Riparian forest impacts and dynamics on large rivers managed for multiple uses; insights from the Sacramento (California, USA) and Rhône (France)

Impacts et dynamiques de la ripisylve des grands fleuves gérés pour des usages multiples ; perspectives du Sacramento (Californie, USA) et du Rhône (France)

J.C. Stella[1], H. Piégay[2], C. Gruel[2], J. Riddle[1], B. Raepple[2]

[1] State University of New York College of Environmental Science and Forestry (Syracuse, NY, USA)
[2] Environnement Ville et Société (EVS), CNRS UMR 5600, ENS de Lyon (France)

RÉSUMÉ

Nous comparons le développement de la ripisylve et de la plaine alluviale de deux des fleuves les aménagés situés dans des régions au climat méditerranéen, le Sacramento (Californie, USA) et le Rhône aval (sud-est de la France). Le Rhône a été canalisé au 19e siècle pour la navigation, et depuis les années 1940, des barrages ont été construits sur les deux fleuves. Ces interventions ont permis une réduction des inondations et de la migration du chenal actif. Nous avons conduit des inventaires forestiers extensifs dans des tronçons réglementés des deux systèmes pour comparer la composition, la structure et la dynamique de la ripisylve avant et après la construction des barrages. Sur le Sacramento, il y a eu une réimplantation d'espèces d'arbres dominantes sur une période d'un siècle. La transition des saules aux peupliers (*Populus*) s'est faite sur 20 ans, et la transition vers la forêt mixte a commencé après 50-60 ans. Sur le Rhône, les placettes après la construction des barrages ont des caractéristiques géomorphologiques et floristiques différentes des placettes plus vieilles (pré-barrage). Dans les deux contextes, il y a eu très peu de recrutement d'espèces pionnières, car elles dépendent de conditions dynamiques pour leur régénération. Par contre, les jeunes placettes des deux fleuves ont accueilli beaucoup de semis d'*Acer negundo,* une espèce exotique et envahissante en Europe. Ces résultats suggèrent que les processus de colonisation et de propagation suivant la régulation du débit sont similaires dans les deux systèmes. Globalement, le Sacramento peut servir de système de référence prédictif pour le Rhône, où des projets de restauration sont en cours pour améliorer la structure et la fonction de la ripisylve.

ABSTRACT

We conducted a cross-ecosystem study to compare riparian forest and floodplain development along two of the most heavily modified rivers in mediterranean-climate regions, the middle Sacramento (California, USA) and the lower Rhône (SE France). The Rhône was heavily channelized in the 19th century for navigation, and both rivers have been dammed since the 1940's, with major reductions in peak flows and channel migration. We conducted extensive forest inventories and sampled fine sediment depth in regulated reaches within both systems, and compared pre- versus post-dam forest development and linked patterns of floodplain development. On the Sacramento, forest composition showed shifting tree species dominance across a century-long chronosequence. The transition from willow to cottonwood (*Populus*) occurred within 20 years, and the transition to mixed forest started after 50-60 years. On the Rhône, the pre- versus post-dam surfaces at each site had distinct geomorphic and floristic characteristics. There was very little post-dam recruitment of poplar and willow, which are pioneer species that rely on dynamic geomorphic conditions. Young floodplains on both rivers supported vigorous recruitment by *Acer negundo* (box elder), which is non-native and invasive in Europe, suggesting that similar mechanisms drive its colonization and propagation following flow regulation. Overall, the Sacramento can serve as a predictive reference system for the Rhône, where significant restoration efforts are underway to improve riparian structure and function in diverted river reaches.

KEYWORDS

Chronosequence, ecogeomorphology, forest dynamics, riparian corridor management, river restoration

1 INTRODUCTION

1.1 Background

In populous, water-limited regions, humans have profoundly altered the river and floodplain environment to satisfy society's demands for water, power, navigation and safety. River management also profoundly alters riparian forests, which respond to changes in disturbance regimes and sediment dynamics. In this study, we compare forest and floodplain development along two of the most heavily modified rivers in mediterranean-climate regions (Table 1), the middle Sacramento (California, USA) and the lower Rhône (SE France). The Sacramento was dammed in 1942 (Shasta Dam) and is now managed for irrigation, hydropower and flood control. The Rhône channel was engineered for navigation prior to 1900, and since then has been dammed and diverted at 18 sites for hydropower and irrigation. In the context of these ongoing stressors, regional, state and national agencies in both basins have organized processes for assessing the cumulative ecological impacts and for integrating ecosystem protection within large-scale basin planning initiatives (Table 1). These include the Central Valley Flood Protection Plan in California (www.cvfpb.ca.gov/CVFPP/) and the Plan Rhône in France (www.planrhone.fr/). Therefore, understanding the status and future trends of the riparian forest is critical for assessing impacts and prioritizing conservation and restoration actions on both rivers. By pairing the studies on these two rivers, we seek to identify processes that operate generally on large, managed river systems and principles relevant for riparian ecosystem restoration elsewhere.

1.2 Study objectives

The overarching goals of the study are to compare forest and floodplain development along the middle Sacramento and lower Rhône rivers, synthesize ecological processes in common, and identify how each system may serve as a reference (e.g., restoration targets) for the other. Specific objectives are:

- *To document the existing riparian forest composition and structure*
- *To develop a floodplain chronosequence of forest dynamics with geomorphic evolution*
- *To project future trends and implications for river management*

Table 1. Sacramento and Rhône basin characteristics

	Sacramento Basin (USA)	Rhône Basin (France)
Basin area	71,432 km²	98,000 km²
River length	719 km	813 km
Max. river elevation	1,120 m	2,100 m
Mean Q (and range)	665 m³/s (28–18,406 m³/s)	1,710 m³/s (360– 13,000 m³/s)
Major human impacts	Water impoundment and diversion; agriculture runoff and pollution; climate change	Water diversion for navigation and hydropower; PCBs and heavy metals; climate change
Major management agencies and stakeholders	CA Dept. of Water Resources; U.S. Fish and Wildlife Service; The Nature Conservancy; CA Dept. of Fish and Wildlife	CNR; EDF; CNRS Observatoire Hommes-Milieux Vallée du Rhône; Zone Atelier Bassin du Rhône; Région Rhône-Alpes
Relevant statutes	Central Valley Flood Protection Act; CVPIA; US Clean Water Act; U.S. Endangered Species Act	Plan Rhône (2004); Domaine public fluvial (DPF); EU Water Framework Directive (WFD)

2 METHODS

In both systems, we conducted extensive forest inventories along regulated reaches (~160 km long). We also measured fine sediment depth and floodplain elevation in order to link forest dynamics with pre- versus post-dam patterns of deposition and floodplain development. Sampling details include:

2.1 Middle Sacramento data collection

- Inventoried 431 plots distributed across 19 large point bar sites along the river
- Plots stratified by vegetation type and floodplain age
  - o 8 woody vegetation map classes (e.g., deciduous forest types, herbaceous cover, scrub)
  - o 11 floodplain ages, 1904 – 2007 (dated from historical maps and air photos)
- 500 m^2 plots with woody species inventory; subplots for understory regeneration
- Cored 1140 trees to determine age, growth rates, and floodplain colonization timing
- Measured fine sediment depth to assess floodplain accretion rates
- Modeled population age structure for dominant tree species using diameter-age relationships

2.2 Lower Rhône data collection

- 88 plots distributed among four river sectors (Pierre-Bénite, Péage de Rousillon, Montélimar, Donzère-Mondragon)
- Plot sampling methods adapted the French national inventory protocol for riparian areas
- Plots stratified by management period:

  - o pre-channelization (~1860's)
  - o pre-dam (1950's - 1970's)
  - o post-dam (current)
- Measured fine sediment depth and texture
- Measured coarse woody debris (for carbon stocks)

3 RESULTS

3.1 Middle Sacramento forest dynamics

Forest composition on the Sacramento showed shifting tree species dominance across a floodplain chronosequence spanning >100 years (Figure 1).The transition from willow to cottonwood (*Populus*) occurred within 20 years since floodplain creation, and the transition to mixed forest started after 50-60 years. Modeled population age structure of *P. fremontii* (Fremont cottonwood) and *Acer negundo* (box elder) had high densities of young cohorts and a negative exponential decrease with age. All box elder recruitment occurred after Shasta dam.

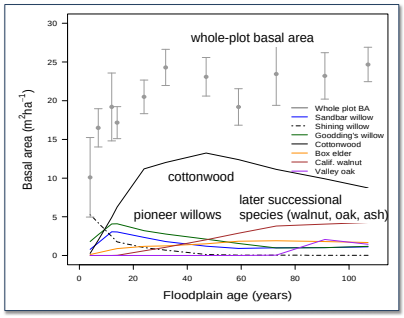

Figure 1. Shifting dominance (basal area) of riparian tree species with floodplain age, Sacramento River.

3.2 Lower Rhône forest dynamics

Floodplain areas on the Rhône that transitioned to forest in the pre-dam period for each sector were at higher elevation, and supported 30-50% more basal area and 20-30% more shrub and vine cover than those that emerged in the post-dam period.There was very little post-dam recruitment of poplar and willow, which are pioneer species that rely on dynamic geomorphic conditions (Figure 2). In contrast, post-dam floodplains had abundant seedlings of box elder, which is non-native and invasive in Europe.

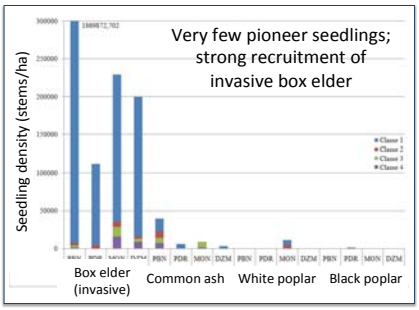

Figure 2. Seedling density in four Rhône River sectors showing high regeneration of box elder compared to native pioneers.

4 DISCUSSION

4.1 Riparian forest dynamics on multi-use rivers

Results indicate that the two riparian ecosystems support similar tree communities, with several willows and a single poplar species dominating early-successional habitats, and a combination of ash, walnut and oak replacing the pioneers as the forest ages. Despite the similar community structure, the Rhône today is much less dynamic than the Sacramento due to extensive channelization and more intensive flow regulation imposed by its many dams and bypass canals. As a result, the Rhône riparian zone supports much less disturbed, young pioneer habitat and a less diverse forest age structure; almost all of the current forest stands established immediately following construction of the local dam. Furthermore, the prevalence of box elder, which is shade-tolerant but poorly adapted to disturbance, on floodplains that stabilized after dam construction on both rivers suggests similar mechanisms of colonization and propagation following flow regulation.

4.2 Implications for river management

The similarities between systems suggest that we can use the Sacramento chronosequence as a reference system for the Rhône.Near-term goals for both systems are to (1) work with agencies to prioritize management actions to diversify forest age and structure; (2)project forest trends on both rivers under climate change and different river management scenarios; and (3) model carbon stocks and evaluate carbon credits associated with proposed river management actions.

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