State-and-Transition Models and Ecological Thresholds: Bridging Theory and Application

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Professional Reinvention

Presentation Objectives

- Evaluate ecological foundation upon which alternative rangeland evaluation procedures have been developed.
- Illustrate the gap that exists between theory and application of these procedures.
- Describe a framework to develop, interpret and apply ecological thresholds for land management.

Rangeland Vegetation Dynamics

- Evaluation of shifts in species composition has been a cornerstone of rangeland ecology.
- Vegetation evaluation provides a means to:
  - Identify rangeland management options
  - Draw inferences concerning ecosystem function
  - Assess the limits of ecosystem sustainability
- Consequently, a critical need exists for accurate and effective procedures to evaluate vegetation dynamics on rangelands.

Events that Promoted Change in Rangeland Ecology

- Ecological anomalies and criticisms of the range model
  - disturbances other than grazing were deemphasized
  - succession has a single equilibrium point
  - could not account for woody plant encroachment

Briske et al. 2005

Events that Promoted Change in Rangeland Ecology

- Political momentum provided by the Rangeland Health Report, National Research Council (1994)
  - Inconsistent use of rangeland evaluation procedures
  - Inability to assess the status of the Nation's rangelands

Bridging Theory and Application

Non-Equilibrium Paradigm	Ecological Site Descriptions
Multiple Stable States	State & Transition Models
Multiple Pathways	Thresholds
Ecological Thresholds	Rangeland Health

Two Ecological Paradigms

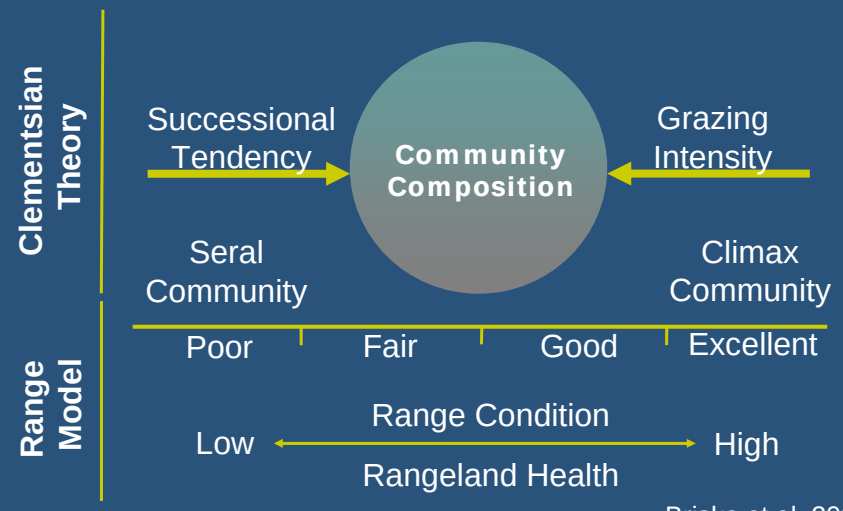
- Non-equilibrium paradigm
  - Characterized by the “flux of nature” metaphor
  - Ecosystems possess a limited capacity for internal regulation and are more vulnerable to external disturbances
    - Multiple equilibrium points possible.

Briske et al. 2003

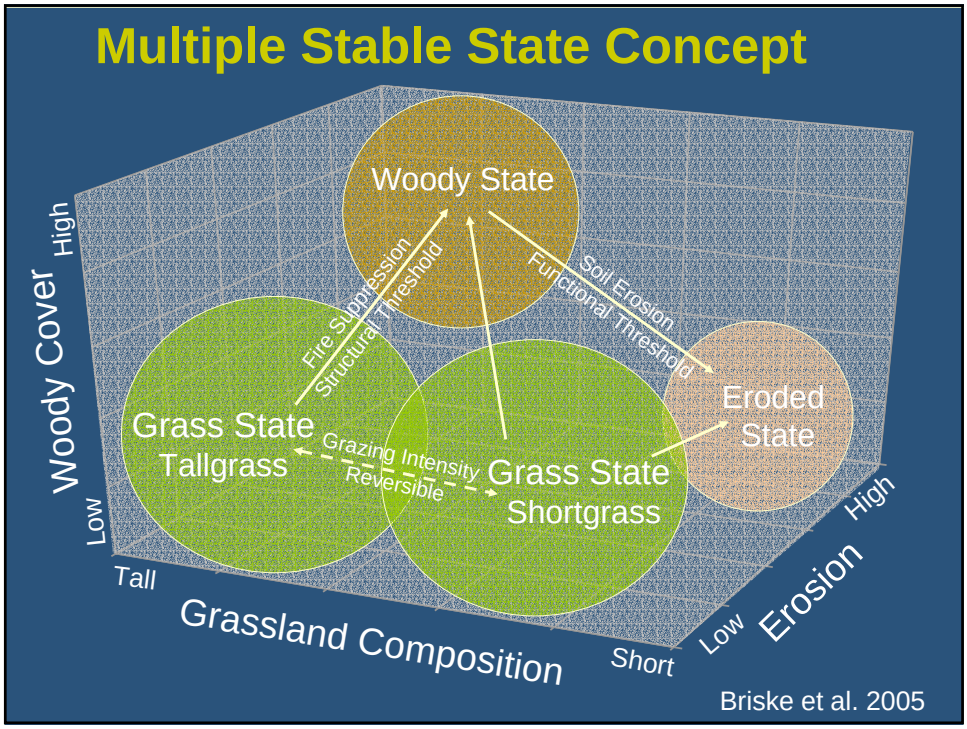
Two Ecological Paradigms

- Equilibrium paradigm
  - Characterized by “balance of nature” metaphor
  - Ecosystems possess capacity for internal regulation through negative feedback mechanisms
    - Intra- and interspecific competition and plant-animal interactions.

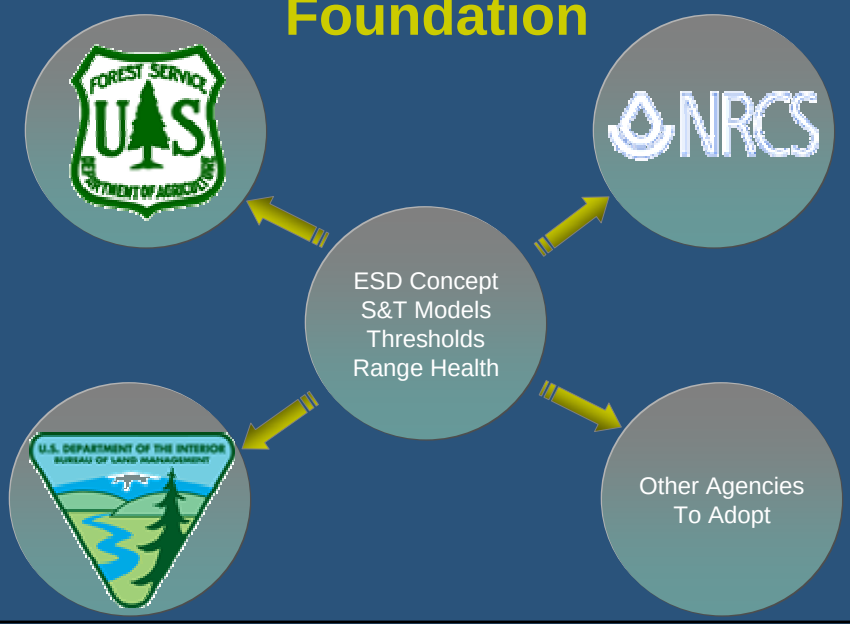
Range Condition Concept



Briske et al. 2005


Multiple Stable State Concept
Woody State
Fire Suppression
Structural Threshold
Soil Erosion
Functional Threshold
Grass State
Tallgrass
Grazing Intensity
Reversible
Grass State
Shortgrass
Eroded
State
Woody Cover
High
Low
Tall
Grassland Composition
Short
Low
Erosion
High
Briske et al. 2005

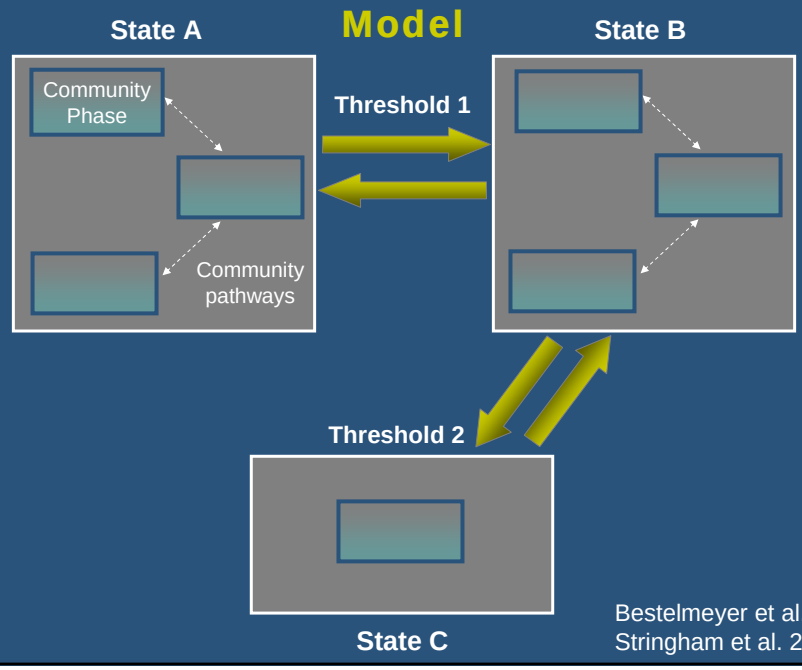
ESD'S: New Rangeland Foundation



State and Transition Model Framework

- Represent framework to organize information for management purposes
  - Management language
- Does NOT constitute an ecological model of vegetation dynamics and does NOT represent alternative theory to Clementsian succession.
- Information required to construct models include:
  - Recognition of potential alternative states
  - Identification of potential transitions between states
  - Knowledge to achieve favorable transitions and to avoid unfavorable transitions

State-and-Transition Model

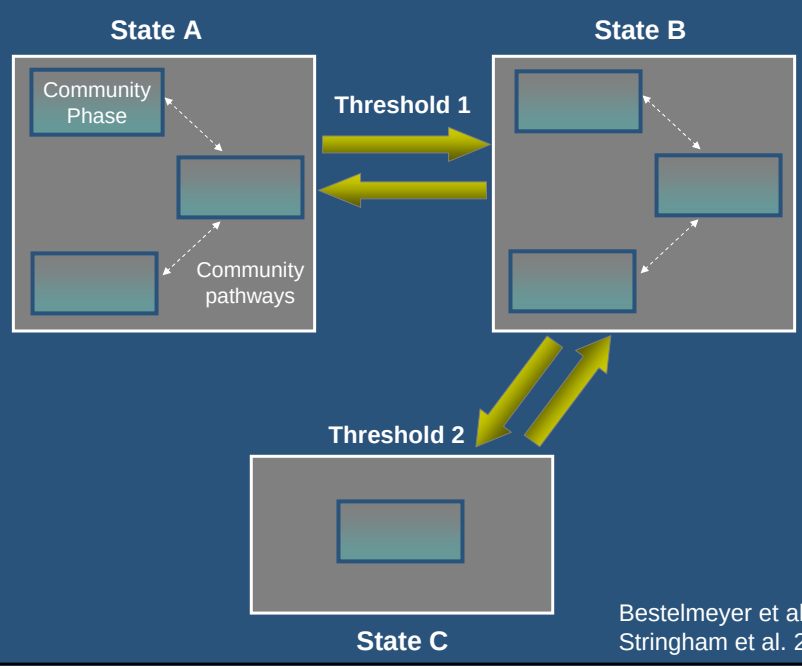


Bestelmeyer et al. 2003
Stringham et al. 2003

Management Implications

- Managers must consider both continuous vegetation dynamics within stable states as well as discontinuous vegetation change (i.e., thresholds) between states.
- Vegetation management within stable states enables managers to “condition the resource” to modify threshold occurrence (Watson et al. 1996).
- Perception that vegetation dynamics are driven entirely by eposodic events decreases incentives for adaptive management and suggests that management is unimportant (Stafford Smith 1996; Watson et al. 1996).

State-and-Transition Model



Bestelmeyer et al. 2003
Stringham et al. 2003

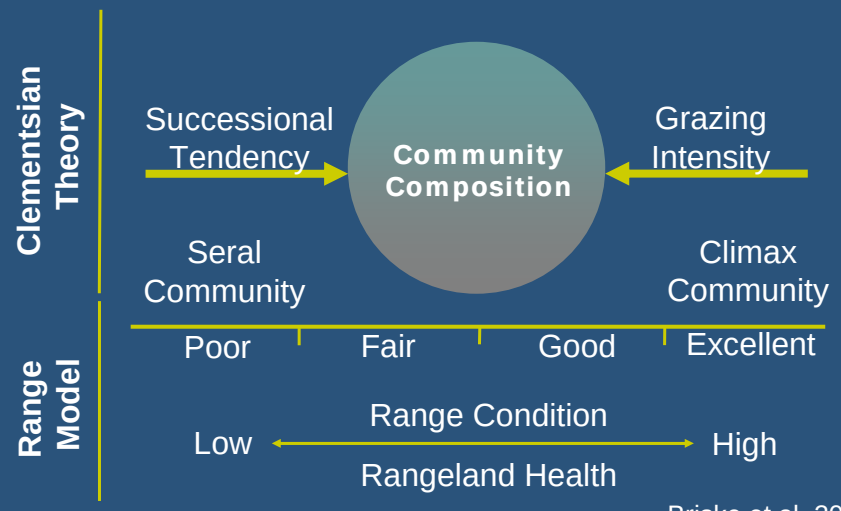
Rangeland Health Revisited

- Rangeland health was introduced at the time the range model was developed.
  - "Range condition is rangeland health; it is the relative position of a range with regard to a standard set up by management objectives within the practicable potentialities of the site."

    Lincoln Ellison 1949 Journal of Forestry

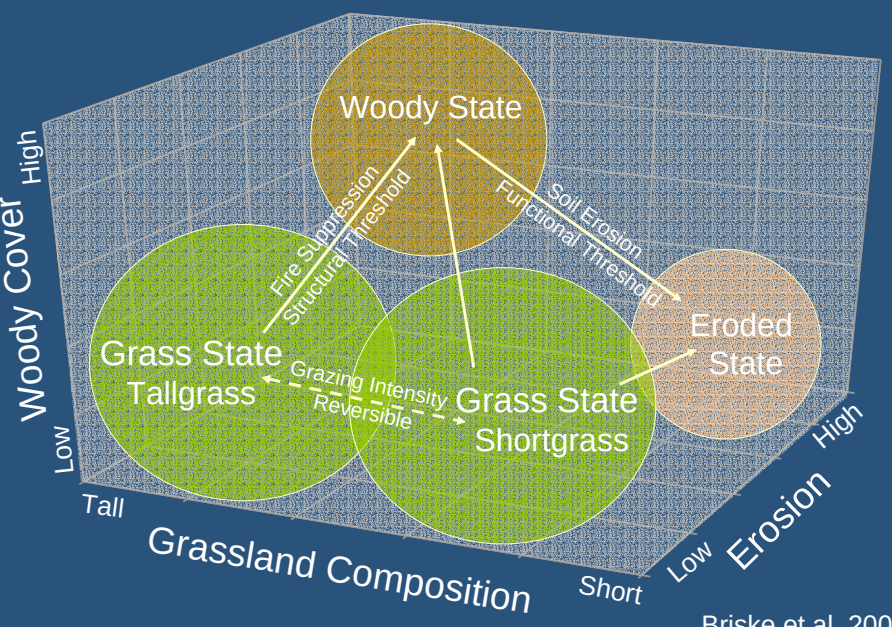
    E.J. Dyksterhuis 1949 J. Range Manage.
- Why has rangeland health been revisited?

Range Condition Concept



Briske et al. 2005

Multiple Stable State Concept



Briske et al. 2005

Rangeland Health Definition

- "The degree to which the integrity of the soil, vegetation, water and air as well as the ecological processes of the ecosystem are balanced and sustained."
- Ecological integrity describes "the maintenance of the functional attributes characteristic of a locale, including normal variability".

Pyke et al. 2002

Why is Rangeland Health Problematic?

- Difficult to translate current definitions of rangeland health into operational terms.
- Health requires that we identify and quantify ecosystem processes from a point in time assessment of community and soil attributes.
  - Describe functional thresholds from structural thresholds.

Why is Rangeland Health Problematic?

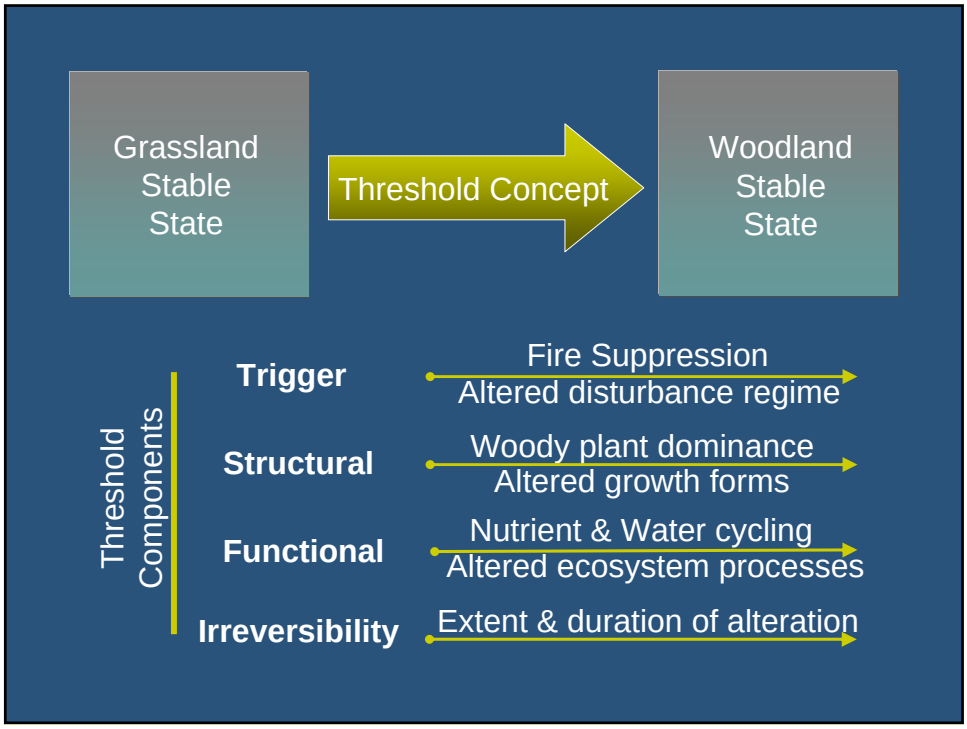
- Site Conservation Threshold (SRM Task Group 1995)
- Type, amount, and pattern of vegetation required to prevent accelerated erosion.
- Even this simple threshold has proven difficult to define and predict.

Do We Understand Thresholds?

- What events initiate threshold development?
- What ecological mechanisms establish thresholds?
- At what point do thresholds become irreversible?
- Can threshold occurrence be anticipated?
- Do all thresholds possess similar components?
- Can thresholds be applied to land management?

Threshold Definitions

- Ecosystems may move from one stable domain to another and remain in an altered configuration – (Holling 1973)
- Boundaries in time and space between two states that are not reversible on a practical time scale without management intervention – (Friedel 1991)
- Boundaries in time and space between any and all states, such that one or more of the primary ecological processes has been irreversibly changed and must be actively restored before return to the previous state is possible – (Stringham et al. 2003)



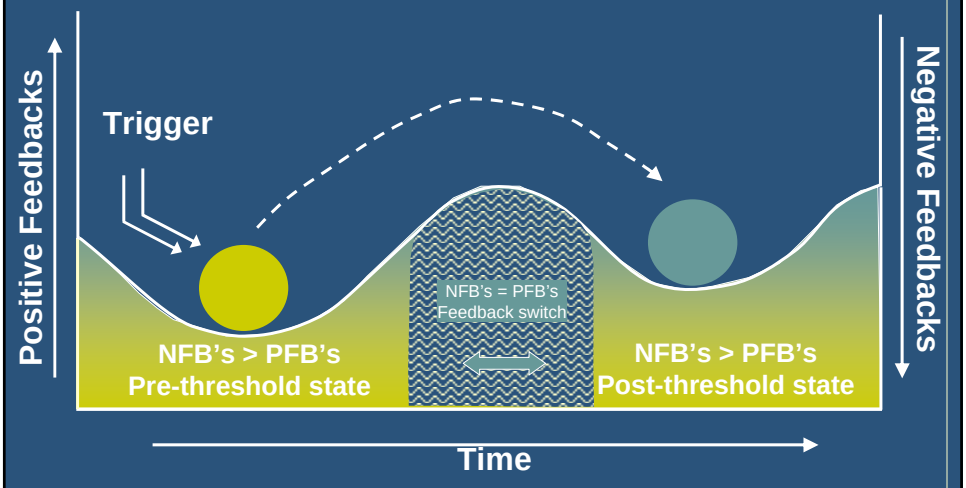
Threshold Components

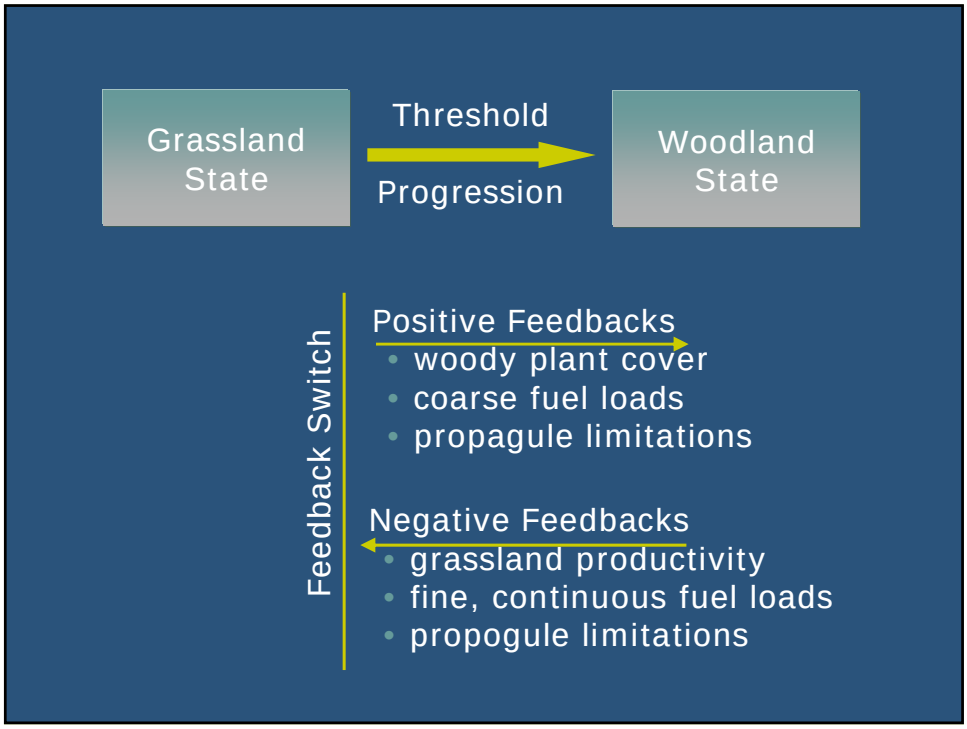
- Triggers - event(s) that initiate threshold progression by inducing a switch from negative to positive feedbacks.
- Feedbacks - ecological processes that reinforce (e.g., negative) or degrade (e.g. positive) resilience of a stable state.

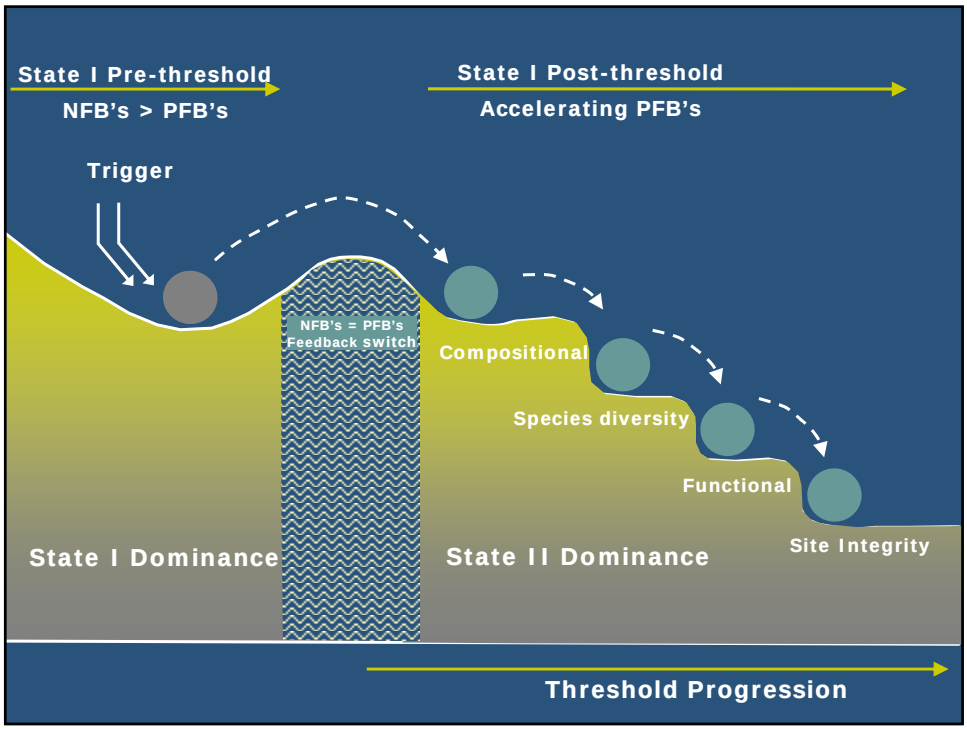
Threshold Components

- Threshold categories – series of ecological processes that reduce resilience of the pre-threshold state during threshold progression.
- Threshold trajectories – developmental pathways of post-threshold states after a threshold has been exceeded.
- Operational thresholds – series of probabilities that determine threshold occurrence, trajectories, and reversibility.

Feedback Switch Mechanism




Grassland State
Threshold
Progression
Woodland State
Feedback Switch
Positive Feedbacks
• woody plant cover
• coarse fuel loads
• propagule limitations
Negative Feedbacks
• grassland productivity
• fine, continuous fuel loads
• propogule limitations

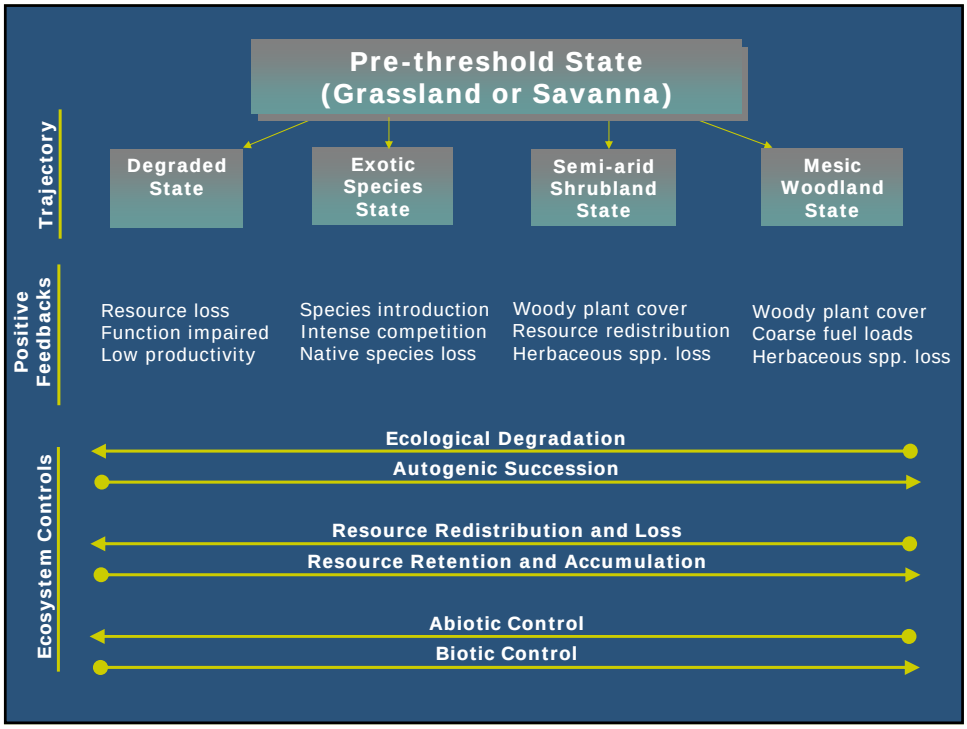

State I Pre-threshold
NFB's > PFB's
State I Post-threshold
Accelerating PFB's
Trigger
NFB's = PFB's
Feedback switch
Compositional
Species diversity
Functional
Site Integrity
State I Dominance
State II Dominance
Threshold Progression

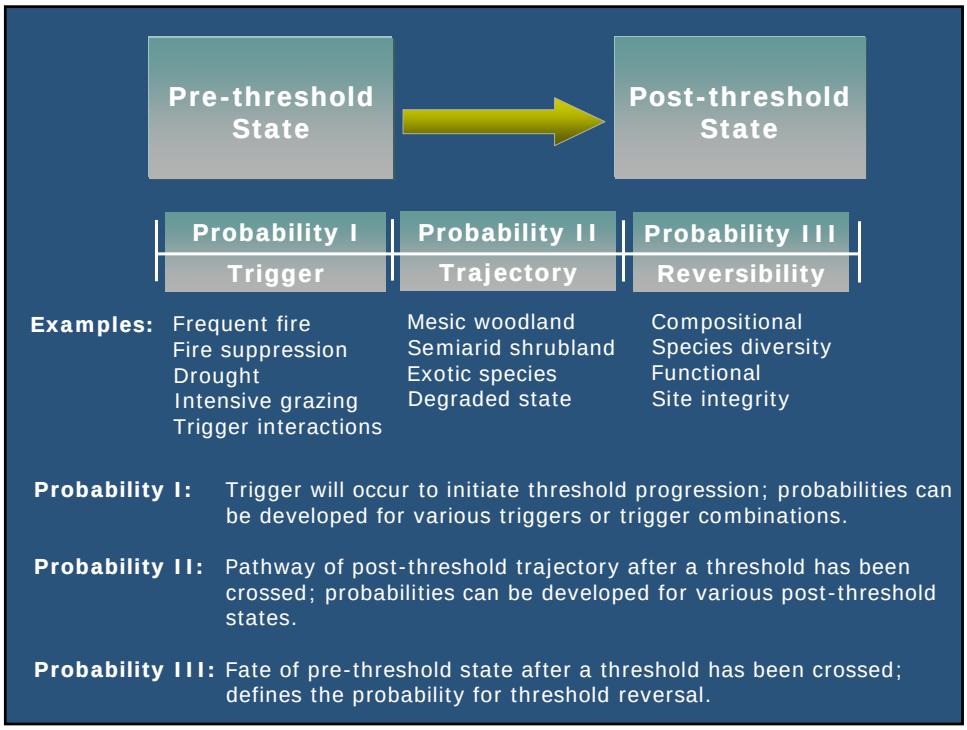
Threshold Categories

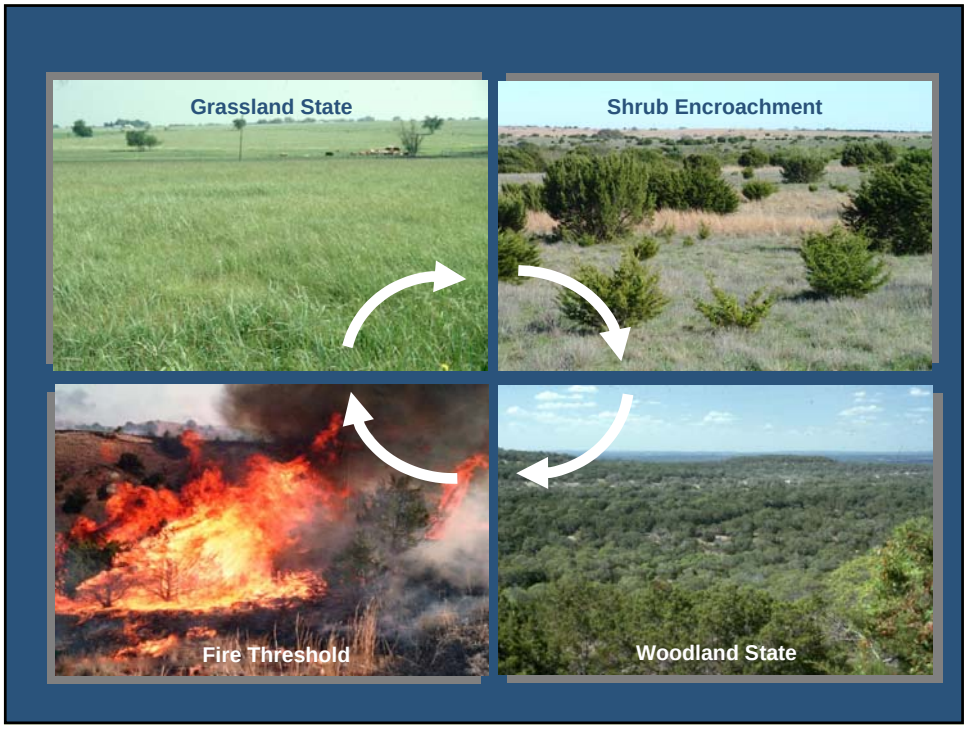
- Compositional category - modification of species and growth form composition, spatial vegetation distribution, and the presence of invasive species; removal of dominant species from the post-threshold state will reverse the threshold.
- Species diversity category - species and genetic diversity of the pre-threshold state have become locally extinct; propagule addition will be required to reverse the threshold.

Threshold Categories

- Functional category - positive feedbacks have progressed to the extent that ecological processes will no longer support dominants of the pre-threshold state; restoration prescriptions will be required to reverse the threshold.
- Site integrity category - degradation has progressed to the extent that site characteristics of the pre-threshold state have been greatly modified; opportunity for threshold reversal has been lost.


Pre-threshold State
(Grassland or Savanna)
Trajectory
Degraded State
Exotic Species State
Semi-arid Shrubland State
Mesic Woodland State
Positive Feedbacks
Resource loss
Function impaired
Low productivity
Species introduction
Intense competition
Native species loss
Woody plant cover
Resource redistribution
Herbaceous spp. loss
Woody plant cover
Coarse fuel loads
Herbaceous spp. loss
Ecosystem Controls
Ecological Degradation
Autogenic Succession
Resource Redistribution and Loss
Resource Retention and Accumulation
Abiotic Control
Biotic Control


Pre-threshold State
Post-threshold State
Probability I
Trigger
Probability II
Trajectory
Probability III
Reversibility
Examples:
Frequent fire
Fire suppression
Drought
Intensive grazing
Trigger interactions
Mesic woodland
Semiarid shrubland
Exotic species
Degraded state
Compositional
Species diversity
Functional
Site integrity
Probability I: Trigger will occur to initiate threshold progression; probabilities can be developed for various triggers or trigger combinations.
Probability II: Pathway of post-threshold trajectory after a threshold has been crossed; probabilities can be developed for various post-threshold states.
Probability III: Fate of pre-threshold state after a threshold has been crossed; defines the probability for threshold reversal.


Grassland State
Shrub Encroachment
Fire Threshold
Woodland State