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Analysis

Economic Outcome of Classical Biological Control: A Case Study on the *Eucalyptus* Snout Beetle, *Gonipterus platensis*, and the Parasitoid *Anaphes nitens*

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ABSTRACT

Despite the importance of invasive pests, few studies address the costs and benefits of the strategies used to control them. The present work assesses the economic impact of the *Eucalyptus* snout beetle, *Gonipterus platensis*, and the benefits resulting from its biological control with *Anaphes nitens* in Portugal, over a 20-year period. Comparisons were made between the real situation (with *A. nitens*) and three scenarios without biological control: 1) replacement of *Eucalyptus globulus* by resistant eucalypts; 2) insecticide use; and 3) offset of yield losses by imported wood. A cost-benefit analysis was performed to evaluate a programme that aimed to accelerate *A. nitens* establishment. Although *A. nitens* provides adequate pest control in several regions, 46% of the area planted with eucalypts is affected by the beetle, causing wood losses of 648 M euros over 20 years. Losses in the three hypothetical scenarios were estimated at 2451 M-7164 M euros, resulting in benefits from biological control of 1803 M–6516 M euros, despite the fact that only partial success was achieved. Anticipating biological control by just one, two, or three years resulted in benefit-cost ratios of 67, 190, and 347, respectively. Because nonmarket values were not accounted for, these figures are likely underestimated.

1. Introduction

Invasive alien species pose a major threat to natural and managed ecosystems, and can have substantial ecological and economic impacts. Biological invasions by insects alone cost at least 70 billion US dollars per year globally, but this value is greatly underestimated due to the lack of reliable cost assessments (Bradshaw et al., 2016). Classical biological control (CBC) is a particularly useful strategy to manage non-native species that attain pest status in their introduced range due to the absence of natural enemies (Kenis et al., 2017). Between 1870 and 2010, 2384 species of natural enemies have been introduced for CBC of insect pests worldwide, leading to the control of 172 of 588 target pests (Cock et al., 2016). Despite the high number of programmes undertaken, analyses weighing economic costs and benefits of CBC have hardly been assessed (Greathead, 2003; Kenis and Branco, 2010; Naranjo et al., 2015). The scarcity of economic studies arises from many causes, including lack of funding for post-release monitoring, long periods from release until full field establishment of the biological control agent, difficulty in assessing impacts of CBC programmes, or difficulty in assigning monetary values to externalities (Cock et al., 2015; McFayden, 2008). In addition, when successful control is achieved the problem disappears and the focus shifts to other problems (Paine et al., 2015).

Gonipterus platensis (Marelli) (Coleoptera: Curculionidae) is one of three species from the Australian genus *Gonipterus* that were accidentally introduced in other parts of the world, where they became pests of eucalypts (Hurley et al., 2016; Mapondera et al., 2012). CBC with the egg parasitoid *Anaphes nitens* (Girault) (Hymenoptera: Mymaridae) has been the strategy most commonly used to reduce *Gonipterus* spp. populations. This natural enemy was first used in South Africa, in 1926 (Tooke, 1955). It was also introduced in New Zealand, North and South America, and Europe (Arzone and Vidano, 1978; Hanks et al., 2000; Tooke, 1955). Good results were obtained with *A. nitens* in many countries, but complete success was not always achieved, especially in

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the case of *G. platensis* in some regions in South America, Western Australia, and Southwestern Europe (Loch, 2008; Mapondera et al., 2012; Reis et al., 2012; Valente et al., 2004).

The present work was conducted in Portugal, which is a relevant country for eucalypt wood production. The Tasmanian blue gum, *Eucalyptus globulus* Labill., is the most extensively planted forest species in the country, covering ca. 812,000 ha (ICNF, 2013). This value represents over 50% of the total area occupied by *E. globulus* in Europe and over one fourth of the area planted with this species worldwide (Cerasoli et al., 2016; Harwood, 2015). *Eucalyptus globulus* plantations are the main source of raw material for pulp and paper production, one of the most important industries in the country. Despite the high socio-economic importance of eucalypt stands, the vast area occupied by monocultures of this exotic species may be perceived as having negative ecological effects (Veiras and Soto, 2011). Similarly to other managed forest plantations, eucalypt stands may be the source of ecosystem disservices and can generate negative externalities, such as competition with other plant species and soil erosion. However, such negative impacts can be effectively avoided by adopting adequate forest design and management practices (Branco et al., 2015). One aspect that has generated much controversy is the invasive potential of eucalypts. Even though a few species have been listed as invasive, eucalypts seldom spread considerable distances from planting sites (see Rejmánek and Richardson, 2011). In recent studies, Fernandes et al. (2016, 2017) showed that *E. globulus* does not display invasive behaviour in Portugal. On the other hand, eucalypt stands can provide many ecosystem services, which have been summarised by Branco et al. (2015).

Prior to the detection of the snout beetle in Portugal, in 1995 (Valente et al., 2004), *A. nitens* had already been introduced in Spain, in 1994 (Pérez Otero et al., 2003). Natural dispersion of *A. nitens* from Spain would probably have been enough to promote the establishment of the parasitoid in Portugal, as there are no relevant geographical barriers between the two neighbouring countries. Nevertheless, a programme to rear and release *A. nitens* in Portugal was launched in 1997, aiming to accelerate the benefits from this biological control agent. Around 300,000 parasitoids were released over a period of four years (1997–2000), after which *A. nitens* rapidly established. Within one year, parasitism rates in some plantations reached up to 80% (Valente et al., 2004). Currently, i.e. 20 years later, *A. nitens* is widely distributed across the country and successful control of *G. platensis* populations has been achieved in several areas. However, in some inland regions of northern and central Portugal, with cooler climate than the southern and coastal areas, the parasitoid remains ineffective (Reis et al., 2012; Valente et al., 2004).

Despite the high economic importance of eucalypts worldwide and the vast distribution of *Gonipterus* spp., little information is currently available on either the economic impact of these insects or the economic benefits resulting from their control. In California, Jetter and Paine (2004) assessed the benefits of controlling *G. platensis* attacking urban trees as the average amount that a household would be willing to pay (sensu Boardman et al., 1996) for a public pest control programme. The authors concluded that each household would pay about 21 times more to import and release *A. nitens* than for the implementation of a chemical control programme. Paine et al. (2015) reported complete control of *G. platensis* by *A. nitens* in California, with a benefit-cost ratio ranging from 428 to 1070 for a total investment of 2.6 M US dollars in CBC programmes that targeted the snout beetle and seven other eucalypt pests. In Portugal, Reis et al. (2012) found that defoliation by *G. platensis* severely affects the yield of *E. globulus* plantations, causing up to 86% wood loss in some areas. However, to date, neither the effect of *G. platensis* nor of the parasitoid has been economically assessed.

By assessing the economic impact of this key forest pest and the economics of its biological control, the present case study aims to discuss the importance of weighing costs and benefits of CBC on pest management decision making. The specific objectives of this study were to assess: i) the economic impact of *G. platensis* in *E. globulus* plantations in Portugal; ii) the economic benefits resulting from partial control of *G. platensis* by *A. nitens*, by comparing expected losses of eucalypt wood under three hypothetical scenarios without biological control, over a period of 20 years; and iii) the economic outcome of the biological control programme conducted in Portugal with the aim of anticipating the expected benefits of *A. nitens* natural dispersion.

2. Material and Methods

2.1. Economic Impact of G. platensis in Portugal

2.1.1. Area Affected During the Spreading Phase

During the dispersion phase of *G. platensis* in Portugal (1996–2003), field surveys were conducted annually to assess the area affected by the snout beetle (as described in Appendix 1).

2.1.2. Damage by G. platensis

To assess the area currently affected by the snout beetle, a survey was conducted between 2011 and 2014 over an area of ca. 85,000 ha of *E. globulus* plantations (managed by The Navigator Company) that extended to all Territorial Units of Continental Portugal (as described in Appendix 2 and Fig. S1). The distribution of *G. platensis* attacks in 2011–2014 was extrapolated per NUTS3 region (Nomenclature of Territorial Units for Statistics, version 2010; EUROSTAT, 2016) for the period between 2004 and 2016, using the available national forest inventories (ICNF, 2013). According to these inventories, the area planted with eucalypts in Continental Portugal was 717,246 ha in 1995, 785,762 ha in 2005, and 811,943 ha in 2010. Based on these numbers, the total area planted with eucalypts was assumed to be 717,246 ha from 1996 to 2004, 785,762 ha from 2005 to 2009, and 811,943 ha from 2010 to 2016. Because *G. platensis* populations were still establishing between 1996 and 2003 (see Section 2.1.1 and Appendix 1), the economic impact in a given year during this period was assumed to have occurred only in areas already occupied by the insect in the previous year.

2.1.3. Wood Loss Estimates

The percentage of tradeable wood production loss (*WPL*) was assessed for each defoliation level (see Section 2.1.2) using Eq. (1) (Reis et al., 2012), where *D* is percent defoliation by *G. platensis*:

$$WPL = 5.428e^{0.0027}.\ D \quad (1)$$

This equation was developed for conditions similar to those of the present study and is, to the best of our knowledge, the most adequate model available, even though it probably underestimates wood loss, as stated by its authors. For plantations having Very high defoliation, *WPL* was assumed to be 100% rather than the 72% given by Eq. (1), because even if some biomass is produced it will not have commercial use for pulping (C. Valente, personal observation). Based on this assumption and on the class marks of the defoliation intervals for each level of attack, the following categories of *WPL* were obtained: 100% (Very high defoliation); 42% (High defoliation); 16% (Moderate defoliation); 7% (Low defoliation); and 0% (No damage). Tradeable wood volume lost per year (*WVL*; m^3ob·year^{-1}, where ob means over bark) per NUTS3 region was estimated with Eq. (2) by applying *WPL* to the potential annual productivity (*PAP*; m^3ob·year^{-1}) for *E. globulus* without defoliation:

$$\text{WVL} = \text{WPL. PAP} \quad (2)$$

PAP was assessed for NUTS3 using 3PG model (Landsberg and Waring, 1997) parametrised with unpublished data from The Navigator Company for *E. globulus*. The model ran with soil data collected in each plantation [stoniness, soil texture, soil depth, and suitability class for *E. globulus* according to Sousa et al., 2013] and climate data (average monthly rainfall, average monthly minimum temperature and average monthly maximum temperature, from the climate normal of