Elements of restoration ecology
Conservation Biology Fall 2006
ECOL/GEOS 406R/506R

Don Falk
Laboratory of Tree-Ring Research
University of Arizona

Elements of talk

- Why restore?
- “Restoration ecology” *cf.* “Ecological Restoration”
- Restoring ecological composition, structure, functions and processes
- “Restoration” in a changing world
- Bringing people into the frame
- Your observations and questions
Why restore?

Degradation by human land use

Altered ecological processes

Major disturbance events

Others?

Definitions:

- **Ecological Restoration**: “The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.” — *SER International Primer on Ecological Restoration, Science & Policy Working Group, (Version 2, October, 2004)*

- **Restoration ecology**: 1. The study of relationships among organisms and the abiotic environment, in a context of ecological restoration. 2. The scientific study of patterns and mechanisms operating in ecological restoration.” — *Falk et al., 2006*
Goals of Ecological Restoration

- Restore ecosystems to conditions consistent with their evolutionary environments
- Connect sustainable human communities with sustainable wildlands
- Conserve wildlands for present and future generations

Covington, 2000

Ecological theory and restoration ecology

- Ecological restoration (practice) is grounded in vernacular, pragmatic knowledge
- Restoration ecology seeks to explain, not simply to perform
- Increasing links to ecological theory and allied disciplines
Some relevant areas of ecological theory:

- Ecophysiology and autecology
- Population and ecological genetics
- Population and metapopulation dynamics
- Community interactions, species interactions, assembly processes
- Food webs and trophic cascades
- Disturbance ecology
- Ecosystem processes, biogeochemical and energy cycling
- Climate change and paleoecology
- Allied disciplines (hydrology, soil science, biogeochemistry)

The three fundamental elements of restoration:

1. A defined reference condition.
2. A disrupted ecosystem.
3. A defined desire future condition.
Ecological composition (who is there?)

- Census of species and functional groups
- Traditional focus of ER

Photos R. Robichaux and US Forest Svc.

Interactions of ecological structure and composition

- **Composition**: Census and relative abundance of species and functional groups
- Traditional focus of ER
- **Structure**: 3-dimensional arrangement of compositional elements
- Also applied to temporal distribution (e.g. “age structure”)
Restoring ecological composition: Genetic diversity

Within-population genetic composition:

- $H_o$: Average observed heterozygosity
- $H_e$: Average expected heterozygosity
- $P$: Percentage of polymorphic loci
- $A$: Average alleles per locus

Among-population composition:

- $Q_{ST}$: Proportion of quantitative trait variance among populations
- $F_{ST}, G_{ST}$: Proportion of total molecular marker variation among populations, averaged over loci
- $K_{ST}$: Proportion of mean substitutions per nucleotide site within populations, averaged over sites

Genetic distance:

- Fraction of alleles and frequencies not shared among pair of populations

Genetic similarity:

- Fraction of alleles and their frequencies shared among a pair of populations

Restoring genetic structure depends on the existing distribution (if any) of genetic variation

Falk et al. 2006
Restoring population and metapopulation dynamics

*Argyroxiphium kauense* photos courtesy Rob Robichaux and the Silversword Alliance
Restoring metapopulation structure and dynamics

Maschinski, 2006
Extirpated, extant and potential reintroduction sites for *Jacquemontia reclinata* along the eastern coast of South Florida

Maschinski, 2006

**Restoring functioning ecological communities**
Restoring species interactions

- Pollination
- Dispersal
- Herbivory, predation
- Competition
- Trophic structure and dynamics
An example of restoring species interactions: pollination ecology

Pollen transport webs for four hay meadows. Pollen groups are rectangles at the top of each web, insects at the bottom. Interactions link the pollen and insect species. Relative abundance of species is indicated by width of the rectangles; frequency of each interaction type is indicated by width of the line.

Trophic interactions and structure can determine the resilience and function of restored ecological communities

Menninger & Palmer, 2006
**Alternative Dynamic States**

- Extreme events can push system into a new resistant state
- New domain dominated by disturbance process (constant disturbance in system)
- Examples: shifts from forest or woodland to shrub fields with radically different fire regime
- New state can exclude recolonization by previously dominant vegetation

---

**Affirmative evidence of type conversions to new state**

Pine with multiple surface-fire scars in what is now an oak shrub field, Rincon Mts following a major fire in 1867

Iniquez, 2006
Restoring ecological processes

- More variable and difficult to characterize
- Functional ecology, demographic processes, species interactions, biotic-abiotic interactions, disturbance processes, biogeochemical and hydrologic cycles
- **A focus on ecological processes may provide a useful model for restoration ecology in many systems**

Naeem 2006; Falk 2006

Process-centered restoration in a New Mexico ponderosa pine forest
What is a process-centered model?

• Ecological processes are placed at the center of restoration design
• A range of process values estimated (based on suitable reference)
• Composition and structure are varied as needed to bring process within targeted range, or left to equilibrate on their own

Falk 2006; Cortina et al. 2006

Developing and applying a process-centered restoration model

Monument Canyon Research Natural Area, New Mexico, USA: An old-growth southwestern forest

• SW Jemez Mountains, mean elev. 2,500 m (8,200 ft)
• Mostly interior ponderosa pine forest, some mixed conifer
• 256 ha protected as Research Natural Area since 1932
• Living trees date to 1498 (most after 1600); dead wood to 1300's
Composition
MCN species richness ~ 90 vascular spp. (mostly understory herbs and grasses)

<table>
<thead>
<tr>
<th>Primary tree species</th>
<th>Common name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abies concolor</td>
<td>White fir</td>
</tr>
<tr>
<td>Juniperis scopulorum</td>
<td>Rocky Mountain juniper</td>
</tr>
<tr>
<td>Pinus edulis</td>
<td>Pine</td>
</tr>
<tr>
<td>Pinus flexilis</td>
<td>Limber pine</td>
</tr>
<tr>
<td>Pinus ponderosa</td>
<td>Ponderosa pine</td>
</tr>
<tr>
<td>Populus tremuloides</td>
<td>Quaking aspen</td>
</tr>
<tr>
<td>Pseudotsuga menziesii</td>
<td>Douglas-fir</td>
</tr>
<tr>
<td>Quercus gambelii</td>
<td>Gambel oak</td>
</tr>
<tr>
<td>Robinia neomexicanus</td>
<td>New Mexico locust</td>
</tr>
</tbody>
</table>

Pre-settlement forest structure
Typical median overstory density in open stands
40 – 100 trees ha⁻¹
Pre-treatment total forest structure
\[ \approx 3,500 – 9,000 \text{ trees ha}^{-1} \]
Figure 7. Composite fire timeline for Monument Canyon, NM

Falk & Swetnam 2003; Falk 2004

Focus on restoring frequent surface as the keystone process
PCR: Methods

1. Begin with bracketed estimates of (a) fire regime and (b) individual fire events under historical conditions
2. Model effects of structural treatments on fire behavior and effects across a range of prescriptions
3. Set structural prescription to achieve process target values
4. Test model on the ground and adapt

Covington et al. 2001; Fulé et al. 2004; Falk 2006

Modeling restoration outcomes

• Modeling in FVS 6.31, Nexus 2.0, Behave+
• 32-48 km hr\(^{-1}\) windspeed @ 6 m
• Slope 5%
• Surface fuel moisture:
  – 1 hr fuels 3-8%
  – 10 hr 4-10%
  – 100 hr 5-12%
• Live fuel moisture 80-100%
• Fuel models 9-10

Fulé et al. 2004; Falk 2006
**Target (reference) values for key fire behavior and effects (response) variables**

- Primarily surface fire, occasional torching OK
- Overall flame height \( \leq 2 \text{ m} \)
- Headfire spread rate \( \approx 3 - 4 \text{ m min}^{-1} \)
- Fireline intensity \( \leq 1000 \text{ km m}^{-1} \)
- TI \( \geq 40 \text{ km hr}^{-1} \), CI \( \geq 65 \text{ km hr}^{-1} \)
- Percent mortality by size class
  - \( \leq 2\% \) overstory trees (\( \geq 40 \text{ cm dbh} \))
  - \( \geq 80\% \) saplings and understory trees (\( \leq 15 \text{ cm dbh} \))


---

**Structural (input) variables**

Thin progressively across a range of maximum thin diameters: unthinned – 40 cm (16 in). This alters:
- Tree density (stems ha\(^{-1}\))
- BA (m\(^2\) ha\(^{-1}\))
- Crown base height distribution (m)
- Crown bulk density (kg m\(^{-3}\))
- Size distribution (dbh, cm)

Graham *et al.* 2004; Peterson *et al.* 2005
Changes in fire behavior and effects

- Fire type shifted from active crown to surface fire
- Most target process values were achieved by thinning trees ≤ 22 cm (9 in) dbh
- Thinning into larger size classes did little to improve process restoration

Proportion of response by max diameter thinned
Treatments

- 100 ha thinned 2006; half of site left as control
- Integrated into 3,500 ha (9,000 ac) San Juan/Cat Mesa rx fire area

Funding support: Collaborative Forest Restoration Program
Restoring landscape-scale structure and function

Rodeo-Chediski Fire, 2002

- Functioned at scales that dwarf project-level management
- Restoration should be conducted at the scale at which key ecosystem processes operate

Sisk et al., ForestERA Project, NAU

Q: Can restoration ecology rise to the challenge of ecology in a context of global change?
“The global consequences of human activity are not something to face in the future -- they are here with us now....We are changing Earth more rapidly than we are understanding it.” – Vitousek et. al (1997)

Climate change is a fundamental context for ecological restoration in the 21st century

A question for you: What does changing regional and global climate mean for restoring ecosystems?

 Courtesy Henry Diaz, NOAA and US Forest Service
Trees are long-lived dominants; once established they tend to tolerate environmental stress and persist. Forests are often thought of as slow-changing, gradually adjusting to new conditions through competition and establishment (Allen, Swetnam, et al.)

But, once thresholds of environmental stress are exceeded, rapid changes can occur through massive forest dieback.
Temporal change in the climate envelope on the scale of decades to years...

Pacific Decadal Oscillation

El Niño/Southern Oscillation

...centuries...

Reconstruction of annual rainfall in western New Mexico

1950s DROUGHT
…millennia…

…millions of years…
Bringing people into the frame

Restoration offers:

✓ A way for people to be involved directly in healing their local ecosystem
✓ A way of learning the sense of place by direct experience
✓ A way of teaching how ecosystems work, and where their limits are
✓ A way of building loyalty and affection for where people live
Some closing thoughts…

- The need for restoration is driven by ongoing degradation of ecosystems
- Restoration is a global undertaking, practiced locally
- Restoration ecology, the science of restoration, is in its infancy
- Restoration includes the interactions of ecological composition, structure, and processes
- Restoration can bring people into the frame in a positive way
- Changing climate presents huge challenges – and an equally huge opportunities – for “restoration”