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Effects of forest management on physical habitats and fish assemblages in Iberian eucalypt streams

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ABSTRACT

In Portugal, more than 150,000 ha of eucalypt plantations are managed under best management practices (BMP), in compliance with international certification systems. Some of these forestry areas extend to streams, and the riparian areas are thus protected from productive land uses. However, many other eucalypt plantations present riparian zones that are not managed under BMP and are often occupied by agricultural uses. To test the effects of forest management on physical habitats and fish assemblages in Iberian eucalypt streams, we selected three different stream reach types: (1) reaches in catchments dominated by native vegetation associations, and presenting semi-natural riparian zones (reference-REF); (2) reaches surrounded by certified eucalypt plantations (i.e., managed under BMP), and consequently, presenting protected riparian buffer zones (PRZ); and (3) reaches surrounded by eucalypt plantations (dominant) and some oak forests, and presenting disturbed riparian zones with agricultural land use (DRZ). All sites represented small, low-gradient, warmwater streams in Central Portugal (Tagus basin), and their upstream land cover was dominated by natural/semi-natural uses. PRZ sites were abiotically similar to REF sites, although PRZ sites generally presented lower potential cover for fish and tended to support a riparian vegetation that was a little more fragmented. PRZ sites supported fish assemblages that were similar to those in reference reaches, although at the functional level we found a higher abundance of native invertivores in REF sites. DRZ reaches, on the other hand, differed substantially from the other two groups. DRZ sites presented disturbed riparian vegetation (removal or substitution of native trees by exotic and/or non-woody species), eroded and modified channels, and a degradation of stream habitats (lack of riffle–poll complexes, higher silt contents, and lower potential cover for fish). The fish assemblages were also quite different, with a higher abundance of alien specimens (mainly *Gobio lozanoi*) and generalist spawners, and a lower proportion of native invertivores and lithophils. Riffles and morphological alteration explained the greatest proportion of variance in species composition. Our study showed that protecting stream riparian zones by implementing BMP may mitigate the effects of eucalypt forestry on Iberian fish assemblages. However, given that there are a few differences in physical condition and biological integrity between streams associated with certified plantations and reference streams we suggest additional riparian management measures in the certified areas, such as restoration of the native vegetation, removal of alien plants, and improvement of the stream habitat.

1. Introduction

The Australian native tree *Eucalyptus globulus* (eucalypt) was introduced to Portugal in the second half of the 19th century (Barreiro and Tomé, 2012). Nowadays, this species is common and widespread, occupying more than 800,000 ha in 2010 – i.e. approximately 26% of the total forested area in the country (ICNF, 2013). More than 150,000 ha of these eucalypt plantations are managed under best management practices (BMP), in compliance with international certification systems (CELPA, 2013). When the forestry management areas extend to river systems, one of the most common practices in certified eucalypt plantations is the protection and restoration of riparian buffer zones – i.e. stream-side areas that include terrestrial and aquatic ecosystems and are not managed for agriculture or forestry. BMP associated with the riparian areas include reduced-impact logging practices (such as setting many roads back from riparian areas) and the protection of native riparian vegetation. As a rule for small-sized streams in our study area, the protected riparian buffers possess a total width of about 60 m (30 m per margin strip). Important functions of the riparian zones include thermal buffering, provision of invertebrates as food

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for fishes, nutrient and sediment trapping, enhancement of bank stability, and provision of woody debris and rootwads as habitat for fish (Gregory et al., 1991; Naiman et al., 1993; Pusey and Arthington, 2003). Particularly in Mediterranean-type environments, riparian corridors represent ecosystems with high habitat patchiness and biodiversity (Corbacho et al., 2003; Aguiar and Ferreira, 2005; Stella et al., 2013), and their protection is thus critical to ensuring the integrity of the aquatic systems. However, in many other Portuguese eucalypt-dominated landscapes, especially in non-certified plantations, the riparian zones are frequently occupied by several agricultural uses, such as cropping and livestock grazing.

Research has highlighted the importance of forestry BMP in maintaining the physical and water quality characteristics of stream ecosystems (see reviews: Clinnick, 1985; Hutchens et al., 2004; Northcote and Hartman, 2004; Edwards and Williard, 2010). The bioassessment studies on BMP effectiveness also suggest these measures provide an overall benefit in terms of protecting stream biota, although most studies are focused on macroinvertebrate assemblages (e.g. Graynoth, 1979; Adams et al., 1995; Kreutzweiser et al., 2005; McCord et al., 2007). In commercial harvest areas in Central Amazonia that were certified as practicing sustainable forestry, reduced-impact logging also did not have significant impacts on fish communities and appeared to be a viable alternative to clear-cut practices (Dias et al., 2010). The protection of native riparian vegetation is an important-albeit not the only component of BMP guidelines. In forestry areas dominated by exotic tree species, native riparian vegetation can play a particularly important role in mediating the impacts of plantations on rivers (Graça et al., 2002). This mitigating role was evident for the invertebrate communities in Iberian streams flowing through eucalypt plantations (Abelho and Graça, 1996; Ferreira et al., 2015). In a project carried out in New Zealand landscapes dominated by exotic pine forests, riparian buffer strips also had an overall benefit on native fish (Rowe et al., 2002) and invertebrate assemblages (Quinn et al., 2004).

From these studies, we conclude that the knowledge of BMP effectiveness in relation to aquatic systems comes mostly from non-Mediterranean areas (particularly in North America and Oceania), with a lack of scientific information concerning overall fish–forestry interactions in Iberian eucalypt plantations. We are unware of any studies that evaluate the role BMP play in catchments subjected to logging in Mediterranean areas, when it comes to maintaining the biological quality of river systems (*sensu* Water Framework Directive) and the biotic integrity of fish communities. Fishes are good environmental quality indicators because they are sensitive to a range of biological, physical and chemical disturbances (Simon and Lyons, 1995; Karr and Chu, 1999; Pont et al., 2006; Ferreira et al., 2007b), providing a useful broad guideline of BMP, including an assessment of their success.

Agricultural practices are the most widespread cause of stream degradation, increasing nonpoint inputs of nutrients and sediments, and altering habitats (Wang et al., 1997; Henley et al., 2000; Allan, 2004; Hermoso and Clavero, 2011). Agricultural land use is generally considered a key variable for measuring the human impacts on stream ecosystems and a good predictor of both physical habitat quality and in-stream biotic integrity. Biological communities are structured by factors that operate across multiple spatial scales, from microhabitats to ecoregions (Ricklefs, 1987; Lawton, 1999), and thus the effects of agricultural land use are pervasive at the catchment and local levels (Wilson and Xenopoulos, 2008; Feld, 2013). Previous studies on agricultural-dominated catchments have indicated that agricultural uses within the riparian areas can affect the structure of fish assemblages and the stream environment (Lammert and Allan, 1999; Stewart et al., 2001; Heitke et al., 2006). However, only a few studies that address largely forested watersheds have focused on the importance of land use at smaller spatial scales (e.g. Jones et al., 1999), and little is known about the effects that riparian agricultural land use in forestry landscapes has on streams, as in Iberian eucalypt plantations where BMP do not extend to the lotic systems.

Against this background we designed a study to investigate to which extent protected riparian buffer zones can mitigate the impacts of eucalypt plantations on Mediterranean fish assemblages, while simultaneously attempting to clarify the ecological consequences of not protecting those areas from high-impact uses (mainly agricultural land uses). We selected the middle part of a Portuguese river basin – the Tagus basin – where the patchy nature of land uses allowed us to compare reference sites dominated by native vegetation to eucalypt plantations presenting both protected and degraded riparian zones. We hypothesised that protecting riparian buffers by implementing BMP would mitigate the impacts of eucalypt silviculture. We therefore expected harvested sites with good quality riparian areas to present stream habitats and fish assemblages similar to those in reference sites. We also tested our expectation that harvested sites with agricultural riparian land use would present altered and impaired habitats, and that these changes would be associated with changes in species composition and functional attributes of fish assemblages.

2. Material and methods

2.1. Study area and site selection

We selected fifteen sites that drain small catchments in the central part of the Portuguese River Tagus basin (Fig. 1). The study area is characterized by a Mediterranean climate, with high floods occurring from autumn to late winter, and a gradual decline in flow during late spring and summer (Gasith and Resh, 1999). The study reaches were similar in catchment size and channel dimensions for each reach type and represented small, low-gradient warmwater streams (Table 1). Only two sites occurred within the same catchment, but they were spaced out 4.5 km from each other, thus reducing problems of spatial autocorrelation (Santos et al., 2011; Oliveira et al., 2012). Typically in these Mediterranean streams, fish assemblages are poor in native species, but with a high proportion of endemic forms, mostly cyprinids, and may include a few widespread alien species (Oliveira, 2006). Although study sites presented some differences in land use at the catchment scale, land cover was dominated by natural/semi-natural uses (e.g., forests, Mediterranean woodlands) (Table 1), and no major impacts (e.g. hydrological disturbance, pollutant sources) were detected. In most of the study area the population density was low – generally less than 50 inhabitants/km^2. Riparian forests were typically dominated by the common alder (*Alnus glutinosa*), the narrow-leafed ash (*Fraxinus angustifolia*), and willows (*Salix* spp.). Three different reach types were compared, each with five replicates, hereafter reference (REF), protected riparian zone (PRZ), and disturbed riparian zone (DRZ) sites (Fig. 1): (1) REF sites had catchments dominated by native forests and Mediterranean shrublands, with most of the riparian vegetation and immediate riparian zones in a semi-natural state; (2) PRZ sites were surrounded by certified eucalypt plantations (i.e., managed under BMP), and consequently, presented riparian zones protected from productive activities. These areas were thus not managed for agriculture or forestry and supported a riparian vegetation that was composed of several strata and was slightly cleared or fragmented by human intervention; (3) DRZ reaches were surrounded by eucalypt plantations (dominant) and some oak forests, and presented riparian zones with agricultural land use, including cropping and livestock grazing; in all but one of the DRZ sites, the riparian vegetation exhibited a