of models were built relevant to the population objective, based on monitoring data gathered over the duration of the FNMP project. Different models were built to capture the uncertainty in future dynamics of the population, especially with respect to the demographic performance of wild-hatched birds; these models make substantially different sets of predictions about the probability of success of the FNMP (measured by positive population growth in the population from 80-100 years after the year of the latest possible release, i.e., 111-131 years from present). Development of these model predictions proceeded in 3 stages: 1) Estimation of survival and productivity parameters; 2) Construction of alternative population viability/decision models; and 3) Simulation of decision scenarios. Finally, given that these models resulted in widely different predictions about the probability of success in establishing a self-sustaining population of whooping cranes in Florida, it was necessary to develop model weights so that a weighted average of the model predictions could be calculated for use in the decision framework. The weights represent the collective uncertainty of the group with respect to these alternative models.

Estimation of survival and productivity parameters.—We first developed a conceptual population model that modeled transitions among female age and breeding classes for both captive-reared (CR) and wild-hatched (WH) segments of the population (Figure 1). This model provided a design template for deriving annual survival rates, breeding class transition probabilities, and productivity rates from data collected on the FNMP. It also provided the underlying structure for the competing decision models that were analyzed via simulation.

We analyzed data from the captive-reared segment of the flock to estimate parameters of annual survival and productivity. We used radio telemetry monitoring of released birds through mid-2007 to obtain apparent rates of survival by sex and age classes. On recommendation from researchers involved in the FNMP program, we treated loss of a bird without confirmation of its mortality as a true removal from the population. This treatment of the data reflects the high confidence of the program managers that the lost bird, whatever its true state, is effectively removed from the breeding pool; hence we use the term “apparent” survival.

For captive-reared females, we also obtained apparent survival rates specific to membership in one of three mutually exclusive breeding classes: *P* - currently or historically paired but no previous production of nestlings, *N* - current or historical nestling producer but no previous production of fledglings, and *F* - current or historical producer of fledglings. The survival analyses also yielded estimates of variability in survival attributable to year, release cohort, and the individual bird. These sources of stochastic variation were later applied in simulation modeling of the population.

We conducted a separate analysis on data from wild fledglings to obtain provisional estimates of survival in the wild-hatched segment of the flock. Because of the scarcity of data, these estimates are distinguished only by sex class and not by age or breeding class.

Lastly, data on pairing and nest activity of CR birds provided estimates of productivity and probability of transition among the breeding classes. A summary of all survival and productivity estimates is provided in Table 2.

Construction of alternative population viability/decision models.— We next constructed three alternative population viability/decision models using sets of available parameter estimates. Each model simulated individual female birds in the population and tracked them through time in response to hypothesized survival and productivity rates, periodic releases of captive-reared female chicks into the population, and random effects. The models differed in how vital rates for the two segments of the population (CR and WH) resembled or differed from each other. In all three models, survival and productivity parameters estimated solely from the captive-reared segment of the population were assumed to apply to simulated CR birds. In the baseline model (Model 1), these estimated rates were assumed to also apply to simulated wild-hatched birds. In an alternative model (Model 2), survival and productivity rates of the wild-hatched segment were assumed to more closely correspond to those of the only wild flock in existence, the Aransas-Wood Buffalo (ARWB) migratory flock. Thus, estimated rates for that population (Link et al. 2003) were applied to simulated WH birds. We applied the estimated overall survival rate from their work (model CAAE) to all age and breeding classes of WH birds. Our simulations also incorporated uncertainties in survival rate due to year-to-year variability and estimation uncertainty; therefore, the survival rate applied to WH birds varied from year to year and among simulation runs. For productivity, we assumed that CR and WH birds share a common rate of transition into the breeder classes (i.e., probability that an unpaired female forms her first pair bond). However, we used the ARWB estimate of average per-breeder productivity rate (0.33; 1938-2001 period) in place of the 3 breeding class-specific productivity rates estimated from the CR data. As we did for the survival rate parameter, we incorporated annual stochastic variation and parameter estimation uncertainty in our simulations of recruitment rate in WH birds, thus recruitment rate varied among years and simulation runs.

A third model – or class of models – considered an Allee-type effect, in which a population requires a "critical mass" of individuals in order to grow. Allee effects may be expected in small, establishing populations (Courchamp et al. 1999, Stephens and Sutherland 1999). There could be various mechanisms by which an Allee effect would operate within the crane flock. For example, a low population density may reduce availability of mates, obscure behavioral cues among potential breeders or foraging birds, or divert energies into sentinel and predator avoidance behaviors (Courchamp et al. 1999). Magnification of the effect of inbreeding depression at low population size is another possible Allee mechanism (Stephens et al. 1999).

Model 3 does not propose an Allee mechanism; it simply suggests that a threshold density of breeders must be reached before productivity rate is enhanced. Under Model 3, the survival portion was kept exactly the same as that in Model 2. However, the productivity rate applied to simulated WH birds depended on a population size condition. When the number of breeding-age females (all females ≥2 years, from both population segments) exceeded a fixed threshold size (B_T), the ARWB estimate of productivity was assumed to apply to simulated wild-hatched breeding-class birds. Otherwise, simulated WH birds received the productivity rate estimate derived from CR birds. By varying the value of B_T, the model could be made to resemble Model

2 ($B_T = 0$) or Model 1 ($B_T \to \infty$). Given a size threshold under this model, exponential growth of the population switches from negative to positive when the threshold is exceeded.

The model set thus portrayed a plausible range of population response consistent with profound uncertainty about performance of wild-hatched birds: performance of WH birds is similar to that of CR birds (Model 1); performance of WH birds is always significantly better than that of CR birds (Model 2); or performance of WH birds is significantly better than that of CR birds only when number of breeding-age females exceeds some size threshold (Model 3).

We derived a goodness of fit measure for Models 1 and 2 by using each model to re-play the entire, exact sequence of bird releases over the period 1993-2004. By doing so, each model was used to predict the population structure as of 2008. Because the models are both stochastic, we generated two distributions of predictions by running each model many times. Each resulting distribution had a center point and a periphery in multivariate space, and the true 2008 population structure could be placed within each one. We interpreted goodness of fit for each model as the distance of the true population structure from the edge of the distribution, relative to the distance from the center point to the edge. Thus, the measure was scaled from 0 to 1, with the respective extremes reflecting poor fit (i.e., the 2008 true population structure lies beyond the edge of all the predictions of the model) or excellent fit (i.e., the 2008 true point coincides with the distribution center point). The goodness of fit measures for Models 1 and 2 were 0.485 and 0.517, respectively. The more favorable value for Model 2 results from its assumption of greater survival in WH than in CR birds, an assumption that has some, but very limited, support from FNMP data (while the survival point estimate is relatively high for WH birds, the uncertainty is substantial; Table 2). Model 3 is distinguished from Model 2 on the basis of productivity of wild-hatched birds, but because there are currently no such data on WH birds, there is no means to assess differential predictive performance of Models 2 and 3.

Simulation of decision scenarios.—The third stage was the simulation of each model under alternative decision scenarios from a common population starting point in 2008. These decision scenarios are described in the *Alternative Actions* section above.

From the 2008 starting point, each scenario was simulated 10,000 times under each alternative model. Under Model 3, we conducted simulations for each of eight different settings of the B_T parameter: 5, 10, 15, 20, 25, 30, 40, and 50 females. All simulations were conducted over a fixed 131-year time frame, a point 100 years beyond the latest possible release under any scenario. In each simulation, we computed the population trend (simple regression of population size) over the last 20 years of the 131-year time frame. For each set of 10,000 simulations, we determined the proportion of simulations that yielded positive population growth.

PVA Results.—The simulation results are displayed in Table 3. Columns of the table correspond to a particular model, or in the case of Model 3, a particular value of the model's breeding density threshold, B_T. Values within each column are simulation outcomes for each alternative release scenario (rows). These outcomes are the proportion of simulations resulting in positive population growth as defined above.

The simulation outcomes reveal two important patterns (Figure 2). First, the outcomes are extremely sensitive to choice of the model. Under Model 1, all release scenarios yield essentially 0 chance of successful population establishment, whereas under Model 2, the population has an excellent chance of establishment (≥0.90) under *any* release scenario, including the scenario of no further releases. Furthermore, the outcomes are sensitive to the choice of the value of B_T in Model 3.

Second, whereas the outcome is not sensitive to the release scenario under either Model 1 or 2, the outcome is highly sensitive to the decision for different values of B_T in Model 3 (Figure 2). For example, if a threshold of 20 breeding-status females is required to trigger greater production in the population, then decisions that release more birds over time are far more likely to establish a population than those that release fewer.

This high sensitivity of outcomes to the choice of model (and consequently to the decision) is noteworthy because despite 15 years of experience with the release program, we do not yet have the data to assess the relative merit of one model against any other, even for models as starkly different as Models 1 and 2. Therefore, without other information, choice of a decision action is not clear cut because system uncertainty remains quite high.

Expert Elicitation of Model Weights.—Given the vastly different predictions displayed in Table 3, it was necessary to develop model weights so that a weighted-average prediction could be calculated for use in the decision framework. Model weights can be thought of (in a Bayesian sense) as the prior belief in the veracity of each model.

We developed model weights in an expert elicitation exercise at the August 2008 workshop. We began by discussing in detail the development of the different models, the (limited) evidence supporting one model over another, and the predictions made by each model. Then, each participant (with the exception of the first and second authors) was asked to place a probability on each of the models. The experts were initially asked to place weight on all 10 of the models displayed in Table 3; the exercise was conducted with each participant working alone. These results were gathered from each participant and then displayed collectively to motivate discussion. After discussion, the group elected to go through the exercise a second time, but this time in 2 steps. First, individuals placed weight on Model 1, Model 2, and Model 3, where the focus was on the experts' belief in the basic dynamics described by each model. In a second step, each expert then allocated the weight that he or she had placed on Model 3 amongst the 8 different versions of Model 3 (i.e., the 8 different threshold population sizes). Again, the results were tabulated and discussed. This occurred at the end of the first day of the workshop. At the beginning of the second day, the group again revisited these weights and went through the exercise a third time. On comparing the averaged weights calculated from each of the 3 iterations, it was clear that, while some individuals had changed their answers substantially between the first and second iteration (average absolute change in weight across the 10 models = 0.042), the change between the second and third iteration was substantially smaller (0.023). Therefore, after the third iteration, the group decided that they had reached a final set of model weights. The weights specified by each expert and the averages for each iteration are displayed in Table 4.

Information Objective

The model for the information objective was derived from the models for the population objective. The predictive model for the information objective measured how likely data yielded by each of the alternative release options could convincingly demonstrate within 20 years that population establishment will not succeed, under the assumption that Model 1 is the best representation of the system. The rationale for such a criterion is that if reintroduction is truly not a viable means to establish a population, then release alternatives that indicate that fact sooner rather than later have greater value from a learning standpoint. To estimate this criterion, Model 1 was simulated 1,000 times for each decision alternative, exactly as described in the section above. Over each successive year in the simulation, the directional change (decrease, no change, or increase) was recorded for each of 3 composite states: wild-hatched age-0, wild-hatched pre-breeders (composite of states age-1, age-2, age-3, and age-4+) and wild-hatched breeders (composite of breeding classes *P*, *N*, and *F*). The focus was on the WH states because the model predictions differ for these states but not for the CR states.

The simulations tracked model confidence weights associated with the assumed true generating model (Model 1) and with two competing models, Model 2 and Model 3 / $B_T = 20$ (i.e., the version of Model 3 that was given the greatest weight in the model weighting exercise); in other words, we simulated the process by which a true model could be identified from a set of 3 uncertain but plausible candidate models. Bayesian updating was used to update the model weights each year, where the new model weight in year t+1 is equal to the model weight in year t multiplied by the likelihood of the model, given the data (i.e., the observation from the "true" model). The weights were set equal in year 1 (1/3 assigned to each model). The likelihoods were calculated by simulating forward from the current state many times (n=1000) under each of the 3 models, and calculating the probability, each year, of observing a particular pattern of changes in the 3 composite states (3 directional changes for each of 3 composite states yields 9 possible observable patterns under each model; e.g., decrease in WH age 0, no change in WH pre-breeders, and increase in WH breeders is one such pattern). The model output was the probability of attaining a model weight of ≥0.95 on Model 1 (again, where we are assuming for the purposes of the exercise that Model 1 is the true model) at 2029 (i.e., 20 years from 2009). A low score implies that the release alternative is relatively uninformative, compared to one with a greater score.

DECISION ANALYSIS

The predictions from the models for each objective, under each alternative action, are displayed in Table 5. Given the multi-objective nature of the problem, it was necessary to make tradeoffs between the objectives in order to determine the optimal action. The SMART technique (Simple Multi-Attribute Ranking Technique; Goodwin and Wright 2004) was used to conduct the tradeoffs analysis.

The first step was to develop objective weights, which reflect the relative importance of each objective, using the swing weighting technique (Goodwin and Wright 2004). Experts were asked to imagine a hypothetical alternative under which all of the objectives were at their least-preferred level (given the range reflected in Table 5); that is, an option with the highest cost, lowest number of birds available for alternative restoration projects, lowest probability of population establishment, poorest public relations performance, and lowest information gain. Each expert was then asked: if just one of the objectives could be moved ("swung") from the least-preferred to the most-preferred value, which objective would it be? The first objective identified was given a rank of 1, the second a rank of 2, and so on until all 6 objectives (the cost objective was evaluated as two independent subobjectives) had been ranked. The ranked objectives were then given a rating between 0-100, with 100 given to the objective that received rank 1. The 0-100 ratings reflect relative importance of the objectives. Again, we conducted the exercise multiple times to ensure that participants understood the technique and had a chance to discuss the results as a group, before the final weights were determined. Each respondent's ratings were normalized to the sum of his/her ratings. The final consensus weight for objective *j*, W_j, was computed by averaging normalized ratings for the objective over all respondents (Table 6).

Next, the scores within each objective in Table 5 were normalized to convert to a scale of 0 to 1, with the most desirable outcome for a given objective scoring a 1, and the least scoring a 0. The normalized score for alternative action *i* relative to objective *j* based on the original score $(S_{i,j})$ was computed as

$$N_{i,j} = \frac{S_{i,j} - \min_i(S_{i,j})}{\max_i(S_{i,j}) - \min_i(S_{i,j})}$$

for objectives where the desired direction of the original scores was high (i.e., alternative restoration project objective, population objective, public relations objective, information objective), or alternatively

$$N_{i,j} = \frac{\max_i(S_{i,j}) - S_{i,j}}{\max_i(S_{i,j}) - \min_i(S_{i,j})}$$

where the desired direction of the original scores was low (i.e., cost objectives). Normalized scores are shown in Table 7.

We then calculated a final score for option i (F_i) as the sum over all objectives (*j*) of the product of the swing weight (W_j) and the normalized scores:

$$F_i = \sum_{i,j} W_j \times N_{i,j} \ .$$

DECISION ANALYSIS RESULTS

The alternative with the highest cumulative score (F_i) was 3 cohorts per year for 10 years, with an immediate start (Table 7). This strategy was followed by alternatives of 3 cohorts per year for 15 years, 2 cohorts per year for 15 years, and 2 cohorts per year for 10 years (with an immediate start, winter of 2009-2010, in all cases). Also ranking high were releases of 2 or 3 cohorts for 5 years or 20 years. In summary, these results indicate that the most favorable decisions involve immediate releases of 2 to 3 cohorts, with the number of years being apparently less critical. However, immediate releases of 1 cohort per year or any of the alternatives involving skipping (i.e., alternatives allowing for a split of CR birds between the FNMP and the EMP) are also ranked higher than alternatives involving delayed releases or no additional releases. The alternative involving no additional releases was ranked 21st out of 29 alternatives; poorer than anything but delayed releases of only 1 or 2 cohorts (for any number of years).

DISCUSSION AND CONSIDERATIONS

The high weight that was placed by the experts on the population and information objectives (Table 6) drove the results toward favoring alternatives involving continued releases (rather than the alternative involving no further releases). The top-ranked alternative (3 cohorts per year for 10 years) ranked third highest on the information objective, and fourth highest on the population objective. The no further releases alternative ranked lowest on these 2 objectives (although it ranked highest on the FWC cost objective, which was also weighted relatively heavily by the experts).

While the experts generally had relatively low confidence in the future success of the FNMP based on their prior weights on the population models (the highest model-averaged projected probability of success was approximately 41%; Table 5), the experts also noted that this probability, again based on their prior model weights, was sensitive to the selected alternative. In the poorest-performing alternative from a population objective standpoint (no further releases), the probability of future success was only 9%. The method used to develop the objective weights explicitly took this range into account; that is, the experts highly valued the opportunity to "swing" this probability of population success from 9% to 41%.

The critical uncertainty captured in the population modeling involves the demographic (survival and reproductive) performance of WH birds. Fourteen years after the first releases into the FNMP, there is not adequate information to conclude that these WH birds survive better than their CR parents, though early evidence points in that direction. There is essentially no information to evaluate the potential reproductive success of WH birds, as these birds have only just begun to move into the paired breeding class. In addition, the low and declining sample size restricts the potential for learning about breeding success of WH birds, and this is expected to continue without additional releases, especially due to the fact that males are underrepresented in the population (a factor not captured in our female-only model).

However, based on the performance of CR birds in the FNMP (captured in Model 1) and early indications of the performance of CR birds in the EMP (extremely low reproductive success to date), captive-reared birds do not perform very well post-release. It is possible that either CR birds in the EMP will prove to be better performers over time or with different management approaches, or that CR birds in a novel reintroduction program (e.g., Louisiana) would perform better. Barring these possibilities, the success of any whooping crane restoration effort will depend on WH birds performing better than their CR parents. It follows that resolution of the uncertainty regarding whether WH birds will, in fact, perform better is critical to determining whether restoration of whooping crane populations is feasible, or instead if all recovery efforts should focus on the Aransas-Wood Buffalo population. Given the large time required to resolve this uncertainty (> 14 years based on the FNMP example), the FNMP may be the most likely opportunity to do so in an amount of time that is meaningful for management decision-making in the next 10-15 years. This learning opportunity will be strengthened with further releases (Information Objective; Table 5).

While we assumed, in Model 2 and Model 3, that WH birds would perform as well as birds from the ARWB, we also note that it is not necessary, to attain a high probability of population success, that the WH birds perform demographically at this level. The critical uncertainty is not whether the WH birds do as well as the ARWB birds, but whether they do sufficiently better than their CR parents to sustain the FNMP. In an earlier analysis (not presented here), results indicated that reproductive success within 5% of that attained by the ARWB would lead to >75% probability of success under some alternative release scenarios.

The productivity rates projected by the models for CR birds reflect whatever factors limited performance over the 1993-2007 period of analysis. Possible factors include demographic imbalance of sexes, reproductive dysfunction (inbreeding related or otherwise), unfavorable climatic conditions (Spalding et al. In Press), and loss of habitat. Whether these factors affect CR and WH birds equally is at the root of what makes management of this population uncertain, as its resolution implies whether the release strategy is able to drive the dynamics of the population in the face of these uncontrollable factors.

The low observed rate of productivity in the CR segment over 1993-2007 may be attributed in part to the demographic imbalance of sexes resulting from high male mortality. Male whooping cranes in the Florida flock have not lived past 10 years of age. Longevity for whooping cranes of the only self-sustaining flock is estimated to be 22-30+ years (Lewis 1995), and captive male whooping cranes have lived to 40 years of age. It is possible that the same mortality factors that are “limiting” survival of captive-released males (predation and power line collisions) in Florida may also affect male wild-fledged birds. Of 9 chicks fledged in the wild thus far in Florida, only 2 have been males. Of the 5 surviving wild-fledged birds, 1 is a male. It is currently paired with its sibling (offspring from a different breeding season).

Results from necropsy show that 12% of females and 6% of males of the Florida flock have dysfunctional reproductive tracts that may prevent them from ever reproducing (Spalding et al. In Review). Inbreeding associated with a genetic bottleneck (all whooping cranes today are derived from 6 to 8 founders when the population reached a low in 1941, Canadian Wildlife Service and U.S. Fish and Wildlife Service 2005) is one possible cause. Loss of genetic diversity may have a similar negative effect on wild-fledged whooping cranes.

Productivity of whooping cranes in Florida has been limited, in part, by drought and the resulting lack of suitable water level in marshes. During the 10 years since this flock began nesting, only 4 years have had enough water to result in appreciable breeding attempts (Spalding et al. In Press). Lack of suitable water can be expected to also affect productivity of wild-fledged whooping cranes.

The future of whooping cranes in Florida is threatened by loss of habitat from development. Some of the state's best crane habitat lies in western Lake/eastern Sumter County. Currently, ≥33% of the flock (30 birds total) reside on 3 ranches in this area. In 2006, one of the few years when water levels were suitable for nesting, 6 pairs nested on one of these ranches and raised 3 chicks to fledging. This is the only property to have >1 chick fledge in a season. Unfortunately, this property and another of the 3 have been purchased for development. The properties will be built up with self-contained communities complete with schools, etc. Other crane habitats in central Florida are similarly threatened. From 1974 to 2003, suitable crane habitat in Florida declined an average of 16.6% during each of the 10-year increments (Nesbitt and Hatchitt, 2008). Habitat loss negatively affects both captive-reared birds and wild-fledged birds.

FUTURE DIRECTIONS

The decision analysis was based on the premise of alternative fixed schedules of bird releases over time. Our analyses also presumed that birds would be released in fixed-size cohorts of 8 birds each, in an equal balance of males and females. These assumptions were necessary to facilitate the analysis; however, we attempted to explore the full potential range of population response to releases of chicks by investigating a wide diversity of duration, magnitude, and frequency of releases.

In practice, releases of birds, should more occur, will not likely be so prescribed, either for intentional or unintentional reasons. Over the 1993-2004 history of releases, survival of released chicks into the first summer post-release has varied substantially (Table 1). Post-release survival may be strongly influenced by climate conditions immediately prior to or during the release period. An efficient release strategy might take into account anticipated climatic conditions and limit number of releases when conditions for released birds are expected to be poor. Similarly, an efficient strategy may recognize demographic conditions in the population, e.g., an expected pulse of birds entering breeding status, and adjust number of releases accordingly to take advantage of or to remedy the situation. The strategy may also take into account what has been learned about the dynamics of the population to that point, with number of releases varying on the basis of what knowledge has begun to emerge about performance of wild-hatched birds.

In other words, decision making could be made dynamic and state dependent, in which number of releases is a varying decision over time, depending on current or expected environmental conditions, population status, and degree of understanding. Such a decision making framework would rely on models that make predictions about outcomes of releases through time, just as the models above. Should the strategic decision be made to commence releases, the above models could serve as a starting point for building a dynamic decision framework.

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Table 1. Numbers of female captive-reared and wild-hatched whooping cranes occupying different age and breeding classes in the FNMP. Empty cells have no birds occupying those classes in that year. Age classes are 0 years (or released for captive-reared birds), 1, 2, 3, and 4+ years. Breeding classes (shaded columns) are currently or previously paired, but never produced a nestling (*P*), previously produced a nestling, but never a fledgling (*N*), or previously produced a fledgling (*F*).

	Captive-Reared Birds								Wild-Hatched Birds							
Year	**Released**	**1[a]**	**2**	**3**	**4+**	**P**	**N**	**F**	**0**	**1**	**2**	**3**	**4+**	**P**	**N**	**F**
1993	8	1														
1994	9	7				1										
1995	6	5	5			1										
1996	20	19	3	5		1										
1997	15	11	12	1	3	5										
1998	8	1	7	8	2	9										
1999	18	15		4	2	14	1									
2000	11	5	9		5	14	1									
2001	9	9	4	6	4	15	1	1								
2002	10	4	7	1	5	10	4	2								
2003	7	7	2	5	1	12	4	2	1							
2004	5	5	2	1	3	14	2	2	1	1						
2005	2	1	1		1	12	3	4		1	1					
2006				1	1	10	3	4	4					2		
2007					1	9	3	4		4				2		
2008						7	2	4		1	2			1		

[a]Birds surviving to 1 July following release in preceding winter.

Table 2. Estimates of apparent annual survival rate by age and breeding class for captive-reared females, by age class for captive-reared males, and by sex class for wild-hatched birds; estimates of annual breeding transition and productivity rate for captive-reared females.

	Female			Male		
		95% credible interval[1]			95% credible interval[1]	
Age / breeding class	mean	Lower	Upper	Mean	Lower	upper
Annual survival rates – CR birds						
Never-paired birds						
Post-release to age 1	0.664	0.0	1.0	0.647	0.0	1.0
Age 1	0.672	0.0	0.999	0.646	0.0	0.999
Age 2	0.766	0.469	0.938	0.731	0.411	0.925
Age 3	0.821	0.556	0.955	0.792	0.499	0.946
Age 4+	0.805	0.512	0.948	0.774	0.461	0.935
Female breeding classes						
P class[2]	0.816	0.540	0.952			
N class[3]	0.785	0.454	0.950			
F class[4]	0.936	0.703	1.000			
Annual survival rates – WH birds (provisional[5])						
	0.888	0.0	1.0	0.743	0.0	1.0
Annual breeding transition rates – female CR birds						
Pr(paired | age 1 unpaired)	0.257	0.005	0.788			
Pr(paired | age 2 unpaired)	0.243	0.008	0.805			
Pr(paired | age 3 unpaired)	0.393	0.034	0.966			
Pr(paired | age 4+ unpaired)	0.297	0.024	0.962			
Pr(nestling, no fledgling | *P*)	0.153	0.001	0.743			
Productivity rates – female CR birds						
Pr(fledgling | *P*)	0.052	0.0	0.232			
Pr(fledgling | *N*)	0.002	0.0	0.028			
Pr(fledgling | *F*)	0.363	0.121	0.651			

[1]Posterior probability of true parameter value lying within indicated bounds = 0.95
[2]*P* = paired or historically paired, no history of nestling production
[3]*N* = nestling producer, no history of fledgling production
[4]*F* = fledgling producer.
[5]Based on survival of 6 of 9 WH birds. At time of the report, 1 additional WH bird had died.

Table 3. Simulation outcomes (proportion of simulations yielding positive population growth) for alternative release strategies (delay [years] until first release, duration [years] of releases, numbers of cohorts released/year) under alternative models of population growth. Model 3 hypothesizes increased productivity when number of females ≥2 years in the population passes a threshold (B_T).

Release Strategy			Model 2	Model 3								Model 1
Delay	Duration	Cohorts		$B_T = 5$	$B_T = 10$	$B_T = 15$	$B_T = 20$	$B_T = 25$	$B_T = 30$	$B_T = 40$	$B_T = 50$	
	0	0	0.900	0.759	0.422	0.097	0.004	0.001	0.001	0.001	0.001	0.002
1	5	1	0.907	0.813	0.601	0.311	0.070	0.009	0.002	0.001	0.001	0.002
1	5	2	0.916	0.841	0.677	0.439	0.189	0.055	0.013	0.002	0.001	0.001
1	5	3	0.911	0.857	0.727	0.533	0.303	0.136	0.045	0.004	0.001	0.002
1	10	1	0.915	0.851	0.714	0.481	0.175	0.032	0.006	0.001	0.001	0.002
1	10	2	0.923	0.875	0.777	0.636	0.424	0.226	0.086	0.007	0.002	0.002
1	10	3	0.935	0.896	0.816	0.696	0.543	0.380	0.232	0.057	0.008	0.001
1	15	1	0.921	0.866	0.771	0.587	0.246	0.061	0.014	0.002	0.002	0.001
1	15	2	0.932	0.897	0.833	0.727	0.561	0.369	0.187	0.028	0.005	0.002
1	15	3	0.938	0.912	0.861	0.786	0.671	0.551	0.407	0.155	0.037	0.002
1	20	1	0.926	0.884	0.810	0.658	0.303	0.086	0.017	0.002	0.002	0.002
1	20	2	0.937	0.916	0.864	0.794	0.667	0.486	0.282	0.050	0.010	0.002
1	20	3	0.951	0.930	0.889	0.843	0.756	0.662	0.550	0.259	0.087	0.002
11	5	1	0.907	0.835	0.558	0.150	0.010	0.003	0.001	0.002	0.002	0.003
11	5	2	0.911	0.855	0.640	0.254	0.047	0.010	0.005	0.003	0.003	0.006
11	5	3	0.924	0.858	0.680	0.345	0.112	0.038	0.011	0.003	0.002	0.004
11	10	1	0.916	0.857	0.625	0.204	0.021	0.008	0.005	0.006	0.006	0.015
11	10	2	0.921	0.875	0.724	0.395	0.134	0.046	0.017	0.003	0.002	0.003
11	10	3	0.936	0.893	0.766	0.512	0.276	0.154	0.068	0.014	0.003	0.002
11	15	1	0.921	0.873	0.664	0.251	0.039	0.009	0.004	0.002	0.002	0.004
11	15	2	0.935	0.893	0.776	0.494	0.236	0.107	0.043	0.010	0.002	0.001
11	15	3	0.944	0.913	0.821	0.623	0.425	0.274	0.163	0.046	0.014	0.001
11	20	1	0.922	0.883	0.712	0.286	0.059	0.014	0.005	0.002	0.001	0.002
11	20	2	0.940	0.912	0.810	0.590	0.346	0.186	0.088	0.017	0.005	0.002
11	20	3	0.948	0.927	0.858	0.703	0.540	0.405	0.281	0.104	0.036	0.001
1	10 (eo)[a]	1	0.904	0.818	0.628	0.321	0.054	0.005	0.001	0.002	0.002	0.001
1	10 (eo)	2	0.914	0.844	0.712	0.477	0.184	0.040	0.007	0.001	0.001	0.001
1	20 (eo)	1	0.911	0.862	0.721	0.396	0.073	0.009	0.003	0.001	0.001	0.001
1	20 (eo)	2	0.927	0.886	0.812	0.661	0.326	0.099	0.023	0.002	0.001	0.002

[a]"eo" indicates releases would occur only every other year during the 10 or 20 year period.

Table 4. Results from 3 iterations of expert elicitation of model weights for Models 1 and 2 and 8 versions of Model 3, which vary by the threshold level (B_T) for the Allee effect (models described in detail in text). Individual experts' scores are recorded, along with averages across experts. The average results from the third iteration were used to develop predictions for the population objective.

Iteration	Expert	M 2	M 3								M 1
			B_T= 5	B_T = 10	B_T = 15	B_T = 20	B_T = 25	B_T = 30	B_T = 40	B_T = 50	
1	1	10	0	0	0	0	0	0	0	0	90
	2	70	0	0	0	30	0	0	0	0	0
	3	0	0	0	100	0	0	0	0	0	0
	4	25	0	0	0	15	10	0	0	0	50
	5	0	0	0	20	20	60	0	0	0	0
	6	0	0	0	0	0	0	10	20	30	40
	7	0	0	20	50	30	0	0	0	0	0
	8	20	0	0	10	20	20	10	0	0	20
	Avg.	15.6	0	2.5	22.5	14.4	11.3	2.5	2.5	3.8	25
2	1	10	0	0	0	0	0	0	0	0	90
	2	10	0	0	0	45	45	0	0	0	0
	3	10	10	10	10	10	10	10	10	10	10
	4	25	0	0	0	5	5	5	5	5	50
	5	0	0	0	14	14	42	0	0	0	30
	6	0	0	0	4	8	16	8	4	0	60
	7	0	0	10	40	30	0	0	0	0	20
	8	20	0	0	0	0	0	13.2	13.6	13.2	40
	Avg.	9.4	1.3	2.5	8.5	14.0	14.8	4.5	4.1	3.5	37.5
3	1	20	0	0	0	0	0	0	0	0	80
	2	10	0	0	0	50	40	0	0	0	0
	3	10	10	10	10	10	10	10	10	10	10
	4	0	0	0	0	5	5	10	10	20	50
	5	0	5	5	5	15	15	10	10	10	25
	6	0	0	0	4	8	16	8	4	0	60
	7	0	0	10	20	40	10	0	0	0	20
	8	10	0	0	0	0	0	20	20	20	30
	Avg.	6.3	1.9	3.1	4.9	16.0	12.0	7.3	6.8	7.5	34.4

Table 5. Model predictions for each of 6 objectives (Cost, Alternative Restoration, Public Relations, Population, and Information). The models and measurement scales are described in detail in the text. Model predictions for the Population objectives are model averaged over the 3 population viability models, also described in text.

Release Strategy			Cost (millions)		Alt. Rest.	Pub. Rel.	Population	Information
Delay	Duration	Cohorts	Cost A	Cost B	(# of cohorts)	(0-1 scale)	(Probability)	(Probability)
	0	0	$9	$0	60	0	0.090	0.657
1	5	1	$9.375	$0.715	55	1	0.119	0.758
1	5	2	$9.425	$1.430	50	1	0.154	0.802
1	5	3	$9.475	$2.145	45	1	0.191	0.865
1	10	1	$9.750	$1.430	50	1	0.152	0.785
1	10	2	$9.850	$2.860	40	1	0.232	0.905
1	10	3	$9.950	$4.290	30	1	0.289	0.927
1	15	1	$10.125	$2.145	45	1	0.175	0.795
1	15	2	$10.275	$4.290	30	1	0.287	0.917
1	15	3	$10.425	$6.435	15	1	0.358	0.937
1	20	1	$10.500	$2.860	40	1	0.193	0.795
1	20	2	$10.700	$5.720	20	1	0.332	0.925
1	20	3	$10.900	$8.580	0	1	0.411	0.934
11	5	1	$9.975	$0.715	55	1	0.101	0.721
11	5	2	$10.025	$1.430	50	1	0.117	0.720
11	5	3	$10.075	$2.145	45	1	0.137	0.806
11	10	1	$10.350	$1.430	50	1	0.113	0.699
11	10	2	$10.450	$2.860	40	1	0.145	0.759
11	10	3	$10.550	$4.290	30	1	0.194	0.792
11	15	1	$10.725	$2.145	50	1	0.116	0.677
11	15	2	$10.875	$4.290	40	1	0.178	0.745
11	15	3	$11.025	$6.435	30	1	0.249	0.805
11	20	1	$11.100	$2.860	50	1	0.122	0.701
11	20	2	$11.300	$5.720	40	1	0.216	0.752
11	20	3	$11.500	$8.580	30	1	0.303	0.785
1	10 (eo)[a]	1	$9.375	$0.715	55	1	0.117	0.721
1	10 (eo)	2	$9.425	$1.430	50	1	0.154	0.788
1	20 (eo)	1	$9.750	$1.430	50	1	0.129	0.725
1	20 (eo)	2	$9.850	$2.860	40	1	0.199	0.826

[a]"eo" indicates releases would occur only every other year during the 10 or 20 year period.

Table 6. Weights assigned to each objective, determined by averaging over individual respondents' ratings.

Objective	Weight
FWC Costs (Cost A)	0.163
Partner Costs (Cost B)	0.100
Alternative Restoration Project Needs	0.156
Public Relations	0.033
Population Establishment	0.387
Information	0.161

Table 7. Normalized model predictions for each of 6 objectives (Cost, Alternative Restoration, Public Relations, Population, and Information), and the average (weighted by objective weights (Table 6)). The normalized values were calculated according to equation in the text, with a value of '1' being most and a value of '0' being least preferred.

Release Strategy			Cost		Alt. Rest.	Pub. Rel.	Population	Information	Weighted Average	Rank
Delay	Duration	Cohorts	Cost A	Cost B						
	0	0	1.00	1.00	1.00	0.00	0.00	0.00	0.419	21
1	5	1	0.85	0.92	0.92	1.00	0.09	0.36	0.499	12
1	5	2	0.83	0.83	0.83	1.00	0.20	0.52	0.542	8
1	5	3	0.81	0.75	0.75	1.00	0.31	0.74	0.598	7
1	10	1	0.70	0.83	0.83	1.00	0.19	0.46	0.508	11
1	10	2	0.66	0.67	0.67	1.00	0.44	0.89	0.625	4
1	10	3	0.62	0.50	0.50	1.00	0.62	0.96	0.657	1
1	15	1	0.55	0.75	0.75	1.00	0.26	0.49	0.496	13
1	15	2	0.49	0.50	0.50	1.00	0.61	0.93	0.628	3
1	15	3	0.43	0.25	0.25	1.00	0.83	1.00	0.651	2
1	20	1	0.40	0.67	0.67	1.00	0.32	0.49	0.472	15
1	20	2	0.32	0.33	0.33	1.00	0.75	0.96	0.616	6
1	20	3	0.24	0.00	0.00	1.00	1.00	0.99	0.619	5
11	5	1	0.61	0.92	0.92	1.00	0.03	0.23	0.416	22
11	5	2	0.59	0.83	0.83	1.00	0.08	0.23	0.411	23
11	5	3	0.57	0.75	0.75	1.00	0.15	0.53	0.460	16
11	10	1	0.46	0.83	0.83	1.00	0.07	0.15	0.373	27
11	10	2	0.42	0.67	0.67	1.00	0.17	0.36	0.398	24
11	10	3	0.38	0.50	0.50	1.00	0.32	0.48	0.426	20
11	15	1	0.31	0.75	0.83	1.00	0.08	0.07	0.331	28
11	15	2	0.25	0.50	0.67	1.00	0.28	0.31	0.385	26
11	15	3	0.19	0.25	0.50	1.00	0.50	0.53	0.444	18
11	20	1	0.16	0.67	0.83	1.00	0.10	0.16	0.320	29
11	20	2	0.08	0.33	0.67	1.00	0.39	0.34	0.390	25
11	20	3	0.00	0.00	0.50	1.00	0.67	0.46	0.442	19
1	10 (eo)[a]	1	0.85	0.92	0.92	1.00	0.08	0.23	0.476	14
1	10 (eo)	2	0.83	0.83	0.83	1.00	0.20	0.47	0.534	10
1	20 (eo)	1	0.70	0.83	0.83	1.00	0.12	0.24	0.446	17
1	20 (eo)	2	0.66	0.67	0.67	1.00	0.34	0.60	0.539	9

[a] "eo" indicates releases would occur only every other year during the 10 or 20 year period.

Figure 1. Female-based population model for projecting dynamics of the FNMP through time. Birds released (*R*) into the population survive annually into successive age classes of unpaired birds (C_1, C_2, C_3, C_{4+}), and unpaired birds may themselves survive and become paired (C_P). Paired birds may then survive and produce no young, nestling(s) that do not fledge, or fledgling(s). Likewise, birds that have produced only nestlings previously (C_N) may become fledgling producers (C_F). All fledglings produced by any of these types of breeders become the 0 age class of the wild-hatched segment. Pathways within the wild-hatched segment are similar to the captive-reared segment, although the rates of transition may differ between the two segments.

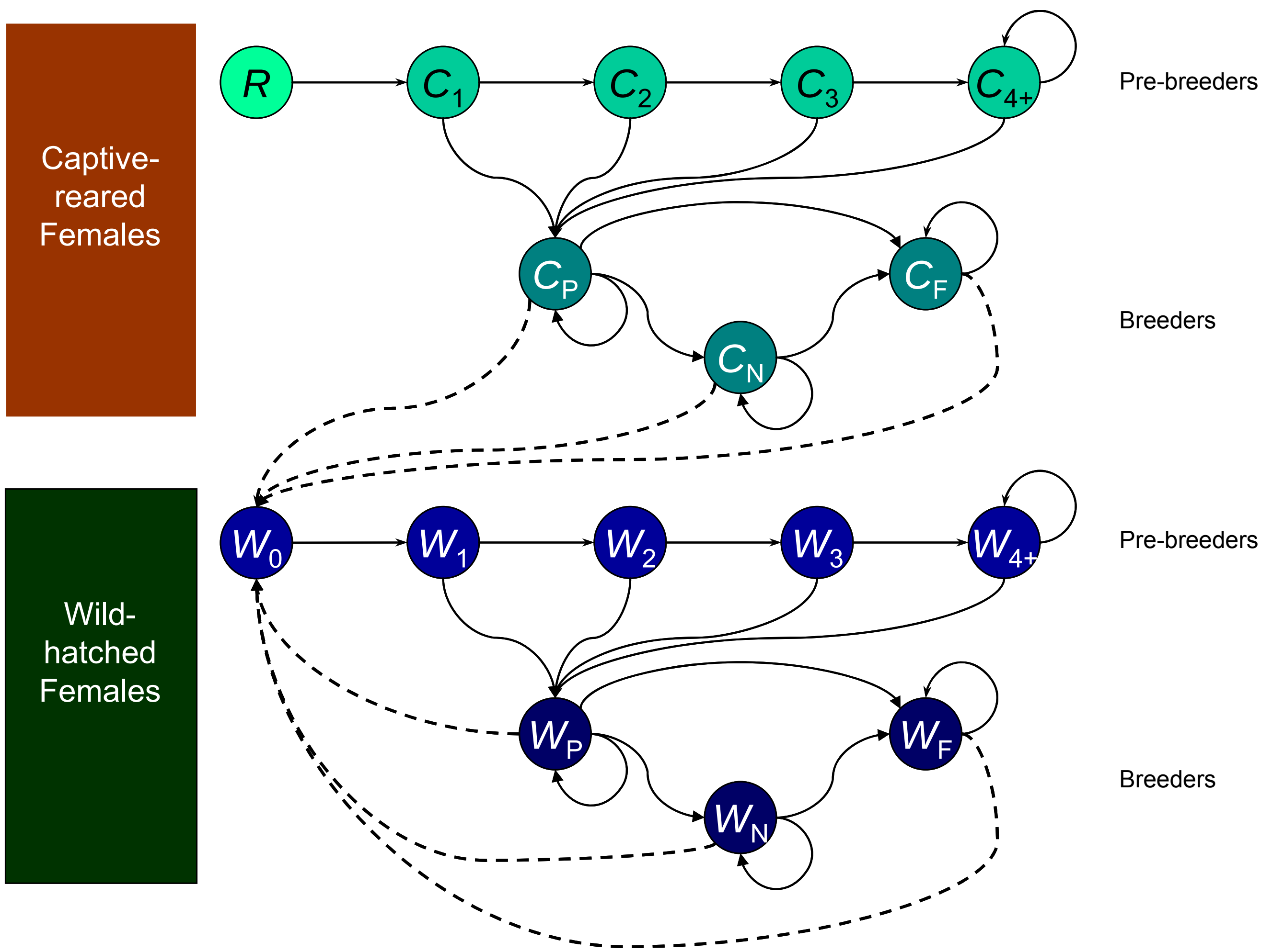

Figure 2. Simulation outcomes (proportion of simulations yielding positive population growth) for alternative release strategies under 3 alternative models of population growth. Time delay until the first release and duration of release are displayed on the horizontal axis. Outcomes are plotted for 1 (short dashes), 2 (medium dashes), or 3 (solid line) cohorts per year under Model 1 (squares), Model 2 (circles), and case $B_T = 20$ of Model 3 (triangles). Under Models 1 or 2, the outcome is insensitive to the decision, resulting either in extirpation (Model 1) or establishment (Model 2) in every case. Under Model 3, the outcome is highly sensitive to the release decision, and the response pattern reveals greater probability of success with intensive release activity that occurs earlier and persists longer.