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Research paper

Influence of debris flows on macroinvertebrate diversity and assemblage structure

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ABSTRACT

The middle catchment of the Nu River is highly susceptible to debris flows. Differences in flow and substratum conditions among mainstem reaches correlate with debris flow depositions from lateral tributaries. We studied the impacts of debris flows on macroinvertebrates, especially responses in their diversity and assemblage structure to habitat modification at 22 sites in three habitats: barrier lakes and debris dams, formed by debris flow deposits barring the river, and unaffected mainstem sections. Unaffected mainstem sites supported the most diverse macroinvertebrate assemblage, with mean taxon richness, density and biomass 1.4, 1.1, and 23.6 times higher than those of debris dam sites, and 2.1, 4.2, and 7.4 times higher than those of barrier lake sites, respectively. Variance analysis revealed significant differences in diversity indices, and both taxonomic and functional feeding group composition among habitats. Although barrier lakes and debris dams had lower taxon richness, the two affected habitats contributed 17 and 16 exclusive taxa, respectively, to total taxon richness. Redundancy analysis identified habitats could be characterized by water temperature, electrical conductivity, flow velocity, and median particle size of substratum type. Significant differences in flow velocity and substratum median particle size among habitats were attributed to debris flows. Distinct assemblages within barrier lakes were associated with fine sediments. By altering habitat conditions, debris flows affect macroinvertebrate assemblages, reducing diversity locally in affected reaches, contributing to variation in diversity and assemblage structure throughout the catchment. Three genera (*Cricotopus* sp., *Pseudocloeon* sp. and *Monodiamesa* sp.) are proposed as potential indicator taxa for unaffected mainstem, debris dam and barrier lake habitats, respectively.

1. Introduction

Debris flows represent discrete and catastrophic disturbances in montane stream environments globally (Cover et al., 2010; Lamberti et al., 1991). They are a major hydrologic controller of in-channel and riparian geomorphic environment structure in mountainous landscapes (Lamberti et al., 1991; Swanson et al., 1998; Stock and Dietrich, 2003) and can severely affect stream ecosystems (Lamberti et al., 1991). Landslides occurring on steep slopes initiated by heavy rain often enter tributaries to create debris flows, in which are mass movements of water, sediment and wood (Imaizumi et al., 2008; Lamberti et al., 1991; Sidle and Ochiai, 2006). These flows directly kill or displace aquatic biota (Lamberti et al., 1991), and indirectly influence them through riparian vegetation and channel configurations (Kobayashi et al., 2013; Rosenberger et al., 2011), and changing in-stream habitat conditions (Danehy et al., 2012).

Given their episodic and unpredictable nature, the effect debris flows have on aquatic ecosystems has received little attention (Danehy et al., 2012; Kobayashi et al., 2013) beyond the biological responses of fish such as trout (Roghair et al., 2002; Rosenberger et al., 2011), and macroinvertebrates (Kiffney and Edmonds, 2004; Kobayashi et al., 2010, 2013; Snyder and Johnson, 2006), or both (Danehy et al., 2012; Lamberti et al., 1991).

Macroinvertebrate indicator taxa often used in river ecological assessments are sensitive to ecological stress (Gerth and Herlihy, 2006; Balderas et al., 2016). One month following one debris flow, macroinvertebrate taxon richness increased rapidly; within a year, density and taxon richness within disturbed and undisturbed areas was comparable, or the former exceeded the latter (Lamberti et al., 1991). Post debris flows, assemblage structure in one study remained unstable for two years (Lamberti et al., 1991), but stabilized in three years in another (Snyder and Johnson, 2006). From these two studies, it is

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apparent that macroinvertebrate assemblages might recover from debris flows within several years. Aquatic insects capable of in-stream drift or aerial dispersal can recolonize rapidly, but some other taxa probably require more time to recover (Cover et al., 2010); one once-dominant amphipod (*Gammarus nipponensis* Uéno) remained absent for more than 30 years following debris flows in headwaters (Kobayashi et al., 2013). Debris flows can also influence macroinvertebrate assemblage functional feeding group (FFG) composition (Danehy et al., 2012).

Most research on the effects of debris flows on assemblage structure has occurred in headwater environments; almost none has been undertaken on mainstems above third order. Debris flows can travel many kilometers from headwaters into higher-order streams (Benda et al., 2005). When entering mainstem reaches they often increase in size through accumulation of mobilized debris (Lamberti et al., 1991). Disruptive and abrupt debris flow deposits can alter riverine environments, such as sediment texture in the mainstem reach where they stop (Poole, 2002; Lloyd et al., 2005). Identification of environmental factors that influence assemblage structure is an essential step in river protection and restoration (Richards et al., 1993).

Where the Nu River passes through the Nujiang Grand Canyon in the northwestern Yunnan Province, China, frequent debris flows from side tributaries create highly dense mainstem debris dams. Not only do these debris flows threaten the safety and property of local residents, they stress local aquatic ecosystems. Debris dams form barrier lakes upstream and scour reaches downstream. Habitat conditions have been changed with the Nu River, with barrier lakes locally increasing water depth, fine sediment deposition, and decreased water velocity upstream, and having the opposite effect downstream. Although the volume of individual debris flows can be small, their widespread and perennial nature means that they can exert considerable impact on the entire local aquatic ecosystem.

We suspected that debris flows and resulting dams affected macroinvertebrate assemblage structure, that different habitats had different macroinvertebrate assemblages, and that significant relationships might exist between assemblages and environmental variables. Our study objectives were to determine the distribution of macroinvertebrates in the Nu River, relate variation in their assemblage structure to that of habitat, and identify the role debris flows have in shaping local macroinvertebrate assemblages.

2. Methods

2.1. Study area

The Nu River flows across southwest China, from its source in the Tanggula Mountains on the Tibetan Plateau; it is known as the Salween after entering Myanmar. The Nu River mid-region catchment was included within the Three Parallel Rivers of Yunnan Protected Areas, a UNESCO World Heritage Site that was designated a hotspot of global biodiversity (UNESCO, 2003; Zhou and Chen, 2005). This river has come under increasing pressure for hydropower development (Magee, 2006). Local macroinvertebrate assemblages throughout it are poorly known.

The study area, located in the Nu River basin, western Yunnan Province, extends from north to south across Gongshan, Fugong and Lushui, three counties of the Nujiang Lisu Autonomous Prefecture, and Baoshan City. Valley elevations range from more than 1500 m in the north to less than 700 m in the south. Outstanding geological features of the area include its relatively high relief, strong neotectonic movement, and frequent seismic activity; it has a monsoon climate, with heavy rain, hail, and other weather disasters being common (Tang, 2005). Average annual temperature exceeds 12 °C, and average annual precipitation decreases from north to south (1550–1850 mm in Gongshan to 850–1100 mm in Baoshan) (Fan and He, 2012). Average winter discharge is 455.9 m^3/s detected at Daojieba ganging station in Baoshan (Luo et al., 2016).

In general, forests and unused land account for more than 70% of the area in all districts (Luo et al., 2002). Human activities consist primarily of cultivation, with cultivated land area increasing from north to south, accounting for 1.1%, 4.4%, 7.2% and 19.8% of the areas in Gongshan, Fugong, Lushui and Baoshan, respectively (Luo et al., 2002). In this region, ecological changes are mainly controlled by natural factors (Yan et al., 2010), natural factors are considered to be more powerful than human activities on driving soil erosion (Feng et al., 2008; Yan et al., 2010).

The Nu River drains in a pinnate manner, with numerous short side tributaries, many of which are highly susceptible to debris flows. Surveys and statistics reveal some 372 debris flow spots occur in this area (Tang, 2005), with zones highly susceptible to debris flows covering a ribbon-like area of 10–15 km width from Gonshan to Lushui (Tang, 2005). These high-gradient tributaries, coupled with low vegetation cover and sufficient loose material and runoff, result in a high incidence of debris flows in the upper reaches (Borga et al., 2014). But incidence decreases in the lower reaches downstream of Lushui where the valley gradually opens up.

Debris flows strongly influence mainstem geomorphology, with mass deposition of materials smothering the original bottom, reorganizing bed structure. Erosion strips fine material away, leaving only coarse material behind. Debris flow bodies gradually develop over several-hundred-meters downstream in resistance structures formed by large boulders meters in diameter. Those boulder accumulation areas have been called “debris dams.” Upstream of debris dams, reservoirs, referred to as “barrier lakes” about 2–4 km length form, where water depth increases, flow velocity decreases and fine particulate matter deposits. Below these two habitats, the lower segment unaffected by debris flow is referred to as “unaffected mainstem”. These unaffected regions remain in a balanced state of riverbed erosion in a short timescale, with hydrological conditions (e.g., flow velocity and particle size of substrata) intermediate between debris dams and barrier lakes.

To describe macroinvertebrate assemblage structure in different habitat types, we undertook a systematic survey at 22 sites in three habitats: eight sites each in upper-segment debris dam (DD) and barrier lake (BL) habitats, and six sites in lower-segment unaffected mainstem (UM) habitat (Fig. 1).

2.2. Sampling and analysis

2.2.1. Macroinvertebrate sampling and environmental variable measurement

Field sampling was undertaken during winter of 2015 in base-flow conditions, following the protocol by Plafkin et al. (2013). At each site, three random subsamples were collected in comparable habitat at locations of 1 m^2. Macroinvertebrates were collected using a kick net (1 m × 1 m, 0.5 mm mesh), placed against the direction of water flow. A plastic brush was used to disturb and dislodge macroinvertebrates from substrata, which we endeavored to sample by scouring all movable substrata. Samples were fixed in 95% alcohol, and identified in the laboratory. Each three subsamples were pooled to represent one site.

All individuals were identified to genus or species using appropriate identification guides (e.g., Epler, 1977; Morse et al., 1984; Wiggins, 1998). Genus-level taxonomic criteria were used for data analyses. Taxa were divided into one of five FFGs according to Barbour et al. (1999) and Duan et al. (2010): collector-gatherers, collector-filterers, shredders, scrapers, and predators. See Appendix A Table A1 for taxonomic composition and FFG classification of macroinvertebrates in the study area.

Environmental variables included location (longitude, latitude and elevation), hydrological conditions [flow velocity (V), water depth (D), substratum median particle size (D50)], and water quality [pH, dissolved oxygen (DO), water temperature (T), and electrical conductivity