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Fire, floods and woody debris: Interactions between biotic and geomorphic processes

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ABSTRACT

Fire and floods interact in the riparian zone as processes that structure plant communities and landforms. Although much of the immediate impact of fire is on the vegetation, fire-related changes in runoff, sediment supply, riparian vegetation, and woody debris volume have ongoing geomorphic impacts on the valley floor. Consequent hydrogeomorphic changes, in turn, affect the composition and distribution of vegetation. This paper reviews these interactions, and provides an example of how fires and floods intersect to supply burnt trees as woody debris. Because the temporal and spatial distribution of woody debris is initially controlled by patterns of tree mortality, ecological disturbances, like fire, can be an important source for pulses of woody debris in riparian systems. To understand these interactions, we examine woody debris inputs 3 years after a wildfire in the riparian gallery forests of the western Transverse Ranges, California. Within our sample of 339 burned stems, snags fell in distinctive patterns: species were variable in susceptibility to falling, and fell at greater rates at sites with greater subsequent flooding. Discordance between the species composition of fallen snags and that of overall burned stems indicates that variability in forest composition must be considered in predicting post-disturbance inputs of woody debris. Variation in snagfall timing among species suggests that woody debris inputs are likely to occur in multiple, sequential pulses after wildfire. The role of flooding is superimposed on this ecological influence, as the timing and spatial variability of floods affect the recruitment of woody debris from the supply of snags created by fire.

1. Introduction

The importance of connections between riparian ecology and fluvial geomorphology has been so widely accepted (e.g. Malanson, 1993) as to be considered axiomatic, and research in recent years has been focused on the details of these connections in a variety of contexts (Hupp and Osterkamp, 1996; Tabacchi et al., 2000). Because these connections can include causal influences working in both directions, the potential for feedback among ecological and fluvial processes has been an important topic in this research (Bendix and Hupp, 2000), notwithstanding the challenges of demonstrating feedbacks with field data (Malanson and Butler, 1990). In this paper we consider the role of woody debris as an element of the riparian landscape that links ecological and hydrogeomorphic processes, and the potential importance of fire as a source of woody debris. We discuss the interactions and potential feedbacks initiated by wildfire as an event that may trigger debris inputs, and provide an example from southern California.

The geomorphic significance of woody debris in stream channels has been well established in recent years (Gurnell et al., 2002; Montgomery and Piégay, 2003). Accumulation of debris adds roughness elements to the channel, and to the floodplain, in the case of overbank flows. Increases in roughness coefficient can be logically expected to reduce mean flow velocity, although actual measurements show that this impact is not always significant (Gippel, 1995). In turn, localized reduction of velocity in the channel and on the valley floor affects the quantity and the spatial detail of sediment deposition (Keller and Tally, 1982; Lancaster et al., 2001; Faustini and Jones, 2003; May and Gresswell, 2003a). Direct impacts on fluvial forms include creation of depositional features, redirection and reshaping of the channel, and in some instances scour features reflecting the redirection of flow (Abbe and Montgomery, 1996; Montgomery et al., 2003).

The impacts of woody debris on flow conditions and landforms inevitably affect the subsequent distribution and composition of riparian vegetation. The establishment and survival of riparian species are demonstrably linked to specific fluvial landforms and the distribution of flood energy (Hupp and Osterkamp, 1985; Bendix, 1999).

The importance of woody debris has in turn spurred attention to the origins of the wood (Robison and Beschta, 1990; Benda et al., 2003a; May and Gresswell, 2003b), which depending on the biogeomorphic setting may be derived from either the surrounding hillslopes (Lancaster et al., 2001) or the riparian zone itself (Piégay et al., 1999).

Because the supply of wood in the channel is necessarily dependent on biotic processes (Benda and Sias, 2003), and because some of those processes themselves are affected by hydrogeomorphic

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factors (Bendix and Hupp, 2000), the incorporation of woody debris into the channel represents a conspicuous example of the recursive biogeomorphic interactions highlighted by Stallins (2006). Riparian vegetation is, however, affected by biotic processes other than those affected by the immediate fluvial environment (Benda et al., 2003a). Here, we focus on one of these exogenous (to the fluvial system) processes, wildfire.

Fire can be an important process in riparian environments (Pettit and Naiman, 2007a). As an agent of large scale mortality, it provides the potential material for woody debris in the valley bottom. As a consumer of wood as fuel, it also provides the potential for another feedback loop, where woody debris accumulations affect the severity of subsequent fire by concentrating fuels (Pettit and Naiman, 2007b). Wildfire also affects fluvial processes by increasing rates of hillslope runoff through loss of vegetation and creation of hydrophobic soils, and by triggering the delivery of sediment from surrounding hillslopes (Nasseri, 1989; Keller et al., 1997). Thus, several potential feedback loops are embedded within the set of interactions involving wildfire, woody debris, fluvial processes/landforms, and riparian vegetation. These interactions are summarized in Fig. 1, and are briefly described below:

a) Woody debris affects flow conditions, sediment transport, and deposition by blocking/deflecting streamflow or increasing hydraulic roughness.
b) Disturbance by floods and sediment deposition affect the distribution and composition of riparian vegetation.
c) Riparian vegetation provides fuel for wildfires.
d) Wildfires kill riparian trees, providing a source of woody debris.
e) Riparian vegetation provides wood for woody debris (even in the absence of wildfire).
f) Wildfire affects fluvial processes by increasing runoff and sediment supply from adjacent slopes.
g) Woody debris affects fire severity by providing dead fuel on the valley floor.
h) Floods contribute woody debris by felling standing stems, and may mobilize debris that is already present.
i) Riparian vegetation affects flood velocity through its contribution to hydraulic roughness, and may stabilize streambanks with its roots.
j) Wildfire affects riparian vegetation by killing plants.

In this paper, we use data from two small southern California streams to address a little-studied subset of this complex web of interactions: arrows d and h, which represent the linkage between fire, floods and supply of woody debris. Our particular focus is on detailing the conversion of standing fire-killed trees (snags) to woody debris in the channel or floodplain.

Conversion of standing trees to woody debris is almost always related to tree mortality. Dead trees are more likely to fall than live ones (although mortality and tree fall may be coincident; see Webb and Erskine, 2003 for one riparian example). Because wildfire can cause extensive tree mortality in a given event, it has the potential to

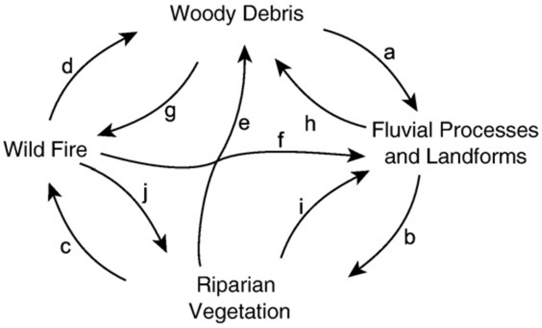

Fig. 1. The network of interactions and feedbacks that may occur among wildfire, woody debris, fluvial processes/landforms, and riparian vegetation. Influences represented by the arrows are discussed in the text.

significantly affect the quantity and/or timing of the recruitment of woody debris. DeBano et al. (1998) extrapolated from the findings of Spies et al. (1988) in non-riparian conifer stands to suggest that catastrophic fire would cause an immediate, abrupt pulse in course woody debris (CWD), followed by a decline to levels below those that preceded the fire. The dip in CWD, caused by the absence of mature trees to contribute new debris, would take several centuries to return to pre-fire levels. Bragg's (2000) models of the recruitment of large woody debris (LWD) similarly showed a pulse of in-stream LWD loading after fire, with the quantity then fluctuating much more through a 300 year simulation than in undisturbed watersheds. His conclusion differed from DeBano et al.'s, in that he indicated that a lag of 30 years occurs after the fire before peak debris loadings, because it would take decades for burned snags to actually fall into the channel. Such a lag may explain why comparison of a watershed burned in the 1988 Greater Yellowstone fires with an adjacent unburned stream (Zelt and Wohl, 2004) found that the burned stream did not have significantly more abundant LWD than the reference stream 11 years after the fires; the authors noted that abundant snags were still standing.

In a floodplain context, the rate and timing of snags falling is likely to be affected by subsequent hydrologic events, as floods may knock multiple snags over rather than leaving them to decay and fall individually. Again, biogeomorphic complexity links processes (Stallins, 2006), as flood severity is often responsive to wildfire (Nasseri, 1989). Once snags have fallen, floods also play a role in mobilizing the resultant debris. Stems that remain where they fall may add roughness to either the channel or floodplain, depending on location, but only those that are mobilized by floodwaters will join the debris accumulations that serve to substantially alter stream channels.

The length of time burned snags stand before conversion to in-stream woody debris is important, because it determines the timing and shape of the presumed post-fire pulse of debris recruitment. This timing, in turn, may also be critical in relation to inorganic sediment transport. Whereas fires in steep terrain often result in increased sediment delivery to streams (Florsheim et al., 1991; DeBano et al., 1998; Benda et al., 2003b), the presence of woody debris affects the transport of sediment (Keller and Swanson, 1979; May and Gresswell, 2003a,b). Indeed, Keller and Tally have argued "Debris is significant in the routing of sediment through the fluvial system by providing an upstream buffer during times of high sediment input…" (1982, p. 195). Since high sediment input follows fire, the speed with which burned snags become geomorphically relevant debris may in turn determine whether that wood helps to determine the rate at which the post-fire sediment moves through the system.

Accordingly, this paper aims to clarify the details of short-term conversion of burned snags to woody debris in the fluvial system ("snagfall") and the subsequent mobilization. We use the example of a fire that burned an extensive riparian gallery forest in the Transverse Ranges of southern California to address several questions about snagfall between 1 and 3 years after the fire:

i) How many of the burned snags fell during this time, and what was the species composition?
ii) Did snags differ by species or size in the rate at which they fell?
iii) How did flooding after the fire affect the rate at which snags fell?
iv) How did flooding affect the mobilization of fallen snags?

2. Study area and disturbance context

We collected data from within the perimeter of the Wolf Fire that burned 87.6 km^2 of chaparral in the Los Padres National Forest, in June 2002. We sampled along two tributaries of Sespe Creek: Potrero John Creek and Piedra Blanca Creek, whose floodplains had burned in the fire (Figs. 2 and 3). Both watersheds (11.5 km^2 and 34.2 km^2, respectively) are characterized by steep slopes and shallow soils, with (pre-fire) cover

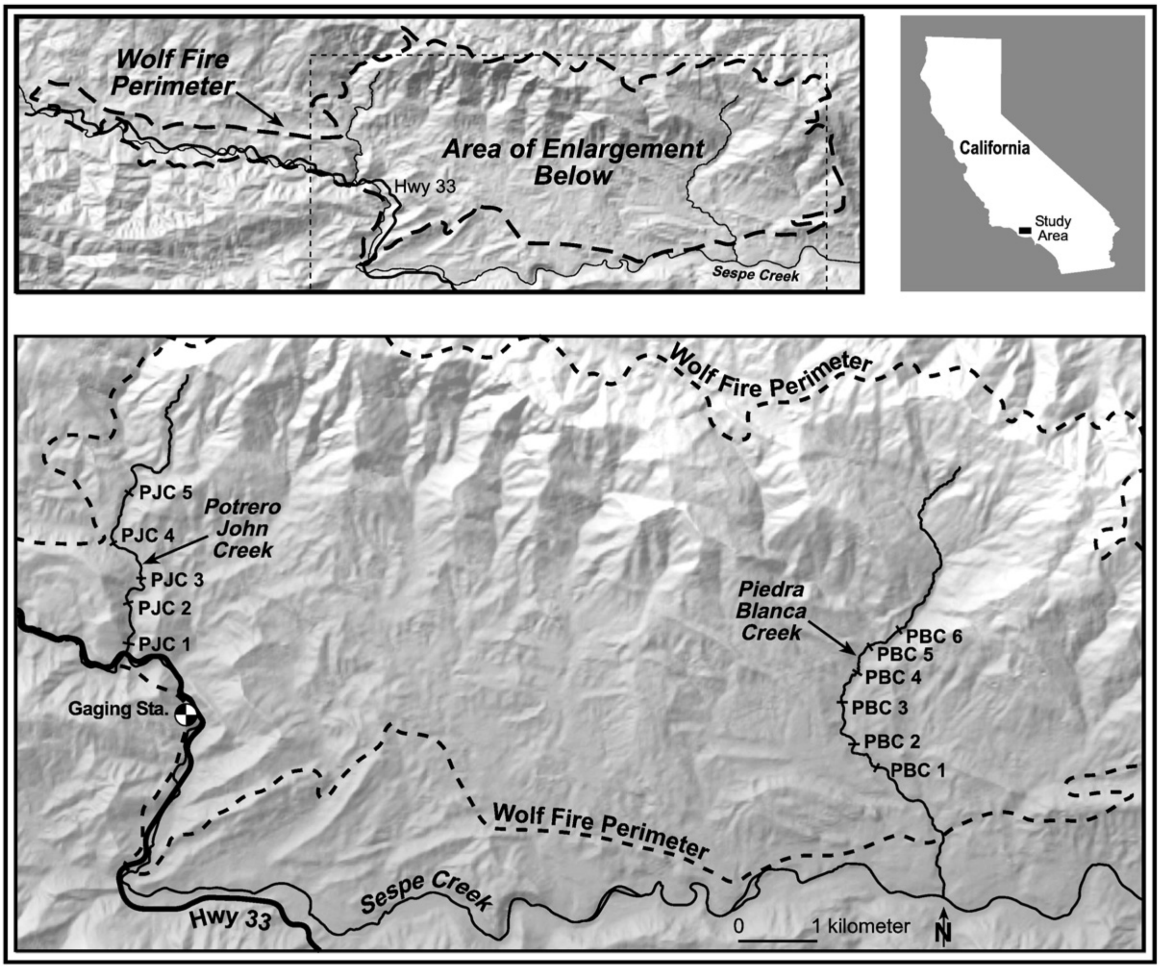

Fig. 2. Location of Wolf Fire, with study site locations.

on the hill slopes of chaparral, principally *Adenostoma fasciculatum* (chamise) and *Arctostaphylos* sp. (manzanita). Because of the dearth of trees in this landscape, these streams differ from those in forested environments, where trees from surrounding hill slopes may constitute a significant source of woody debris (Benda and Sias, 2003; Rulli et al., 2005).

Consequently, the sole source of woody debris in the stream channels is from the riparian zone. Although many local streams have insufficient woody growth to provide significant debris, riparian communities in the region are quite variable (Bendix, 1994), and Piedra Blanca Creek and Potrero John Creek had substantial (by local standards) growth of *Alnus rhombifolia* (white alder), *Populus fremontii* (Fremont cottonwood), *Quercus agrifolia* (coast live oak), *Quercus dumosa* (scrub oak) and *Salix* sp. (willows) on the valley floors.

Fig. 3. Standing and fallen snags in 2005, Piedra Blanca Creek.

The region is characterized by a Mediterranean-type climate, with dry summers and precipitation concentrated in winter and early spring. Frontal storms in January and February 2005 caused extensive flooding through the area (Fig. 4), with the largest having a recurrence interval of 7.7 years at a gage on Sespe Creek located between the mouths of the two tributaries. Local floods of comparable recurrence interval and magnitude have been demonstrated to have significant, albeit spatially variable, geomorphic and ecological impacts (Raphael et al., 1994; Bendix, 1998); this was, thus, the first potentially effective flood to follow the 2002 fire.

Valley floor morphology is variable, but along most reaches a compound channel exists (Graf, 1988), with a single channel at low flow expanding to occupy multiple braided subchannels during high flows. Typical width of the main channel is 5 to 10 m, with the subchannels somewhat narrower. The presence of these high flow channels crossing the floodplain means that even woody debris that does not reach the main channel may have a hydrogeomorphic impact during floods. The alluvial fill of the valleys varies from sand to boulders.

Visible impacts of woody debris on stream channels in these valleys are not uncommon. We have observed accumulations of debris that have caused channel deflection (Fig. 5a), channel re-routing (Fig. 5b) and channel blockage with plunge pools forming downstream of the

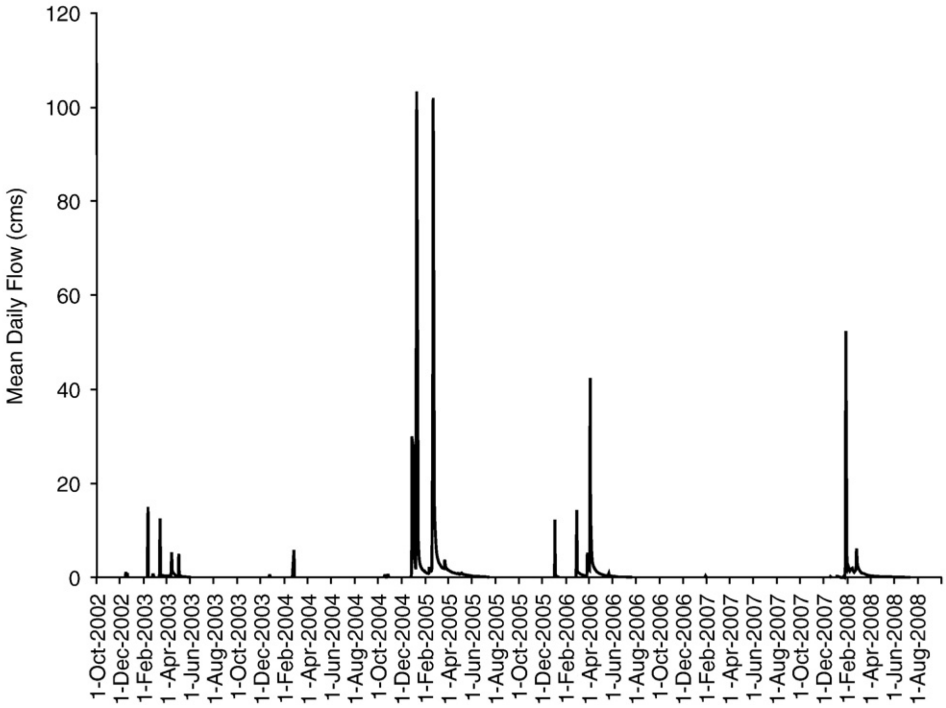

Fig. 4. Mean daily discharge at the stream gage on Sespe Creek.

debris accumulation (Fig. 5c). These effects can be seen along the main channel and in the high flow channels that dissect the floodplain.

3. Methods

3.1. Field data collection

In July, 2003 we established 11 transects across valleys of the two streams, at elevations between 950 and 1400 m. Transect locations were selected to provide roughly even spacing along the streams. The vegetation at all transect locations, as well as along intervening reaches, was severely burned. The transects extended to the slope break at the valley wall on each side, and, thus, included the primary channel, floodplain, and in some instances low alluvial terraces. We located six 5×10 m quadrats along each transect, parallel to the valley axis, and spaced evenly from each other. Depending on the valley width, the distance between these quadrats varied from 0 to 4 m. The valley floor at one site (PBC6) was too narrow to accommodate more than five quadrats, so there were a total of 65 quadrats at the 11 transects, with the transects ranging in length from 25 to 50 m.

Within each quadrat, we recorded species and diameter at breast height (DBH) of all stems greater than 3 cm DBH, living and dead. Here, we report only on the dead (i.e., no living foliage visible in 2003 or 2005) stems. *Salix* sp. are treated collectively, because without foliage individual species could not be distinguished. Although we observed woody debris on the valley floor in some quadrats, virtually none appeared recently burned, which suggests that snags killed in the Wolf Fire were still standing when we collected our 2003 sample.

In July 2005, we relocated the transects (which are permanently marked with buried metal stakes) and recorded whether each snag in the 2003 sample was still standing or had fallen. For those that had fallen, we recorded whether they were still present on the ground, or were gone from the quadrat (presumably transported by flood-waters, the only agent capable to remove them). At one site, several snags had been cut with chainsaws by a trail crew; evidence of surrounding stems suggested they would have been unlikely to have fallen otherwise, so we recorded these as though they were still standing.

We used an automatic level, rod and tape to survey the cross-section of the valley at each transect. We measured the height to which flood debris was trapped on each transect as an indicator of the maximum stage of the February 2005 flood, and used these stage data to calculate the mean depth to which each quadrat had been flooded. Whereas depth is an imperfect indicator of flood energy, it does contribute to stream power. Because the snags are vertical, the greater the depth of flow, the greater the area of a given snag that is exposed to the energy of the stream, which makes this a useful flood measure for our purposes.

3.2. Analysis

Research question i involves descriptive data, and required only tabulation. For question ii we calculated the ratio between the percentage of each species among the fallen snags and its percentage in the overall data from 2003. (For example, if Species A had constituted 20% of the burned snags in 2003, but accounted for 30% of the stems that had fallen by July 2005, the ratio would be 1.5. A ratio that exceeds 1.0 would indicate that snags of Species A had fallen at a rate disproportionate to the overall population of snags). To assess the influence of snag size we calculated similar ratios, with size class substituted for species, and also graphed the numbers of standing and fallen snags by size class for the overall dataset and for each species. We also used a *t*-test to test for difference in the mean diameter of standing and fallen snags. For questions iii and iv, we used *t*-tests to test for difference in the mean flow depth for standing vs. fallen snags and for fallen snags still present vs. snags that had been transported from the quadrat. For these tests, the depth assigned to each snag was mean flow depth for the quadrat in which it was (or had been, if gone) located, as calculated from the heights of flood debris.

4. Results

4.1. Question i: number and composition of fallen snags

Mortality from the fire was very high (94%), with 339 of the 362 stems in the sample quadrats killed. Of the 339 snags resulting from the fire, 57 (16.8%) had fallen 2 years later. Most of the fallen snags

Fig. 5. Channel alterations by woody debris accumulation, as observed in the study area.

were *A. rhombifolia* and *Salix*, with limited numbers of *Q. dumosa*, *Cercocarpus betuloides*, *P. fremontii* and *Amorpha californica* stems falling as well (Table 1, Fig. 6).

4.2. Question ii: impact of species and size on rate of snagfall

Little accord occurred between overall species composition of snags and the proportion of those snags that fell. *A. rhombifolia*, the most abundant species overall, was disproportionately likely to have fallen, whereas most of the other common taxa (with the notable exception of *Salix*) were under-represented among the fallen snags (i.e. the ratio in Fig. 6 is <1.0). In particular, none of the 33 *Arctostaphylos glauca* snags (9.7% of the total sample) had fallen.

Standing snags varied in size from 3 cm to 69.2 cm, whereas those that had fallen ranged from 3 cm to 33 cm (Fig. 7). The predominance of the smallest size class in Fig. 7b might seem to support an assumption that small snags were the least sturdy and, hence, most prone to fall, but this was not actually the case. Among the fallen snags, those <10 cm were not proportionate to the overall numbers, whereas snags between 10 cm and 30 cm were disproportionately likely to fall (Fig. 8). The mean diameter of snags that fell (11.4 ± 10.9 cm) was actually larger than that of snags that did not (11.0 ± 8.0 cm), although the difference is insignificant ($t = -0.34$, $p > 0.5$, $n = 339$).

Combining species and size information (Fig. 9), snags of *A. rhombifolia* with DBH 10–20 cm were most likely to have fallen, followed by other size classes of the same species. *Q. dumosa* and *P. fremontii* also show differentiation in snagfall rates by DBH, whereas snagfall of *Salix* was unrelated to size.

4.3. Question iii: flooding and snagfall

The mean flood depth for snags that fell (1.05 ± 0.68 m) was significantly greater than for those that did not (0.40 ± 0.56; $t = 6.64$, $p < 0.0001$, $n = 339$). The impact of flooding was also evident within species—snags that fell were subject to deeper flooding than those that did not in the two most common taxa, *A. rhombifolia* ($t = -2.79$, $p < 0.01$, $n = 105$) and *Salix* ($t = -6.01$, $p < 0.0001$, $n = 92$). It is also notable that the three species experiencing no snagfall at all (*A. glauca*, *Rhamnus californica* and *Q. agrifolia*) occurred only in higher quadrats, which had experienced virtually no flooding (Table 1), and suggests location rather than inherent durability that prevented them from falling.

4.4. Question iv: flooding and woody debris transport

Of the 57 snags that had fallen by July 2005, 43 (75%) were gone from the quadrats in which they had been recorded in 2003. The snags that had been mobilized were from quadrats that had experienced deeper flood depths (1.14 ± 0.69 m) than those that had remained

Table 1
Total number of snags, mean size of snags, percentage of snags fallen, and depth of submergence in the 2005 flood for species in the sample.

Species	# of snags	DBH (cm) ± SD	Percent fallen	Mean flood depth (m) ± SD[a]
Alnus rhombifolia	105	18.3 ± 12.0	30	1.02 ± 0.72
Amorpha californica	4	3.4 ± 0.7	25	0.16 ± 0.19
Salix sp.	92	7.0 ± 6.2	17	0.54 ± .54
Quercus dumosa	55	6.2 ± 4.0	11	0.03 ± 0.06
Cercocarpus betuloides	18	3.5 ± 1.0	11	0.12 ± 0.17
Populus fremontii	18	16.6 ± 11.3	6	0.53 ± 0.24
Arctostaphylos glauca	33	8.2 ± 4.0	0	0.11 ± 0.09
Rhamnus californica	8	3.5 ± 0.76	0	0.01 ± 0.01
Quercus agrifolia	6	29.3 ± 20.3	0	0.03 ± 0.02

[a] Depth for each snag was recorded as the mean depth of the quadrat within which it was sampled.

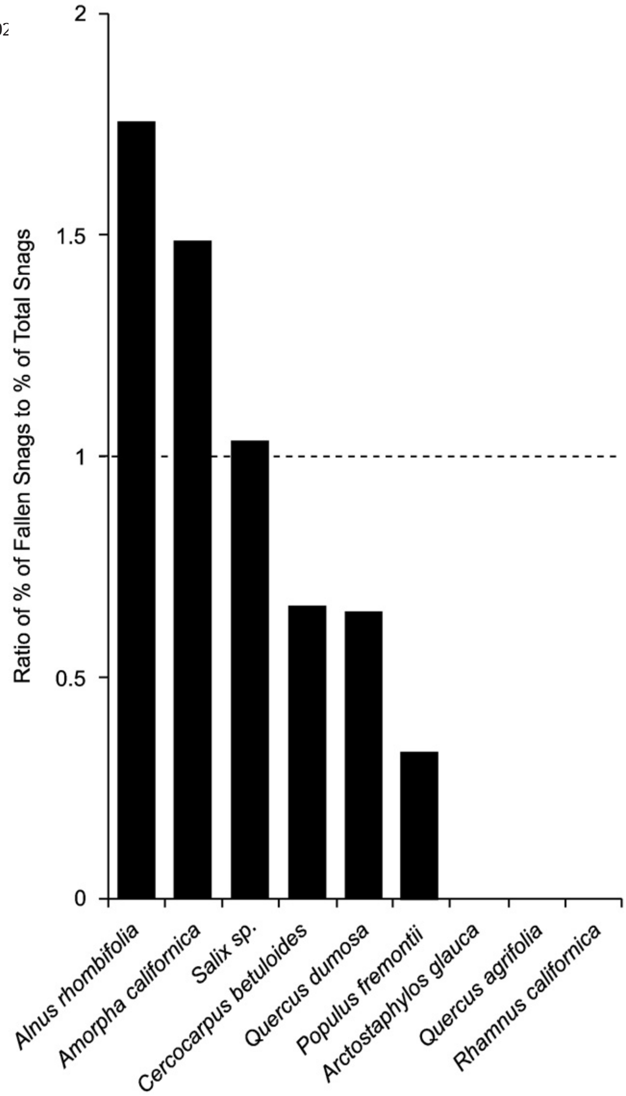

Fig. 6. Ratios of the percentage of each species among fallen snags, relative to the total percentage of that species among all snags (standing and fallen).

where they fell (0.80 ± 0.62 m), but the difference is insignificant ($t = -1.57$, $p > 0.10$, $n = 57$).

5. Discussion

The variance in snagfall shown in these results indicates that the rate at which dead stems from wildfire enter the fluvial system is affected by species differences and subsequent flood history. The timespan of this study does not allow for any definitive conclusions about longer term trends, but these results do suggest that while wildfire may result in stand-wide mortality, the resulting contribution of woody debris to streams may not be straightforward.

Rather than a single pulse of debris recruitment (Fig. 10a; c.f. Bragg, 2000), the varied rates of snagfall suggest that where multiple species are present on the valley floor, multiple, smaller peaks may be spread out over time, and reflect the varied time to failure for snags of different species (Fig. 10b). The number and size of peaks and scaling of the temporal axis in a given valley will depend on the diversity and characteristics of species represented in the landscape. In this region, where the composition of riparian communities may vary widely even in a given watershed (Bendix, 1994), the differences among species indicate that total inputs of woody debris after fire will be highly dependent upon local ecological detail: if the riparian community is dominated by *A. rhombifolia*, relatively rapid debris recruitment might be expected, whereas if *Q. agrifolia* dominates, a delay on the order of years to decades (at least) is more likely. The rapid response would be similar to that postulated by DeBano et al. (1998), whereas the latter timespan would be more similar to those modeled by Bragg (2000) and observed by Zelt and Wohl (2004) for conifer-dominated streams in the Rocky Mountains.

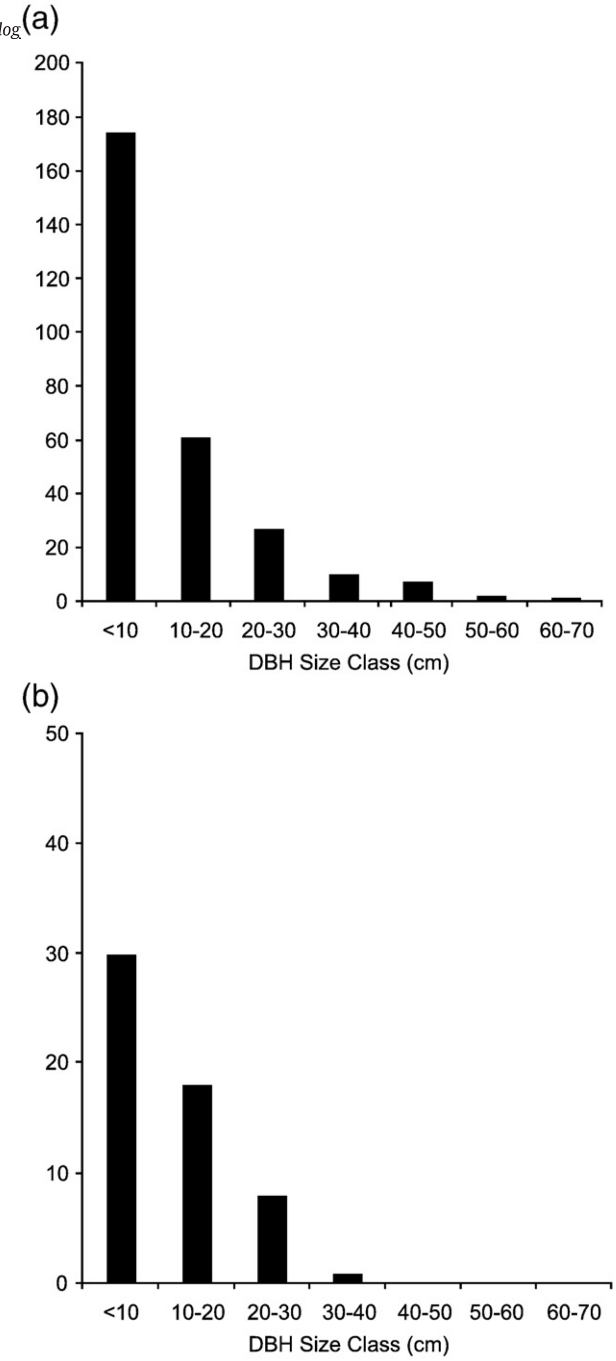

Fig. 7. Number of (a) standing snags and (b) fallen snags, by size class.

The role of flooding, in turn, complicates the temporal and spatial aspects of this species-based interpretation. Given the evident impact of flooding, large floods soon after a catastrophic wildfire are likely to hasten the occurrence of the snagfall peaks, and perhaps shorten the wavelengths. But this impact will be varied spatially—floods will have the greatest impact on snags in the channel, and the least impact on terraces. The occurrence of the debris recruitment pulses,

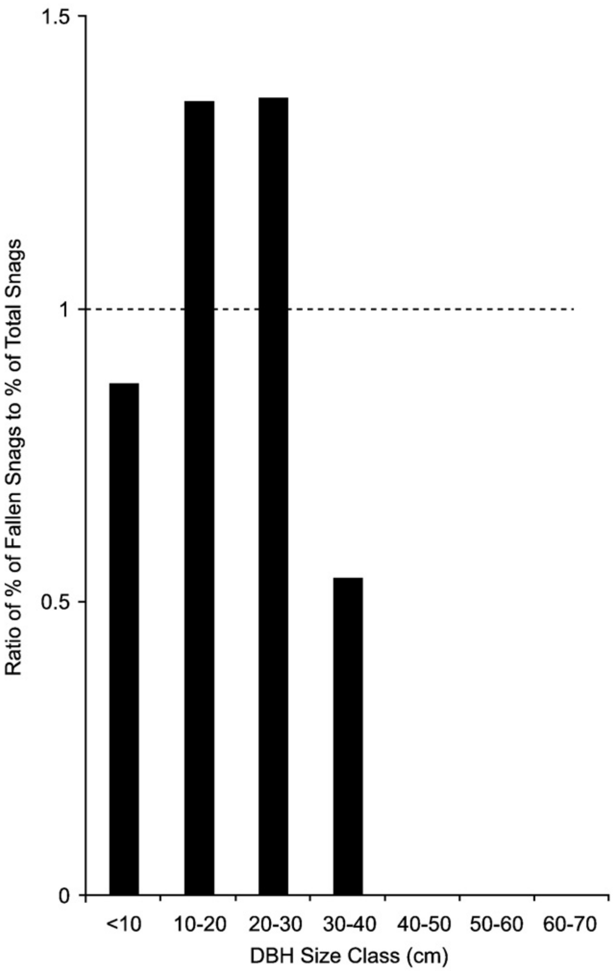

Fig. 8. Ratios of the percentage of each size class among fallen snags, relative to the total percentage of that size class among all snags (standing and fallen).

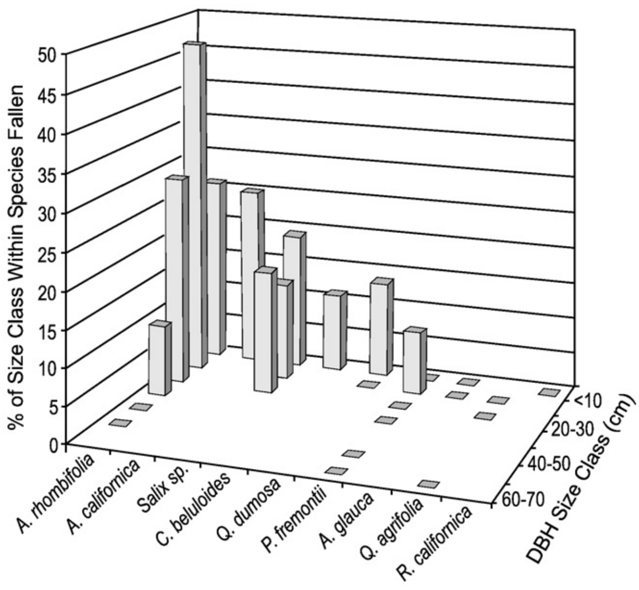

Fig. 9. Percentage of snags that fell within each size class of each species. Two-dimensional polygons denote species-size combinations within which no snags fell; empty spaces reflect species-size combinations that did not appear in the dataset.

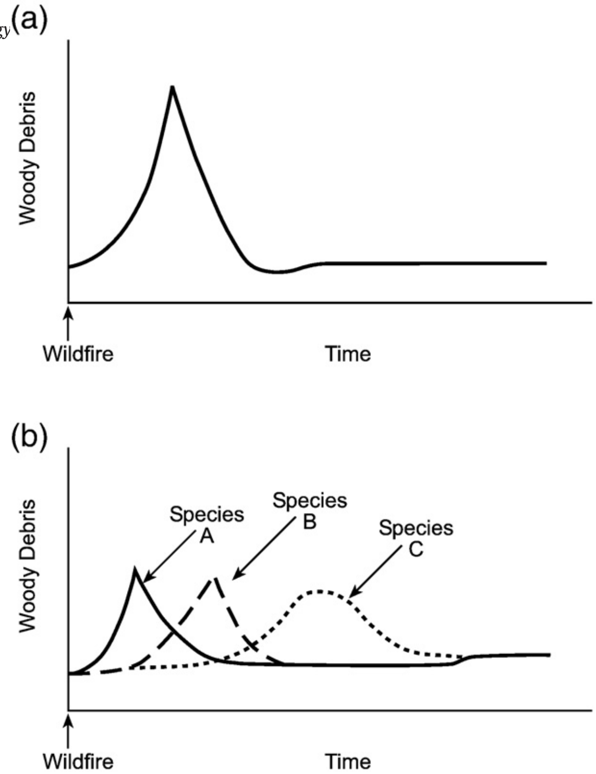

Fig. 10. Two conceptual views of the inputs of woody debris following wildfire: (a) single pulse reflecting homogeneity of burned forest; and (b) multiple pulses reflecting varied time to failure of snags of different species.

hypothesized in Fig. 10b, will, thus, be accelerated at the lowest elevations of the valley floor, but delayed and attenuated at the highest.

The flood depth, although significantly related to snagfall, is not related to the subsequent mobilization of the fallen stems. Whereas the reasons why some debris remained in place are unclear, at least the high percentage of fallen snags that did move suggests that even a moderate flood is enough to mobilize woody debris from across much of the floodplain.

It is likely that the apparent influences on snagfall of species and flood depth are not entirely independent of each other. The tendency of some species to grow preferentially on certain landforms means that some of the species relationship simply reflects the flood conditions where species are located. It would be oversimplistic to attribute all of the species differences in the rate of snagfall to fluvial influences, as the relationship between flood depth and the percent of species that fell is far from perfect (Table 1). Indeed, some of the characteristics that allow species to persist in flood-prone locations, such as trunk strength, rooting characteristics and substrate preferences (Bendix, 1999) might also allow snags of those species to persist longer without falling despite greater exposure to floods.

The degree of differentiation in rates of snagfall across the valley floor is likely to also vary from reach to reach, as local valley morphology determines the distribution of flood impacts across the valley (Bendix, 1999). Although distant from the primary channel, the details of snagfall across the valley floor are not irrelevant to fluvial processes, because high flow channels are present on the floodplain and on low terraces. Visible accumulations of heavily weathered older woody debris of comparable dimensions to the snags generated by the Wolf Fire attest to the capacity of woody debris to block or redirect these high flow channels (Fig. 5). As flooding favors disproportionately rapid snagfall in the channel, biogeomorphic feedbacks are again evidenced, as the most rapid woody debris inputs are in and near the channel, where they may tend to obstruct subsequent flows (and sediment transport). The wide variance in rates of snagfall among species, however, means that availability of "new" woody debris to contribute to storage of post-fire sediment (sensu Keller and Tally, 1982), while possible, will depend on the species composition of the burnt vegetation along any given reach.

The issues raised here are not unique to this study area. Our results suggest that in any environment the results of a seemingly homogenizing event (catastrophic wildfire) may actually be uneven along temporal and spatial axes. That is, the supply of woody debris may vary through time, depending on the susceptibility of different species to snagfall after burning and on the timing and magnitude of subsequent floods. At any given time the spatial distribution of woody debris across the valley bottom is likely to vary in response to the distribution of species with varied rates of snagfall and to the varied severity of flooding.

The importance of among-species variance in rates of stemfall is presumably limited to valley bottoms with heterogeneous forest composition, and future research could test the range of environments in which patterns of woody debris input do indeed emerge, as well as whether they similar patterns can be discerned after other types of stand-destroying disturbance (e.g. pest infestation). Longer term studies are also needed to determine whether the speculative inference, illustrated in Fig. 10b, accurately projects the future supply of woody debris.

6. Conclusions

This study provides the first detailed data regarding the supply of woody debris in the riparian systems within the southern California chaparral landscape. Following the 2002 Wolf Fire, 94% of trees in our sample were killed, and of these 16.8% fell within 2 years. Species were variable in the rate at which burned snags fell, with *A. rhombifolia* being particularly vulnerable to rapid snagfall. Snag size proved to be unimportant, as small snags did not fall at greater rates than larger ones. In general, snags that did fall were located in sites that experienced deeper flooding than those that did not. Flood depth did not, however, affect the likelihood of stems being transported once they had fallen. These findings indicate that short-term rates of snagfall following wildfire are influenced by the species composition of burned stems and by post-fire flood depth. Thus, although wildfire resulted in large numbers of burned snags across the valley floor, the rate at which these stems are recruited into the fluvial system as woody debris varies by the ecological characteristics of the stems and the geomorphic setting.

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