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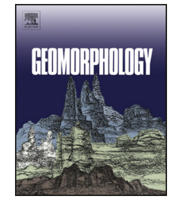

# Large wood, sediment, and flow regimes: Their interactions and temporal changes caused by human impacts in Japan

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ABSTRACT

Water, sediment, and large wood (LW) are the three key components of dynamic river-floodplain ecosystems. We examined variations in sediment and LW discharge with respect to precipitation, the presence of dams, land and river use change, and related channel incision and forest expansion on gravel bars and floodplains across Japan. The results indicated that unit sediment discharge and unit LW discharge were smaller in southern Japan where precipitation intensity is generally much greater. Effective precipitation, an index that takes current and antecedent precipitation into account, was a strong predictor of discharge in small watersheds, but not in larger watersheds. However, precipitation intensities related to unit sediment discharge in intermediate and large watersheds were smaller than those associated with unit LW discharge, which we attribute to differences in particle shape and size and also transport mechanisms. The relationship between river flow and discharge of sediment and LW lead us to posit that discharges of these components are supply limited in southern Japan and transport limited in northern Japan. The cross-sectional mean low-flow bed elevation of gravel-bed and sand-bed rivers in Japan decreased by ~0.71 and 0.74 m on average, respectively, over the period 1960–2000. Forest expansion on bars and floodplains has been prominent since the 1990s, and trees apparently began to colonize gravel bars ~10 to 20 years after riverbed degradation began. Forest recovery in headwater basins, dam construction, gravel mining, and channelization over the past half century are likely the dominant factors that significantly reduced downstream sediment delivery, thereby promoting channel incision and forest expansion. Changes in rivers and floodplains associated with channel incision and forest expansion alter the assemblages of aquatic and terrestrial organisms in riverine landscapes of Japan, and climate change may contribute to this change by intensified precipitation. Additionally, regime shifts of water, sediment, and LW may continue or they may reach a dynamic state of quasi-equilibrium in the future. Continued monitoring of these three components, taking into account their geographic variation, is critical for anticipating and managing future changes in river-floodplain systems in Japan and around the world.



## 1. Introduction

River and floodplain ecosystems are sustained by water and material flows delivered from contributing watershed areas. Among those flows, water is the most fundamental component because it transports materials that shape heterogeneous structures and various functions of river-floodplain ecosystems. Water transports organic matter, nutrients, and organisms from headwater basins to lowland rivers (Vannote et al., 1980). Among these materials transported by water flows, sediment is an essential component in creating river and floodplain morphology (Leopold et al., 1964) and provides substrates for organisms. Large wood (LW) is another major contributor to instream and floodplain habitat diversity and disturbance regimes (Gregory et al., 2003).

Water, sediment, and LW are the three key components that provide templates for river-floodplain ecosystems to function (Gurnell et al., 2002; Fig. 1). Streamflow carries sediment and LW pieces and determines the landscape patterns of bars, floodplains, and LW distributions (Nakamura and Swanson, 1993). Additionally, variation in streamflow supplies moisture for riparian forests (Shin and Nakamura, 2005), may disturb riparian forest patches, and can transport LW pieces into streams. In turn, variations in flow depth and velocity, channel units (e.g., pools, riffles), and the extent of the hyporheic zone are largely determined by sediment and LW accumulations (Wondzell and Swanson,

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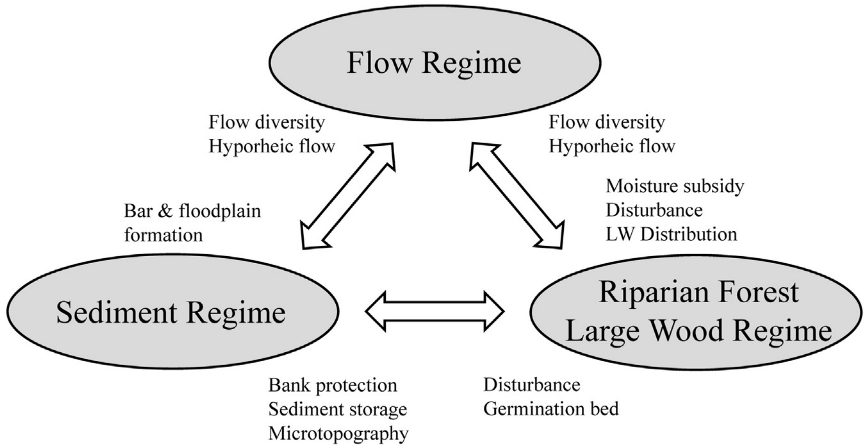


**Fig. 1.** Large wood, sediment, and flow regimes providing templates for river-floodplain ecosystems.

1996). Sediment deposits provide germination sites for riparian trees, although excessive deposition may bury and destroy some riparian trees (Nakamura et al., 2007). Conversely, riverbank and floodplain deposits are stabilized by root networks. During floods, riparian trees function as roughness elements that reduce flow velocity, promoting sediment deposition and storage. Large wood pieces on bars and floodplains promote deposition and erosion of sediment, resulting in heterogeneous substrate patches at the local scale (Gurnell et al., 2005).

Among the three components, water has received the most attention by ecologists because organisms living in rivers and on floodplains exhibit life history traits attuned to variation of water discharge (Poff et al., 1997). Thus, the natural flow regime and its roles in river and floodplain ecosystems have been examined for various organisms (Lytle and Poff, 2004). The adverse effects of dams on river-floodplain ecosystems as a result of altering the natural flow regime have also been noted (Bunn and Arthington, 2002; Poff et al., 2007).

By contrast, although sediment regimes have been a research focus for geomorphologists, they have received relatively little attention from ecologists (Wohl et al., 2015), except for the effects of fine sediment on periphyton biomass (e.g., Yamada and Nakamura, 2002), benthic invertebrates (e.g., Wood and Armitage, 1997) and salmonid spawning habitats (e.g., Suttle et al., 2004). Many studies have focused on ecosystem recovery after sediment-related disturbances, such as sedimentation and debris flows (Lamberti et al., 1991). However, those studies dealt with single disturbance events rather than sediment regimes. Additionally, many studies have focused on the dynamics and distribution of LW, roles of LW in habitat formation, and modification of movement and transformation of energy, nutrients, and food for stream dwelling organisms (Maser and Sedell, 1994). However, the LW regime at the watershed scale has been scarcely investigated (Benda et al., 2003).

River-floodplain systems undergo major shifts in regime in response to natural and human-induced changes in the contributing watershed that affect water, sediment, and LW regimes. Changes in these regimes cascade downstream through river networks, affecting aquatic and riparian ecosystems (Nakamura et al., 2000). Special circumstances in Japan provide an unusual opportunity to interpret such changes: >40 years of record of water and sediment discharge and a decade-long record of LW discharge at dams in small and large watersheds spanning nearly 20° of latitude and a range of climatic settings across Japan document rather systematic and dramatic change in river-floodplain characteristics.

This study aims to examine 1) spatial patterns in sediment and LW regime responses to precipitation over the gradient of latitude spanning Japan, 2) impacts of dams on the transfer of sediment and LW and their cascading effects on river morphology, 3) temporal trajectories of change in river morphology and riparian vegetation in response to human activities on the timescale of decades, and 4) discuss possible future changes in the river-floodplain ecosystem.

## 2. Methods

We divide the analysis of long-term sediment and LW discharge and precipitation records for two sets of watersheds upstream of sampled reservoir sites: (i) the subset of quasi-natural watersheds without dams and limited land use in order to assess discharge relationships to precipitation independent of these human influences, and (ii) the full set of records to assess influences of upstream dams and reservoir management. We also use data sets on the history of changing river morphology and riparian forest cover to understand their relation to land use on the timescale of decades.

### *2.1. Study area*

The Japanese archipelago runs from latitude 26°N to 45°N in the northwestern Pacific Ocean and precipitation varies along this latitudinal (LAT) gradient. The annual precipitation in southern and central Japan (south of 36°N latitude) ranges from ~2000 to 4000 mm, while annual precipitation in northern Japan (north of 36°N latitude) ranges from ~1000 to 2000 mm. The precipitation pattern is controlled largely by the frequency of typhoons. Southern and central Japan are frequently hit by typhoons, causing serious floods in summer and autumn. Northern Japan experiences few typhoons and precipitation is dominated by snowfall in winter, which results in snowmelt floods in spring.

### *2.2. Large wood and sediment regime responses to precipitation at a national scale*

We compiled a database of sediment and LW discharge, which have been monitored at reservoir sites on a yearly basis since the 1980s by local reservoir management offices. Sediment accumulation beneath the water surface generally was surveyed using the weight-drop method or a single/multibeam echo sounder, and sediment discharge ($m^3\ y^{-1}$) was calculated based on net changes in volume between two consecutive years. Large wood accumulation was estimated from a survey of the water surface area occupied by driftwood pieces or was calculated by counting the number of trucks filled with driftwood pieces after their removal from each reservoir. The volume of LW was converted to biomass weight using a conversion factor (0.4 Mg $m^{-3}$; Harmon et al., 1986; Seo et al., 2008). Annual discharge values were converted to a per unit of watershed area basis with SED discharge as $m^3\ km^{-2}\ y^{-1}$ and LW discharge as kg $km^{-2}\ y^{-1}$.

To examine the influence of precipitation variability on unit SED and LW discharge under quasi-natural conditions, we first extracted from

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