GfÖ
GfÖ Ecological Society of Germany, Austria and Switzerland
Basic and Applied Ecology 17 (2016) 576–585
Basic and Applied Ecology
www.elsevier.com/locate/baae

Contrasting effects of irrigation and fertilization on plant diversity in hay meadows

Isabell B. Müller*, Constanze Buhk, Dagmar Lange, Martin H. Entling, Jens Schirmel

University of Koblenz-Landau, Institute for Environmental Science, Fortstraße 7, D-76829 Landau, Germany

Received 27 July 2015; accepted 28 April 2016
Available online 6 May 2016

Abstract

Extensive grassland management practices are crucial drivers to maintain biodiversity. However, it is challenging to combine biodiversity conservation with high agricultural yields. Traditional lowland meadow irrigation used to be a common management practice to improve hay production. However, it has been widely abandoned throughout Europe due to land use intensification. In an observational field study we examined the long-term impact of traditional irrigation, fertilization and biomass production on plant diversity of hay meadows. Traditional meadow irrigation enhanced plant alpha diversity (Simpson diversity and Evenness) and beta diversity (heterogeneity of multivariate dispersions). However, we found annual differences in the strength and significance of these effects, possibly due to different weather conditions. In contrast, plant species richness was unaffected by irrigation but consistently negatively influenced by the amount of applied N fertilizer. Moreover, we found significant relations between plant alpha diversity and biomass which were either unimodal (plant species richness and Simpson diversity) or negative (Evenness). Our results confirm the generally negative effects of fertilization on plant species richness. The moderately higher plant alpha and beta diversity in irrigated meadows may be a result of the heterogeneous within and between site environmental conditions induced by the annually repeated irrigation events. We conclude that traditional meadow irrigation is compatible with the conservation of plant diversity. Even stronger conservation benefits could be expected from diversified irrigation schemes that include longer-term inundation to favor even more hygrophilic plant communities.

Zusammenfassung

Extensive Grünlandbewirtschaftung liefert einen wesentlichen Beitrag zum Erhalt der Biodiversität. Die Vereinbarkeit von Biodiversität und hohen landwirtschaftlichen Erträgen stellt jedoch eine große Herausforderung dar. Traditionelle Wiesenbewässerung war eine weitverbreitete Bewirtschaftungsform zur Steigerung des Heuertrags. Als Folge der Intensivierung der Grünlandnutzung wurde die Wiesenbewässerung jedoch vielerorts aufgegeben. In unserer Feldstudie untersuchten wir den Langzeiteinfluss von traditioneller Wiesenbewässerung in Kombination mit Düngung und Biomasseproduktion auf die Phytodiversität. Unsere Ergebnisse zeigten einen überwiegend positiven Einfluss traditioneller Wiesenbewässerung auf die pflanzliche Alpha-Diversität (Simpson-Diversität und Äquität) und Beta-Diversität (*heterogeneity of multivariate dispersions*). Die Stärke und Signifikanz der Effekte unterschied sich jedoch zwischen den beiden Untersuchungsjahren, was möglicherweise an den verschiedenen Witterungsbedingungen lag. Im Hinblick auf die Artenanzahl konnten wir keinen Effekt der Bewässerung feststellen, es zeigte sich aber ein negativer Effekt der Menge an Stickstoffdünger. Weiterhin zeigten sich sowohl unimodale

*Corresponding author. Tel.: +49 06341 280 31521.
E-mail address: rudolph@uni-landau.de (I.B. Müller).

http://dx.doi.org/10.1016/j.baae.2016.04.008

(Artenanzahl und Simpson-Diversität) als auch lineare (Äquität) Zusammenhänge zwischen der pflanzlichen Alpha-Diversität und Biomasse. Die überwiegend höhere pflanzliche Alpha- und Beta-Diversität in bewässerten Wiesen resultiert vermutlich aus der jährlich wiederkehrenden künstlichen Bewässerung, die sowohl auf Flächen- als auch auf Landschaftsebene heterogen ist. Diese Ergebnisse zeigen dass traditionelle Wiesenbewässerung mit dem Erhalt der Biodiversität in Wirtschaftsgrünland vereinbar ist. Deutlich wertvoller für den Naturschutz könnten jedoch diversifizierte Bewässerungsmethoden sein, die auch länger andauernde Überflutung zur Förderung stärker hygrophiler Vegetationstypen umfassen.

Keywords: Flood irrigation; Grassland; Meadow irrigation; Phytodiversity; Plant biomass

Introduction

Semi-natural grasslands are key habitats for biodiversity conservation (Poschlod & Wallis DeVries 2002; Baur et al. 2006) but have declined due to management intensification and abandonment within the past centuries (Poschlod, Bakker, & Kahmen 2005, Wesche, Krause, Culmsee, & Leuschner 2012). In grasslands, plant species diversity and vegetation structure are mainly determined by soil nutrient availability, frequency and timing of mowing or grazing, natural and anthropogenic disturbances such as flooding, drought and fire as well as land improvement (Hopkins & Holz 2006). Extensive management practices are crucial drivers for biodiversity (Waldhardt 2003; Kleijn et al. 2009). However, it is challenging to combine biodiversity conservation with efficient agricultural land-use (Tscharntke et al. 2012), as high biomass production in grasslands seems to entail low species richness (Guo 2007; Lamb 2008).

In Central Europe, land use patterns of extensive management have been developed over centuries and have thus shaped regional species and habitat assemblages. This makes it necessary to understand the impact of traditional management regimes on the regional biodiversity (Jongman 2002). Traditional grassland management regimes are characterized by no or low fertilizer applications, low stocking rates and late cutting and are frequently seen as the key for maintaining grassland biodiversity, which has become a primary goal of environmental policy (Muller 2002; Isselstein, Jeangros, & Pavlu 2005). Agri-environment schemes promote traditional extensive grassland management to preserve biodiversity by compensation payments but their efficiency is questionable (Kleijn & Sutherland 2003, Humbert, Pellet, Buri, & Arlettaz 2012).

Lowland meadow irrigation using open water channels used to be common to improve hay production (moistening irrigation and fertilizing irrigation), soil temperature regulation and pest control (Leibundgut 2004; Schellberg 2005; Leibundgut & Kohn 2014a). These traditional irrigation systems have been widely abandoned throughout Europe due to the ongoing intensification of agriculture or have been replaced by e.g. sprinkler-irrigation systems (Hassler 1995; Riedener, Rusterholz, & Baur 2013, Leibundgut & Kohn 2014a). In Germany, irrigation history can be traced back to the 12th and 13th century (Endriss 1951) and had its prime time during the 19th century, where a relevant fertilization effect of irrigation is assumed because river water contained unfiltered sewage (Schellberg 2005). Irrigation techniques were adapted to the local conditions and historical development creating heterogeneous landscape patterns (Leibundgut & Kohn 2014a) possibly influencing biodiversity at larger spatial scales. Since then, water meadows in Germany decreased from about 250,000 ha to a few thousand hectares during the 20th century (Leibundgut 2004). The general character of these water meadows is largely replaced by areas of intensified agriculture and their naturally high biodiversity is degraded (Leibundgut 2004).

Meadow irrigation and fertilization can influence both the floristic composition and species richness through various factors. The impact of fertilization is well studied but results are manifold (Humbert, Dwyer, Andrey, & Arlettaz 2016): the reaction varies from unimodal (Kleijn et al. 2009) over linear decrease with rising nitrogen input (Suding et al. 2005) to exponential decrease in species richness (Kleijn et al. 2009). Mineral nitrogen fertilization promotes the growth of nitrophilous grass species and thus has a detrimental effect on plant diversity by competitive exclusion of less nitrophilous (Gaujour, Amiaud, Mignolet, & Plantureux 2012 and references therein) and understory species (Hautier, Niklaus, & Hector 2009). Species with a low abundance are the first to disappear if meadows are fertilized with nitrogen (Suding et al. 2005; Kleijn et al. 2009), which has negative effects for plant species diversity (beta diversity). Irrigation management with frequent flooding and draining and the installation of the open water channels can shape mosaic-like vegetation patterns reflecting the varying soil-water conditions (Hoppe 2012; Riedener et al. 2013) and affecting plant diversity (Riedener et al. 2013; Andrey, Humbert, Pernollet, & Arlettaz 2014) as well as functional composition (Müller et al. 2016).

Both meadow irrigation and fertilization aim to increase biomass production (Leibundgut 2004). Intensively managed grasslands with high fertilization rates and high biomass production, however, go along with low species richness (Lamb 2008). The negative impact of fertilization on species diversity is well-studied whereas the long-term consequences of irrigation on both biodiversity and biomass production remain controversial (Hassler 1995 and references therein).