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Review

Identifying and managing the ecological risks of using introduced tree species in Sweden's production forestry

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ABSTRACT

Introduced tree species are increasingly being considered for use in production forestry due to production targets, and demand for a diversity of wood products. However, prior to expanding their use, active consideration needs to be given to the breadth of potential ecological consequences associated with each introduced tree species. Ecological consequences include the invasion and modification of sensitive ecosystems, changes in habitat provision for native taxa, altered risk of pest and pathogen outbreaks, and hybridization with native con-generics. Here we review the scientific literature to assess the potential ecological consequences from expanding the use of introduced tree species within Swedish forestry. We use an interdisciplinary approach to evaluate ecological risks, and our assessment is based on the scenario that a proportion of Norway spruce (*Picea abies*) monocultures in southern Sweden will be replaced by monocultures of Sycamore maple (*Acer pseudoplatanus*), Douglas fir (*Pseudotsuga menziesii*), hybrid aspen (*Populus tremula tremuloides*), or hybrid larch (*Larix eurolepis*/*L. marschlinsii*). Our results highlight that univariate consideration of the ecological consequences of exotic tree species can be highly misleading, due to the complex suite of costs, benefits, risks and uncertainties that each tree species brings to the region of introduction. We discuss our results in relation to conflicting management goals, and the lack of reversibility of some adverse ecological outcomes. We also highlight the need for assessments of ecological risk to facilitate evidence-based decision making by stakeholders. Our results provide a foundation for adaptive management programs aiming to limit the extent to which introduced tree species used in production forestry are accompanied by adverse ecological impacts.

Contents

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1. Introduction

Approximately 25% of the world's plantations consist of introduced tree species (FAO, 2010). This level of usage is driven primarily by the capacity of introduced tree species to achieve increased levels of production, or to provide timbers with specifically desired wood characteristics (Richardson, 1998; Dodet and Collet, 2012). Yet, the associated production benefits of using introduced tree species must be considered in light of the associated ecological risks. The use of introduced tree species in plantations has exacerbated declines in stand-level biodiversity (Peterken, 2001), contributed to pest and pathogen introductions (Wingfield et al., 2001), has resulted in the invasion of sensitive ecosystems (Essl et al., 2010) and may also lead to the genetic dilution of native con-generics via hybridization (McKay et al., 2005; Goto et al., 2011). Solely with respect to invasiveness, approximately 60% of invasive tree species identified are used in forestry (Haysom and Murphy, 2003). Furthermore, assessments of the conifer family Pinaceae reveals that species used in commercial forestry are significantly more likely to escape, and become naturalized or invasive than those species not selected for use in forestry (Essl et al., 2010; see Castro-Díez et al., 2011, for relevant discussion of Australian Acacias). Countries are therefore faced with the difficult trade-off between using introduced tree species to achieve desired production gains and avoiding adverse ecological impacts associated with the extensive usage of introduced tree species.

Sweden's forests are extensive, covering seventy percent of the country's total land area (SFA, 2010); but the vast majority bear only superficial resemblance to unmanaged forest ecosystems. Over 90% of Sweden's productive forest land is use for forestry, with the majority of production stands subjected to rotational clear-cutting, often in combination with extensive thinning and soil scarification. As a result, forest production outcomes are exceptional, as the country can provide 10% of the world's sawn timber, pulp and paper using slightly less than 1% of the world's commercial forest area (Lundgren and Ingemarson, 2009). In 2003 the annual cut in Sweden reached a level that approximated the sustainable maximum annual cut (Nilsson et al., 2011). Whereas this could have resulted in stabilization of forest productivity, it has instead prompted discussion regarding how forest yield could be further increased. Recent analyses have highlighted the potential for using introduced tree species to achieve these increases (Nilsson et al., 2011), and as a means of diversifying timber production as part of climate change adaptation efforts. The potential for the expanded usage of introduced tree species is large, as only a small proportion of Sweden's forest area is currently comprised of non-endemic tree species (~2%, Forest Europe, 2011). As such, increased reliance on introduced tree species could cause a substantial shift in the character of Sweden's forests. Furthermore, as the vast majority of forest area in Sweden is allocated for production and lies outside of any secure protective framework (Gustafsson and Perhans, 2010; CBD, 2011), changes to these production forests has the potential to further affect the conservation status of many of Sweden's forest-dependent animal and plant species.

Here we assess the potential ecological costs and benefits from a suggested increased reliance on four tree species introduced to southern Sweden for use in production forestry. Our assessment is based on the scenario of a proportion of Norway spruce (*Picea abies*) monocultures in southern Sweden being replaced by monocultures of either Sycamore maple (*Acer pseudoplatanus*), Douglas fir (*Pseudotsuga menziesii*), hybrid aspen (*Populus tremula tremuloides*), or hybrid larch (*Larix eurolepis*/*L. marschlinsii*). We conduct a review of the available evidence for the risk of these tree species to; (1) alter the composition of forest-dependent taxa in production stands (for better or worse), (2) become invasive, (3) hybridize with endemic tree species, and to facilitate outbreaks of (4) pathogens and (5) pests. We use our results to highlight the necessity for species-specific and comprehensive considerations of ecological risks when developing management strategies for introduced tree species. We discuss the complicating issues of conflicting management goals, the lack of reversibility of some adverse ecological outcomes, and highlight the need for assessments of ecological risk to facilitate evidence-based decision making by stakeholders. We also discuss how uncertainty may be reduced by targeted research and adaptive management programs, and the overriding benefits of shifting towards more resilient ecosystems. We see this exercise as an essential step to fostering discussion among interested parties regarding the alternative forest futures available, and their associated implications for forest ecology.

2. Methods

We searched electronic databases using different combinations of Boolean search terms. The databases used were Google (http://www.google.se/), Google Scholar (http://scholar.google.se/), and Web of Science (http://www.isiwebofknowledge.com/). We used the following search terms: "*Acer pseudoplatanus*", "*Pseudotsuga menziesii*", "*Populus tremula*", "*Populus tremuloides*", "*Larix eurolepis*", "*Larix marschlinsii*", "*Larix decidua*", "*Larix kaempferi*", "Sycamore maple", "Douglas fir", "hybrid aspen", "hybrid larch", "invasiv*", "hybrid*", "pest*", "patho*", "disease*", "fung*", "rot*", "decay*", "biodivers*", and "conserv*" (hybrid larch is referred to as both *Larix marschlinsii* and *Larix eurolepis*). Search terms were run in separate or limited combinations depending on the requirements or limitations of the database used. We also obtained papers from colleagues and through reference lists from published studies including major review articles and books. Furthermore, we obtained information from government studies, authorities and reports (see Table 1).

We define "risk" as the capacity for a chosen action to result in an undesirable outcome, and assess these risks by estimating their likelihood. We define the terms "introduced", "naturalized", and "invasive" based on the criteria of Richardson and Rejmanek (2004). We define "introduced" taxa as a species which occurs outside of its natural range. We define a species as "naturalized" if it is able to independently reproduce and sustain populations over several life cycles (Richardson and Rejmanek, 2004; Broncano et al., 2005). We define "invasive" species as those which produces large numbers of offspring at considerable distances (>100 m) from parent plants (Richardson and Rejmanek, 2004).

Assessing ecological implications from the widespread use of an introduced tree species requires an anchor from which to base any comparison. As 47% of production forests' standing volume in southern Sweden (Götaland, approximately defined as south of 59°N) is composed of Norway spruce (*Pinus abies*) (SFA, 2011), we have chosen this land-use as our baseline for such a comparison. The four introduced tree species we consider are generally established in southern Sweden on land previously dedicated to the production of Norway spruce. The only notable exception is hybrid aspen, which is also established on previous agricultural land. No species considered presently contributes more than a small fraction of total standing volume on productive forest land in Sweden (SFA, 2011).

In order to compare the risks associated with the four tree species, we adopted a graphical method based on a pie chart. Each tree species is represented by a pie divided into five slices, each slice representing one of five ecological issues considered. The biodiversity slice is green, whereas the other issues (hybridization, invasiveness, pests and pathogens) are red. This is to indicate that