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Evidence of *Pseudotsuga menziesii* naturalization in montane Mediterranean forests

Maria J. Broncano [a], Montserrat Vilà [b,*], Martí Boada [a]

[a] *Institute of Environmental Science and Technology (ICTA), Edifici C, Universitat Autònoma de Barcelona, 08193 Bellaterra, Barcelona, Catalonia, Spain*

[b] *Center for Ecological Research and Forestry Applications (CREAF), Edifici C, Universitat Autònoma de Barcelona, 08193 Bellaterra, Barcelona, Catalonia, Spain*

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Abstract

Invasion of natural habitats by conifer species is a well-known phenomenon worldwide. Here, we describe naturalization by the American *Pseudotsuga menziesii* (Douglas fir) in Montseny Natural Park (Catalonia, NE Spain). Establishment of seedlings started 15 years after plantation. Seedling density was positively associated to low tree density, small plantation area, grazing and the presence of a shrubland understorey of intermediate cover. Seedling recruitment outside the plantations occurred at high altitudes (>1000 m). In less than 30 years after plantation, *P. menziesii* invaded adjacent areas 100 m far from the plantation. We conclude that at high altitudes, under disturbance, seedling establishment can take place as soon as planted trees produce cones. Therefore, the time-lag appears to be primarily related to propagule availability.

Keywords: Alien plant; Douglas fir; Forest inventory; Time-lag; Tree invasion

1. Introduction

Invasion by alien species is considered a component of global change threatening the conservation of native species and ecosystems worldwide (Mack et al., 2000; Levine et al., 2003). The introduction of alien plants to a new region can be deliberate, for instance, by planting of species as ornamentals, crop and for wood or fibre production. Most introduced plant species remain confined to where they have been planted. Furthermore, in general, deliberately introduced plants do not reproduce, disappearing once they have finished their life cycle or have been removed. However, there are cases in which after a time-lag that from a few years to several decades depending on the species and habitat, introduced plants reproduce without human intervention and can colonize natural ecosystems, first adjacent to where they have been planted and even at long distance later on (Kowarik, 1995). Richardson et al. (2000) define naturalized plants as "those that

* Corresponding author. Tel.: +34 93 5813584; fax: +34 93 5814151.
E-mail address: montse.vila@uab.es (M. Vilà).

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reproduce consistently and sustain populations over more than one life cycle and for at least 10 years without direct intervention by humans; often recruit offspring freely, usually close to adult plants, and do not necessarily invade various ecosystems. In contrast, invasive plants produce reproductive offspring in large numbers, at considerable distances from parent plants and thus have the potential to spread over a considerable area''. Ecologists even label a plant as invasive which spreads by seed more than 100 m from the source of introduction in less than 50 years or less than 6 m in 3 years for taxa spreading vegetatively (Pysek et al., 2004). To assess the invasion status of particular species is crucial, in order to understand differences in the invasion process between ecosystems or regions, and also to aid management strategies to prevent or reduce the impact of invasive species on natural ecosystems.

Commercial forest trees are one of the cases in which cultivated trees can colonize and invade natural ecosystems. The most problematic species are those that have been widely planted for a long period of time such as eucalypts and conifers (Peterken, 2001; Richardson, 1998; Richardson and Rejmánek, 2004). Eucalypts and conifers have been extensively planted for timber production and environmental management (i.e. dune stabilization, erosion control). Apart from event factors related to plantation history and propagule pressure, species traits also influence invasion. For conifer species, it has been shown that small seed size (<50 mm), short juvenile period (<10 years) and short interval between large seed crops are traits associated to their potential to invade (Richardson et al., 1994; Rejmánek and Richardson, 1996; Richardson and Rejmánek, 2004).

In addition, environmental and biotic factors interact with the introduced species to promote naturalization and invasion. Disturbance has been recognized as the paramount factor facilitating establishment of invasive species (Hobbs, 1989; Hobbs and Huenneke, 1992). A global analysis of the extrinsic factors promoting pine species invasion has highlighted that provided enough propagules are present, disturbances, especially if they increase the supply of limiting resources, generate an open window for invasive species establishment (Richardson and Bond, 1991; Richardson and Higgins, 1998). For example, during the 1970s, in Sweden more than 565,000 ha of *Pinus contorta* were planted. Currently, there is an invasion of this species in forests dominated by *P. sylvestris* and *Picea abies*. More than 70% of the seedlings are located in disturbed areas (Anderson et al., 1999). In Chile, *Prosopis* spp. invades shrublands mainly affected by fire and domestic grazing (Archer, 1995). At the regional scale, disturbance is the reason that the distribution of most alien species is associated to road construction and urban development (Hobbs and Huenneke, 1992).

The Northwestern American tree *Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco (Pinaceae) has been planted extensively for forestry in European countries such as France, Germany and Great Britain where the total extent of planted land is larger than 300,000 ha (Hermann, 1987). *P. menziesii* is considered a serious conifer invader which has escaped after cultivation or planting for wood production in Argentina, Austria, Bulgaria, Chile and Great Britain (Richardson and Rejmánek, 2004) and to regions adjacent to its native area of distribution (Barnhart et al., 1996).

Here, we explore patterns of naturalization of *P. menziesii* (Douglas fir, hereafter) within a protected mountain area in Catalonia (NE Spain). Two approaches were used for this purpose. Firstly, we conducted an extensive survey of tree plantations to relate regeneration (i.e. presence of seedlings) to forest structure, management practices and environmental parameters. Secondly, we quantified Douglas fir colonization in heathlands adjacent to the plantation to ascertain invasion. Our hypothesis was that due to a time-lag between introduction and naturalization, naturalization will be positively related to time since tree plantation, and to factors increasing soil disturbance such as grazing.

2. Material and methods

2.1. Study site

In Spring 2003, we conducted a forest survey in the Montseny Natural Park located in the Barcelona province (latitude 41°42′–41°52′N, longitude 2°16′–2°33′E) and declared a UNESCO Biosphere Reserve in 1978. This mountainous area has a very acute climatic gradient. The weather is typically Mediterranean in the lower areas with main annual rainfall around 800 mm and mean annual temperatures of 15 °C (Cardedeu meteorological station). Above 1000 m altitude, the weather is temperate. In the highest altitudes from 1600 to 1700 m, the mean annual temperature is 7 °C (Turó de l'Home meteorological station). Therefore, the area encompasses a large phytogeographic gradient including Mediterranean, Sub-Mediterranenan and Eurosiberian chorologies (Bolòs, 1983). A major agricultural land abandonment and depopulation took place five decades ago. During the 1950s and the following decades, some former croplands were transformed to tree plantations (Boada, 2000).

2.2. Survey of Douglas fir plantations

In Montseny, there are 230 Douglas fir plantations occupying a total of 250 ha. We selected 40 plantations larger than 0.5 ha located from 552 to 1357 m of altitude. The area of each plantation was delimited by photo-interpretation and on-screen digitizing, using 1:25,000 orthophotomaps as support. A vectorial polygon was obtained, which was finally converted into a raster format with a pixel size of 5 m by the Miramon program (Pons, 2001). In each plantation, we randomly placed a 10 m radius plot in which we counted and measured the diameter at breast height (DBH) of all trees. In each plot core, increments from two randomly selected adult trees were taken to calculate tree age. A simple characterization of the plot was made considering the altitude measured by a GPS; understorey shrub cover: none or low (<30%), middle (30–65%) or abundant (>65%); grazing by domestic animals (yes or no) estimated by the presence of sheep and goat scats and silvicultural treatments (none, timber removal, lower branch clearing or both).

Within each plot we randomly selected a 5 m × 5 m subplot in which we counted the number of Douglas fir seedlings and measured their height. The age of seedlings was estimated by measuring the height and counting the tree rings of seedlings in the area by the function: age = −8.848 + 4.75 ln (height), $n = 273$, $r^2 = 0.86$. We noted the presence of Douglas fir seedlings within a 100 m radius outside the plantation. If seedlings were present inside the plantation, we considered that Douglas fir was naturalizing, while the presence of seedlings in adjacent areas was an indication of incipient invasion.

We tested the relationship between Douglas fir seedling density and age with the independent continuous variables plantation area, tree density and tree age by single correlation analysis. The effect of grazing was tested by a Mann–Whitney *U*-test and the effect of understorey cover with a Kruskal–Wallis test. Due to the small and unbalanced sample size, it was not possible to build a model testing the relationship of all independent variables on seedling performance. A logistic regression was used to test the association of Douglas fir invasion with plantation area, tree density, tree age and altitude.

2.3. Invasion in areas adjacent to plantations

To further ascertain invasion, we selected two plantations located on a south facing slope. Les Roques de Sta Helena is located at 1055 m altitude, has 1700 trees/ha and was planted 31 years ago. El Turó de l'Àngel is located at 1357 m altitude, has 400 trees/ha and was planted 33 years ago.

In the adjacent area to the plantations, there is a grazed heathland vegetation dominated by *Calluna vulgaris*, *Erica scoparia*, *Sarothamnus scoparia* and *Juniperus communis*, where we placed 5 m × 5 m plots within five transect belts at 0, 10, 25, 50, 75 and 100 m to the plantation. Within each plot we measured seedling density and height. As in the previous survey, seedling age was estimated from seedling height. We tested if seedling density and age differed between plantations and if these parameters changed with distance to the plantation by a nested ANOVA.

3. Results

3.1. Correlates to Douglas fir seedling establishment

Mean (± S.E.) plantation area was 2.5 ± 0.48 ha. The larger plantation was 11.1 ha. Mean plantation age was 30.67 ± 1.4 years and ranged from 10 to 54 years (Fig. 3); tree density was 8845 ± 72 trees/ha and ranged from 300 to 2100 trees/ha; DBH ranged from 0.13 to 0.49 m. Stands with lower branch clearing were the youngest (ANOVA, $F_{(3,37)} = 7.30$ $p = 0.0007$) and had the lowest DBH (Kruswall–Walis test $H = 7.88$, $p = 0.048$).

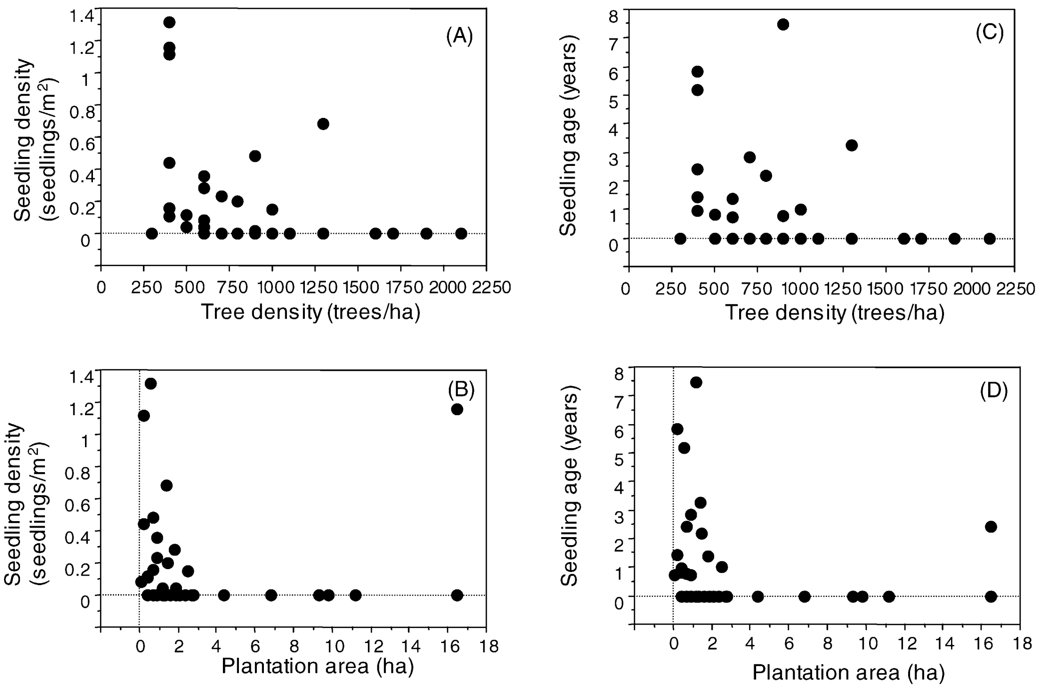

Fig. 1. Relationship between plantation area and tree density with seedling density and mean seedling age within *Pseudotsuga menziesii* plantations in Montseny Natural Park (Catalonia, NE Spain).

Half of the plantations had established seedlings. The presence of seedling establishment was negatively correlated to tree density (Logistic Model Coefficient = 0.003, $P = 0.022$) (Fig. 1). Of the plantations which had seedlings, tree density (Spearman rank correlation, Rho = −0.475, $P = 0.003$), plantation area (Spearman rank correlation, Rho = −0.373, $P = 0.023$), understorey structure (Kruskal–Wallis $P = 0.039$) and grazing (Mann–Whitney U, $P = 0.042$) had a significant effect on seedling density. There were more seedlings in small plantations (Fig. 1B), with intermediate understorey cover (Fig. 2) and if grazing was present (mean ± S.E.: 0.34 ± 0.14 seedlings/m^2 in grazed versus 0.12 ± 0.05 seedlings/m^2 in ungrazed).

Seedling age ranged from 1 to 14 years. On average, seedling establishment occurred when the plantation was 27.8 ± 1.3 years old. The earliest establishment occurred when a plantation was only 20 years old (i.e. currently 25-years-old plantations with 5-year-old seedlings). There was not a significant relationship between mean seedling age and any of the independent variables analysed such as tree density (Fig. 1C) and area of the plantation (Fig. 1D). There was neither a correlation between plantation age and maximum seedling age because there are many plantations of more than 20 years old without seedlings (Fig. 3).

Of the 40 sampled plantations, 11 (27.5%) had seedlings which had escaped into adjacent areas. Only the altitude of the tree plantation was associated to seedling establishment outside the plantations. On average, invasion occurred at high altitudes (mean

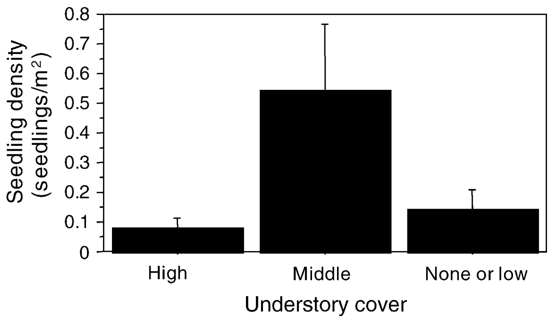

Fig. 2. *Pseudotsuga menziesii* seedling density within plantations with different understorey cover in Montseny Natural Park (Catalonia, NE Spain).

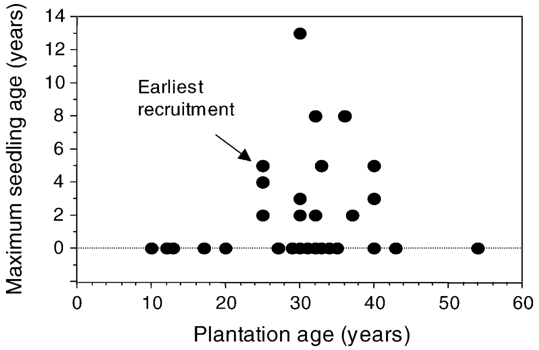

Fig. 3. Relationship between *Pseudotsuga menziesii* plantation age and maximum seedling age in Montseny Natural Park (Catalonia, NE Spain). The arrow indicates the plantation with the earliest seedling recruitment.

± S.E.: 1045.1 ± 67.5 m, logistic regression, $P = 0.042$).

3.2. Invasion in areas adjacent to plantations

There were no significant differences in the patterns of invasion between the two sampled plantations ($F_{(11,58)} = 1.08$, $P = 0.303$). However, distance to the plantation had a significant effect on seedling density ($F_{(11,48)} = 4.52$, $P = 0.0001$). Seedling density decreased with distance from the plantation: maximum density in Roques de Sta Helena was reached at 0 m (6960 ± 1656.9 seedlings/ha) and in Turó de l'Àngel at 10 m (4240 ± 1848.67 seedlings/ha). Seedlings were not present more than 100 and 75 m from the plantation in Roques de Sta Helena and Turó de l'Àngel, respectively (Fig. 4A, B).

There were no significant age differences between the two plantations ($F_{(1,311)} = 3.68$, $P = 0.06$). Maximum age was 16 years in Roques de Sta Helena and 18 years in Turó de l'Àngel. Therefore, in both plantations, invasion started when the plantation was 15 years old. Most seedlings were >6 years old and still there is an ongoing recruitment (Fig. 5A and B). Age of seedlings was dependent on distance to the plantation ($F_{(9,302)} = 3.38$, $P = 0.0006$). On average, the oldest seedlings were located 10 m from the plantations in Roques de Sta Helena = 7.9 ± 0.43 years (Fig. 4C) and at 75 m in Turó de l'Àngel = 11.8 ± 0.44 years (Fig. 4D).

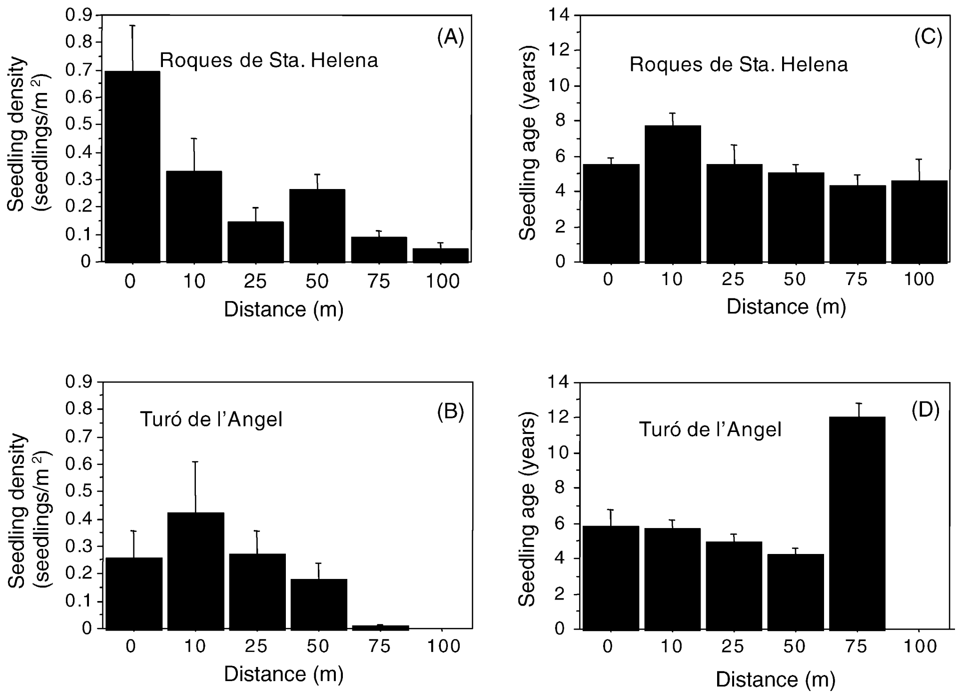

Fig. 4. Mean (±S.E.) density and age of *Pseudotsuga menziesii* seedlings in relation to distance to the plantation in two localities of Montseny Natural Park (Catalonia, NE Spain).

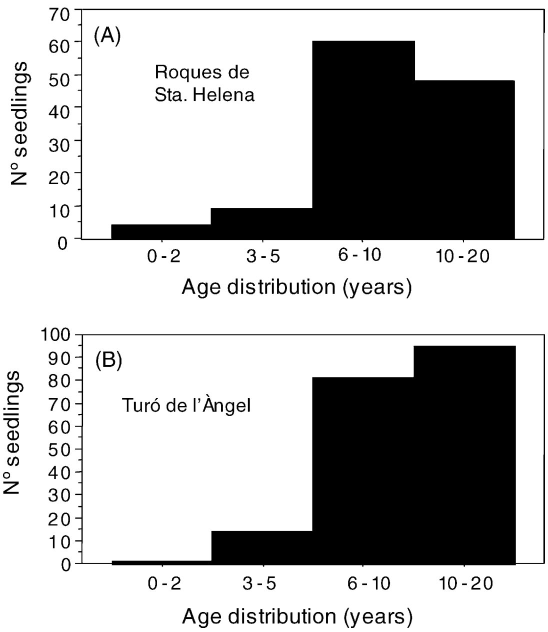

Fig. 5. Distribution of ages of *Pseudotsuga menziesii* seedlings invading heathlands adjacent to plantations in two localities of Montseny Natural Park (Catalonia, NE Spain).

4. Discussion

We found that the Douglas fir is invading in Montseny Natural Park. Douglas fir plantations act as focus of invasion into adjacent heathland communities. To our knowledge, despite the Douglas fir being known as an invader in temperate European regions such as in the Czech Republic, Germany and Ireland (Richardson and Rejmánek, 2004) this is the first time naturalization and incipient invasion of this species is described in the Mediterranean Basin.

Propagule pressure, measured as tree plantation area and tree density, did not increase seedling recruitment. The pattern of seedling abundance of this species suggests that seedling establishment is enhanced by disturbance and light availability. Disturbance is generated by sylvicultural practices, timber removal and grazing. Plantations with low tree density are usually the oldest ones (correlation, $r^2 = 0.13$, $p = 0.013$) in which there has already been some timber exploitation. During timber extraction an understorey develops due to soil disturbance and canopy opening. Similarly, trampling by livestock (i.e. sheep, goats) reduces competition with grasses and herbs and puts seeds in contact with soil that otherwise would be covered by litter which inhibits germination. Grazing and browsing rank as the main type of disturbance (30.14%) implicated in pine invasion in the Northern Hemisphere followed by deforestation due to logging or fuel–wood cutting (21.99%) (Richardson and Bond, 1991). Simberloff et al. (2002) also describe Douglas fir dispersal several hundred meters far from its propagule source in open and disturbed areas (e.g. ridge tops, roadsides and remnant pastures) in Isla Victoria (Argentina). These invasion patterns match with those in its native range where the Douglas fir is considered a pioneer semi-shade tolerant species whose regeneration is favoured by selective canopy clearing. In fact, in its native range, Douglas fir can also expand into grasslands adjacent to Douglas fir forests (Hermann and Lavender, 1990).

It was striking to find no relationship between plantation age and maximum seedling age. Although some old plantations had no seedlings, we found that seedling establishment can start 15 years after plantation. This is the same age that the Douglas fir can produce cones and viable seeds. Therefore, the time-lag between introduction and naturalization is very short compared to other tree species (Kowarik, 1995) and it is not due to any adaptation to the environmental conditions of the site.

In some plantations, there is recruitment of seedlings into adjacent areas. However, seedlings invading into adjacent areas do not have a reversed J-shaped distribution of ages, suggesting that recruitment apparently followed a disturbance event and it is progressive in time. Surprisingly, we also did not find an advancing age front pattern of invasion as described by reaction–diffusion models (Frappier et al., 2003). The spatial and temporal invasion patterns into adjacent areas to the plantation suggest that although the plantation acted as an initial invader source, there are isolated advancing patches as a result of reproductive saplings.

In conclusion, we have presented clear evidence that the Douglas fir is able to invade at high altitudes in the Mediterranean Basin region matching its environmental requirements in the native range (Spiess and Franklin, 1989). Naturalization can occur as soon as planted trees are reproductive if management practices such as clearing or grazing open the tree canopy and disturb the soil, respectively.

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