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Land-use abandonment owing to irrigation cessation affects the biodiversity of hay meadows in an arid mountain region

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ABSTRACT

In arid regions, irrigation is required to secure agricultural production including the production of hay. The Valais, a dry inner alpine valley of Switzerland, has a long tradition of meadow irrigation. However, in the 20th century irrigation was stopped on marginal, poorly accessible areas usually accompanied by the entire abandonment of these meadows. The aim of this study was to examine the consequences of land-use abandonment resulting from the cessation of irrigation for the biodiversity of species-rich hay meadows in the Valais. We compared soil characteristics and species richness and composition, habitat specificity and functional traits of plants and gastropods of three serial stages of succession (each five hay meadows, early abandoned meadows and young forests). Soil moisture was lower in young forests than in the other two stages. Soil nitrogen content decreased following abandonment, which was due to the cessation of fertilization. The three successional stages did not differ in plant species richness but harboured distinct plant communities. Gastropod richness increased with progressive succession and species composition of hay meadows differed from those of the two other stages. The proportion of grassland (plants) and open-land (gastropods) species decreased following abandonment. Furthermore, meadow abandonment led to an increase in the height of non-woody plant species, a later start of seed shedding, a change in the type of plant reproduction and an increase in the shell size of gastropods. In conclusion, this study showed that extensive land-use, which is strongly linked to irrigation, is required for the characteristic species-rich hay meadows of this arid mountain region.

1. Introduction

Semi-natural grasslands including hay meadows are of high conservation value owing to their high species richness (Baur et al., 2006; Poschlod and WallisDeVries, 2002; Riedener et al., 2013). The high biodiversity of these grasslands is a result of traditional management practices, which have been applied for many centuries (Poschlod and WallisDeVries, 2002). Since the mid 20th century, however, alterations in socio-economic conditions led to the intensification of land-use or to the abandonment of semi-natural grasslands throughout Europe (Fischer et al., 2008; Stöcklin et al., 2007; Strijker, 2005). As a result, the total area of semi-natural grasslands declined (Strijker, 2005) and plant species richness was negatively affected (Jacquemyn et al., 2011; Niedrist et al., 2009; Tasser and Tappeiner, 2002; Wesche et al., 2012).

In arid regions, agricultural activity including the production of hay essentially depends on irrigation. As a consequence, far-reaching irrigation systems have been constructed in several arid mountain regions of Europe (Rodewald, 2008). One of these regions is the Valais, Switzerland, where a long tradition of meadow irrigation exists (Crook and Jones, 1999). In the Valais, meadows are traditionally irrigated using open water channels, whereby the water is conducted from the channel to the meadow based on gravity (Crook and Jones, 1999). However, in the 20th century, the modernization and rationalization of agriculture led to two main changes in the irrigation practices of this region. Traditional meadow irrigation was replaced by more efficient sprinkler irrigation systems and irrigation was stopped on marginal areas with poor accessibility (Crook and Jones, 1999; Werner, 1995). As a consequence of the cessation of irrigation, the productivity of these meadows decreased leading to the abandonment of mowing or to conversion to pastures (Werner, 1995).

While numerous papers addressed the effects of mowing or grazing abandonment on biodiversity, the effects of irrigation abandonment has to our knowledge not been examined so far. The aim of this study was to investigate the consequences of land-use abandonment resulting from the cessation of irrigation for the biodiversity of species-rich hay meadows in the Valais. For this, the biodiversity of three serial stages of succession (hay meadows, early abandoned meadows and young forests) was compared.

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The majority of studies on land-use abandonment considered only the effects on plant species, even though other organisms might respond as well (Baur et al., 2006; Cremene et al., 2005). Therefore, the species richness of plants and gastropods were used as a proxy for biodiversity in this study. These organisms are considered as ideal diversity indicators in small-scale habitats owing to their high habitat specificity and low mobility (Boschi and Baur, 2008; Gaujour et al., 2012). Functional traits of these organisms were also considered because they represent another aspect of biodiversity and therefore supplement the taxonomy-based analysis.

This study focused on the following questions: (1) Does land-use abandonment owing to the cessation of irrigation (henceforward: meadow abandonment) lead to a change in soil conditions? (2) Does meadow abandonment affect the species richness and number of threatened species of plants and gastropods? (3) Does meadow abandonment affect the composition and habitat specificity of species? (4) Is there a shift in functional traits with ongoing succession?

2. Methods

The study was conducted in two areas on the south-facing slope of the Rhone valley in the Valais, Switzerland, namely in Ausserberg (AU; 46°19′ N, 7°51′ E) and Birgisch (BM; 46°19′ N, 7°57′ E). The two areas are situated 8 km apart. Both are characterized by a small-scale patchy landscape consisting of different land-use types including hay meadows, woodlands and settlements. Mean annual temperature in this region is 9.4 °C and total annual precipitation is 596 mm with the lowest amount of rainfall during the vegetation period (MeteoSwiss, 2013).

Three different serial stages of succession were considered: extensively managed hay meadows (ME, $n = 5$) belonging to the *Trisetetum* association (Ellenberg, 1986), early abandoned hay meadows (AB, $n = 5$) with naturally growing shrubs, and young, naturally regrown forests (NF, $n = 5$), resulting in a total of 15 study sites (Table 1). Three groups of study sites, each group containing all three successional stages were situated in AU and two groups in BM. Average distances among study sites within a group ranged from 50 m to 1.5 km in AU and from 0.2 to 0.9 km in BM. Detailed information on the land-use of the study sites were obtained by personal interviews with farmers and the age of forest stands was estimated from old maps. The hay meadows investigated are irrigated every 2nd to every 3rd week during the vegetation period using the traditional irrigation technique. In autumn, the hay meadows are grazed for a few days.

Study sites were situated underneath a water channel on an elevation of 1237 ± 4 m a.s.l. (mean ± SE) in AU and 1120 ± 7 m a.s.l. in BM (ANOVA, $F_{1,11} = 310.19$, $p < 0.001$). Sites in AU were south exposed (186 ± 8°) while sites in BM were south-east exposed (140 ± 10°; ANOVA, $F_{1,11} = 11.53$, $p = 0.006$). Inclination averaged 21.7 ± 2.5° (SE) and did not differ among study sites in the two areas (ANOVA, $F_{1,11} = 1.62$, $p = 0.23$). Furthermore, the study sites of the three successional stages did not differ in elevation, exposure and inclination (ANOVA, all $p > 0.10$).

One 10 m × 10 m sampling plot was established in a homogenous part of each study site. Sampling plots were placed at least 2 m from water channels and trails and 3 m from roads to minimize potential edge effects.

2.1. Surveys

Plant species richness and abundances of single species were assessed in a 5 m × 5 m subplot established in a randomly chosen corner of each 10 m × 10 m sampling plot. The cover of each plant species in the herbaceous layer (herbs and woody plants up to 40 cm height) was estimated using the Braun-Blanquet (1964) method. To complete the species list of the entire sampling plot, the other three 5 m × 5 m subplots were searched for 20 min each and all new species were recorded. In addition, we counted the number of shrubs (40 cm to 2 m high) and trees (>2 m) occurring in the 10 m × 10 m plot, excluding dead individuals. Coppiced shrubs and trees were regarded as different individuals. Plant species were identified according to Lauber et al. (2012). Two surveys were carried out between May and September 2011, one in spring and the other in autumn.

Two methods were used to assess the species richness and relative abundance of terrestrial gastropods (Oggier et al., 1998). First, one person visually searched for living snails and empty shells in each 10 m × 10 m plot for 30 min. Second, a soil and litter sample was collected at randomly chosen spots within each sampling plot using a shovel (in total 1 L per plot). Soil samples were put through sieves (smallest mesh size 1 mm) and examined under the binocular microscope. Gastropod shells were sorted out of the samples and identified according to Turner et al. (1998). Gastropod surveys were carried out twice in each plot (first sampling: first week of July 2010 and from 15 June to 7 July 2011; second sampling: September 2010 and from 24 August to 21 September 2011). For the analyses, data of both surveys were pooled. Snails can be detected in any weather due to the presence of empty shells. Slugs were not considered because their activity depends largely on weather conditions.

2.2. Soil characteristics

To assess the soil characteristics of the study sites, four soil samples approximately 50 cm apart were taken to a depth of 5 cm using a soil corer (diameter 5 cm; volume 100 cm^3) at the edge of each of the four subplots in October 2010 and 2011. For the analyses, the mean value of the four samples from a given study site was used. The soil samples were sieved (mesh size 2 mm) and dried for six days at 50 °C. Soil moisture (%) was determined using the fresh weight to dry weight ratio and soil pH was assessed in distilled water (1:2.5 soil:water) (Allen, 1989). Total soil organic matter content (%) was determined as loss-on-ignition of oven-dried soil at 750 °C for 16 h (Allen, 1989). Total soil organic nitrogen content was assessed using the standard method of Kjeldahl (Bremner, 1965) and total carbonate content (%) was measured by the addition of hydrochloric acid and subsequent back titration with sodium hydroxide (Allen, 1989). Finally, total phosphorous content and plant available phosphorous content were assessed using standard methods (Allen, 1989).

2.3. Red List species and trait data

Information on threatened plant and gastropod species was obtained from the Red List of ferns and flowering plants of Switzerland (Moser et al., 2002) and the Red List of Mollusca (gastropods and bivalves) (Rüetschi et al., 2012). Species were considered as threatened if they were classified as critically endangered, endangered, vulnerable or nearly threatened.

Data of nine plant traits (Table 2) were obtained from the databases BIOPOP (Jackel et al., 2006), LEDA (Kleyer et al., 2008), BiolFlor (Klotz et al., 2002) and CloPla3 (Klimesova and de Bello, 2009) and additional information from Lauber et al. (2012), Grime et al. (1988) and personal observations. Species which were found exclusively in a single subplot (5 m × 5 m) were excluded as were 10 species with missing values for some traits, because the method used does not allow for missing values. Since succession implies the increase in woody species, we excluded the eight woody species resulting in a total of 105 plant species in the analysis. For gastropods, data of six traits were obtained from Kerney et al. (1983),