Lecture 8: Population dynamics

I. Introduction

A. Objectives

1. Introduce basic determinants of population dynamics
2. Review basic concepts of population models
3. Illustrate how population models are used in management contexts

B. Background and definitions

1. Population = individuals of a single species interacting and sharing the same space and gene pool

   a. key attributes -- abundance, age structure, genetic composition
   -- all commonly represented mathematically

   b. spatial boundaries often poorly understood for fishes

2. Why study population ecology?
   - Understand patterns of distribution / abundance
   - Understand adaptations in ecological context
   - Develop management tools

3. Population dynamics (how and why populations change)
   a. rates of change (increase or decrease)
   b. magnitudes of change (fluctuations in numbers of individuals)
   c. relationships of these to environmental factors

II. Rates affecting populations

- some analogous to rates affecting individuals (eg, growth rate)
- some <u>not</u> analogous … individuals (eg, death rate)
- population size (no. of indiv's) is basic attribute of a population

A. Equation for predicting population size (N) at some future time (t):

$$N_t = N_0 + \text{Recruits (or births)} - \text{Deaths} + \underbrace{\text{Immigrants} - \text{Emigrants}}_{\text{for now, assume cancel each other}}$$

Assume non-overlapping gen's

B. Mortality (M) – number of deaths over an interval of time (eg, 1 year)
Predation, disease, starvation, extreme conditions, etc.

1 − M = survival rate (more commonly used in models)

overhead

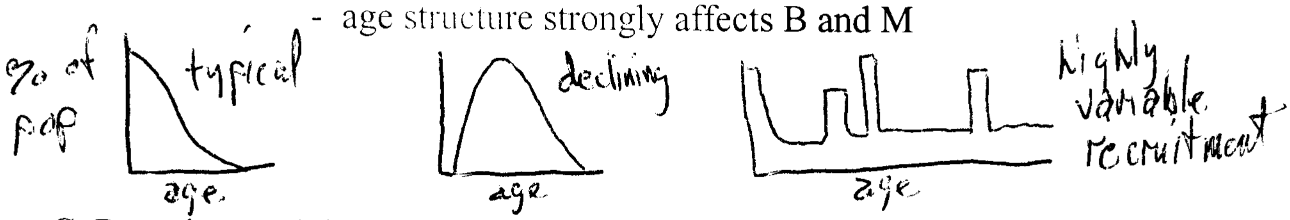
1. Survivorship curves -- plots of probability of surviving to a given age

   a. general patterns: Type I, some mammals; Type II, some birds; Type III, most fishes; reflect parental care

   b. Type III curve -- high fecundity, mortality high at first then drops

2. Estimating mortality rate
   a. age- / -size specific (nearly all fishes)
   b. follow a cohort of individuals through time (eg, mark-recapture)

   c. plots of age structure (proportional distribution of age classes
      - plots provide rough picture of variation in mortality
      - age structure strongly affects B and M



C. Recruitment (R) – rate at which new fish are added to the adult population in an interval of time; f(birth, survival)

1. In fisheries, focus on harvest size, age (e.g. mesh size of nets)

2. Related terms: year-class strength (number surviving to a given year)
   cohort (collectively, the individuals born in a given period) (year)

3. Environmental determinants
   fecundity, number of females, spawning success predation, harvest
   sensitivity to environ. fluct's (eg, severe flood, change in temp.)

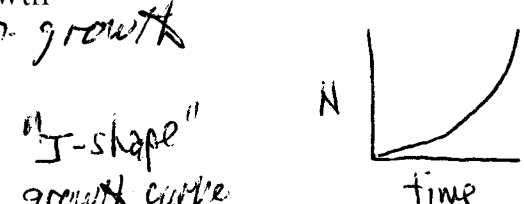
III. Models of regulation of animal abundance $N_t = f(N_c, R, M)$
many variations in model representations

A. For now, assume $\Delta N/\Delta t = R - M$
assume $I = E$

$\Delta N/\Delta t \rightarrow$ rate for discrete interval (yr1 vs yr2)
$dN/dt \rightarrow$ instantaneous rate (slope on growth curve)

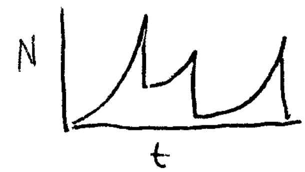
"All models are wrong, but some are useful"
use models to answer questions when "all else is equal"

B. Density-independent (exponential) growth
simplest model of pop growth



1. Density-independent factors -- mostly abiotic
   floods, droughts, temperature flux, anoxia

2. Exponential model of population increase
   - population increases rapidly but may be periodically decimated (J-shaped curves)



a. $\Delta N/\Delta t = (R_t - M_t)N$ or $\Delta N/\Delta t = \lambda N$ or $N_{t+1} = \lambda N_t$
   λ = finite rate of increase (over specified time-step)

   $dN/dt = (R_I - M_I)N$ or $dN/dt = rN$ or $N_t = N_0 e^{rt}$
   r = instantaneous rate of increase
   r_{max} = intrinsic rate of increase (under stable age distribution)
   $\lambda = e^r$ if r = 0, λ = 1 (no change in pop'n)

   choice of discrete vs continuous representations of pop'n growth affects mathem. tractability/tools but not interpret. of model results

2 overheads (range of r)

b. instantaneous rate of increase (r) and population growth rate (λ)
   - useful indices of population's capacity to grow
   - strongly affected by female fecundity, age at maturity, population age structure, environmental effects on R, M

overhead

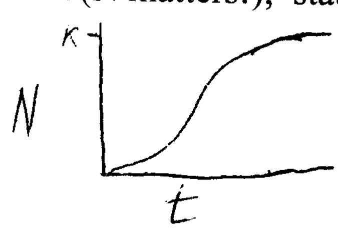
c. life tables
   - statistical device to summarize R, M across age classes (most fishes have age-structured populations)
   - comprise the nuts and bolts of population models
   - use to calculate λ, r, generation time (G), other pop'n param's
   - G = ave. age of parents of all offspring from a single cohort

sometimes "T"

   l(x) = prop. of original cohort surviving to age x (cant ↑ with age)
   = prob. of indiv. surviving to age x (cumulative, not age-specif.)
   m(x) = ave. no. of offspring born in a time period to a ♀ of a given age

3. r-selected species
   - hi fecundity, mortality; early maturing; eg, boom/bust cycles of herrings

C. Density-dependent (logistic) growth
   - models add negative feedback term (N matters!); stabilizes growth rate
   - S-shaped growth curves



1. Density-dependent factors -- mostly biotic
   - ability to find mates, competition for resources, predation, disease
   - may interact with abiotic factors (refuge from flood, DO in iced lake)

2. Basic logistic model of population increase
   - initial rapid growth, then decreases near asymptote
   - other equations can also describe such sigmoidal growth

   a. $dN/dt = r\,N \underbrace{(1 - N/K)}$ or $dN/dt = r\,N \underbrace{(K - N)/K}$

   neg. feedback term

   - growth rate determined by proximity to K (stabilizing influence)
   - if N<K, N ↑ (+ growth); if N>K, N ↓ (- growth)

   b. carrying capacity, K
   - mathematically: birth rate = death rate
   - biologically: no. of individ's environ. can sustain
   - determined by limiting factors collectively (abiotic and biotic)
   - relatively constant value of N can be used as mgmt benchmark

   overhead

3. K-selected species
   - lo fecundity, mortality; late maturing; eg, sharks, cavefishes

D. Other factors that could be incorporated into models (so far, very simplistic)
1. Competition with other species
   may ↑ as N ↑
2. Predation
   may ↑ as N ↑
3. Emigration and immigration
   E may ↑ as N ↑ I may ↓ as N ↑
4. Environmental variability
   - R and M vary both randomly and predictable
   - representing envir. variation in models → population fluctuation

E. The realism vs tractability tradeoff
   - mathem. difficult to incorporate many factors into 1 model
   - highly realistic (specific) model wouldn't be generally applicable
   - the most useful models focus on a few key variables, param's

IV. Applications (to fisheries mgmt and species conservation)

A. Stock-recruitment models

stock = adult spawners   recruits = newly-catchable individuals

1. General form

overhead (S-R curve)

- derived from logistic-type model (negative feedback to N)
- sharp dip at lo stock density (impaired mating)
- gradual dip at hi stock density (limited resources)
- yield (harvestable recruits) = dN/dt

overhead (Ricker curve)

2. Usefulness in predicting future stock / setting fishing quotas
- monitor status of stock, predict production of recruits
- Ricker curves often used to set limits on fishery

overhead (growth vs N)

3. Usefulness in estimating maximum yield
- want maximum pop'n growth rate (minimum wait until harvest) AND maintain constant stock size for future production
- yield (dN/dt) / stock (N) is maximal (MSY) at logistic inflection (K/2)

B. Population viability analysis

1. Predict future population size or determine viability, persistence
- often applied to rare, imperiled species
- based on survival, reproduction rates (life tables)

2. Organize and recognize gaps in data
- based on attempts to complete life table

overhead (tables)

3. Determine rates with most influence on population growth
- estimates often based on expert guesses (reasonable ranges)
- use sensitivity analyses to identify which rates to "manage"
- elasticity = sensitivity to small Δs in other parameter values, as they affect the parameter of interest (eg, λ)

C. Limitations
- all model param's based on past observations – may not apply to future
- mathematically difficult to incorporate realistic environ. variability