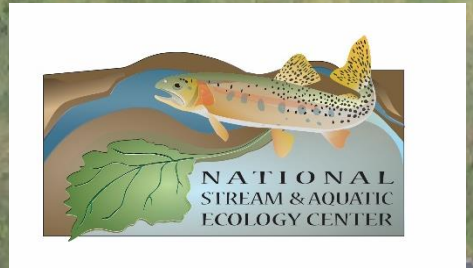
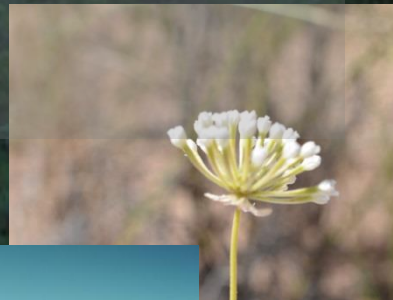




# WFWARP Riparian Program



- Environmental Flow Determination
- Monitoring Protocol Development
- River Restoration
- Litigation Science Support on Water-Related Issues
- Direct Technical Support to National Forests and Grasslands



Global change

Process domain

Guilds

Response

Properly functioning

*Desired condition*

Lag time

Functional redundancy

Ecosystem functioning

**Threats**

Ecological integrity

Ecological site description

**Ecological integrity**

FUNCTIONAL TRAITS

Hierarchical organization

**Vulnerability**

Species diversity

Ecosystem services

Resistance

**Resilience**

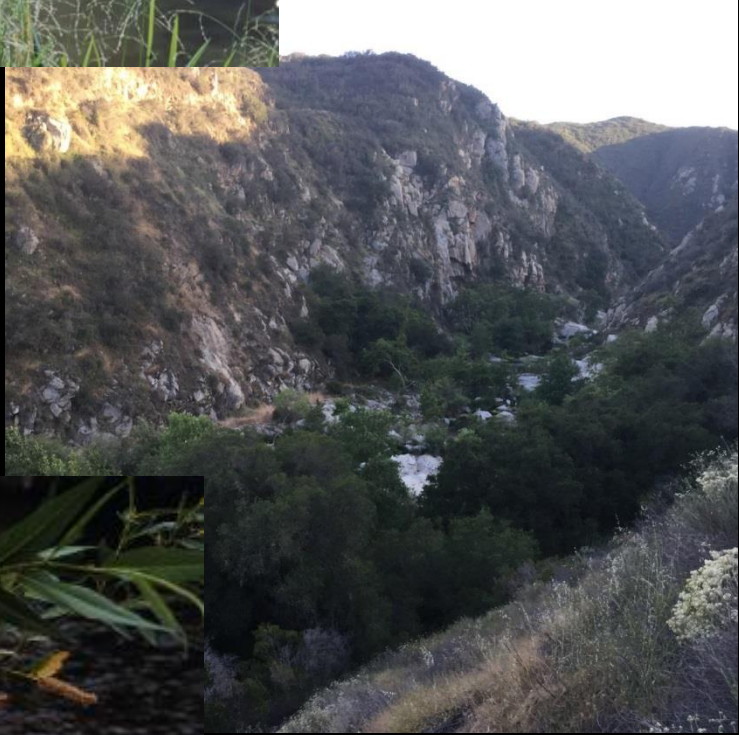
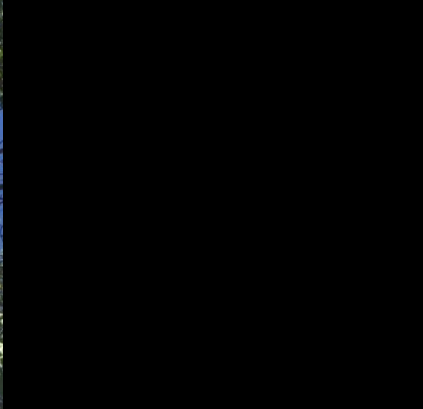
Health

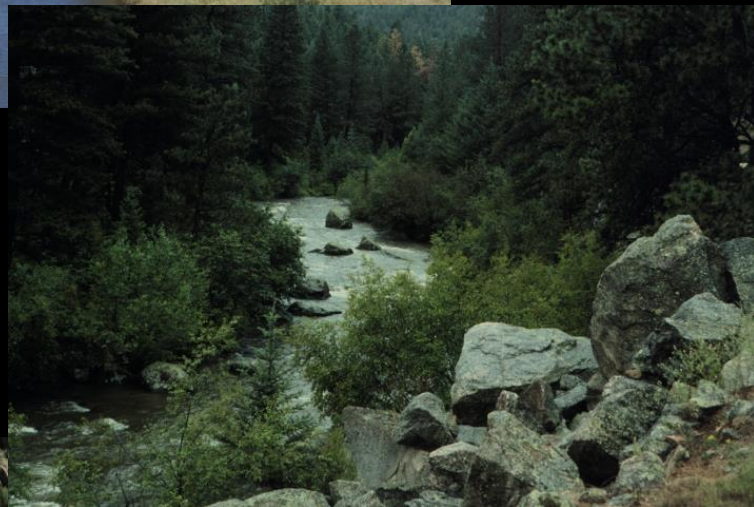
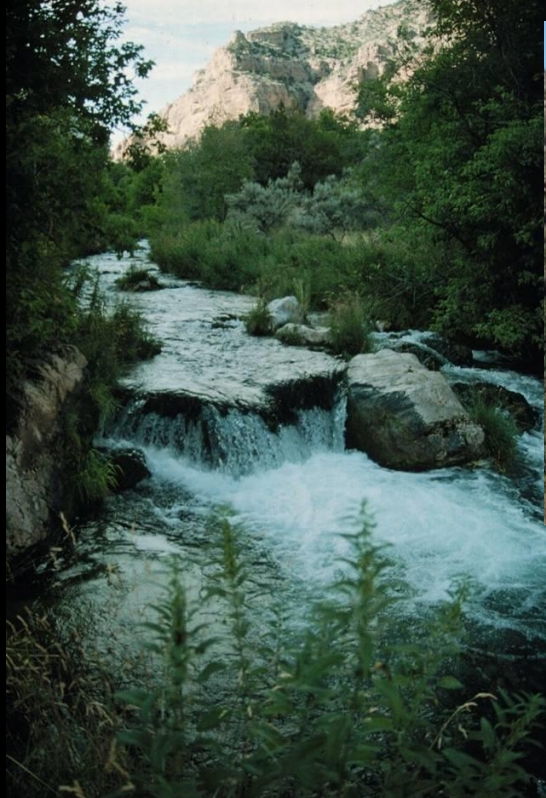




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Scale

Region



Segment



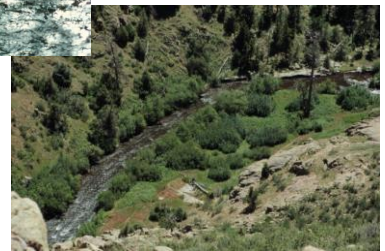
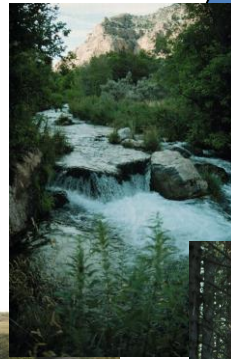
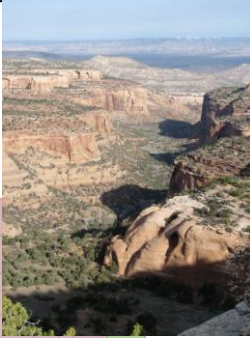
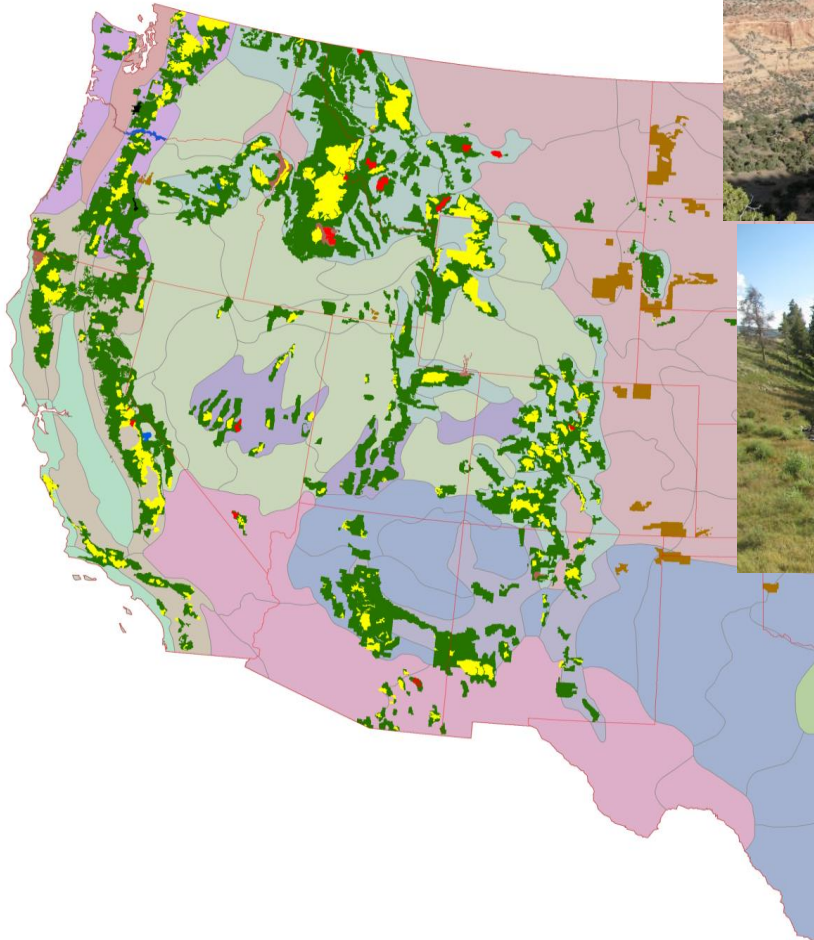
Reach

Ecoregion

Valley Form

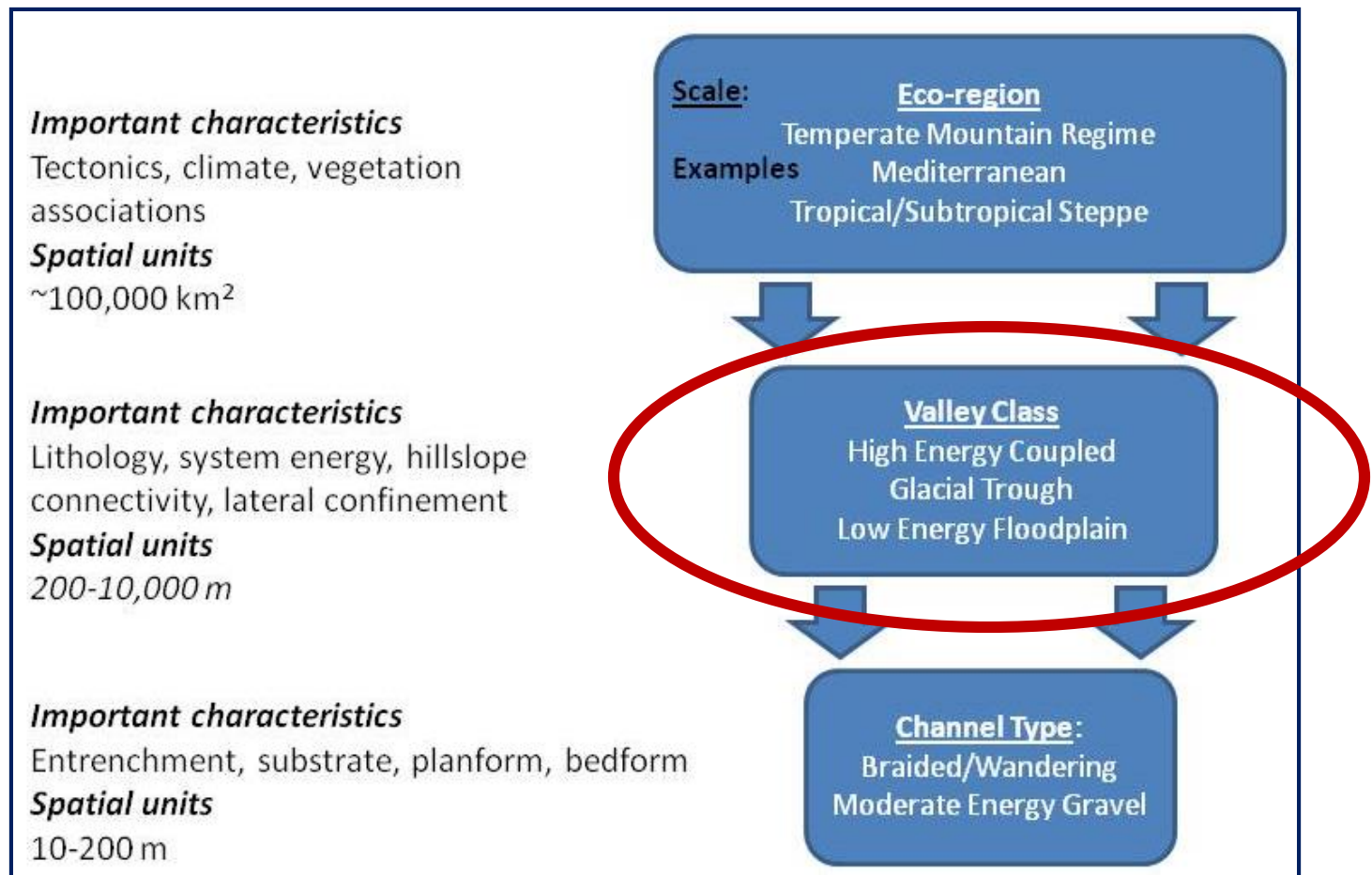
Channel Type

Riparian Area



# HGVC organization and scale

- A hierarchy of spatial scales
- **Open framework** strongly urges the user to input **regional** values for some key thresholds

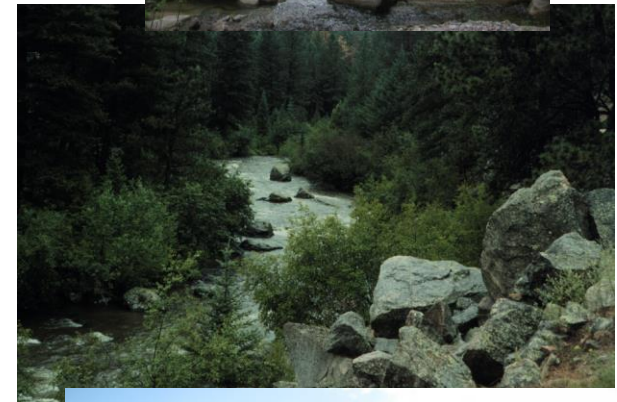


# Geomorphic Valley Classification

E. Carlson and B. Bledsoe

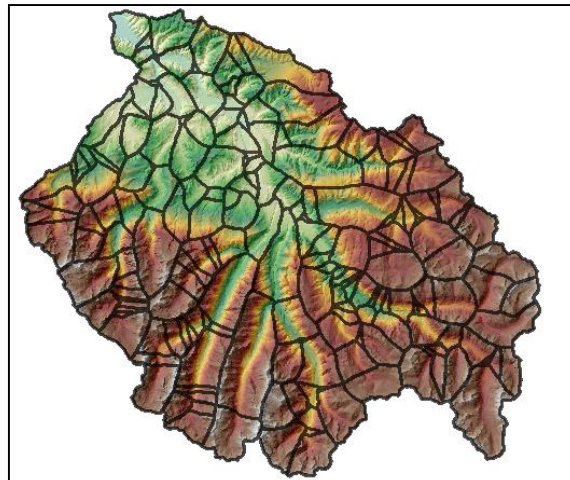
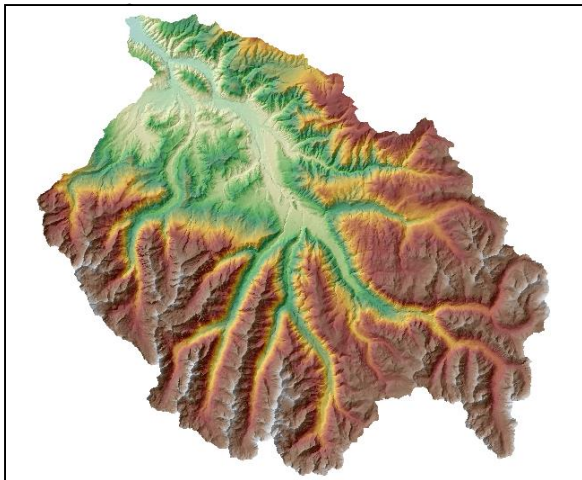
- 1) System energy
- 2) Valley confinement
- 3) Hillslope coupling

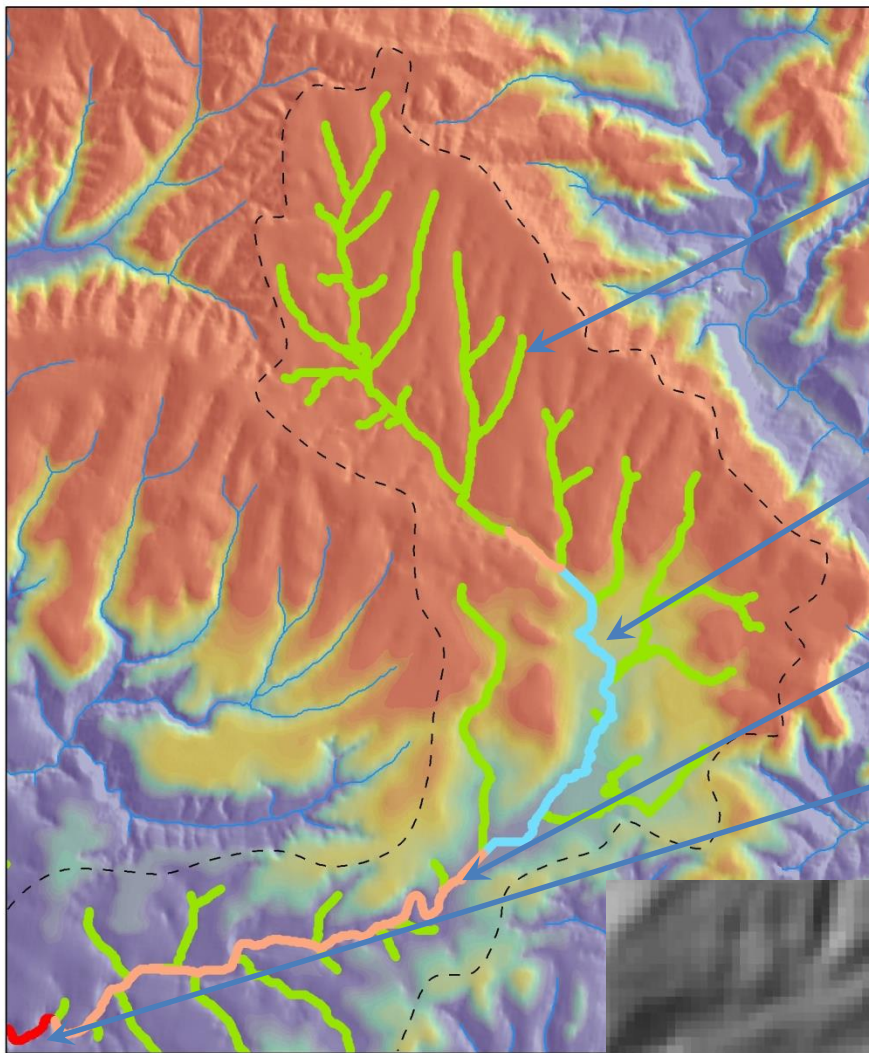
Headwater	> 4%	Confined	Steep
High-energy Coupled	> 4%	Confined	Steep
High-energy Open	> 4%	Unconfined	Steep
Moderate-energy Confined	0.1 - 4%	Confined	Low-Steep
Moderate-energy Unconfined	0.1 - 4%	Unconfined	Low-Steep
Canyon	Variable	Confined	Steep
Gorge	Variable	Confined	Steep
Glacial Trough	< 4%	Unconfined	Moderate-Steep
Low-energy Floodplain	< 0.1%	Unconfined	Low-Moderate



# Bringing it all together

- Input Layers and Regional Metrics:
  - DEM, Q100, Hillslope angles, Bankfull width parameters, Debris flow runout
- Behind the scenes:
  - Segment by segment analysis of channel, valley and hillside components
- End products:
  - Shapefiles of valleys (Hydro, Geo, and Hydro-Geo), hillslopes
  - Rasters for streams, channel width, Q100 flow volume



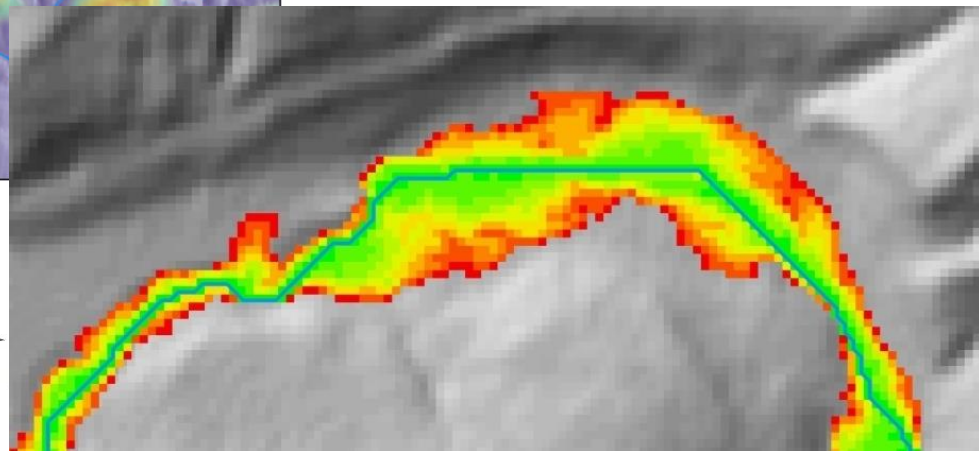


High energy coupled valley

Canyon

Moderate energy unconfined valley

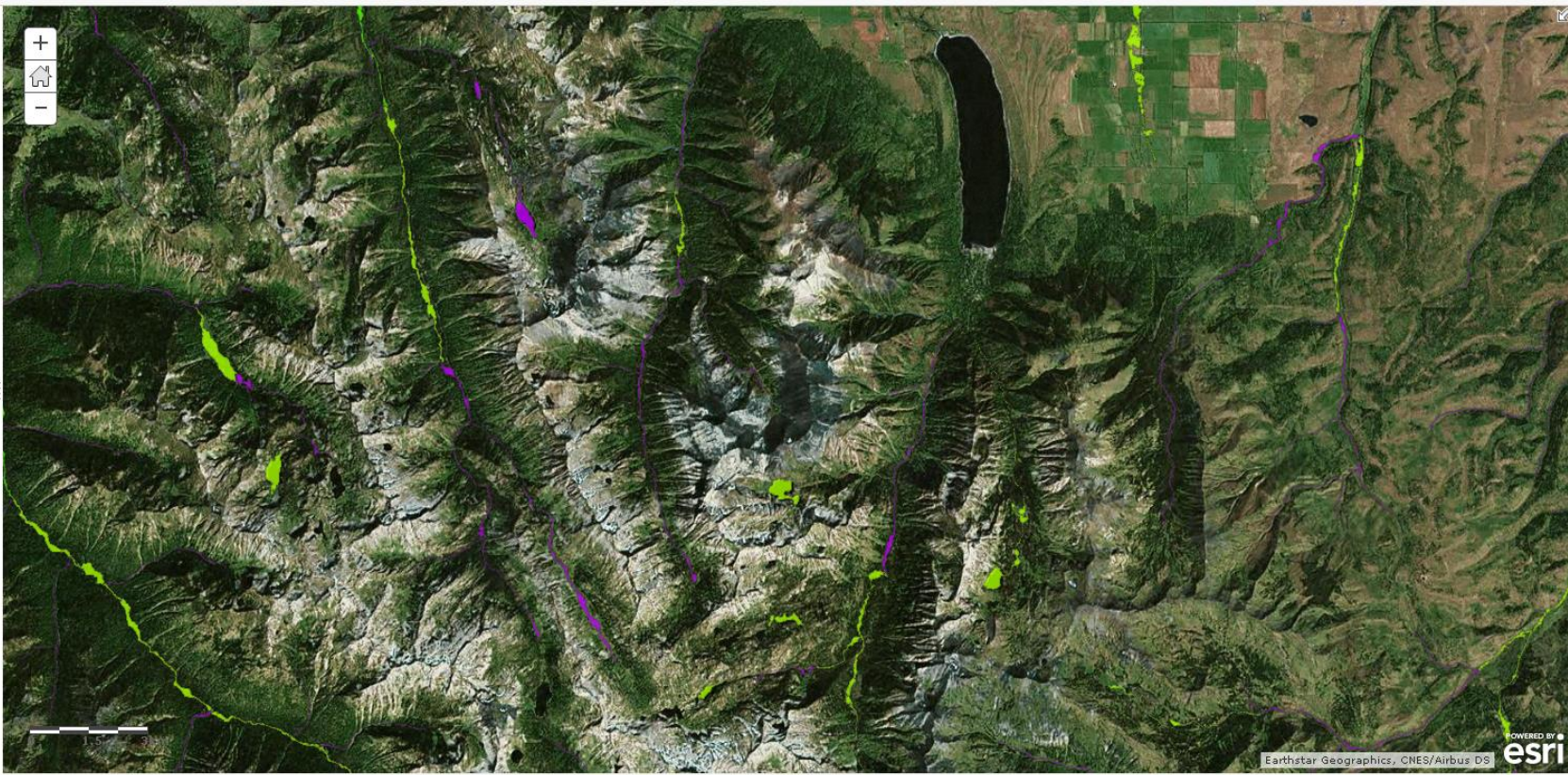
Low energy floodplain



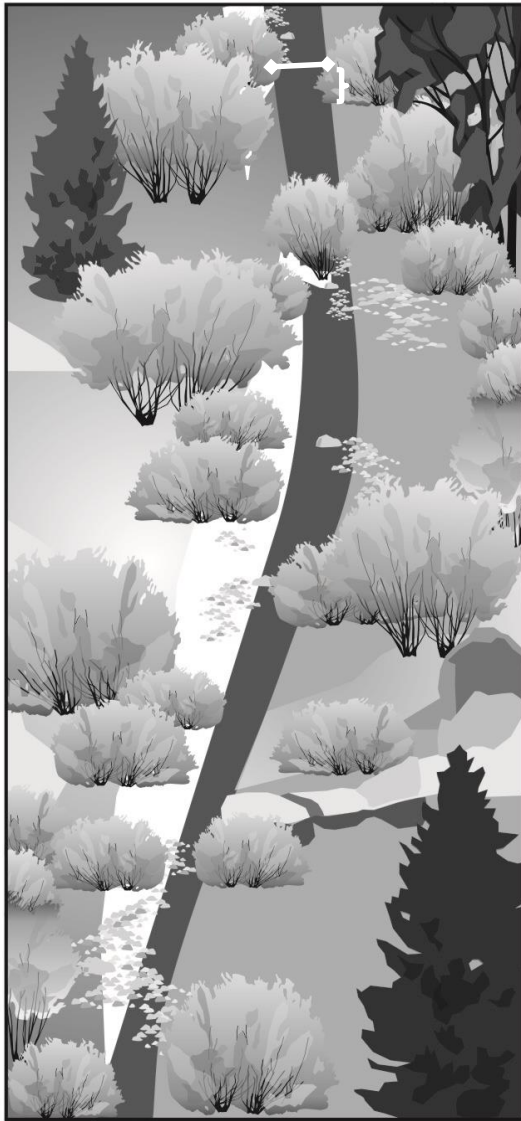
Contents

- VCA Region 17
- Region6 HGVC
  - HEC
  - GOR
  - CAN
  - MEC
  - MEO
  - GLA
  - LEF
  - Other
- Region5 HGVC
- Region4 HGVC
- Region3 HGVC
- Region2 HGVC
- Region1 HGVC
- Imagery

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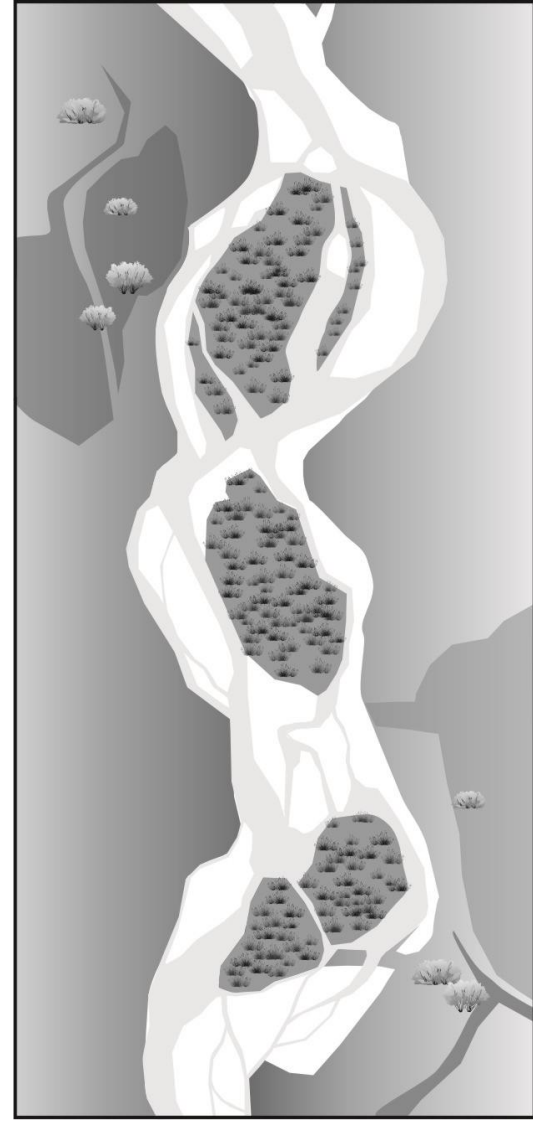
Narrow-straight



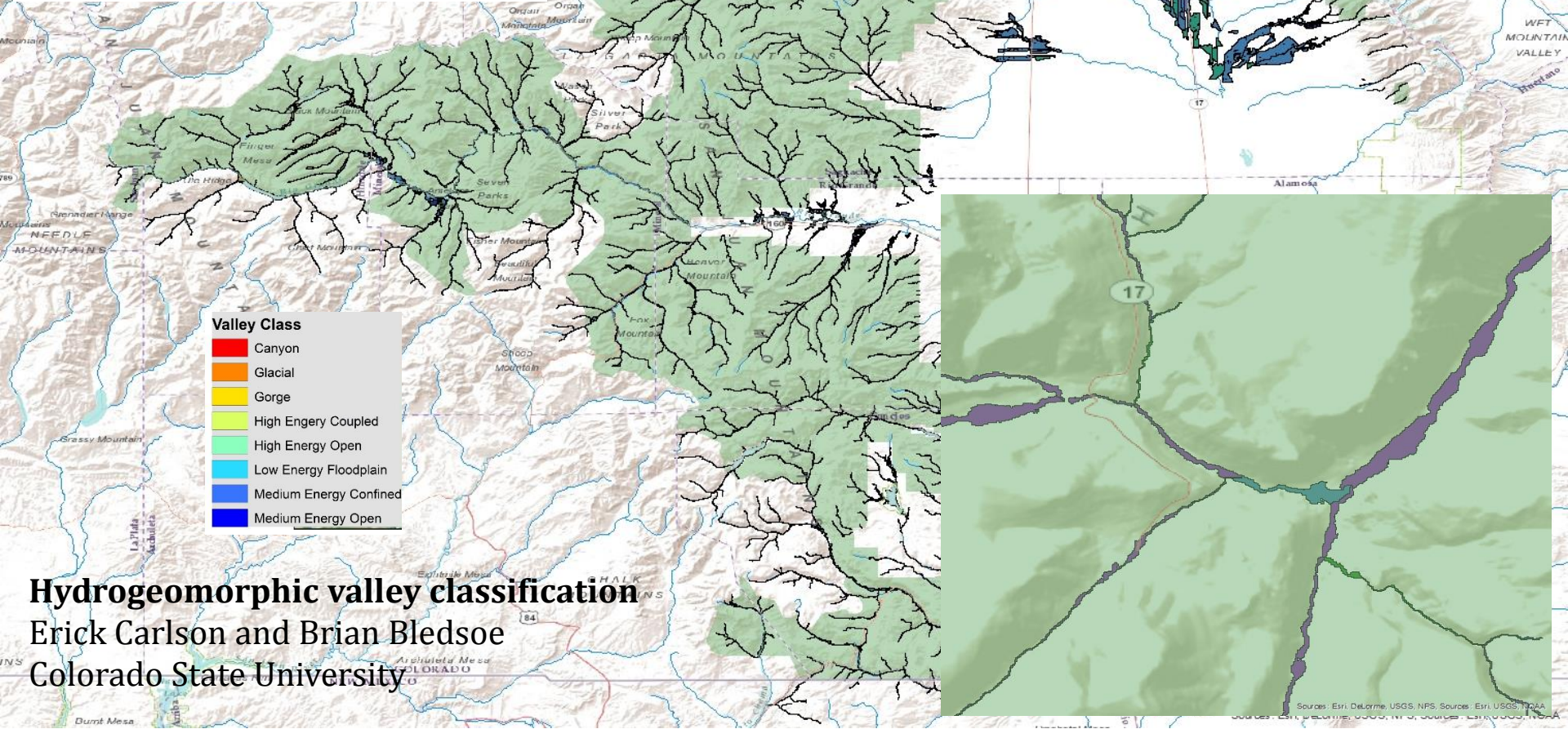
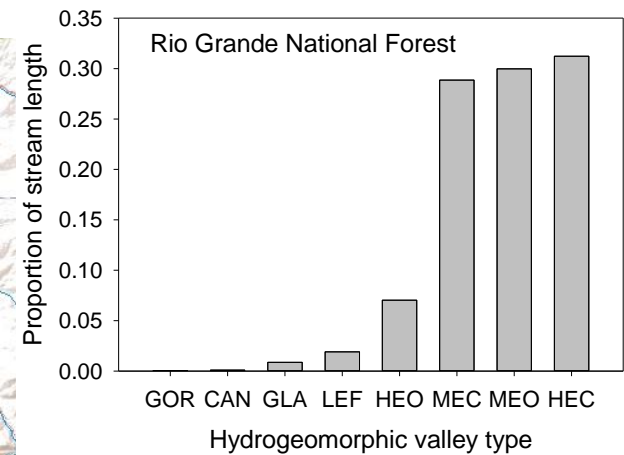
Meandering



Braided-Anastomosing







Desired conditions?



How to quantify, monitor, and set measurable goals?



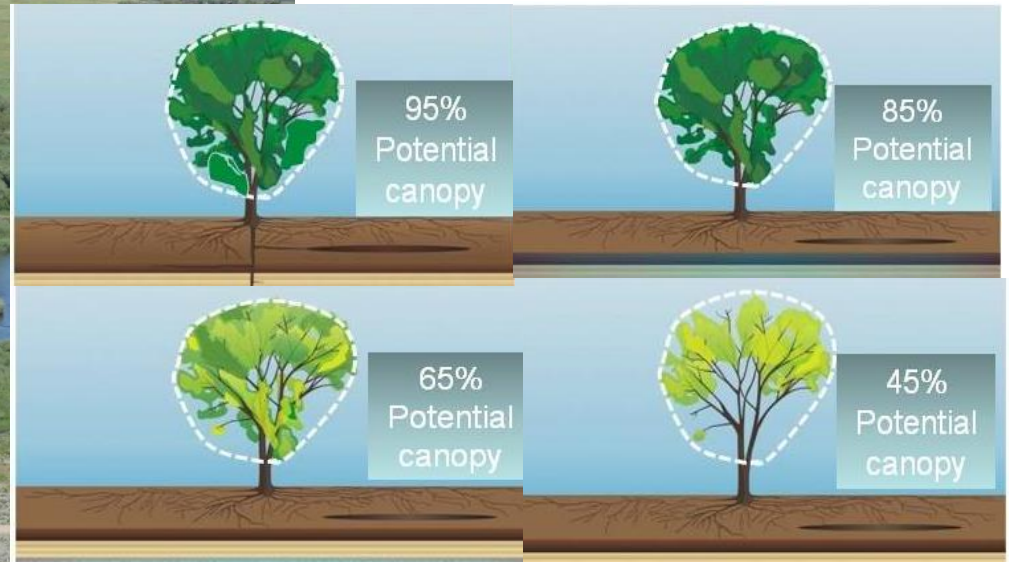
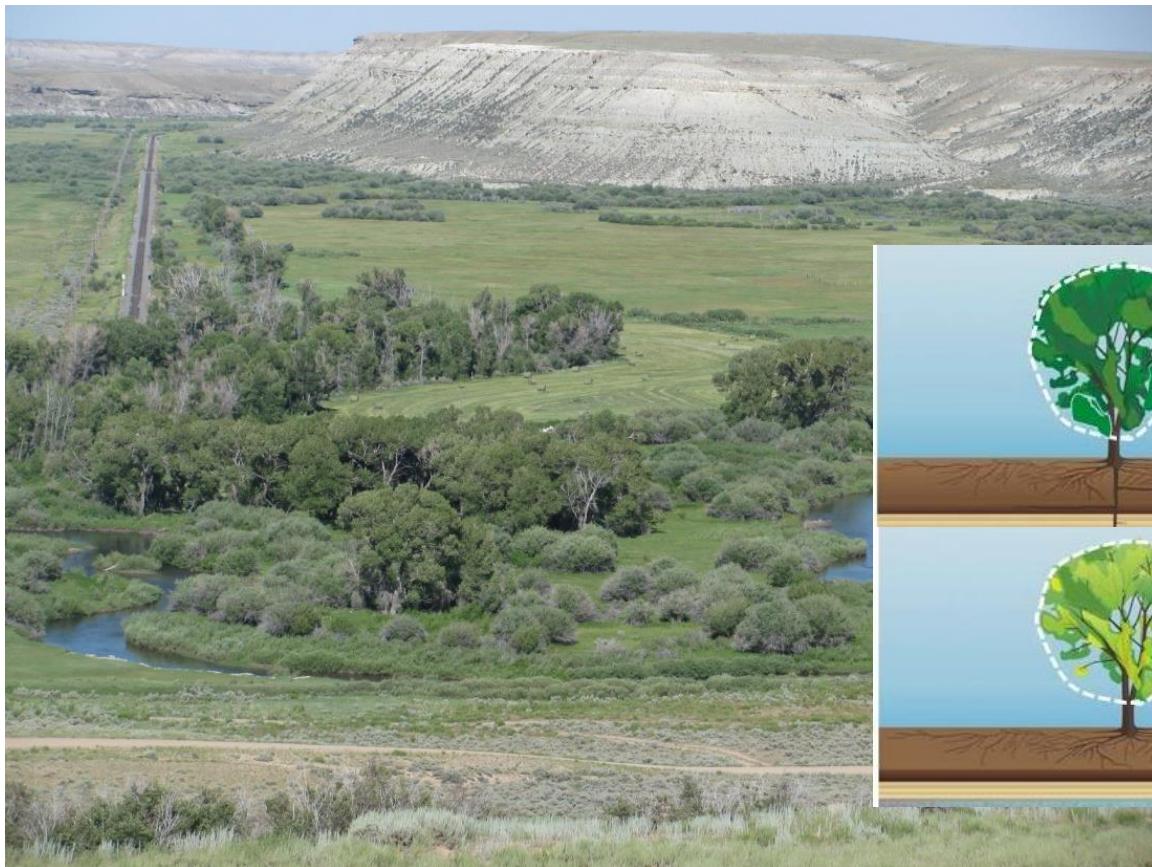
Need to identify reference or 'desired condition' sites and measure over time



Quantify reference conditions in a range of valley and channel types

# Riparian vegetation monitoring: Line-point intercept and point centered quarter sampling

- Plant species composition and vertical structure
- Tree stem density, basal area, and condition



*Scott et al. 1999*

- Channel cross sections and fluvial  
Classification  
Width to depth  
Form
- Reach longitudinal profile  
Gradient  
Longitudinal profile
- Substrate characterization  
Bare soil, gravel, cobble, boulder,  
bedrock, water

Combined:

- Opportunity for trend monitoring
- Ability to hydraulically model to develop rating curves
- Measurable attributes of desired or reference conditions



# National Riparian Protocol

Project-level monitoring  
Field data collection  
and analysis tools

## U.S.D.A. Forest Service National Riparian Vegetation Monitoring Protocol Conterminous United States



Prepared by  
The U.S.D.A. Forest Service  
National Riparian Technical Team  
July, 2011



<http://www.fs.fed.us/biology/watershed/riparian.html>



Geomorphology 123 (2011) 304–310

Contents lists available at ScienceDirect

**Geomorphology**

Journal homepage: [www.elsevier.com/locate/geomorph](http://www.elsevier.com/locate/geomorph)

Geomorphic and process domain controls on riparian zones in the Colorado Front Range

Ellen E. Wohl<sup>a</sup>, David M. Merritt<sup>b,c</sup>

<sup>a</sup> School of Earth and Atmospheric Sciences, Georgia Institute of Technology, 770 Chastain Ave., Atlanta, GA 30332, USA  
<sup>b</sup> Department of Geological Engineering and Science, Colorado State University, Fort Collins, CO 80523, USA  
<sup>c</sup> Department of Geology, Colorado State University, Fort Collins, CO 80523, USA

ESPM SURFACE PROCESSES AND LANDFORMS

Earth Surf. Process. Landforms 40, 304–310 (2011)  
 Copyright © 2011 John Wiley & Sons, Ltd.  
 Published online 4 October 2011 in Wiley Online Library  
[www.interscience.wiley.com](http://www.interscience.wiley.com) DOI: 10.1002/esp.1651

### Downstream effects of stream flow diversion on channel characteristics and riparian vegetation in the Colorado Rocky Mountains, USA

Sharon T. Calkin<sup>1</sup>, Tzayana S. Blachuk<sup>2</sup>, Ellen Wohl<sup>3</sup>, Elizabeth Schuckenberg<sup>4</sup>, David M. Merritt<sup>5</sup> and Kathleen A. Dain<sup>6</sup>

<sup>1</sup> Medicine Bow National Forest, Larimer, WY, USA  
<sup>2</sup> Lassen National Forest, Susanville, CA, USA  
<sup>3</sup> Department of Geosciences, Colorado State University, Fort Collins, CO, USA  
<sup>4</sup> Routt National Forest, Steamboat Springs, CO, USA  
<sup>5</sup> USDA Forest Service, NRI&C, Fort Collins, CO, USA  
<sup>6</sup> Rocky Mountain Research Station, Fort Collins, CO, USA

Received 1 May 2010; Revised 9 September 2010; Accepted 11 September 2010  
 \*Correspondence to: Ellen Wohl, Department of Geosciences, Colorado State University, Fort Collins, CO 80523-1402, USA. E-mail: ellen.wohl@colostate.edu



**ABSTRACT.** Flow diversions are widespread and numerous throughout the semi-arid mountains of the western United States. Diversions vary greatly in their structure and ability to divert water, but can alter the magnitude and duration of base and peak flows, depending upon their size and management. Channel geometry and riparian plant communities have adapted to unique hydrologic and geomorphic conditions existing in the areas subject to fluvial processes. We use geomorphic and vegetation data from low-gradient (2.7%) streams in the Rocky Mountains of north-central Colorado to assess potential effects of diversions. Data were collected at 37 reaches, including 16 paired upstream and downstream reaches and five unpaired reaches. Channel geometry data were derived from surveys of bankfull channel dimensions and substrate. Vegetation was sampled using a line-point intercept method along transects oriented perpendicular to the channel, with a total of 100 sampling points per reach. Elevation above and distance from the channel were measured at each vegetation sampling point to analyze differences in lateral and vertical zonation of plant communities between upstream and downstream reaches.

Geomorphic data were analyzed using mixed effects models. Bankfull width, depth, and cross-sectional area decreased downstream from diversions. Vegetation data were analyzed using biological diversity metrics, richness, evenness and diversity, as well as multivariate community analysis. Evenness increased downstream from diversions, though reduced frequency of woody indicator species and increased frequency of upland indicator species. Probability of occurrence for upland species downstream of a

### FLUVIAL RIPARIAN CLASSIFICATION FOR NATIONAL FORESTS IN THE WESTERN UNITED STATES

THESIS

Submitted by  
Erick A. Carlson

ESPL logo

ESPM SURFACE PROCESSES AND LANDFORMS

Earth Surf. Process. Landforms 39, 1245–1258 (2011)  
 © 2011 John Wiley & Sons, Ltd.  
 Published online 21 April 2011 in Wiley Online Library  
[www.interscience.wiley.com](http://www.interscience.wiley.com) DOI: 10.1002/esp.1577

### Modeling the functional influence of vegetation on streambank cohesion

Paul J. Ellen Wohl<sup>a</sup> and David M. Merritt<sup>b</sup>

<sup>a</sup> School of Earth and Atmospheric Sciences, Georgia Institute of Technology, 770 Chastain Ave., Atlanta, GA 30332, USA  
<sup>b</sup> Department of Geology and Environmental Science, Utah State University, Utah, Sweden



**ABSTRACT.** The importance of vegetation in adding cohesion and stabilizing streambanks has been widely recognized in sectors of fluvial geomorphology, including stream restoration and studies of long-term channel change. Changes in plant form, height, branching, and root architecture have been attributed to the impacts of vegetation on hydraulic roughness and stability. However, these studies focus either on flume studies where analog vegetation is used, or case studies featuring trees, which is commonly invasive. We present functional differences of bank-stabilizing root characteristics and add cohesion with vegetation categorized as woody and non-woody and by the vegetation groups of trees, shrubs, grasses, and forbs. Field root morphology and tensile strength of 14 species common to riparian areas in the southern Rocky Mountains, in field along streambanks in the montane and subalpine zones of the Colorado Front Range. Using the vegetation root component of a physically-based bank stability model (BSTEM), we estimated the added cohesion for various sediment textures with lists of each of the 14 species. Significant differences exist between woody and non-woody vegetation and between the four species categories with respect to the coefficient of the root tensile strength curve, lateral root extent, and maximum root diameter.

Example Section

USFS National Riparian Protocol

Field data entry form

Recorder:       River name:

Conductor:       Date:

Plot date:       Site name:

UTM or Lat Lon:       Transect number:

Channel width:       Reach length:

Stream type:       Way type:

Site-level design condition:

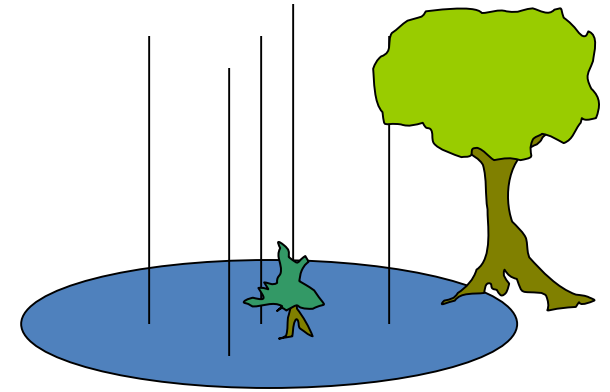
delimitation of floodplains and riparian zones

of debris among ecotopes, despite their nearby presence along a wide variety of rivers and stream form and process and valley bottom management can be defined based on frequency of inundation (reviewed in Malby et al., 1998) or morphologic criteria (Nanson and Cooke, 1992; Roggen, 1994; Verly et al., 2004). Definitions for riparian zones range from those that are process-delimitation criteria (Cargill et al., 1991) to those that are specific delimitation instructions to multiple interacting processes that together (Cargill et al., 2004). Riparian zones are commonly associated or commensurate (USFS RIVS, 2004) to lead to omission errors if a disturbance removes the characteristic vegetation. Of hydrology, delimiting a riparian area as a groundwater for at least part of the growing (1997); this definition is applicable in riparian jurisdictions (legally defined) worldwide, but that it is not applicable in seldom-inundated riparian vegetation because of the

# Vegetation and habitat structure and provisions

## Bird Habitat

- Basal area woody vegetation
- Standard deviation woody tree diameter
- Foliage height diversity
- Mean vegetation cover (various height classes)
- Foliage hits



## Mammal-Reptile Habitat

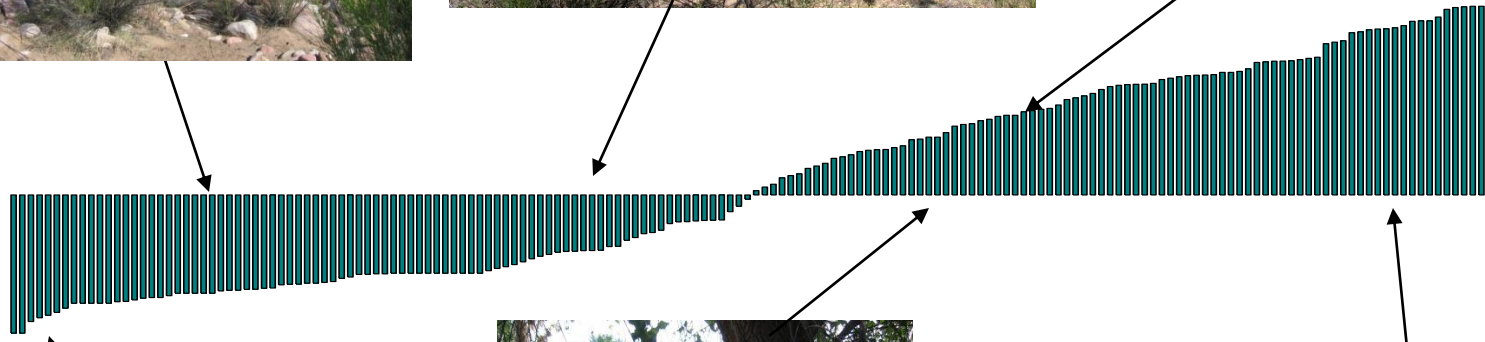
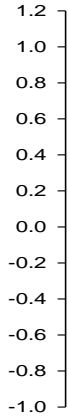
- Basal area woody vegetation
- Standard deviation woody tree diameter
- Riparian tree overstory
- Abundance of seedlings
- Mean and SD vegetation cover
- Cover sandy substrate



Merritt, D.M. and H.L. Bateman. Linking streamflow and groundwater to avian habitat in a desert riparian system. *Ecological Applications* 22:1973-1988.

McElhinny *et al.* 2006. An objective and quantitative methodology for constructing an index of stand structural complexity. *Forest Ecology and Management* 235:54-71.

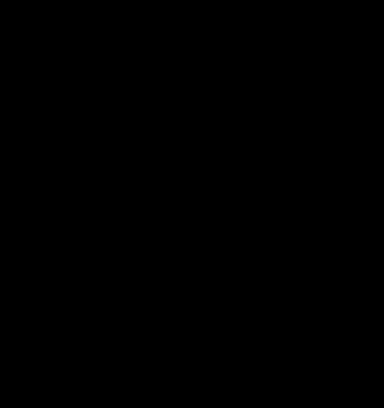
Bird habitat structural diversity



Desired conditions?



Linking pattern to process?

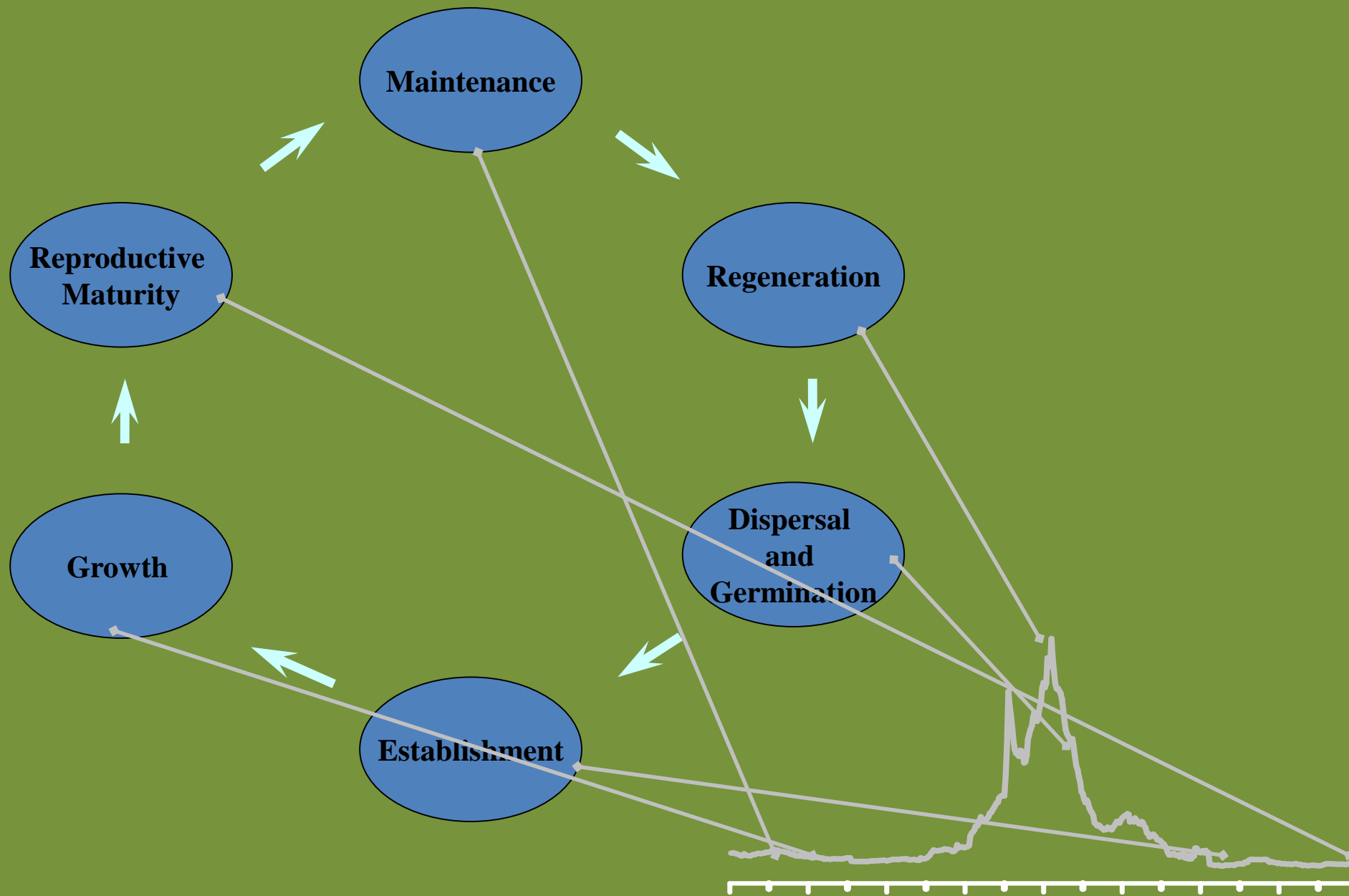


Answer is probabilistic

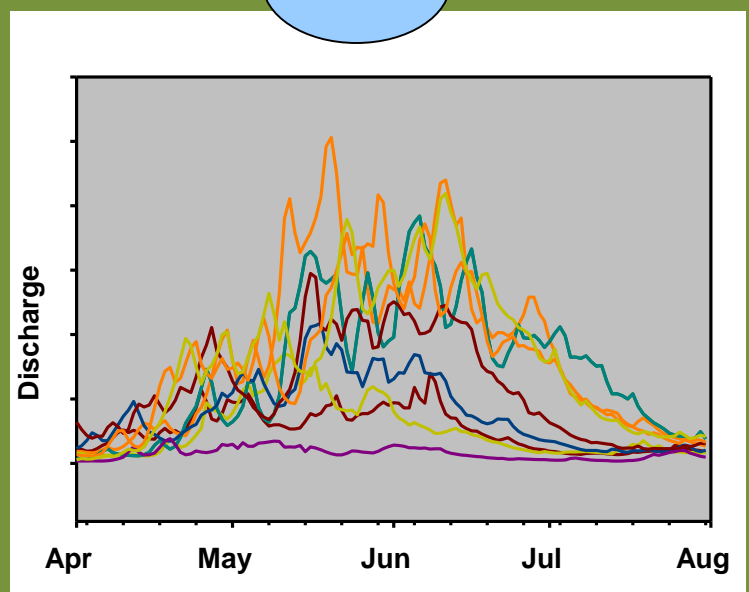
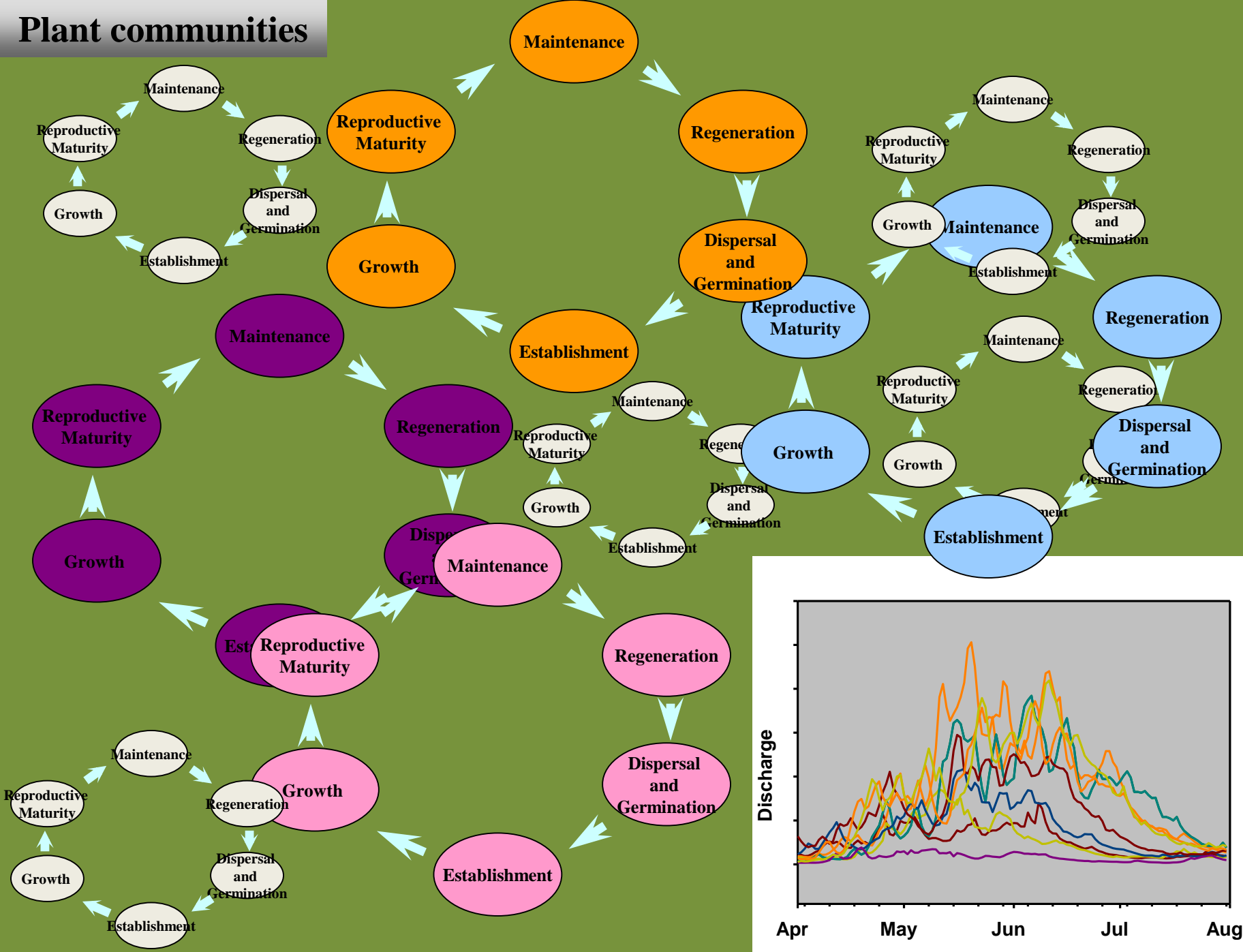


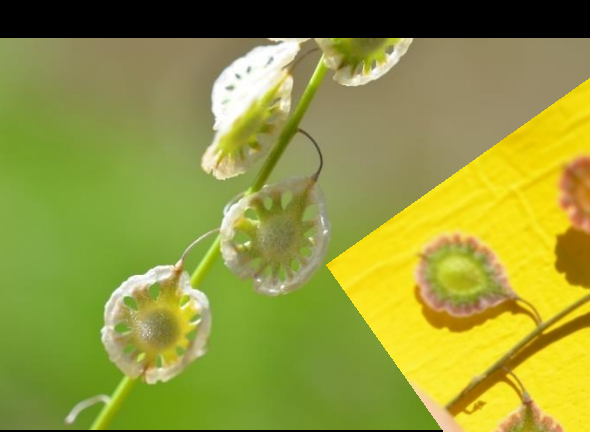
Link current patterns to measured processes (e.g., hydrology)

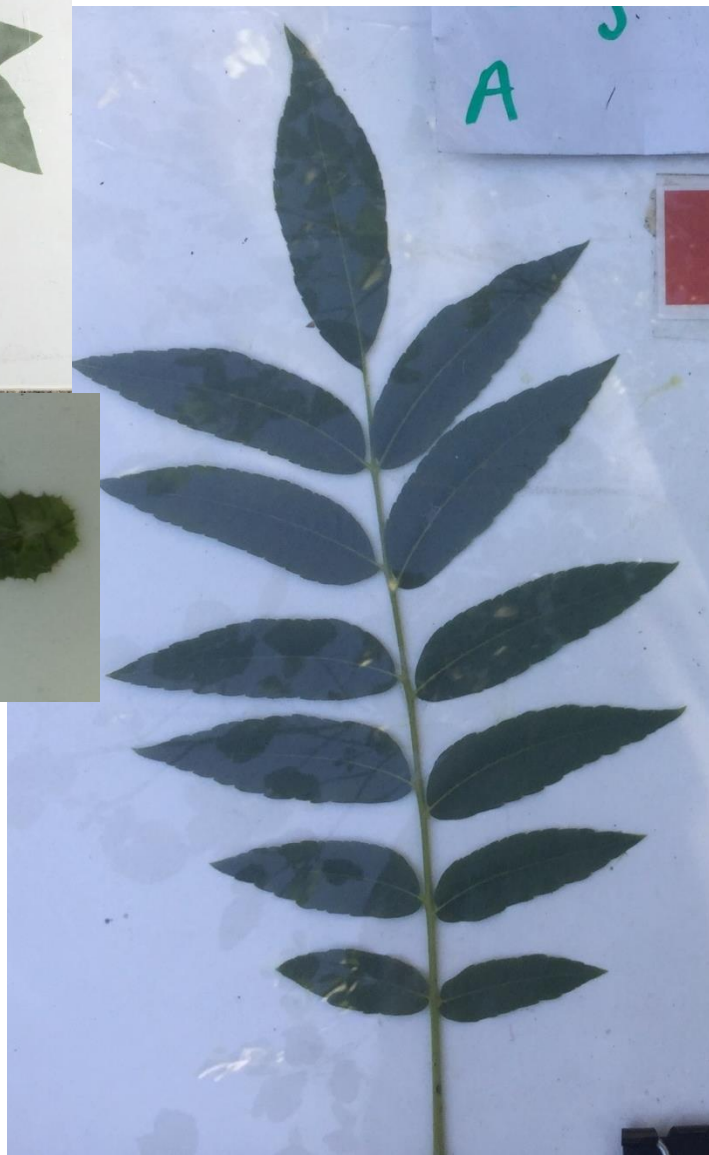
# Individual plants

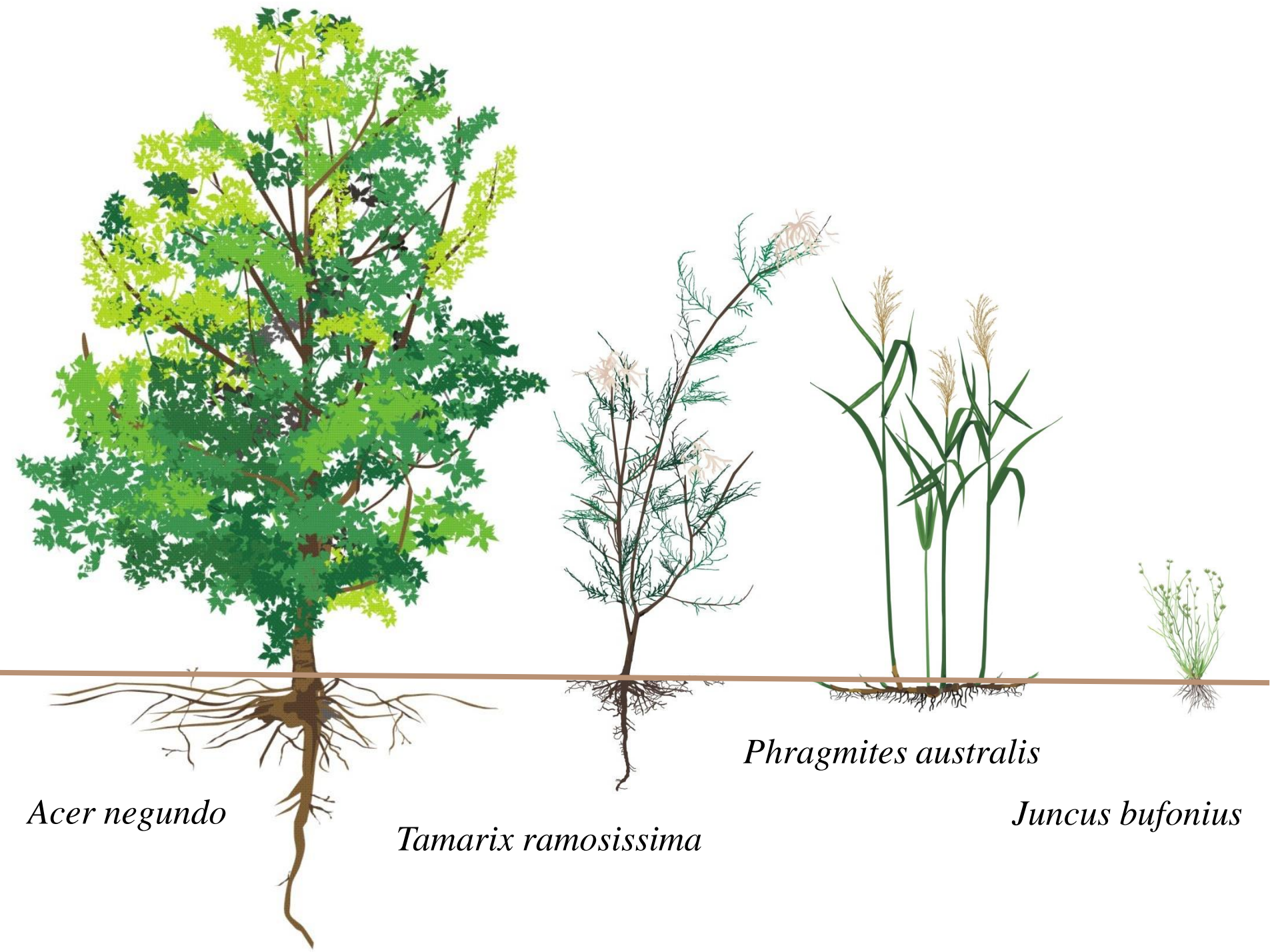


# Plant communities









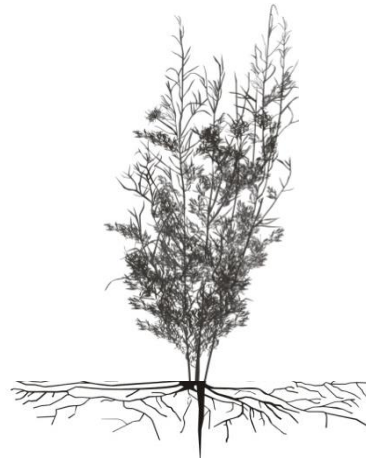
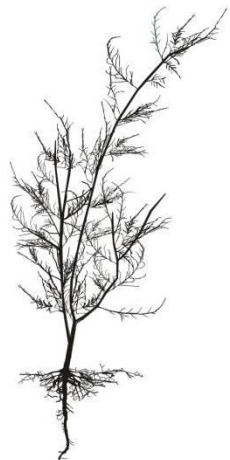
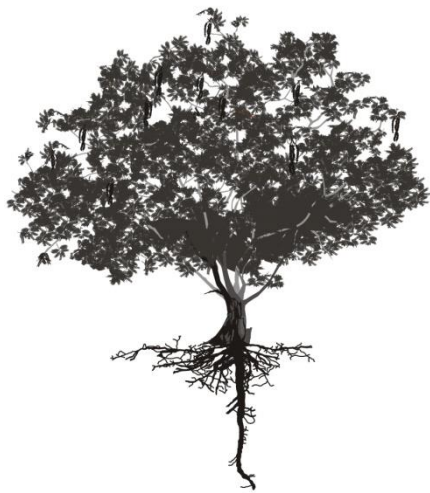
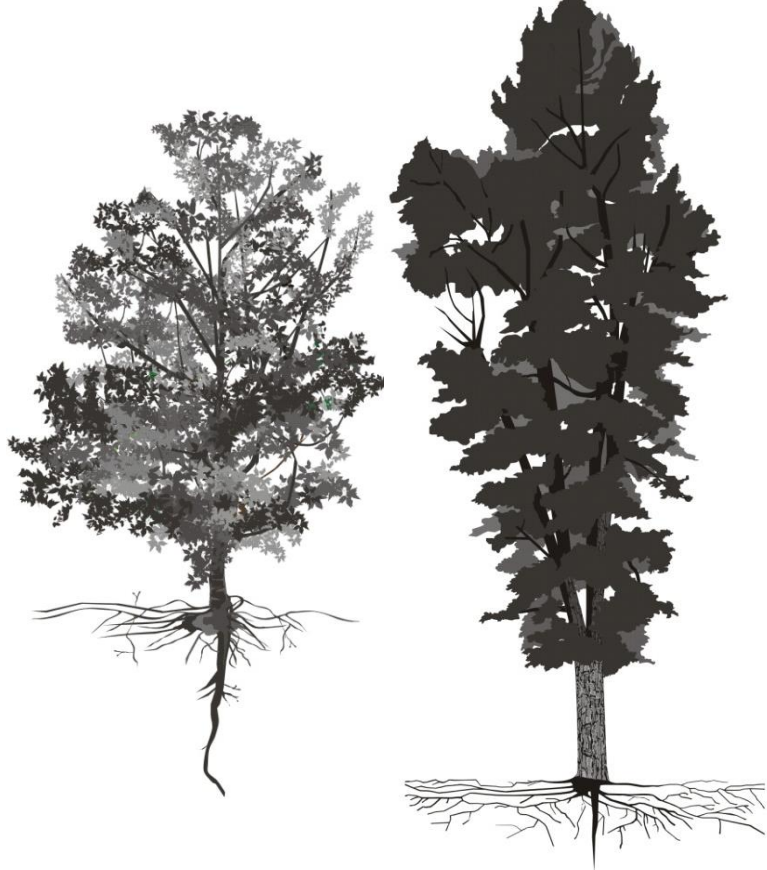
*Acer negundo*

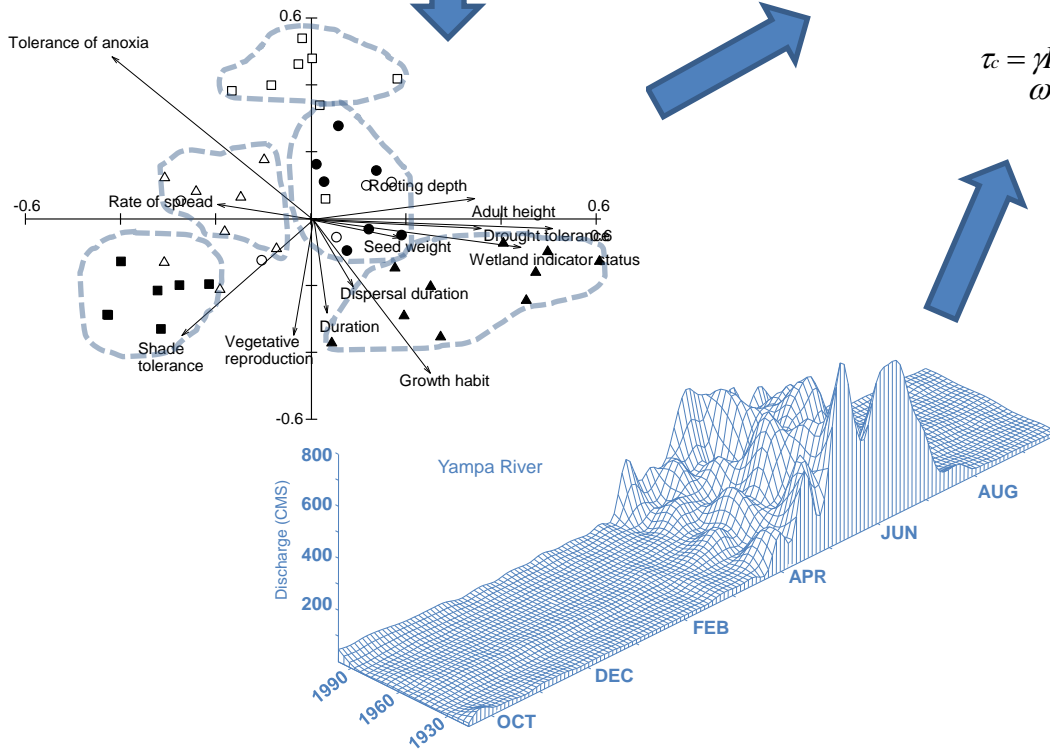
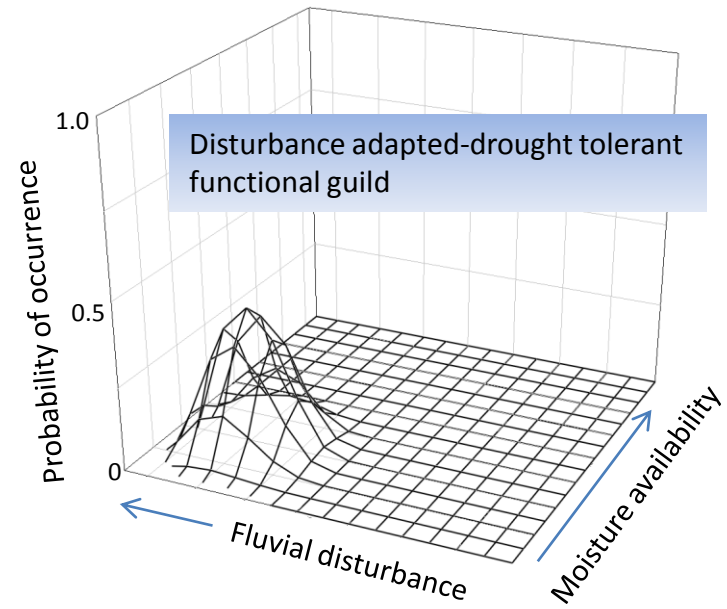
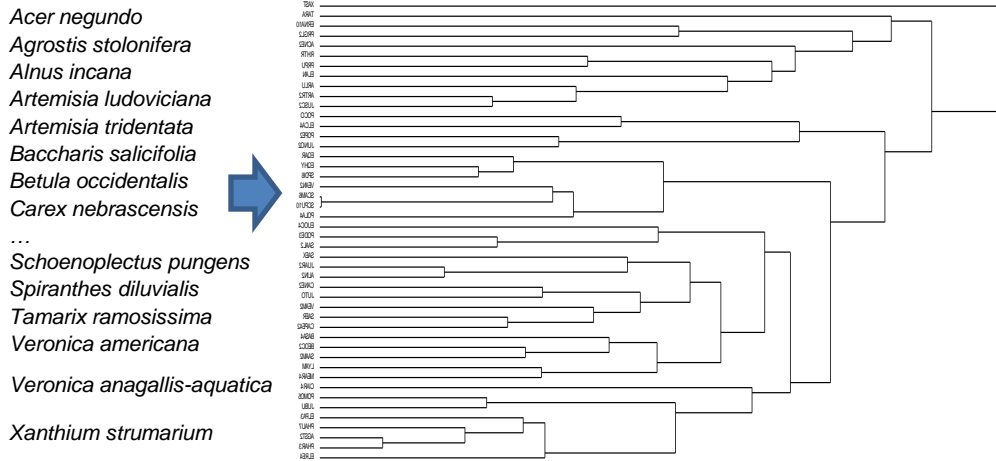
*Tamarix ramosissima*

*Phragmites australis*

*Juncus bufonius*



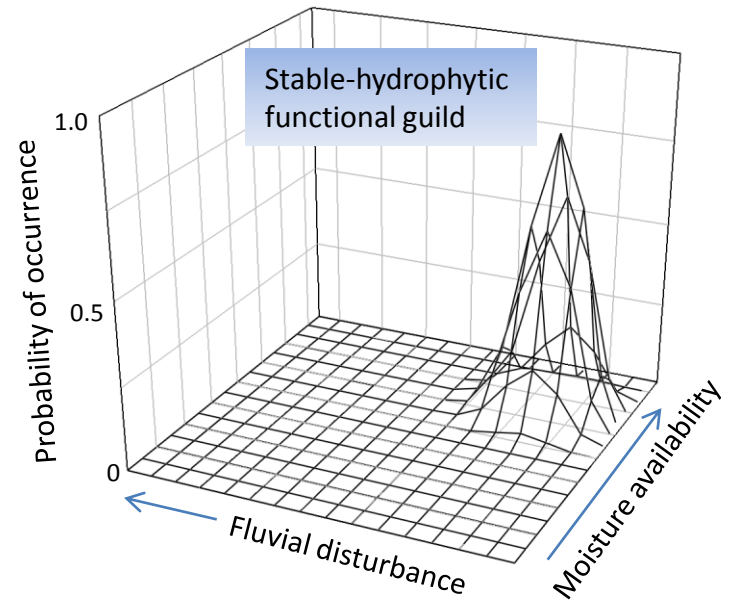




$$\tau_c = \gamma RS$$

$$\omega = \gamma QS$$

Flow duration ...



## Guild 7

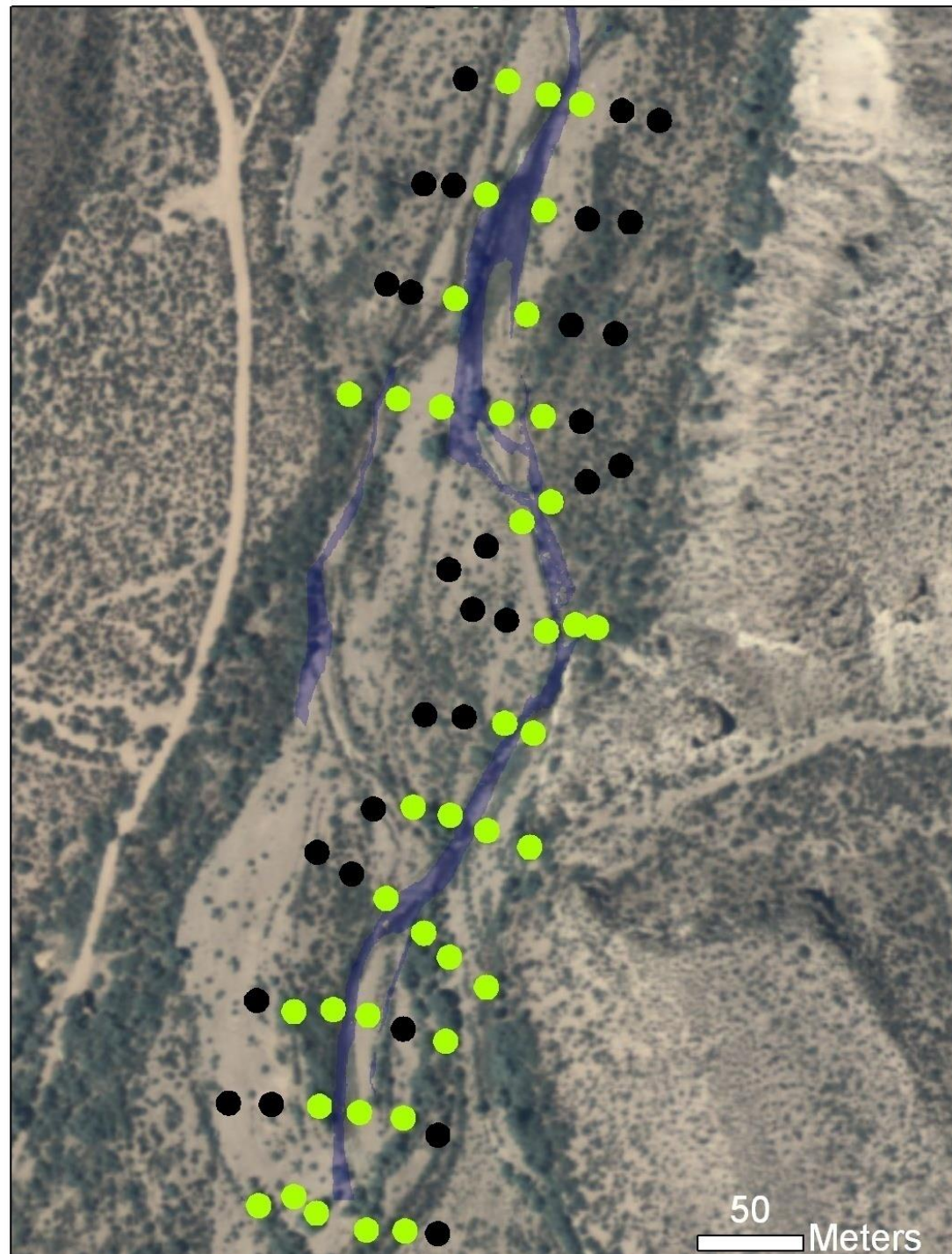
### Riparian forest:

- High canopy
- Disturbance-adapted
- Phreatophytic
- Anaerobic

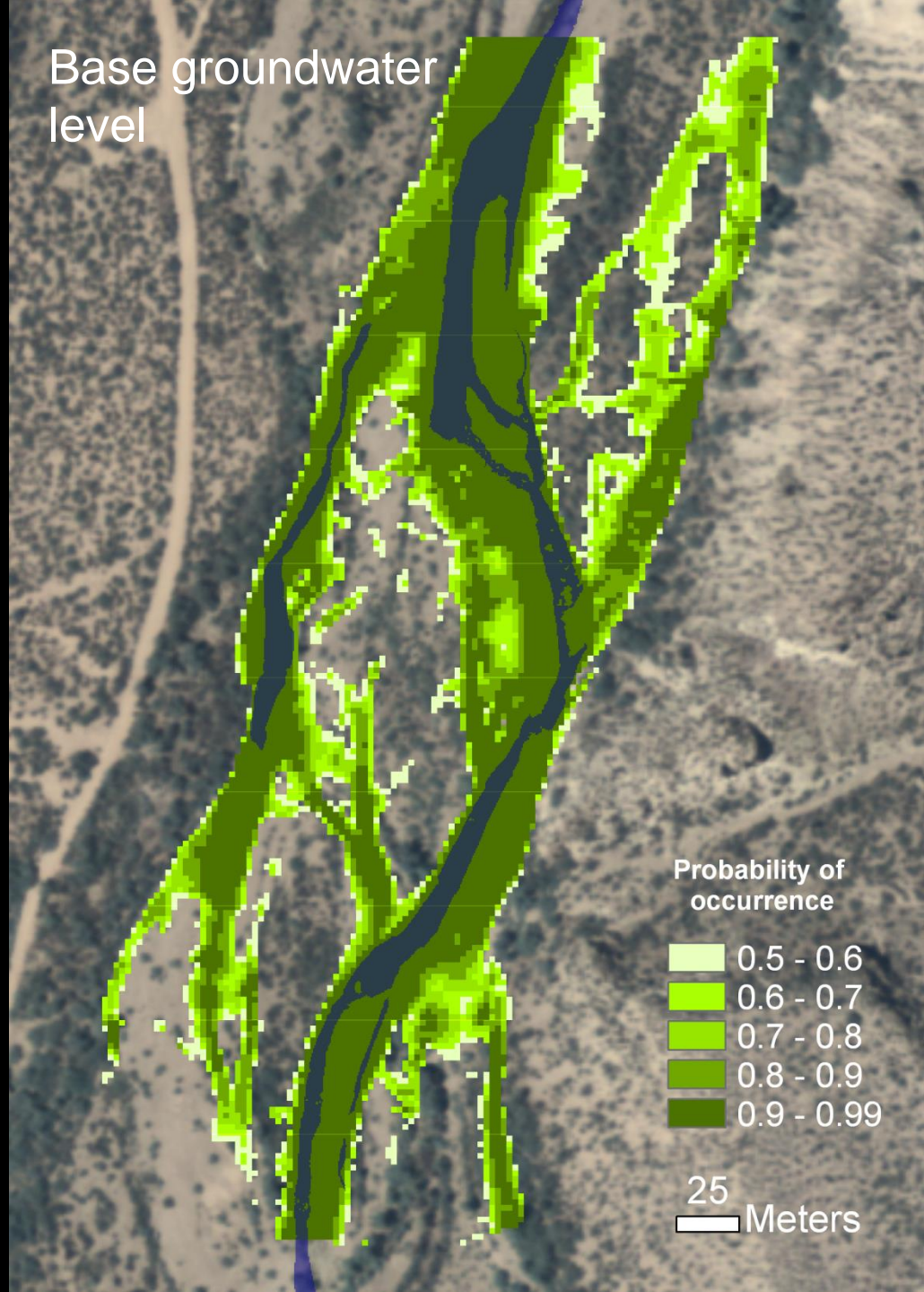
*Populus fremontii*

*Salix gooddingii*

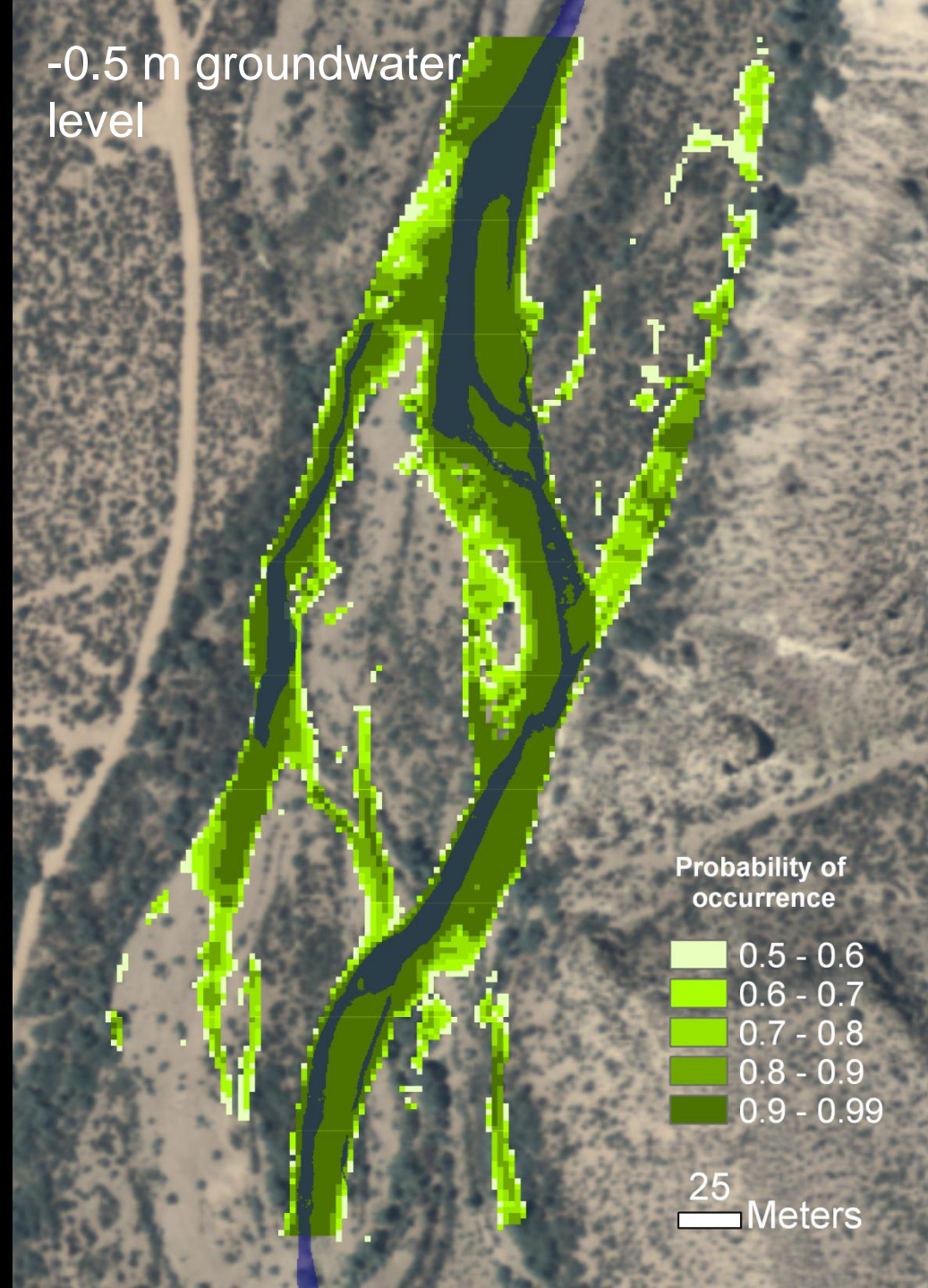
*Celtis laevigata*



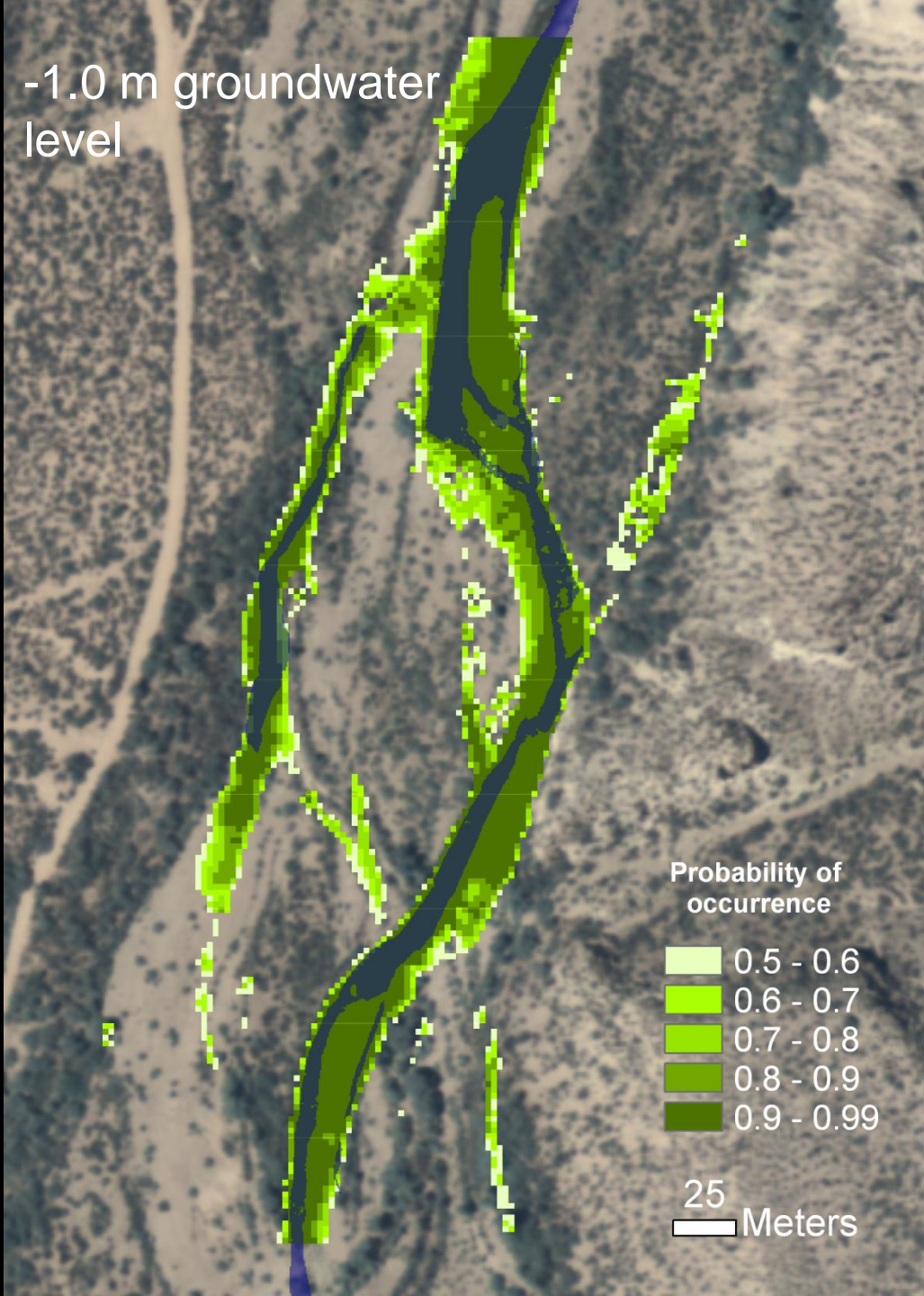
Base groundwater  
level



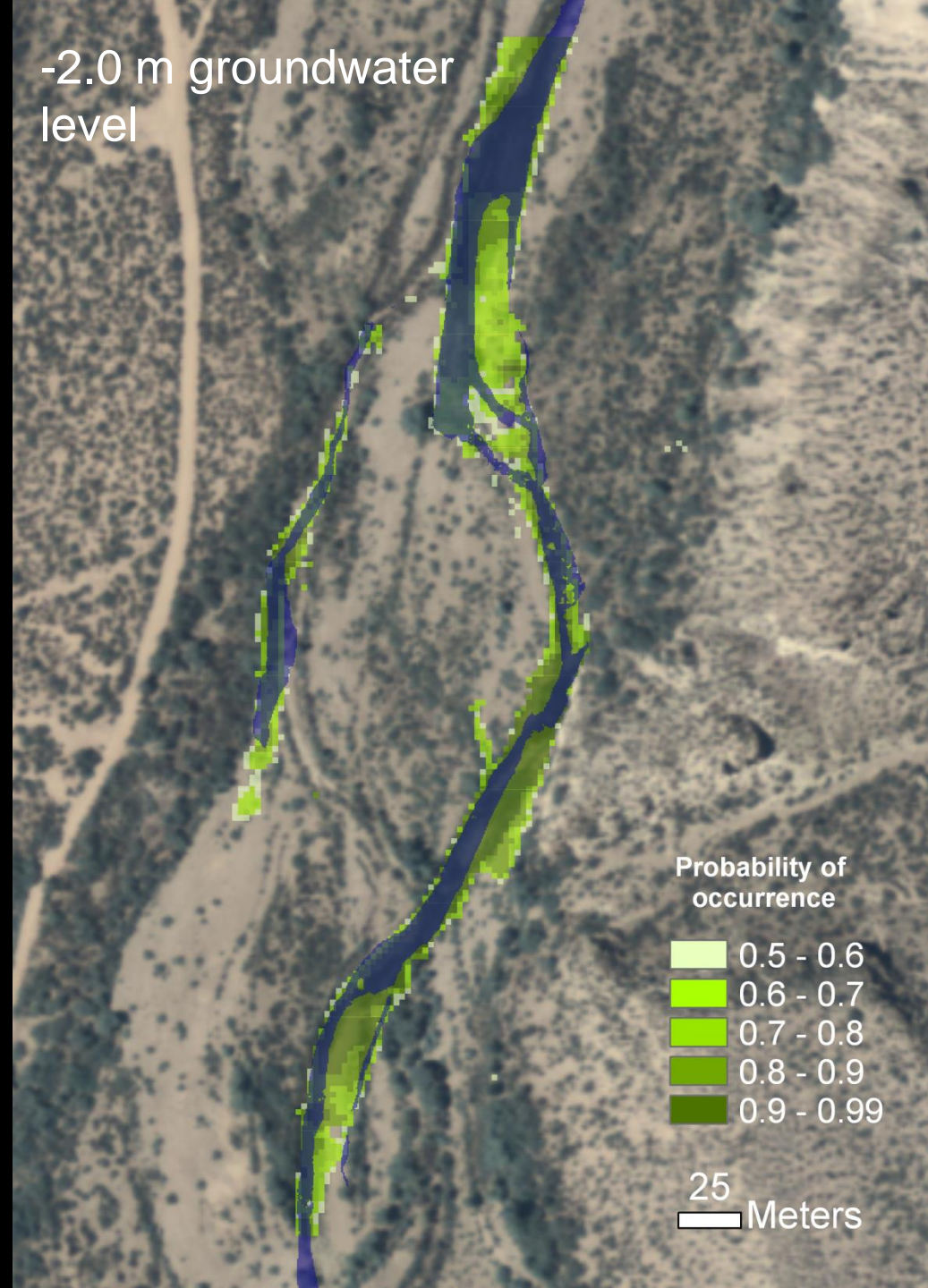
-0.5 m groundwater level

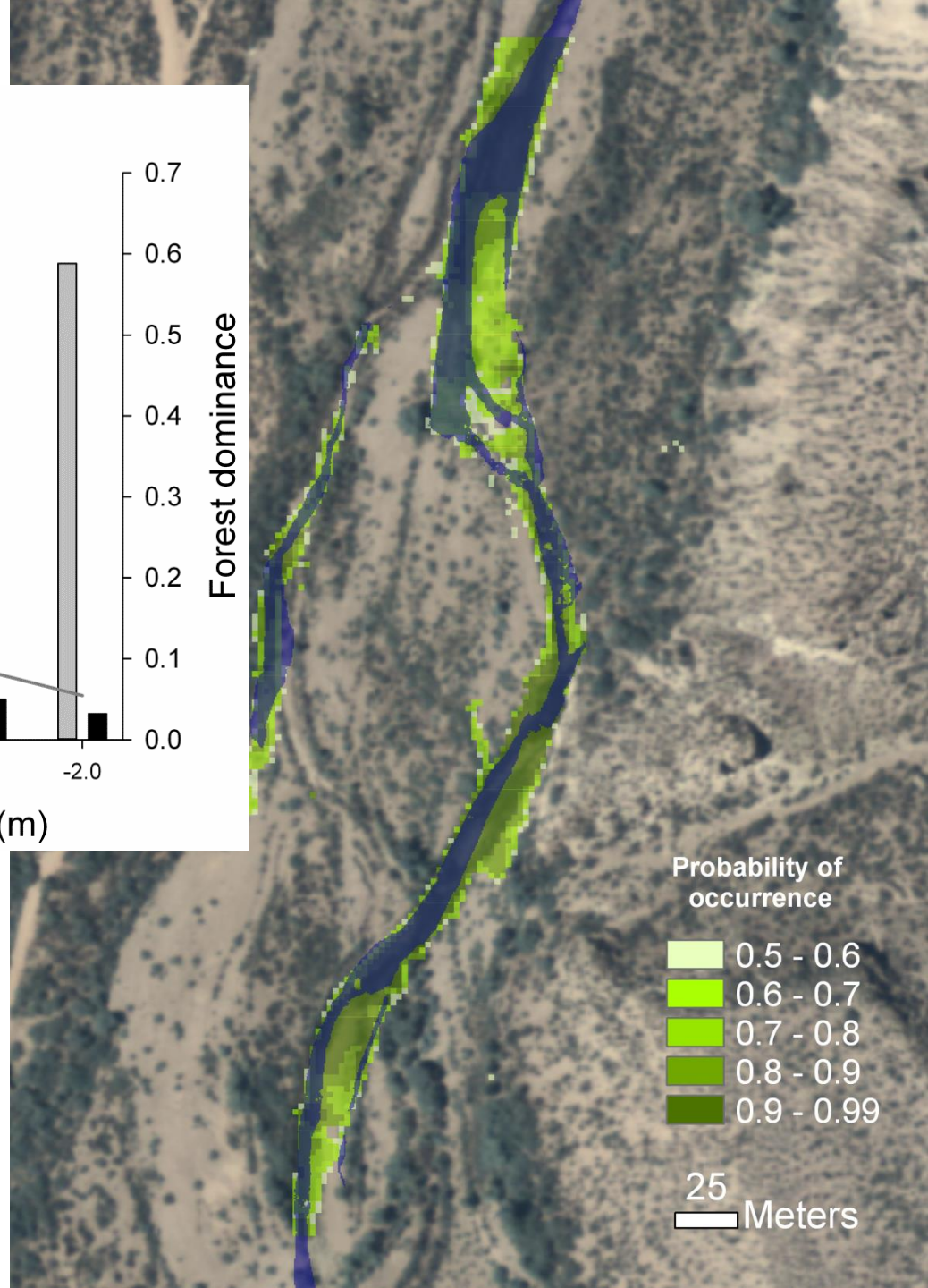
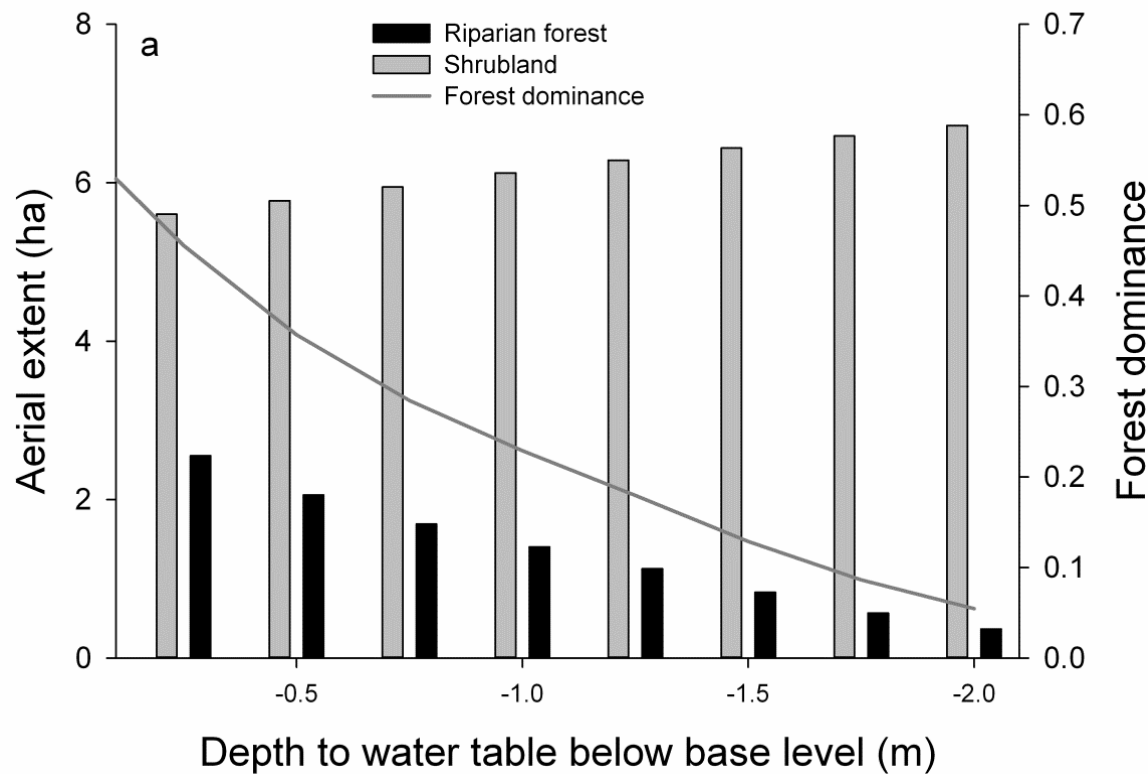


-1.0 m groundwater level

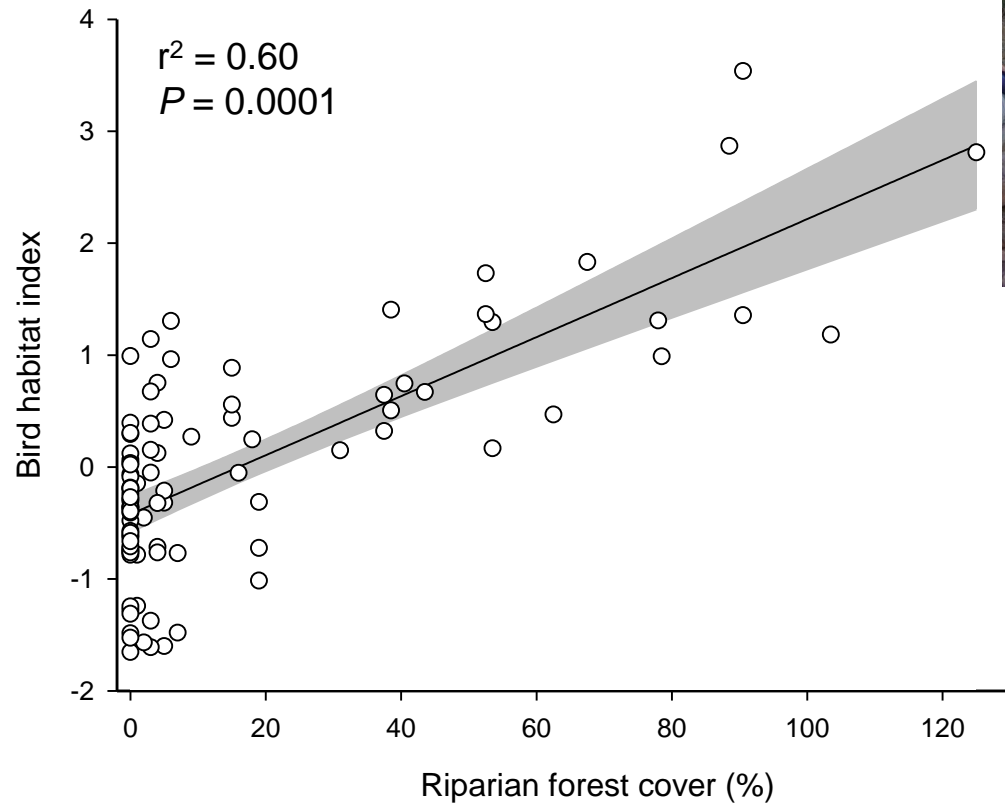


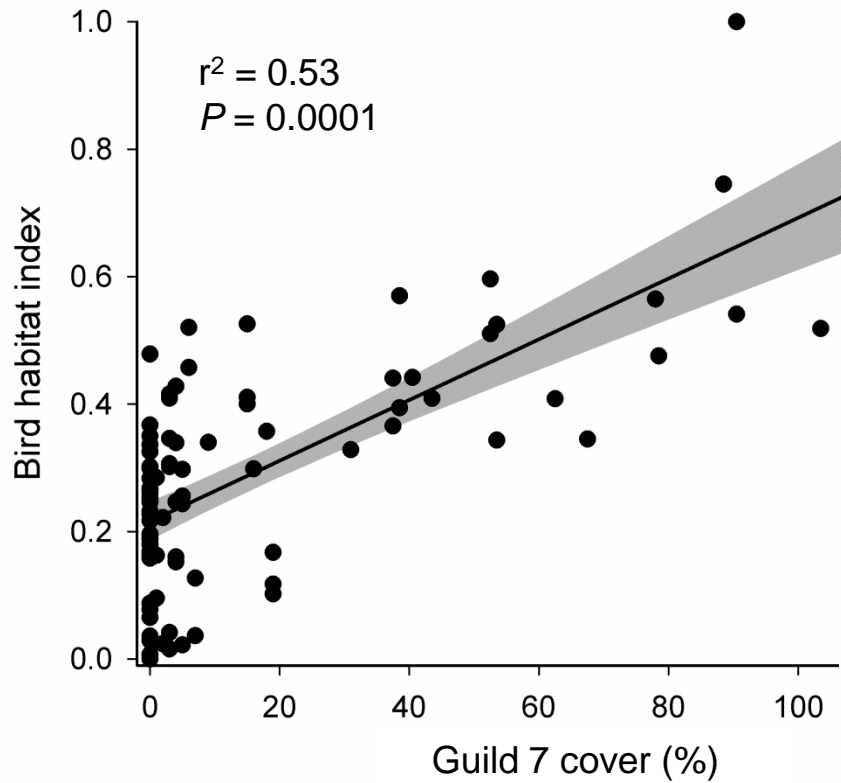
-2.0 m groundwater level



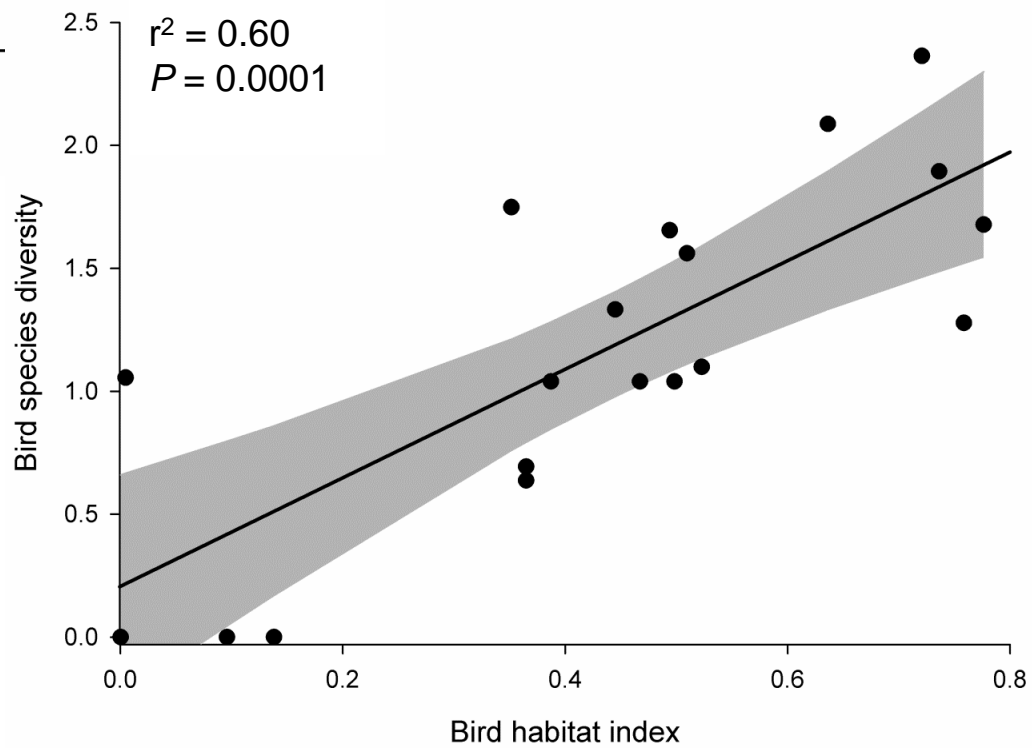


*Merritt and Bateman.  
Ecological Applications. 2012.*



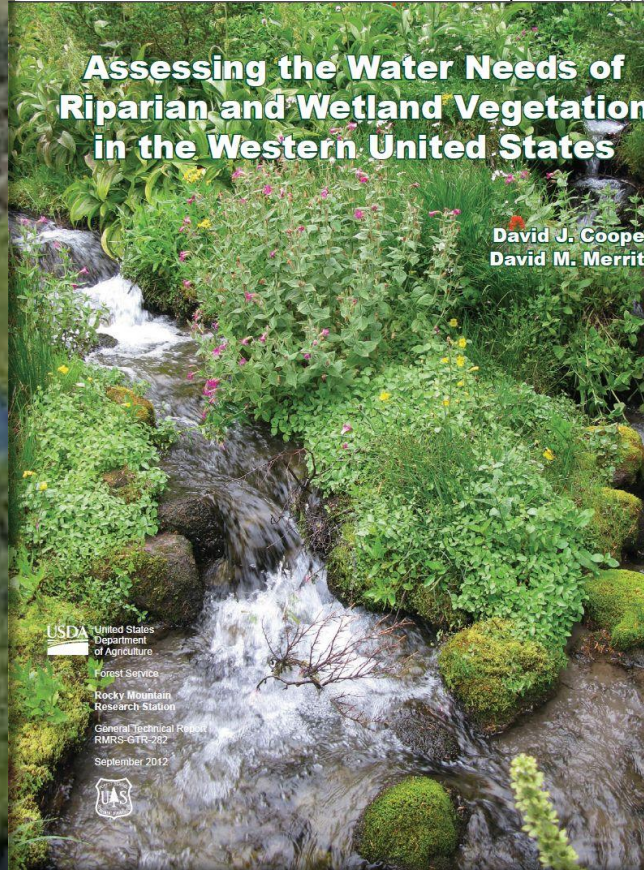


*B. Grice*



Species, cover  
and guild modeling

Instream flows  
and groundwater  
levels necessary to  
sustain desirable  
vegetation



## Assessing the Water Needs of Riparian and Wetland Vegetation in the Western United States

David J. Cooper  
David M. Merritt

USDA United States  
Department  
of Agriculture  
Forest Service  
Rocky Mountain  
Research Station  
General Technical Report  
RMRS-GTR-262  
September 2012



[www.treearch.fs.fed.us/pubs/41207](http://www.treearch.fs.fed.us/pubs/41207)

## Freshwater Biology

Freshwater Biology (2010) 85, 206–225

doi:10.1111/j.1365-2427.2009.02206.x

## Theory, methods and tools for determining environmental flows for riparian vegetation: riparian vegetation-flow response guilds

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DAVID A. LYTTLE<sup>§</sup>

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<sup>‡</sup>Department of Biology and Graduate Degree Program in Ecology, Colorado State University, Fort Collins, CO, U.S.A.  
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### SUMMARY

1. Riparian vegetation composition, structure and abundance are governed to a large degree by river flow regime and flow-mediated fluvial processes. Streamflow regime exerts selective pressures on riparian vegetation, resulting in adaptations (trait syndromes) to specific flow attributes. Widespread modification of flow regimes by humans has resulted in extensive alteration of riparian vegetation communities. Some of the negative effects of altered flow regimes on vegetation may be reversed by restoring components of the natural flow regime.

2. Models have been developed that quantitatively relate components of the flow regime to attributes of riparian vegetation at the individual, population and community levels.

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## Riparian plant guilds of ephemeral, intermittent and perennial rivers

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### SUMMARY

1. Plant functional types (or guilds) increasingly are being used to predict vegetation response to global changes. Continued human population growth coupled with projected warmer and drier climate will alter the hydrologic regimes of many arid-zone rivers, including intermittent rivers. We aimed to identify (i) woody plant guilds associated with distinct stream types of an arid region and (ii) plant traits indicating adaptation to the selective pressures of water availability and fluvial disturbance.

2. We used hierarchical clustering to identify 11 plant guilds from floodplains, terraces and uplands of eight Arizona rivers that vary in surface flow permanence, depth to ground water and intensity of fluvial disturbance.

3. Six guilds were riparian pioneers with small, wind-dispersed seeds, three guilds were late-seral, shade-tolerant riparian taxa with large animal-dispersed seeds, and two guilds were composed of desert xerophytes. Within the riparian pioneer and seral groups, guilds varied in water acquisition and productivity traits including wood density and rooting depth.

4. The community-weighted traits varied or covaried with water availability and fluvial disturbance. Root: shoot ratio, canopy height and leaf area were influenced strongly by water availability, with the latter two showing a nonlinear response to changes in water table depth. Leaf length increased, and wood density decreased, as sites became wetter and more fluvially disturbed. Community-weighted seed mass, seed dispersal and spinescence varied most strongly with elevation above thalweg (an indicator of decreasing fluvial disturbance).

5. These analyses will enable prediction of changes in the relative abundance of plant types and plant traits in response to changes in stream flow regimes, such as shifts towards greater intermittency. The distribution patterns of guilds among riparian habitat types emphasise the importance of focusing conservation efforts not only on the limited number of perennial rivers remaining in arid regions, but also on intermittent and ephemeral rivers with shallow water tables.

**Keywords:** desert stream, plant functional type, riparian vegetation, trait, wood density

### Introduction

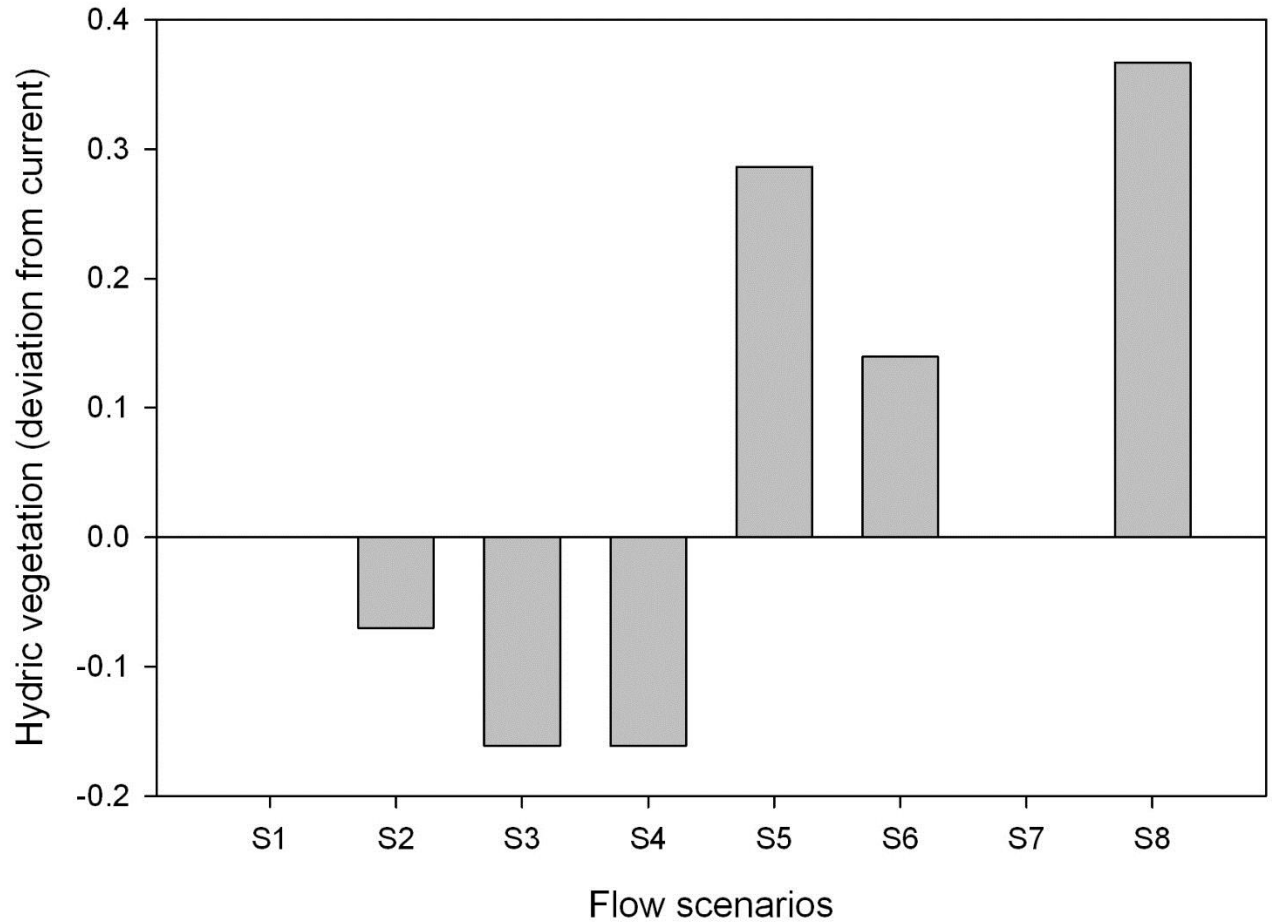
Anthropogenic changes to stream hydrology have substantially altered the distribution, abundance and species composition of riparian plant communities (Patten, 1998; Tockner & Stanford, 2002; Stella *et al.*, 2012). Increasing global pressures on freshwater resources, coupled with climate change, will drive further changes in stream surface and subsurface flows (Palmer *et al.*, 2009).

Alterations are likely to be greatest in highly populated dryland regions (Döhl, Fiedler & Zhang, 2009).

Water is the primary limiting factor for vascular plants in dryland regions. In some desert rivers, stream flows are increasing owing to effluent discharge, agricultural return flow and urbanisation, but for many others, flows are decreasing owing to groundwater pumping, diversion of surface water and climate-linked reductions in stream and groundwater recharge (Serrat-Capdevila

# Decision support tool: consequences of alternative futures

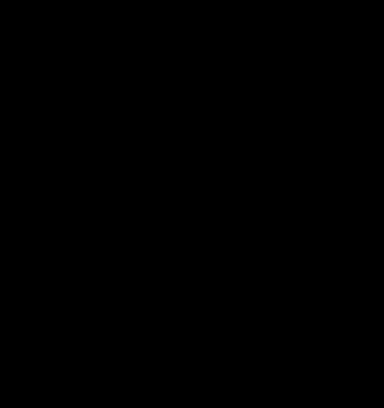
- S1 - Cct
- S2 - Reservoir Exp.
- S3 - S1 + Hotter, drier
- S4 - S2 + Hotter, drier
- S5 - S1 + Wetter, cooler
- S6 - S1 + Wet, cool
- S7 - S1 + Wet, cool, early
- S8 - S2 + Wetter, cooler, early



Desired conditions?



Species composition  
or functional  
composition?



Not a steady end state  
for most rivers

Answer is probabilistic

Alternative 'stable'  
states



What about warmer,  
drier future?  
NRV changes...

## Opportunities for the Forest Service to influence the flow regimes of streams

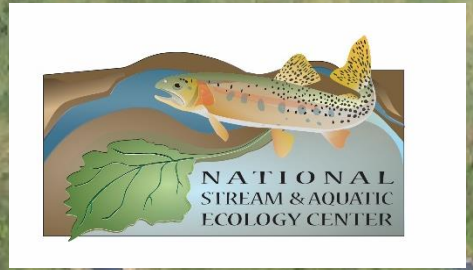
- Forest Plan Standards and Guides – National Forest Management Act
- Conditioning land use authorizations (easements for ditches and points of diversion)
- Input into Federal Energy Regulatory Commission hydropower dam relicensing (4e authority)
- Negotiating with local, state, and private entities (transfers)
- Implied and expressed Federal Reserved Water Rights
- Wild and Scenic River designation
- State Water Rights systems (instream or minimum flow programs) when appropriate.

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