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Pine afforestation changes more strongly community structure than ecosystem functioning in grassland mountain streams

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ABSTRACT

In the past decades, afforestation of grassland landscapes has gained importance both as an economic activity and a mechanism to mitigate anthropogenic carbon emissions. This study evaluates the effect of pine afforestation on grassland streams analyzing changes in two integrative ecological indicators: leaf litter breakdown and primary production. We compare those results with changes in structural attributes of benthic biota (primary producers and invertebrates). Six contiguous first-order streams were selected in the upper basin of the Ctalamochita river (Córdoba, Argentina): three reference streams draining grasslands and three streams draining *Pinus elliottii* afforestations. Two in situ experiments were performed to compare leaf litter breakdown and primary production between grassland and afforested streams. Additionally, invertebrate assemblages in leaf litter and riffles, and periphyton standing stock were sampled and assessed. Nine out of 26 structural indicators showed differences between stream types but indicators measuring changes at the basal level of the food web (i.e. detritus and primary producers) were less sensitive than those recording changes in consumers. Our attempt to measure direction and magnitude of changes on stream functioning following afforestation was halted by our simple implemented methodology (i.e. leaf pack method for leaf litter decay and biofilm accrual on natural stone substrates for primary production assessments); only 1 out of 4 indicators differed. We argue that the lack of strong differences in elemental measurements of primary production and needle decay between afforested and grassland streams resulted from compensating opposing forces controlling such processes, i.e. higher grazing vs. higher sunlight in grassland streams and higher shredding vs. lower microbial decomposition mediated by lower temperature in afforested streams. Attributes related to the invertebrate compartment showed the highest sensitivity to afforestation, emphasizing their value as biological indicators of stream ecological integrity.

1. Introduction

The integrity of lotic ecosystems is threatened by multiple human impacts of physical (e.g. dams, channelization), chemical (e.g. pollutants), and biological (e.g. invasive species) nature (Allan and Castillo, 2007). Land use changes can affect lotic ecosystems through all these pathways, being particularly intense in the case of grassland converted to tree plantations. While this vegetation transition may provide valuable benefits to societies (e.g. labor economy, timber production, flood regulation), several studies have quantified negative impacts, such as reduction in water quantity (Jackson et al., 2005; Little et al., 2009) and quality (Farley et al., 2008), and to a lower extent impaired functioning of lotic systems (Ress and Ribbens, 1995; Thompson and Townsend, 2004).

Catchment afforestation with species that have contrasting ecological characteristics compared to those commonly found in their hosting environment may have strong effects on aquatic ecosystems. On the one hand, direct changes in hydrology have already been acknowledged with negative effects of exotic plantations (pines) replacing native temperate forests in the water yield of large catchments in Chile (Little et al., 2009). Similarly, Farley et al. (2005) found that tree plantation in grasslands and shrublands reduced up to 40% and 75% (pines and eucalyptus, respectively) of the annual water discharge. These studies pointed out that the effects were proportionally stronger in low flow periods, raising concern on the environmental costs that afforestations face while delivering

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their better known benefits of wood, runoff regulation, erosion control, and carbon sequestration. On the other hand, changes on biotic components associated to afforestations have been more elusive. In New Zealand, Thompson and Townsend (2003) found little effects of land use at the catchment scale on structural components of stream food webs when comparing native mixed forests vs. pine plantations, but strong changes between native grassland and pines. In Ireland, Giller and O'Halloran (2004) reviewed the magnitude of changes resulting from pine afforestations in moorlands and showed that negative effects on the ecology of streams were regionally dependent and not always deleterious for the environment, probably because of the ecological nature of moorlands.

The establishment of evergreen conifers in grassland landscapes is expected to produce strong stream impacts, not only as a consequence of large inputs of coarse organic matter such as leaf litter and woody material but also by imposing heavy shading and affecting stream sunlight and temperature year around. Additionally, conifer needles break down slowly (Webster and Benfield, 1986; Robinson et al., 2000) since they have thick waxy cuticles containing large amounts of compounds that inhibit or delay matter cycling by aquatic decomposers and detritivores (Bärlocher and Oertli, 1978a,b). Therefore, afforestation of grassland streams is expected to have direct strong effects on energy and matter fluxes through stream food webs, which should be expressed both in terms of community attributes (abundance and composition) and also on key ecosystem processes (i.e. stream primary production and organic matter decomposition).

Generating information about the direction and magnitude of the ecological impact of afforestations becomes essential since an integrative understanding of the influence of tree plantations on ecosystem services will help to develop suitable management strategies and more sustainable forestry systems and policies (Jobbágy et al., 2006). Catchment management practices that alter energetic linkages between aquatic and terrestrial habitats can affect associated ecosystem processes, and ultimately the provision of ecosystem services of importance to humans. Such effects might not always be inferred from common biomonitoring schemes, which are typically based on assessment of community structural parameters rather than functional attributes related to important ecosystem-level processes (Mckie and Malmqvist, 2009).

Impacts of anthropogenic activity on ecosystems can affect both structural and functional components but these broad groups of attributes do not necessarily respond with the same sensitivity and timing. Stressors might cause changes to structure but not function (Death et al., 2009), to function but not structure (Mckie and Malmqvist, 2009; Riipinen et al., 2009), or to both (Friberg et al., 2009; Young and Collier, 2009). Adequate characterization of ecosystems requires information on both structure and function since both aspects provides a more complete picture of ecosystem health than either aspect alone (Gessner and Chauvet, 2002; Young et al., 2008; Riipinen et al., 2009; Feio et al., 2010). Although functional indicators have been suggested to be considered as complementary to traditional monitoring tools (Young et al., 2008; Friberg et al., 2009) their response to anthropogenic stressors has yet been little assessed.

Headwaters streams in Sierras de los Comechingones (Córdoba, Argentina) drain grasslands that were afforested with pines in the late 1970s. This marked vegetation shift may have important implications on the structure and functioning of the aquatic environments. Previous research in the study streams has reported a reduction in annual water yield of nearly 50% in afforested watersheds (Jobbágy et al., 2013), but no evidence of stream water acidification (Farley et al., 2008) or changes in ions loading (Jobbágy, unpublished data) associated to biogeochemical changes from pine plantations were found. This study aims to evaluate the effect of pine afforestation on key ecosystem-level processes in grassland (control) streams by analyzing changes in leaf litter breakdown and primary production. Additionally, we compared those findings with changes in commonly used structural attributes of benthic biota (invertebrates and primary producers) to assess ecological effects of pine plantations. Pine afforestation of grassland streams are expected to cause: (i) lower primary production due to a lesser exposure to sunlight in afforested compared to grassland streams, and as a consequence lower abundance of periphyton feeders (i.e. scrapers), (ii) higher pine needle decay rate as a result of the large ambient abundance of coarse organic matter (needles and woody material) which is anticipated to support large abundance of decomposers and detritivores (e.g. shredders). Alternatively, afforested streams may present lower total invertebrate abundance and richness if invertebrate communities originally inhabiting grassland streams were inefficient or unable of consuming the low-quality pine needles. Finally, we discuss the tradeoffs of implementing structural or functional indicators in stream ecosystem biomonitoring.

2. Materials and methods

2.1. Study area

The study was carried out in streams of the Ctalamochita river upper basin, Córdoba, Argentina (Fig. 1). Annual precipitation in the region reaches 725 mm occurring mostly between spring and the end of summer (October–March) (Cabido et al., 2003) whereas maximum temperature reaches 34 °C in summer (December–March) and decreases up to −5 °C in winter (June–September). Lithology is dominated by granite but localized patches of metamorphic rocks (gneiss, schist, migmatite) are also present.

Six first-order streams with similar drainage area were selected in the Santa Rosa stream sub-basin (which belongs to the Ctalamochita river basin). Three streams drain grasslands (control streams) and each one has a contiguous stream that drains plantations of *Pinus elliottii* (afforested streams) (Fig. 1, Table 1). Study sites in each stream were selected considering stream reaches with similar slope, altitude and orientation. Grasslands at this altitude are dominated by *Festuca hieronymi*, *Nassella filiculmis*, *Schizachyrium condensatum* and *Eragrostis airoides* (Oggero and Arana, 2012) and they are primarily used for extensive livestock grazing. Although the largely established idea has been that these grasslands are climatically determined and that their characteristics respond mainly to natural abiotic factors (Cabido et al., 1987), more recent studies have suggested that they have, at least in part, an anthropogenic origin (Cingolani et al., 2008). The long periods of domestic grazing with associated fire (used as a management tool to favor grass regrowth) and the increased erosion processes have led to the modification of floristic composition and structure of natural grasslands (Cingolani et al., 2003).

Most afforested areas in the region were established in the late 70s as a result of a tax deferral plan implemented by the Córdoba government. Currently, nearly 36,000 ha of the Sierras de los Comechingones in Córdoba are afforested with pines between 900 and 1600 m a.s.l. (Plevich et al., 2002). In the study area, *Pinus elliottii* is the dominant tree in the plantations followed by *Pinus radiata* and *Pinus taeda*.

2.2. Experimental procedure and field and laboratory methods

Between May and August 2008, two in situ experiments were performed at each of the six study streams to compare leaf litter breakdown and primary production between grassland ($n = 3$) and pine afforested ($n = 3$) streams. Experiments were carried out