Estuarine, Coastal and Shelf Science 180 (2016) 51–58

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

White willow sexual regeneration capacity under estuarine conditions in times of climate change

Heike Markus-Michalczyk [a,*], Dieter Hanelt [b], Julian Denstorf [a], Kai Jensen [a]

[a] Applied Plant Ecology, Department Biology, University of Hamburg, Ohnhorststraße 18, D-22609 Hamburg, Germany
[b] Aquatic Ecophysiology and Phycology, Department of Biology, University of Hamburg, Ohnhorststraße 18, D-22609 Hamburg, Germany

ARTICLE INFO

Article history:
Received 7 December 2015
Received in revised form
12 April 2016
Accepted 26 June 2016
Available online 29 June 2016

Keywords:
Tidal forested wetlands
Salinity and tidal flooding stress
Salix alba
Germination
Early establishment of willows

ABSTRACT

Tidal wetlands provide both habitats for coastal populations and wildlife, and ecosystem services for human welfare. Building with nature regarding cost-effective coastal protection is of increasing interest. Much research has been carried out on plant reproduction capacities in mangroves and salt marshes, but less is known on this issue in tidal freshwater wetlands. Willows are being successfully used for bank stabilization in riverine habitats, however, today white willow softwood forests in tidal wetlands are highly fragmented, and restoration is required e.g. by the European Habitats Directive. Recently, tolerance to increasing salinity and tidal flooding was found for vegetative propagules of floodplain willows. However, the establishment of autochthonous sexual recruits is necessary to conserve the genetic diversity of local populations, and thus may be preferable in restoration. The germination and early seedling establishment of *Salix alba* (white willow) was experimentally studied under simulated estuarine conditions. The species tolerance to increasing salinity (0, 0.5, 1, 1.5, and 2) was tested in a climate chamber, and its tolerance to flooding at different tidal treatments (control, spring tide, daily tide 15 min and 2 h flooding) in the greenhouse. Germination was neither affected by increasing salinity nor by tidal flooding. *Salix* seedlings established up to salinity 1.5, but cotyledon performance and radicle growth was largely reduced at salinity 2. Under tidal flooding, seedling growth was similar in all treatments. However, in the treatments with daily tides seedling anchorage in the substrate took more than two weeks, and fewer seedlings reached a suitable length to approach the high water line. We assess *S. alba* sexual regeneration under estuarine conditions as generally possible. Further studies are needed on the effects of sedimentation-erosion processes on willow establishment in the field, especially on feedbacks between *Salix* survival and tidal wetland evolution.

1. Introduction

Coastal wetlands provide both floodplain habitats and valuable services for human welfare (Kirwan and Megonigal, 2013). Many coastal populations experience an increasing risk of flood disasters due to climate change induced sea level rise, land subsidence and reduced sediment supply, and adapted coastal engineering is increasingly challenged by these changes (Bouma et al., 2013). Moreover, catastrophic impacts of extreme whether events such as hurricanes and typhoons require more effective flood protection strategies, including engineering based on nature and coastal wetlands (Temmernan and Kirwan, 2015).

Estuaries form a major transition zone between land and sea with steep gradients in energy and physicochemical properties, and experience hazards due to extreme events, human activities and climate change (Jennerjahn and Mitchell, 2013). Elliott and Whitfield (2011) highlight the variety of estuarine ecosystem services, societal benefits and human induced pressures surpassing those of many other ecosystems. Eslami-Andergoli et al. (2014) assess estuarine tidal wetlands as one of the most vulnerable ecosystems, facing sea level rise, climate and anthropogenic changes that may experience an abrupt regime shift when approaching a tipping point. However, Kirwan and Megonigal (2013) show feedbacks of marshes and mangroves on wetlands vertical elevation change through natural processes that may allow some wetlands to resist the deleterious effects of sea-level rise. Accordingly, Möller et al. (2015) experimentally demonstrated

* Corresponding author.
E-mail address: heike.markus-michalczyk@uni-hamburg.de (H. Markus-Michalczyk).

http://dx.doi.org/10.1016/j.ecss.2016.06.025
0272-7714/

vegetation attenuating waves and stabilizing sediments in temperate salt marshes even under storm surge conditions, and Alongi (2008) demonstrated tropical mangroves ability to keep pace with sea-level rise due to soil accretion. He suggests resilience to recover after disturbance may be coupled with mangroves key life history traits as pioneer plant characteristics.

Throughout the temperate zone, *Salicaceae* life characteristics are interpreted as adaptations to the highly disturbed riverine floodplain environment enabling plants to be particularly successful in exposed sediments that are often dominant in floodplain habitats (Karrenberg et al., 2002). Willow species provide specifically high water flow resistance (Wunder et al., 2011), and willows are proposed as ecosystem engineering species due to their high resilience to flood disturbance (Borsje et al., 2011). Bouma et al. (2013) suggest a more sustainable flood protection in suitable locations and on a large scale by implementing appropriate ecosystem creation, corresponding to willow softwood floodplain forest restoration.

From a nature conservation perspective, restoration of flood plain forests is required. According to estimations of the UNEP World Conservation Monitoring Centre (2000), a loss of more than 90% of alluvial forests comprising *Salicaceae* can be assumed, e.g. in Germany only 15–20% of natural (forested) flood plains are remaining (BMU and BfN, 2009). Furthermore, white willow softwood forests are listed as priority habitats in Annex I in the EU Habitats Directive (EU Habitats Directive, 1992). In addition to consider hydrological conditions to identify restoration sites of riparian *Salix* (Radtke et al., 2012), in tidal freshwater wetlands a rising sea level must be considered regarding possible rapid losses of area and biodiversity (Baldwin and Mendelssohna, 1998). Willow forests are the final stage of succession in many temperate tidal freshwater forests. Successful restoration depends on understanding how climate change with expected increasing salt water intrusion and inundation will affect willows in tidal freshwater wetlands.

Willow establishment by vegetative propagules dispersed by hydrochory is well confirmed for the low lying riverine zone (e. g. Francis and Gurnell, 2006; Asaeda et al., 2011; Radtke et al., 2012). In tidal wetlands, willow habitat may be affected by a projected moderate sea level rise of up to 60 cm until 2081–2100 (IPCC, 2013). It is clear from recent analysis that relative mean sea level is rising around the UK (Robins et al., 2014). According to a study on effect of climate change on 96 estuaries in England and Wales (Prandle and Lane, 2015), tidally-dominated estuaries will be vulnerable to saline intrusion whereas saline intrusion lengths will increase in proportion to the related decrease in river flow (and vice versa). Similarly, salt intrusion may affect estuaries on the continental Europe, with simultaneously increasing tidal amplitude e.g. in the Elbe estuary (Gönnert et al., 2007), where willow habitats in tidal wetlands largely occur. Floodplain forest regeneration by small and juvenile willows might be specifically threatened by increasing tidal flooding and salt intrusion. Recently, Markus-Michalczyk et al. (2014) demonstrated juvenile white willow salinity tolerance up to oligohaline conditions and a tolerance to tidal flooding up to 60 cm (Markus-Michalczyk et al., 2015). However, less is known on willows sexual regeneration capacity under estuarine conditions. According to Leyer et al. (2012), the softwood woodland shrubby vegetation is dominated by *Salix triandra* L. and *S. viminalis* L., whereas the arboreal vegetation is characterized by *S. alba* L. and *S.* x *rubens* Schrank (a hybrid of *S. alba* and *S. fragilis*). Compared to *S. x rubens*, vegetative propagation ability in *S. alba* is less pronounced, due to reduced brittleness of twigs at their bases (Beismann et al., 2000). White willows propagate vigorously via seeds, and thus sexual regeneration capacity is of specific importance for restoration.

We state that the floodplain willow *Salix alba* L. (white willow) is able to germinate and establish in tidal wetlands in conditions of projected moderate climate change scenarios, and thus willow softwood forest regeneration by sexual recruits in time of sea level rise may be successful. Specifically we aimed to answer the questions (i) if *S. alba* seed germination and seedlings early establishment is possible under oligohaline conditions, and (ii) if *S. alba* seed and seedlings tolerate tidal flooding.

2. Materials and methods

2.1. Sampling sites

Tidal wetlands at the Elbe estuary served as sampling sites for *Salix* seed sources used in experiments on salinity and flooding tolerance of germination and early growth. Two tidal wetlands with remaining willow stands were selected as *Salix* sampling sites according to the salinity gradient: site 1 (53° 53′00.32 N/9° 14′57.00 O) at the turbidity maximum zone of the estuarine brackish stretch with salinity at about 5; site 2 (53° 28′28.96 N/10° 02′12.35 O) at the upper reach of the estuarine tidal freshwater stretch with salinity <0.5 (ARGE Elbe, 2008). The tidal range at site 1 is about 2.8 m and at site 2 3.8 m (BSH, 2010). Anthropogenic impacts (e.g. river deepening and embankments) led to a gradual increase of the tidal amplitude within the last 150 years (Bergemann, 2006), and in the future, rising sea levels and saltwater intrusion might threaten vegetation in remaining tidal wetlands (Neubauer and Craft, 2009). In addition to the dominant factors salinity and flooding, mineral sediment deposition plays a key role in the Elbe estuary. Butzeck et al. (2014) found grain sizes of <63 μm (mud) up to medium and fine sand (63–630 μm), with higher mud deposits at low elevations and more sandy deposits at high elevations. At higher elevated European tidal wetlands, various willow species settle as the first stage of succession to tidal willow wetland forests (Struyf et al., 2009). In previous studies, vegetative willow propagules originating from these tidal wetlands were found to tolerate oligohaline conditions (Markus-Michalczyk et al., 2014), and tidal flooding (Markus-Michalczyk et al., 2015). To test the salinity and flooding tolerance of sexual recruits as well, we thus used *Salix alba* specimen from these sites as seed sources.

2.2. Salinity experiment

2.2.1. Salinity treatments on Salix alba seeds and seedlings

At site 1 along the estuarine brackish stretch, soil salinity (according to the decision of the Joint Panel of Oceanographics salinity is expressed using the Practical Salinity Scale, defined as a pure ratio, and thus has no dimensions or units) up to 2 was found at *Salix alba* stands during the growing season (Markus-Michalczyk et al., 2014). Here, *S. alba* specimen were repeatedly observed in order to determine seed maturity. On July 7th· 2013, mature and partly open capsules with ripe seeds were collected, and stored in a paper bag at ambient temperature until July 8th.

In a recent study on *Salix* in tidal wetlands (Markus-Michalczyk et al., 2014) the salinity tolerance of vegetative propagules was found limited up to salinity 2.0. Since seeds, germination and early seedling establishment are considered as the most critical life stages of a plant (e.g. Fenner and Thompson, 2005) we assumed that *S. alba* seedlings salt tolerance could have been not more than 2. We thus conducted the salinity experiment in five levels up to salinity 2 (salinity 0, 0.5, 1, 1.5 and 2.0). For each of the five salinity levels, eight petri dishes were used as replicates (N = 8), resulting in 40 petri dishes. Filter paper was put in the petri dishes, and salinity solutions were prepared with tap water and additive-free sea salt (Meersalz, Alnatura, Bickenbach, Germany). In a pilot