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Review

A review of invasive alien species impacts on eucalypt stands and citrus orchards ecosystem services: Towards an integrated management approach

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ABSTRACT

Multidisciplinary knowledge on the impact caused by invasive alien species (IAS) on ecosystems is crucial for guiding policy makers in the adoption of sustainable management measures. This research was focused on insect IAS impacts on two managed ecosystems: eucalypt plantations and citrus orchards. It begins with an identification of the wide range of ecosystem services (ES) and disservices provided by each of these managed ecosystems, according to the methodology proposed by the Millennium Ecosystem Assessment. Subsequently, a comprehensive review of studies that promoted the identification and valuation of direct and indirect impacts IAS impacts on these ecosystems was performed. From the synthesis of previous findings, an integrative management framework is advanced. This links the identification of ES, drivers of change and development of IAS management strategies by means of assessment processes that account for multiple dimensions of ES values. The article concludes with a discussion on the challenges underpinning assessment and valuation approaches that inform the design of inclusive strategies and interventions to tackle IAS impacts.

1. Introduction

Invasive alien species (IAS) are defined as non-native species that threaten ecosystems, habitats or species (CBD, 2008) and are currently considered the second most important cause of biodiversity loss after habitat destruction (Wilcove et al., 1998; IUCN, 2011). Over the last century, the rate of biological invasions has sharply risen, mainly due to globalization trends: intensified travelling, population growth, migratory fluxes, liberalization of regulatory trade regimes and consequent increase of global trade (Pimentel, 2002; Perrings et al., 2005; Kettunen et al., 2008; van Wilgen et al., 2008). Additionally, global warming may also contribute considerably to the increase of invasions by alien species (Sala et al., 2000).

IAS cause negative impacts on biodiversity, ecosystem services, socio-economy and human health (CBD, 2008; EEA, 2012), which poses the question on how to develop and implement integrated management strategies that account for the multidimensional consequences of biological invasions. In this study, developed in the context of the research project "EXOT – Coping with alien pests in citrus and eucalyptus: implementing best strategies plant system models", contribution is given to the current debate in two ways: i) by the presentation of an in-depth literature review of the approaches used to assess the impacts of invasive IAS on eucalypt plantations and in citrus orchards ecosystem services (ES); ii) by developing a conceptual framework supporting the identification of possible eucalypt stands and citrus orchards ES and disservices, assessment of the multidimensional impacts of IAS, including those arising from chemical control measures, and the consequences of these changes to human well-being.

The Millennium Ecosystem Assessment (MEA) defines ES as "the benefits humans derive from nature" and classifies ES into 4 categories: supporting (e.g. soil formation and nutrient cycling), provisioning (e.g. provision of food, timber and water), regulating (e.g.

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regulation of carbon flows, flood, drought, land degradation and disease), and cultural (e.g. recreational, aesthetic and spiritual) (MEA, 2003). The MEA approach was chosen for the analysis since it allows for the establishment of a link between ecological and socio-economic effects of IAS, as it is based on the assumption that should an ecological change occur, it will have repercussions in ecosystem services (ES) and thereby an impact upon human well-being. Well-being is here broadly defined as access to basic materials for a good life, freedom of choice and action, health, good social relations, and security (MEA, 2003; Pejchar and Mooney, 2009).

The two types of ecosystems studied – eucalypt plantations and citrus orchards – were selected for this study due to: i) their worldwide social and economic relevance; and ii) the fact that an increasing number of IAS are currently being introduced in these ecosystems, thus affecting their productivity and resilience, as well as human well-being. To our best knowledge, the present work is the first attempt to advance a general approach to identify, characterize and evaluate the wide range of ES provided by eucalypt plantations and citrus orchards, so that changes caused in these ecosystems by IAS, as well as measures to counter them, can be further estimated.

The article will proceed as follows. Section 2 provides an overview of the main features of the selected ecosystem types followed by an identification of the associated ES. A review of studies that have addressed the impacts of insect IAS on eucalypt stands and citrus orchards is presented in Section 3. Section 4 describes the proposed framework for integrated management of IAS impacts, while Section 5 draws some general conclusions.

2. Eucalypt stands and citrus orchards ecosystem services

2.1. Overview of selected ecosystem types

Though most species of the genus *Eucalyptus* (Myrtales, Myrtaceae) are native to Australia and Tasmania, they have been grown outside their native range for over two centuries. *Eucalyptus* is currently the most widely planted genus in the world, being cultivated in more than 100 countries, in all continents except Antarctica (Turnbull, 1999; Lawson, 2007; Zegeye, 2010). The genus bioecological traits have granted its success as an exotic for industrial monocultures worldwide, with published reports suggesting that there are at least 12 million ha of plantations (Turnbull, 1999) and estimations rising to 20 million ha (GIT Forestry, 2012). In terms of wood annual increment, *Eucalyptus grandis*, *Eucalyptus camaldulensis*, *Eucalyptus tereticornis* and *Eucalyptus globulus* are currently the most important species (Eldridge et al., 1993). The success of eucalypt commercial plantations outside their native range is attributed to factors such as fast growth rate, tolerance to a wide range of climatological conditions and to poor soils, unpalatability to grazing animals, ability to coppice after harvest and resprout from dormant underground buds after fire (FAO, 1979), and relative resilience to environmental stress and diseases. Another crucial reason for their initial success, was due to the fact that the first plantations outside their native range were raised from seed, and thus, remained relatively free of pests and diseases for some years (Paine and Millar, 2002). This trend is gradually changing as IAS expansion increasingly compromises worldwide production.

With respect to the genus *Citrus* (Sapindales, Rutaceae), it includes a wide number of cultivated species, most of which are hybrids derived from a few ancestral species, thought to originate from Southeast Asia (Gmitter and Hu, 1990; UNCTAD, 2012). Sweet orange (*Citrus sinensis*) is the main crop representing 70% of worldwide citrus yield, but other fruits such as tangerines, mandarines, clementines, lemons, limes, pomelos and grapefruits are also included in this group (UNCTAD, 2012). Citrus commercial plantations are grown within a broad band of approximately ±40° latitude of the equator, where winter temperatures remain above freezing and allow tree survival, in areas with suitable soil and enough water availability to support tree growth and fruit production (Talon and Gmitter, 2008). Major producer regions include Brazil, Southern USA, Southern China, the Mediterranean Basin, South Africa, Australia and Mexico (UNCTAD, 2012). Citrus are amongst the most important and widely grown fruit crops, with a reported production of 105.4 million tons in 2004–2005 (FAO, 2006). The existence of a high number of pests and diseases of citrus trees has since long been acknowledged, however, the species rate of spread into new areas has gradually increased along with globalization (Talon and Gmitter, 2008; Gottwald, 2010).

2.2. Eucalypt stands ecosystem services and disservices

Production of timber, firewood and pulpwood are regarded as the most important **provisioning services** supplied by eucalypt plantations, although several other equally important material goods can be obtained. Among them, the essential oils, which may comprise up to 5% of the leaves fresh weight (Ohmart and Edwards, 1991) and are usually extracted from branches trimmed from the stems of trees felled for other purposes (Feleke, 2010), have proven medicinal and industrial value. Eucalypts can be used as a source for cleaning, deodorizing and insect repellant products, food supplements, cough syrups, vapor baths, decongestants and in sweets. They can be used for making mulching, fertilizers and support an abundant and nutritive monofloral honey production, as its flowers are highly attractive to honey bees and rich in pollen and nectar (Allsopp and Cherry, 2004; Foelkel, 2007). Additionally, their use for bio-energy production is currently increasing (Gonzalez et al., 2011; Dougherty and Wright, 2012). In addition to the direct provisioning services described, forestry rights can in some countries be used as assets for loan appliances or mortgage financing, even independently of land ownership (Feder and Noronha, 1987; Yu and Gaoli, 2011). In such cases eucalypt stands represent possible sources of credit for the stand owners.

With respect to **regulating and supporting services**, eucalypt plantations can contribute to the protection of land and water systems (FAO, 1988). They have been successfully used for erosion control, as long as adequate techniques are employed, such as contour planting (Teketay, 2000). Some species with a strong taproot and expanded lateral root systems, such as *E. globulus*, have been grown in several regions for catchment protection and flood mitigation. As fast growing eucalypts trees are efficient biomass producers, and since carbon sequestration is proportional to biomass production, they have the capacity of fixing high amounts of carbon dioxide by photosynthesis, thereby acting as one of the best genus for carbon sink (Zegeye, 2010). Although contested by some authors, the establishment of plantations on degraded sites can help restore vegetative cover, increase biological diversity, enhance soil structure and the diversity of the soil flora and fauna, and improve the microclimate conditions (Yaojian, 2003). Their floral characteristics allow them to provide an indispensable food source for honey bees when other pollinator dependent crops are not blooming thus supplying an important pollination regulating service (Allsopp and Cherry, 2004; Keasar and Shmida, 2009).

Several **cultural services** have also been described in the literature in association to eucalypt stands. Due to their evergreen foliage and flower display, some eucalypt species are commonly used in urban forests (Paine and Millar, 2002) and have recreational and aesthetic value. Whenever an understorey is present, it is possible to find several forest birds that, if in coexistence with glades and other less dense vegetation areas, may provide refuge and a rest