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A tool for tracking floodplain age land surface patterns on a large meandering river with applications for ecological planning and restoration design

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Abstract

An alluvial river channel typically meanders by eroding its outer banks and depositing sediments on the inside of bends, producing new land surfaces. Over time the landscape pattern created by these processes is important to the understanding of riparian plant ecology and the spatial structure of riparian forest development for restoration planning and design as well as other purposes. The middle sector of the Sacramento River is an actively meandering channel that deposits sediments in discrete new areas from fluvial geomorphic events creating a land age gradient. Newly formed land undergoes a primary succession by woody species such as willow and cottonwood communities that provide habitat for important conservation target species in California. Conservation and restoration of primary and secondary successional processes is an important management goal on the Sacramento River. The objectives of this paper were: (1) to develop and codify new methods to track the surficial chronological patterns of floodplain land age in a meandering river system, and (2) to analyze land production and the spatial distributions of gravel bars, riparian vegetation communities, and forest structure in relation to the land age gradient. Results from the ecological analysis indicate 71% of extant riparian vegetation was located within the 101-year meander zone; willow (18%) and cottonwood (31–43%) had the highest proportional canopy cover on lands aged 1–9 and 10–44 years, respectively. Potential applications of this approach for conservation and restoration planning and design of alluvial river floodplains are discussed.

Keywords: Meander migration; Floodplain age; Primary succession; Canopy structure; GIS cartographic modeling; Sacramento River; Ecological cascade effect

1. Introduction

1.1. Background

The riparian landscape of a meandering river system is a heterogeneous land mosaic that can change rapidly through time in response to fluvial geomorphic factors (Gregory et al., 1991; Malanson, 1993; Bayley, 1995; Steiger et al., 2005). This study addresses key questions that are important to help guide the rehabilitation of alluvial riparian ecosystems and to show how documenting the chronological development of floodplain deposits can elucidate ecological patterns of riparian vegetation for purposes of restoration planning, design, and management.

The concept of "the landform system composed of a nested hierarchy of subsystems each having different levels of sensitivity and recovery, the whole being subject to a temporal stream of input (i.e., process) changes" (Petts and Bravard, 1996 quoting Chorley et al., 1984) is fundamental to understand riparian landscape dynamics (van Coller et al., 2000; Dixon et al., 2002; Turner et al., 2004). Malanson (1993) argued that riparian systems are a shifting mosaic of patch dynamics in a continuous state of multi-dimensional (space–time) change. Therefore, a method of analyzing riparian vegetation structure and development (i.e. succession) should reflect the effects of temporal sequences and spatial patterns of fluvial geomorphic disturbances (Benda et al., 1998).

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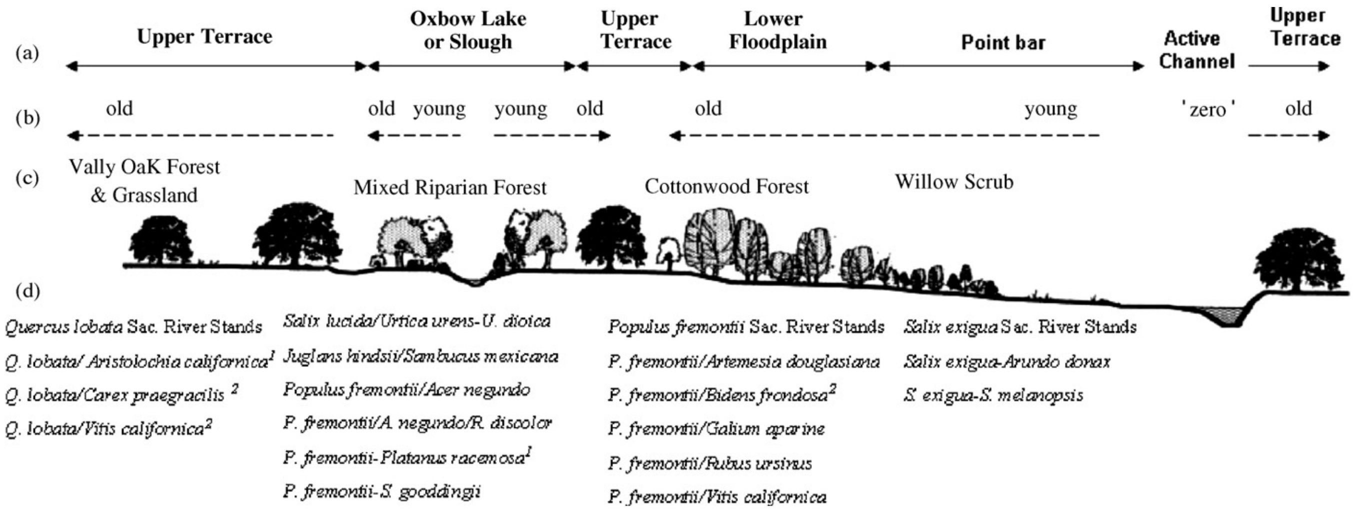

Fig. 1. A cross-section of the Sacramento River floodplain depicting an idealized riparian toposequence: (a) solid lines show the extent of fluvial geomorphic floodplain zones, (b) dashed lines indicate generalized floodplain age gradients, (c) plant communities identified by Holland (1986), and (d) plant species associations described by Vaghti (2003) and others. 1, Rivas-Martinez et al. (1999); 2, Tu (2000). Illustration adapted from Vaghti and Greco (2007) and Conard et al. (1980).

The typical geomorphic structure of a floodplain in a low-gradient or piedmont alluvial river includes eroding cut banks, depositing pointbars, frequently inundated lower floodplains, and infrequently inundated upper terraces (Fig. 1a). The sinuous pattern created by erosion of banks and deposition on pointbars is self-maintaining over time through progressive bend migration (Leopold et al., 1964; Hickin, 1974; Ferguson, 1977). Land reworked through erosion and deposition processes of an active channel creates new land surfaces devoid of vegetation. Bend evolution and channel migration rates are largely a function of local flow magnitude, sediment characteristics, and bank properties (Hughes, 1977; Johannesson and Parker, 1989; Larsen, 1995; Larsen et al., 2006). Human influences on river flows (from dams and diversions) and on bank erosion (i.e. riprap or other revetment) can significantly reduce channel migration rates. However, it should be noted that due to uncertainty and the degree of interactions among those human influences, determination of a single causality can be difficult to achieve (Piégay and Schumm, 2003). Inter-annual climatic variation can produce a range of runoff volumes from a watershed and result in episodic rates of channel migration (Hickin, 1977; Larsen et al., 2006). High flow events can cause large deposits on the margins of pointbars or can initiate meander bend cutoff events to create oxbow lakes (i.e. floodplain water bodies) (Hooke, 2004). Over time oxbow lakes undergo a gradual terrestrialization process due to sediment deposition and accumulation of organic matter (Malanson, 1993; Morken, 2002; Piégay et al., 2002).

To effectively plan, manage, and restore degraded alluvial river systems, there is a need to develop quantitative models to describe and predict geomorphic processes and riparian vegetation community patterns. For a review of some new tools in fluvial geomorphology see Kondolf and Piégay (2003) and for riparian ecology and conservation see Naiman et al. (2005). An approach to quantifying the spatial patterns of meander migration that takes geomorphic processes into account is the mapping of low-flow channels at various time intervals to produce a 'floodplain surface age' map (Gilvear and Bravard, 1996). A good example of this approach was an analysis of the development of alluvial floodplains from ca. 1840 to 1980 in the River Dane Valley in Cheshire, N.W. England by Hooke et al. (1990). The analysis depicted five floodplain age classes representing the time periods: 1840–1870, 1870–1910, 1910–1947, 1947–1968, and 1968–1980. However, Hooke et al. (1990) did not present a formal method for creating the map of floodplain surface ages. To our knowledge, there is not a study in existing literature that formalizes a method to document floodplain surface age for meandering rivers. There is much information regarding the input data for such a map. Historical maps and photographs are typical sources of information for geomorphic studies of channel change, but have limitations in terms of availability, accuracy, and interpretation (Gurnell et al., 2003). Lewin (1977) noted how graphical representation of low-flow channel data can vary from historical maps and photographs and that river stages are rarely recorded. Most of these problems were overcome in this study by acquiring a long time series of photographs and maps, controlling for spatial resolution, employing consistent interpretation rules, and linking photograph dates to historical flow records (see Greco et al., 2003; Greco and Alford, 2003a,b).

A suitable approach to represent the phenomenon of surficial floodplain chronology, or floodplain age, is cartographic modeling using a geographic information system (GIS). Cartographic modeling is a map overlay process that uses functions to combine the features and attributes of multiple map layers into a single map layer (Tomlin, 1990; Lo and Yeung, 2002). Temporal GIS data structures and models to track geographic changes over time are becoming more prevalent in resource management (Ott and Swiaczny, 2001; Peuquet, 2002), such as the development of the ArcGIS Tracking Analyst Software Extension (ESRI, 2003a). Several GIS methods to detect and quantify landscape change are reviewed in Mitchell (1999). In particular, the 'space–time composite' modeling approach described by Langran (1993) uses a series of time slice overlays (time interval snapshots) of the same geographic area to systemati-