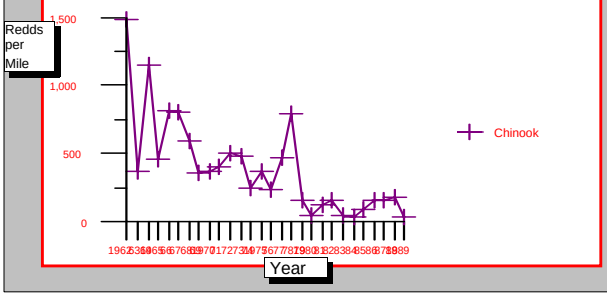
Stochastic Population Growth

Stochastic Population Growth: Spring Chinook – Lemhi River: Spawners Counted



Stochastic Population Growth

- Dennis, Munholland, Scott (1991)
- Stable but variable mean rate of change
- Constant long term trend

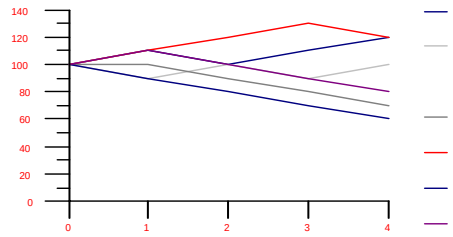
Trend

- Let $r_i = \ln (N_i / N_{i-1})$
- $\tau_i = t_i - t_{i-1}$
- Trend = Mean (change / time)
- Estimate of trend =[Mean r_i]
- $\mu = \Sigma r_i / \Sigma \tau_i = \ln (n_q / n_0) / t_q - t_0$
- $= \ln (838 / 39{,}012) / 27$
- $= - 0.1422$

Variance of rate of change

- $\sigma^2 = \Sigma\{(1/\tau_i)[r_i - \mu \tau_i]^2\} / \{q - 1\}$
- $= 0.645$

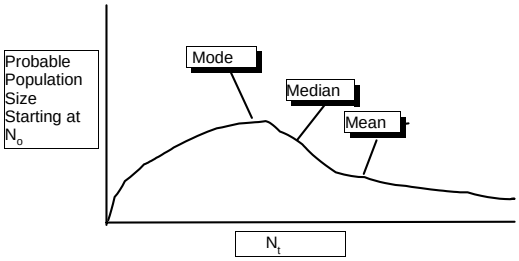
Predicting Future Population



Predicting Future Population

- We cannot predict exactly what the population size will be.
- But future population sizes are not all equally likely.
- We must describe them with a distribution.

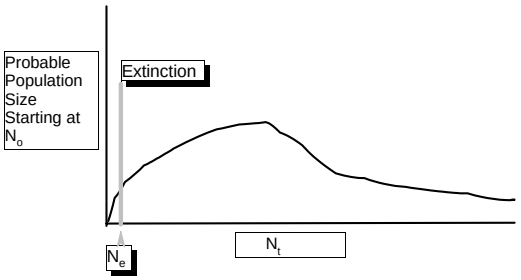
Predicting Future Population



Predicting Future Population

- Mean = $N_0 \exp(\mu + 0.5\,\sigma^2)t$
- Median = $N_0 e^{\mu t}$

Predicting Future Population



Probability of Extinction

- $p = \begin{cases} 1.0, & \text{for } \mu < 0.0 \\ \exp(-2\,\mu\, x_d / \sigma^2), & \text{for } \mu > 0.0 \end{cases}$
- where $x_d = \ln(N_q / N_e)$,
- N_e = Extinction Threshold
- $x_d = \ln(840/30)$

Time to extinction

- Conditional mean time to extinction =
- $T = x_d / |\mu|$
- = ln (840/30) / 0.142 = 23.4 yrs

Is there no hope?

- $p = \begin{cases} 1.0, & \text{for } \mu < 0.0 \\ \exp(-2\,\mu\, x_d / \sigma^2), & \text{for } \mu > 0.0 \end{cases}$
- what if we used water first for fish and ocean conditions cooperated so that trend was flat (μ=0.001)
- then $p_{extinction} = 0.99$
- for μ=0.03 $p_{extinction} = 0.75$
- for μ=0.10 $p_{extinction} = 0.0002$

Estimation

- You can calculate the values for this model of stochastic population growth on a calculator by calculating the natural log of lambda at each time period and the interval between surveys. Or you can use a program by Oz Garton called STOCHMVP.
- STOCHMVP will calculate the probability of persistence for a metapopulation consisting of a specified number of identical populations too.
- Or you can simulate the population using a program such as RAMAS Metapopw.exe

Will these predictions be correct?

- Assumptions:
- Long-term trend continues (constant μ)
- Variance around that trend is normally distributed.
- No density-dependence

Minimum Viable Population

- Definition: "A minimum viable population for any given species in any given habitat is the smallest isolated population having a 99% chance of remaining extant for 1000 years despite the forseeable effects of demographic, environmental and genetic stochasticity and natural catastrophes." (Shaffer 1981)

Genetic Stochasticity

- Deleterious genetic effects of very small numbers of breeders
- Inbreeding depression, founder effect
- Loss of heterogeneity leads to accumulation of lethal genes & effects
- N_e - Effective population size used to calculate this

Demographic Stochasticity

- Random effects of small numbers of individuals in the population.
- Example: 10 animals with 50% survival
- On average 5 will be alive next year
- but with only 10 individuals its like flipping a coin.
- Could be 6 or 4, or 7 or 3, or even 10 or 0 next year.

Environmental Stochasticity

- Random changes in birth and death rates produce random fluctuations in r_t or λ_t
- Random fluctuations in physical factors such as weather (particularly temperatures and rainfall/snow at key seasons)
- Other "random" impacts on b and d due to parasites, predators, disease,...

Natural Catastrophes

- Extreme cases of environmental stochasticity (excessively high mortality)
- Examples:
  - Puerto Rican Parrot populations were decimated by Hurrican Hugo a decade ago
  - Black-footed Ferret almost wiped out by parvovirus

Estimating MVP

- Dennis et al (1991) showed that Probability of reaching extinction threshold (N_e) within time t is equal to probability of reaching threshold times conditional probability of reaching it within time t:
- = Prob($N<N_e$) Prob($T<t|N<N_e$)
- = p cdf (cumulative distribution function of cond. time to extinction)

Persistence and MVP

- Probability of persistence to time t
- = 1 - p cdf
- Calculate the Minimum Viable Population size by finding the population size which produces the desired probability of persistence using STOCHMVP.

Results for Lemhi Spring Chinook

- Using Shaffer's original definition of a minimum viable population as one which provides a 99% chance of persistence for 1000 years and assuming persistence means staying above 30 spawners,
- then if the population were stabilized ($\mu = 0.0001$)
- MVP = 2.4×10^{23}

Results for Endangered Species

Species	MVP
Yellowstone Grizzly Bear	3800
Palila	6.1×10^{14}
Laysan Finch	3.4×10^{18}
Whooping Crane	20,800
Kirtland's Warbler	34,150
California Condor	2.9×10^{10}
Puerto Rican Parrot	14,600

What's wrong?

- These are impossible.
- Species may never have been this abundant.
- But these species probably existed as a series of populations constituting one or more metapopulations.

Minimum Viable Metapopulation

- Assuming completely independent populations in terms of environmental stochasticity:
- For s populations the probability of at least one population persisting
- = 1 - (p cdf)^s

Spring Chinook Minimum Viable Metapopulation

- Under a less stringent goal of 95% probability of persistence for 100 yrs
- MVMetaP Number of Populations
- 59,400,000 2
- 499,000 3
- 40,700 4
- 9,500 5
- 3,670 10
- 426

Complications: Independence of Populations

- Palila: There are 2 subpopulations for this species and there is no correlation between populations in these 2 areas (r=0.035, n=15, P=.902)
- Spring Chinook on Salmon River: Lemhi and South Fork are the 2 largest subpopulations and their rates of change are moderately correlated (r=0.480, n=27, P=0.011)

Complications

- Normal Distribution of x's (r_t's)
- Density Dependence
  - Increased birth rate or lowered death rate at low population sizes (Ricker type model) increases probability of persistence
  - Allee effects (the opposite of above) decreases probablity of persistence
- Spawners are only one age-class
  - Holmes et al 2001 showed 5-year running sum is a better index to total population size.

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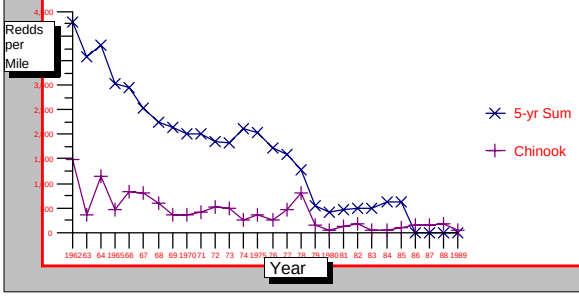

Spring Chinook Minimum Viable Metapopulation

- Applying Holmes (2001) approach applied to 5-yr moving-sums:
- σ^2=0.044
- Under our less stringent goal of 95% probability of persistence for 100 yrs:
- Number of Populations MVMetaP
- 1 1330
- 2 379
- 3 197
- 5 105