Available online at www.sciencedirect.com

ScienceDirect

Forest Ecology and Management 235 (2006) 1–13

Forest Ecology and Management

www.elsevier.com/locate/foreco

Review

Flooding tolerance of Central European tree and shrub species

C. Glenz [a,*], R. Schlaepfer [a], I. Iorgulescu [a], F. Kienast [b]

[a] *Laboratory of Ecosystem Management, Environmental Science and Technology Institute, EPFL, Lausanne 1015, Switzerland*
[b] *Division Landscape Dynamics and Management, WSL, Birmensdorf 8903, Switzerland*

Received 9 February 2005; received in revised form 5 May 2006; accepted 17 May 2006

Abstract

Extensive efforts have been made in recent years to restore rivers with a view to increasing the ecological value of riparian areas and the surrounding landscape and to improving the protection provided against extreme flooding events. One of the important factors for the successful establishment and survival of tree and shrub species in enlarged river corridors (particularly in lowlands) – and in retention basins – is their capacity to survive in anoxic conditions, i.e. their flooding tolerance. The importance of improving our understanding of flooding tolerance and the associated factors is underlined by the increasing interest shown in these issues by landscape planners and forestry services throughout Europe. Knowledge about the physiological and metabolic response of most Central European tree and shrub species is still incomplete. From a management perspective, there is a high level of interest in exploiting factors that incorporate these physiological and metabolic processes, but in ways that are easy to implement and to evaluate in the field. This paper presents a synthesis of knowledge available on the response of Central European tree and shrub species to flooding and highlights the main biotic and abiotic factors that influence species response. The modelling of the impact of flooding on plant species, the success of restoration projects, the planning of retention basins and even the estimation of the economic repercussions of flooding events on forestry could be improved through better knowledge of the flooding stress response of individual tree and shrub species arising from more systematic investigation.

Keywords: Central Europe; Flooding tolerance; Processes; Anoxia; Riparian forest; River restoration

1. Introduction

Extensive efforts have been made in recent years to restore rivers (and their systems) with a view to increasing the ecological value of riparian areas and the surrounding landscape (creating corridors) and to improving the protection provided against extreme flooding events (Buijse et al., 2002). ‘‘River widening’’ (e.g. Habersack et al., 2000), i.e. the enlargement of the section between the levees with the aim of re-establishing quasi-natural river dynamics and the associated typical riparian vegetation, is a popular restoration measure. The ecological success of such restoration projects, and river restoration in general, depends on the information available on the interacting ecological, hydraulic and geomorphological processes responsible for riparian vegetation succession. Apart from life history strategies (e.g. seed dispersal strategies, vegetative growth), one of the important factors for the successful establishment and survival of tree and shrub species in enlarged river corridors (particularly in lowlands) – and in retention basins – is their tolerance to flooding (Streng et al., 1989).

In general, flooding tolerance is evaluated (quantified) in terms of the growth response of trees, the level of injury sustained and survival (Kozlowski, 1997) in relation to specific flooding characteristics, mainly flooding level (depth) and duration. The term ‘‘flooding tolerance’’ occasionally also includes species life history strategies (e.g. stem flexibility, high number of seeds) which enable survival in highly disturbed areas, however, in the context of this paper, flooding tolerance is used to express the capacity to survive in anoxic conditions (Hook, 1984). The lack of oxygen affects vital physiological and metabolic pathways and is expressed in symptomatic terms by a decline in growth or even the death of the plant species.

The importance of improving our understanding of flooding tolerance and the associated factors is underlined by the increasing interest shown in these issues by landscape planners and forest services throughout Europe. Important investigations

---

* Corresponding author.
E-mail address: christian_glenz@yahoo.com (C. Glenz).

0378-1127/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2006.05.065

were carried out on the river Rhine in Germany in the aftermath of the extreme flooding events of 1987 and 1999 with the aim of providing a better understanding of the impact of flooding on tree species and of relating flooding depth and duration to the extent of tree damage observed. Based on the findings of this investigation, tolerance thresholds were proposed for each species, which have been incorporated into forest management practices along the river Rhine and into the planning of retention basins (Pfarr, 2002). However, conflicting observations revealed that flooding tolerance is more complex than expected and the question remains as to what we really know about the effect of flooding or flooding tolerance of tree and shrub species, in particular Central European tree and shrub species. Most of the studies on flooding tolerance were carried out overseas and there some excellent reviews exist that provide important insights into the ‘‘flooding tolerance’’ mechanisms, including the associated anatomical and physiological adaptations, of mainly non-European tree and shrub species (e.g. Hook and Crawford, 1978; Bell and Morley, 1979; Kozlowski, 1984; Armstrong et al., 1994). One of the main ways in which plants adapt to flooding involves the capacity of aerial tissues to absorb O_2, basipetal O_2 transport through the stems, diffusion of O_2 out of roots to oxidize the rhizosphere for the purpose of increasing absorption of macronutrients by roots and the oxidizing of toxic compounds in flooded soils into non-toxic compounds. Morphological adaptations, such as hypertrophied lenticels, aerenchyma tissues and adventitious roots increase the uptake of O_2 by aerial tissues and promote its transport into the root system. In addition to the supply of oxygen, the survival of flooding by woody plants depends on the ability to control metabolism, the availability of abundant energy resources, the provision of essential gene products, the synthesis of macromolecules and, finally, protection against post-anoxic injury (Armstrong et al., 1994). These metabolic processes, morphological and physiological adaptations have also been observed in some well-analysed European species, in particular *Alnus glutinosa* and *Salix alba*. However, the knowledge of the physiological and metabolic response of most of the other Central European tree and shrub species remains incomplete. From a management perspective, there is a high level of interest in exploiting factors that incorporate these physiological and metabolic processes, but in ways that are easy to implement and to evaluate in the field. This is evident in the opportunistic field observations that do not relate tree damage caused by flooding to detailed physiological or morphological processes, but which try to find a relationship to more easily quantified factors (e.g. flooding depth, flooding duration). However, the question remains as to the ways in which biotic and abiotic factors affect species response and whether they can actually be used to express flooding tolerance. In order to answer this question in-depth knowledge is required with respect to the nature of these biotic or abiotic factors, the general response of the individual species to these factors and their links to physiologic and metabolic processes.

Opportunistic field observations of adult tree and shrub species in Europe have mainly been carried out on the rivers Rhine (e.g. Krause, 1982; Dister, 1983; Späth, 1988; Hügin and Heinrichfreise, 1992; Splunder et al., 1995; Siebel and Bouwma, 1998; Biegelmaier, 2002; Späth, 2002), Elbe (e.g. Patz et al., 2000; Roloff et al., 2002), Danube (e.g. Karpati and Karpati, 1971), Oder (e.g. Gorzelak, 2000) and Rhone (e.g. Pautou and Decamps, 1985). More systematic studies of seedlings have also been carried out under controlled laboratory conditions (e.g. Vester, 1972; Hughes et al., 1997; Siebel and Blom, 1998; Siebel et al., 1998). A considerable proportion of the information available on the flooding tolerance of Central European tree and shrub species consists of qualitative data (e.g. Siegrist, 1913; Moor, 1958; Ehlers, 1960; Goettling, 1968; Heller, 1969; Wendelberger, 1973; Gulder, 1996). However, a synthesis of the field observations and laboratory studies on Central European tree and shrub species with respect to the factors that influence flooding response has not yet to be carried out. Thus, in this paper we attempt to summarize the available knowledge about the response of Central European tree and shrub species to flooding and, with the help of the experience gained overseas, to highlight the main biotic and abiotic factors that influence species response to flooding.

We expect that this will provide helpful insights for future modelling approaches implemented in the context of river restoration projects and possibly also contribute to the improvement of experimental set-ups for data collection in the field with a view to defining tolerance thresholds.

2. Species response to submersion

Plant responses to submersion vary. They include injury, inhibition of seed germination, changes in vegetative and reproductive growth, changes in plant anatomy, and promotion of early senescence and mortality (Kozlowski, 1997). However, the most significant and common symptom found in trees affected by flooding is a decline in shoot growth (Dickson et al., 1965; Kozlowski, 1984; Frye and Grosse, 1992; Blom et al., 1994; Ewing, 1996; Gravatt and Kirby, 1998). Frye and Grosse (1992) analysed the growth response of tree seedlings of 22 mainly European species following a 120-day flood. The study revealed an extremely high reduction of height grown for *Tilia cordata*, *Prunus padus*, *Acer pseudoplatanus*, *Prunus serotina* and *Acer saccharinum* together with a very poor recovery in the 2nd year for the species *Rhamnus cathartica*, *Sorbus aucuparia*, *Betula pubescens*, *Betula pendula* and *Acer campestre*. An increase in diameter growth was observed for *Quercus robur* and *Fraxinus excelsior*; this phenomenon often observed in flood-tolerant species as they produce more intercellular spaces and lower density cells, thus enabling oxygen transport.

Soil inundation reduces not only the shoot growth, but also the root growth of most woody plants. The lack of oxygen, the accumulation of toxic metabolites (e.g. aldehydes, organic acid, ethanol) and the accumulation of carbon dioxide due to the restriction of the soil-atmosphere gas exchange by the flooding (Ponnamperuma, 1984) can inhibit root formation and branching and the growth of existing roots and mycorrhizae as well as causing root decay (Kozlowski, 1997). Hence, the reduction of shoot and root growth is the result of the inhibition