Incorporating Temporal Variation into a Population Model

1. Decide which model to use (discrete, den independent, etc.)
2. Decide which parameters to model as a random variable (b,d vs. R,\(\lambda\))
3. **Decide which distribution to use**
4. Incorporate RV(s) into population model
5. Run pop model for time period of interest
6. Calculate proportion of times population meets some criteria

Incorporating Stochasticity into Density-Independent Models

Temporal, Demographic, and Individual

![Image of lynx in snow]
Stochasticity, Heterogeneity, and Variation

Variation (math)
• Marked difference or deviation from the normal or recognized form, function, or structure.

Stochastic (stat)
• Involving or containing a random variable(s): stochastic calculus.
• Involving chance or probability: a stochastic stimulation.
• Of, relating to, or characterized by conjecture; conjectural.

Heterogeneous
• Consisting of dissimilar elements or parts; not homogeneous.
• Completely different; incongruous.

Stochasticity, Heterogeneity, and Variation

Variation – spatial, temporal, individual, demographic, sampling

Stochasticity – including variation in a model, usually done as a stochastic process
**So What’s a Deterministic Model?**

**Deterministic** – The philosophical doctrine that every state of affairs, including every human event, act, and decision is the inevitable consequence of antecedent states of affairs.

**Deterministic model** – the outcome (at any time step) is determined solely by the inputs; nothing is left to chance. In deterministic models, vial rates (b, d, i, e) or R, $\lambda$ are constant.

\[
N(t+1) = N(t) * (1+R) \Rightarrow N(t) = N(0) * (1+R)^t
\]
Types of Stochasticity

**Sampling Variation** – results from our inability to measure the population without error (we observe $\hat{N}$ and not $N$).

**Process Variation** - Variation through time and space of the true population size. Variation in the true population size is termed process variation, because of stochasticity in the population growth process.

---

**Sampling Variation**

1. Sampling variation is confounded with demographic variation
2. We do not include sampling variation in population models
3. Measure - spatial, temporal, and individual variation, plus demographic + sampling variation sum

Why is there this measuring problem???
Types of Stochasticity

Sampling Variation – results from our inability to measure the population without error (we observe $\hat{N}$, and not $N$).

Process Variation - Variation through time and space of the true population size. Variation in the true population size is termed process variation, because of stochasticity in the population growth process.

### Process Variation

1. Temporal variation (environmental)
2. Spatial (environmental)
3. Demographic (Bernoulli / binomial)
4. Individual heterogeneity (phenotypic & genotypic)
Temporal Variation

Annual variation
such as typical annual differences in weather

Catastrophes
such as severe storms or fire

How important is temporal variation?
Modeling Temporal Heterogeneity

- If possible, take advantage of historical data to find extremes
- Model vial rates (b, d, i, e) or R, λ as random variables
- Normal or beta distribution commonly used

Demographic Variation

- Internal rather than external
- Chance variation in actual fates of different individuals within a period
- Like randomness in coin flip
- “Fixed”
- Can not separate from sampling variation
Small populations can go extinct due to demographic variation alone – but the population has to be REALLY SMALL.

The cut-off below which you must really worry about the effects of demographic stochasticity is often estimated as ~20 individuals per class or ~100 individuals total (Morris and Doak 2002).
Modeling Demographic Heterogeneity

• **Continuous Models**
  – Time to next birth or death modeled as Poisson process

• **Discrete Models (Annual)**
  – **Individual based**
    • whether individual gives birth or dies modeled as Bernoulli process
  – **Population based**
    • number born (added to population) modeled as binomial process
    • number die (subtracted from population) modeled as binomial process

---

**Individual Variation**

• Lifelong, phenotypic and genotypic
How important is individual variation?

![Graph showing persistence (%) vs individual SD with different N0 values]

### Modeling Individual Heterogeneity

- Based on individual survival and fecundity
- Including in a model via a covariate?
Required for Population Model

1. DATA!
2. Population model (Discrete? Density Independent?)
3. Include temporal variation
4. Include spatial variation
5. Include individual variation
6. Include demographic variation