Forest Ecology and Management 411 (2018) 195–202

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

# Spatial analysis to identify invasion colonization strategies and management priorities in riparian ecosystems

B. Sosa*, D. Romero, G. Fernández, M. Achkar

*Laboratorio de Desarrollo Sustentable y Gestión Ambiental del Territorio, Instituto de Ecología y Ciencias Ambientales, Facultad de Ciencias, Universidad de la República, Iguá 4225, esq. Mataojo, Montevideo, PC 11400, Uruguay*

A R T I C L E I N F O

*Keywords:*
Biological invasion
Control strategies
*Gleditsia triacanthos*
Fluvial bank
Invasive front
Spatial analysis

A B S T R A C T

Exotic species have different strategies to invade a new area. Invasive species limited by establishment have a wide dispersion range and high seedling mortality rate. Riparian forests are harsh environments for the establishment of plants. In this sense, we tested the hypothesis that the invasive process of *G. triacanthos* is limited by establishment in a riparian forest of the Uruguay River and that it begins in the fluvial bank at the transition zone between forest and grassland and moves towards the shore border. We expected that: (1) the distribution pattern of adults of *G. triacanthos* would be decoupled from the distribution pattern of seedlings and saplings (pre-reproductive stages); (2) the population would have a cluster distribution pattern related to the occurrence of punctual events that favoured the development to adult stages; and (3) the abundance of seedlings, saplings and adults would be higher in the transition zone (between forest and grassland) than in the shore border of the fluvial bank.

The spatial pattern of *G. triacanthos* along the Uruguay River was analyzed using spatial point pattern analysis: autocorrelation indexes, hot spots and wavelet analysis. The effect of the fluvial bank position on the abundance of *G. triacanthos* was evaluated using non-metric multidimensional scaling (NMDS). This methodology allowed us to detect a primary invasion area, an invasion focus and the dispersal area. This pattern corresponded to an infiltration invasion pattern limited by establishment. It did not seem to be affected by position in the fluvial bank. This information could be relevant to establish correct decision-making in the control of an invasive process and provide an applicable methodology for any other invasion process, especially in riparian ecosystems.

## 1. Introduction

Biological invasions and climate change are one of the main threats to biodiversity conservation (Gallardo et al., 2013). The effects of invasive species in native ecosystems is mainly recognized because of species displacement and consequent global biodiversity homogenization (López-Darías et al., 2008). Riparian forests are one of the ecosystems most vulnerable to the effects of biological invasions (Richardson et al., 2007). In the long term, the establishment of invasive species may reduce forest diversity and change key ecosystem processes, such as water catchments, infiltration and evaporation. These processes are essential for the function of riparian ecosystems and human welfare (Richardson et al., 2007).

Exotic species have different strategies to invade a new area. Martin and Canham (2010) identified two colonization strategies in exotic tree invasions in mountain forests: invasive species limited by dispersion and invasive species limited by establishment. Martin and Canham (2010) detected that invasive species limited by dispersal have mean seed dispersal distances that are comparable to the dominant native tree species, and suggested that its spread in closed-canopied forest will be partially dispersal-limited. Invasive species limited by establishment produce a large amount of seeds and have a wide dispersion range. These species have a high seedling mortality rate, and their failure in seedling establishment suggests that they would depend on ecosystem disturbances to colonize new areas (Martin and Canham, 2010). Highly dynamic ecosystems, such as riparian forests (Tockner et al., 2010), are harsh environments for the establishment of plants (Naiman and Décamps, 1997). For example, flooding process erodes the substrate and generates anoxia conditions (Goodson et al., 2001). In this sense, we expect that the invasion process would be limited by establishment in riparian ecosystems and for invasive species that have a wide dispersion range (hydrocoral species for example). Fluvial processes could also facilitate the establishment of invasive tree species: erosive processes can produce tree fall, which generates patches with a higher light

* Corresponding author.
*E-mail address:* beatriz@fcien.edu.uy (B. Sosa).

https://doi.org/10.1016/j.foreco.2018.01.039
Received 5 September 2017; Received in revised form 11 January 2018; Accepted 21 January 2018

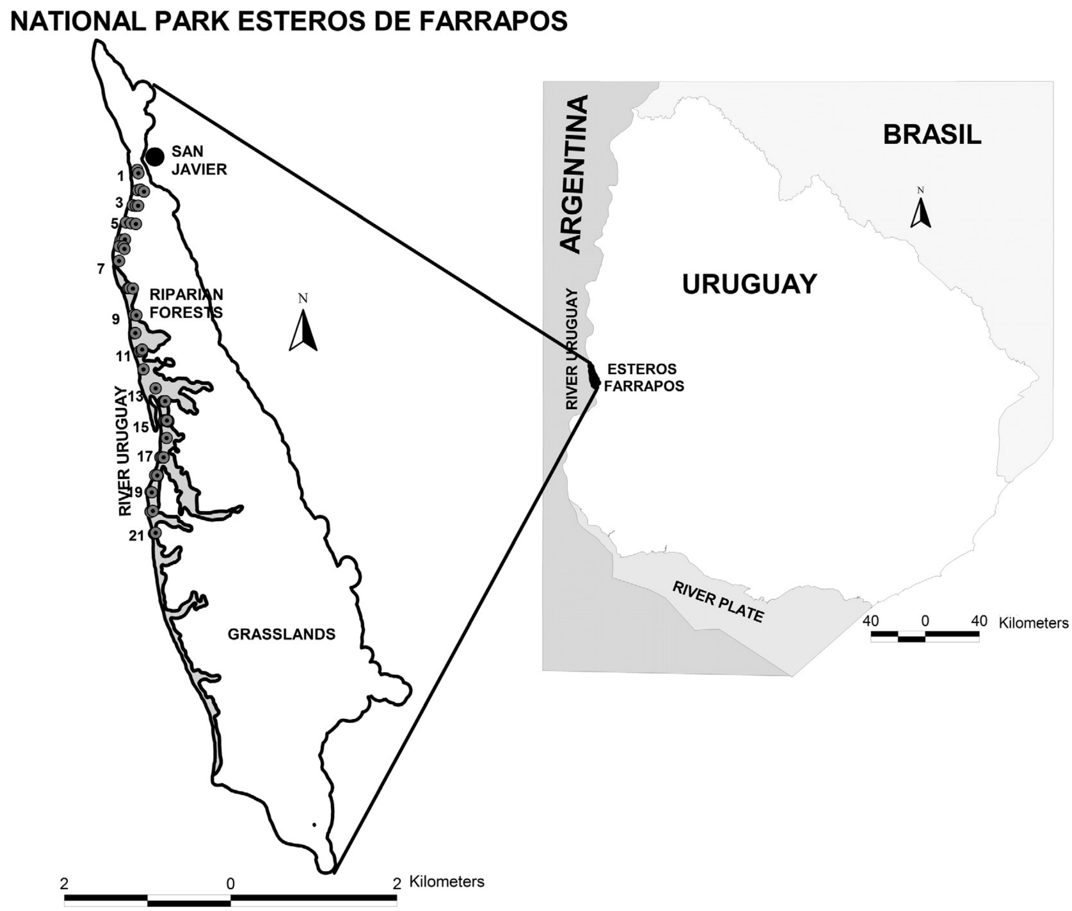


**Fig. 1.** Study area in the National Park Esteros de Farrapos and sampling points.

availability that facilitates the establishment of shade intolerant trees, and deposition increases sedimentation, which drives changes in community composition (Jolley et al., 2017).

Geoforms defined as any type of geomorphic unit without hierarchical distinctions (Toomanian., 2013). In riparian systems gravel bars, terraces and islands are examples of geoforms (Naim et al., 2005). These features have a direct effect on both dispersal and establishment in riparian ecosystems (Corenblit et al., 2007). During dispersion, propagules are concentrated in accordance with the depositional processes of the riparian system (Gurnell, 2007); then, the microtopography would facilitate propagule establishment if it generated a suitable environment (Steiger, 2005). Models and empirical works have suggested that vegetation establishment in riparian forest mainly occurs on the fluvial bank adjacent to the water course (Corenblit et al., 2007; Bradley and Smith, 1986). The fluvial bank as well as the macrochannel floor favour the establishment of invasive species (Cushman and Gaffney, 2010; Tabacchi et al., 2005; Hood and Naiman, 2016). On the other hand, Pauchard and Alaback (2006) concluded that the invasive process begins in the boundary of the fluvial bank in the transition zone between forest and grassland because of the border effect. The invasive species requirements could also explain the diversity of patterns identified in the invasion front on the fluvial bank. For example, most woody invasive species has a low tolerance to shade but others can tolerate shade; (Martin et al., 2009). In this sense we expect that for invasive species with low tolerance to shade the invasive process begins at the boundary of the fluvial bank where light availability increases. Therefore due to the heterogeneity dynamics and complexity of fluvial systems and the diversity or life traits, it is necessary to increase the number of studies to clarify the invasion pattern and relationships with fluvial geoforms.

The spatial analysis of ecological processes such as biological invasions continues to attract more attention (Dale and Fortin, 2014). Specifically, the spatial pattern analysis of biological invasions can be used to infer their dynamical processes (Fang, 2005; Eliot and Fajardo 2009) and could also be a novel and essential tool in the management of invasive species. It has been suggested that control of the new focuses of invasion is more efficient than control of the main already-invaded areas (Wittenberg and Cock, 2001). In this sense, a programme to control invasive species should define its priorities in the following order: prevent recruitment in non-invaded areas, remove invasion focuses, prevent invasion propagation, and reduce or remove the main invaded areas.

In this work, we analysed the spatial pattern of the woody invasive species *Gleditsia triacanthos* in the Uruguay River to clarify its invasion process in this riparian ecosystem. In fluvial systems, seedling establishment is limited by fluvial processes such as erosion or deposition, and we thus expected that the *G. triacanthos* invasive process in this area would be limited by establishment. We also evaluated the hypothesis that the invasion process begins in the fluvial bank at the transition zone between forest and grassland, where deposition is a main process and where light availability is higher and that the invasion process moves towards the shore border on the fluvial bank. We expected that: (1) the distribution pattern of adults of *G. triacanthos* would be decoupled from the distribution pattern of seedlings and saplings (pre-reproductive stages); (2) the population would have a cluster distribution pattern related to the occurrence of “safe sites” that favoured seedling survival and development to adult stages; and (3) the abundance of seedlings, saplings and adults would be higher in the transition zone (between forest and grassland) than in the shore border of the fluvial bank.