Agriculture, Ecosystems and Environment 222 (2016) 30–37

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Effects of farming practice on populations of threatened amphibious plant species in temporarily flooded arable fields: implications for conservation management

Sara Altenfelder*, Johannes Kollmann, Harald Albrecht

Department of Ecology and Ecosystem Management, School of Life Sciences Weihenstephan, Technical University Munich, 85350 Freising, Germany

ARTICLE INFO

Article history:
Received 2 September 2015
Received in revised form 27 January 2016
Accepted 2 February 2016
Available online 12 February 2016

Keywords:
Temporary ponds
Amphibious plants
Conservation management
Seed bank
Zero-inflated models

ABSTRACT

Intensification of land use has led to a severe decline of arable plants in the past decades, particularly among species of marginal habitats, such as temporarily flooded fields. Few studies have focused on the factors controlling the population dynamics of these species, and on suitable strategies for more effective conservation. To investigate the effects of farming practice on plant populations of temporarily flooded fields, we determined above-ground and below-ground densities of four annuals (*Elatine alsinastrum, Limosella aquatica, Myosurus minimus* and *Peplis portula*) in a 3-year on-farm experiment. A fully-factorial experiment combined the treatments soil tillage, presence of crops, fertilisation and herbicide application. Soil tillage had a positive effect on plant establishment, whereas herbicide application had a negative effect on the establishment of all study species. Plant densities were controlled by application of fertilisers and herbicides, with the most significant effects on *L. aquatica* and *M. minimus*. Soil seed densities were mainly affected by environmental factors, but tillage also significantly reduced the seed densities of *E. alsinastrum* and *P. portula*. Other farming practices had a minor impact. Thus, reduced management can help in maintaining populations of rare amphibious plant species. The effect of different crops, crop rotation and the timing of management will help in developing the most appropriate management strategies for conservation of these plant species.

1. Introduction

Land use and the abiotic environment both determine species compositions of plant communities in agricultural landscapes (Fried et al., 2008; Pinke et al., 2012). Most arable plant species are adapted to traditional farming with soil tillage in autumn or early spring, low fertilisation, mechanical weeding and little seed cleaning (Burrichter et al., 1993; Fried et al., 2008). During the past decades, however, arable biodiversity has experienced severe declines owing to intensified land use and soil melioration (Sutcliffe and Kay, 2000; Meyer et al., 2013; Sutcliffe et al., 2015). This development has prompted efforts to improve the situation for plants and animals that depend on traditional agricultural management.

Causes and consequences of the declining agro-biodiversity have been investigated (Fried et al., 2009; Storkey et al., 2012), with results implemented in several conservation schemes, for example, 'field margin strip programs' (Schumacher, 1980; Marshall and Moonen, 2002), 'production-integrated compensatory measures' (Litterski et al., 2008), '100 fields for biodiversity' (Meyer et al., 2010) and 'high nature value farmland' (PAN et al., 2011; Sutcliffe et al., 2015). However, a shortcoming of most conservation programs is their almost exclusive focus on plants or animals from terrestrial arable habitats, whereas conservation of, for example, species of temporarily flooded arable fields has rarely been addressed.

Temporarily flooded fields have a flora quite distinct from terrestrial arable habitats, including numerous rare and endangered species (Hoffmann et al., 2000; Bissels et al., 2005; Eliáš et al., 2011; Lukacs et al., 2013). Plant species of these habitats naturally occur in riparian habitats of shallow lakes, ponds and rivers (Deil, 2005). As these ecosystems have experienced a steep decline due to drainage of wetlands and river regulation (Dynesius and Nilsson, 1994; Bilz et al., 2011), temporarily flooded fields have become secondary habitats for the associated species. However, few studies of conservation management of the respective plant communities have been published.

The specific vegetation of temporarily flooded fields is determined by irregular water fluctuations, by regular disturbance

* Corresponding author at: Chair of Restoration Ecology, Technical University Munich, Emil-Ramann-Str. 6, 85350 Freising, Germany.
E-mail address: sara.altenfelder@tum.de (S. Altenfelder).

http://dx.doi.org/10.1016/j.agee.2016.02.002
0167-8809/

by tillage and weed control and by competition with crops and common weeds. In wet years, temporary abandonment of farming provides favourable conditions for amphibious plants, most of which produce large amounts of seeds that can persist in the soil seed bank for decades (Salisbury, 1970; Harper, 1987; Bossuyt and Honnay, 2008). As a persistent soil seed bank slowly responds to changing management conditions, it reflects the long-term management history of a given site (Ryan et al., 2010), and acts as a buffer for periods of unfavourable management. However, little is known about specific effects of agricultural management on the population dynamics of species occurring in temporarily flooded fields.

Timing and frequency of soil tillage, weed control and water level fluctuations determine the population dynamics of individual species. Tillage in fall favours winter annuals like *Myosurus minimus* that germinate immediately after seedbed preparation, and then flower and reproduce in spring, whereas tillage in spring supports summer annuals. Flooding in late winter with a water-level drawdown in spring is also advantageous for summer annuals, including amphibious plants. Given that herbicides affect plants mainly at the time of application (Kleijn and van der Voort, 1997; Storkey et al., 2010), their efficacy depends strongly on treatment timing and on species-specific germination requirements. Spraying in fall and early spring affects mainly winter annuals, whereas late-spring application determines the abundance of summer annuals. Competition is another factor influencing arable plants. Crops compete with rare species for light, thus reducing their establishment and reproduction (Epperlein et al., 2014). Fertilisation increases cover of crops and of competitive weeds, while reducing germination, growth and seed production of rare arable plants through shading and nutrient competition (Bilalis et al., 2010). There is very little research assessing the effect of farming practices and water regime on the establishment and seed banks of annual plants of temporarily flooded fields.

In the present study, we investigated the main factors controlling population dynamics of four annual plant species of temporarily flooded fields under different management regimes. The following hypotheses were tested in a factorial field experiment in northeast Germany:

(i) Regular soil tillage increases establishment and reproduction of short-lived amphibious species of temporarily flooded fields.
(ii) Herbicide applications favour late-germinating amphibious species by removing early-developing competitors.
(iii) Fertilisation benefits crops and competitive weeds, thereby reducing plant density and seed production of amphibious species.
(iv) Crop competition reduces plant density and seed production of amphibious species resulting in a decline of their soil seed bank.

2. Methods

2.1. Study site

To ensure homogeneous site conditions and even land-use history, the experiment was conducted on one conventionally managed farm ('Agrar GmbH Parstein-Bölkendorf'), located in northeast Germany (federal state of Brandenburg; 53°0′52N, 13°59′E; 55 m a.s.l.). The moraine landscape and fertile, alkaline luvisols with an almost neutral soil reaction is a product of glacial till deposited during the last ice age and the early Holocene. Glacial sedimentation processes also left numerous kettle holes which are temporarily or permanently inundated. Depending on the permeability of the subsoil and on precipitation, the water level and also the area of these wetlands fluctuate. The region is characterized by a temperate climate with an average annual temperature of 9 °C and about 500 mm of precipitation (1981–2010; DWD, 2014). Above-average precipitation in at least 2 successive years regularly leads to extensive flooding. In aerial photographs over 12 years (Schmidt, 1996), the inundated area varied between <1% and 15% of the study area.

Seven temporarily ponds spread over 60 ha were selected for the study according to the presence of the four target species. The geographical distances between these ponds were 0.2–1.0 km with a mean of 0.5 km.

2.2. Study species

Four study species that have been reported to occur in temporarily flooded arable fields (Pietsch and Müller-Stoll, 1974; Albrecht, 1999; Hoffmann et al., 2000; Nagy et al., 2009; Popiela et al., 2013) were selected. Nomenclature of species follows Wisskirchen and Haeupler (1998).

Elatine alsinastrum L. (whorly waterwort, Elatinaceae) is a semi-aquatic therophyte adapted to temporarily flooded habitats. This species has a short reproduction cycle, being able to produce large amounts of persistent seeds under favourable conditions. It is distributed throughout Europe and Western Asia (Meusel et al., 1978; Popiela et al., 2013), being rare throughout its whole distribution range (Lansdown, 2014).

Limosella aquatica L. (water mudwort, Scrophulariaceae) and *Peplis portula* L. (spatulaleaf loosestrife, Lythraceae) are summer annuals with a short life cycle adapted to semi-aquatic habitats. Like *E. alsinastrum*, both species develop variable morphological forms, depending on the water level (Hegi, 1926; Hartl and Wagenitz, 1965). *L. aquatica* has its distribution range throughout the northern hemisphere except the Arctic, whereas *P. portula* occurs in most parts of Europe (Jäger, 2011); neither species is threatened on a global scale (Lansdown, 2014), but both have been declining in recent decades and thus are considered vulnerable (*L. aquatica*) and near-threatened (*P. portula*) on a regional scale (Landesumweltamt, 2006).

M. minimus L. (tiny mousetail, Ranunculuaceae) is a winter annual of temporarily flooded sites that can tolerate flooding, but does not change morphologically (Conert et al., 1974). Its distribution ranges from Europe to Western Asia and North America (Jäger, 2011). Owing to its early flowering in spring, it is particularly exposed to herbicide application in arable fields (Edesi et al., 2012). In the study area, this species is considered near-threatened (Landesumweltamt, 2006).

2.3. Experimental design

A fully factorial field experiment was established with and without soil tillage, crops, fertilisation and herbicide application. The treatment combinations were randomly assigned to plots where the study species occurred. Together with the control plots (no treatment), there were a total of 16 variants. Each variant was replicated six times, resulting in 96 plots per species. Owing to limited occurrence of some of the study species during plot establishment in spring 2012, we decided to include plots with more than one study species, and neglected possible interactions among the small and low competitive species. In total, 178 plots were established.

The response of the study species to the different treatments was recorded on 1-m^2 plots that were positioned in June 2012. In autumn 2012, all plots were ploughed to a depth of 20 cm to ensure equal starting conditions. In 2012, we counted the plants of each study species as a reference prior to application of the different