Feedbacks between riparian vegetation and fluvial processes at multiple scales in natural and managed rivers

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Fluvial – Vegetation Interactions

- Fluvial forces interact with woody riparian plants in complex ways to influence the coevolution of river morphology and floodplain plant communities.

- How do feedbacks occur between local-scale vegetation change (composition and density) and corridor-wide evolution of river morphology?

Introduction
Small scale experiments
Large scale study
Conclusion
A need to bridge scales of inquiry

- Small vs. large scales
- Mechanistic vs. observational
- Simplicity vs. realism
- Physical vs. ecological approaches

Schoneboom et al., 2011. 10.1007/978-3-642-17475-9_18

Corenblit et al., 2007. ESPL 10.1016/j.earscirev.2007.05.004

Montgomery & Buffington 1998
Ecosystem changes can happen quickly

Virgin River, 2010 (a 10-20 year flood)
But how do we get from single flood events ...

... to long-term patterns of floodplain/vegetation coevolution?

Stella et al., 2011. Ecosystems 10.1007/s10021-011-9446-6
Management context #1

- How does vegetation size, density, and composition influence flow hydraulics and channel morphodynamics?
- Sediment equilibrium vs. deficit conditions
- Controls on plant uprooting force
- Implications for floodway mgt.


Management context #2

• Tamarisk in the U.S. Southwest influences both riverine plant communities and geomorphic processes.
• Can we use environmental flows to help control tamarisk’s spread?
Kui et al. -- an integrated suite of multi-disciplinary studies that contrasted the responses of tamarisk (*Tamarix* spp.) and cottonwood (*Populus fremontii*) in terms of

1. differences in vulnerability to scour and burial during floods;
2. interactions and feedbacks between plants and river morphodynamics; and
3. long-term coevolution of river floodplains and riparian communities following flow regulation from dams.

Li Kui
Monospecific trials; straight flume (manuscript in prep)

Mixed species; large outdoor meandering channel (Kui et al., 2014, *WRR*)

Multiple species mortality in burial (Kui & Stella, 2016, *Forest Ecol. & Mgt.*)

>50 years; river corridor evolution (Kui et al., 2017, *Ecohydrology*)

Temporal scales

- Seconds
- Hours
- Years
- Decades

Spatial scales (m²)

- Individuals: $10^{-1}$
- Patches: $10^0$
- Stands: $10^1$
- Reaches: $10^2$
- River corridors: $10^3$
- Vegetation communities: $10^4$
- >50 years: $10^5$
- >10 years: $10^6$
- >100 years: $10^7$

Introduction

Small scale experiments

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Small scale: plants in a patch

- Understand differences in plant morphological traits between cottonwood and tamarisk.
- Quantify plant burial and dislodgement during floods
- Quantify sediment deposition patterns

Pre-flood

Post-flood

Buried plants

Dislodged plants
**Results:**

**Plant structure**

- **Tamarisk:** Shrubby plant with lower crown and higher root biomass.
- **Cottonwood:** Single-stem plant with higher crown and lower root mass.
Two flume systems controlled discharge and sediment inputs.

Straight channel $\rightarrow$ sediment deficit conditions $\rightarrow$ plant dislodgement

Meandering channel $\rightarrow$ sediment equilibrium $\rightarrow$ plant burial
### Plant mortality

<table>
<thead>
<tr>
<th>Location</th>
<th>Species</th>
<th>Plant size</th>
<th>Density</th>
<th>Lost by</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight channel</td>
<td>cottonwood</td>
<td>short</td>
<td>sparse</td>
<td>Dislodgement</td>
<td>64%</td>
</tr>
<tr>
<td></td>
<td>cottonwood</td>
<td>tall</td>
<td>sparse</td>
<td>Dislodgement</td>
<td>38%</td>
</tr>
<tr>
<td></td>
<td>tamarisk</td>
<td>short</td>
<td>sparse</td>
<td>Dislodgement</td>
<td>47%</td>
</tr>
<tr>
<td></td>
<td>tamarisk</td>
<td>tall</td>
<td>sparse</td>
<td>Dislodgement</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>cottonwood</td>
<td>short</td>
<td>dense</td>
<td>Dislodgement</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>cottonwood</td>
<td>mixed size</td>
<td>dense</td>
<td>Burial</td>
<td>13%</td>
</tr>
<tr>
<td></td>
<td>tamarisk</td>
<td>mixed size</td>
<td>dense</td>
<td>Burial</td>
<td>39%</td>
</tr>
<tr>
<td></td>
<td>mixed</td>
<td>mixed size</td>
<td>sparse</td>
<td>Burial</td>
<td>19%</td>
</tr>
<tr>
<td></td>
<td>mixed</td>
<td>mixed size</td>
<td>dense</td>
<td>Burial</td>
<td>19%</td>
</tr>
</tbody>
</table>

- **Plant size**: shorter plants were more vulnerable
- **Different species** responses to mortality mechanisms:
  - Dislodgement: cottonwood loss > tamarisk loss
  - Burial: tamarisk loss > cottonwood loss
- **Density** effects: plants in sparse patches were more vulnerable

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**Introduction**

**Small scale experiments**

**Large scale study**

**Conclusion**
Summary – small scale experiments

- Larger plants had decreased vulnerability to floods
- Tamarisk had
  - greater frontal area $\rightarrow$ sediment deposition $\rightarrow$ increased plant burial
  - greater root mass $\rightarrow$ stabilized soils $\rightarrow$ reduced plant loss to scour.
- Both species and density influenced sediment deposition patterns.
Monospecific trials; straight flume (manuscript in prep)

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Multiple species mortality in burial (Kui & Stella, 2016, *Forest Ecol. & Mgt.*)

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Large scale: long-term river and vegetation evolution

- How does vegetation develop on high vs. low floodplains?
- How do channel width, braiding, and sinuosity respond in tamarisk vs. cottonwood dominated reaches?

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Methods – aerial photo interpretation

- Seven aerial photo series from 1953 to 2009 were analyzed in GIS.
- **Vegetation**: 3 cover types (cottonwood/willow, tamarisk, other vegetation) 2 densities (dense >50%, sparse <50%)
- **Geomorphology**: low vs high floodplains

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Analysis – two scales, two directions

- **Reach scale:**
  - species (tamarisk vs. cottonwood-willow),
  - geomorphic change (width, braiding, sinuosity)

- **River scale:**
  - vegetation area change × time × geomorphic surface × species

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Results – river scale veg area

- Flood magnitude and frequency decreased since dam construction (1968)
- Vegetation cover quadrupled since dam completion.

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**Chart:**
- Pre-dam and Post-dam periods.
- Peaks of flood magnitude depicted.
- Total vegetation area plotted.

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**Sections:**
- Introduction
- Small scale experiments
- Large scale study
- Conclusion
Geomorphologic changes

- Channel narrowed by 70%.
- Sinuosity increased slightly.
- Channel braiding decreased by 33%.
- Tamarisk had stronger effects on river morphology than cottonwood.
## Effects of vegetation type on reach-scale geomorphologic changes

Linear mixed model results quantifying the influence of local vegetation cover on adjacent channel morphological changes (width, sinuosity, and braiding index).

<table>
<thead>
<tr>
<th>Response</th>
<th>Vegetation Type</th>
<th>Coefficient Estimate</th>
<th>Standard Error</th>
<th>F value</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel width (m)</td>
<td>Cottonwood/willow</td>
<td>-0.627</td>
<td>0.161</td>
<td>15.18</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Tamarisk</td>
<td>-0.501</td>
<td>0.137</td>
<td>13.37</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Sinuosity (m m(^{-1}))</td>
<td>Cottonwood/willow</td>
<td>0.021</td>
<td>0.022</td>
<td>0.89</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Tamarisk</td>
<td>0.036</td>
<td>0.018</td>
<td>3.92</td>
<td>0.05</td>
</tr>
<tr>
<td>Braiding index</td>
<td>Cottonwood/willow</td>
<td>-0.441</td>
<td>0.328</td>
<td>1.8</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>Tamarisk</td>
<td>-0.632</td>
<td>0.276</td>
<td>5.25</td>
<td>0.03</td>
</tr>
</tbody>
</table>
Plant/geomorphic feedbacks in the river environment

- Interactions vary depending on species, plant size, and density
Conceptual model of river change

A  Undammed channel

B  Post-dam short term (1-5 year)

C  Post-dam long term (>10 years)

Abiotic driver:
Modified hydrology

Biotic driver:
Vegetation expansion

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Management implications

Are environmental flow releases effective for tamarisk control?

- Small tamarisk suffer greater burial mortality → brief window of opportunity
- Very high uncertainty in system-wide response to flow releases, depending greatly on flood hydraulics and sediment supply
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