Adaptive Harvest Management of Age-Structured Goose Populations

Preliminary Report (October 2003)

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1. Background

The need to identify optimal harvest policies is apparent for many waterfowl populations, and particularly for the Atlantic Population (AP) of Canada geese (*Branta canadensis*) whose numbers declined significantly in the 1980's and early 1990's (Hestbeck and Malecki 1989, Hestbeck 1995). Sport-hunting seasons for this population were closed in the U.S. from the fall of 1995 to the winter of 1999. Hunting seasons have been reinstated, but are currently at restrictive to moderate levels in the U.S. Continuation of sport harvest for AP geese and maintenance of the population within desired bounds is contingent upon effective harvest management and monitoring programs. Effective management will need to incorporate multiple objectives and must be accomplished with incomplete knowledge of the system and in the presence of various types of uncertainty including environmental variation, partial system control, model uncertainty, and partial system observability.

Adaptive management provides a useful framework for making sequential decisions in the presence of uncertainty (Walters 1986, Williams 1996, Johnson et al. 1997). Adaptive harvest management (AHM) is currently used to set regulations for mallard harvest management (USFWS 2002) but we are not aware of any attempts to use these decision-making techniques for any species or population of geese. Developing an AHM protocol for AP geese will require extending approaches currently used for other waterfowl to account for fundamental differences in the demography and management of ducks and geese. To date, most applications of adaptive management to waterfowl harvesting have relied on simple scalar population models (Johnson et al. 1997, USFWS 2002). Such scalar models assume all individuals in the population have the same responses to environmental stressors. By contrast, goose populations have significant age structure as a result of relatively high survival rates and age-dependent productivity (Raveling 1981, Raveling et al. 2000). Previous investigations have shown that optimal harvest management of age-structured populations is conditional on the age-structure of the population and on age-specific differences in vulnerability of harvest (Evan Cooch, Cornell University, pers. comm.). Adequate description of the population dynamics of geese will therefore require age-structured models; derivation of goose harvest strategies from existing scalar models may significantly hinder management performance by failing to take advantage of increased harvest potential and to accommodate decreased harvest potential driven by intrinsic and extrinsic changes in the age structure.

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

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

In late August 2003, representatives from the USFWS, USGS, CWS, Atlantic Flyway, and Cornell University met to draft the preliminary modeling and analysis framework for the adaptive harvest management of AP Geese. In the following report, we summarize the basic structure of the AHM plan for this population; derivation of the basic framework was based on the expertise of the participants at the meeting, and a series of assumed management objectives. Developing specific AHM protocols for managing structured populations will require addressing all components above. In this report, we summarize our progress to date in (i) developing an appropriate set of models to describe system dynamics for AP geese, and (ii) specifying the general problems of optimization to meet objectives for such models.

2. Management objective

2.1 Preliminary statement of the objective

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

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

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

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

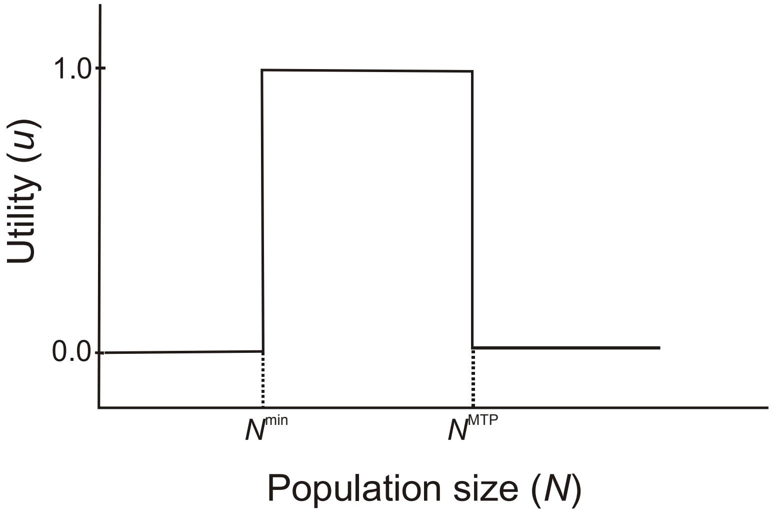
We think this objective will hold the population as close to the maximum tolerable population size as possible (thus, allowing the greatest harvest), while guarding against the risk of the population getting out of control.

Mathematically, these objectives can be expressed as

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

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

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



2.2 Theoretical challenges to optimizing harvest of a structured population

While the stated objective is conceptually simple (use of harvest to maintain population levels between a minimum and a maximum value, while maximizing opportunities for harvest), in practice, there may be several difficulties related to the harvest of a structured population. Preliminary research has shown that when populations are structured by age or some other state variable, and subject to harvest management, the equilibrium harvest vector can be described as a set, with a maximum value beyond which harvest decreases the population irrespective of the age-structure of the harvest, and a minimum value for which the opposite is true (Evan Cooch, Cornell University, pers. comm.). The elements of this harvest set are determined by (i) the number of age- or stage-classes, and (ii) the reproductive value vector at the time of harvest. In other words, in a structured population, the effect of harvest depends on the ability to control the age-structure of the harvest. However, age-specific harvest for many species is generally not possible. The critical question for goose management is how much the age-structure of the harvest can be altered by management actions, if at all. This difficulty is, in turn, compounded by the change in the dynamics of a structured population following harvest: unless the harvest consists of individuals of different ages in direct proportion to the asymptotic stable age distribution, response of the population to harvest will exhibit the transient non-linear fluctuations characteristic of such population following a perturbation. These problems in system control contribute significantly to the overall uncertainty in goose harvest management.

In addition, a characteristic of age-structured populations is their tendency to exhibit population 'momentum', i.e. for a population trajectory to continue in a certain direction following a management action (Keyfitz 1971, Caswell 2001). Therefore, it may be several years before the ultimate impacts of a particular management action can be observed. Population 'momentum' has important, but as yet unexplored, implications for both the frequency of decision-making (i.e., how often to update the state) and the updating of alternative population models. Again, this contrasts with most adaptive management plans for *r*-selected species, where evidence suggests that a management action in year *t* will lead to detectable changes in year *t*+1.

3. Historical data and operational monitoring

3.1. *Historical data*

Monitoring of APCG on the breeding grounds in the Ungava Peninsula of Northern Quebec was first conducted by Malecki and Trost in 1988. In 1993, an aerial survey using fixed-wing aircraft was initiated by CWS and USFWS over the same area. This survey has been conducted on an annual basis since then. In addition to aerial surveys, capture and marking of APCG with leg bands and neck collars was conducted from 1986 to 1988 in Ungava Bay, Hudson Bay, and James Bay by Malecki and collaborators. Finally, an intensive study of the breeding biology and demographics of APCG was conducted between 1997 and 2002. This study was conducted in Ungava Bay and Hudson Bay and focused on obtaining reproductive parameters (nest initiation and hatching dates, clutch size, nest success, etc.) from most of the important breeding sites in the region. A main study area was located along Hudson Bay at the Polemond River where field crews collected precise information over the entire nesting and pre-fledging period. A large sample of geese were also captured and banded during the course of this study at major brood rearing sites located along Ungava Bay and Hudson Bay.

3.2. *Operational monitoring*

The population status of APCG is monitored each year by estimating the number of breeding pairs on the Ungava Peninsula. This transect-based aerial survey is conducted in mid to late incubation (usually mid to late June). Preseason banding is conducted in late July or early August. Banding is focused on groups with young. Samples are banded on both the Hudson Bay and Ungava Bay coastal areas. Total geese banded each year ranges from 3,000-6,000 on the Hudson Bay coast and 2,000-3,000 on the Ungava Bay coast. The number of young per adult female in the banded sample provides an assessment of annual productivity. In addition, an annual survey, less intensive than the 1997-2002 breeding study, that involves nest searching (early June) on widely scattered plots with a return to measure nest success (during preseason banding operations) will likely be continued.

4. Projection model structure

To date, the most thoroughly studied applications of AHM to harvested waterfowl have relied on fitting and (ultimately) optimizing simple scalar population models, where $N_{t+1} = f(N_t +$ anthropogenic factors + natural factors). Such scalar models are homogenous, in that all individuals in the population are assumed equivalent in underlying biology (although in some instances some minor level of age- or sex-specific differences are included).

While such scalar models are perhaps appropriate for many (if not most) duck species, which can be conveniently (if not entirely appropriately) described as *r*-selected, there is reason to believe they may be inappropriate for populations that are more *K*-selected, such as long-lived species of geese. For such species, where there is often significant age-structure, simple scalar models are generally inappropriate. As such, simple extension of current duck AHM plans (which are based on homogenous scalar models) to goose populations may result in models that do a poor job of predicting, as a consequence of not accounting for the structure of the population. Further, given the complexity of the realized dynamics of structured populations under natural conditions (where the general assumptions of time-invariance and (thus) stable age or stage-distributions are often strongly violated), the likelihood of a significant disparity between results predicted from scalar versus age-structured models would seem to be high under many reasonable scenarios.

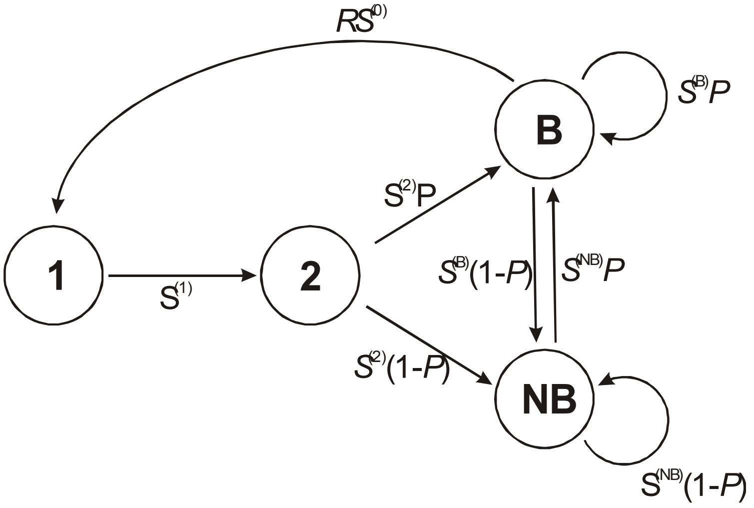
For the purposes of development of this AHM application, the APCG is defined as those geese breeding on the Ungava Peninsula. By this delineation, we assume that geese in the Atlantic population outside this area are either few in number, similar in population dynamics to the Ungava birds, or both.

4.1. Deterministic population models

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

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

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



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

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

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

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

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

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

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

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

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

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

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

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

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

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

In our base model, we make several simplifying assumptions. First, we assume that breeding begins at age 3 in APCG. However, while evidence from other goose populations is that breeding propensity increases with age, in the absence of age-specific estimates for APCG, we assume that breeding propensity (P) is constant over all breeding ages in a given year (note: in the future, we may consider relaxing this assumption, making use of estimates from closely related species nesting at similar latitudes). Second, we assume that breeding individuals have the same per capita breeding success (*R*), independent of age; while we know this is unlikely to be true, since geese typically show age-specific differences in reproductive output until at least age 5 yr, age-specific estimates of per capita breeding success are not available for APCG (note: in the future, we may consider relaxing this assumption making use of estimates from closely related species nesting at similar latitudes). Third, since goose species exhibit a monogamous breeding system, with evidence of a 50:50 sex-ratio throughout the life cycle (Cooch et al. 1997), we do not recognize sex structure in the model dynamics (thus, $N_t^{(\mathrm{B})}$ is the number of adult breeders, male and female, at time *t*). Fourth, we assume that the probability of a state transition (i.e., between breeder and non-breeder) is random, and not Markovian, that is, that the probability of breeding, P_t in year *t* is not a function of breeding state (B or NB) in year *t*–1. Recent evidence from snow geese and brant suggests that such transitions are, in fact, likely to be at least first-order Markovian, but there are no data available at present for AP, or other populations of Canada geese.

As one component of our research, we will consider the implications of the reduced model structure on the derivation of optimal harvest strategies, and will use this information to inform the design or re-design of future monitoring and research efforts for APCG.

4.1.1 Survival process

Among goose species, mortality is judged to be additive, although natural mortality of first-year (juvenile) geese is likely density-dependent in some cases. Under the additive mortality model, harvest mortality is additive to natural mortality. This can be expressed generally in the form

$$S_{t,age} = S'_{t,age}\left(1 - K_{t,age}\right)$$

where *S*′ is the survival in the absence of harvest, and *K* is the harvest rate (adjusted for crippling loss). For APCG, we allow for the possibility that *S*′ and *K* both vary as a function of breeding status, such that

$$S_t^{(\mathrm{B})} = S_t'^{(\mathrm{B})}\left(1 - K_t^{(\mathrm{B})}\right),$$

$$S_t^{(\mathrm{NB})} = S_t'^{(\mathrm{NB})}\left(1 - K_t^{(\mathrm{NB})}\right),$$

and since neither 1- or 2-year-olds breed,

$$S_t^{(1)} = S_t'^{(\mathrm{NB})}\left(1 - K_t^{(1)}\right), \text{ and}$$

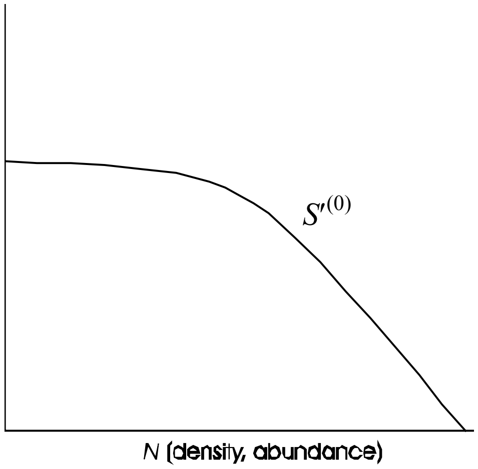
$$S_t^{(2)} = S_t'^{(\mathrm{NB})}\left(1 - K_t^{(2)}\right).$$

These adult survival rates ($S^{(B)}$, $S^{(NB)}$, $S^{(1)}$ and $S^{(2)}$) are effectively deterministic. In contrast, variation in juvenile survival includes variation in natural mortality $S'^{(0)}$ due to annual (stochastic) variation in some extrinsic environmental factor z (see below), and a monotonic declining function of total population abundance (N^{tot}), at some threshold value. Thus,

$$S_t^{(0)} = S_t'^{(0)}\left(1 - K_t^{(0)}\right), \text{ where}$$

$$S_t'^{(0)} = f\left(N_t^{tot}, z\right)$$

and $N^{tot}=N^{AP}+N^{RES}$, where N^{AP} = abundance of APCG, and N^{RES} = abundance of molt migrant resident Canada geese present on the APCG breeding grounds. *Note*: we let N^{RES} be an external driving variable (i.e, we will not attempt to develop and embed dynamic models of resident geese in the decision problem, but we will examine optimal harvest policies under different, but fixed, levels of N^{RES}). The proposed shape for the density-dependence of $S'^{(0)}$ is shown below.



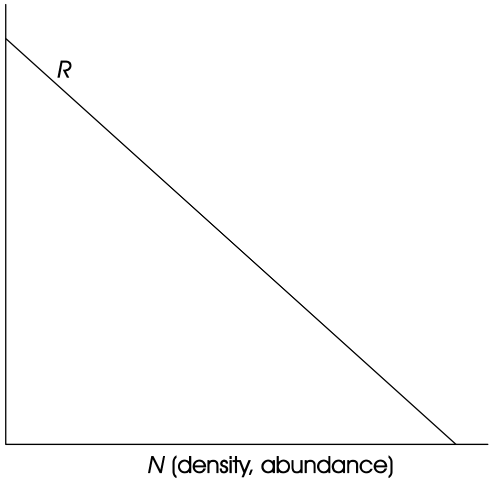
4.1.2 Reproductive process

Among goose species, annual reproductive rates strongly depend on (i) the proportion of birds P which breed every year and (ii) the annual reproductive output and fledging success R. Both P and R are believed to be affected by stochastic extrinsic environmental factors (z, representing, in particular, the timing of snow melt on the breeding grounds); and R is believed to negatively depend on population abundance at the time of breeding, as mediated by egg laying, gosling growth, and gosling survival (Cooch 2002, Cooch et al. 2001, Francis et al. 1992, Larsson and Forslund 1994, Loonen et al. 1997, Sedinger et al. 1998, Williams et al. 1993).

$R_t = f(N^{tot}=N^{AP}+N^{RES},z)$, where N^{AP} = abundance of APCG, and N^{RES} = abundance of molt migrant resident Canada geese present on the APCG breeding grounds (see above).

$P_t=f(z)$

R_t has been shown in virtually all other goose species to decline linearly, and monotonically with increasing population abundance N, as shown in the following graph.



Note that this contrasts with the decline in juvenile survival, which occurs only when the population size has achieved some threshold size (see above).

4.1.2 State variables

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

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

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

There are several other state variables of interest, however, namely, $N^{(1)}$, $N^{(2)}$, and $N^{(\mathrm{NB})}$. Since annual harvest decisions need to be made based on the total population size (N^{tot}), which is the sum of contributions from various non-breeding age classes as well as the number of breeding individuals, annual variation in abundance of non-breeding individuals ($N^{(\mathrm{NB})}$, $N^{(1)}$, and $N^{(2)}$; *cf.* 3.1) will need to be derived using population reconstruction techniques. Population reconstruction involves estimation of unseen parameter values given a time series of observed population vectors. In most cases, population reconstruction involves estimating the most likely projection matrix, given a time series of population vectors (where number of individuals in each age class at each time is known; *sensu* Dennis *et al*., 1997; Wood, 1997). However, in our case, estimates of N^B, R and z only are available (not the complete population vector); in effect, we seek to estimate some parameter values given the dynamics of other parameters in the model. Recent extensions of Bayesian statistical methods to population reconstruction may provide an adequate solution (Link et al., *in press*). We will need to figure out how to embed these sorts of techniques within an adaptive management optimization application.

5. Harvest dynamics: decision variable

Our understanding is that APCG regulations currently are chosen to achieve an intended adult harvest rate. We propose using intended harvest rate of breeding adults as the decision variable in the AHM model, for three reasons. First, managers of this population are used to thinking about harvest *rates*, and a given regulations package may be more likely to maintain a consistent rate rather than a consistent total harvest. Second, for the purposes of this research and prototype AHM development, we want to focus on a continuous decision variable, rather than discrete regulations packages, to avoid the uncertainty associated with the packages. A full-fledged application of AHM for APCG will have to also develop models that link regulations packages to harvest rate. Third, the focus is on breeding adults because the reward band study will produce direct estimates of the harvest rate of breeders (since it is breeders that are being banded).

The challenge from the modeling standpoint is figuring out how an intended adult breeder harvest rate translates into a realized kill rate vector (the kill rate for each age-class). Three elements play a role. (1) Relative vulnerabilities will be used to translate harvest rate for adult breeders into harvest rates for the other age-classes. (2) A model of limited capacity for harvest, due to finite hunter numbers and maximum effort, will be used to calculate realized harvest from intended harvest. (3) A crippling rate will be used to calculate kill rates from harvest rates. These steps are described in more detail below.

The first step is to derive intended harvest rates for each age-class from an intended breeding adult harvest rate, by establishing the differential vulnerabilities of adults and juveniles. Let the decision variable, intended breeding adult harvest rate, be given by $h_t'^{(\mathrm{B})}$. The other intended harvest rates are functions of the current population vector and the differential vulnerabilities:

$$h_t'^{(\mathrm{NB})} = f_1\left(h_t'^{(\mathrm{B})}, \mathbf{n}_t, d_t^{\mathrm{NB}}\right) \text{ , and}$$

$$h_t'^{(0)} = f_2\left(h_t'^{(\mathrm{B})}, \mathbf{n}_t, d_t^{0}\right),$$

where the harvest rates of one- and two-year-old birds are assumed to be the same as for non-breeders. The differential vulnerabilities may, in turn, be functions of population density and population structure:

$$d_t^{\mathrm{NB}} = f_3\left(\mathbf{n}_t\right), \text{ and}$$

$$d_t^{0} = f_4\left(\mathbf{n}_t\right).$$

Note that as written, vulnerability is scaled relative to intended harvest rate for breeding adults. We believe that age-specific harvest rate is a function not only of the size of the population, but of its age-structure at the time of harvest (since there is some evidence of age-structure effects on harvest vulnerability).

The next step is to calculate realized harvest rates from intended harvest rates, where this calculation reflects the limits to the amount of harvest that can be achieved. From the intended harvest rates and the post-breeding population vector, one can calculate the intended stage-specific harvest totals, for example,

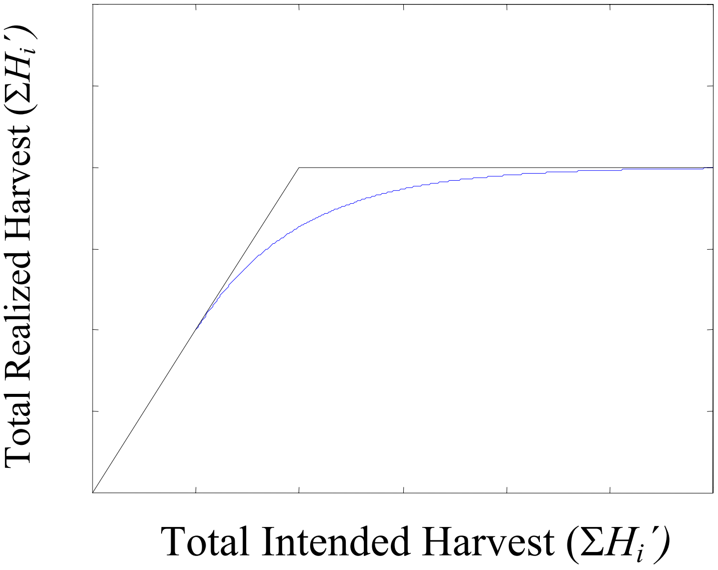
$$H_t'^{(0)} = h_t'^{(0)} N_t^{(0)},$$

$$H_t'^{(1)} = h_t'^{(1)} N_t^{(1)},$$

etc., which assumes that summer survival of geese is nearly 1. Next we need to develop a relationship between the intended total harvest and the realized total harvest,

$$H_t^{(i)} = f_i\left(H_t'^{(i)}, \sum_i H_t'^{(i)}\right)$$

something like the graph below, where the different lines represent alternative models for how the limits to harvest are felt.



Finally, from the realized harvest totals, the realized harvest rates are calculated.

The last step is to calculate realized kill rates from realized harvest rates. This will be done by using a crippling rate that is constant across age-classes.

The end result is that the decision variable, intended harvest rate of breeding adults, is translated into a vector of realized kill rates. These kill rates are then used in conjunction with the survival submodel (see section 4.1.1 above) to calculate annual survival rates.

6. Analysis assignments and Timeline

To date, we have made significant progress in constructing the base model, and in identifying key conceptual and analytical needs. The next phase of the work will involve estimating parameters for the elements of the model. At our meeting, specific objectives were identified and assigned.

6.1 Analysis

Analysis	*Personnel*	*Timeline*
Function relating *R* and *P* to population size (N) and environmental factors (z) $R_t = f(N_{tot}=N_{\mathrm{AP}}+N_{\mathrm{RES}}, z)$, $P_{\mathrm{t}}=f(\mathrm{z})$	*Reed, Hughes, Harvey*	February 1, 2004
Estimation of $N^{(\mathrm{NB})}$, $N^{(1)}$, $N^{(2)}$ using reconstruction methods	*Boomer, Runge, Link*	January 1, 2004
Survival rate estimation S^0, S^{B} $\mathrm{S}'^{0} = f(N^{\mathrm{tot}}, z)$	*Reed*	February 1, 2004
Vulnerability analysis based on MVP, SJBP populations. $h_t'^{(\mathrm{NB})} = f_1\left(h_t'^{(\mathrm{B})}, \mathbf{n}_t, d_t^{\mathrm{NB}}\right)$ $h_t'^{(0)} = f_2\left(h_t'^{(\mathrm{B})}, \mathbf{n}_t, d_t^{0}\right)$ $d_t^{\mathrm{NB}} = f_3\left(\mathbf{n}_t\right)$ $d_t^{0} = f_4\left(\mathbf{n}_t\right)$	*Sheaffer, Cooch*	February 1, 2004
Optimization (structured population): considerations of momentum, population structure uncertainty, and timing of updating.	*Hauser, Cooch, Runge*	Prototype optimization by late February 2004

6.2 Timeline

- 15 October 2003. Progress report (this document) available.
- 26-27 January 2004. APCG AHM development panel (Cooch, Johnson, Runge, Boomer, Harvey, Reed, Serie, Sheaffer) reconvenes at Patuxent for next working meeting.
- 29 February – 5 March 2004. AF Technical Section Meeting, Jekyll Island, Georgia. Cooch to present update on this project. Written progress report available that outlines the decision structure, model structure, parameter estimation, and preliminary optimization.
- 20-23 April 2004. AHM Working Group, Orlando, Florida. Preview the AHM model and results. Get feedback.

- 15 October 2004. Final report sent to Atlantic Flyway, USFWS, others. This will conclude the development work conducted under this project. Further refinement and development into an operational program will become the responsibility of the USFWS Division of Migratory Birds.

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