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Wood decay in desert riverine environments

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ABSTRACT

Floodplain forests and the woody debris they produce are major components of riverine ecosystems in many arid and semiarid regions (drylands). We monitored breakdown and nitrogen dynamics in wood and bark from a native riparian tree, Fremont cottonwood (*Populus deltoides* subsp. *wislizeni*), along four North American desert streams. We placed locally-obtained, fresh, coarse material [disks or cylinders (~500–2000 cm^3)] along two cold-desert and two warm-desert rivers in the Colorado River Basin. Material was placed in both floodplain and aquatic environments, and left *in situ* for up to 12 years. We tested the hypothesis that breakdown would be fastest in relatively warm and moist aerobic environments by comparing the time required for 50% loss of initial ash-free dry matter (T_{50}) calculated using exponential decay models incorporating a lag term. In cold-desert sites (Green and Yampa rivers, Colorado), disks of wood with bark attached exposed for up to 12 years in locations rarely inundated lost mass at a slower rate (T_{50} = 34 yr) than in locations inundated during most spring floods (T_{50} = 12 yr). At the latter locations, bark alone loss mass at a rate initially similar to whole disks (T_{50} = 13 yr), but which subsequently slowed. In warm-desert sites monitored for 3 years, cylinders of wood with bark removed lost mass very slowly (T_{50} = 60 yr) at a location never inundated (Bill Williams River, Arizona), whereas decay rate varied among aquatic locations (T_{50} = 20 yr in Bill Williams River; T_{50} = 3 yr in Las Vegas Wash, an effluent-dominated stream warmed by treated wastewater inflows). Invertebrates had a minor role in wood breakdown except at in-stream locations in Las Vegas Wash. The presence and form of change in nitrogen content during exposure varied among riverine environments. Our results suggest woody debris breakdown in desert riverine ecosystems is primarily a microbial process with rates determined by landscape position, local weather, and especially the regional climate through its effect on the flow regime. The increased warmth and aridity expected to accompany climate change in the North American southwest will likely retard the already slow wood decay process on naturally functioning desert river floodplains. Our results have implications for designing environmental flows to manage floodplain forest wood budgets, carbon storage, and nutrient cycling along regulated dryland rivers.

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1. Introduction

The woody debris produced by riverine forests can strongly affect ecosystem structure and functioning (Maser and Sedell, 1994; Gurnell et al., 1995; Francis et al., 2008; Iroumé et al., 2010; Wohl, 2013). Dead tree boles and limbs affect fluvial geomorphic processes (Gurnell et al., 2002; Gurnell and Petts, 2006), serve as a major carbon pool, and influence in-stream dynamics of nitrogen and other nutrients (Aumen et al., 1985; Robertson et al., 1999; Bilby, 2003; Elosegi et al., 2007; Thevs et al., 2012). Both large- and medium-sized woody debris [hereafter, coarse woody debris (CWD), broadly defined as material with no dimension <1.5 cm] serve as a primary substrate for aquatic biofilms and benthic invertebrates (Spänhoff and Cleven, 2010), and as a source of shelter and other resources for aquatic and terrestrial animals (Mac Nally and Horrocks, 2002; Braccia and Batzer, 2008; Ballinger et al., 2010). Leaching and decomposition processes during CWD breakdown on floodplains can have strong local effects on soil nutrient dynamics (Zimmerman et al., 1995; Hafner et al., 2005).

The widespread degradation and loss of floodplain forests due to land and water resources development (Tockner and Stanford, 2002) has generated world-wide interest in their ecology, conservation, and management (Hughes and Rood, 2003; Andersen, 2005; Rood et al., 2005; Mac Nally et al., 2011; González et al.,

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2012). Cierjacks et al. (2011) noted high organic carbon stocks in floodplain forests compared to other terrestrial ecosystems, and Guyette et al. (2002) reported CWD had a much longer mean residence time in a Missouri stream than in nearby upland, suggesting riverine environments may be valuable carbon sinks. Carbon budgets have been developed for only a few riverine ecosystems, in part because of gaps in the knowledge base—including decay dynamics—required for modelling wood budgets (Wohl et al., 2012).

There are relatively few assessments of wood decomposition rates in riverine environments (Spänhoff and Meyer, 2004; Braccia and Batzer, 2008), and we are aware of only one in a semiarid- or arid-region (dryland) riverine ecosystem (Ellis et al., 1999). Dryland riverine ecosystems occur in both cold- and warm-temperate regions, and because of fluvial influences on hydrology, contain a mix of environments that range from xeric through mesic to aquatic. This complexity makes extrapolation from other ecosystems as well as broad generalizations regarding breakdown rates difficult.

Here we present data on breakdown of wood and bark from a native riparian tree along four dryland rivers, and document accompanying changes in nitrogen (N) concentration. We assess breakdown on two cold-desert sites with similar climates but different flow-related hydrology, and two warm-desert sites that differ in both climate (seasonal rainfall pattern) and flow pattern. Within each site, we monitored breakdown at locations that we categorized as either dry- or moist-floodplain, or periodically- or continuously-wet active channel. We hypothesized that wood breakdown, like leaf litter breakdown in dryland floodplain environments (Andersen and Nelson, 2006), would be primarily microbial. Based on the dependency of microbial activity on moisture and temperature regimes (Meentemeyer, 1978; Liu et al., 2013), we predicted decomposition within each type of desert to be slowest in the driest floodplain locations, and most rapid in continuously wet locations. Because we use locally-obtained wood in each desert, our results add to the data necessary for developing regional dryland river wood, carbon, and nutrient budgets. Although regional differences in wood quality confound cold- and warm-desert comparisons, taken together, our results from these two types of North American desert provide insight into processes operating globally in dryland riverine environments.

2. Methods

We used a time-series approach to monitor change in ash-free oven-dry mass (AFDM) and N content in three types of natural "woody" material: wood with attached bark ("W&B"), wood lacking bark ("W"), and bark alone ("B"). In all cases, the material was from Fremont cottonwood [a common name regionally attached to the ecologically similar *Populus fremontii* subsp. *fremontii* S. Watson and *P. deltoides* subsp. *wislizenii* (S. Watson) Eckenwalder, as well as their intergrades; taxonomy follows Eckenwalder (1977)]. The material was obtained from either healthy trees we harvested or recently wind-thrown trees, and with one minor exception the trees were growing at or near the site where monitoring subsequently took place. We worked along four rivers, two each in cold- and warm-desert environments (Table 1). The material was deployed on both the vegetated floodplain and in the active channel. Floodplain locations were classified as either "moist" or "dry" based on annual inundation probability (I_P) (moist: $I_P > 0.33$; dry: $I_P < 0.10$). Active channel locations included those inundated most years ($I_P > 0.5$; "bank and bar"), as well as locations where the material was continuously immersed ("in-stream"). Deployed materials varied between the cold- and warm-desert sites in size, form, and structural characteristics (e.g., bark thickness) related to tree age. Values for site inundation parameters (annual probability of inundation and typical inundation duration) are based on either topographic measurements combined with stage–discharge measurements or field observations and judgement (Supplemental Online Information Table S1). The four rivers and the associated differences in source material and deployment patterns are described below.

2.1. Cold-desert sites: Green and Yampa rivers (Colorado Plateau–Great Basin Desert)

We worked on the floodplain of the highly-regulated Green River in Browns Park National Wildlife Refuge (BP) and in both floodplain and active channel environments of the unregulated Yampa River at Deerlodge Park in Dinosaur National Monument (DLP; Fig. 1). Both sites are in alluvial valleys. Green River discharge at BP (annual mean ~55 m^3/s; Table 1) is controlled by Flaming Gorge Dam. The dam reduced peak flood discharge >50%,

Table 1
Hydrologic, geographic, and climate characteristics at the four primary riverine sites where Fremont cottonwood woody debris breakdown was monitored. Elevation ranges are for the most-downstream and most-upstream locations used at a site.

Characteristic	Cold-desert sites		Warm-desert sites	
	Green River[a]	Yampa River[a]	Las Vegas Wash[e]	Bill Williams River
Latitude (°N)	40.76	40.45	36.10	34.27
Elevation (m ASL)	1635	1705	~400–650	~150–350
River flow regime	Highly regulated	Free-flowing	Effluent-dominated	Highly regulated
Mean annual discharge (m^3/s)	~55	~58	~6	<3
Months of annual peak flow (period of record)	May–June (1992–2011)	Late April–early June (1982–2011)	August, October–February (2001–2011)	February–April (2006–2011)
Annual precipitation (cm)	21[a]	30[a]	11	12–21
Seasonal precipitation pattern	Evenly distributed	Evenly distributed	Bimodal; February & July peaks	Bimodal; January & August peaks
Annual pan evaporation[d] (cm)	155	155	288	269
Mean annual air temperature (°C)	9.1[b]	7.3[b]	20.7	22.0[c]
Mean minimum air temperature in coldest month (°C)	−13.4	−16.8	4.1	2.3
Study period	2000–2012	2000–2011	2008–2010	2006–2010
Approximate range of discharge during the study period (m^3/s)	125–250	5–750	6–200	1–65

[a] Climate data from US National Weather Service records for stations at Maybell, Colorado (20 km east of Deerlodge Park) and Brown's Park Refuge, Colorado (5 km west of the study site) unless otherwise noted. (Source: http://www.hprcc.unl.edu/wrcc/states/co.html, accessed 14 May 2012.)
[b] Based on 2000–2007 data collected on site (D.C. Andersen, unpublished data).
[c] Data for Parker, Arizona (20 km south of the mouth of the Bill Williams River). (Source: http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?azpark, accessed 14 May 2012.)
[d] Data for Grand Junction, Colorado; Boulder City, Nevada; Yuma, Arizona (Farnsworth and Thompson, 1982).
[e] Temperature and precipitation data for Las Vegas, Nevada (Gorelow and Stachelski, 2012).