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Forest Ecology and Management 212 (2005) 184–198

Forest Ecology and Management

www.elsevier.com/locate/foreco

Environmental gradients in the Turkwel riverine forest, Kenya: Hypotheses on dam-induced vegetation change

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Received 14 July 2004; received in revised form 4 March 2005; accepted 30 March 2005

Abstract

The ecology of arid and semi-arid floodplain forests in Africa is being deliberately altered by the construction of dams. There is, however, a widespread lack of baseline data to support detailed assessments of dam-induced impacts on downstream forest composition. In the Turkwel River, north-western Kenya, fragmented discharge records reveal that the river flow regime has changed significantly after the impoundment of the Turkwel Gorge Dam in 1990. In order to generate hypotheses on the impacts of river damming, a series of 93 sample plots (30 m $\times$ 30 m) were distributed across and along the entire Turkwel River floodplain. The vegetation gradients were summarized by detrended correspondence analysis and correlated with measured environmental variables. Canonical correspondence analysis was then used to partition the compositional variation on hydrological, climatic, land-use, and edaphic variables. The gradient approach was compared with the scales of spatial autocorrelation among ordination axes and environmental variables to detect causal vegetation-environment relationships. Results show that the main vegetation gradient was strongly correlated with distance to the river channel, elevation, and subsoil electrical conductivity, while the second gradient was strongly correlated with distance to the river mouth and rainfall. Increased lateral distance and elevation was interpreted as a reduction in flooding frequency and duration towards the dry and saline edge of the riverine zone. Floodplain inundation is believed to combine with post-flood water tables in determining suitable conditions for forest regeneration. The longitudinal gradient represented a regional change in water regime from the mesic upstream to the xeric downstream section of the river. Variation partitioning illustrated the crucial importance of hydrology, which explained 63% of the total compositional variation, as compared to soils (43%), climate (34%), and land-use (4%). There were also significant interactions between hydrology, soils, and climate. It is hypothesised that the Turkwel riverine forest will experience shifts in the lateral as well as longitudinal vegetation gradients due to reductions in peak and mean flows. This study demonstrates an efficient and straightforward approach for assessing the possible impacts of river flow regulation in the absence of detailed hydrological data and long-term vegetation records.

Keywords: Constrained ordination; Dam impoundment; Floodplain forest; Riparian vegetation; Turkana; Variation partitioning

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doi:10.1016/j.foreco.2005.03.037

1. Introduction

Dam construction on arid and semi-arid rivers changes the flow regime and typically alters the composition and extent of floodplain forests (Rood and Heinze-Milne, 1989; Rood and Mahoney, 1990; Rood et al., 1995; Shafroth et al., 2002). The magnitude, direction, and time-scale of these alterations depend on the delicate interplay between hydroperiod (i.e., flooding frequency, duration, timing, and depth; e.g., Furness and Breen, 1980; Hughes, 1990; Auble et al., 1994), river geomorphology and fluvial landforms (e.g., Hupp and Osterkamp, 1985; Medley, 1992), alluvial water tables (e.g., Stromberg et al., 1996; Shafroth et al., 2000), substrate texture, salinity, and nutrient content (e.g., Dunham, 1989; Busch and Smith, 1995), climatic conditions (Wyant and Ellis, 1990), wildfires (Oba, 1990), and land-use (e.g., Hughes, 1984; Stave et al., 2001). The complex ecology of floodplain forests combined with the widespread lack of long-term vegetation records calls for a gradient approach by which future vegetation change can be hypothesised from the knowledge of contemporary vegetation-environment relationships. According to Økland (1996), indirect gradient analysis (i.e., ordination) is the preferred method for generating hypotheses in exploratory vegetation research. In addition, recent developments in the use of (partial) constrained ordination techniques to partition the variation in multivariate data matrices on several groups of explanatory variables (Vandvik and Birks, 2002; Qian et al., 2003; Økland, 2003) have provided a powerful tool for quantifying the separate and joint effects of multiple environmental gradients in floodplain forests.

The need for assessing the links between river flow regulation and forest composition is particularly evident in arid and semi-arid Africa where numerous rivers have been developed for hydroelectric and irrigation purposes, and where forest products provide crucial inputs to local livelihoods (e.g., Adams and Hughes, 1986; Hughes, 1994). The direct effects of dam construction on downstream hydrology are mainly the trapping of suspended sediments in the reservoir and a flattening of the hydrograph (Petts, 1984; Maingi and Marsh, 2002). The altered flow regime might prevent floodplain inundation and thereby reduce the recharge of alluvial aquifers. Because individual species have different and often highly specific inundation and soil moisture requirements for their regeneration (e.g., Mahoney and Rood, 1991), the elimination of overbank flooding events might promote a homogenisation of vegetation composition (Townsend, 2001). Moreover, dam-induced alterations in river flow regularity or downstream flow duration might have significant effects on the distribution and depth of floodplain water tables. The subsequent adjustments in woody species composition are inherently hard to assess and predict due to disparate lag times between environmental change and vegetation response, as well as poor hydrological records (Hughes, 1988, 1994). Inadequate knowledge of the past river flow regime in many African rivers imposes major methodological challenges to the assessment of dam-induced environmental impacts. However, in the absence of detailed hydrological records, elevation and distance provide well-established correlations with flooding frequency and duration (Dunham, 1989; Hughes, 1990; Van Coller et al., 2000; O'Connor, 2001).

Among the rivers that have been affected by dam construction is the Turkwel River in north-western Kenya, which supports a luxuriant floodplain forest with an abrupt boundary to the adjacent semi-desert dwarf shrubland. The forest is used as a dry-season grazing refuge by the semi-nomadic Turkana pastoralists, whose livelihood relies on the herding of domestic animals (cattle, camels, donkeys, goats, and sheep). Valuable tree species such as *Acacia tortilis* (Forssk.) Hayne, *Faidherbia albida* (Del.) A. Chev., *Hyphaene compressa* H. Wendl., *Cordia sinensis* Lam., and *Salvadora persica* L. supply fodder for livestock, as well as firewood, construction materials, edible fruits, and medicines. Grazing and wood extraction is controlled by an informal forest management system called *ekwar*, which prescribes semi-private usufruct rights to riverine trees (Barrow, 1990; Stave et al., 2001). Traditional land-use also involves the cultivation of sorghum (*Sorghum bicolor* (L.) Moench) in recently abandoned riverbeds or on meander scars along the riverbank (Morgan, 1974). While these traditional gardens might promote forest regeneration (Oba et al., 2002), irrigation schemes and settlements have encroached into the floodplain forest during the last couple of decades. The increasing number of sedentary agro-pastoralists and town-