Riparian Tree Response to Variability in Climate and Altered Streamflow along the Dolores River, Colorado

Adam P. Coble
November 30, 2010
River Damming in the Western U.S.

Dams per Area

Storage/Runoff Ratio

Quartiles
- Highest
- Second
- Third
- Lowest

Graf, 1999
An Example of Streamflow Alteration

Merritt and Cooper, 2000
Dam-Induced Channel Adjustments

Unregulated

Mature *Populus* forest
Young *Populus* forest

Regulated

*P. deltoides/Sarcobatus/Chrysothamnus/Seriphidium* desert shrubland

*Salix, Eleocharis, Juncus* fluvial marsh

Merritt and Cooper, 2000
Impacts of River Regulation on Riparian Forests

- Reduced forest area
- Reduced tree abundance
- Loss of seedling habitat
- Decline in seedling establishment
- Reduced tree growth

- Increased seedling survivorship
- Increased forest density

Primary Cause: Reduced High Spring Flows
McPhee Dam constructed in 1984

Dolores River

Mean Daily Discharge (m³/sec)

Research Questions 1 and 2

- Does river regulation affect riparian tree establishment along the Dolores River?
- What streamflow conditions facilitate riparian tree establishment?
Controls over Riparian Tree Growth

- Growth +/- associated with streamflow
- Growth response to climate and streamflow can change due to river regulation (Reily and Johnson, 1982)
  - Unregulated river: streamflow
  - Regulated river: temperature and evapotranspiration
- Growth response to climate and streamflow dependent on geomorphic characteristics
  - Wide, alluvial valleys: streamflow
  - Bedrock constrained reaches: temperature
Research Question 3

- How does tree growth response to streamflow and climate differ among regulated and unregulated reaches?
Native Riparian Tree Species

*Populus angustifolia*
(narrow-leaf cottonwood)

*Populus deltoides* subsp. *wislizenii*
(broad-leaf cottonwood)

*Acer negundo*
(box-elder)
Delineation of Segments

- 6 Reaches defined by Dolores River Dialogue
- Divided each reach into 2, 3, or 5 segments
- 1 study site per segment
Tree Sampling

- Assigned trees to 5.0 cm dbh size class
- 3 trees per size class per topographic position per segment
Tree Age Estimation and Tree Growth Measurement

- Estimated tree age (39.6% of trees) using template method

- Measured ring width for mature trees (established prior to 1984) using WinDEDNRO (Regent Instruments Inc., Quebec)
## Number of Trees Used in Analysis

<table>
<thead>
<tr>
<th>Analysis</th>
<th>narrow-leaf</th>
<th>broad-leaf</th>
<th>box-elder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Establishment</td>
<td>224</td>
<td>204</td>
<td>90</td>
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<tr>
<td>Growth</td>
<td>136</td>
<td>67</td>
<td>70</td>
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</tbody>
</table>
Data Analysis

- 20 Environmental Variables
  - Mean Temperature
  - Total Precipitation
  - Maximum Streamflow
  - Minimum Streamflow
  - Mean Streamflow
  - Palmer Drought Severity Index

- Winter (Oct. – Mar.)
- Spring (Apr. – Jun.)
- Summer (Jul. – Sept.)

- Previous Yr. Maximum Flow
- Subsequent Yr. Maximum Flow

- 3 Climate Stations
- 5 Gauge Stations
Streamflow Alteration Pre- and Post-dam

Prior to dam construction (1961-1984)

<table>
<thead>
<tr>
<th>Month</th>
<th>Upper Dolores</th>
<th>Upper Dolores - MVIC Diversion</th>
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<tbody>
<tr>
<td>J</td>
<td>10</td>
<td>10</td>
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<td>F</td>
<td>20</td>
<td>20</td>
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<td>M</td>
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<td>M</td>
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<td>J</td>
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<tr>
<td>J</td>
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<td>70</td>
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</table>

After dam construction (1985-2008)

<table>
<thead>
<tr>
<th>Month</th>
<th>Upper Dolores</th>
<th>McPhee</th>
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</thead>
<tbody>
<tr>
<td>J</td>
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<td>A</td>
<td>40</td>
<td>40</td>
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<tr>
<td>M</td>
<td>50</td>
<td>50</td>
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<tr>
<td>J</td>
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<td>60</td>
</tr>
<tr>
<td>J</td>
<td>70</td>
<td>70</td>
</tr>
</tbody>
</table>
Research Questions

- Does river regulation affect riparian tree establishment along the Dolores River?
- What flow and/or climate events facilitate establishment of native riparian trees?
- How does tree growth response streamflow and climate differ among regulated and unregulated reaches?
Establishment Models:

**Upper Dolores**
- Winter Mean Temp (+)
- ROC = 0.729
- \( r^2 = 0.126 \)
- \( p = 0.0039 \)

**Reaches 1 and 3**
- Winter Mean Temp (+)
- Spring Precipitation (-)
- ROC = 0.889
- \( r^2 = 0.412 \)
- \( p < 0.0001 \)
**Broad-leaf Cottonwood Establishment**

**Establishment Model:**

Reach 6

**Summer Min. Flow(+)**

ROC = 0.755

$r^2 = 0.158$

$p = 0.0029$
Box-elder Establishment

a) Upper Dolores

Year


Number of Trees

(3) (2)

b) Reaches 1 and 3: Lower Dolores

Year


Number of Trees

Pre-dam

(7)

Post-dam

(4)
Research Questions

- Does river regulation affect the number of recruitment events?
- What flow and/or climate events facilitate establishment of native riparian trees?
- How does tree growth response to variation in streamflow and climate differ among regulated and unregulated reaches?
Relationships between Cottonwood Establishment and Spring Maximum Flow

- Spring maximum flow explained little variation in cottonwood establishment

- Further substantiated by establishment models and large number of establishment events during the post-dam period (1985-2008)

![Graph of Spring Maximum Flow](image)
Box-elder Establishment

- Observed a few positive significant relationships between box-elder establishment and spring maximum flow (Upper Dolores & Reaches 4 through 6)

- Logistic regression models
  
  Streamflow variables:  
  - summer mean flow (+)  
  - spring min. flow (+)  
  - spring max. flow (+)  
  - summer min. flow (+)  

  Temperature variables:  
  - winter mean temp. (-)  
  - spring mean temp. (-)  
  - summer mean temp. (-)  

- High streamflow facilitated box-elder establishment
- High temperatures negatively impacted establishment
- Streamflow: stronger controls over box-elder establishment compared to cottonwood
Box-elder established at higher topographic elevations compared to cottonwood

Cottonwood: channel or ephemeral channels

Box-elder: intermediate zones between channel and 1st bench
Streamflow: stronger control over box-elder growth compared to cottonwood

<table>
<thead>
<tr>
<th>Reach</th>
<th>Regulation Status</th>
<th>Mean Flow</th>
<th>Narrow-leaf $R^2$</th>
<th>Box-elder $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reach 3</td>
<td>Pre-dam</td>
<td>Winter</td>
<td>0.423*</td>
<td>0.112</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spring</td>
<td>0.274*</td>
<td>0.441*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Summer</td>
<td>0.214</td>
<td>0.438*</td>
</tr>
<tr>
<td></td>
<td>Post-dam</td>
<td>Winter</td>
<td>0.019</td>
<td>0.143</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spring</td>
<td>0.212</td>
<td>0.585**</td>
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<tr>
<td></td>
<td></td>
<td>Summer</td>
<td>0.407*</td>
<td>0.470*</td>
</tr>
</tbody>
</table>

* p-value < 0.05
Streamflow: stronger control over box-elder growth compared to cottonwood

Correlations between growth and mean flow

<table>
<thead>
<tr>
<th>Reach</th>
<th>Regulation Status</th>
<th>Mean Flow</th>
<th>Broad-leaf $R^2$</th>
<th>Box-elder $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reach 4</td>
<td>Pre-dam</td>
<td>Winter</td>
<td>0.119</td>
<td>0.032</td>
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<tr>
<td></td>
<td></td>
<td>Spring</td>
<td>0.232</td>
<td>0.452*</td>
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<tr>
<td></td>
<td></td>
<td>Summer</td>
<td>0.275*</td>
<td>0.358*</td>
</tr>
<tr>
<td></td>
<td>Post-dam</td>
<td>Winter</td>
<td>0.087</td>
<td>0.441*</td>
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<tr>
<td></td>
<td></td>
<td>Spring</td>
<td>0.145</td>
<td>0.323*</td>
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<tr>
<td></td>
<td></td>
<td>Summer</td>
<td>0.205</td>
<td>0.409*</td>
</tr>
</tbody>
</table>

* p-value < 0.05
Mature box-elder trees grew at higher topographic elevations compared to cottonwood.

- **Cottonwood**: 0.76 – 1.22 meters above active channel
- **Box-elder**: 1.2 – 2.4 meters above active channel
Research Questions

- Does river regulation affect the number of recruitment events?
- What flow and/or climate events facilitate establishment of native riparian trees?
- How does tree growth response to streamflow and climate differ among regulated and unregulated reaches?
Narrow-leaf cottonwood growth: shift in seasonal response to streamflow

<table>
<thead>
<tr>
<th>River</th>
<th>Reach</th>
<th>Growth vs. Mean Flow - $R^2$</th>
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</thead>
<tbody>
<tr>
<td>Winter</td>
<td>0.055</td>
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<tr>
<td>Spring</td>
<td>0.274*</td>
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<tr>
<td>Summer</td>
<td>0.125</td>
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</tr>
<tr>
<td>Winter</td>
<td>0.003</td>
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<tr>
<td>Spring</td>
<td>0.072</td>
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<tr>
<td>Summer</td>
<td>0.323*</td>
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<tr>
<td>Winter</td>
<td>0.423*</td>
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<tr>
<td>Spring</td>
<td>0.274*</td>
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<td>0.214</td>
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<tr>
<td>Winter</td>
<td>0.019</td>
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<tr>
<td>Spring</td>
<td>0.212</td>
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<tr>
<td>Summer</td>
<td>0.407*</td>
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</tbody>
</table>

*p-value < 0.05
Narrow-leaf cottonwood growth: shift in seasonal response to streamflow

Pre-dam (1961-1984)
Spring streamflow → Growth

Post-dam (1985-2008)
Summer streamflow → Growth

Graph:
- Blue line: Upper Dolores - MVIC Diversion (Pre-dam)
- Red line: McPhee Release (Post-dam)

Discharge (m³/s)
0 10 20 30 40 50 60
J F M A M J J A S O N D
Month
Shift in Growth Response at Reach 4 for two species

<table>
<thead>
<tr>
<th>Species</th>
<th>Post-dam (1984– 2008)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Box-elder</td>
<td>Winter PDSI (r² = 0.414)</td>
</tr>
<tr>
<td>Broad-leaf cottonwood</td>
<td>Summer PDSI (r² = 0.391) Summer MIN Flow</td>
</tr>
</tbody>
</table>
In Conclusion:

• **Does river regulation affect riparian tree establishment along the Dolores River?**
  
  • Observed frequent establishment events for all species under regulated streamflow
  
  • Our results suggest no apparent affect on the number of establishment events of broad-leaf cottonwood and box-elder
In Conclusion:

- What streamflow conditions facilitate riparian tree establishment?
  - Cottonwood: no positive association with spring maximum flow
  - High streamflow facilitated box-elder establishment in both spring and summer seasons
In Conclusion:

- How does tree growth response to streamflow and climate differ among regulated and unregulated reaches?

  - Shifts in growth response:

    Narrow-leaf cottonwood: growth more sensitive to summer flows under dam regulated flows

    Broad-leaf Cottonwood
    Box-elder

    Pre-dam (Canal diversion) Streamflow Post-dam (Dam regulation) PDSI
In Conclusion:

- How does tree growth response to streamflow and climate differ among regulated and unregulated reaches?
  - At Reach 4, growth more sensitive to drought under dam regulated flows
  - **Streamflow alteration** increased sensitivity to regional drought.
Streamflow Recommendations for Cottonwood Establishment

- Cottonwood maintain seasonal variation in streamflow
  - High streamflow during the months of May – June
  - Base flows in summer months at or above long-term average
Streamflow Recommendations for Cottonwood

- Extreme departure from seasonal variation in streamflow resulted in:
  - Loss of habitat for cottonwood
  - Decline in cottonwood establishment

Merritt and Cooper, 2000
Streamflow recommendations for box-elder

- Maintain above average streamflow during spring and summer seasons

(1985-2008)
Streamflow Recommendations for Native Riparian Tree Growth

- Sensitivity to PDSI increased due to river regulation
- Climate models predict more frequent drought (Seager et al., 2007)
Acknowledgements

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Mark Youngquist
Larry and Jim Suckla
The Nature Conservancy
Bureau of Land Management
U.S. Forest Service
Questions?
Data Analysis

- Multiple logistic regressions were used to model riparian tree establishment (establishment vs. non-establishment)

- **Establishment year**: a year of large recruitment events where two or more trees established in a reach

- Prior to logistic regression analysis – screened out variables using a univariate test

- Stepwise logistic regression used to select climate and flow variables

- Multivariate models of tree **growth** selected based on lowest AIC value
Tree Age Estimation: Comparison of Two Methods

1) Template method (Applequist, 1958)

2) Age-diameter at coring height model

\[ y = 1.5453x \]

\[ R^2 = 0.8742 \]

- Pith
- No Pith

<table>
<thead>
<tr>
<th>Observed Age</th>
<th>Predicted Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<tr>
<td>1</td>
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</tbody>
</table>

Observed Age vs. Predicted Age graph
River Damming and Diversion Increased Growth Sensitivity to Drought

**P. angustifolia** (1961-2008)

- $R^2 = 0.001$
- $R^2 = 0.300^*$

* p-value < 0.05
River Damming and Diversion Increased Growth Sensitivity to Drought

*P. angustifolia* (1961-2008)

\[ R^2 = 0.111 \]

\[ R^2 = 0.454^* \]

*p-value < 0.05*
River Damming and Diversion Increased Growth Sensitivity to Drought

*Populus deltoides* (1961-2008)

* $R^2 = 0.075$
* $R^2 = 0.260^*$

* $p$-value < 0.05
Dam-Induced Channel Adjustments

Unregulated

Mature Populus forest
Young Populus forest

Regulated

P. deltoides/Sarcobatus/
Chrysothamnus/Seriphidium
desert shrubland

Salix, Eleocharis, Juncus
fluvial marsh

Merritt and Cooper, 2000