Chapter 10

Traditional Water Meadows: A Sustainable Management Type for the Future?

Constanze Buhk, Jens Schirmel,
Gerlach Rebekka and Oliver Frör

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.79429

Abstract

Traditional meadow irrigation techniques were once widespread throughout Europe and served as a method of grassland intensification before the era of mineral fertilization. Close to Landau (Palatinate), Germany, there are several hectares of traditionally irrigated water meadows that are irrigated twice a year in parts since the medieval age or irrigation has been reinitiated since the 1990. In a research project "WasserWiesenWerte", we analyzed the ecological and socio-economic value of meadow irrigation. We compared extensively to semi-intensively used meadows with fertilizer application between 0 and 80 kg N/ha per year which were either irrigated or nonirrigated. The results were very motivating. Biomass production is increased by about one-third with irrigation. At the same time, several species groups did not decrease in frequency and diversity in the meadows under irrigation. In contrast, some especially rare species seemed to even profit. Ditch structures turned out to be especially important refuges for sensible meadow species and added a large quantity of additional species to the landscape diversity. We propose that the revitalization of traditional irrigation techniques should be considered when extensively managed grassland—especially hay meadows—are prone to either intensification or abandonment.

Keywords: biodiversity conservation, ditch structures, extensive grassland management, hay meadows, hay quality, land-use intensification, traditional meadow irrigation, recreational value, traditional water meadows

1. Introduction

Species rich grasslands are among the most threatened ecosystems in Europe [1–3]. They suffer either from abandonment or intensification—both processes lead to species loss [4, 5].

However, to sustain future ecosystem services, stability, and high quality living environments, biodiversity is a crucial good and has to be protected and promoted according to the Convention on Biological Diversity treaties setup by the UN [6]. To conserve large scale meadow landscapes in a modern world, innovative ideas are needed to combine nature conservation and economic aspects [7].

Since the medieval ages, but especially around 1900, a widespread technique throughout Europe to improve hay yields was traditional meadow irrigation [8]. Short-term flooding of the meadows via irrigation and drainage ditches twice to three times a year was done to use the fertilization effect of the stream water and to achieve an elongation of the vegetation period [9]. With World War II followed by the need for massive food production and the development of mineral fertilizers in 1950, most irrigation systems were abandoned, and meadows were transformed to crop land [10]. Today, only a few actively traditionally irrigated water meadows exist [9]. A landscape with active traditional meadow irrigation is the Queich River Plain East of the city of Landau in Palatinate, Germany. In the research project "WasserWiesenWerte", we studied the economic and ecological values of 18 water meadows in contrast to 18 nonirrigated meadows along the Queich river (Palatinate, Germany) as well as the socio-economic value of the landscape. We asked the following questions: is it possible to reduce the amount of fertilizers applied under irrigation keeping hay yields high and hay quality good? Which is the effect of irrigation on biodiversity of plants and animals living on meadows? How do species of conservation concern react to traditional irrigation? Does landscape attractiveness increase to combine the economic and ecological values with high recreational and touristic value? Could this traditional technique of intensification be a way out of the dilemma that farmers need to either heavily fertilize or abandon extensive meadows to find economically viable management solutions?

In many parts of Europe remains of former traditional meadow irrigation systems can still be found. However, the potential of the technique might be overlooked in many places.

2. Traditional water meadows

2.1. Traditional water meadows in Europe

Traditional irrigation techniques in grasslands were widely used until about the middle of the twentieth century [8], this is, when the techniques were replaced with modern systems using electric power supply and sprinkler irrigation and liquid manure or mineral fertilization to improve economic output of grasslands. Traditional methods of intensification, like traditional meadow irrigation techniques, are based on gravity and the natural movement of water from a river or stream [8, 9]. Meadows are either deliberately inundated by the damming of adjacent streams or ditches or the water slowly trickles over the surface of a slope. The time of inundation is usually kept short ("flash inundation"). The relief of the irrigated area is crucial to allow fast drainage, to avoid adverse effects of stagnant water [8, 11].

The widespread use of traditional meadow irrigation throughout Europe was by far not focused to dry areas only [8]. The positive effects found are not only restricted to the water supply but also to soil quality, making available of nutrients, pest control or elongating the growing period [9]. From Finland and Sweden in the North to Southern Spain or Sicilia in the South as well as from France in the West to Eastern Romania, traditional water meadow techniques were applied [8].

There is a large variety of management practices depending on region and natural settings. A rough separation of the techniques can be done into practices used in mountainous regions in contrast to techniques applied in valley floors and flat areas [8]. The application of traditional meadow irrigation in mountainous areas is often especially straightforward as the water is directed into ditches that follow the contour lines and the natural inclination of the hillslope which is sufficient to avoid stagnant water conditions. Irrigation systems in flat areas often were constructed with major effort as the surface level had to be adapted thoroughly. A ditch system allowing water division as well as a drainage system has to be constructed.

Traditional meadow irrigation clearly differs from modern sprinkler irrigation. The soil is not just wetted from above but soaks thoroughly. Above ground plant parts are often not even wet after irrigation, but soil water is effectively filled up to the local water holding capacity. The negative effects of large water drops splashing onto the soil surface closing soil pores, compacting the soils, and eventually leading to soil erosion—which are often problems under sprinkler irrigation—are avoided. Further, large water losses by the evaporation from the plant surfaces are reduced. It could be shown that traditional irrigation techniques are leading to a renewal of ground water resources [8] and increases water retention in the landscape. The potential negative argument traditional irrigation methods would be a waste of water that do not necessarily hold, if such secondary effects are included into the evaluation [8, 12, 13].

2.2. Traditional water meadows along the river Queich

While traditional water meadows in the region of Palatinate still covered one-third of the whole meadow area in 1936, hardly any traditionally irrigated meadows remained by 1960 [14]. This was not due to the low effectiveness of the systems, but it was the result of a large change in agriculture with abandonment on the one hand and intensification and transformation to arable land on the other hand. Many small farms were given up, food production on arable fields became extremely important during and after World War II, and the maintenance of irrigation systems was labor intensive. Since the introduction of mineral fertilizers after 1950, there seemed to be no need to keep on using meadow irrigation techniques as an alternative method to improve yields seemed to have been found.

The study region is part of the Upper Rhine Rift Valley located between the cities of Landau (49°19′N, 8°12′E) and Germersheim (49°22′N, 8°36′E) in the lower Queich valley. It belongs to the FFH habitat directive area "Queichniederung" [15]. The area under flush irrigation today has a size of more than 400 ha and is the largest actively traditional irrigated meadow landscape in Germany and one of the largest in Europe [9]. In parts (about 90 ha), meadow irrigation in the area continued since the medieval age. The larger parts were reactivated since 1996. The streams responsible for the large scale irrigation system are the river Queich and its side streams Fuchsbach and Spiegelbach. They originate from the Palatinate Forest region, a mountain range built from acidic sandstone from the Buntsandstein period.

Altogether, there are nine active sluices along the river Queich, one along Fuchsbach and two along the Spiegelbach. In the area, a large system of sluices, irrigation ditches, and drainage ditches was constructed (**Figure 1**). Two to three times a year, the irrigation follows the meadows downstream. Starting with the first sluice, the water is dammed slowly and flows into a main ditch (**Figure 2**). From here, there are several secondary ditches and even smaller distribution ditches to cover the area. Side sluices remain closed at the beginning of the irrigation but are opened successively as the water slowly covers the adjacent meadow areas (**Figure 3**). Water soaks slowly into the soil. When a section is well irrigated, the side sluices are opened and the water continues to flows to meadows further down the ditch. The first irrigation usually transports organic material from the river and the ditch to the sluices. The material is removed to guarantee the permeability of the ditch (**Figure 3**). With the successive opening of the side sluices, the water proceeds to wander over the meadows. Every main sluice is closed for 2–4 days, depending on the size of the irrigation area. The remaining water slowly flows into drainage ditches that drain back into the river. Simultaneously to the reopening of the first main sluice, the next main sluice further downstream is closed to use the increased water volume to irrigate the next sections. The irrigation follows an exact plan and is organized by the adjacent communities and farmer associations. They are based on the land owners' irrigation water rights that origin from ancient times. The sluices are never closed completely but allow a steady water flow to not affect the ecology of the stream ecosystem. A minimal water level is to be guaranteed. This avoids conflicts with other water users. In very dry periods, this may lead to a reduced size of the irrigation as the areas located at the far ends of the distribution ditches may not be reached by the water during the irrigation days of the respective section [9].

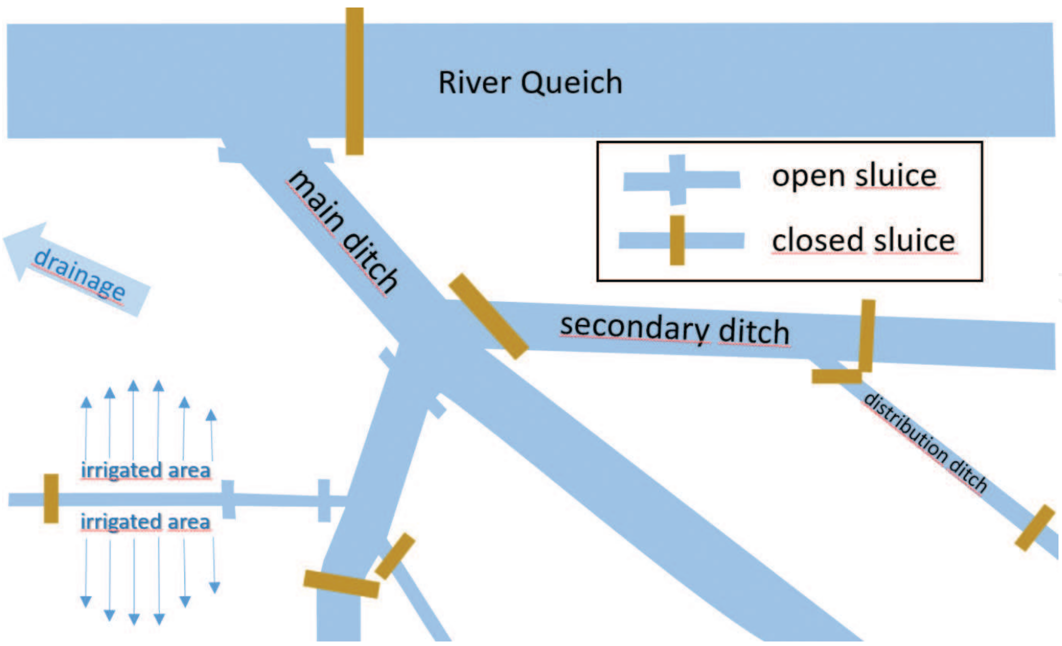

Figure 1. Scheme of the irrigation system found along the river Queich (redrawn and adapted from [8]). See text for explanation.

http://dx.doi.org/10.5772/intechopen.79429

Figure 2. Main sluice (near Mörlheim) along the river Queich (right side of the photo). The sluice is closed which allows water to flow into a main ditch (upper left side of the photo; photo: Martin Alt).

Figure 3. Irrigated meadows to the left and to the right during spring irrigation. Side sluices are closed until the adjacent meadows are irrigated. The water level is not rising high above the surface during irrigation but soaks the soils from the sides (photo: Martin Alt).

The majority of the meadows are irrigated twice a year. The first irrigation starts by mid-April and ends by mid-May. The second period starts from mid-July and ends by mid-August. Historically, autumn irrigation also played an important role. This was done mainly to increase the organic debris that was transported with the water on the meadows to be used as fertilizers the next spring. Further, it was used as a rodent and mole control agent. Autumn irrigation is also known in the area to be effective to reduce the poisonous autumn crocus (*Colchicum autumnale*) in the area. Today, the autumn irrigation is not practiced any more. The amount of debris and nutrients that is transported with the river water today is very low, thanks to the existence of treatment plants.

3. Ecological, economic, and socio-economic values of traditional meadow irrigation

In our research project, the potential value of the traditional meadow irrigation in the Queich valley for species conservation and biodiversity, for the farmers' income, and for the recreational and touristic value were studied. The ecological value was mainly studied by comparing irrigated and nonirrigated meadows. All studied meadows were selected along a fertilization gradient from 0 to 80 kg N/ha per year. The following parameters were measured:

- Plant diversity and vegetation composition
- Diversity and species composition of several animal groups (butterflies, carabids, grasshoppers, snails, and woodlice)
- The activity of soil fauna
- Soil nutrient status, organic substance, and water retention capacity
- The quality and nutrient supply with the irrigation water
- The biomass (hay) production from two cuts over a period of 2 years
- Hay quality
- Additional income of the farmers based on the traditional meadow irrigation.
- Vegetation composition in ditches compared to other edge structures and the quality of differently managed forms of ditches
- The attractiveness for visitors of the area

Vegetation composition as well as plant diversity is clearly influenced by irrigation [16, 17]. The effect varies from year to year, but there seems to be rather an increase in plant species diversity than a decrease [16]. Mineral nitrogen fertilization, in contrast, turned out to be clearly negative on species richness though the nitrogen input of the studied meadows was low to moderate with up to 80 kg N/ha per year. This is especially relevant, as **biomass production** increased on average by about one-third under irrigation, while only half of this effect was measured for the influence of fertilization [18]. This demonstrates that an increase in biomass production does not necessarily lead to plant species loss. This well-known effect of fertilization induced biomass increase [4] does not necessarily occur if biomass is increased due to traditional meadow irrigation. Species composition is changing under irrigation allowing more space for herbs growing in low zones near the ground. Especially, semi-rosette and rosette plants increased under irrigation as did legumes [17]. The impact of the ratio of the cover of grasses to herbs is not consistent between the datasets. While in earlier datasets, grasses seemed to be reduced under irrigation [17], later analyses showed the contrary trend. However, the effect to increase grasscover in contrast to herbs is in both datasets higher under fertilization than under irrigation.

It is difficult to explain the positive effect on productivity as probably a large number of effects sum up and interact. Interestingly, the water retention capacity of soils of irrigated meadows was higher (marginally significant) than of nonirrigated meadows, while fertilization had a significantly negative effect on the water retention (**Figure 4**). The same pattern (positive irrigation effects and negative fertilization effects) is found regarding the water content after field sampling determined gravimetrically several weeks after spring irrigation (**Figure 4**). A linear model including irrigation as a fixed factor and amount of N fertilization in kg N/ha as a covariate gives the following results: water retention capacity [% vol.] (irrigation $p = 0.063$; N fertilization $p = 0.046$) and water content of the field samples in late spring (irrigation $p < 0.001$; N fertilization $p = 0.093$). The capacity to store water from precipitation in times without irrigation is therefore higher. As humidity in soils (not stagnant conditions) lead to high microbial activity and activity of other soil organisms [18], this may explain a continuous supply with nutrients on the water meadows in contrast to the other meadows which temporarily suffer from drought. Measured nutrients showed no significant pattern as the diversity of soil conditions overlaid the pattern we expect to be induced by the management. Fertilization did show a negative effect on soil fauna activity in spring but not during autumn sampling [18]. Nutrient supply of nitrogen and phosphorus with the irrigation water is probably insignificant, as analyses of the water suggest low nutrient input with the irrigation water (**Table 1**). While nitrate, nitrite, ammonium, and phosphate inputs are very low, the input of some minerals especially boron, magnesium, and chloride are high. They seem to have their origin in the sewage water from several treatment plants along the river as analyses of the outflow of two treatment plants in the area suggest (**Table 1**, bottom lines). As a consequence, soils of irrigated meadows had significantly elevated values of magnesium (positive irrigation effect $p = 0.013$) and boron (positive irrigation effect $p = 0.019$; negative fertilization effects 0.053; **Figure 5**). Chloride in the soils was not measured. Irrigation water pH was high (**Table 1**) and may contributed to decrease acidification processes. Soil pH, however, was not significantly increased under irrigation but stabilized. Variance of soil pH between nonirrigated meadows was clearly higher in contrast to irrigated meadows.

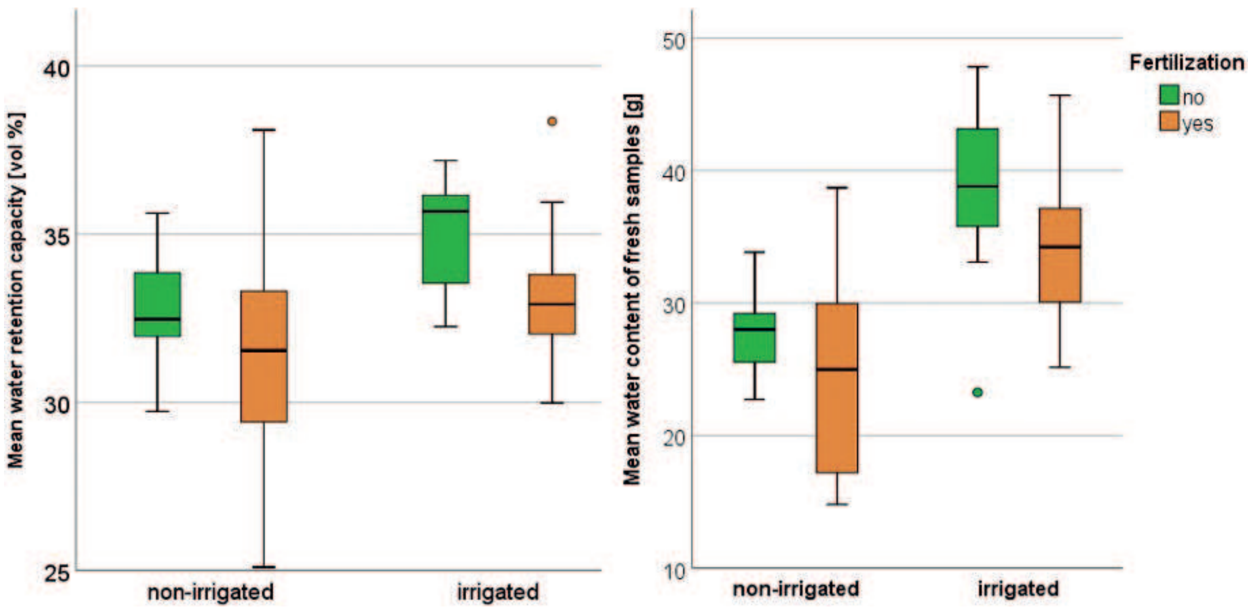

Figure 4. Water retention capacity and water content after field sampling in the month of May.

Day	Site	EC	pH	T	Cl	NO_3	PO_4	SO_4	Na	NH_4	K	Ca	Mg	Al	B	Cu	Fe	Mn	Pb	Zn
18-Apr	OB 1	328	8.0	10.8	26.9	5.1	0.0	23.1	17.7	0.0	3.7	30.9	7.7	3.6	47.9	1.2	4.5	40.0	0.5	3.6
18-Apr	OB 2	330	8.0	9.7	19.8	3.7	0.0	17.3	12.4	0.0	2.7	24.9	6.1	4.0	41.5	2.1	4.8	30.3	1.3	3.1
20-Apr	OB 3	358	8.2	8.8	18.9	3.6	0.0	21.0	13.4	0.0	2.7	28.1	6.3	3.6	45.5	0.8	5.5	25.3	1.7	3.2
28-Apr	OH 1	400	8.1	11.4	31.8	7.2	0.0	41.8	26.3	0.0	5.8	36.0	7.6	3.7	43.0	1.2	3.7	36.3	0.0	4.4
2-May	OH 2	442	7.8	12.2	30.9	2.7	0.0	32.1	23.4	0.0	6.2	25.5	6.0	4.1	50.9	1.5	11.6	6.9	0.5	5.0
4-May	KH 1	445	7.7	12.5	40.5	5.4	0.0	46.8	34.5	0.9	8.5	43.1	9.8	4.9	72.0	0.9	9.3	7.8	0.0	7.1
4-May	KH 2	443	7.8	12.9	42.0	5.6	0.0	44.1	36.5	0.9	11.8	40.6	9.5	4.6	77.5	1.6	9.2	16.5	0.3	7.1
5-May	BH 1	500	7.8	15.5	43.8	5.7	1.0	60.4	45.2	0.9	13.5	31.3	9.2	4.3	73.8	1.6	11.2	37.6	0.0	4.3
5-May	BH 2	496	7.8	15.5	21.3	3.2	1.0	35.4	21.8	0.0	4.0	26.9	3.6	4.3	56.3	1.6	9.7	4.4	0.0	5.3
5-May	BH3	551	7.7	16.5	26.5	3.3	1.0	41.4	50.2	0.9	17.0	46.7	10.7	7.2	63.7	1.8	17.5	10.9	0.3	10.4
Mean		429	7.9	12.6	30.2	4.6	0.3	36.3	28.1	0.4	7.6	33.4	7.7	4.4	57.2	1.4	8.7	21.6	0.5	5.4
sd		75	0.2	2.6	9.3	1.5	0.5	13.3	13.0	0.5	5.0	7.8	2.2	1.1	13.6	0.4	4.2	13.9	0.6	2.3
Sewage plant 1		754	7.5	14	65	4.2	0.8	77	51	1.6	12	42	7.0	5.4	54	1.2	11	83	1.1	13
Sewage plant 2		1104	7.2	15	151	2.3	0.0	49	90	3.0	22	70	15.4	8.5	260	1.3	50	33	0.8	31

Table 1. Water chemical characteristics measured in irrigation ditches during irrigation in different areas during spring irrigation in 2017. Legend: EC (electric conductivity in µs/cm), T (temperature in °C), most nutrients are presented in mg/l irrigation water. Al, B, cu, Fe, Mn, Pb, and Zn are presented in µg/l. Nitrite was below detection limit and is not shown. The last lines show mean values measured in the outflows of two local sewage treatment plants in the area at four different points of time in spring 2017.

http://dx.doi.org/10.5772/intechopen.79429

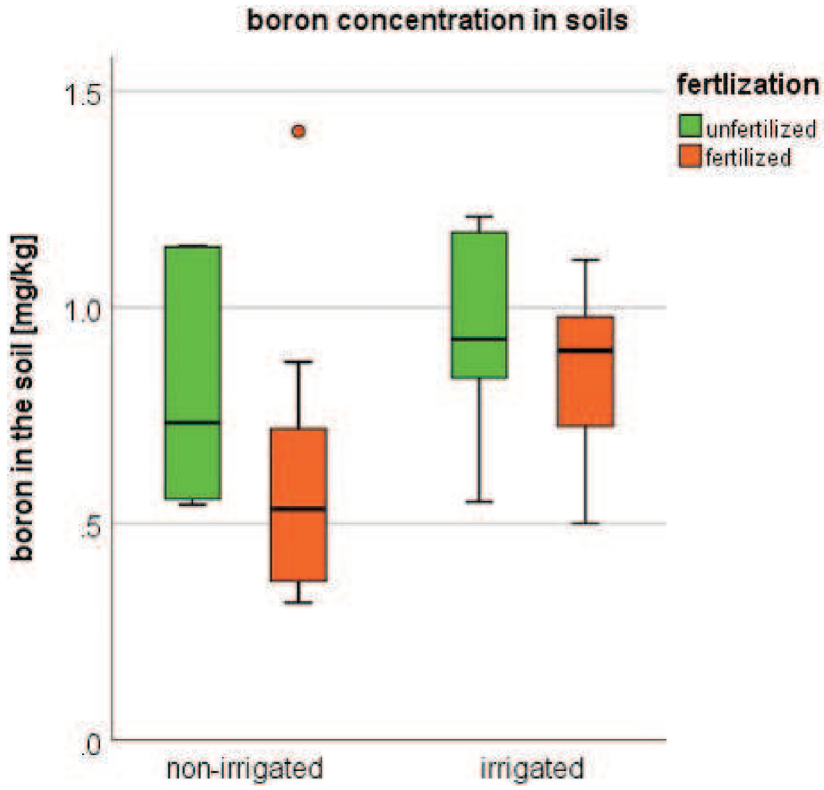

Figure 5. Boron concentration in soils in relation to irrigation and fertilization impact.

Nutrient input—especially of the micro-nutrient boron—may also contribute to the vegetation shift of irrigated meadows and to the conservation of species richness though biomass production is clearly enhanced [19]. For the micro-nutrient boron, there exists only a narrow window between deficiency and toxicity and different plant species groups and even genotypes within the same species tend to react differently to low or elevated boron values [20, 21]. Grasses tend to suffer from boron toxicity at lower concentrations as compared to several herbal species, especially legumes [20, 22], which could explain the observed vegetation shift [16, 17].

Hay quality does not differ significantly between irrigated and nonirrigated meadows [18]. The energy content of the hay produced on any of the meadows (irrigated and/or fertilized) would not be sufficient to serve as basic food for modern high productivity cattle. However, the food is perfect quality hay for horses or extensively raised cattle of older breeds. The quality mainly reflects the development phase of the vegetation when cut and is little affected by the management itself [18].

The elevated productivity lead to significant higher **income of the farmers** under traditional irrigation compared to farmers producing hay on nonirrigated meadows [18]. Astonishingly, the use of mineral fertilizers did not increase the income in a significant way. Nonirrigated and nonfertilized meadows did not draw any profits and their profitable management depended on governmental subsidies within agri-environmental schemes. Irrigation helped to improve the profit in most cases to reach a positive balance without the necessity to receive subsidies [18].

The hay in the region is primarily produced for horses which are very abundant in the rich outskirt of larger industrial areas. The economic analysis comprised a quantitative survey with farmers assessing their land-use practices as well as associated costs and revenues.

The **composition and diversity of the fauna** also responds to irrigation. Irrigation clearly changed invertebrate species assemblages of carabids, grasshoppers, and spiders toward more moisture-dependent species and probably increased overall diversity at the landscape scale [23]. Although irrigated meadows have a higher biomass than nonirrigated ones, effects of traditional meadow irrigation on species richness of invertebrates were generally weak and taxon-dependent. Irrigation had no significant effect on species richness of butterflies, carabids, spiders, and woodlice in lowland meadows [23, 24]. Effects on grasshoppers are not clear and differed among years and were either neutral [23] or slightly negative [24]. However, irrigation turned out to be important for species of conservation concern. The number of endangered carabid species and individuals was two to three times higher in irrigated meadows than in nonirrigated ones. Moreover, irrigation increased flower richness of the meadows [18], which in turn favored the occurrence of endangered butterfly species [18]. Thus, irrigation can have indirect positive effects on invertebrates via the provision of important resources. In contrast to irrigation, only weak effects of fertilization were found on invertebrate diversity [23]. However, functional diversity of grasshoppers was strongly negatively affected by fertilization [24]. Thereby, even relatively moderate fertilizer inputs (in our study system up to 80 kg N/ha per year) reduced functional diversity of grasshoppers, while this effect was not obvious when solely considering species richness. Moreover, increasing fertilizer applications reduced the number of specialized butterflies, while generalists were not affected [18]. To conclude, traditional meadow irrigation is compatible with invertebrate biodiversity conservation in European grasslands.

Next to measures at the single meadow or patch scale, traditional meadow irrigation should also be evaluated concerning its effect on the landscape scale as **species diversity of the landscape** is mainly influenced by the heterogeneity of different habitats in the area and not just by the richness of a single meadow. This became obvious observing species of snails in ditches and on the meadows themselves. While the species richness and composition at the meadows is low with about 7 species per m^2, the species and individual numbers increased to on average over 15 species in ditches with maximum values of over 20. Here, the snails profited from the high heterogeneity of site conditions in the ditches with dry and sunny as well as humid or even wet sites in the ditches and similar heterogeneity of organic debris and nutrients that were clearly higher in irrigation ditches as compared to drainage ditches. Even two red list aquatic snail species could be regularly found in the irrigation ditches. They survive in local puddles that remain wet most of the year [18].

Several organisms are mobile and cannot be studied at single meadows. This is the case with white storks. Their population development since the reactivation of major parts of the meadows is very well documented [25]. The white storks profit from the irrigation, as they find plenty of food during spring, when the juveniles need plenty of food close to their nests (**Figure 3**), and in late summer, when storks prepare to fly south. Many storks raised in the area of meadow irrigation emigrate to other regions in previous years, which shows that the donor effects [25]. Other bird species might decrease as their nesting sites are flooded. However, as there are several areas and patches that are not irrigated, the diversity is obviously not decreasing as bird observations in the area demonstrate [15].

Similar to the snails, the vegetation composition along **ditches** was heterogeneous and species rich [26]. Overall plant diversity in the ditches contributed one-third of the total species pool. This means that about one-third of all the species found in the sampled quadrats were found in ditches only. Many species of herbs typically found in extensively used grasslands seemed to use the rims of the ditches as refuges from the semi-intensively used meadows and were common here, while sometimes only sparsely found in the meadows themselves (**Figure 6**) [26]. Locally, species preferring wet habitat increase overall richness (**Figure 7**). The quality of the ditches for plant diversity varied according to ditch size, sedimentation, and successional stage. The larger and deep trapezoid well maintained ditches had highest richness in contrast to smaller and strongly overgrown and silted up ditches [26]. However, the large variety of differently maintained ditches finally made up the very high overall diversity found in the landscape. This is the result of the diverse management techniques and frequencies used by the different communities concerned. Commonly, the ditches are mown or mulched once a year (usually in late winter) and maintained with excavators once every two to more than every 10 years depending on the community and ditch location [26].

The **touristic and recreational value** was assessed by conducting a travel cost analysis with visitors of the meadows in the Queich valley. The touristic and recreational value was estimated to be between 0.38€ and 2.54€ per visit depending on whether the opportunity costs of time were taken into account or not. Since most of the visitors were from the direct vicinity of

Figure 6. Drainage ditch with the defined area for a vegetation analyses (blue line). Ditches play an important role in overall biodiversity as they provide various different niches and serve as refuge for sensible plants and animals which escape from more intensive meadow management techniques. The corresponding data is published in [26] (photo: Melanie Meier).

Figure 7. Irrigation ditch after first cut in June. Remaining standing water from the last irrigation in may serves as a habitat and food source for a large variety of organisms. It clearly contributes to the heterogeneity of the landscape (photo: Melanie Meier).

the meadows, most people did not incur real financial costs to visit the meadows. About 20% of the visitors use the meadows more than 100 times per year for recreational purposes. The main activities in the meadows are cycling, walking, watching nature, and excursions with children. More than 60% of the visitors state that they would have stayed at home if they had not had the chance to go to the meadows on the day they were interviewed. This shows the substantial value of the meadows for the local population. However, more than 40% of the visitors traveled more than 20 minutes, 15% even more than 1 h to visit the meadows. About 3% of the visitors stayed overnight in the area and came to visit the meadows mainly to watch the gathering of the white stork population in spring and early autumn. Next to the storks, the beauty of the semi-open landscape as such, the diversity and the traditional irrigation infrastructure are mentioned to attract the visitors (**Figure 8**).

Apart from these mentioned socio-economic values, the value of the **cultural heritage** can be considered to be substantial. In a two-volume book, Leibundgut and Vonderstrass [9]

http://dx.doi.org/10.5772/intechopen.79429

Figure 8. Beautiful landscape with high recreational and touristic value. The high numbers of storks also attract visitors. The active traditional irrigation system also contributes to our cultural heritage (photo: Martin Alt).

described the role and the extension of meadow irrigation in Europe. On the European level, a group of actors from Switzerland, Germany, Belgium, Austria, the Netherlands, Sweden, Great Britain, and France is currently working on an application of irrigated meadows as UNESCO world heritage sites. This shows the importance of those irrigated meadows still have in some regions. Obviously, meadow irrigation systems are popular and bear witness to a century long innovation and tradition. On the other hand, the once widely spread meadow irrigation systems are now found only very locally. In the area of the Queich valley, the local interest group Queichwiesen comprised of a very diverse group of actors like representatives of local administration, environmental NGOs, and farmers jointly pursues the acknowledgement of the irrigation meadows in the world heritage list.

4. Conclusions

Traditional meadow irrigation proved to increase productivity in a very effective and more sustainable way than mineral fertilization did. Summarizing our manifold data on flora, fauna, and soil characteristics, the management method creates multifunctional habitats and production sites. They offer multiple ecosystem services of all four categories defined in the Millennium Ecosystem Assessment report by the UN: supporting, provisioning, regulation as well as cultural services [27]. We explain this by the positive effect of this management practice on soil carbon or humus [28] and the related positive effect on soil organisms [29]. Next to the multiple services for productivity and biodiversity found at the single meadows, there are larger scale services provided at the landscape scale. The heterogeneity of the irrigation, the variety of habitats that are created by the ditches (irrigation and drainage), and the mixture with other habitats in the region provide a beautiful landscape for animal life and human well-being (recreation and tourism).

Acknowledgements

We thank the DBU (German Environmental Foundation) for funding of the WasserWiesenWerte project as well as the Federal State of Rhineland-Palatinate, Ministry of Science (MBWWK) for the funding of activities within the framework of "AufLand" research initiative. For their contributions in data acquisition, we thank various students of the University Koblenz-Landau. Further, we thank the communities, the Landschaftspflegeverband Südpfalz as well as many of their farmers for their valuable cooperation.

Conflict of interest

We declare that there are no conflicts of interest.

Author details

Constanze Buhk[1]*, Jens Schirmel[2], Gerlach Rebekka[3] and Oliver Frör[4]

*Address all correspondence to: buhk@uni-landau.de

1 Institute for Environmental Sciences, Geoecology and Physical Geography, University of Koblenz-Landau, Landau, Germany

2 Institute for Environmental Sciences, Ecosystem Analyses, University of Koblenz-Landau, Landau, Germany

3 Institute for Environmental Sciences, Geoecology and Physical Geography/Environmental Economics, Germany

4 Institute for Environmental Sciences, Environmental Economics, University of Koblenz-Landau, Landau, Germany

References

[1] Habel JC, Dengler J, Janišová M, Török P, Wellstein C, Wiezik M. European grassland ecosystems: Threatened hotspots of biodiversity. Biodiversity and Conservation. 2013;**22**:2131-2138

[2] Henle K, Alard D, Clitherow J, Cobb P, Firbank L, Kull T, McCracken D, Moritz RFA, Niemelä J, Rebane M, Wascher D, Watt A, Young J. Identifying and managing the conflicts between agriculture and biodiversity conservation in Europe–a review. Agriculture, Ecosystems and Environment. 2008;**124**:60-71. DOI: 10.1016/j.agee.2007.09.005

[3] Wesche K, Krause B, Culmsee H, Leuschner C. Fifty years of change in central European grassland vegetation: Large losses in species richness and animal-pollinated plants. Biological Conservation. 2012;**150**:76-85. DOI: 10.1016/j.biocon.2012.02.015

[4] Zechmeister HG, Schmitzberger I, Steurer B, Peterseil J, Wrbka T. The influence of land-use practices and economics on plant species richness in meadows. Biological Conservation. 2003;**114**:165-177. DOI: 10.1016/S0006-3207(03)00020-X

[5] Isselstein J, Jeangros B, Pavlu V. Agronomic aspects of biodiversity targeted management of temperate grasslands in Europe-a review. Agronomy Research. 2005;**3**:139-151

[6] Convention on Biological Diversity. Decision Adopted by the Conference of the Parties to the Convention of Biological Diversity at its Tenth Meeting [Internet]. 2010

[7] Tscharntke T, Tylianakis JM, Rand TA, Didham RK, Fahrig L, Batáry P, Bengtsson J, Clough Y, Crist TO, Dormann CF, Ewers RM, Fründ J, Holt RD, Holzschuh A, Klein AM, Kleijn D, Kremen C, Landis DA, Laurance W, Lindenmayer D, Scherber C, Sodhi N, Steffan-Dewenter I, Thies C, van der Putten WH, Westphal C. Landscape moderation of biodiversity patterns and processes - eight hypotheses. Biological Reviews. 2012;**87**: 661-685. DOI: 10.1111/j.1469-185X.2011.00216.x

[8] Leibundgut C, Kohn I. European traditional irrigation in transition part I: Irrigation in times past - a historic land-use practice across Europe. Irrigation and Drainage. 2014;**63**:273-293. DOI: 10.1002/ird.1826

[9] Leibundgut C, Vonderstrass I. Traditionelle Bewässerung - ein Kulturerbe Europas. 1st ed. Langenthal: Merkur Druck; 2016

[10] Leibundgut C, Kohn I. European traditional irrigation in transition part II: Traditional irrigation in our time - decline, rediscovery and restoration perspectives. Irrigation and Drainage. 2014;**63**:294-314. DOI: 10.1002/ird.1825

[11] Ondrasek G, Rengel Z, Petosic D, Filipovic V. Land and water management strategies for the improvement of crop production. In: Parvaiz A, Saiema R, editors. Emerging Technologies and Management of Crop Stress Tolerance: A Sustainable Approach. Elsevier; 2014. pp. 291-313

[12] Guillet D. Rethinking irrigation efficiency: Chain irrigation in northwestern Spain. Human Ecology. 2006;**34**:305-329. DOI: 10.1007/s10745-006-9020-6

[13] Merot A, Wery J, Isbérie C, Charron F. Response of a plurispecific permanent grassland to border irrigation regulated by tensiometers. European Journal of Agronomy. 2008;**28**:8-18. DOI: 10.1016/j.eja.2007.04.004

[14] Fiedler K-H. Die Wiesenbewässerung im Saarland und in der Pfalz [Dissertation]. Saarbrücken: Universität des Saarlandes; 1965

[15] Keller P. Die Queichniederung – Portrait einer Landschaft. Mainz: Gnor; 2013

[16] Müller IB, Buhk C, Lange D, Entling MH, Schirmel J. Contrasting effects of irrigation and fertilization on plant diversity in hay meadows. Basic and Applied Ecology. 2016;**17**:576-585

[17] Müller IB, Buhk C, Alt M, Entling MH, Schirmel J. Plant functional shifts in central European grassland under traditional flood irrigation. Applied Vegetation Science. 2016;**19**:122-131

[18] Buhk C, Schirmel J, Frör O, Gerlach R. WasserWiesenWerte: Wiesenbewässerung - Eine produktive Bewirtschaftungsform mit hohem Wert für Mensch und Natur?: Final Report of DBU Project AZ 31109 [Internet]; 2017

[19] Steidinger B. Qualitative differences in tree species distributions along soil chemical gradients give clues to the mechanisms of specialization: Why boron may be the most important soil nutrient at Barro Colorado Island. The New Phytologist. 2015;**206**:895-899. DOI: 10.1111/nph.13298

[20] Gupta UC, Jame YW, Campbell CA, Leyshon AJ, Nicholaichuk W. Boron toxicity and deficiency: A review. Canadian Journal of Soil Science. 1985;**65**:381-409

[21] Reid RJ, Hayes JE, Post A, Stangoulis JCR, Graham RD. A critical analysis of the causes of boron toxicity in plants. Plant, Cell & Environment. 2004;**27**:1405-1414. DOI: 10.1111/j.1365-3040.2004.01243.x

[22] Marschner H, Marschner P, editors. Marschner's Mineral Nutrition of Higher Plants. 3rd ed. Amsterdam, Boston, MA: Academic Press; 2012

[23] Schirmel J, Alt M, Rudolph I, Entling MH. Effects of traditional flood irrigation on invertebrates in lowland meadows. PLoS One. 2014;**9**:e110854. DOI: 10.1371/journal.pone.0110854

[24] Schirmel J, Gerlach R, Buhk C. Disentangling the role of management, vegetation structure and plant quality for Orthoptera in lowland meadows. Insect Science. 2018: In Press. DOI: 10.1111/1744-7917.12528

[25] Dorner I, Tietze DT. Die Wiederansiedlung des Weißstorchs Ciconia ciconia in Rheinland-Pfalz. Vogelwarte. 2015;**53**:99-110

[26] Meier M, Gerlach R, Schirmel J, Buhk C. Plant diversity in a water-meadow landscape: The role of irrigation ditches. Plant Ecology. 2017;**218**:971-981

[27] Assessment ME. Ecosystems and Human Well-Being: Synthesis [Internet]. 2005

[28] Banwart SA, Noellemeyer E, Milne E, editors. Soil Carbon: Science, Management and Policy for Multiple Benefits. CABI: Wallingford, Oxfordshire; 2015

[29] Wagg C, Bender SF, Widmer F, van der Heijden MGA. Soil biodiversity and soil community composition determine ecosystem multifunctionality. Proceedings of the National Academy of Sciences of the United States of America. 2014;**111**:5266-5270. DOI: 10.1073/pnas.1320054111