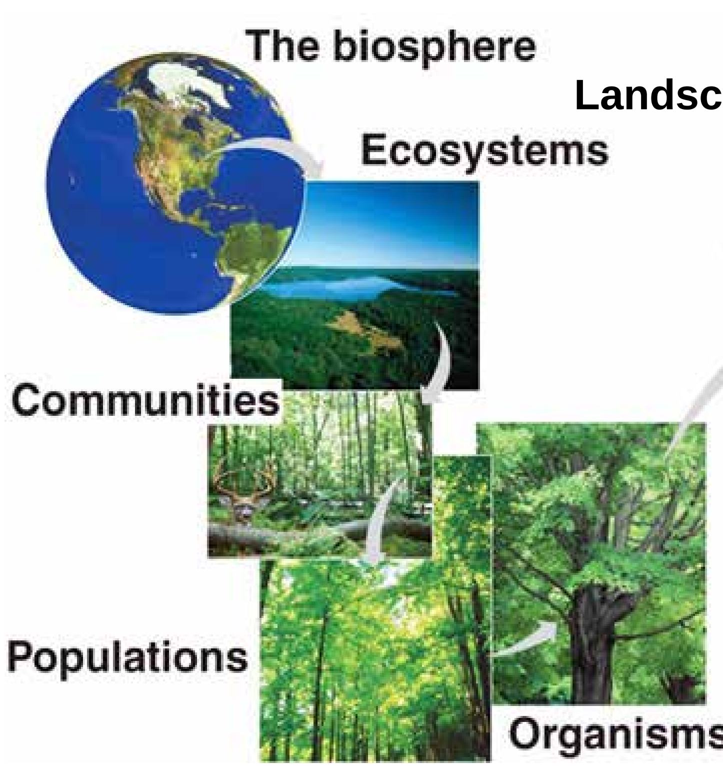
Population Biology in a Restoration Context

- Objectives:
  - How can population biology ↔ restoration ecology ↔ ecological restoration?
    - Population characteristics
    - Population viability analysis (Ch. 4)
    - Metapopulation analysis (Ch. 4)
    - Populations & ecological genetics (Ch. 2)

Population Biology in a Restoration Context

- Ecological Hierarchy



Landscapes

(Individuals)

Population Biology in a Restoration Context

- Populations & Population Ecology
  - Group of potentially interbreeding & interacting individuals of the same species living in the same place & time
  - Study of the abundance, distribution, & dynamics of a group of individuals of the same species living in the same place & time

Acacia koa **population**

Population Biology in a Restoration Context

- Populations
  - Most organisms exist for most/all of their lives as members of a population
  - 3 “laws” of population ecology (Rockwood 2006)
    - Populations tend to grow exponentially
    - Populations show self limitations
    - Consumer-resource interactions tend to be oscillatory
  - There are both advantages and disadvantages to being a member of a larger population

Population Biology in a Restoration Context

- Populations – Advantages
  - Protection
    - Wind and temperature extremes
  - Reproduction
    - Critical lower population size and density
  - Genetic diversity
    - Aggregation promotes genetic variation
      - Improves probability of survival w/ changing environment
  - Intraspecific competition
    - Natural selection for high fitness

Population Biology in a Restoration Context

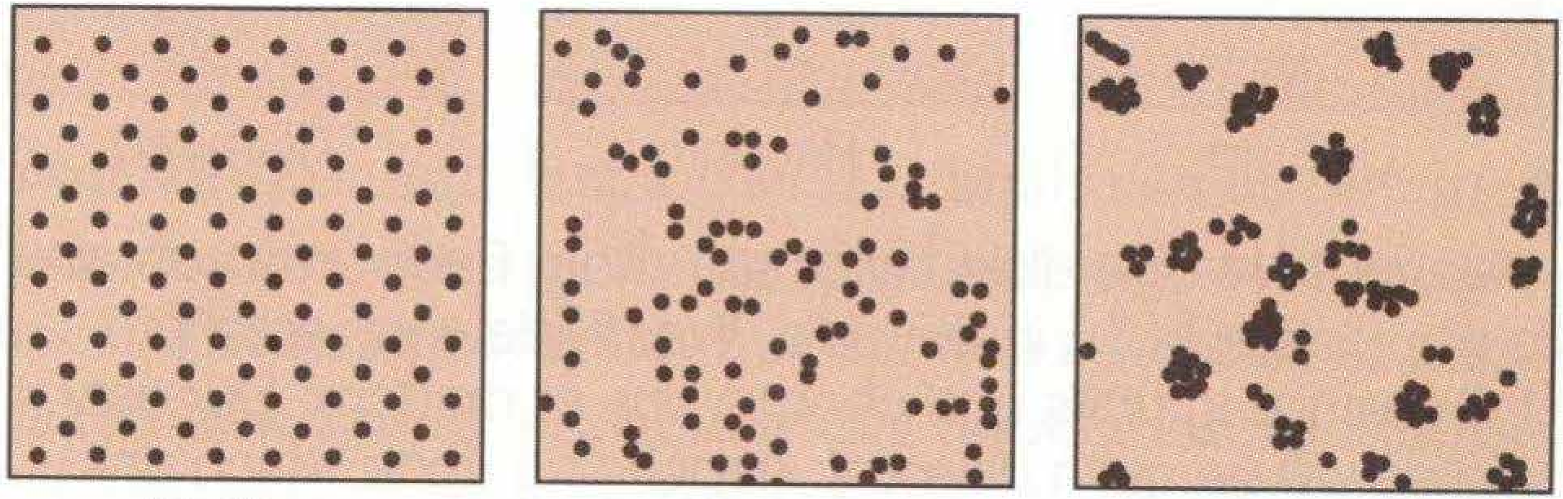
- Populations – Disadvantages
  - Intraspecific competition
    - Specialized to compete for same resources in space and time
  - Alteration of physical environment
    - Resource limitation
  - Stress
    - Physical proximity
  - Disease transmission
  - Physical interference

Population Biology in a Restoration Context

- Population characteristics
  - Density and distribution patterns
  - Age/size class structure
  - Growth rates
    - Determined by birth (natality), mortality, immigration, and emigration
  - Reproduction: transfers genetic characteristics from one generation to the next (→ fitness)
  - Intra- and inter-population interactions (→ Community Ecology)

Population Biology in a Restoration Context

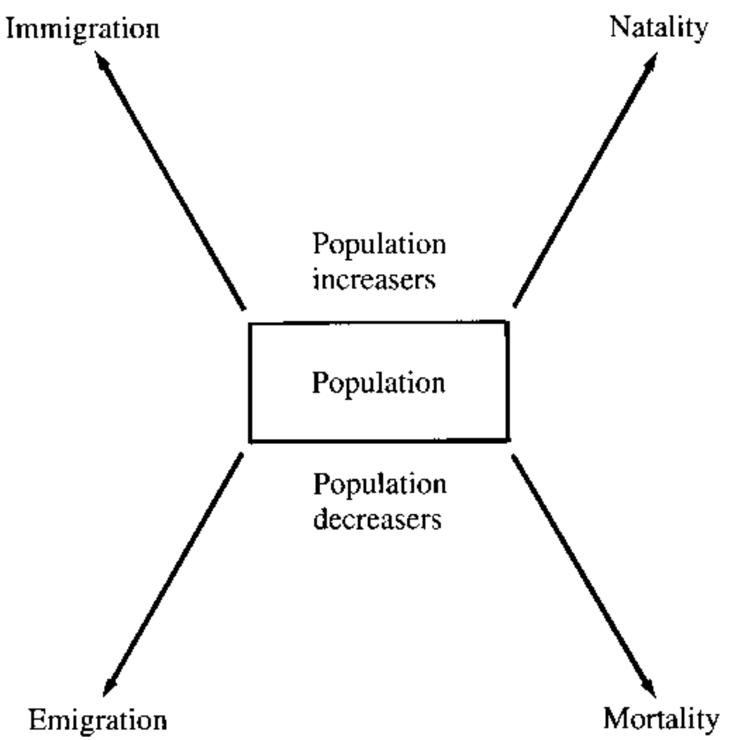
- Population Density & Distribution



Uniform Random Clumped

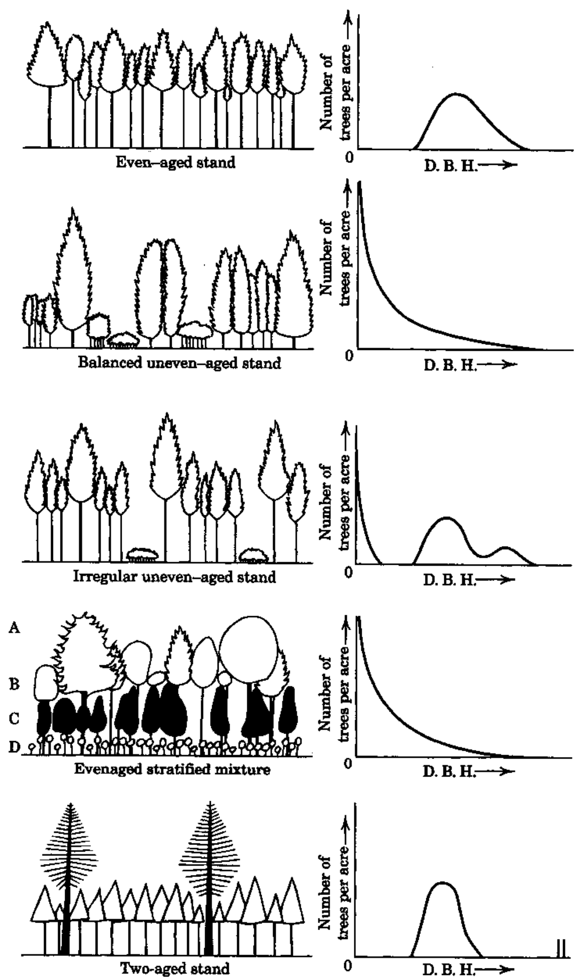
Population Biology in a Restoration Context

- Population Size



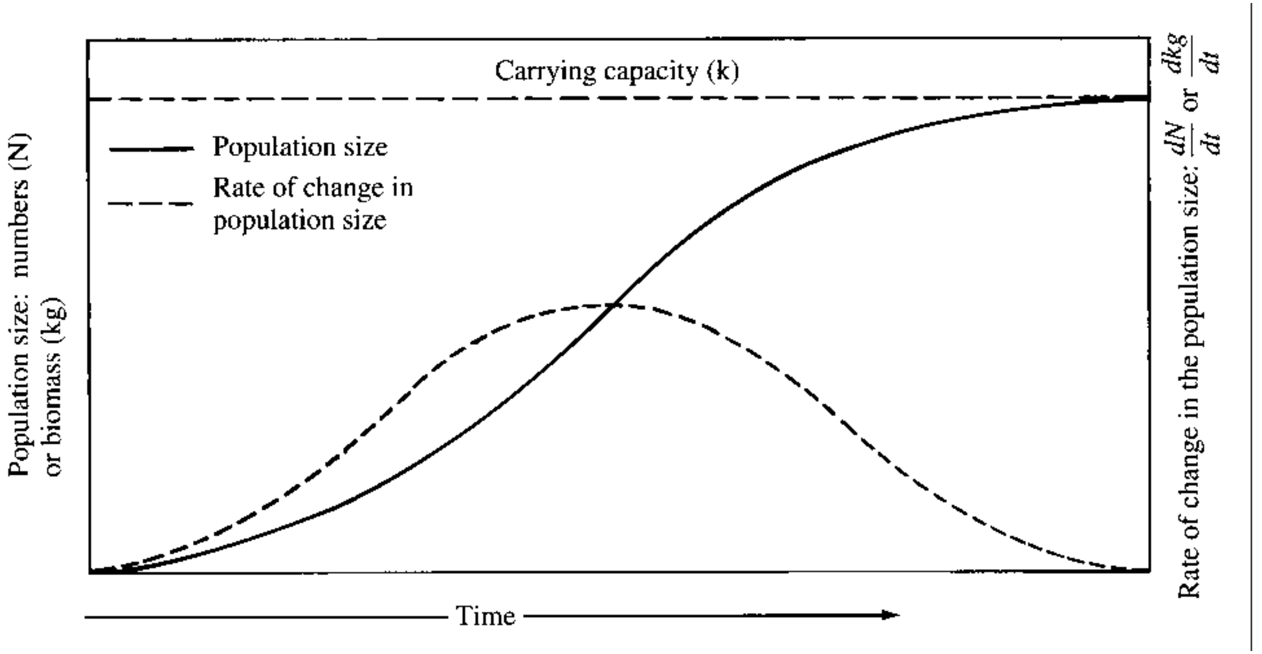
Population Biology in a Restoration Context

- Population Age/Size Structure



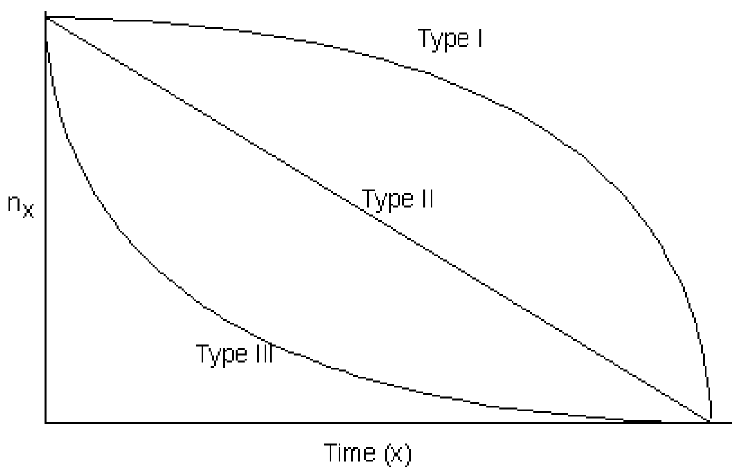
Population Biology in a Restoration Context

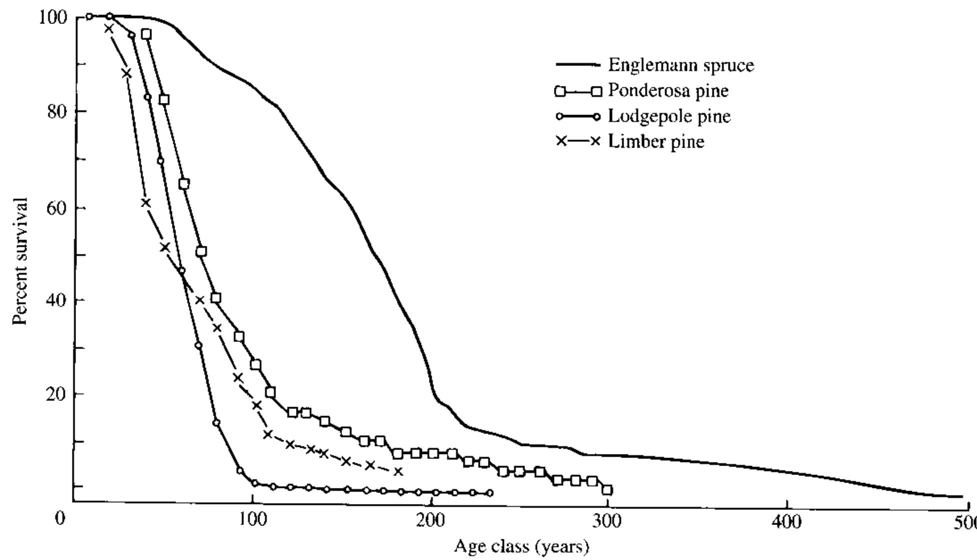
- Population Growth Rates



Population Biology in a Restoration Context

- Population Mortality





Population Biology in a Restoration Context

- Populations are complex, dynamic, & variable
  - Spatial and temporal variability
  - Environmental variability
  - Genetic variability
  - Demographic variability
    - Size, structure, and distribution
  - Interactions between all of the above = **POPULATIONS ARE IN CONSTANT FLUX**
  - Most critical factor for restoring most populations is the removal of the key factor(s) that caused the original decline in the population

Population Biology in a Restoration Context

- Population models
  - Boring (?), but important…
  - Important for conservation & restoration management
    - Help plan restoration projects
    - Document compliance/success of restoration projects
  - Lots of inherent assumptions in population models → Is their widespread application appropriate?
    - Better than nothing
  - Two main types of population models:
    - Population viability models
    - Metapopulation models

Population Biology in a Restoration Context

- Population models
  - p. 43 of 339 pp. in "*Introduction to Population Ecology*"

$$dN/dt(1/N) = r\left(1 - \frac{N}{K}\right) = r\left(\frac{K-N}{K}\right)$$

Multiplying both sides of the equation by N reveals the usual form of the logistic.

$$dN/dt = rN\left(\frac{K-N}{K}\right) \qquad (2.8)$$

Although the logistic is in the form of a differential equation, it is fairly easy to understand how it affects population growth. Again, it is useful to examine what the equation does to the growth rate, r. As above, we will distinguish between r_a, the actual growth rate as modified by carrying capacity, and r_m, the density-independent growth rate. r_m has also been called r-max or the Malthusian parameter. r-max represents the maximal growth rate of a genotype as it interacts with the environment without competition.

$$r_a = r_m\left(\frac{K-N}{K}\right) \qquad (2.9)$$

When the population is very small, $N \approx 0$, and $\left(\frac{K-N}{K}\right) \approx 1$. Therefore, $r_a \approx r_m$.

When $N = 0.5K$, then the expression $\left(\frac{K-N}{K}\right) = 0.5$, and $r_a = (0.5)r_m$.

When $N = K$, the expression $\left(\frac{K-N}{K}\right) = 0$ and $r_a = 0$.

Finally, when $N > K$, the expression $\left(\frac{K-N}{K}\right) < 0$. Therefore r_a is negative and the population drops back toward K.

The differential form of the logistic equation can be integrated and solved, resulting in the following:

$$N_t = \frac{K}{1 + e^{a-rt}} \qquad (2.10a)$$

where a is a constant of integration.

Dividing both sides of the equation by K yields:

$$\frac{N_t}{K} = \frac{1}{1 + e^{a-rt}}$$

Taking the inverse:

$$\frac{K}{N_t} = 1 + e^{a-rt}$$

Population Biology in a Restoration Context

- Population Viability Analysis (PVA)
  - Used to understand and predict the persistence of populations over time
  - Require long-term data sets and in-depth understanding of a particular species' biology
    - Dormancy, seed bank, survival rates, reproductive rates, age of reproductive maturity, dispersal mechanisms, impacts of stochastic events, mortality rates, etc.
  - Restoration questions that can be addressed:
    - What size site is needed for a founding population?
    - What type of propagule should be used?
    - Is the restored population sustainable over the long term?
    - How many individuals are needed to start a sustainable pop.?

Population Biology in a Restoration Context

- Population Viability Analysis (PVA)
  - Minimum Viable Population (MVP)
    - What is the minimum size needed to restore a sustainable population with an acceptable probability of persistence?
    - Obviously will depend on species and site
      - Reproductive characteristics
      - Mobility
      - Proximity to other populations (metapopulations)
      - Environmental constraints, site degradation, etc.
    - Need a lot of individuals for a population to persist
      - *Cirsium pitcheri*: >400 adult transplants or >1,600 seedlings or >250,000 seeds to start a restored population with <5% risk of extinction over 100 years (Bell *et al*. 2003)

Population Biology in a Restoration Context

- Population Viability Analysis (PVA)
  - Minimum Viable Population (MVP)
  - Need a lot of individuals for a population to persist
    - 50-100 individuals from early deterministic models
    - 1,000-1,000,000 individuals from stochastic models
      - Incorporates demographic and/or environmental stochasticity
        - » Chance events typically dominate long-term outcomes

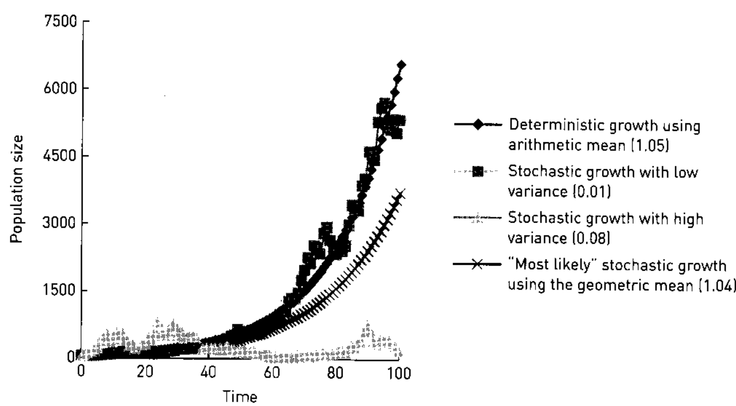


Figure 1.8 Deterministic versus stochastic growth with high and low variance. Initial population size = 50; $\lambda = 1.05$, except where noted.

(Rockwood 2006)

Population Biology in a Restoration Context

- Population Viability Analysis (PVA)
  - Minimum Viable Population (MVP)
    - Since population dynamics are largely dominated by stochastic events, models must take them into account
      1) Environmental
      2) Natural “catastrophes”
      3) Demographic
      4) Genetic
    - Smaller populations are much more susceptible to stochasticity than larger populations
    - *If restored populations are typically ≤1,000 individuals, does the restored population stand a chance in the long term???*

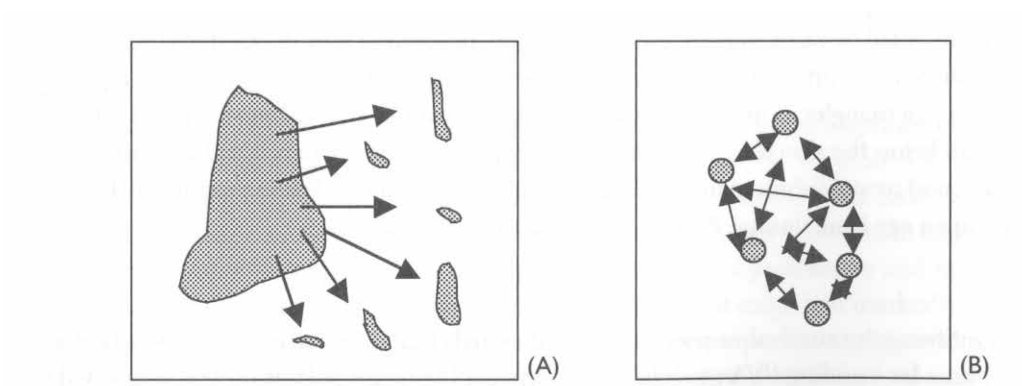
Population Biology in a Restoration Context

- Metapopulation Analysis
  - *A population consisting of many local populations*
    - “*regional assemblages of species, with long-term survival depending on a balance between local extinctions and recolonizations in a patchwork of fragmented landscapes*”
  - Local populations are influenced by immigration, emigration and extinction, <u>in addition to</u> local birth and mortality processes
  - Links population ecology (local abundance) with biogeography (regional occurrence)
    - Closely related to landscape ecology (spatial ecology)
  - Largely rooted in conservation biology applications
    - Widespread habitat fragmentation

Population Biology in a Restoration Context

- Metapopulation Analysis
  - Incorporates both temporal and spatial variability
  - Requires good information on dispersal and spatial patterns
  - For a given species, discreet patches of suitable habitat are surrounded by a matrix of unsuitable habitat

Mainland Island Model   Levin Model



*Most metapopulations lie somewhere in the middle

(Maschinski 2006)

Population Biology in a Restoration Context

- Metapopulation Analysis
  - Useful for developing restoration strategies that deal with intra-population processes
    - e.g., removing or adding local populations
  - Restoration questions that can be addressed:
    - What value do individual restored patches have for a species' overall persistence on the landscape?
    - What is the minimum viable metapopulation (MVM) size needed for long-term persistence of a species?
    - What is the minimum amount of suitable habitat (MASH) needed for long-term persistence of a species?
  - Metapopulation models suffer from the same data limitations as population viability models
    - Long-term data, data, and more data on species biology

Population Biology in a Restoration Context

- Metapopulation Analysis – Key principles

1. Probability of extinction decreases as average patch size increases, as the fraction of large patches increases, and as the total number of patches increases.
    - The largest patches have the lowest extinction risk, and they determine time to extinction of the metapopulation
2. Metapopulation persistence is only possible if recolonization > extinction.
3. As maximum reproductive rate increases in a patch, the probability of extinction decreases.
4. “Rescue effect”: decrease in extinction risk by increasing the number of immigrants that increase patch occupancy
5. “Establishment effect”: an increase in the proportion of suitable habitats occupied by a species increases colonization via dispersal and augmentation

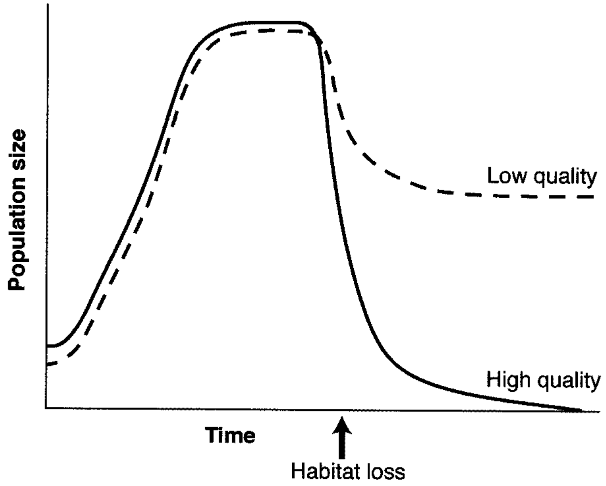
Population Biology in a Restoration Context

•Metapopulation Analysis – Key principles

6. Heavy emigration makes local populations smaller and more vulnerable to extinction.
7. The closer the patches, the higher the migration between patches and the greater the likelihood of recolonization of vacant patches.
8. Larger patches have a greater probability of contributing migrants to a metapopulation; therefore the genetic composition of the largest population greatly influences the metapopulation.
9. Patch arrangement and corridor quality influence metapopulation size:
   - Landscapes with lots of interior patches support a larger metapopulation than those with more peripheral patches.
   - An increase in the number of high quality corridors increases metapopulation size.

Population Biology in a Restoration Context

- Habitat source-sink dynamics
  - Quality of the habitat (habitat heterogeneity) and habitat-specific demographic rates
  - Lots of local populations in poor habitat vs. fewer populations in good habitat?
    - Higher quality/more productive source habitats sustain metapopulations over the long term



90% Removal

(Maschinski 2006)

Population Biology in a Restoration Context

- Population and ecological genetics
  - Genetic diversity within a population is critical:
    - provides the means to respond to environmental variability
    - is the base for adaptive evolution and biodiversity
    - influences interactions with physical environ. & other species
    - largely defines a species function within an ecosystem
      - body shape & size, physiological processes, behavioral traits, reproductive charac., environ. tolerance, dispersal & colonization, seasonal & annual cycles, disease resistance, etc.
    - ameliorates effects of inbreeding and founder effects
    - "*To overlook genetic variation is to ignore a fundamental force that shapes the ecology of living organisms*"
    - "*Genetic variation is often the invisible dimension of ecological restoration*"

Population Biology in a Restoration Context

- Population and ecological genetics
  - Genetic diversity is the primary basis for adaptation to environmental uncertainty (variability)
    - All environments change
      - short-term and evolutionary time scales
      - Historic range of variability (HRV) can be used to define the known range of environmental variation
    - Genetic diversity provides the means for populations to persist in space and time within a variable environment (fitness)
      - Broad range of genetic variation → persistence in variable environments
    - Restoration ecology is challenged by the need to:
      - Introduce sufficient diversity to allow adaptation to environmental change
      - Avoid introducing genotypes that are poorly adapted to the current or future environment of the restoration site

Population Biology in a Restoration Context

- Population and ecological genetics
  - Genetic diversity reduces potentially deleterious effects of inbreeding, founder effects, etc.
    - Impacts the survival and fitness of individuals
      - *Inbreeding:* mating among closely related individuals → homozygosity at key gene loci
      - *Inbreeding depression:* reduction in overall fit of organisms from inbreeding and low heterozygosity (vs. *outbreeding depression*)
      - *Genetic drift:* chance selection of genotypes that allow deleterious alleles to become fixed (or purged)
      - *Genetic rescue:* adding new genetic material to inbred populations
      - *Census population* (the number of individuals counted) vs. *Effective population size* (number of individuals that contribute genes to succeeding generations)
      - *Founder effect:* loss of genetic variation when a new colony is established by a small number of individuals

Population Biology in a Restoration Context

- Population and ecological genetics
  - Ecological genetics can inform restoration ecology by:
    - Identifying goals of restored populations
      - How similar is the source population to the population we wish to augment?
      - Should we combine material from multiple source populations?
      - How do we manage for genetic, demographic, and environmental stochasticity?
    - Selecting source populations
      - Can we substitute geographic or ecological distance for genetic distance?
      - Should we use regional mixtures and let nature sort it out?
    - Sampling the diversity of source populations
      - How many individuals should be sampled from each population?
      - How many pop. should be sampled to create the source pool?
      - What is the probability of a sample surviving to establishment?

Week 4 Readings/Lecture Slide Highlights

1. Populations are highly variable in space and time (i.e., populations are in a constant state of flux), and this variability should be explicitly considered at all stages of ecological restoration (e.g., choice of reference site, source of propagules for (re)introduction, metrics of success, etc.).

Week 4 Readings/Lecture Slide Highlights

2. Population models have the potential to inform many aspects of ecological restoration (how many individuals to reintroduce, from where to get source material, etc.), but require a tremendous amount of long-term data on the biology of a particular species that is not available for many (most?) species.

Week 4 Readings/Lecture Slide Highlights

3. When (re)introducing a population, genetic considerations (i.e., provenance and diversity) are critical parameters to consider. General guidelines are to use: (*i*) as local of a source population as possible, and (*ii*) with as high a genetic diversity as possible. However, the opposite will be true for some circumstances (e.g., in the case of augmenting an existing but very small and/or very locally adapted population).

Week 4 Readings/Lecture Slide Highlights

4. To create a self-sustaining population/metapopulation, a very large number of individuals/populations need to be established. Most ecological restoration projects fall far short of these recommended numbers.

Week 4 Readings/Lecture Slide Highlights

5. It is not enough to consider the restoration of a single population. Rather, the restoration of that single population should be done in the context of the larger metapopulation. This will include consideration of issues ranging from the size and spatial distribution of a single restored patch in relation to other patches/populations, to the potential need to restore multiple patches in a spatially appropriate manner to insure the long-term sustainability of the overall metapopulation.