

# Modeling Alternative Alpine Vegetation States Resulting From Climatic Shifts And Feedbacks From Plant-Animal Interactions

Rob Klinger  
Steven Ostoja  
Matt Brooks

USGS-BRD  
Western Ecological Research Center  
Yosemite Field Station

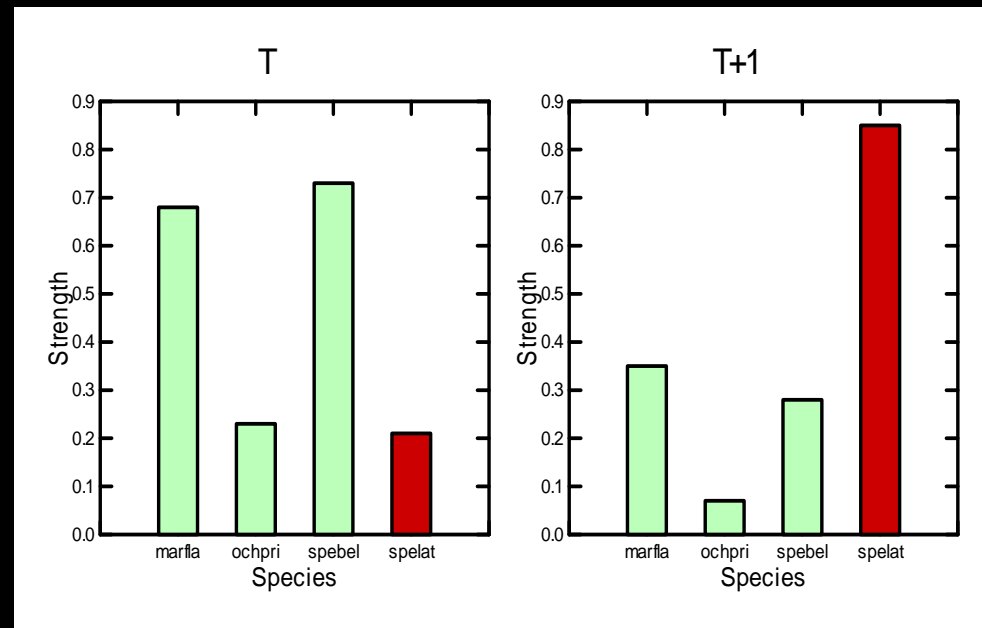
# Climate Change & Alpine Ecosystems

- The "canary in the coal mine" ecosystems
  - Elevation constraint
  - Temperature constraint
- Pattern analysis focus
  - Range shifts of plant and animal species
  - Vegetation boundaries change



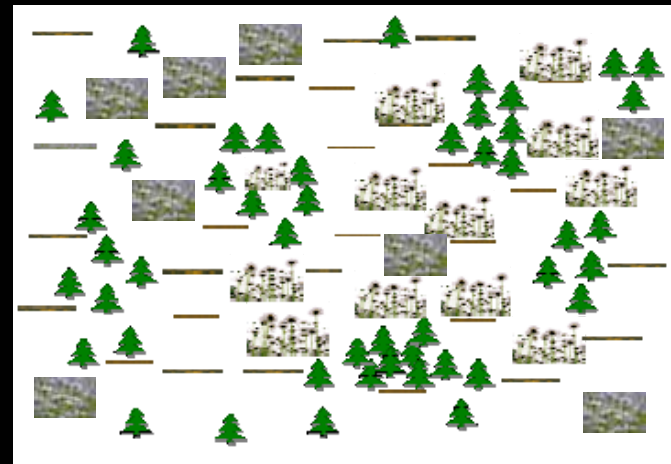
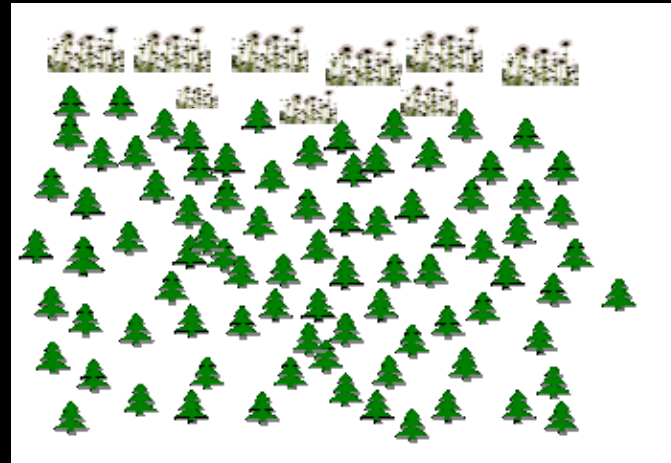
# What Are Implications Of Climate Shifts & Range Changes On Ecological *Processes*?

- Consequences to ecosystems?
  - Functional group changes
    - Local extinctions
    - Changes in relative abundance
    - Novel species
  - Changes in distribution of interaction strengths

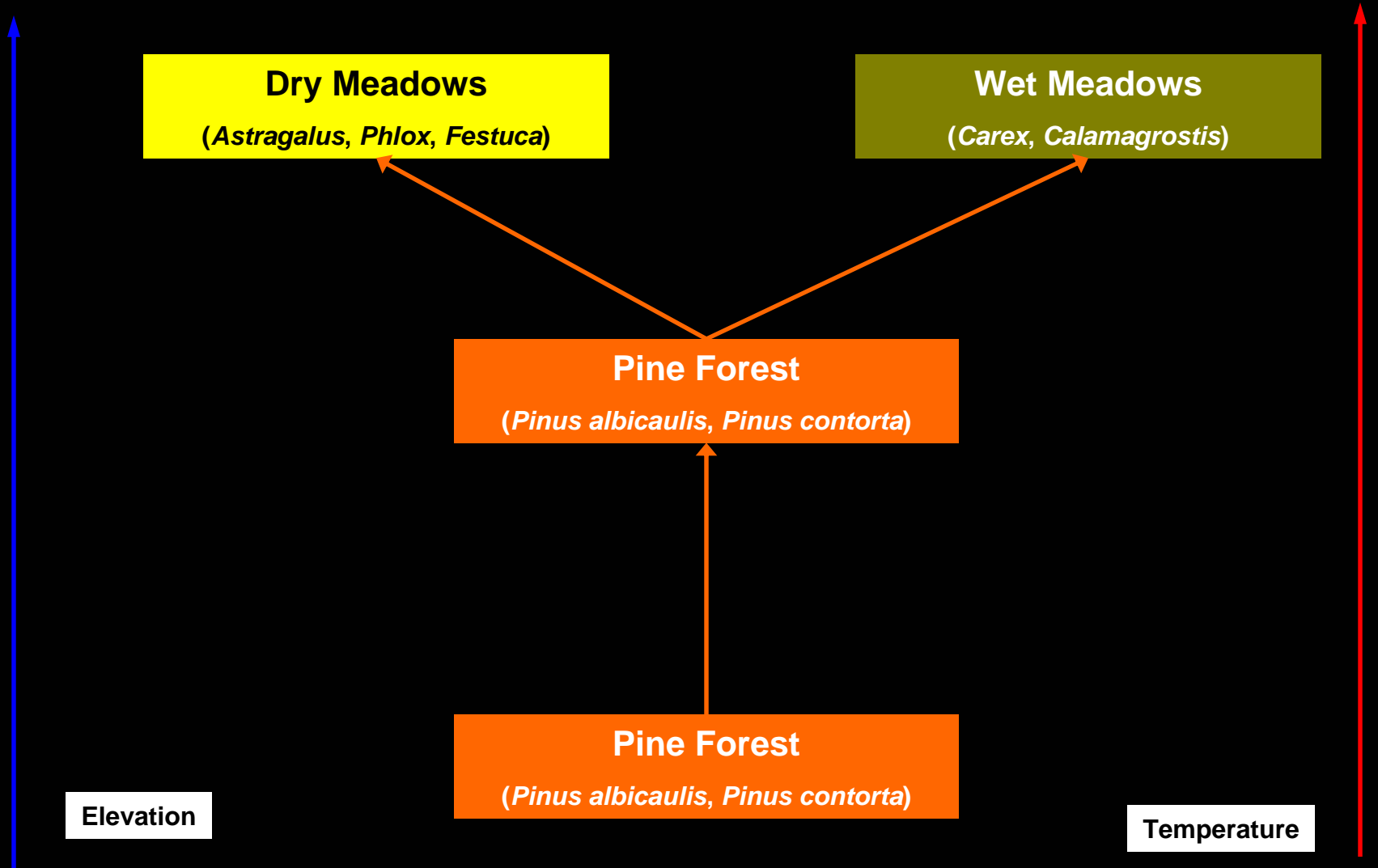


# Two Basic Questions

- Deterministic transition to relatively homogenous state or alternative stable states (high heterogeneity)?
- What processes would drive and then maintain alternative states?



# Deterministic, Climate-Driven Transition



# Interplay Of Multiple Factors

- Variable Range Shifts

- *Beever et al. 2003, 2008*
- *Berteaux et al. 2006*
- *Floyd 2004*
- *Floyd et al. 2005*
- *Grayson 2005*
- *Griffin et al. 2008*
- *Moritz et al. 2008*
- *Rowe 2007*

- Physical Factors

- *Butler et al. 2007*

- Temperature-productivity relationship

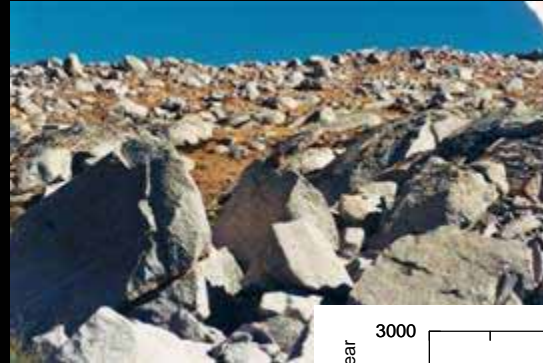
- Longer growing season

- Biotic Interactions

- *Cannone et al. 2007*
- *Emmerson et al. 2004*

- **Feedbacks!**

- *Malanson et al. 2007*
- *Klinger & Rejmanek in press*



# Evidence For Development Of Complex Pathways

## Species-interactions

- **Competition**

- *Gordon & Rice 1993, 2000*
- *Klanderud 2005*
- *Klanderud & Totland 2005*
- *Suttle et al. 2007*

- **Predator-prey**

- *Callaghan et al. 2004*
- *Emmerson et al. 2004*

## Plant-animal interactions

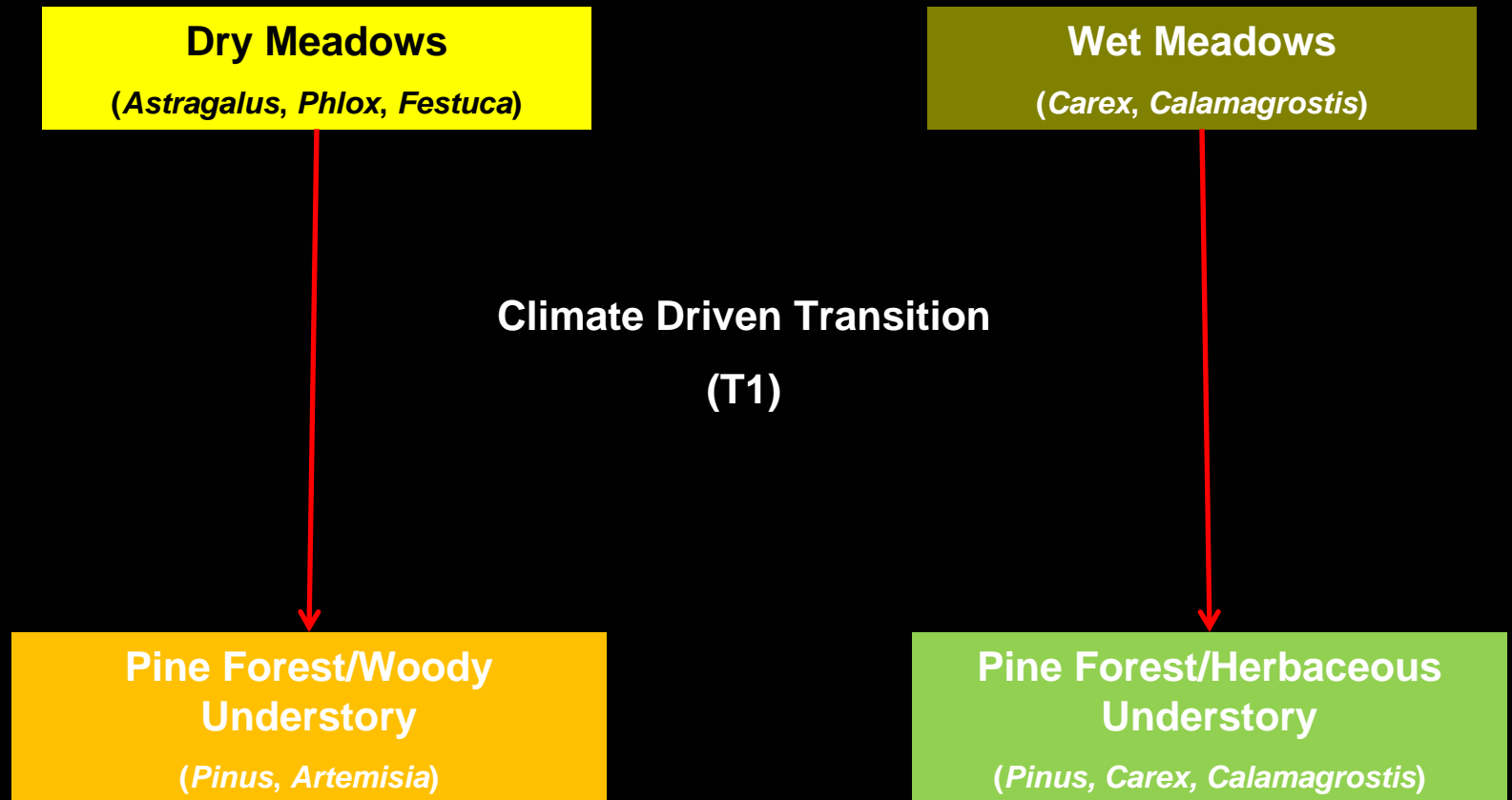
- **Herbivory**

- *Aho et al. 1998 (Rocky Mtns., pika)*
- *Bagchi et al. 2006 (Himalayas, small mammals)*
- *Cairns et al. 2004, 2007*
- *McIntire & Hik 2005*
- *Pyke & Marty 2005*
- *Watson 1976*

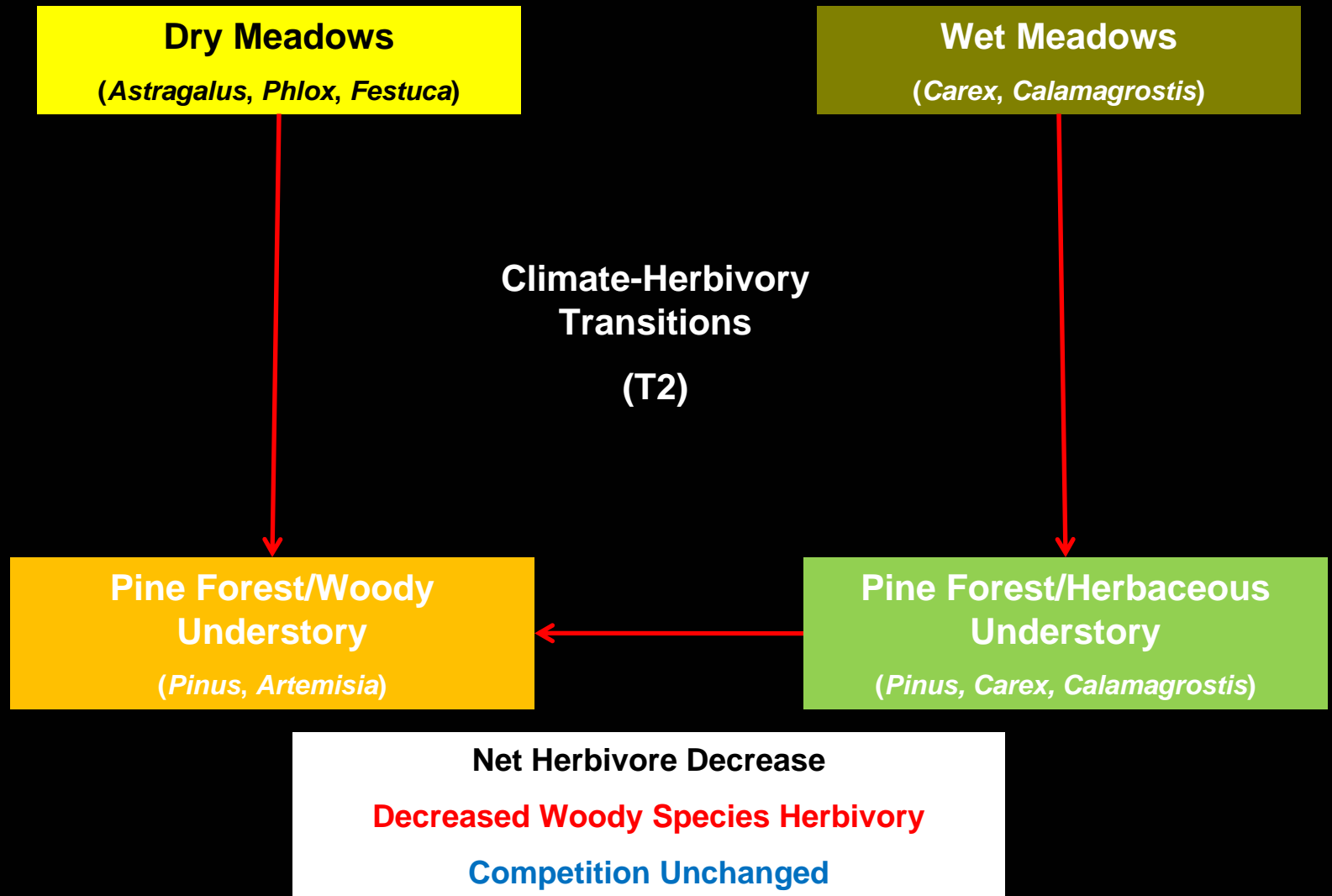
- **Granivory**

- *Castro et al. 1999, 2002*
- *Garcia 2001*
- *Siepielski and Benkman 2008*

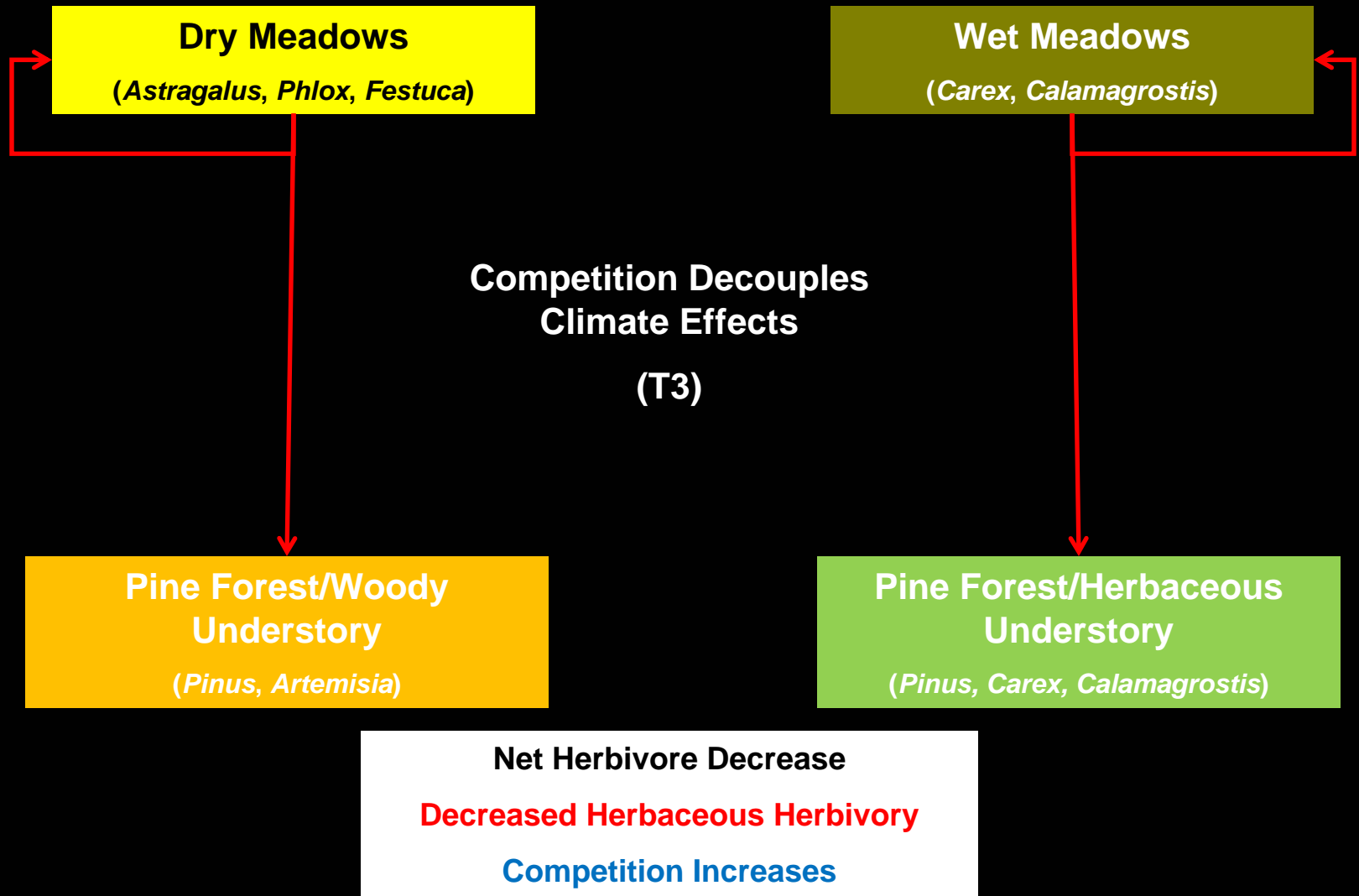
# Alternative States & Pathways



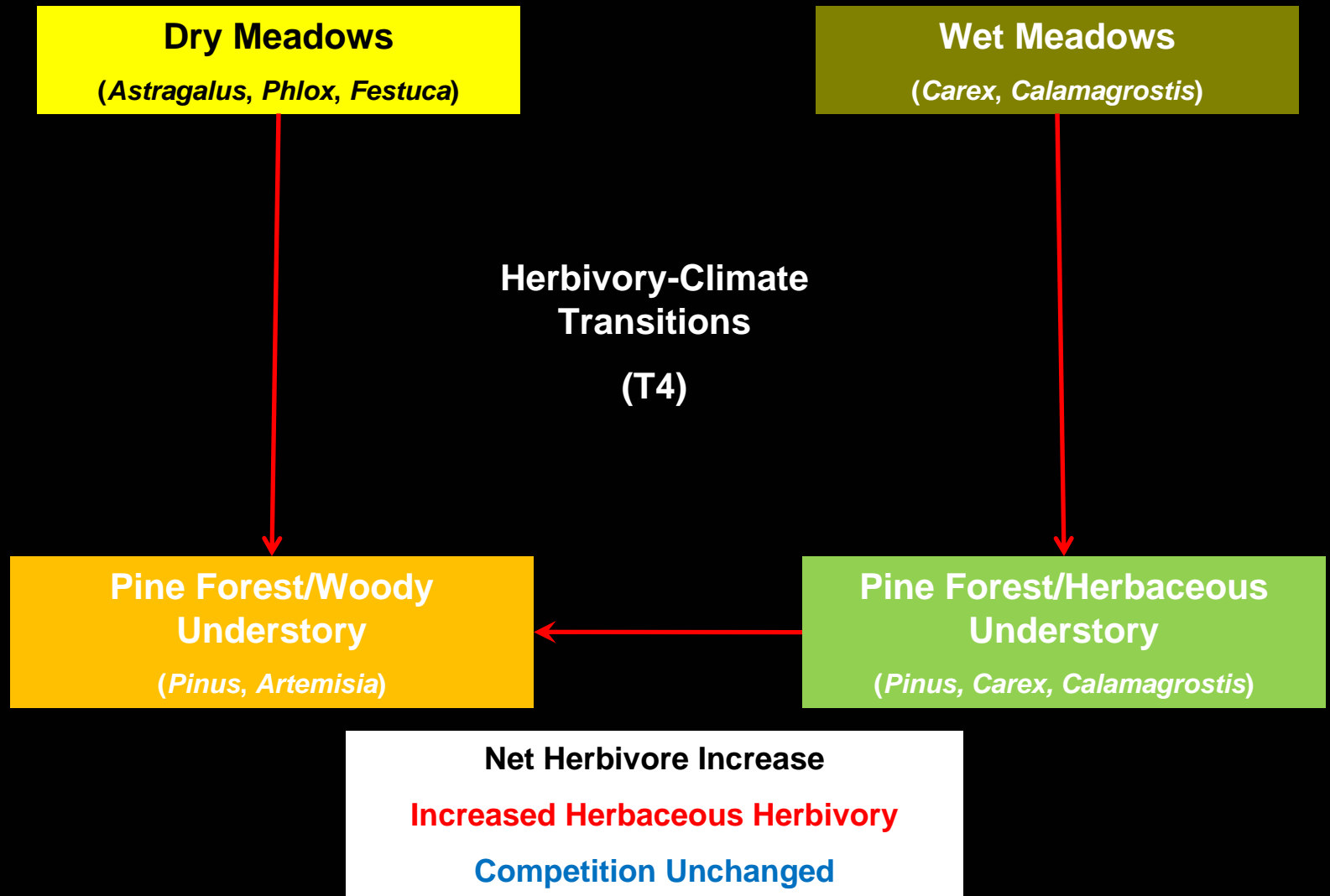
# Alternative States & Pathways



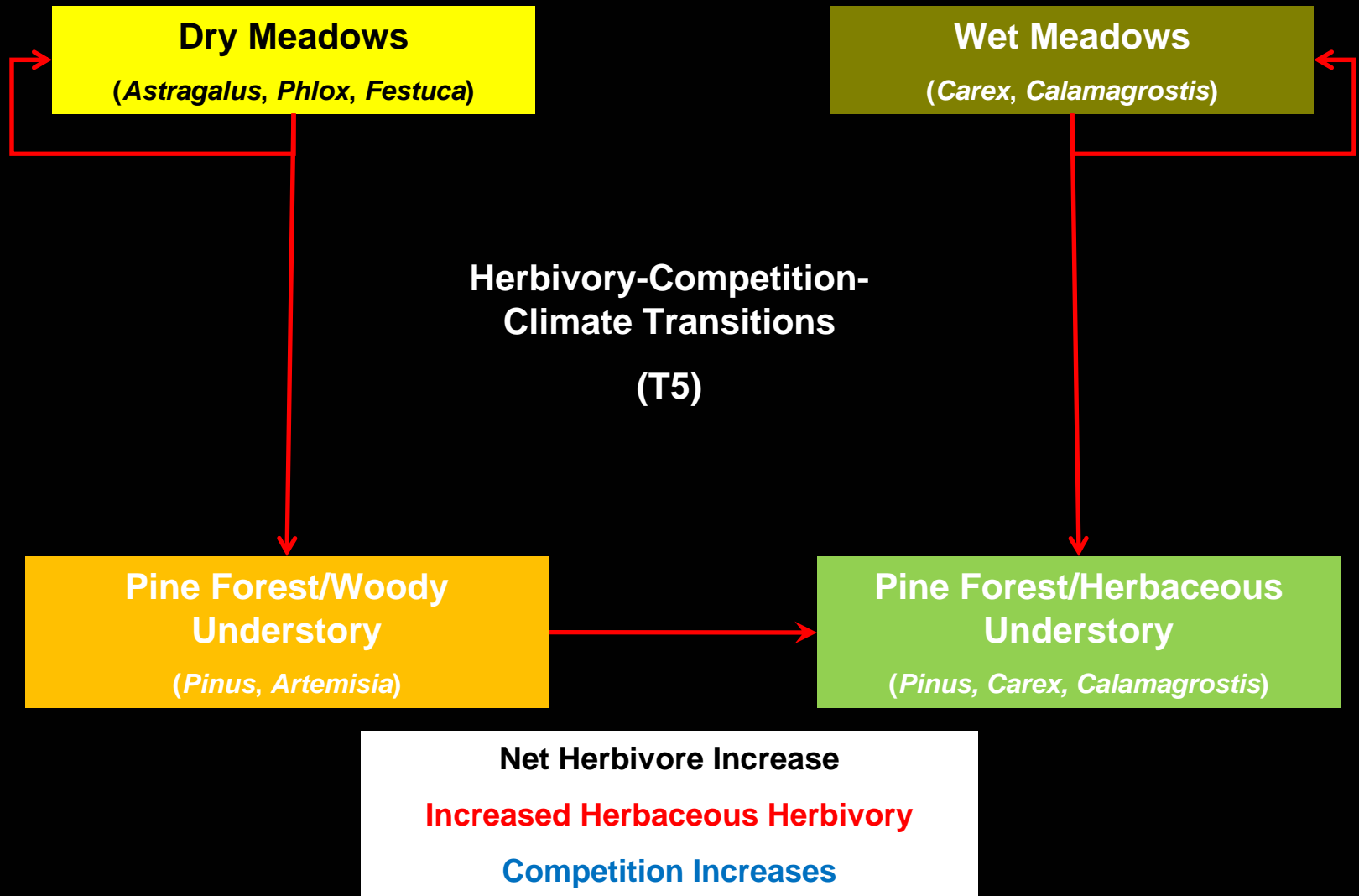
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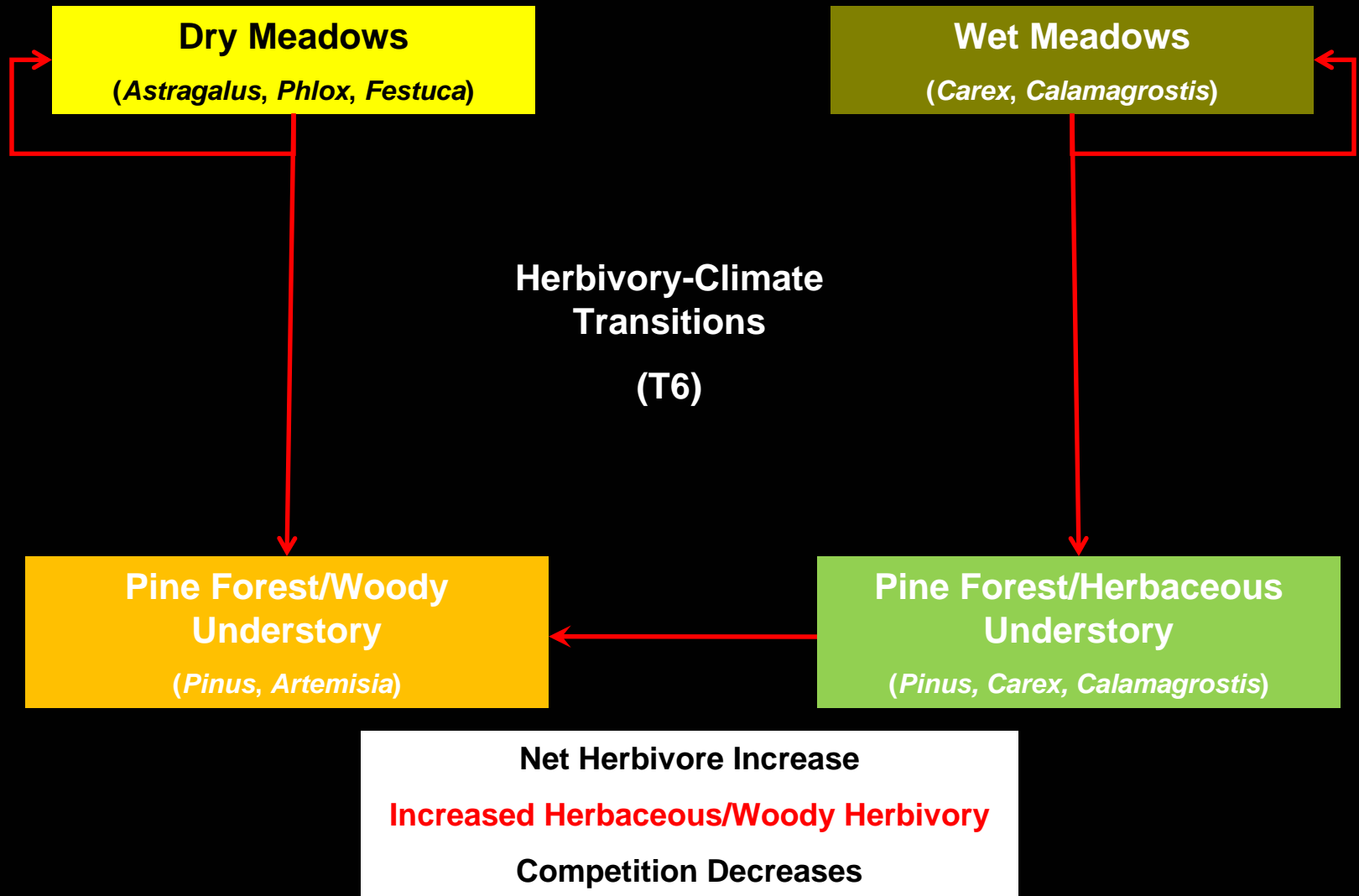
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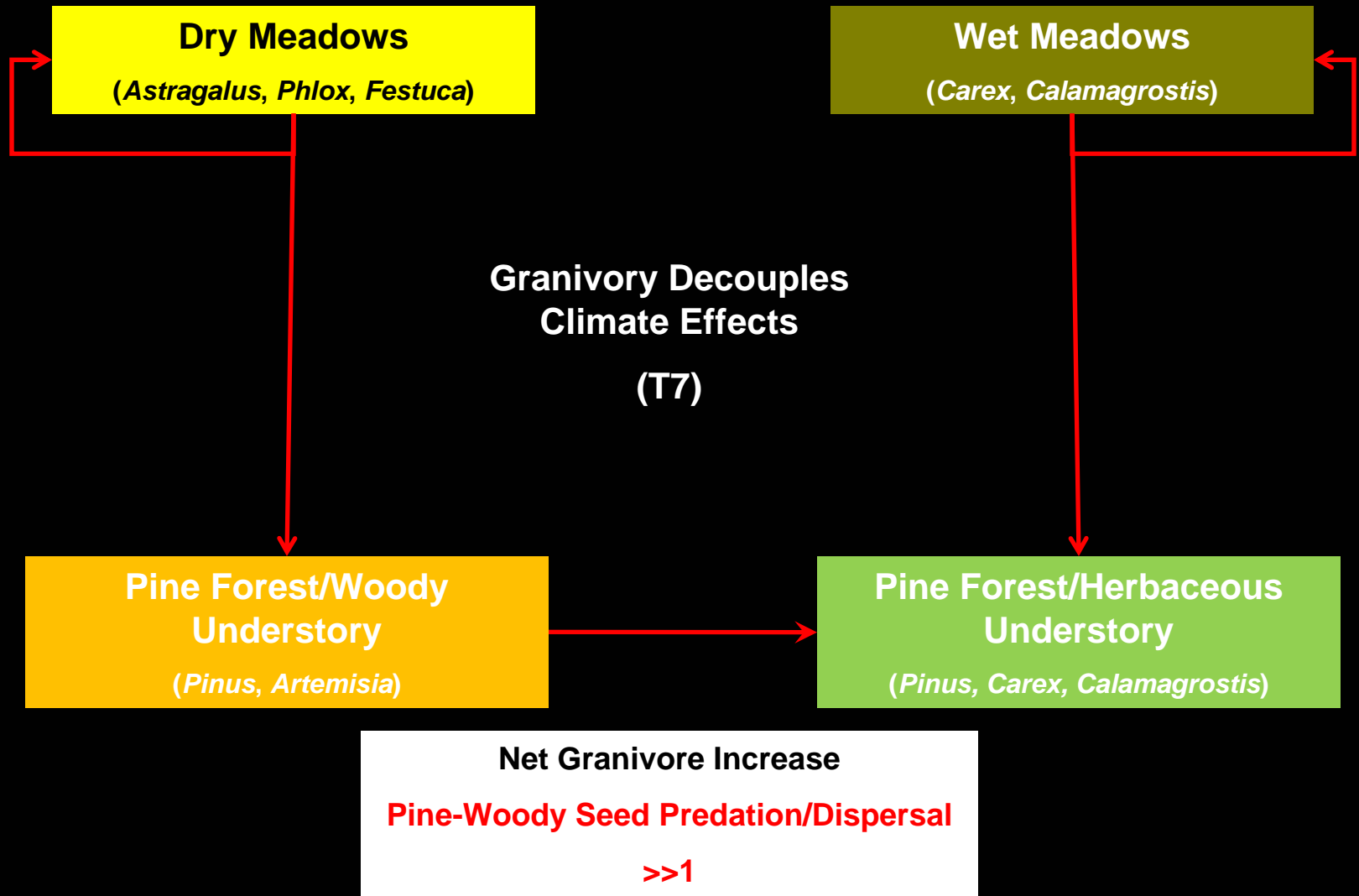
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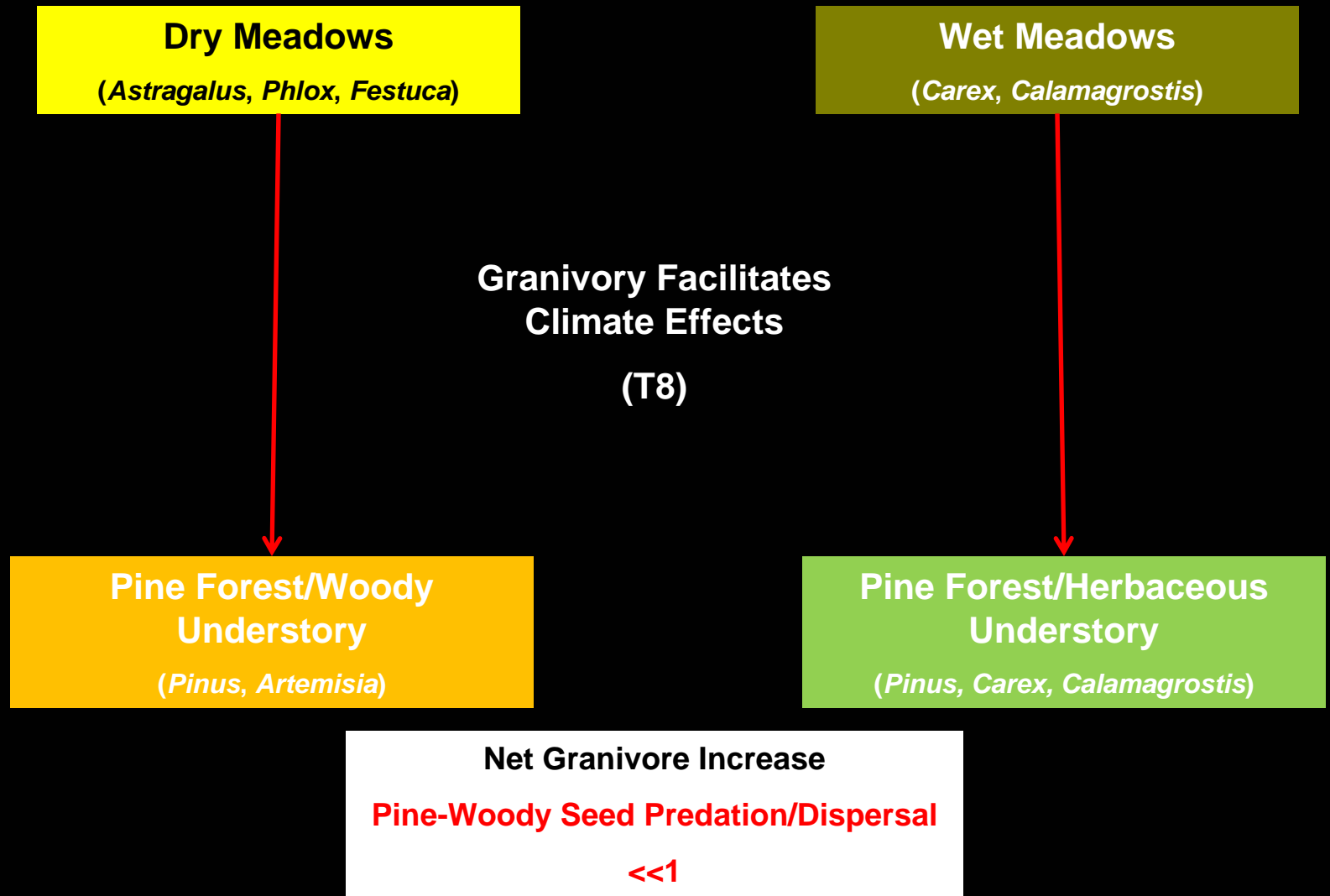
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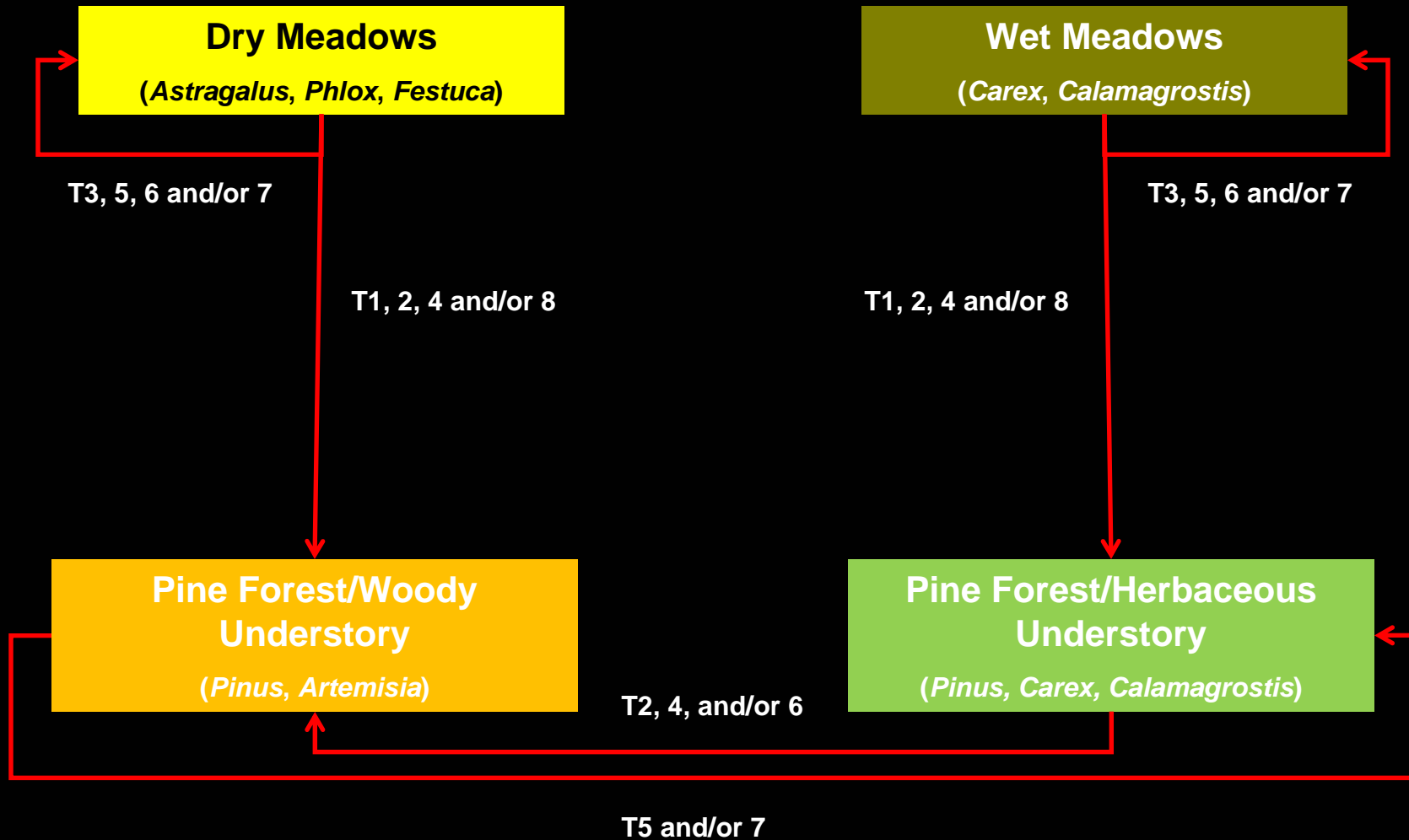
# Alternative States & Pathways



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# Alternative States & Pathways



# Quantifying Likelihood Of Alternative States

- Markov models
- Stochastic estimation of probability of transitioning from one state to another
- Probability that the system  $X$  at time  $t$  ( $X(t)$ ) is in state  $x(t)$  given only the information that the system was in state  $X(t-1)$  at  $t-1$   
$$[P(X(t+1) = x(t+1)|X(t) = x(t), X(t-1) = x(t-1)\dots, X(1) = x(1))] = [P(X(t+1) = x(t+1)|X(t) = x(t)],$$
- In English: State of a system at time  $t$  effects state at next time step
- “Memoryless” (first-order models) or very short-term memory (second-order models)
- Matrix (eigenvalue-eigenvector) solution

# Advantages & Disadvantages Of Markov Models

## Advantages

- Probabilistic
- Relatively straightforward to calculate transition rates
- Well suited to multiple species studies
- Integrates simultaneous acting processes and multiple species responses
- Assumptions can be tested
- **Predicts long-term species composition and likelihood of defined states**

## Potential Disadvantages

- Assumes state at  $t + 1$  depends only on state at time  $t$
- Assumes transition probabilities are constant
- Assumes density and spatial arrangement of organisms do not have a major influence on transition probabilities

# Estimating Transition Rates

## Large-scale Observations

- Landsat images (time series) and/or historic photos
- Landscape-level vegetation types
- Estimates proportion of vegetation types at landscape scale

## Small-scale Experiments

- Experimental plots (enclosures/open) along gradients of elevation and distance from forest patches
- Sow in seeds of *Pinus*
- Quantify removal rates and fate
- Estimates relative abundance of species at local scale

# Expected Benefits Of Stochastic Versus Deterministic Approach

- Explicit link between range shifts of animals and ecosystem function
- Identification of likely mechanisms driving ecosystem transformations
- Testable
  - Null and alternative models
- Ecologically meaningful but still tractable

