Goal: For a river reach anywhere in the world, quantitatively predict:

1) all aspects of wood budget (Inputs, Storage, Outputs)
2) fluctuations in all parameters through time & space
3) geomorphic & ecological effects of wood

So, what are the knowledge gaps that keep us from doing this?
I. Wood Budget: Components of Geomorphic & Biotic Context

- Forest dynamics
- Hillslope dynamics
- Valley-bottom dynamics
- Channel dynamics
- Biota (beaver)
- Network (tributary) dynamics
**Forest dynamics**
- Stand characteristics (spatial density, tree age & size, species composition)
- Mortality (individual, mass – fire, insects, windstorm)

**Hillslope dynamics**
- Mass movements (debris flows, landslides, avalanches) that recruit trees

**Network dynamics**
- Tributary inputs of wood, water, sediment

**Valley-bottom dynamics**
- Floodplain storage of wood, water, sediment

**Channel dynamics**
- Wood transport, bank erosion, water & sediment discharges

**Biota (beavers)**
- Wood recruitment & stabilization, formation of secondary channels
Components of Wood Budget

\[ \Delta S = \left[ L_i - L_o + \frac{Q_i}{\Delta x} - \frac{Q_o}{\Delta x} - D + B \right] \Delta t \]

Benda & Sias, 2003
$L_i = I_m + I_f + I_{be} + I_s + I_e$

chronic forest mortality

tree topple, fire & windstorm

bank erosion

mass movements

exhumation of buried wood

Benda & Sias, 2003
Early numerical simulations focused on recruitment
(Beechie et al., 2000; Bragg, 2000; Welty et al., 2002; Gregory et al., 2003)

More recent models focus on

- forces acting on wood (Merten et al., 2010; Rafferty, 2013)
- stochastic prediction of wood load (Eaton et al., 2012)
- wood loads & related physical processes (Lancaster et al. 2003)

Knowledge gap:
Diverse models have end prediction of storage, but need much more region-specific calibration & testing
Need more effective consideration of how stable wood influences wood in transport or how multiple pieces affect individual/collective mobility
II. Temporal & spatial fluctuations: space

North St. Vrain Creek, Colorado, USA

Wohl & Cadol, 2011
Δ$S_c = [L_i - L_0 + Q_i/\Delta x - Q_0/\Delta x - D + B]\Delta t$

$L_i = I_m + I_f + I_{be} + I_s + I_e$

Wohl, 2011a
Abbe & Montgomery, 2003

recruitment mechanism

landsiding

IN-SITU

Bank input

Orthogonal log steps

Oblique log steps

Flow Deflection

Valley

Combination

Bar Apex

bar top deposits

bank deposits

Debris Flow-Flood

Deflection

Apex

Rafts

bench

Valley

Deflection

large alluvial channels

$S < 0.01$

$0.02 < S < 0.20$

$2^{nd} - 4^{th}$ order

channel network

$> 3^{rd}$ order

$S < 0.03$

transport

no effect

alters channel

no effect

alters channel

no effect

alters channel

bank erosion

waterfalls

erosion

erosion

Abbe & Montgomery, 2003
Longitudinal & lateral extent of floodplain

Drainage area

Channel size

Wood mobility

transport jams

rafts

wide continuous

moderate continuous

narrow discontinuous

in situ jams

beaver dams

Wohl, 2014
Knowledge gap:
Within a region, lack of data on downstream trends in wood load in unaltered rivers with drainage areas exceeding ~ 300 km²

*(Fox & Bolton, 2007)*

Knowledge gap:
Between regions, limited data for full climatic-biotic range in temperate zone, & very limited data for tropics & boreal zones
CR = La Selva, Costa Rica
WA1 = Western Washington
WA2 = Western Washington
WA3 = Cascade Range, WA
OR1 = Western Oregon
OR2 = Coast Range, Oregon
AK = Southeast Alaska
BC = SW British Columbia
MI = Northern Michigan
CO1 = Front Range, Colorado
CO2 = Front Range, Colorado
WY1 = Bighorn Range, Wyoming
WY2 = Absaroka Range, WY
WY3 = Bridger-Teton NF, WY
SA = Southern Andes, Chile
TF = Tierra del Fuego, Argentina
AU = Southeast Australia
NZ = South Island, New Zealand

Cadol et al., 2009
boreal
temperate
tropical

low, transient wood loads
(rapid decay, mobile)
(Wohl et al., 2012)

wood highly variable between sites

??? maybe moderate to high wood loads

(285, 423, 640, 500)
Locations of field studies on instream wood published in English-language journals

Relative dearth of studies in high and low latitudes
Temporal fluctuations

Measured short-term fluctuations

Wohl & Goode, 2008
Channel-spanning logjams in Rocky Mountain National Park, USA

- **2010**: Days since 1 May: 0, 50, 100, 150
  - Discharge (m³/s): 0, 5, 10, 15

- **2011**: Days since 1 May: 0, 50, 100, 150
  - Discharge (m³/s): 0, 5, 10, 15

- **2012**: Days since 1 May: 0, 50, 100, 150
  - Discharge (m³/s): 0, 5, 10, 15

- **2013**: Days since 1 May: 0, 50, 100, 150
  - Discharge (m³/s): 0, 5, 10, 15

- **2014**: Days since 1 May: 0, 50, 100, 150
  - Discharge (m³/s): 0, 5, 10, 15

**NSV**, **Ouzel**, **Cony**, **Hunters**

- **number of jams**: 0, 20, 40, 60, 80, 100, 120, 140
- **no peak**
- **high, short peak**
- **high, long peak**
- **no peak**
- **autumn flood**
- **normal year**

- **Blowdown**
- **Flood**
Longer term fluctuations in wood load on forest floor
Colorado Front Range
Knowledge gap:
Relatively little published on temporal fluctuations of wood within a river segment or drainage basin, & particularly for unmanaged rivers (e.g., Gurnell & Sweet, 1998 & Lassettre et al., 2008 for managed rivers)
III. Geomorphic & ecological effects of wood: geomorphic

- reach-scale within channel
  - hydraulics & local scour \textit{(Shields \& Smith, 1992; Mutz, 2003)}
  - sediment transport \textit{(Brooks et al., 2003)}
  - forced alluvial bed \textit{(Montgomery et al., 1996)}
  - wood, vegetation \& planform \textit{(Gurnell et al., 2012)}

- reach-scale across valley bottom
  - log jams \& avulsions \textit{(Phillips, 2012)}
  - multi-thread channels \textit{(Wohl, 2011b)} \& floodplain large wood cycle \textit{(Collins et al., 2012)}
Meandering

Abandoned channel/oxbow

Anastomosing

Buried wood jam “hard point”

Braided

Ephemeral patches of pioneer vegetation

Collins et al., 2012
Knowledge gaps:

- quantifying flow resistance & obstruction – numerous case studies in field & flumes (e.g., Young, 1991; Shields & Gippel, 1995; Dudley et al., 1998; Manga & Kirchner, 2000; Wallerstein et al., 2001; Curran & Wohl, 2003; Hygelund & Manga, 2003; Wilcox & Wohl, 2006; Wilcox et al., 2006; Daniels & Rhoads, 2007; Manners et al., 2007) –
  
  but no widely applicable formula or technique
Knowledge gaps:

• quantifying sediment storage – numerous case studies (e.g., Megahan, 1982; Klein et al., 1987; Bugosh & Custer, 1989; Nakamura & Swanson, 1993; Smith et al., 1993; Thompson, 1995; Hart, 2002; Haschenburger & Rice, 2004; Fisher et al., 2010; Ryan et al., 2014) & numerical models for particular river systems (e.g., Lancaster et al., 2003; Eaton et al., 2012)
• no broadly applicable conceptual model
Drainage area (km$^2$) / Stored sediment per unit area of channel

- Jammed steps & sediment wedges
- Dispersed wood & sediment
- Wood rafts & floodplain sediment

Spearman correlation coefficient = 0.89

Wohl & Scott (in review)
Knowledge gaps:

- documentation of potential alternative stable stables
  - wood-rich vs wood-poor (Wohl & Beckman, 2014)
  - high vs diminished biogeomorphic complexity of floodplain (Collins et al., 2012)

- linear vs threshold effects of wood load (e.g., Wohl, 2011b; Beckman & Wohl, 2014a)

- potential for emergent properties (e.g., anastomosing channels)

- effects of dramatic historical reductions in wood loads
Ecological effects

• reach-scale within channel
  • habitat abundance & diversity
    \((Carlson \textit{et al.}, 1990; Richmond \& Fausch, 1995)\)
  • enhanced nutrient storage & uptake
    \((Buckley \& Triska, 1978; Ward \& Aumen, 1986; Beckman \& Wohl, 2014b)\)
  • greater biomass \((Gowan \& Fausch, 1996; Nagayama \textit{et al.}, 2012)\)

• reach-scale across valley bottom
  • floodplain habitat abundance & diversity \((Harmon \textit{et al.}, 1986)\)
  • floodplain nutrient storage & uptake \((Naiman \textit{et al.}, 2010)\)
  • floodplain biomass \((Benke, 2001)\)
Ongoing “Leaky Rivers” project research indicates greater wood loads & measures of physical complexity are associated with greater nutrient uptake greater insect predator (fish, riparian spiders) biomass & diversity
Knowledge gaps:

• linear versus threshold effects for habitat, diversity, and/or biomass

• potential for emergent properties

• is wood ecologically important where transient (tropics)?

• effects of dramatic historical reductions in wood loads
**Additional knowledge gaps**

- big rivers

- most areas outside of Pacific Northwest

- effect of wood loads on wood transport (we have a start with existing numerical models (Eaton, Lancaster) & flume studies (Braudrick & Grant, 2000, 2001; Bocchiola et al., 2006)

- temporal variation (HRV or NRV)

- how to effectively reintroduce/manage wood

- education/outreach for river restoration & management to counter negative perceptions (Chin et al., 2008)

- effective level of instream wood to create desired environmental effects (e.g., linear or threshold?)
  - ELJs (Abbe & Brooks, 2011; Gallisdorfer et al., 2014)
For a river reach anywhere in the world, quantitatively predict:

- all aspects of wood budget (I, S, O)
- fluctuations through time & space
- geomorphic & ecological effects of wood

Need:

- more case studies from diverse environments
- syntheses, meta-data, conceptual models, & numerical simulations for:
  - hydraulics
  - sediment dynamics
  - channel & floodplain morphology
  - ecological effects (habitat, nutrients, thresholds leading to alternative stable states)
- education & outreach on benefits of wood
effects: linear, threshold?

fluctuations through time?

how much? stable? mobile?
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