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Amazon river flow regime and flood recessional agriculture: Flood stage reversals and risk of annual crop loss

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SUMMARY

The annual flood cycle is an important driver of ecosystem structure and function in large tropical rivers such as the Amazon. Riparian peasant communities rely on river fishing and annual floodplain agriculture, closely adapted to the recession phase of the flood pulse. This article reports on a poorly documented but important challenge facing farmers practicing flood recessional agriculture along the Amazon river: frequent, unpredictable stage reversals (*repiquetes*) which threaten to ruin crops growing on channel bars. We assess the severity of stage reversals for rice production on exposed river mud bars (*barreales*) near Iquitos, Peru. Crop loss risk is estimated based on a quantitative analysis of 45 years of daily Amazon stage data and field data from floodplain communities nearby in the Muyuy archipelago, upstream of Iquitos. Rice varieties selected, elevations of silt rich bars where rice is sown, as well as planting and harvest dates are analyzed in the light of the timing, frequencies and amplitudes of observed stage reversals that have the potential to destroy growing rice. We find that unpredictable stage reversals can produce substantial crop losses and shorten significantly the length of average growing seasons on lower elevation river bars. The data reveal that local famers extend planting down to lower bar elevations where the mean probabilities of re-submergence before rice maturity (due to reversals) approach 50%, below which they implicitly consider that the risk of crop loss outweighs the potential reward of planting.

1. Introduction

Riverine plants and animal communities are known to have complex adaptations to natural flow regimes (Poff et al., 1997; Poff and Zimmerman, 2010). These flow regimes also determine the nature and functioning of vital ecosystem services, including fisheries, timber and crops grown on the nutrient-subsidized river floodplains (Tockner and Stanford, 2002). Farmers cultivating the floodplain of major tropical rivers have developed annual cropping strategies that exploit the productivity associated with the annual, long duration flood cycle (Chibnik, 1994; Fox and Ledgerwood, 1999). Peasants reliant on riverine ecosystem services require exacting (if informal) knowledge of the details of the local natural flow regime. Here we focus on the challenge posed by frequent and unpredictable stage reversals which inundate economically important crops sown on channel bars during annual flood recession along the Amazon river.

The Amazon river has the largest fringing floodplain of the world's major rivers (Tockner and Stanford, 2002) and the lowlands – comprising the active channel and floodplain (or *várzea*) – are important sites for agricultural production. Cultivated since pre-history, the active bars, levees, back swamps and terraces of the Andean tributaries and main stem of the Amazon river are sown in commercial and subsistence crops by farmers living in floodplain and river bluff communities (Roosevelt, 1980; Hiraoka, 1985). Andean-derived alluvium of the white water rivers provides more fertile young soils (Entisols), particularly in the western basin, than the deeply weathered, acid and nutrient poor soils (Ulitsols/Oxisols) common on the upland or *terra firme* where colonization, deforestation and agricultural development have focused (Barrow, 1985; Smith et al., 1995). Although flood recessional agriculture promises higher yields, farmers face the risk of crop loss to flood waters. Flood risk that shortens the growing season and imperils the livelihoods of floodplain farmers is a major impediment for development of the agricultural potential of the lowlands of Amazonia (Petrick, 1978; Junk, 1982; Barrow, 1985; Chibnik, 1994; Smith et al., 1995; Padoch et al., 1999; Kvist and Nebel, 2001; Labarta et al., 2007).

1.1. Flow stage reversals and their impacts

In addition to the annual flood pulse, sudden reversals in the direction of river stage changes that occur along the Amazon river

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and its formative tributaries are likely to have important effects on riparian ecosystems, aquatic life and recessional agriculture in the lowlands. Known regionally as "*repiquetes*", such week scale reversals in the seasonal trend of stage change, occur regularly during both falling and rising annual stages. They have been described on the main stem of the Amazon (Petry, 2000; Rios Arevalo, 2005; Da Silva et al., 2012) and are evident from annual daily stage records for both the Marañón and Ucayali rivers that combine near Nauta, Peru, to form the Amazon (see Senamhi, 2012; Armijos et al., 2013: Fig. 3). Along the mainstem Amazon in Peru, the large zonal and meridional span of its major tributary drainages favors asynchronicity of tributary inflows and make stage reversals common. Reversals on the rising limb, according to folk knowledge, stimulate fish spawning as the forests flood (Goulding, 1980; Villacorta-Correa and Saint-Paul, 1999), possibly triggered by changes in conductivity (Crampton, 2008). Prolonged stage retreats during flood season that draw water off the food rich floodplain may increase fish larvae and juvenile mortality (Petry, 2000). During the seasonal falling limb, reversals causing sudden stage rises re-submerge turtle nests on sand bars and suffocate eggs before occlusion (Garcia Mora, 2005).

Reversals are also problematic for farmers cultivating flood lands (Ministerio de Agricultura, 2008). As floodwaters recede and farmers sow their crops on newly exposed alluvial soils, reversals can expose seed to fish predation, waterlog soils, bury seed in sediment, and drown young plants (Rios Arevalo, 2005); more importantly – and often overlooked – they shorten the soil exposure period and thus the growing season. Farmers possess rich hydrological knowledge, including about *repiquetes* (Tomasella et al., 2013; Pinho et al., 2014), and select and plant their crops by elevational zones, with the slowest maturing at highest elevations (e.g., levee tops: plantain, perennial tree crops) and fastest maturing at lowest elevations (mud bars: rice; sandbars: cowpea) (Denevan, 1984). Climate change that is predicted to significantly alter inundation patterns in western Amazonian rivers (Sorribas et al., 2016; Langerwisch et al., 2013; Guimberteau et al., 2013; Marengo and Espinoza, 2016) and future dams on Andean montane rivers that disrupt sediment supply (Constantine et al., 2014) may have significant effects on stage reversals and the prospects for lowland agriculture.

Our field studies of recessional agriculture near Iquitos were focused on four floodplain communities in the Muyuy archipelago. Communities ranged in size from 14 to 30 households and the primary occupation of most households was lowland agriculture, complemented by fishing, non-timber forest extraction and wage labor. Most households are poor: the mean annual income for 2014 was 1334 $US/capita and households held on average 641 $US in assets. The primary crops grown include rice, maize, plantain, sugar cane and vegetables. Seven rice varieties were planted on exposed river bars in 2013 with maturation times of 75–150 days (List, 2016).

1.2. Objectives

In this paper we examine occurrence of stage reversals along the Amazon river near Iquitos, Peru, based on a long-term (45 year) daily river stage record. We assess the risk of rice crop losses due to reversals near Iquitos and recommend strategies for mitigation. We first characterize reversal events by quantifying their seasonality, frequency and magnitude over the 45 year record. We then determine the probabilities of a sufficient crop growing season being reached over the range of rice planting elevations and dates which were observed in local communities. Our focus is primarily on rainfed lowland rice that is grown on active bars and is an extensively grown, economically important commercial crop in the region.

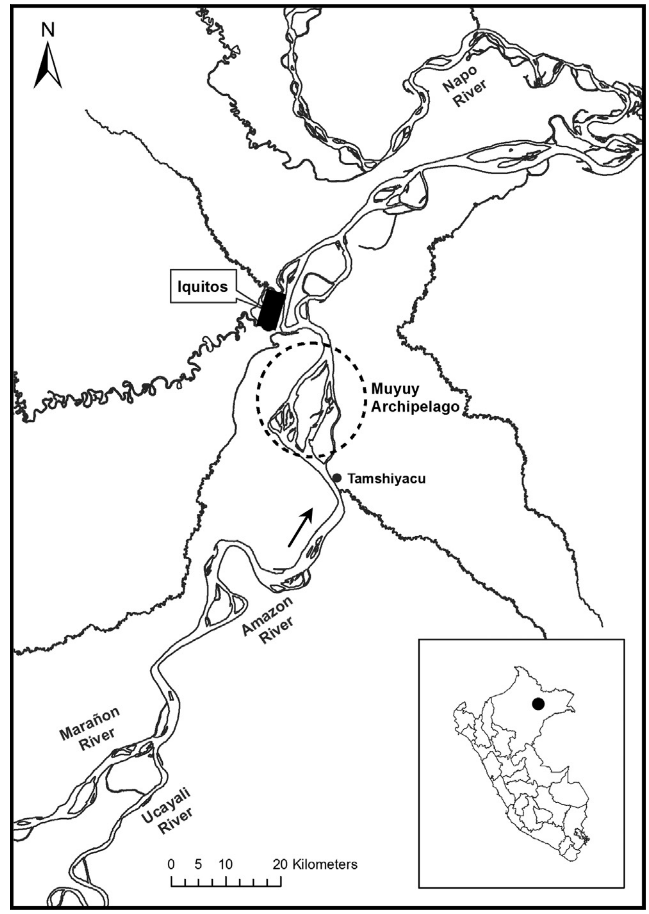

Fig. 1. Study area, northeastern Peru.

2. Study area

The study area is situated along the Amazon river, between Iquitos, the largest urban centre of northeastern Peru, and the town of Tamshiyacu, 38 km upstream (south) (Fig. 1). In the study reach, the floodplain is up to 24 km wide and includes a large and erosionally active anabranching structure comprised of the islands of Muyuy and Panguana (see Kalliola et al., 1992; Frias et al., 2015). In the study reach, the basin area of the upper Amazon river is 726,400 km^2, lying between 0.5° and 15.60° S. Long term mean discharge is 32,000 m^3/s (Espinoza et al., 2009a) and total suspended sediment yield is 500–700 × 10^6 t/yr (Armijos et al., 2013). Water level variations along the Amazon are the result of seasonal precipitation patterns over large sub-basins spread over this 15° latitude belt, which are modulated inter-annually by the Atlantic SST and ENSO cycles (Lavado Casimiro et al., 2013; Espinoza et al., 2011, 2015). Discharge in the study reach is a composite from the Amazon river's two formative upstream drainage basins – the Marañón River (a 358,000 km^2 drainage, flowing from the north) and Ucayali River (353,000 km^2 drainage, from the south; Fig. 1). The Ucayali river conveys about twice the sediment load but only 70% of the discharge of the Marañón (Armijos et al., 2013). Trends in precipitation and temperature in the Peruvian Amazon headwaters over 40 years are described in Lavado Casimiro et al. (2013). Headwater precipitation and runoff regimes are seasonally and spatially complex and highly variable, to the extent that out-of-phase regimes are observed in nearby stations (Laraque et al., 2007). Overall, precipitation over the northern tributaries tend to peak in northern hemisphere summer while the southern tributaries precipitation peaks in winter (Espinoza