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Exploring the hydrology and biogeochemistry of the dam-impacted Kafue River and Kafue Flats (Zambia)

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ABSTRACT

Wetland processes are strongly influenced by hydrologic factors such as precipitation, surface runoff, and flooding dynamics. Anthropogenic disturbances to flooding regimes can thus substantially alter wetland habitat and biogeochemistry. The Kafue Flats, a large floodplain (~6500 km^2) along the Kafue River in South-Central Zambia, is a wetland impacted by upstream and downstream hydropower dams. The main purpose of this study was to develop a water budget for the Kafue Flats under current conditions, quantify nutrient and organic carbon concentrations in the river, and use the combined information to estimate biogeochemical budgets. A water balance was developed for the Kafue Flats at a subcatchment scale for the years 2002–2009 using daily hydrological data. In addition, bi-monthly flow and chemical measurements were performed over 1 year (May 2008–May 2009) at multiple stations. Evapotranspiration was an important process in the Flats, accounting for up to 49% of total hydrologic outputs in some subcatchments. Direct precipitation contributes substantial to water inputs to the flats: runoff from the upstream catchment accounted for 45% of water inputs to the Kafue Flats, while the remaining 55% came from direct precipitation to the Kafue Flats from its subcatchment. Estimates from the wet season suggest that ~75% of the water flowing in the river's main channel as it exits the Flats spent some time within the highly productive floodplain. This exchange between the floodplain and the river appeared to play an important role in nutrient and carbon export to the river's main channel and out of the wetland. The floodplain was a net source of phosphate (220 t/year), total nitrogen (1300 t N/year, of which ~90% was organic nitrogen) and total organic carbon (50,000 t C/year) to downstream systems. Thus, when considering dam impacts and altered flooding dynamics in this system, potential changes to carbon and nutrient cycling also need to be taken in to consideration, which may have implications for nutrient availability within the Kafue Flats and nutrient export to downstream systems.

1. Introduction

Hydrology is an important driver of biogeochemical processes in floodplain ecosystems (Junk et al., 1989; Tockner et al., 2000). Important floodplain processes such as particle deposition (OldeVenterink et al., 2006), organic matter mobilization, and nutrient turnover (Baldwin and Mitchell, 2000) are governed by the exchange between river and floodplain. In tropical areas with distinct rainy and dry seasons, floodplains are often seasonal wetlands with high productivity (Neue et al., 1997) and high biodiversity. While the effect of hydrological exchange between river and floodplain on biogeochemistry has received substantial attention in temperate systems (e.g., Tockner et al., 1999; Wiegner and Seitzinger, 2004; Hunsinger et al., 2010), studies in tropical systems are sparse (e.g., Bouillon et al., 2007; Nwankwor and Anyaogu, 2000). Studies in the Okavango delta have shown that organic matter mobilization and transport is a direct effect of hydrological river–floodplain exchange (Mladenov et al., 2005, 2007).

We explored interactions between the river and the floodplain and their influence on organic carbon (OC) and nutrient exports in the Kafue River and Kafue Flats system in southern Zambia (Fig. 1). The Kafue River Basin (KRB) is the most economically active basin in Zambia and a major tributary of the Zambezi River (Fig. 1). Anthropogenic water uses in the basin are dominated by hydropower, mining, and irrigation. These activities, in particular mining and hydropower, have led to degraded water quality along some stretches as well as altered hydrology in the KRB (Kambole, 2002). Two large dams, Itezhi Tezhi (ITT) and Kafue Gorge (KG), regulate the flow through the lower KRB. The Kafue Flats, a large (~6500 km^2) and high-value ecosystem (Ramsar site), lies between these two dams. One of the major impacts of the Itezhi Tezhi and Kafue Gorge dams has been a change in the extent and duration

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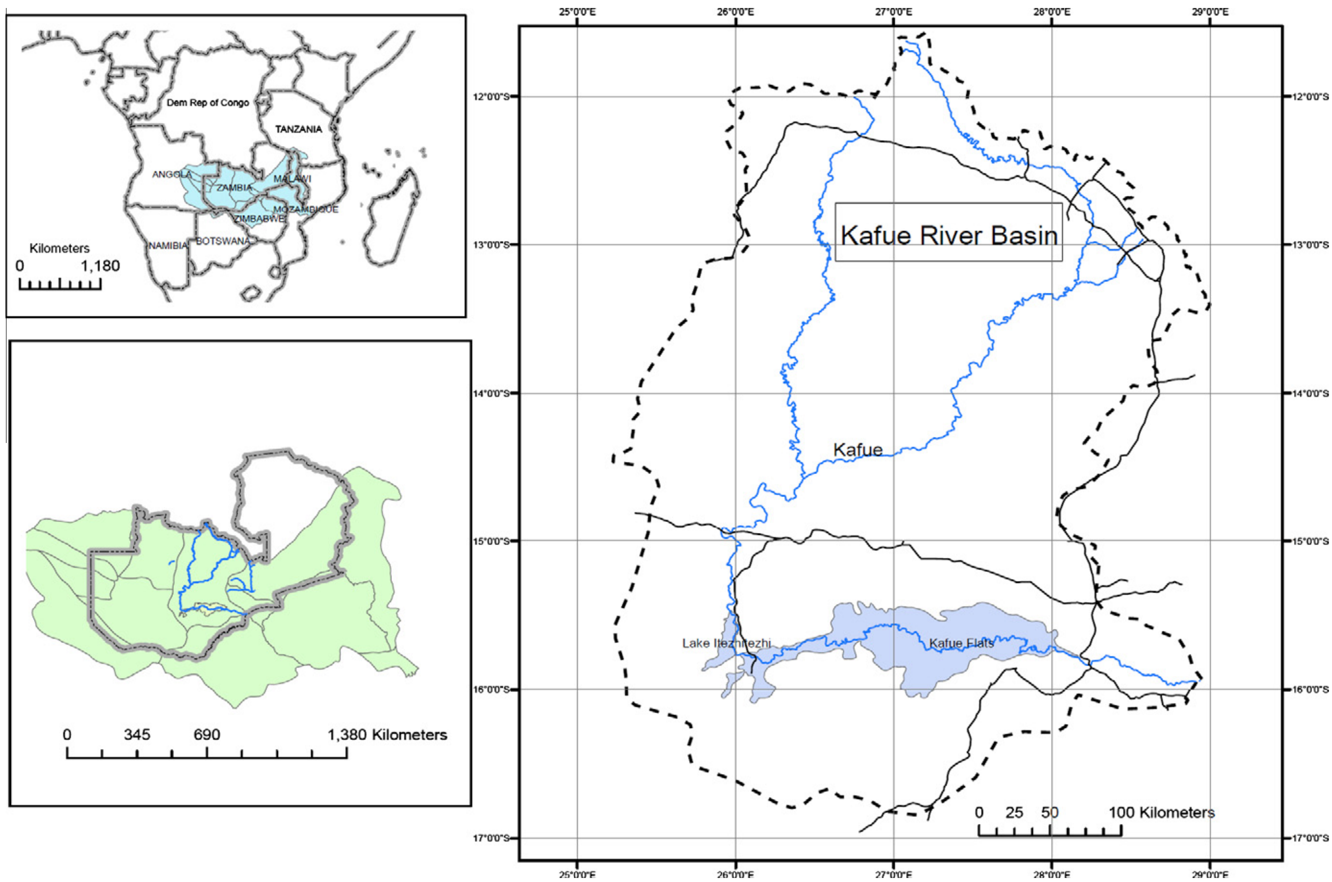

Fig. 1. The Zambezi River Basin in Southern Africa and the location of the Kafue River Basin and the Kafue Flats.

of the flooding (Mumba and Thompson, 2005), and studies suggest that altered hydrology due to dam operation have substantially influenced this systems' ecology (Dudley and Scully, 1980; Obrdlik et al., 1989). While the hydrology of the Kafue River Basin and Kafue Flats has been studied extensively, there is limited information on river–floodplain interactions and how this influences the biogeochemistry of Kafue Flats and the Kafue River (Salter, 1985).

The main goals of this study were to (i) characterize the spatial and temporal variability in the relative importance of different water inputs (riverine input, direct precipitation, lateral inputs) and river–floodplain exchange in the Kafue Flats and (ii) characterize the temporal and spatial variability of N, C, and P concentration, speciation and loads over an annual cycle, in the Kafue River as it flows through the Kafue Flats. To explore these goals a network of river stations was established and bi-monthly field trips over the course of 1 year were conducted to measure discharge and collect water samples for chemical characterization. Using these measurements, combined with daily hydrological data collected by local agencies, we developed water balance, nutrient (N, P) and carbon loading estimates at subcatchments scale along the Kafue River.

2. Methods

2.1. Study area: the Kafue River and Kafue Flats floodplain system

The Kafue River Basin (KRB) is one of the major sub-basins in the Zambezi Basin in Southern Africa (Fig. 1). The Kafue River is ~1500 km in length and has a catchment area of 154,000 km^2 (Obrdlik et al., 1989; Mumba and Thompson, 2005). Its drainage basin can be subdivided into three sub-basins: the upper half of the catchment area in the wetter northern part of Zambia, north of the ITT dam; the central basin that includes the Kafue Flats and extends from ITT to the KG dam and the lower Kafue, downstream of KG dam, where the river drops steeply from the plateau and joins the Zambezi River (Pinay, 1988; Scott Wilson, 2003; Euro Consult Mott MacDonald, 2008). The KRB has a tropical climate with two distinct seasons, a wet season between November and March and a dry season between April and October. The daily mean temperature varies from 13 °C to 20 °C in July and from 21 °C to 30 °C in November (Yachiko, 1995). The average annual rainfall over the Kafue flats floodplain is 850 mm and is concentrated in the wet season (Yachiko, 1995). The study area for this project extends from Hook Bridge (K0, Fig. 2), upstream of ITT dam, up to the confluence with the Zambezi River (K7, Fig. 2). From ITT dam the river meanders for approximately 400 km through the Kafue Flats, over a west–east distance of ~200 km. The river's gradient through the Flats is extremely shallow, 0.04 m per km in the western half and 0.01 m per km in the eastern half, resulting in a total elevation drop of 10 m. (Ellenbroek, 1987; Pinay, 1988; Scott Wilson, 2003).

The Kafue Flats wetland covers between 4400 and 6500 km^2 (Dudley, 1979; Obrdlik et al., 1989; Scott Wilson, 2003; Mumba and Thompson, 2005; Ramsar, 2006), and the flooded area varies seasonally and interannually. There are seasonally flooded natural meadows, creeks, braided channels, back swamp levees, lagoons, and large flats (Welcomme, 1975; Ellenbroek, 1987; Ramsar, 1999). Most of the floodplain is covered with grass, and there are woodlands on higher grounds (Ellenbroek, 1987; Ramsar, 1999). The Kafue Flats floodplain extends 40–56 km at its widest point (Scott Wilson, 2003; Mumba and Thompson, 2005). Since the construction of the Itezhi Tezhi and Kafue Gorge dams in the 1970s the extent and duration of the flooding in the Kafue Flats has been altered (Mumba and Thompson, 2005).