The Beauty and Ecosystem Functions of Small Shallow Waters: A Narrative Systematic Review on Agricultural Drainage Ditches.

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Layman summary

Over many decades, the number of plant and animal species has gone down. One of the reasons for this is the growing use of land for producing food, wood, and other natural products. Farmers also use chemicals that cause harm to plants and animals. In areas with a lot of farming, drainage ditches are common and help in managing water. However, these ditches can potentially be home to many plants and animals. Next to this, they might even be able to reduce the harm form chemicals used in farming. This review looks at these possibilities for ditches in the European union. After searching scientific databases, 98 scientific papers were chosen.

The results show that ditches can indeed be home to many plants and animals, including rare ones. However, the number of species does not reflect a range very different species. There is a real possibility that the species in ditches are all similar. Because of this, the number of different types of work that these species offer their surrounding can still be low. Managing ditches to create differences in the landscape can help avoid this.

It was also found that ditches with plants growing in them can help reduce harm for farming activities. Plants and soils can stop chemicals from spreading to other areas or even destroy them. This can help stop these chemicals from reaching other places and doing harm there. Designing ditches with low slopes and healthy vegetation growing in and near the ditches can be a solution to increase plants and animals and decrease chemical harm. Maintaining ditches to reach this goal is important. Mowing part of the ditch and every now and then removing the soil from the ditch helps to keep them effective. Now it's important to find out how factors such as temperature, climate, and timing of maintenance make a difference. With that knowledge, we can manage ditches the best way possible to increase the number of species and reduce harm from farming activities.

Abstract

Growing agricultural land use and use of agrochemicals have led to pressure on ecosystems and are among the causes for the decline in biodiversity. In agriculturally dominated landscapes, ditches provide interesting opportunities for enhancing biodiversity and mitigating detrimental effects of agricultural practises. This review aimed to qualitatively explore the value of ditches for 1) biodiversity and 2) mitigating agricultural pollution. A systematic search was performed using the Pubmed, Web of Science and SpringerLink databases for primary papers published in the last 25 years and conducted in the EU. 98 eligible papers were identified, and a thematic saturation approach was chosen for this review. Ditches were found to have the capacity to enhance biodiversity by cumulatively harbouring many species, including rare and endangered ones. That said, homogenisation and loss of functional diversity were identified risks. Maintaining heterogeneity and creating microhabitats though management is important for maintaining ecological value. On top of this, ditches were also found to have valuable nutrient and pesticide retention capacity. This capacity is driven by denitrification, plant uptake, microbial degradation, sorption to soil, and trapping sediment. Vegetation and buffer zones were found contribute to trapping sediment, increase retention time and sorption surface thus enhancing retention efficiency. Additionally, availability of organic matter was also found to increase sorption of hydrophobic pesticides and affect microbial functionality. Designing ditches with low slopes, vegetation in ditch beds and buffer zones can help achieve the dual purpose of enhancing biodiversity and mitigating agricultural pollution. Maintenance strategies of ditches were shown to be able to both positively and negatively affect biodiversity. Mainly breaking dominance of nitrophytes and creating heterogeneity in microhabitats were beneficial. With careful planning, maintenance strategies can be designed to maximise both outcomes. Variables such a soil climatic factors, soil properties and ditch design need to be understood to allow for adequate interpretation of these values and correctly designing strategies.

1. Introduction

Biodiversity

Biodiversity entails all natural ecosystems and the organisms within them, on this planet. From single-celled organisms and fungi, to insects and mammals, the tree of life represents beauty in countless shapes, colours, sizes, and functions. Many of these ecosystem functions are indispensable, such as pollination, energy cycling, and climate regulation. Besides vital ecosystem functions, biodiversity also holds intrinsic worth, offering aesthetic beauty that enriches our daily lives. Preserving biodiversity is essential to maintain resilient natural systems, their ecosystem functions, and their inherent worth.[1]

Agriculture

Agriculture is one of the most crucial industries in the world, producing food for billions of people[2]. The modern approach to agriculture involves technologies such as highly advanced machinery and synthetic agrochemicals. However, older traditional practises such as irrigation and drainage are also still used. The Netherlands, like any flood plain area in the world, is famous for its water richness. The Netherlands also has over half of its surface area dedicated to agricultural activities[3]. With the land being both rich in water and agriculture, ditches are a major element of the landscape. Ditches are created by human (so artificial watersheds) that allow for water removal, contributing to agricultural efficiency by improving timing of farming operations, changing water and nutrient regimes, and changing landscape structure[4]. However, these networks are also a major cause off the dissemination of excess nutrients and chemicals used in agriculture, thereby contributing to the pollution of downstream aquatic and terrestrial ecosystems[5].

Biology of Drainage Ditches

Ditches have long been thought crucial in supporting biodiversity. Ditches are potentially biodiverse habitats that provide refuge to native species in an otherwise unnatural landscape, which might otherwise be displaced[4, 6]. These aquatic habitats also serve as conduits of energy transfer, linking aquatic systems with adjacent terrestrial ecosystems. That water and land are nearby and connected makes that the soil is extremely vital and ready for many different plant growths (cultured and natural). By retaining water and supporting diverse life forms, ditches provide essential ecological functions, particularly in landscapes heavily modified by human activity. On top of this, vegetated or ecological ditches with high levels of biodiversity have been researched for their potential to mitigate pollution caused by agricultural practises. Vegetated ditch ecosystems provide self-purifying capacity, contributing to water quality and ecosystem health. Denitrification, sediment retention, microbial degradation of nutrients and harmful chemicals, and uptake of minerals and metals are all proposed pathways via which ditches might reduce pollution from agricultural practises.[7]

Ensuring the ecological integrity of ditches, therefore, benefits both natural systems and human populations. Proactive management and conservation efforts can sustain their multifunctional roles in human-dominated landscapes.

Conflicts

It is a fact that in our country we have steered on increased efficiency of the agricultural industry, and this often conflicts with conservation goals. Agriculture is also a key topic in the sustainable development goals for 2030 that the international community has subscribed to. The second goal "Ending world hunger" demands that we " double the agricultural productivity" by 2030 to solve world hunger[8]. However, the goal also specifies that "*resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality"*[9]. Together with goal fifteen, "*life on land"* demanding that we conserve and restore biodiversity[10], we have found ourselves in a spot where we carry the responsibility of combing food production with the conservation of terrestrial and freshwater biodiversity. Especially freshwater biodiversity is of urgent importance since a recent study found that a quarter of freshwater fauna is threatened with extinction[8].

There are multiple conflicts between agriculture and the conservation of biodiversity. An obvious one being land use change: increasing agricultural land at the cost of the natural environment. But there are also more complex conflicts. For instance, the use of pesticides to ensure good crop development and protect crops from pests[11] can have adverse effects on both animal[11, 12] and human health[12]. Especially the decrease in wild pollinators has been of much concern[13], both for the agricultural sector and conservation efforts. Another problem is the nitrogen cycle. By using animal manure or synthetic fertilisers, crops can be provided with much needed nutrients to grow, increasing the yield per surface area or allowing for crop production on non-fertile land[2]. However, excess nutrients can disrupt the natural balances of healthy soils and overload the nitrogen cycle[2]. This can lead to the loss of the natural vegetation on adjacent land and eutrophication in freshwater systems[14].

Opportunities

It is clear that ditches provide an interesting land-water nexus and can potentially balance agricultural and ecological interest. However, the potential value of biodiverse ditches is not fully known and has not been extensively reviewed. Even more, the EUS' Water Framework Directive[15] concerns itself only with waters with a width three meters across or more. Therefore, ditches generally fall outside of the scope of this directive, resulting in ditches not being mandatorily monitored[16]. In the Netherlands, for example, all rivers, 90% of water ways and canals, 70% of small flowing water, but only 0.5% of ditches are included in the directive[16]. This might very well be a missed opportunity since ditches can add up to cover astounding distances: In the Netherlands, ditches cover a total of 330.000 km, far exceeding the 6200 km of small flowing water (e.g. creeks & springs)[16].

In this review, the aim was to explore qualitatively the value of drainage ditches in agricultural landscape. This has been addressed by answering two research questions: 1) What is the value of ditches for biodiversity? 2) What value do vegetated or ecological ditches have in mitigating pollution in an agricultural landscape?

2. Methods

2.1 Systematic Search

For this systematic review, the scope was limited to the subject of agricultural open ditches or tile drainage in EU member states with a focus on either water quality or biodiversity. Water quality includes excess nutrients such as phosphorus, nitrogen, and organic carbon, among others. On top of this, chemical pollution was also included. On the topic of biodiversity, both the value of ditches for biodiversity as well as the value of biodiversity for the ditch/water quality were considered.

To obtain the papers to include in this review, a handful of papers were read to orient on the topic and produce adequate search terms. After the search terms, shown in table 1, were expanded to further prevent irrelevant hits, a search was be performed on November 12th, 2024, using the Pubmed, Web of Science and SpringerLink. Only peer-reviewed articles that were published were included in the search.

*Table 1. **The sets of terms used to the systematic search.** An '*' indicates that all words with that stem are included. This was done to include various words with one term, for instance plural and singular. The first set was limited to titles only. All other sets were applied to all fields.*

Set	Terms
1: Title	Ditch* OR Drainage*
AND	
2: All Fields	Value* OR Quali* OR Biodivers* OR Wildlife OR Conserv* OR Ecolog* OR Fauna OR Flora OR Biolog* OR Ecosystem* OR Natur* OR Service* OR Amphibian
NOT	
3: All Fields	Poach* OR Noise OR Light OR Salini* OR Salt* OR Seawater* OR Virus* OR Parasite* OR Fishing OR Fishery OR Urban* OR In Vitro
Year Published	
4	2000-2025
Language	
5	English OR Dutch

Sorting of the articles was carried out in Rayyan by a single reviewer in a three-step process. In the first step, only titles were screened. Papers with clearly different topics were excluded as well as retracted papers and comments. In the second step, titles and abstracts were screened further. The third step was resolving all articles labelled as 'maybe' by full text screening. Steps two and three were carried out based on predetermined inclusion criteria. Only primary articles published after January first, 2000, that were written in either English or Dutch were considered. All studies had to have been conducted in countries that fall under the Water Framework Directive[15] of the European Union. Studies using models or simulations such as micro- or mesocosms, numerical models or computer simulations were excluded. Studies conducted on other drainage structure as ditches or tile drainage such as, constructed wetlands, streams, ponds, lakes, and rivers were excluded. Lastly, only ditches in an agricultural setting were included. For this review, agriculture was defined to include crop production, orchards, and grasslands and pastures for livestock. Forestry, rice cultivation, water-meadows and indoor livestock keeping settings were excluded.

2.2 Data Extraction

For the data extraction, a thematic saturation[17] oriented approach was chosen. In this approach, the author reads the papers for new information and relationship for certain themes. When repetitive themes and relations are identified, saturation is reached.

3. Results

3.1 Descriptive Analyses of the Collected Literature

The searches in PubMed, Web of Science and SpringerLink yielded a total of 9297, 3893 and 187 results, respectively. After the search results were uploaded to Rayyan, duplicates were automatically detected and resolved by hand, resulting in 2886 papers being excluded. In total, 10,491 papers were left to be screened by a single reviewer. After screening of titles, 9243 papers were excluded. After that, twelve papers were excluded because they could not be retrieved. During screening of abstracts and full text screening, 1138 papers were excluded. 137 were excluded for not having the right scope. 707 papers were excluded because the study was conducted outside of an EU member state. 94 papers were excluded on the basis of simulation of model approaches. In 121 studies, ditches were not relevantly considered and therefore excluded. 48 studies were carried out in landscape different than an agricultural one. Lastly, 31 studies were excluded because they were reviews or meta-analyses. At the end, the total number of included papers was 98.

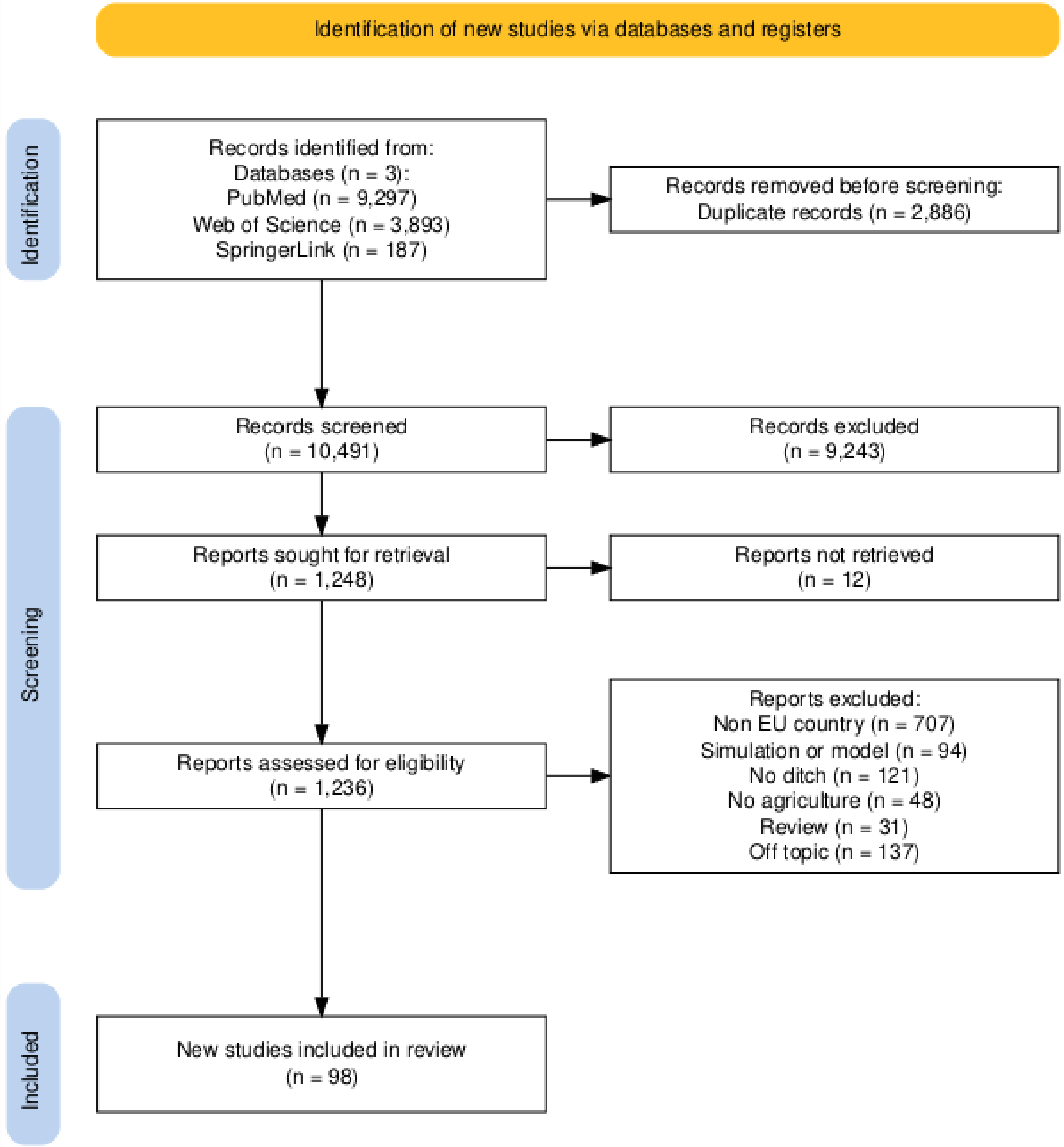

Figure 1. Prisma flowchart of the sorting process. *Over three databases, 9297, 3893 and 187 papers yielded by the search. After duplicate screening was performed, 2886 were excluded leaving 10491 papers to be screened. Based on screening titles, 9243 papers were excluded, after that 12 papers could not be retrieved and were also excluded. Of the final 1236 papers, 1138 papers excluded after reading the abstracts. Exclusion reasons were research not conducted in a EU member state, performed as a simulation or model, not concerning ditches or agriculture, generally being of topic or being a review. The final number of included studies was 98. The figure was made using an online PRISMA flow diagram tool*[18].

Of the 98 included studies, only eight focussed on tile drainage. All studies were published between 2000 and 2024, with the latter half of the 2010s representing the largest part, as can be seen in figure 2. Geographically, the studies covered a large part of the EU, with 21 countries being represented. Most studies were conducted in the Netherlands, with 36. Germany and Ireland are the second and third countries with the most studies, with eleven and eight, respectively. Seven studies were conducted in France and six studies were carried out in Italy. Multiple countries are represented with three studies having been conducted there, being the Czech Republic, Greece, Slovakia, Slovenia, and Sweden. Denmark, Finland, Hungary, and Switzerland all have two studies that have been carried out within their borders. The final countries are all represented by one study having been conducted there, those being Belgium, Estonia, Latvia, Lithuania, Poland, Romania, and Spain.

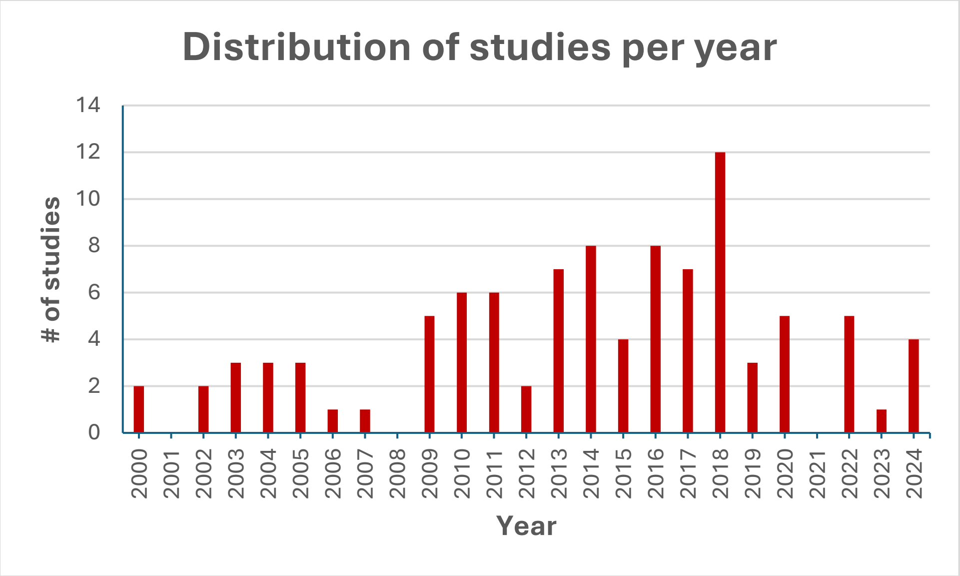

Figure 2. The distribution of the included studies per year.

3.2 The Ecological Value

Biodiversity was discussed by many papers, and from various perspectives. Diversity of insects and macroinvertebrates were assessed, as well as fish, amphibian, birds, and plants. For convenience, insects are separately discussed from other macroinvertebrates.

There was one study, conducted in the Dutch bulb area, which had its scope on macrofaunal β -diversity. They found that ditch communities became more dissimilar with increased sample intervals. The study showed that macrofaunal β -diversity had spatial and temporal variation. The effect was present up to seven months, after which samples remained equally dissimilar. Furthermore, β-diversity showed to be sensitive to agricultural disturbances with less disturbed ditches (e.g. dune ditches) in the same area showing higher median β -diversity.[19]

Insects

For insects, both ditch banks as well as the underwater habitats of ditches can potentially be important secondary habitats[20]. Here, five studies were included that assessed different insect groups in ditches. One study looked at the taxonomic and functional diversity of true bugs[20]. Another study focussed on larvae of caddisfly and dragonfly in relation to ditch management[21]. The third study assessed biodiversity on field margins and ditch banks and specifically discussed adult butterflies and dragonflies[22]. The fourth study assessed diversity of aquatic beetles[23] and the last study looked at orthopterans[24].

The study on true bugs was carried out in Hungary in 2018. They identified that sandy ditches had a more complex vegetation structure than surrounding agricultural lands. The authors identified this as a likely important driver of bug communities in these habitats. Furthermore, they found that saline grassland ditches provided a habitat for saline marshland bug communities. However, because of the generally low dispersal capabilities of these salt marsh species, their success in colonising suitable ditches is potentially limited. In line with this, they mention that generalist species associated with drainage ditches have high colonisation potential, which is contributed to the fact that these species have the capacity to cross open crop lands to find the isolated ditches. It is noted that a high prevalence of generalists, and replacement of specialists, can lead to taxonomic homogenisation and loss of functional diversity in bug communities. The authors conclude that habitat stress (e.g. salinity and aridity) and landscape matrix are the main factors contributing to conservation value of ditches. Greater distance between ditches and the nearest cropland lowers the pressure of invasive and ruderal species on the ditch habitat and invasively overgrown ditches only contribute to richness of habitat generalists and not to functional diversity.[20]

The study looking at caddisfly and dragonfly larvae found different effects of ditch management on the two groups. For caddisflies, ditch-scoop cleaning in September-October and mowing-basket cleaning in July to mid-September resulted in the highest chance of finding caddisfly larvae. The effect of water depth was found to follow an optimum curve, with the highest chance of caddisfly finding larvae between 60 and 80 cm. The number of years since dredging was also found to have a small effect. A lower chance of caddisfly larvae was observed for the first two years after dredging. Lastly, there was a negative linear association between the chance of finding caddisfly larvae and phosphorus supply on adjacent fields.[21]
For dragonfly larvae, no significant effect of timing or method of ditch cleaning was observed. Water depth did show a significant effect on the chance of finding larvae, with the highest chance being between 40 and 80 cm.[21]

The Dutch study assessing the butterfly and dragonfly species diversity in field margins recently established found that a significant number of transect showed higher species richness in the years after the start of the experiment. The author did state that nectar and caterpillar food source seemed more important for butterfly diversity than plant species diversity.[22]

The aquatic beetle diversity in agricultural ditches was assessed in a study conducted in the east German lowland area. There, it was found that almost a third of all know national aquatic beetle families were present in the ditches. This increased to 42% for known regional families. The ditches also harboured fifteen rare and three very rare species, showing that these anthropogenic habitats provide valuable surrogate habitats for aquatic beetles.[23]

The conservation value of ditch banks for Orthopterans in an agricultural environment was assessed in a Hungarian study. There were no significant differences in species richness between isolated ditch banks, semi-isolated ditch banks and control meadows, and even some species with high natural value were collected in ditches. This shows that ditch banks are valuable habitats for the majority or Orthopterans, including rare species. However, there were significant differences in abundance, suggesting that abundance is more affected than species richness. Especially the abundance of sedentary species was affected by extend of isolation, with sedentary species having lowest abundance in isolated banks. The study also showed that mobility traits prominently influenced abundance patterns, explaining why sedentary species are presumably unable to colonise isolated ditch banks. Lastly, the density of woody vegetation was shown to negatively impact the total abundance of Orthopterans.[24]

Macroinvertebrates

Eight studies on macroinvertebrates were read before reaching saturation. One study focussed on the effect of pesticides regimes on overall macroinvertebrates[25]. Three studies focussed on lentic[26-28], one on lotic[29] and one on benthic[30] macroinvertebrates. One study looked at Molluscan fauna[31]. The last study was concerned with biodiversity in field margins and ditch banks in general but specifically mentioned nematodes[22].

First, a Dutch experimental field study researched the effect of different spraying regimes (33, 67 and 100 of surface area sprayed) of a pesticide on the macroinvertebrate community. They found that all taxa except *Muscidea* had a treatment related decline, particularly in the sprayed sections. The effects were most pronounced between 37 and 44 days after application after which recovery of the community began. They noted that non-sprayed areas could provide refuge for species to avoid greater exposure, with increased distance to the directly sprayed areas and a lower proportion of sprayed surface area further decreasing treatment effects.[25]

Lentic macroinvertebrates

With ditches presenting the most extensive aquatic habits in agricultural land in northwest Europe, researchers in the Netherlands compared the taxonomic composition of lentic macroinvertebrate assemblages in ditches with those in small lakes. The lakes were fourteen times wider and slightly deeper but had comparable sapropellium layer thickness. The observed taxon richness of ditches was comparable to that of small lakes, as was the number of nationally uncommon or rare species supported in these habitats. However, the estimated 'true' taxon richness of ditches was higher than that of lakes. On top of that, the invertebrate assemblages in ditches were more diverse.[26]

In a different Dutch study, the effect of abiotic variability structures on invertebrate communities in agricultural ditches was researched. Drainage ditches of three different soil types were compared: Peat, sand, and clay. The sand soil ditches had the highest concentration of phosphates. The clay soil ditches showed the highest HCO_3 and calcium concentrations. Peat soil ditches had the highest concentrations of chloride, potassium, iron, and nitrogen whilst also having the lowest calcium and HCO_3 concentrations and water transparency. There was no effect observed for soil region on the cumulative number of species between the three types of ditches, were α-diversity was 25 or 26 species. The γ-diversity was higher, ranging between 111 and 134 species. Notably though, 43 species were only observed six times or less over all ditches. Despite the comparable species richness across the different soil regions, considerable variation between individual ditches, and high species turnover was observed. Additional turnover was observed related to abiotic factors such as pH, transparency, variability in macro-ions and nutrients. It was generally found that low pH and variable transparency were beneficial for invertebrate diversity. However, abiotic factors only predicted a small portion of community variation, eluding that invertebrate communities are largely driven by other environmental factors (e.g. food availability, habitat structure, toxic pollutants, etc.).[27]

Another Dutch research team assessed the influence of a poor underwater light climate and oxygen stress on the macroinvertebrate communities of ditches. Results showed that poor light conditions alone did not affect the macroinvertebrate communities. However, poor light conditions together with anoxic conditions resulted in a delayed effect on the communities: although most taxa could survive an anoxic period, they did not remain unaffected in the weeks after.[28]

Lotic macroinvertebrates

In Slovakia, a study conducted in the Žitný Ostrov researched the crustacean zooplankton diversity in drainage ditches. They found 58 species in total, with an average of twelve and the highest number of species in a single ditch being as high as 22. Of these 58 species, seven were rare. Although individual ditches showed a relatively low α-diversity, the ditches cumulatively provide a valuable contributor to γ-diversity.[29]

Benthic macroinvertebrates

A 2022 study in Italy sampled the benthic macroinvertebrate communities of ditches and found that agricultural ditches provide different habitats from the river they are fed from and thus create a mosaic of aquatic habitats with higher environmental microhabitat heterogeneity. While there was only little effect on the number of taxa, the taxonomic composition of the communities showed great differences as a result of this heterogeneity. For functional diversity, differences where still observed, although in all but one of the sites, collector gatherers dominated the community.[30]

Nematodes

One study assessed the biodiversity development in field margins and ditch banks recently taken out of production. They found that after establishment of the field margins, the number nematodes harmful to agricultural practices increased with the years. According to the authors, this should not be expected to harm crops in adjacent fields since nematodes cannot readily disperse.[22]

Molluscs

A Slovakian study assessed the molluscan diversity in ditches in the Danubian Lowlands and found that ditches are a significant habitat type. Although higher species richness was found in the main ditches (Width >5m) and not in the side ditches (width <5m), side ditches still harboured up to 22 different molluscan species. Furthermore, three rare species only occurred in these side ditches.[31]

Fish

There was only one study that discussed fish. The Dutch researchers compared presence and abundance of fish between lakes and ditches in the same peatland area. They found that lakes harboured a higher number of fish species, but did not differ from ditches in number of organisms or biomass per ha.[26]

Amphibians

Only one study over the last 25 years was found and included in this search. The Dutch study focussed specifically on larvae and the effect of dredging and cleaning. They found that timing of ditch cleaning and dredging, as well as dredging method had significant effects on the larvae presence. Ditch cleaning between July and mid-September was association with a 20% increased chance of finding amphibian larvae. For dredging, the highest chance of finding larvae was associated with suction pipe dredging. The first three years after dredging, the chances of finding amphibian larvae were significantly lower. The same effect was observed for timing of dredging, with dredging between April and august being detrimental regardless of method.[21]

Plants

From the included studies discussing plant diversity in ditches, seven were read before reaching saturation. Two studies assessed the plant communities in agricultural ditches[32, 33]. One study looked specifically at the suitability of agricultural ditches for endangered fen meadow species[34]. Another study compared composition of aquatic plants in lakes and ditches in a peatland area[26].

One study looked at the role of ditches in dispersal[35]. The last two studies looked at specific aspects in relation to anthropogenic influence. The first focussed on the use of pesticides and manure[22], and the other looked at successional stage heterogeneity[36].

First, a German study, conducted in the river Queich catchment area, compared irrigation and drainage ditches with meadows and field paths and analysed the local and regional pant species diversity. The study found that field paths and ditches adjacent to the meadows had 10 to 35 % higher species richness, with ditches harbouring 122 of the in total 146 found species. It was also found that poorly maintained, filled-up ditches, had only about halve the species richness of well-maintained ditches and showed a higher proportion of nitrophytes.[33]
Second, a study conducted in the Supraśl river valley, Poland, assessed the condition of ditch plant communities in relation to their habitat valorisation over a ten-year period. They found that ditches provided a habitat for a large diversity of species. However, the number and viability of these species within these habitats is affected by antropopressures, and research showed that ditch bottoms provided better conditions for plant communities than ditch slopes.[32]

Third, the habitat suitability of drainage ditches for endangered fen meadow species was investigated in Eider-Treene-Sorge lowland, Germany. Fen meadow species are unable to keep up with nitrophytes in agricultural lands due to the high input of fertilizers. The researchers found 220 species in total with an average of 35 per 50m^2. Twenty species belonged to the meadow target species, although eight of them were only found on one plot. The study found a significant effect of time passed since the last ditch management. In the first season after dredging, the diversity of the ditch slopes was highest with many mudbank pioneers and annual plants. These species would become rare in the second season and disappear hereafter. Agricultural grassland communities would dominate the second and third seasons. Ditches that had been dredged more than three years ago showed the lowest diversity as reeds began to dominate. Aquatic species diversity was less affected by dredging. In conclusion, ditch banks can be species rich habitats and can even be a refuge for endangered meadow species. For this, the dominance of nitrophytes and other strong competitors can be regulated through the level of anthropological disturbance, with a frequency of three to four years being most practical for both the ditch functionality and the plant community regeneration.[34]

With ditches presenting the most extensive aquatic habits in agricultural land in northwest Europe, researchers in the Netherlands compared the taxonomic composition of lakes and agricultural drainage ditches. There was a higher taxon richness, and number of growth forms, for hydrophytes in the lakes. Contrasting this, helophyte taxon richness was comparable between ditches and lakes, with number of growth forms also being similar once rare growth forms were included.[26]

In a French study, the role of ditches as corridors for seed and pollen dispersal was studied. They found that ditches can serve a key corridors for plant dispersal. However, this is species specific and favours certain dispersal types.[35]

Lastly, the effect of anthropogenic influence was the focus of two Dutch studies. The first study researched the effect of field margins and ditch banks on biodiversity, looking specifically at long term effects of not applying pesticides and manure. It was found that species richness of field margins and ditch banks increased in the years after establishment. Parallel to this, the study also found that harmful weed cover declines in these years.[22]
The second study sought out to understand the importance of successional stage heterogeneity. They were able to identify seven clusters as successional stages, and landscapes containing all seven stages harboured 35 aquatic plant species. Landscapes that had gradually lost early successional stages harboured fewer aquatic plant species, with an average loss of seven

species. The study concluded that β-diversity is an important component of γ-diversity in ditches in a peat landscape. Over 70 % of β-diversity arose as a result of differences in successional stages, clearly showing that successional stage heterogeneity is an important component of regional diversity of aquatic vegetation.[36]

3.3 Ecological Ditches in an Agricultural Setting

Nine papers were read to explore the value of ditches and their ecosystem services in an agricultural land. First, one paper describes the ecosystem services provided by ditches in Slovakia[37]. Three papers discussed nitrogen retention and denitrification[38-41]. Two papers were concerned with phosphorus runoff[38, 40]. Next, two papers focussed on pesticide runoff mitigation[42, 43]. Finally, there were two papers assessing organic matter degradation by microorganisms and the impact of agriculture on this process.[44, 45]

In the Slovakian lowlands, a study identified multiple ecosystem services (ESS) of drainage ditches. Experts were asked to rate these ESS based on their significance with the studied area. The highest rated ESS were related to agricultural production: 1) surface water for non-drinking purposes, and 2) flood protection and reflect the need for irrigation and water regulation. After this, 3) biomass provisioning of both reared and wild animals and their outputs, together with 4) biomass provisioning of cultivated crops was also rated significant. This reflects the purpose of the landscape, namely food production.[37]
Other ESS were rated less significant. 5) biomass provisioning of wild plants and their outputs was considered of moderate significance. The different benefits of this ESS discussed were timber logging of tree lines along ditches, harvesting fruit for non-commercial use, honey production, and various applications of reeds. Reeds, however, were low in abundance in the study area and did not contribute to biomass production. Next to this, 6) micro and regional climate regulation was also considered moderately significant. Vegetation is noted to have the ability to increase relative humidity through transpiration and capture of horizontal precipitations. Taller vegetation contributes to this as well, by limiting wind.[37]
The second least significantly rated ESS was 7) cultural ESS. Physical and intellectual interactions with the landscape and its ecosystems contribute to recreation trough fishing, hunting, bird watching, hiking, and cycling trails. It is mentioned that well-conditioned habitats more strongly supply this ESS. Air and water pollution, as well as absence of rare birds can make habitats less attractive to people.[37]
The least significantly rated ESS was 8) pollution regulating ESS. Ditches and their riparian vegetation have the potential to regulate land-based pollution. Trees, grasses, and herbs can provide active phyto-degradation or phyto-stabilization of agrochemicals. Lines of trees among ditches were also mentioned to be able reduce odour and noise, although the actual effects are small. Within the study area, there was barely potential nor demand for this ESS.[37]

The first study on nitrogen retention was study carried out in Dutch agricultural peatlands and sought out understand the effect of land-use, vegetation and soil type on denitrification in ditches. There it was found that ditches with a fine sandy sediment showed the highest denitrification rates, followed by clay and peat sediment ditches. On top of this, ditches with duckweed covering the complete water column also had higher denitrification rates due to duckweeds creating lower oxygenated conditions. After this, floating vegetation had better denitrification rates than submerged of absent vegetation. The main components explaining denitrification rates were availability of nitrogen and low oxygenated conditions.[39]
The second study, a two-year study in the Czech Republic, assessed the capability of a vegetated ditch to retain nutrients and suspended solids. The vegetated ditch was 200 meters long and dominated by Phragmites *australis*, *Typha latifolia* and *Glyceria maxima*. Over two years, the ditch

showed a total nitrogen removal efficiency of 38.3% and 52.6%, respectively. The majority of the total nitrogen removal was due to denitrification (i.e. the elimination of Nitrate-nitrogen(N-NO^3)). Nitrate-nitrogen removal efficiency 41.4% in the first year and 62.2% in the second year. Plant uptake of nitrogen accounted for 26.3% of the removed nitrogen[38].

Third, in a study conducted in northern Italy, the nitrogen pollution mitigation of a vegetated ditch ditches fed by nitrate-rich groundwater was assessed. The ditch vegetation was dominated by *Typhoides arundinacea,* accounting for 90% of plant biomass, followed by *Elodea canadensis*. Nitrogen removal peaked in July at 20.89% in the vegetated ditch. The vegetated ditch showed 1.5 to 3.3 times higher denitrification rates than an unvegetated ditch at all times. Plant mediated denitrification was observed to be the main force behind nitrogen removal. Nitrogen removal trough denitrification was more efficient at night. This was likely caused by less oxygen penetration causing the anoxic zone to be closer to the supply of nitrate. It was noted that longer retention times, a greater aquatic vegetation interface, and adequate availability of labile organic matter promote nitrogen removal and could be maximised by management practises.[40]

Lastly, a study in Finland assessed the leaching of nitrogen in cultivated peatlands. In the third year of the study, two ditches were grass covered whilst other ditches were bare or covered with barley or grass seedlings. The nitrogen runoff from the grass covered ditches was much lower (8.6 mg l^{-1}) than that of the other ditches (14.8 mg l^{-1}). A year later, when the seedling cover had grown to proper vegetative cover, the nitrogen runoff of these ditches matched those that were already grass covered.[41]

The same two-year study in the Czech Republic also assessed phosphorus. There it was reported that total phosphorus removal efficiency was comparable over the two years of the study, being 52.6 and 51.3%. A small portion of the phosphorus removal was because of sequestering in above ground biomass, being 16.9 and 10.2% in the first and second year, respectively. Removal of both nitrogen and phosphorus was comparable to the removal reported in constructed wetlands.

For dissolved organics, the study assessed biochemical oxygen demand (BOD$_5$) and chemical oxygen demand (COD). BOD^5 was reduced by 46.5% and 48.6%, and COD by 48.8% and 40.6% over the respective years. These removed loads were higher than those reported in a constructed wetland. The removal efficiency was heavily dependent on water temperature, with removal efficiency increasing exponentially with rising water temperatures. Total suspended solid removal efficiency was high, reaching 86% and 76% over the two respective years. This was comparable to removal efficiency of constructed wetlands treating agricultural drainage.[38]

A study conducted on Ireland investigated phosphorus runoff via ditches in relation to ditch characteristics. It was mentioned that particulate phosphorus mobilisation due to bank erosion is expected to be greatest in ditches with sleep slopes and higher velocity flowing water. It was also speculated that hedgerows adjacent to ditches and vegetation growth on banks can stabilise banks by increasing root mass. However, adjacent hedgerows were also mentioned as a potential cause for lower in-channel vegetation cover. It was found that banks with low slopes and low discharge were most suitable for storing fine sediment and provide sorption of phosphorus. To retain this capacity, periodical dredging to remove the sediment and prevent sediment saturation was mentioned as a possible strategy. That said, dredging can have adverse effects, and timing should be such that these effects are minimised.[46]

The first of the two studies on the pesticide runoff mitigation potential of vegetated ditches was carried out in the Po Valley. A 500m long ditch was mainly vegetated with *Dactylis glomerata*, *Convolvulus arvensis*, *Lolium multiflorum*, *Poa trivialis*, *Silene alba*, *Rumex crispus*, *Sonchus asper*, *Urtica dioica* on the banks and *Phragmites australis*, *Iris* sp., *Scirpus* sp., *Tipha* sp. in the bed. The ditch was experimentally flooded three times: First with water having high concentrations of herbicides, after which twice with clean water, 27 and 55 later. The herbicides used were mesotrione, S-metolachlor and terbuthylazine. Almost immediately, water concentrations were only 10-49% of those applied. At the end of the

ditch, runoff mitigation efficiency for the three herbicide was 99, 91 and 97%, respectively. After the second flood, S-metolachlor and terbuthylazine were detected again. However, concentrations were lower than the drinking water limit (0.1 µg L^{-1}). During the third flood, no pesticides could be detected. Overall, the vegetated ditch showed great pesticide runoff mitigation capacity and it was calculated that one mm runoff from five ha is mitigated by 99% in 100 m of vegetated ditch with a bed one meter wide for these herbicides.[42]
The second study was conducted in France and assessed the soil properties of ditch beds and banks for potentially different properties contributing to pesticide runoff mitigation. The diuron pesticide sorption capacity was higher in the ditch bed profile than in the ditch bank profiles. This was contributed to the fact that the ditch bed was twice as rich in organic matter, providing efficient sorption sites for hydrophobic molecules. That said, this soil layer also had more properties favouring percolation. For glyphosate, the sorption was suggested to be dependent on the mineral fraction of the soil and not the organic matter, thus creating a different sorption profile.[43]

Microbial resource utilisation and degradation of organic matter was shown to be different for different land use types. Reduced microbial resource utilisation was observed in relating to stronger agricultural perturbations of the environment. It was speculated that these differences were driven by sorption of agrochemicals. Alternatively, it is also speculated that lower quality of organic matter present in ditches constrain functional diversity of the microbial community by limiting microbial resource differentiation.[44] Similar results were found in a different study as well.[45]

4. Discussion

The studies reflected in this review show that ditches can provide valuable services in an agricultural landscape. Ditches have the potential to contribute to biodiversity and can harbour rare and endangered species.

4.1 Biodiversity

Ditches provide important potential terrestrial and aquatic habitats in an agricultural landscape for various plants and animals. These habitats can function as biodiverse refuges for various macroinvertebrates[26-31], true bugs[20], caddisflies[21], dragonflies[21, 22], orthopterans[24], aquatic beetles[23], plants[26, 32-34], and have also been found to positively affect farmland birds[47, 48]. Even for rare and endangered species can find refuge in ditch habitats. The studies included here found rare or endangered macroinvertebrates[26, 29, 31], orthopterans[24], aquatic beetles[23] and meadow plant[34] species to be present in ditch habitats.

Heterogeneity & homogenisation
The capacity of ditches to contribute to biodiversity is not straight forward or immediate. Multiple studies found that individual ditches, or smaller ditch segments harboured only few species[27, 29, 36], showing that α-diversity is not the main strength of ditch networks. Rather, ditches can create a mosaic of habitats[30], cumulatively supporting a large number of species and thus contribute to regional diversity. The finding that successional stage heterogeneity contributed 70% of β-diversity[36] most strongly supports this.
However, species richness does not directly account for functional diversity. Ditches can be isolated structures in otherwise diversity lacking croplands or grass fields. Homogenisation of ecosystems in ditches has been previously mentioned in studies[19, 20, 30, 48]. Multiple of the included studies either mentioned or concluded that dispersal ability of species plays an important role,

potentially explaining why certain species cannot readily colonise ditch habitats[20, 24, 49]. In the literature, this has been described for certain indicator species, as they have limited dispersal capacity or particular depend on a single dispersal vector [50]. This homogenisation can lead to a loss of functional diversity. It was shown that overgrown ditches do not contribute to functional diversity of true bug communities[20], that aquatic beetle communities were dominated by collector gatherers[30], and that microbial functional diversity differentiation can be constrained by the quality of organic matter present[30, 44, 45]. Altogether, heterogeneity and forming a mosaic of different microhabitats seems to be a crucial aspect in the conservational value of ditches.

Design & Maintenance

The ecological values of ditches, both from their aquatic and terrestrial habitats can be compounded by anthropogenic influence. Maintenance actions such as dredging and mowing are quite common to ensure good hydrological functioning of ditches, However, depending on their timing and frequency, these actions can be both detrimental and beneficial. A French study has previously ranked maintenance strategies in increasing order of conservation value: dredging, chemical weeding, burning and mowing[51]. Study included in this review showed that, considering timing and method, dredging could have a significant detrimental impact on the presence of larvae of caddisflies, dragonflies, and amphibians[21], but could also increase diversity in plant community structure on ditch banks[34]. It is clear that maintenance strategies are of significant influence on plant species diversity. Poorly maintained ditches showed only halve the species richness compared well maintained ditches[33] and were overgrown with nitrophytes[33, 34]. Managing the vegetation can break the dominance of these nitrophyles[34] and achieve successional stage heterogeneity when performed in phases.

There are also effects of applying pesticides and manure on, or near, ditches that affect its ecological function. Pesticide application was shown to cause a decline in in macroinvertebrates[25] and was speculated to retard microbial functioning[44]. On top of this, field margins taken out of production and not applied with fertilisers and pesticides were shown to increase in species richness over the following years. Having zones not sprayed agrochemicals can most likely create exposure free refuges for animals[25], decreasing the detrimental effects these substances have. Creating buffer zones next to ditches thus seems to be a wise decision from an ecological standpoint, development vegetation and supporting animal communities in this vegetation and limiting negative effects of agrochemicals. Specifically for farmland birds, such buffer zones have already been described for their importance in proving nesting sites and diverse and more reliable food sources[52].

4.2 Mitigating pollution

Nutrient retention

Studied ditches have shown promising capacity for nutrient retention. Phosphorus, nitrogen, and organic carbon can all be retained by either ditch vegetation, soil, or litter. Nitrogen removal efficiency was observed between 20.89[40] and 52.6%[38]. Denitrification was the main force behind the total nitrogen removal[38, 40], with one study reporting denitrification efficiency rates between 41 and 52%[38]. Denitrification increases with higher temperatures[38], low oxygenated conditions[39, 40], and greater ditch vegetation[39]. Overall, nutrient nitrogen removal in vegetated ditches is 1.5 to 3.3 times higher than in unvegetated ditches[38, 40, 41].

For phosphorus, vegetated ditches were reported to remove ~51%, with 10.2 to 16.9% being attributable to plant uptake[38]. Ditches with low sloped banks and low discharge were found to be most efficient in storing sediment and allowing phosphorus sorption[46]. This matches with another study that concluded that vegetation cover is an effective runoff mitigation strategy, preventing surface runoff[53]. Only one study measured organic matter removal and reported efficiency ranging from 40.6 to 48.6%[38]. For suspended solids, very high removal efficiencies were observed, 76 to 86%[38].

Altogether, vegetated ditches can prevent nutrient runoff via denitrification[38-40], sorption by soil and organic matter[37], trapping sediment[46], and plant uptake[37, 38, 46]. Additionally, vegetation growth can increase the retention time and therefore enhance soil sorption and plant uptake. This potential was previously observed in another study[54].

Pesticide runoff mitigation

Retention of pesticides has been observed at very promising rates. In one study, herbicide retention was reported to be 91 to 99%[42]. Mitigation is caused by multiple processes such as degradation, sedimentation, infiltration and adsorption onto plant surfaces, the relative importance of which is not completely known. It was shown that pesticides have different sorption profiles[43]. It was mentioned that diuron sorption was more efficient in ditch beds rich in hydrophobic sorption sites due to organic matter. Contrasting this, glyphosate sorption was speculated to be dependent on mineral fraction in the soils. This is in accordance with a study reporting glyphosate to have a higher sorption affinity for soils then vegetation or litter and Diuron sorption affinity being high for litter and even higher for ashes[51].

Design & Maintenance

Utilising ditches to mitigate agricultural pollution is possible, based on the observed retention rates. Vegetated ditches, adjacent vegetated buffer zones, constructed wetlands and low-grade weirs are all option that have been discussed[55]. These ecological solutions are especially appealing since in-ditch solution such as managing soil and vegetation are possible without taking land out of production[56]. Management of ditches can therefore clearly be of great significance in an agricultural landscape. In our results, different design and management aspects of ditches have been discussed. Keeping ditches and banks vegetated stabilises the soil, preventing erosion and surface runoff[41, 46, 53]. Similarly, low slopes are more stable than steep slopes[46]. Lower discharge and longer retention time consistently associated with better sorption[38, 40, 46, 54]. Vegetation can assist in slowing water flow and increasing retention time, as well as increase the interface between the water column and organic matter[40]. Lastly, it was noted that taking out ditch sediment via dredging can prevent saturation and thus refresh the nutrient sorption capacity of the sediment layer[46, 54]. However, dredging can have adverse effects, just like other maintenance operations. It is therefore important to consider seasonal fluxes and priorities (e.g. vegetation is important is the period that nutrients and vegetation are applied) when timing these operations[51].

4.3 Opportunities in mutual benefit

There are multiple overlapping themes between the ecological value and pollution mitigation value.

Vegetation in ditches and on adjacent zones support biodiversity, potentially including rare and endangered ones. The same is true for ditches designs with low slopes and vegetated buffer zones. It adds to biodiversity by proving nesting sites, more stable food sources and refuge sites to escape from agrochemical exposure. Additionally, low slopes and vegetated ditches and buffer zones also help stabilise the soil, increase water retention time, increase sorption surface, and trap sediment, thus effectively retaining nutrients and pesticides.

Maintenance activities are necessary to maintain hydrological function but can also break dominance of neutrophiles in plant communities. Furthermore, if carried out in phases, maintenance operation can contribute to the successional stage heterogeneity in the ditch, increasing the overall biodiversity. An example of a strategy adding to this is rotational grazing[57], allowing both functionality of the land, maintaining vegetation cover and contributing to a mosaic of microhabitats. On top of this, periodical dredging could also reestablish the soil sorption capacity for nutrients. That said, maintenance operation can be detrimental and timing needs to carefully considered to yield the best results.

Lastly, soil properties and organic matter availability in the ditch play a role in the nutrient and pesticide sorption capacity. Management strategies utilising natural resources might prove useful in creating soil conditions and organic matter to better retain these agrochemicals and simultaneously contribute to biodiversity and should be researched.

It is important to note that the studies presented in this review have been conducted in multiple countries differing in geography, topology, and climatic conditions. Additionally, it is clear that ditches are not homogenous in design. On top that, management and maintenance regimes are also important variables to take into consideration. These differences, as well as regional differences such as soil type and land-use types can all impact the efficiency of the ecological services ditches provide. Policy makers are encouraged to take these differences into account and make realistic estimations of potential under- or overestimation of the ecological services under different circumstances.

5. Conclusions

Vegetated ditches are valuable for biodiversity, harbouring various plant and animal species, including rare and endangered ones. However, there is a risk of homogenisation in these systems and creating heterogeneity through creating a mosaic of microhabitats seems to be critical. Agricultural perturbations such as land use, application of agrochemicals and ditch maintenance can affect the ecological function of ditches, both positively and negatively.

Vegetated ditches also provide value by retaining agrochemicals. Vegetation stabilises soil, increases retention time and increases the sorption of agrochemicals. The efficiency of these processes is dependent on the vegetation, temperature, soil properties and retention time. Managing and designing ditches for the dual purpose of enhancing biodiversity and mitigation pollution seems possible though implementing low slopes, in ditch vegetation and vegetated buffer zones. Additionally, maintenance strategies are already necessary to maintain hydrological functioning of the ditches, but can also reset sorption capacity of the sediments, help deposit organic matter, and when carried out in phases, can increase the successional stage heterogeneity. That said, depending on timing and method, maintenance operations can be detrimental for various species groups. It is important to understand the variability of climatic factors, soil properties and ditch design to create realistic expectations and design strategies that can maximise both ecological and agricultural value of ditches.

6. Statement on generative AI

During this project, I have sporadically used ChatGPT 4.0 for improving grammar and language clarity of single sentences. On top of this, I have regularly used it to provide me synonyms or definitions. Additionally, I have asked it to provide me names of paragraphs or headers by providing it clusters of topics. Lastly, I have used it once to suggest an outline for the introduction.

For this, I explained what to it what topics I wanted include, where I wanted emphasis, and what the goals for each topic were.

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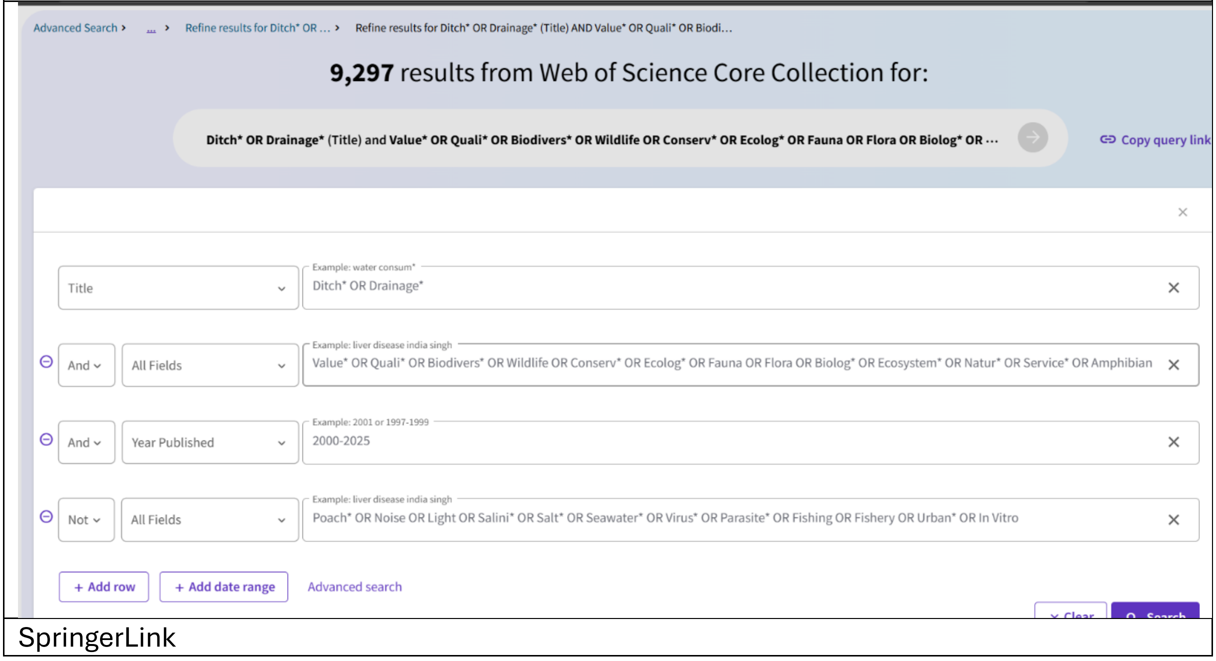
8. Appendix

*Table S2. **The exact sets of terms and setting used to conduct the searches in Pubmed, Web of Science and SpringLink, respectively.** An '*' indicates that all words with that stem are included. This was done to include various words with one term, for instance plural and singular.*

PubMed Query
(((Ditch*[Title] OR Drainage*[Title]) AND (Value* OR Quali* OR Biodivers* OR Wildlife OR Conserv* OR Ecolog* OR Fauna OR Flora OR Biolog* OR Ecosystem* OR Natur* OR Service* OR Amphibian)) NOT (Poach* OR Noise OR Light OR Salini* OR Salt* OR Seawater* OR Virus* OR Parasite* OR Fishing OR Fishery OR Urban* OR In Vitro)) AND (("2000"[Date - Publication] : "2025"[Date - Publication]))
Web of Science
 Advanced Search > ... > Refine results for Ditch* OR ... > Refine results for Ditch* OR Drainage* (Title) AND Value* OR Quali* OR Biodi... **9,297** results from Web of Science Core Collection for: **Ditch* OR Drainage*** (Title) and **Value* OR Quali* OR Biodivers* OR Wildlife OR Conserv* OR Ecolog* OR Fauna OR Flora OR Biolog* OR ...** Title: Ditch* OR Drainage* And All Fields: Value* OR Quali* OR Biodivers* OR Wildlife OR Conserv* OR Ecolog* OR Fauna OR Flora OR Biolog* OR Ecosystem* OR Natur* OR Service* OR Amphibian And Year Published: 2000-2025 Not All Fields: Poach* OR Noise OR Light OR Salini* OR Salt* OR Seawater* OR Virus* OR Parasite* OR Fishing OR Fishery OR Urban* OR In Vitro
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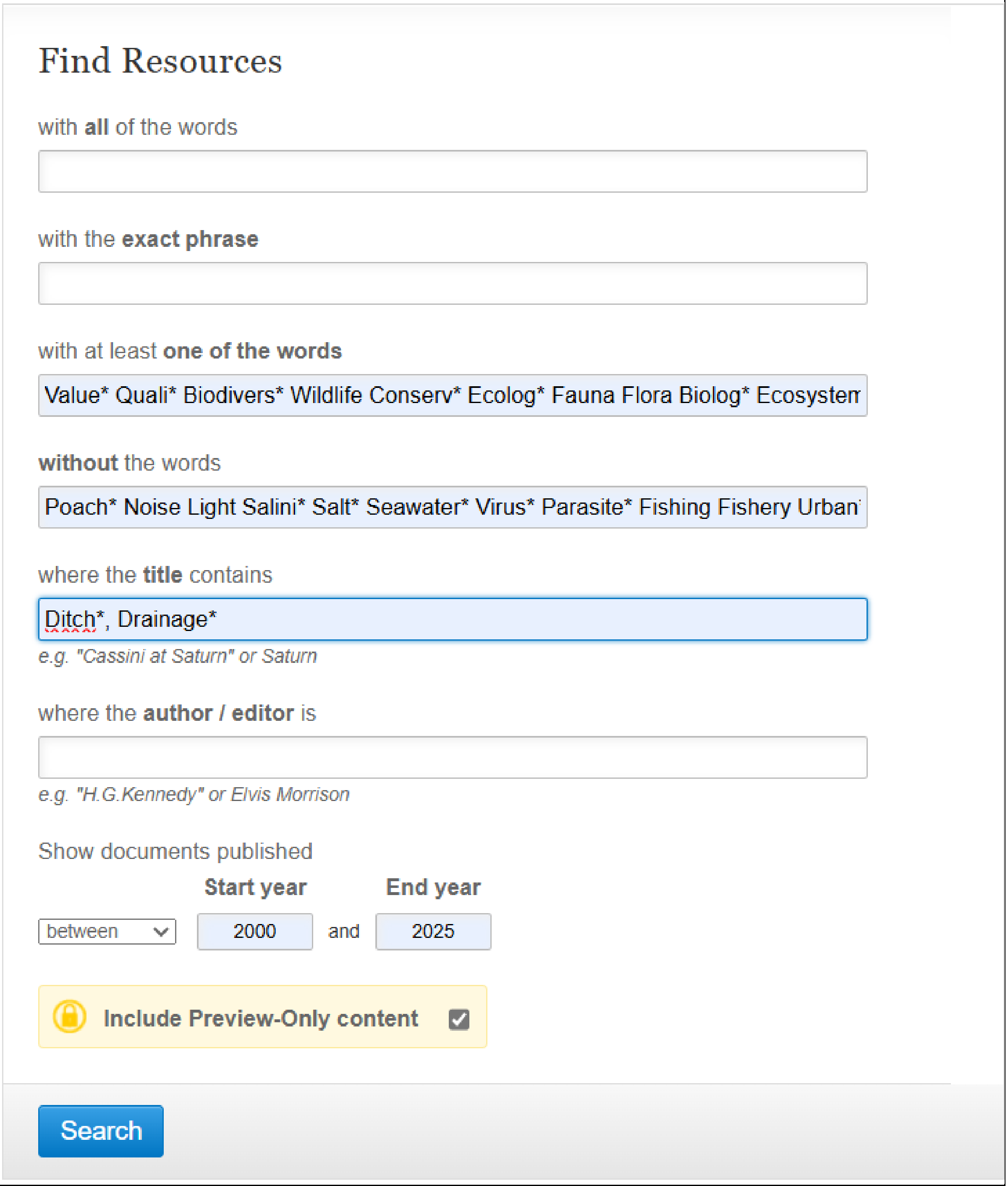

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Table S2. ***Overview of all included papers with year of publication, first author, title, and country where the study was carried out.*** *The first 8 studies are concerned with tile drainage, all other studies with ditches. Studies are sorted by year publication.*

Year	Authors	Title	Country
		Tile drainage	
2005	Deutsch et al.	Variations in the δ15N and δ18O values of nitrate in drainage water of two fertilized fields in Mecklenburg-Vorpommern	Germany
2014	Ulén et al.	Recession of phosphorus and nitrogen concentrations in tile drainage water after high poultry manure applications in two consecutive years	Sweden
2016	Grossel et al.	The effect of tile-drainage on nitrous oxide emissions from soils and drainage streams in a cropped landscape in Central France	France
2016	Zajícek et al.	Event water detection in tile drainage runoff using stable isotopes and a water temperature in small agricultural catchment in Bohemian-Moravian Highlands	Czech Republic
2018	Zajícek et al.	Pesticide leaching by agricultural drainage in sloping, mid-textured soil conditions - the role of runoff components	Czech Republic
2018	Wu et al.	Diatoms as an indicator for tile drainage flow in a German lowland catchment	Germany
2022	Bech et al.	Impact of surface-applied liquid manure on the drainage resistance profile of an agricultural tile-drained clay till field	Denmark
2023	Pham et al.	Leaching of nitrogen, phosphorus and other solutes from a controlled drainage cultivated peatland in Ruukki	Finland
		Ditches	
2000	Colin et al.	Relations between triazine flux, catchment topography and distance between maize fields and the drainage network	France
2000	Twisk et al.	Effects of ditch management on caddisfly, dragonfly and amphibian larvae in intensively farmed peat areas	Netherlands
2002	Geertsema et al.	Plant distribution patterns related to species characteristics and spatial and temporal habitat heterogeneity in a network of ditch banks	Netherlands
2002	Simunic et al.	The content of Pb, Zn and Cd in hydroameliorated soil and drainage water and their uptake by plants	Slovenia

2003	Rimkus et al.	Naturalization of drainage channels in Lithuania and possibilities of their maintenance as water recipients	Lithuania
2003	Blomqvist et al.	Restoration of ditch bank plant species richness: The potential of the soil seed bank	Netherlands
2003	Twisk et al.	The nature value of the ditch vegetation in peat areas in relation to farm management	Netherlands
2004	Scholz et al.	Hydraulic characteristics of groundwater-fed open ditches in a peatland	Germany
2004	Scholz et al.	Water quality characteristics of vegetated groundwater-fed ditches in a riparian peatland	Germany
2004	Leistra et al.	Fate of the insecticide lambda-cyhalothrin in ditch enclosures differing in vegetation density	Netherlands
2005	Hirt et al.	Mesoscalic estimation of nitrogen discharge via drainage systems	Germany
2005	de Zwart et al.	Ecological Effects of Pesticide Use in The Netherlands: Modeled and Observed Effects in the Field Ditch	Netherlands
2006	Arts et al.	Ecological Impact in Ditch Mesocosms of Simulated Spray Drift from a Crop Protection Program for Potatoes	Netherlands
2007	Manhoudt et al.	Management regimes and farming practices enhancing plant species richness on ditch banks	Netherlands
2009	Blomqvist et al.	No improvement of plant biodiversity in ditch banks after a decade of agri-environment schemes	Netherlands
2009	Brock et al.	IMPACT OF A BENZOYL UREA INSECTICIDE ON AQUATIC MACROINVERTEBRATES IN DITCH MESOCOSMS WITH AND WITHOUT NON-SPRAYED SECTIONS	Netherlands
2009	Musters et al.	Development of biodiversity in field margins recently taken out of production and adjacent ditch banks in arable areas	Netherlands
2009	Leng et al.	Restoration of plant diversity on ditch banks: Seed and site limitation in response to agri-environment schemes	Netherlands
2009	Olli et al.	Field study of phosphorous transport and retention in drainage reaches	Sweden
2010	Stamati et al.	Natural attenuation of nutrients in a mediterranean drainage canal	Greece
2010	Litskas et al.	Water quality in irrigation and drainage networks of Thessaloniki plain in Greece related to land use, water management, and agroecosystem protection	Greece
2010	Bonaiti et al.	Efficiency of controlled drainage and subirrigation in reducing nitrogen losses from agricultural fields	Italy
2010	Brock et al.	MACROIN VERTEBRATE RESPONSES TO INSECTICIDE APPLICATION BETWEEN SPRAYED AND ADJACENT NONSPRAYED DITCH SECTIONS OF DIFFERENT SIZES	Netherlands

2010	Leng et al.	Synergy between nature reserves and agri-environmental schemes in enhancing ditch bank target species plant diversity	Netherlands
2010	Leng et al.	Spatial variation in ditch bank plant species composition at the regional level: the role of environment and dispersal	Netherlands
2011	Leng et al.	Effects of mowing date on the opportunities of seed dispersal of ditch bank plant species under different management regimes	Netherlands
2011	Noordijk et al.	Vegetation development in sown field margins and on adjacent ditch banks	Netherlands
2011	Verdonschot et al.	Biodiversity value of agricultural drainage ditches: a comparative analysis of the aquatic invertebrate fauna of ditches and small lakes	Netherlands
2011	Leng et al.	Spatiotemporal variation of plant diversity on ditch banks under different management regimes	Netherlands
2011	Bulc et al.	RUN-OFF TREATMENT OF HIGHLY FLUCTUATING WATERS WITH SUBSURFACE VEGETATED DRAINAGE DITCH AND RIVERBED WITH MEANDERS	Slovenia
2011	Bulc et al.	Vegetated ditches for treatment of surface water with highly fluctuating water regime	Slovenia
2012	Marja et al.	The importance of drainage ditches for farmland birds in agricultural landscapes in the Baltic countries: does field type matter?	Latvia, Estonia & Lithuania
2012	van Zuidam et al.	The Role of Propagule Banks from Drainage Ditches Dominated by Free-Floating or Submerged Plants in Vegetation Restoration	Netherlands
2013	Marja et al.	Type of agricultural drainage modifies the value of fields for farmland birds	Finland
2013	Giakoumakis et al.	An approximate method for estimating nutrient loads in drainage water from a coastal irrigated area	Greece
2013	Ibrahim et al.	SPATIAL AND TEMPORAL VARIATIONS OF NUTRIENT LOADS IN OVERLAND FLOW AND SUBSURFACE DRAINAGE FROM A MARGINAL LAND SITE IN SOUTH-EAST IRELAND	Ireland
2013	van Dijk et al.	Temporal effects of agri-environment schemes on ditch bank plant species	Netherlands
2013	van Zuidam et al.	Occurrence of macrophyte monocultures in drainage ditches relates to phosphorus in both sediment and water	Netherlands
2013	Mukete et al.	VARIABILITY IN MICROHABITATS PREVALENCE IN LOW LYING PEAT POLDER DITCHES OF THE NETHERLANDS	Netherlands
2013	Taboada-Castro et al.	Assessing the Influence of Catchment Land-Use Patterns on the Nutrients and Major Ions Chemistry of Drainage Water	Spain
2014	Favre-Bac et al.	Connectivity and propagule sources composition drive ditch plant metacommunity structure	France

2014	Kavanagh et al.	THE CONTRIBUTION OF A DRAINAGE NETWORK TO THE SPATIAL AND TEMPORAL PATTERNS OF MACROINVERTEBRATE DIVERSITY ACROSS AN AGRICULTURAL HEADWATER CATCHMENT	Ireland
2014	Whatley et al.	The role of emergent vegetation in structuring aquatic insect communities in peatland drainage ditches	Netherlands
2014	Vilar et al.	Typology of diatom communities in the Dutch delta: Recognizing patterns of environmental drivers in nutrient rich ditches	Netherlands
2014	van Dijk et al.	The effectiveness of ditch banks as dispersal corridor for plants in agricultural landscapes depends on species' dispersal traits	Netherlands
2014	Whatley et el.	Macrophyte loss drives decadal change in benthic invertebrates in peatland drainage ditches	Netherlands
2014	Ralf et al.	Shading effects of free-floating plants on drainage-ditch invertebrates	Netherlands
2015	Baken et al.	Phosphorus losses from agricultural land to natural waters are reduced by immobilization in iron-rich sediments of drainage ditches	Belgium
2015	Ernstsen et al.	Long-term monitoring of nitrate transport to drainage from three agricultural clayey till fields	Denmark
2015	Shore et al.	An agricultural drainage channel classification system for phosphorus management	Ireland
2015	Whatley et al.	Temporal abiotic variability structures invertebrate communities in agricultural drainage ditches	Netherlands
2016	Favre-Bac et al.	Ditch network sustains functional connectivity and influences patterns of gene flow in an intensive agricultural landscape	France
2016	Breuer et al.	Seasonality of algal communities in small streams and ditches in temperate regions using delayed fluorescence	Germany
2016	Shore et al.	Characterisation of agricultural drainage ditch sediments along the phosphorus transfer continuum in two contrasting headwater catchments	Ireland
2016	Otto et al.	Vegetated Ditches for the Mitigation of Pesticides Runoff in the Po Valley	Italy
2016	Hunting et al.	Effects of agricultural practices on organic matter degradation in ditches	Netherlands
2016	Rozemeijer et al.	High-frequency monitoring of water fluxes and nutrient loads to assess the effects of controlled drainage on water storage and nutrient transport	Netherlands
2017	Favre-Bac et al.	Connectivity drives the functional diversity of plant dispersal traits in agricultural landscapes: the example of ditch metacommunities	France

2017	Dollinger et al.	Impact of maintenance operations on the seasonal evolution of ditch properties and functions	France
2017	Meier et al.	Plant diversity in a water-meadow landscape: the role of irrigation ditches	Germany
2017	Daly et al.	Field soil and ditch sediment phosphorus dynamics from two artificially drained fields on poorly drained soils	Ireland
2017	Soana et al.	Mitigation of nitrogen pollution in vegetated ditches fed by nitrate-rich spring waters	Italy
2017	Hunting et al.	Agricultural constraints on microbial resource use and niche breadth in drainage ditches	Netherlands
2017	Veraart et al.	Abundance, Activity and Community Structure of Denitrifiers in Drainage Ditches in Relation to Sediment Characteristics, Vegetation and Land-Use	Netherlands
2018	Vymazal et al.	Removal of nutrients, organics and suspended solids in vegetated agricultural drainage ditch	Czech Republic
2018	Dollinger et al.	Contrasting soil property patterns between ditch bed and neighbouring field profiles evidence the need of specific approaches when assessing water and pesticide fate in farmed landscapes	France
2018	Rasran et al.	Ditches as species-rich secondary habitats and refuge for meadow species in agricultural marsh grasslands	Germany
2018	Rolke et al.	Drainage ditches as important habitat for species diversity and rare species of aquatic beetles in agricultural landscapes (Insecta: Coleoptera)	Germany
2018	Torma et al.	Secondary habitats are important in biodiversity conservation: a case study on orthopterans along ditch banks	Hungary
2018	Errico et al.	The effect of flexible vegetation on flow in drainage channels: Estimation of roughness coefficients at the real scale	Italy
2018	Teurlincx et al.	Managing Successional Stage Heterogeneity to Maximize Landscape-Wide Biodiversity of Aquatic Vegetation in Ditch Networks	Netherlands
2018	van der Lee et al.	Dissolved oxygen dynamics in drainage ditches along a eutrophication gradient	Netherlands
2018	Anghel et al.	SEDIMENTS ANALYSIS FROM WATERING DITCHES AND APPROPRIATENESS OF SPREADING THEM ON AGRICULTURAL LAND	Romania
2018	Illyová et al.	Crustacean Zooplankton Biodiversity in Agricultural Drainage Ditches in Danubian Lowland	Slovakia
2019	Lorenz et al.	Data on three-year zooplankton monitoring in ditches of the apple orchard region of Altes Land, Germany	Germany
2019	Musters et al.	Spatial and temporal homogenisation of freshwater macrofaunal communities in ditches	Netherlands

2019	Cejka et al.	Freshwater Molluscan Fauna in Danubian Drainage Ditches in Slovakia: High Species Richness and Conservation Value	Slovakia
2020	Vaikre et al.	Forest ditch maintenance impoverishes the fauna of aquatic invertebrates: Opportunities for mitigation	Estonia
2020	Lorenz et al.	Data on three-year monitoring of benthic macroinvertebrates in ditches of the orchard region of Altes Land, Germany	Germany
2020	Moloney et al.	Ranking connectivity risk for phosphorus loss along agricultural drainage ditches	Ireland
2020	Tamburini et al.	Introducing Life Cycle Assessment in Costs and Benefits Analysis of Vegetation Management in Drainage Canals of Lowland Agricultural Landscapes	Italy
2020	Kozelová et al.	The role of artificial ditches and their buffer zones in intensively utilized agricultural landscape	Slovakia
2022	Kiryluk et al.	PLANT COMMUNITIES IN DRAINAGE DITCHES - CONDITIONS, CHARACTERISTICS AND ENVIRONMENTAL FUNCTIONS	Polen
2022	Norberg et al.	Nutrient losses over time via surface runoff and subsurface drainage from an agricultural field in northern Sweden	Sweden
2022	Schönenberger et al.	Pesticide concentrations in agricultural storm drainage inlets of a small Swiss catchment	Switzerland
2022	Bigalke et al.	Microplastics in agricultural drainage water: A link between terrestrial and aquatic microplastic pollution	Switzerland
2024	Opoku et al.	An integrated connectivity risk ranking for phosphorus and nitrogen along agricultural open ditches to inform targeted and specific mitigation management	Ireland
2024	Apori et al.	Assessment of Nitrate and Phosphate Concentrations in Discharge Water from Ditch Networks across Different Peatland Use Types: Implications for Sustainable Peatland Use Management	Ireland
2024	Chiorino et al.	Biodiversity, Ecological Status and Ecosystem Attributes of Agricultural Ditches Based on the Analysis of Macroinvertebrate Communities	Italy
2024	Šeat et al.	Landscape matrix and substrate jointly shape the trait composition of true bug (Heteroptera) communities in drainage ditches	Hungary