Lecture 13. Management of populations.

Reading:

Hilborn, R. and C. J. Walters. Chapter 3. Behavior of exploited populations. Pages 47-103 *in* Quantitative fisheries stock assessment. Chapman and Hall, New York, New York, USA. 570 pp.

Ludwig, D., R. Hilborn, and C. Walters. 1993. Uncertainty, resource exploitation, and conservation: lessons from history. Science 260:17,36.

Stacey, P. B. and M. Taper. 1992. Environmental variation and the persistence of small populations. Ecological Applications 2:18-29.

Optional:

Anderson, D. R. 1985. Constrained optimal exploitation: a quantitative theory. Pages 105-116 *in* S. L. Beasom and S. F. Roberson, Game Harvest Management.

McCullough, D. R. 1984. Lessons from the George Reserve, Michigan. Pages 211-242 *in* White-tailed deer ecology and management. Wildlife Management Institute.

Walter, C. 1986. Chapter 4. Models of Renewable Resource Systems. Pages 64-128 *in* Adaptive Management of Renewable Resources. Macmillian, New York, New York, USA. 374 pp.

Management of a population requires 4 steps (Hilborn and Walters 1992): definition of a goal, development of a model to evaluate management options to achieve the goal, implementation of the management option selected (along with necessary data collection schemes), and an evaluation procedure to see that the management strategy is working.

1. Goal or objective (some objectives may be hidden). Examples are:
    - Threatened and endangered species -- raise the population level to insure persistence.
        - Minimum viable population
        - Persistence
        - Time to extinction
    - Pest control -- lower the population or more reasonably lower the level of damage (same number of coyotes, only the ones present don't like mutton)
    - Commercially important species -- such as halibut, are managed for maximum sustained yield.
    - Game species --
        - Maximize production of trophy animals
        - Maximize hunter recreation (generating maximum income)
        - Maximize quality of recreation (which may increase license cost)
        - Minimize game damage payments and/or rancher complaints
2. Need a model to be able to develop your management strategies.

    Once you have defined a goal, you have to have some ability to test various management strategies (decisions) to see what level will achieve the goal. Anderson (1985), concerning exploitation, argues that to develop an optimal exploitation system, you need a) birth process as a function of density, and b) death process as a function of density and number harvested (a and b constitute density-dependent relationships in the population). He also advocates including the environmental stochasticity inherent in the natural system in the model. He argues that deterministic models, or simple models such as the logistic where r = b - d, are totally inadequate. He provides the understatement of the century in population biology: "The availability of adequate data will continue to be a serious limitation." In reality, lack of information is deeper than just some poorly estimated parameters. Often basic functional relationships are poorly understood, and are not modeled adequately to provide correct system behavior, regardless of the parameter values used.

Stacey and Taper (1992), concerning population persistence, also argue for models with a) environmental stochasticity, and b) density dependence, including the proper form of the density dependence. In persistence models, as population declines, the compensation for small population size takes the form of increased birth rates and decreased death rates (density dependence), and so is a significant factor in increasing population persistence. Stacey and Taper (1992) tested 2 forms of density dependence with their data: logistic

$$R(t) = R_i\left(1 - \frac{N(t)}{K}\right)$$

$$R(t) = R_i\left|1 - \left(\frac{N(t)}{K}\right)^{\theta}\right|$$

and θ-logistic
However, their data precluded a significant test between these models. Their data did show significant correlations between adult survival and population size, although the lack of correlation is likely a Type II error, and additional analyses are provided by Middleton and Nisbet (1997). In the following table, 4 variables are correlated against population size:

Variable	Sample Size	Correlation	Probability
Adult Survival	9	-0.65	0.058
Juvenile Surv.	9	-0.30	0.434
Reproduction	10	-0.56	0.094

Emigration	9	0.28	0.473

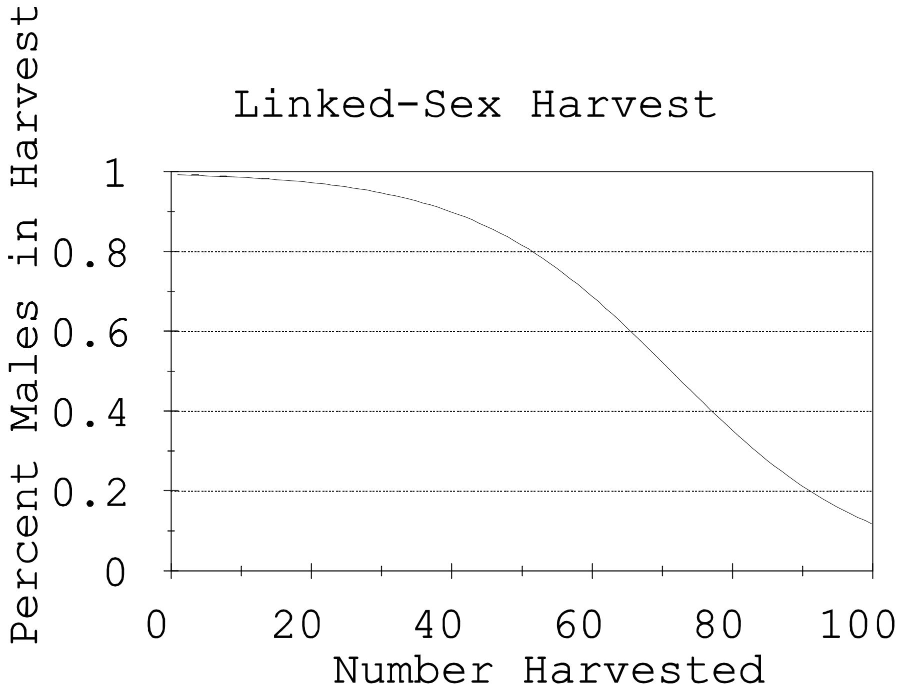
Stacey and Taper (1992) also make some grand-stand statements about data required to build a model: "it can be exceedingly difficult to provide meaningful estimates of persistence time because the results depend so largely on the assumptions that are used to create the model." What a revelation! However, they continue: "Furthermore, even if the model is specified correctly, relatively small errors in the estimation of the parameters can lead to large errors in the predictions (see also Goodman 1984)." They explored 2 functions for incorporating density dependence, illustrating a lack of knowledge on functional forms of a very basic relationship.

To summarize, the need for a model is to guide management: explore options, evaluate options quantitatively, and to formulate optimal decision criterion. Even if the model is built from very poor data, it may be useful in guiding collection of the needed data.

3. Ready to implement our management scheme.

a. Need annual data to maintain an optimal decision (Anderson 1985). Examples are to estimate population size with rigorous estimation schemes, or maybe estimate reproductive rates via helicopter surveys such as CDOW does with deer and elk, or the USFWS and the Canadian Wildlife Service does with air surveys of pot-hole density and brood density, or maybe estimate annual survival rates via radio-collared animals or bands, or estimate harvest taken, or maybe immigration/emigration rates to maintain a metapopulation.

An example of a very simple data collection scheme is McCullough et al.'s (1990) linked sex harvest strategy. Hunters are able to shoot animals of either sex, but antlered males are preferred. For a constant population size, the proportion of males in the harvest is a function of harvest size:



Incremental increases in harvest are used to seek out a pre-determined percentage of males in the harvest. As the harvest size increases, the percent of females in the harvest increases. When too many females are taken, the population eventually declines below MSY, and the proportion of females increases even more in the harvest. Typically, try to adjust the harvest so that 40% of the harvest is female, but this value will depend on the herd productivity and recruitment rates. The least attractive aspect of this strategy is that no additional monitoring data are taken to verify that the system is operating as expected. A stochastic environment could really screw up the works, i.e., a year of really poor over-winter fawn survival. In 2 years, you would have no bucks, and hence see a very large percentage of females in the harvest.

Unfortunately, the strategy turns out to work poorly, even in a deterministic model (Lubow et al. 1996). To understand the problem, consider what is needed to reach the population size for MSY. If I told you the exact population size (and age and sex ratios), plus the true values of the parameters K and r and that the population truly followed a logistic curve (i.e., MSY population size is $K/2$), you could, in theory, immediately reach N_{MSY}. This is because we know under this set of assumptions that $N_{MSY} = K/2$. Now, I could only tell you the proportion of adult females to harvest at MSY. This would imply that I didn't tell you K as above, but only r, because we know that at MSY, the harvest rate is $r/2$, i.e., the MSY harvest is $rK/4 = N_{MSY}r/2$. You would see a gradual decline in N_t until N_{MSY} was reached. The time lag will be on the order of a generation time or so, but not terribly long. However, even less information is provided if I were to only tell you the ratio of females to males to harvest at MSY. If you implemented this sex ratio in your current population, the time lag to achieve the MSY population size is on the order of 10 generation times. Hence, you would probably want additional information to invoke this harvest strategy, like the current population size and *K*.

b. A second part of the implementation process is obtaining public acceptance. There are classic cases where elaborate management plans have failed. For instance, suppose deer hunters would not shoot does under the linked sex strategy described above. Other (documented) failures are antler-point restrictions in deer management, where many animals are harvested, but left in the field, because they are illegal. In the spotted owl controversy, loggers will not accept the proposed guidelines for maintaining the owl population because they interfere with tree harvest. Finally the Colorado black bear controversy (Amendment 10) is an example of lack of public acceptance. Because spring bear harvest is heavily biased towards the taking of males (they come out of hibernation first), the spring harvest can result in a larger bear harvest than fall hunting. Spring bear hunting over bait was an acceptable practice 20 years ago. Now, the public has changed it view. The killing of a sow with newborn cubs is unacceptable. From public surveys, the CDOW found out in the spring of 1992 that 40% of Colorado voters strongly opposed spring bear hunting, and another 14% opposed spring bear hunting. Prior to the amendment being placed on the ballot, 69% said they opposed spring bear hunting and would vote to support the amendment banning spring bear hunting. Other public surveys showed that 21% agreed with the statement "Hunting is a right", 57% agreed with the statement "Legal hunting is okay.", 15% agreed with the statement "Hunting is okay as long as done by wildlife professionals.", and 7% agreed with the statement "No hunting should be allowed period (on any species).". The Colorado Wildlife Commission ignored these results, and persisted with the spring bear season, even though the CDOW biologists strongly recommended against a spring season. In the 1992 November election, 70% of the public supported Amendment 10 that banned spring bear hunting.

Other aspects of understanding the public is to understand the dynamics of the human population affected by the management strategy. Hilborn and Walters (1992) have a chapter on the dynamics of the fishing fleet.

Reasons why economic considerations may lead to over exploitation of a natural resource (from Bulmer 1994:120, taken from Clark 1990).

i. In a monopoly situation sole-owners of a resource stock tend to view it as a capital asset that is expected to earn dividends at the current rate.

ii. In an open-access situation in which the resource is the common property of a group of competing users, each of these users will consider only his own interests and will fail to take into account the costs that his actions may impose on the other users.

4. Periodic evaluation of the management strategy must be performed, along with incorporation of new information, and design of management experiments to test the validity of the strategy.

As an example of the negative side of a management strategy, consider the following short-comings of MSY (Holt and Talbot 1978):

“- focuses attention on the dynamics of particular species or stocks without explicit regard to the interactions between those species or stocks and other components of the ecosystem;
- concerns only the quantity and not the quality of potential yield or other value from the resource;
- depends on a degree of stability and resilience of the resource that may not exist;
- focuses attention on the output from resource use, without regard to the input of energy, or other natural resources, and of human skill and labor required to secure the output;
- may admit, and even encourage, over exploitation.”

Should have criteria specified a priori to evaluate the management program. This idea, along with extending knowledge, is particularly well developed by Walters (1986). He suggests 4 basic issues in developing an adaptive management strategy:

“- bounding of management problems in terms of explicit and hidden objectives, practical constraints on action, and the breath of factors considered in policy analysis;
- represent existing understanding of managed systems in terms of more explicit models of dynamic behavior, that spell out assumptions and predictions clearly enough so that errors can be detected and used as a basis for further learning;
- representation of uncertainty and its propagation through time in relation to management actions, using statistical measures and imaginative identification of alternative hypotheses (models) that are consistent with experience but might point toward opportunities for improved productivity;
- design of balanced policies that provide for continuing resource production while simultaneously probing for better understanding and untested opportunity.”

The major contribution is to use management as an experiment to more clearly understand the system being managed.

Some additional references on adaptive management:

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Holling, C.S. 1978. Adaptive environmental assessment and management. John Wiley, London, United Kingdom.

Lancia, R. A., et al. 1996. ARM! For the future: adaptive resource management in the wildlife profession. Wildlife Society Bulletin 24:436-442.

McLain, R. J., and R. G. Lee. 1996. Adaptive management: promises and pitfalls. Environmental Management 20:437-448.

Noss, R. F., and A. Y. Cooperrider. 1995. Saving nature's legacy: protecting and restoring biodiversity. Island Press (see chapter 9 on monitoring).

Van Winkle, W. et al. 1997. Uncertainty and instream flow standards: perspectives based on hydropower research and assessment. Fisheries 22:21-22.

Examples of population management.

CDOW big game management. Primary objective is to maintain the population at a specified size agreed upon by CDOW, habitat agencies (USFS, BLM) and locals. A secondary objective is to maximize hunter recreation (that has the hidden objective of maximizing revenue). Some DAU's (Data Analysis Units) are specified licenses, meaning that only a limited number of hunters are given licenses to hunt in these units. This is an attempt to maximize quality of recreation. The remainder of the units are unlimited, i.e., anyone can purchase a license and hunt. CDOW can assume that most of the male segment of the herd will be harvested with these over-the-counter licenses. Only a limited number of licenses for harvest of females are provided, with the objective of holding the population at the herd objective.

Data collected:

- December age and sex ratios, providing reproduction rates and the number of males left after harvest.
- January quadrat counts, providing population size. Both of the above are conducted via helicopter.
- Harvest estimates, conducted by phone (over the counter licenses) and mail (limited licenses).

In March, these data are used in the POPII model to determine the harvest needed in the upcoming season. Major weaknesses of the POPII model are that it lacks density dependence (because so little is known to specify a reasonable function). Environmental stochasticity is specified as the "guessed" survival rates to obtain alignment on observed data. Various harvest levels for the upcoming season are tried to maintain the population at the herd objective for the coming year.

One of the concerns with game harvest, particularly the selective harvest of ungulates with large antlers, is the impact on the genetics of the population from continued selection. Ratner and Lande (2001) found with a model that selective harvesting based on size can produce evolutionary changes in equilibrium mean size and abundance. This should come as no surprise, as strong selective pressure is going to cause a change in the population. Harris et al. (2002) discuss four potential effects from sport hunting: 1) it may alter the rate of gene flow among neighboring demes, 2) it may alter the rate of genetic drift through its effect on genetically effective population size, 3) it may decrease fitness by deliberately culling individuals with traits deemed undesirable by hunters or managers, and 4) it may inadvertently decrease fitness by selectively removing individuals with traits desired by hunters. Studies specifically investigating these issues have been rare, but undesirable genetic consequences from hunting have been documented in only a few cases.

North American Waterfowl populations. Anderson

1. Funding:
    - Duck Stamp Program
    - Federal Aid Program
2. Surveys:
    - Breeding Ground Conditions -- 1955
    - Breeding Population Size -- 1955
    - Harvest Estimates -- 1954
    - Age & Sex Ratio Estimates -- 1961
    - Size of Wintering Populations -- 1950
    - Special Surveys
3. Models -- critical since about 1969
    - Production Models
    - Pond Models
    - Population Models (non-logistic)
4. Decision Making
    - National and Flyway Waterfowl Councils
    - NGOs (Audubon, DU)
    - USDI and FWS Committees
    - US and CWS and States and Provinces
5. “Optimal Management” A new initiative
    - Additional Modeling

Alternative Objectives
Stochastic Dynamic Programming

Conclusions about population management. Need good experimental manipulations to achieve models with the quality to be useful in managing populations (Nichols 1991):

Abstract: This essay deals with the relevance of some of the ideas of Romesburg (1981) to population ecology and management of the American black duck (*Anas rubripes*). Most investigations dealing with the effects of hunting regulations on black duck populations have used the hypothetico-deductive (H-D) approach of specifying a priori hypotheses and associated deduced predictions. These investigations have not used manipulative experimentation, however, but have involved severely constrained analyses of historical data and have thus produced weak inferences. The 1982 lawsuit over black duck hunting regulations, the current uncertainty about appropriate black duck management actions, and the frequent skirmishes in the published literature of black duck population ecology are natural consequences of these weak inferences. I suggest that we attempt to take advantage of management and other manipulations by treating them as an opportunity to learn something via experimentation, as recommended by Macnab (1983) and Walters (1986).

Sinclair (1991):

Abstract: This essay explains the need for wildlife management as scientific experiments to achieve reliable knowledge (Romesburg 1981) and emphasizes that science and management are not alternative processes. I explain the rationale behind the scientific method, the construction of hypotheses and their predictions, and how to test them with manipulations available through the management of wildlife. The scale of wildlife management programs makes them suitable for scientific experimentation (Macnab 1983). Problems such as population regulation and predator-prey interactions are used to show that theory is needed to develop proper predictions.

Reasons for the failure of simple MSY harvesting strategies. The MSY harvesting strategy assumes that managers know K, the current population size (N) and can therefore harvest exactly the number of animals to maintain the population at MSY. However, populations are not deterministic, so populations do not grow exactly the same each year, i.e., the process variance is not zero. Further, managers are usually not able to know the critical parameters of the population, i.e., r and K, and are not able to know N each year, but only get an estimate, $\hat{N}$. As a result, following a MSY harvest strategy may lead to unsustainable harvest levels.

Aanes et al. (2002) evaluated alternative harvest strategies for a willow ptarmigan (*Lagopus lagopus*) population on a private estate in Sweden. They fit a theta-logistic model to 32 years of data:

$$\log(N_{t+1}) = \log(N_t - H_t) + \frac{r}{1 - K^{-\theta}}\left[1 - \left(\frac{N_t - H_t}{K}\right)^{\theta}\right],$$

where r is the rate of increase when there is 1bird is in the population and K is carrying capacity. They considered 5 harvest strategies: 1) constant harvesting, where a fixed number of birds were removed each year, i.e., H_t constant; 2) proportional harvesting, where a constant fraction of birds were removed each year, i.e., $H_t = c\hat{N}_t$; 3) restricted proportional harvesting where an upper limit is introduced on proportional harvesting; 4) threshold harvesting, where the estimated number of birds greater than a threshold population is harvested; and 5) proportional threshold harvesting, where only a fixed proportion of the birds above the threshold are harvested, i.e., harvesting only a fixed proportion of the difference between the estimated population size and the threshold when this difference is positive. Restricted proportional harvesting gave slightly higher mean annual yields than proportional threshold harvesting. However, variance in annual yield was reduced by restricted proportional harvesting because periods with low population size became shorter. Uncertainties in population parameters did not affect which strategy was optimal although those uncertainties strongly influenced the expected yield and the uncertainties in the hunting statistics (Aanes et al. 2002). Of course, this last conclusion will be a function of the variance of the population estimates, and so is somewhat specific to this study.

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