Kettle Holes

Subjects: Agriculture, Dairy & Animal Science
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Kettle holes are small water bodies of glacial origin which mostly occur in agricultural landscapes. While they supply numerous ecosystem services (ES), this supply may be negatively affected by agricultural management on surrounding fields.

Keywords: kettle hole ; small water bodies ; wetland ; ecosystem service ; CICES ; agricultural management ; sustainability

1. Introduction

Agricultural landscapes supply multiple ecosystem services (ES) through interacting land uses and geobiophysical settings. These services are defined as the contributions of ecosystem structure and function (in combination with other inputs) to human well-being [1]. Sustainable agricultural management needs to account for site-specific characteristics, including topographic factors and coexisting biotopes. In this regard, a particular challenge to sustainable management arises where fields include kettle holes. Kettle holes are pond-like, depressional wetlands in young moraine landscapes. The term ‘‘kettle holes’’ is preferably used in Europe [2], whereas ‘‘potholes’’ is a synonym used in North America [3]. Kettle holes evolved from topographic depressions formed by delayed melting of remnant ice blocks during the ice retreat after the Pleistocene ~10,000–12,000 years ago [3][4]. Older glaciations created similar depressions, but most were lost as a result of bank erosion and sedimentation. Kettle holes typically range in size from 0.01 to 3 ha. Most undergo severe wet–dry cycles and some have ephemeral water bodies [5].

Kettle holes fulfill important hydrological and ecological functions [6]. Their storage capacity influences a landscape’s water retention function and the moisture they provide through evapotranspiration affects local microclimate [7]. They serve as a refuge for endangered species and comprise habitats that promote biodiversity (e.g., [8][9]). Due to their small size and the usually high number of kettle holes in a region, they offer interesting opportunities for ecological research and modeling. In North America, kettle holes represent one of the largest and hydrologically most diverse populations of inland wetlands [10].

Kettle holes are mostly situated in agricultural landscapes. They are often affected by agricultural management and in turn affect the fields surrounding them. The presence of kettle holes in a field may cause conflicts between nature conservation and farmers’ economic interests [5]. Intensive agricultural management may cause structural degradation in kettle holes, eutrophication, pollution by plant-protection products, or direct habitat destruction [11][12][13]. This may also impair the ecosystem functions and services supplied by kettle holes [14][15][16]. Furthermore, due to soil erosion, many kettle holes are increasingly filled with sediment originating from adjacent fields [17]. This threat is exacerbated by climate change which in many locations increases the probability of high intensity rainfall events and thereby the extent of soil erosion. The projected rise in global mean temperatures [18][19] until the end of the century is also likely to contribute to increased rates of evapotranspiration in many regions, resulting in an increasing rate of kettle holes permanently drying up. Both agricultural management and climate change may impair the ecosystem services supplied by kettle holes [14][15][16].

2. Ecosystem Services Supplied by Kettle Holes

In this part, we address the ecosystem services supplied by kettle holes in agricultural landscapes.

2.1. Hydrological Cycle and Flood Control (CICES Code 2.2.1.3)

Service: The wet–dry cycle characteristic for kettle holes is central for their ability to regulate water flows. Their ability to store additional water provides a valuable flood protection service. The water budget of a kettle hole is determined by winter and early spring inputs. These are primarily driven by snowmelt and runoff over partially frozen soils, direct precipitation and seasonal lateral flows [7][20][21]. Kettle holes with very small catchment areas maintain their water level only by rainfall [22]. Water losses occur through evapotranspiration, spillover and lateral shallow groundwater recharge [20][23]. The water level of kettle holes responds to extremely wet or extremely dry weather conditions [24][25][26]. While evaporation rates can be relatively high, for some kettle holes evaporation alone cannot explain their complete drying-out. Lateral groundwater flow to the wet margins of the water body is a dominant cause of water loss for kettle holes [7][27][28].

Linkages with agricultural management: Water level fluctuations in kettle holes depend on soil and crop management, as well as drainage practices, and mostly follow weather and vegetation cycles [7]. In North America, a significantly lower water table as well as a lower fluctuation of the water levels was detected in kettle holes within grassland landscapes compared to kettle holes within tilled agricultural landscapes [29][30]. Flooding of kettle holes may also lead to crop damages in bordering fields. However, in dry years, kettle holes can act as water suppliers for surrounding crops [31]. This is consistent with findings by Kanwar et al. [32] and Ahmad et al. [33] who found a negative effect on crop yields during wet years and a potential yield improvement during dry years.

2.2. Chemical Condition of Freshwaters (CICES Code 2.2.5.1)

Service: Individually, kettle holes may seem insignificant, but collectively they play an important role in improving water quality in agricultural catchments [34]. Natural vegetation around kettle holes acts as a buffer strip, filtering particles and chemical inputs from runoff, with a positive effect on water quality. Kettle holes are sometimes connected to groundwater. While their filtering effect may improve the water quality, they may also be polluted by contaminated groundwater streams [35] or speed up groundwater pollution if they themselves are polluted.

Linkages with agricultural management: Given the intensification of agriculture, documented eutrophication of kettle holes is not surprising [36][37]. Water quality of kettle holes may be degraded as the result of waterborne or windborne sediment inputs [38], although maintenance of vegetation buffer strips may mitigate some impacts [39]. As some crops leave the soil more prone to erosion, e.g., tuber crops or crops planted in wider rows, and some crops are typically managed with higher amounts of pesticides and fertilizers than others, the choice of crop rotation affects water quality in kettle holes. Adapted management of agricultural fields around kettle holes is necessary to improve water quality. Regular monitoring of the water quality in kettle holes is desirable.

2.3. Nursery Populations and Habitats (CICES Code 2.2.2.3)

Service: This service also includes the protection of gene pools. Habitats for plants provided by kettle holes are often characterized by changing water levels. For instance, low water levels and occasional drying up (dry marsh phase) stimulate plant recruitment from diverse seed banks and increase productivity by mobilizing nutrients. In contrast, high water levels during deluges (lake marsh phase) cause turnover in plant populations, creating greater interspersion of emergent cover and open water, but lower overall productivity [40]. Like all temporary ponds, kettle holes are well known for their richness of annual plant species and often harbor numerous rare and endangered species [41][42]. For example, a study surveying 46 small kettle holes in Germany found 254 plant species, including 21 on the federal state's red list [43][44]. Besides supporting high plant diversity, kettle holes constitute a source of food and water for wild animals such as deer, wild boars, bats and migratory birds [45][46][47][48]. They also provide refuge to many rodents [49]. Kettle holes may function as important stepping stone biotopes in agricultural landscapes. The loss of even small wetlands areas in the landscape may therefore have a strong detrimental effect on biodiversity [50]. While enabling genetic exchange and preventing habitat fragmentation generally contributes to preserving species and gene pools, it may, under very specific circumstances, also have negative implications by facilitating the spread of diseases or invasive species [51].

Linkages with agricultural management: Negative effects of crop management on farmland biodiversity due to artificial drainage, tillage (e.g., increased turbidity and destruction of invertebrate eggs) [52] and high applications of pesticides and fertilizers are well documented [53][54]. Farmland intensification has led to a severe decline in the diversity of plant species [13] and amphibians [15] found around kettle holes. Balancing the interests of biodiversity conservation with agricultural production is important [55][56]. Therefore, Savoie et al. [57] suggest the harvest and energetic use of woody vegetation (shrubs and willows) around kettle holes as a solution. Biomass could be harvested on a 4–5-year cycle. Savoie et al. [57] state that beyond the generation of renewable energy, wood waste could contribute to moisture retention, soil nutrient cycling and the creation of habitat for wildlife, while biomass removal would contribute to reducing nutrient levels, thereby mitigating eutrophication.

2.4. Pollination (CICES Code 2.2.2.1)

Service: Research done by Vickruck et al. [58] demonstrates that small in-field wetland remnants, such as kettle holes, play an important role in supporting native pollinator communities in intensive agricultural landscapes. They are important nesting and foraging resources and support a highly diverse community of native bees [58]. Pollination services provided by wild bee species are crucial to the economy and food security of human populations, as well as playing a pivotal role in maintaining global biodiversity [59][60][61]. However, only one of the papers identified in our literature review addresses the value of kettle holes for pollinator communities. More research is desirable.

Linkages with agricultural management: Pollinator declines have been linked to multiple factors, including pesticides [62], parasites [63], climate change [64][65] and habitat loss [66], of which habitat loss is considered the most pervasive [63][67][68]. Reducing the application of pesticides in the direct vicinity of kettle holes and maintaining herbaceous buffer strips is likely to improve the suitability of kettle holes as habitats for pollinators.

2.5. Chemical Composition of Atmosphere and Oceans (CICES Code 2.2.6.1)

There is disagreement considering the role of kettle holes for climate change mitigation. Withey and van Kooten [69] highlight their potential to store methane and carbon dioxide. Organic carbon sequestration per unit area of sediment has been suggested to be at least an order of magnitude higher in small lakes (including kettle holes) than in larger lakes [70][71][72]. However, while kettle holes are prone to organic matter burial [73][74], dry–wet cycles help to counter silting up [75] as buried material is mineralized again during dry phases [76]. Consequently, Philips and Beeri [77], Gleason et al. [78], Pennock et al. [79], Brinson and Eckles [80] and Tangen et al. [81] indicate that kettle holes are net producers of greenhouse gases (GHG). The net effect of GHG production and mitigation by kettle holes strongly depends on wet–dry cycles and will therefore vary between kettle holes of different hydrological regimes.

Linkages with agricultural management: None of the reviewed articles addressed the influence of agriculture management on GHG production or mitigation by kettle holes. However, as management affects water levels and wet–dry cycles of kettles holes through land cover and potentially artificial drainage, it is likely to also affect their GHG balance.

2.6. Biotic Remediation of Wastes (CICES Code 2.1.1.1)

Service: This service is strongly correlated with the service *Regulation of the chemical condition of freshwaters by living processes* (CICES code 2.2.5.1). Kettle holes play an active role in nutrient cycling [82][83][84]. They use excess nutrients from fertilization of surrounding fields for biomass production. Other pollutants may be broken up by microorganisms living in the kettle holes. While nutrients and other pollutants may also be fixed within the sediment layer, this effect is of only minor importance where kettle holes fall dry for extended periods of time, strongly reducing the amount of sediment.

Linkages with agricultural management: Kettle holes are sinks for nutrients and contaminants from agricultural fields. While they may help to remediate organic wastes, their ability to do so depends on a healthy ecosystem. Management on the fields surrounding kettle holes should seek to minimize erosion, as well as fertilizer and pesticide inputs.

2.7. Local Regulation of Air Temperature and Humidity (CICES Code 2.2.6.2)

Service: As small water bodies, kettle holes increase the humidity in their direct vicinity while the vegetation around them may lower wind speeds [7][85].

Linkages with agricultural management: The colder and moister microclimate around kettle holes may help to mitigate drought effects in surrounding crop areas. However, it is also considered to be conducive to the growth of pathogenic fungi [86]. More research about the extent of services or disservices is desirable.

2.8. Aesthetics from Interactions with Nature (CICES Code 3.1.2.4)

Service: Kettle holes may increase the variability of otherwise monotonous agricultural landscapes and have a positive influence on landscape aesthetics. This service is only mentioned by Lipp [85], who considered it to contribute to the recreation potential of kettle holes.

Linkages with agricultural management: Linkages with agricultural management were not discussed in Lipp [85]. However, aesthetic perception of wetland areas is linked to visual attributes, such as transparency and color of water, as well as presence and appearance of aquatic vegetation [87]. Clear waters are generally preferred [88][89]. High nutrient inputs due to fertilizer application in surrounding fields may therefore lower the supply of this service while buffer strips with visually appealing vegetation may increase it.

3. Conclusions and Recommendations

Water regime, water quality and habitat function of kettle holes can be highly impaired by intensive agricultural management in fields surrounding kettle holes if these practices cause erosion or include high levels of fertilizer and pesticide application. A loss of kettle holes and of the ecosystem services they supply could impact the regulation of water flows in agricultural landscapes and lead to a loss of habitats and biodiversity, including those of endangered amphibian species.

Kettle holes need to be addressed more precisely in policy documents and conservation programs. Policies are required to encourage farmers to better adapt their management in the areas surrounding kettle holes in order to improve kettle hole protection. As farmers can profit only in a very limited way from the ecosystem services supplied by kettle holes, subsidies may provide an important means for balancing economic and environmental considerations.

Providing society and policy makers with information about the ecosystem services supplied by kettle holes and about the threats to this supply contributes to informed decision making and sustainable management. This will also require more field data. More effective monitoring of kettle holes will be of critical importance with regard to understanding and predicting responses of kettle holes to different types of agricultural management, to raise awareness for kettle hole threats, enable enforcement of policies and ensure compliance with conservation requirements.

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