Evaluating Wetland Restoration Success in Kratholm Catchment

Master's thesis

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Abstract

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During the last century, natural wetland areas have rapidly decreased due to drainage, peat extraction, as well as increase of the area of agricultural lands and forested areas, thus leading to wetland biodiversity loss as well as reduction of available ecosystem services provided by wetlands. In Denmark, wetland restoration has been successfully used as a tool to mitigate nitrogen and phosphorus losses from agricultural lands. However, no certain guidelines have been set regarding biodiversity in the restored areas. In Kratholm catchment on Fyn island, many wetland restoration projects have been implemented so far. The aim of the thesis was to evaluate restoration success in 10 wetland restoration projects in Kratholm catchment, focusing on vegetation, plant communities, as well as nitrogen and phosphorus stock in aboveground biomass and nutrient leaching. During the field work, 172 vegetation plots were described, and 50 aboveground biomass samples collected. Species richness in the vegetation plots was low, however species diversity tends to increase with an increase of wetland age. Species preferring half-light conditions, humidity and moderate nutrient rich to nutrient rich soils are dominant in the restored areas. The most common plant communities described were reed beds and humid tall herb fringes. Nitrogen and phosphorus stocks in the dry aboveground biomass were high, however for plant communities that are storing high amount of nitrogen and phosphorus, leaching rates were also high. Nitrogen and phosphorus stock and leaching rates tend to decrease with an increase of wetland age. To increase the nutrient removal and species richness, periodical mowing with biomass removal from the restored areas as well as grazing is suggested. The outcome of the restoration projects regarding the vegetation can be improved, therefore more certain goals should be set for further projects along with the development of management and monitoring plans.

Table of Contents

1. Introduction

Danish wetlands have been restored for more than 20 years with the main aim to reduce the amount of nitrogen and phosphorus entering lakes and streams from agricultural lands (Hoffmann et al., 2011; Audet et al., 2015). During the last decades, natural wetland areas have decreased rapidly, while the application of fertiliser in agricultural lands has increased, thus leading to acute eutrophication problems (Hansson et al., 2005). Even though restoration projects can be evaluated as successful regarding nutrient loss mitigation, there is lack of data on how restoration affects plant biodiversity and vegetation, which is an important part of wetland ecosystems. Clear guidelines for improving biodiversity through wetland restoration projects in Denmark are missing (Audet et al., 2015).

During the last decades, due to species and habitat loss, the conservation of biodiversity has been gradually integrated in the agricultural landscape, which is dominant in Denmark (Brunbjerg et al., 2016). Thus, it is important to enhance the understanding about the vegetation development and plant biodiversity in restored areas over time. In Denmark, a monitoring program to follow the restoration of wetlands has been developed. It includes data on land-use, as well as surveys on environmental effects as well as natural values (Hoffmann and Baattrup-Pedersen, 2007). In 2005, a report on The Action Plans on The Aquatic Environment II was published, stating the areas where the vegetation mapping and monitoring is done and the methodology (Hoffmann et al., 2005). However, solid vegetation descriptions before and after the restoration are often missing. It is a significant information, which can be used for research and monitoring later on.

Another important aspect regarding plant communities in restored wetlands is plant nutrient uptake. During the growing season, wetland plants enclose phosphorus, nitrogen and carbon in tissues that afterward can be released back in the environment (Kröger et al., 2007). Thus, causing additional leaching of nutrients to lakes and watercourses.

To reach a good result of a wetland restoration project, the restoration goals must be well-considered not only regarding the nutrient loss mitigation, but also the biodiversity, which is often left out or covered insufficiently in such type of projects.

1.1. Wetlands in Europe and Denmark

Wetlands are a significant component of Europe's biodiversity, representing a wide range of habitats and species as well as providing important ecosystem services. The main services provided are flood control, groundwater replenishment, stabilisation of shoreline and protection from storms, sediment and nutrient retention export, water purification, biodiversity reservoirs, wetland products, cultural values, recreation and tourism, as well as climate change mitigation and adaptation (Ramsar Convention Secretariat, 2011).

Wetlands include such habitats as mires, lakes, streams, coastal wetlands etc. During the last 100 years, more than two thirds of the total area of natural wetlands in Europe has been lost as a result of peat extraction, raise in the amount of nutrients entering the wetlands, along with drainage to increase the area of agricultural lands and forested areas (Silva et al., 2007). Nowadays, wetlands cover 2% of the total area of The European Union (EU). Only 4% of the territory of EU's network of protected areas Natura 2000 are classified as wetlands. EU member states have reported that the status of 51% of the total area covered by wetland habitats is unfavourable-bad, while more than a half of the river and lake habitats are in unfavourable-inadequate status (European Commission, 2015).

Denmark is rich with lakes and streams, there are more than 7200 lakes with the total area of 57000 ha, while the total length of streams is 64000 km (Skov- og Naturstyrelsen, 2004). It has been calculated that up to 98% of Danish streams have been straightened, thus losing their typical morphological features as well as diversity of plant and animal species (Brookes, 1987). Danish mires cover 90000 ha large area, however in the past, the area of fens, transition mires and bogs were much larger than it is currently. Mire habitats have been primarily lost due to intensification of agriculture and drainage (Skov- og Naturstyrelsen, 2004). In the report on habitat assessment for the period 2007-2012, the status of Danish bogs, mires and fens are described as unfavourable-bad or unfavourable-inadequate. Similar situation is also seen with freshwater habitats. However, wetland and freshwater habitat status has been improved since the reporting for the period 2001-2006. The improvement has been done by enhancing the state of several types of habitats from unfavourable-bad status to unfavourable-inadequate (European Commission, 2013a). It is crucial to continue to improve the status of wetlands in Denmark and Europe in general as well as to restore wetlands that have been degraded and destroyed completely.

1.2. Legislation

The loss of wetlands is not only a problem on a local or European scale, countries worldwide are facing decrease of the area of wetland habitats and loss of biodiversity. One of the first networks developed to promote wetland conservation and sustainable use of wetlands globally was through The Convention on Wetlands of International Importance Especially as Waterfowl Habitat, also known as The Ramsar Convention. The Convection was adopted in 1971, it has three main pillars: (1) a wise use of wetlands, which is reached through national plans, policies, public education etc., (2) suitable wetlands are included in The List of Wetlands of International Importance, also known as The Ramsar List, (3) international cooperation on transboundary wetlands (UNESCO, 1971). In Europe, there are more than 1100 Ramsar sites, 28 are located in Denmark (Ramsar Secretariat, 2019). The surface area of Danish sites is 7400 ha (Miljø- og Fødevareministriet, 2019a).

All EU member states are obliged to achieve goals of different EU directives, four directives are particularly important regarding wetland protection and restoration. The focus of The Council Directive 92/43/EEC, also known as The Habitats Directive, is set on conservation of natural habitats as well as wild flora and fauna, including wetland habitats, plants and animals found in wetland ecosystems. More than 1000 animal and plant species and 200 habitat types are listed in the directive's annexes. (European Commission, 1992). In Denmark, approximately 60 habitat types and 100 species are under the protection of the directive (Miljø- og Fødevareministriet, 2019b). The Council Directive 2009/147/EC or The Birds Directive was issued to improve the conservation of wild birds. Many bird species that are stated in the annexes of the directive are found in wetlands. In general, wetlands are important feeding, breeding and nesting sites for different bird species (European Commission, 2010). Approximately 80 bird species listed in the directive are registered in Denmark (Miljø- og Fødevareministriet, 2019b). The main aim of The Council Directive 2000/60/EC or The Water Framework Directive is to reach a good qualitative and quantitative status for all water bodies - meeting certain standards for ecology, hydromorphology, chemistry and quantity of waters (European Commission, 2000).

In 1991, The Council Directive 91/676 /EEC, also known as The Nitrates Directive, was published to raise concerns about nitrates pollution from the agriculture and protection of water quality (European Commission, 1991).

In addition to the EU directives, EU member states have their own local legislation regarding the conservation of wetlands, wetland restoration, reduction of nitrogen and phosphorus pollution from agricultural lands etc. In Denmark, the implementation of the three directives is closely linked with The Action Plans on The Aquatic Environment. The first action plan was developed in 1987, the second in 1998. Both documents were primarily focusing on reduction of nitrogen emissions from agriculture to aquatic environment. The first action plan was aiming to reduce 50% of nitrogen emissions and 80% of phosphorus in waste waters, while the second plan – to continue the reduction (Grant and Waagepetersen, 2003). The third action plan was published in 2004. In this plan, aside cutting down the nitrogen emissions from agriculture, focus was also set on reduction of phosphorus losses from agriculture (Miljøministeriet og Ministeriet for Fødevarer, 2004). Wetland restoration as an instrument for reduction of nitrogen and phosphorus emissions was included in the second action plan and have been implemented since then. Through the implementation of the action plans, many wetland restoration projects have been carried out in Denmark. However, the projects are focusing on wetlands as tool to reduce the nitrogen and phosphorus emissions rather than restoring wetland habitats and increasing biodiversity.

The current regulation regarding wetland restoration in Denmark is described in two main documents, the first is Statement on Criteria for State Owned Wetland Projects (Miljø- og Fødevareministeriet, 2015). Danish Nature Agency can apply for such type of projects; several criteria should be fulfilled to receive the funding: (1) the wetland has to be included in wetland project catalogue as a potential restoration area, (2) nitrogen reduction in the wetland should be at least 113 kg/ha per year, (3) the project has to be cost-effective taking into account price per kg of nitrogen, (4) during the project, natural hydrological processes should be restored. In addition, it is emphasized that the wetland should not have leaching of ocher or phosphorus, the whole effect of project on wild flora and fauna as well as on Natura 2000 areas, protected plant and animal species should not be negative.

The second regulation is Statement on Subsidies for Wetland Projects and Nature Projects on Carbon Rich Lowland Soils (Miljø- og Fødevareministeriet, 2018). Municipalities and The Nature Agency can apply for the projects. There are four types of such projects: (1) pre-examination of wetland areas potential for nitrogen or phosphorus removal, (2) establishment of wetlands for phosphorus or nitrogen removal, (3) pre-examination of areas for lowland projects, (4) establishment of lowland areas. Each of the project types has a set of criteria, for example, wetlands that are planned to establish for nitrogen removal, must remove at least 90 kg nitrogen per hectare every year, while for phosphorus removal, the minimal size of the catchment area is 2 km^2, etc. Nitrogen removal wetlands and lowland areas must fulfill such criteria as creation of natural or close to natural hydrological regime in the area. However, there is no criteria that must be fulfilled regarding the wild flora and fauna as it was in the case of state-owned projects. A share of the subsidies for restoration of wetlands for nitrogen and phosphorus removal is allocated by The Food and Agriculture Package (Miljø- og Fødevareministriet, 2019c).

The current regulation regarding wetland restoration in Denmark is tightly joint to

The Water Framework Directive - EU member states are required to develop River Basin Management Plans. The first Management Plan for Odense Fjord River Basin, including Kratholm catchment, where this research was done, was issued for the period 2010-2015 (Miljøministeriet and Naturstyrelsen, 2011). For the next period 2015-2021 The Danish Ministry of Environment and Food published The Water District Plan for Jutland and Fyn (Miljø- og Fødevareministriet, 2016).

1.3. Wetland Classification

Term “wetlands” is used to describe a wide range of habitats, however the most commonly used definition of wetlands come from The Ramsar Convention. Within the document, wetlands are defined as: “*Marshes, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is flowing or static, fresh, brackish or salty, including areas of marine water the depth of which at low tide does not exceed six metres*” (UNESCO, 1971). Thus, several groups of wetland habitats can be distinguished: marine, coastal, freshwater, wet meadow, mire, alluvial and swamp wood habitats (Silva et al., 2007). As this research is done in the areas were river, wet grassland and mire habitats have been restored, the classification of these three wetland habitat groups will be further described.

European habitat classification is based on the hierarchical classification of European habitats. The document was developed under CORINE Biotopes project (Commission of the European Communities, 1991). It is suggested that the classification can be used for non-priority habitats as more detailed habitat descriptions have been developed for the habitats mentioned in the Annex I of The Habitats Directive (European Commission, 2013b). According to the CORINE classification, nonmarine waters are divided in (1) lagoons, (2) standing fresh water, (3) standing brackish and salt water, (4) running water. Bogs and marshes fall into five groups – (1) raised bogs, (2) blanket bogs, (3) water-fringe vegetation, (4) fens, (5) transition mires and springs. As mentioned before, grasslands can be part of the riverine system, such grasslands according to the CORINE habitat classification are humid grasslands as well as tall herb communities (Commission of the European Communities, 1991).

Regarding the habitat classification in EU, Interpretation Manual of European Habitats gives a description of more than 200 natural habitat types which are included into the Annex I of The Habitats Directive. Freshwater habitats are divided in two groups – standing water and running water. Standing water section includes different types of lakes and ponds, while running water is classified as rivers. There are several natural and semi-natural grassland types found along the streams, such as the habitat 6450 Northern boreal alluvial meadows. The section of mire habitats include bogs, transition mires, springs, springfens, fens etc. (European Commission, 2013b). Currently in Denmark, seven freshwater habitats and seven bog, mire and fen habitats that are listed in The Habitats Directive are found. Regarding the grasslands that are part of the stream ecosystem, only one habitat has been reported – 6430 Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels (European Commission, 2013a).

CORINE classification has been used as a basis for DANVEG – a database for grassland and mire plant community classification in Denmark (Nygaard et al., 2009). The database consists of lists of vascular plant species and cover from more than 13000 plots described in different locations in Denmark. In total, eight grassland and nine mire plant communities have been defined. The database was used for evaluation of the vegetation in the studied sites. Detailed description of the database is given under the section 2. Methods.

1.4. Wetland Restoration in Denmark

During the past 100 years, wetlands all over the Europe have been drained and modified, some disturbance has been done already a long time before that. It is crucial to protect wetlands as the ecosystems have a unique biodiversity and they provide a set of ecosystem services that are important for humans. Some wetlands have been destroyed to a stage where it is hard to include them in any conservation project, therefore it is significant to implement wetland restoration projects to bring the sites back to the natural state as close as it is possible (Verhoeven, 2014).

Denmark is one of the most active EU member states regarding wetland restoration. It has more than 25 years long experience in wetland restoration. The restoration projects include such actions as stream re-meandering, as well as re-establishment of fens and wet meadows (Hoffmann et al., 2011). It has been calculated that the restoration projects usually take place in areas that were used as agricultural lands (42%) or meadow-lands (39%) (Hoffmann and Baattrup-Pedersen, 2007). So far, more than 200 wetlands have been restored in Denmark (Carl Christian Hoffmann 2019a, personal communication).

However, the wetland restoration projects generally focus on mitigation of nitrogen and phosphorus losses from agricultural lands (Hoffmann and Baattrup-Pedersen, 2007; Audet et al., 2015). No clear guidance has been given for enhancement of biodiversity in wetland areas where the restoration has been implemented (Audet et al., 2015). It is a challenge to set restoration goals for wetland ecosystems as the definition of success can be different among various stakeholders involved in the restoration process. The goals should be set according to the information that is already available, while leaving a place for improvements during the project, if it is needed (Kentula, 2000).

Three types of wetland restoration success can be distinguished – compliance success regarding the terms of agreement, contract etc., functional success, which is characterized by restoration of ecological functions, and landscape success. The first two types of success focus on a project scale, while the third evaluates how restoration of a wetland has changed the landscape (Kentula, 2000). A large share of restoration projects, if the habitat restoration is among the main aims of the project, focus on creation of a habitat, which leads to biota restoration. However, many other factors are playing an important role to reach a successful wetland restoration project. Such as barriers to colonization, shifts in habitat use, introduced species, long-term and large-scale processes as well as inappropriate scales of restoration (Bond and Lake, 2003).

To assure that ecological functions of the wetland ecosystem are restored and the status of the area improved, the wetland management as well as monitoring should be studied more (Kentula, 2000; Suding, 2011). However, often vegetation descriptions prior to restoration are missing, thus it is difficult to follow the direction of vegetation development after the restoration.

In Denmark, one of the largest wetland restoration projects implemented so far is Skjern River Valley restoration near Ringkøbing Fjord in Western Jutland. The total area where the restoration activities were implemented, is 22 km^2. In 1960's, the area was drained, River Skjern straightened, and the landscape became agriculture dominant. The restoration work was done from 1999 till 2002, however the first legal act regarding River Skjern restoration was approved already in 1987 (Andersen et al., 2005). The main restoration objectives for the area were to restore the nutrient retention capacity, thus reducing eutrophication in Ringkøbing Fjord, to restore a wetland with an international value, to promote fishing and to build up recreational and touristic values for the area (Pedersen et al., 2007). During the project, the previously straightened river bed was re-meandered, dikes and a pump station removed. The length of the river increased from 19 km to 26 km. During the evaluation of the restoration success, it was concluded that the amount of nutrients entering Ringkøbing Fjord cannot be significantly reduced through the restoration activities – in this case the focus should be set on the nutrient sources from the whole catchment area. However, the landscape has changed from an agriculture dominated to a more natural landscape, where an ecosystem with a river, lakes, ponds, wetlands, and meadows is created. It has become an important area for birds, amphibians and other animal groups (Andersen et al., 2005). Regarding habitats, a higher habitat and substratum diversity developed after the restoration. A short-term monitoring results showed that the coverage of macrophytes was low while the species diversity increased. In general, the project is considered as successful, habitat management such as grazing of the meadows in the restored area will be an important factor for further ecosystem functioning and processes (Pedersen et al., 2007).

Several wetland restoration projects have been implemented in River Odense basin on Fyn, however in this case it was done under The Action Plans on The Aquatic Environment, instead of creating a separate legal act as it was in the case of River Skjern restoration. Regarding the streams in the research area – Kratholm catchment, the historical data show that the rivers Odense, Silke, Sallinge, Hågerup, and Tørringe brook were regulated in a six-year period from 1944 till 1950. One of the wetland restoration projects carried out in the Kratholm catchment is River Odense restoration near Brobyværk. The aim of the restoration project was to re-meander the stream, restore wet and dry meadows along the stream, thus enhancing the biodiversity in the area and reducing nitrogen input in the stream from adjacent agricultural areas (Madsen and Debois, 2006). Complete vegetation descriptions before and after the restoration are missing from the projects implemented in the Kratholm catchment, thus it is difficult to follow the vegetation and habitat development in the area.

Most of the wetlands in the Kratholm catchment, which is part of River Odense basin, were restored under the second action plan. The criteria for the potential areas according to the guidelines no. 133, 15.07.1998. of the Danish government (Erhvervsministeriet, 1998; Hoffmann and Baattrup-Pedersen, 2007). The document includes several preconditions for the sites such as: (1) restoration sites should be placed in catchments that are discharging in vulnerable lakes, fjords, coastal waters, where an improvement in the environmental conditions will be reached due to the reduction in nitrogen load, (2) the areas should situated in catchments or sub catchments where the streams receive great nitrogen loads or in areas where groundwater is influenced by agricultural activities, (3) natural hydrological conditions and topography should be enabled to maintain the water fluctuations near the soil surface, (4) natural values of the area should be enhanced, (5) project areas should retain phosphorus. In addition, several other criteria were published in a governmental notice no. 966, 16.12.1998 few months later (Miljø- og Fødevareministeriet, 1998; Hoffmann and Baattrup-Pedersen, 2007). The criteria were: (1) the restored areas should remove from 200 to 500 kg N/ha every year, (2) the re-establishment of natural hydrological processes should be dominating in the area, (3) the natural flora and fauna should be benefiting from the project, (4) the leaching of phosphorus or ochre should not be increased. Regarding the vegetation and habitats in the restored areas, no certain goals have been set in the previously mentioned guidelines.

1.5. Vegetation in Restored Wetlands

Even though wetland restoration in Denmark and Europe in general has been done for several decades, there is lack of comprehensive information about the vegetation succession after the restoration work. Most riparian wetland restoration projects, including projects implemented, focus on restoring specific instream conditions instead of looking at the outcomes for biodiversity in the whole riparian system including river and adjacent riparian area (Göthe et al., 2016). In Denmark, a large share of wetland restoration projects focusses on reduction of amount of nutrients entering streams, lakes etc. As the restored areas receive high nutrient loads, it will prevent, for example, developing species-rich plant communities in the area, thus nutrient removal combined with improved plant diversity can be challenging (Audet et al., 2015). While planning restoration, it must be taken into consideration that each restoration area is specific – with a different management history, surrounding habitats, seed bank etc. The restoration success should be assessed against a target; therefore, restoration targets must be well considered.

It is assumed that the restoration success of biota depends on the physical factors (Bond and Lake, 2003). In a research where the response of floodplain vegetation to stream restoration in 20 projects from Europe were analysed. Restoration projects were classified in two groups – large- and small-scale projects with three subgroups in each: (1) primarily widening the stream channel, (2) recreating instream structures, for example, adding a coarse substrate, (3) other measures such as dam removal, remeandering the stream channel etc. It was found that the strongest positive effect on plant communities, regarding the plant diversity and trait composition, has stream channel widening, for example, by removing the bank fixation. It can be explained with increased physical disturbance, such as flooding, which increases availability of open habitats. Within the study, a set of environmental variables were also compared.

Altitude and discharge had a strong positive effect on species and trait diversity (Göthe et al., 2016). However, in this case the authors were looking only at the instream vegetation instead of the whole riparian area in each of the sites.

Besides the physical factors, many other factors can play an important role when restoring biota is among the main goals of a restoration project. Therefore, the restoration should be viewed from a holistic perspective. During the planning phase of habitat and target species restoration, following topics should be covered: (1) potential problems regarding colonization (barriers), (2) habitat requirements for target species in different life stages, (3) response of introduced species compared to native species, (4) the effect of long term and large scale project regarding, for example, monitoring strategy, (5) size of habitat patches for a successful population, community and ecosystem restoration (Bond and Lake, 2003). Such vegetation indicators as annual and perennial species richness, ratio of helophytes and hydrophytes, total plant cover, above- and underground plant biomass, diversity, life forms, key species, plant productivity can be used to describe the changes in vegetation after the restoration (Henry and Amoros, 1995).

In case of River Skjern restoration project, vegetation was described in the stream as well as the adjacent areas. It was found that in 2003, one year after the restoration was finished, the vegetation cover decreased since in some areas it might take a much longer time for plant communities to colonize the newly created habitats. However, many new vascular plant species with a low coverage were registered after the restoration. The most common vascular plants described were Unbranched bur-reed *Sparganium emersum* and Canadian waterweed *Elodea canadensis* (Andersen et al., 2005).

In two restored riparian wetlands in Denmark, Egeskov and Storå, a vegetation survey was done five years after the restoration. Both wetlands were established with the main goal to mitigate nitrogen and phosphorus loss from agricultural to surface waters (Hoffmann et al., 2012). Before the restoration, agricultural fields in crop rotation were dominant in both areas (Carl Christian Hoffmann 2019b, personal communication). The results of the survey showed that the dominant vascular plant species in Egeskov were Broadleaf cattail *Typha latifolia*, Floating sweet-grass *Glyceria fluitans*, Common rush *Juncus effesus*, Creeping soft grass *Holcus mollis*, Common reed *Phragmites australis,* and willows *Salix sp*. The most common species in Storå wetland were *G.fluitans*, Creeping buttercup *Ranunculus repe*ns, and

Common nettle *Urtica dioica* (Hoffmann et al., 2012). However, the pre-assessment of the vegetation in both areas is missing, therefore it is not possible to compare the situation before and after the restoration.

Regarding the mire habitats, it has been found that rich fens that are drained and rewetted after several decades recover very slowly. In a long-term research from Sweden three stages of succession of fens after drainage were distinguished – (1) loss of the typical bryophytes, (2) increase of sedges and bryophytes that are usually present in early successional stages, (3) increased dominance of Purple moor-grass *Molinia caerulea*, Downy birch *Betula pubescens* and Sphagnum moss *Sphagnum spp*. The main reasons for a slow recovery were changes in the substrate over the time, limitation in dispersal, and presence of few dominant species (Malson et al., 2008). Slow changes in vegetation were also seen after restoration of eleven oligotrophic pine fens in Finland that were drained in 1970's and 1980's for forestry purposes. Restoration of hydrology takes relatively short period of time, however changes in species composition several years after the restoration were little (Laine et al., 2011). In both cases the habitat restoration was the main goal and vegetation has been described over a longer period, thus allowing to compare and evaluate how the vegetation changes after the restoration.

In a research, where evaluation ecosystem services of 23 mire sites in NE Germany was done 10 years after restoration, dominant vegetation along with evaluation of peat formation potential, and aboveground biomass and nutrient levels where the main parameters which were taken into consideration. Before the rewetting, the sites were described as fen grasslands that were fertilized and mown 2-3 times a year (Zerbe et al., 2013). The most common vascular species found in the fens were Reed canarygrass *Phalaris arundinacea*, Cock's-foot *Dactylis glomerata*, Tall fescue *Festuca arundinacea*, and Couch grass *Elytrigia repens* (Succow and Joosten, 2001). Five years after the restoration, distribution of Common reed *Phragmites australis* and Broadleaf cattail *Typha latifolia* increased. After 10 years, *P.arundinacea* wetlands disappeared almost completely. One third of the areas after the restoration were covered with a shallow water, where submerged and floating macrophytes such as Duckweed *Lemna spp.* and Rigid hornwort *Ceratophyllum demersum* were common. In relatively small patches a species rich fen vegetation was found. Regarding the main aim – restoration of certain ecosystem services, the restoration has been successful sites as the vegetation established had a high potential for peat formation for example the vegetation where *P.australis* and *Carex sp*. are dominant. In addition, it was found that *P.australis* has a high potential as a nutrient sink – the species accumulated high levels of carbon, phosphorus and nitrogen (Zerbe et al., 2013).

Another crucial parameter in wetland restoration projects is wetland age, describing time since the wetland was restored. The interpretation of young and old wetlands can differ among the studies. For example, in a research on wetland ecosystem services, eight years old wetland was considered as a young wetland, while wetlands that are more than 100 years old were described as natural wetlands (Hansson et al., 2005). In some studies, wetland age is defined by age classes, such as 2 and 20 year or 5, 10, 15, 20 up to 100 years old wetlands (Atkinson and Cairns, 2001; Moreno-Mateos et al., 2012). Timewise, wetland restoration can also be described as short-term, and long-term, for example, setting short-term and long-term restoration goals etc. Again, there is no common interpretation used for these two classes. For example, long-term aspect can be applied for wetlands with restoration age of more than two years (Zedler and Callaway, 1999).

Monitoring is an important component of ecosystem management, allowing to follow long-term change in wetland ecosystems (Erwin, 2009). Various vegetation-based indicators used in monitoring have a different response time, thus the duration of monitoring should be considered thoughtfully (Matthews et al., 2009). It has been found that it takes approximately 30 years for restored wetlands to reach close to reference state regarding vegetation. However, for some criteria such as species richness even 100-year-old wetland did not reach values of reference wetlands (Moreno-Mateos et al., 2012).

In Denmark, where the landscape is agriculture dominant, it may take a long time to reach a close to natural state in restored wetlands. It has been described that the two main factors for a high species richness in restored wetlands, are groundwater level in less than 37 cm depth, as well as low soil phosphorus content - less than 347 μg cm^3 (Audet et al., 2015). In general, the vegetation in riparian zones depends on nutrient and water input from the catchment (Jansson et al., 2007). In a research on environmental controls of plant species richness in wetlands, 35 vegetation plots were described in 10 riparian wetlands that are considered the least disturbed stream ecosystems in Denmark (Audet et al., 2015). The clustering results showed three main groups of species. The first group was formed by species characteristic to meadows, such as Meadow fescue *Festuca pratensis* and Perennial ryegrass *Lollium perenne*. For the second group, the indicator species were Water horse-tail *Equisetum fluviatile* and Reed canary grass *Phalaris arundinacea* and others. The group was described as herb fringe vegetation. Fen species were more abundant in the third group of vegetation plots. However, there were only three indicator species, two bryophyte species among them, - The big trefoil *Lotus pedunculatus*, Pointed spear-moss *Calliergonella cuspidata*, and Marsh thyme-moss *Plagiomnium ellipticum*. The third group of species is defined as a target vegetation for wetland restoration projects in Denmark.

1.6. Nitrogen Removal in Wetlands

High loads of nitrogen and phosphorus to lakes, rivers, and seas can lead to eutrophication and extensive blooms of algae as well as oxygen depletion, when a large amount of oxygen is used during the decomposition process of algae. Lack of oxygen can induce fish deaths, while increased nutrient loads can cause changes in aquatic vegetation, food webs, etc. (European Environmental Agency, 2000). Due to high nutrient input, most of Danish lakes are classified as eutrophic (Jeppesen et al., 1999). Eutrophication is also a significant problem for Danish estuaries. Most of the estuaries are shallow, less than 3 m deep, with a short residence times while the nutrient load reaching the estuaries is relatively high (Conley et al., 2000).

In Denmark, with an implementation of action plans and changes in agricultural practices, it has been possible to significantly reduce the pollution. For the period 1989-2002, nitrogen net nitrogen surplus was decreased for 41% from 136 to 88 kg N/ha per year (Kronvang et al., 2005). As one of the solutions advised to reduce the nitrogen leaching to streams, lakes and coastal waters was restoration of wetlands, thus increasing the denitrification rates (Kronvang et al., 2008).

Through the denitrification process, wetlands remove a high amount of nitrate NO_3^-, which is delivered to wetlands with groundwater and drainage water. Nitrate is removed from the ecosystem through conversion to nitrogen gas N_2, which is performed by denitrifying bacteria (Hanson et al., 1994). The main reason why wetlands are effective for reducing large amounts of nitrate entering streams are carbon rich wetland soils with low oxygen levels (Hoffmann and Baattrup-Pedersen, 2007). In denitrification, carbon is used as an electron donor, while anaerobic environment is important for the denitrifying bacteria, which are facultative anaerobic organisms.

During the evaluation of nitrogen removal success in 10 wetlands restored under the second action plan, the mean nitrogen removal was estimated to 259 kg N/ha per year, while monitoring shows that the values range from 39 to 371 kg N/ha per year with nitrogen removal efficiency varying from 28 to 71% for wetlands that have been irrigated and inundated (Hoffmann and Baattrup-Pedersen, 2007). A similar research was done in two riparian wetlands - Egeskov and Storå - five years after the restoration. Monitoring data showed that the nitrogen removal varied between 28 and 229 kg N/ha per year, which leads to the efficiency between 26 and 75% (Hoffmann et al., 2012).

Part of the nitrogen that is delivered to the wetlands is taken up by above ground biomass. By sampling biomass from the restored Egeskov riparian wetland, it was found that the amount of nitrogen in the vegetation is 127 kg N/ha, while in Storå the amount of nitrogen in the above ground vegetation was 108 kg N/ha. By harvesting the biomass, a large share of nitrogen load is removed from the wetland. On the other hand, the organic matter is an important factor for high denitrification rates as it acts as an electron donor (Hoffmann et al., 2012).

Asides the average aboveground biomass measurements, where different species are sampled together, there are studies looking at nitrogen, phosphorus, and carbon content in a biomass of a particular species. For example, in a restored wetland in Germany, it was measured that *P.australis* can take up to 2.1 t N/ha per year, while *T.latifolia* up to 1.1 t N/ha per year (Zerbe et al., 2013).

Nutrients that are taken up by plants during the growing season, can be lost in the period after the growing season. For example, *P.arundinacea*, which is a common wetland plant species in Denmark, can accumulate a large amount of nitrogen and rapidly loose it at the end of the season. In a research on nitrogen and phosphorus retention by five wetland plant species, *P.arundinacea* retained only 28% of nitrogen in the decomposing shoots after five months of decay. To compare, Common rush *Juncus effusus* was accumulating high rates of nitrogen and retaining 87% of nitrogen (Kao et al., 2003).

1.7. Phosphorus Removal in Wetlands

With the implementation of mitigation programmes during the last decades, Denmark has significantly reduced the phosphorus discharges to Danish coastal waters (Carstensen et al., 2006). During the period 1989-2002, phosphorus input to watercourses was reduced for 82%, while the net phosphorus surplus decreased for 42%, from 19 to 11 kg P/ha per year (Kronvang et al., 2005). Restored wetlands can be a useful tool for a further reduction of the amount of phosphorus entering streams, riparian wetlands where inundation occur are particularly effective for phosphorus removal. The four hydrological paths for phosphorus losses and retention in riparian areas are diffuse flow path with ground water, overland flow with water from agricultural fields next to an area, irrigation of wetlands with the water coming from disconnected tile drains, and inundation with river water (Hoffmann et al., 2009).

Similarly to nitrogen, a significant amount of phosphorus is accumulated in the aboveground biomass. In the study from Egeskov and Storå riparian wetlands, it was found that the amount of phosphorus in the vegetation from Egeskov was 10.3 kg P/ha and 16.5 kg P/ha from Storå. As the amount of accumulated phosphorus in the plant biomass is 8-11 times larger than the annual phosphorus load to the wetland, thus removal of plant biomass from the wetlands could help to take out a significant amount of phosphorus (Hoffmann et al., 2012). A similar conclusion was drawn in a study on rewetted peatlands in Germany (Zerbe et al., 2013).The authors of the study concluded that the biomass of aquatic and wetland plants must be harvested to reduce nutrient levels, especially phosphorus and nitrogen.

In a study from degraded inundated peat soils in Germany, phosphorus level was measured in six wetland helophyte species – *T.latifolia*, *G.maxima*, *P.australis*, *C.riparia*, *C.acutiformis*, and *P.arundinacea* (Zak et al., 2014). It was found that the highest rates of phosphorus accumulation have *T.latifolia* 30.0 kg/ha and *G.maxima* 28.0 kg/ha. The phosphorus uptake ranged from 11.0 kg/ha up to 30.0 kg/ha. When a leaching experiment was performed to find what amount of phosphorus is released in a 24 hours long leaching event, the results showed that the plant species loose from 48% to 83% of the phosphorus stock. The highest leaching occurred for *P.arundinacea*. Asides the leaching experiment, decomposition rates were measured for four species: *T.latifolia*, *P.australis*, *C.riparia*, and *P.arundinacea*, by performing a 154 days long decomposition experiment. It was found that 6-31% of phosphorus was released during the decomposition. Summarizing leaching and decomposition rates, the highest phosphorus loss occurred in *P.arundinacea* samples, where 92% of initial phosphorus content was lost. The lowest rate had *C.riparia* – 72%. Similar values of phosphorus stock in biomass show measurements from certain helophyte and hydrophyte species (Steffenhagen et al., 2008). For example, *P.australis* store 19.0 kg P/ha, *T.latifolia* 29.0 kg P/ha, *G.maxima* 28 kg P/ha etc. Even though data on phosphorus uptake and loss for a particular species are available, there is lack of such data on a plant community or habitat level.

1.8. Aims and Objectives

The aim of the thesis is to evaluate the restoration success of 10 wetland restoration projects in Kratholm catchment. The wetlands in this catchment were restored to remove nitrogen, decrease phosphorus leaching as well as to re-establish natural hydrological processes, which would be beneficial for natural flora and fauna (Miljø- og Fødevareministeriet, 1998). The focus of the thesis is set on testing the effect of wetland age on vegetation and plant communities as well as nitrogen and phosphorus stock and release by plants.

To reach the aim, four main objectives have been set:

1. To describe general vegetation parameters and plant communities in restored sites with a different restoration age and compare to the plant community descriptions of DANVEG database.
2. To analyse the relationship between the dry aboveground biomass, nitrogen, and phosphorus stock, nutrient leaching, and vegetation, as well as wetland age.
3. To develop management recommendations for the restored sites in Kratholm catchment
4. To assess the restoration success and suggest improvements for future restoration projects.

Hypothesis of the thesis: the long-term restoration effect on wetland vegetation is increased species richness and diversity as well as increased nutrient stock and removal by plants.

2. Methods

2.1. Description of the Research Area

The field work was carried out in the Kratholm catchment, located in the Southern part of The River Odense basin on the island of Fyn in Denmark (Figure 1).

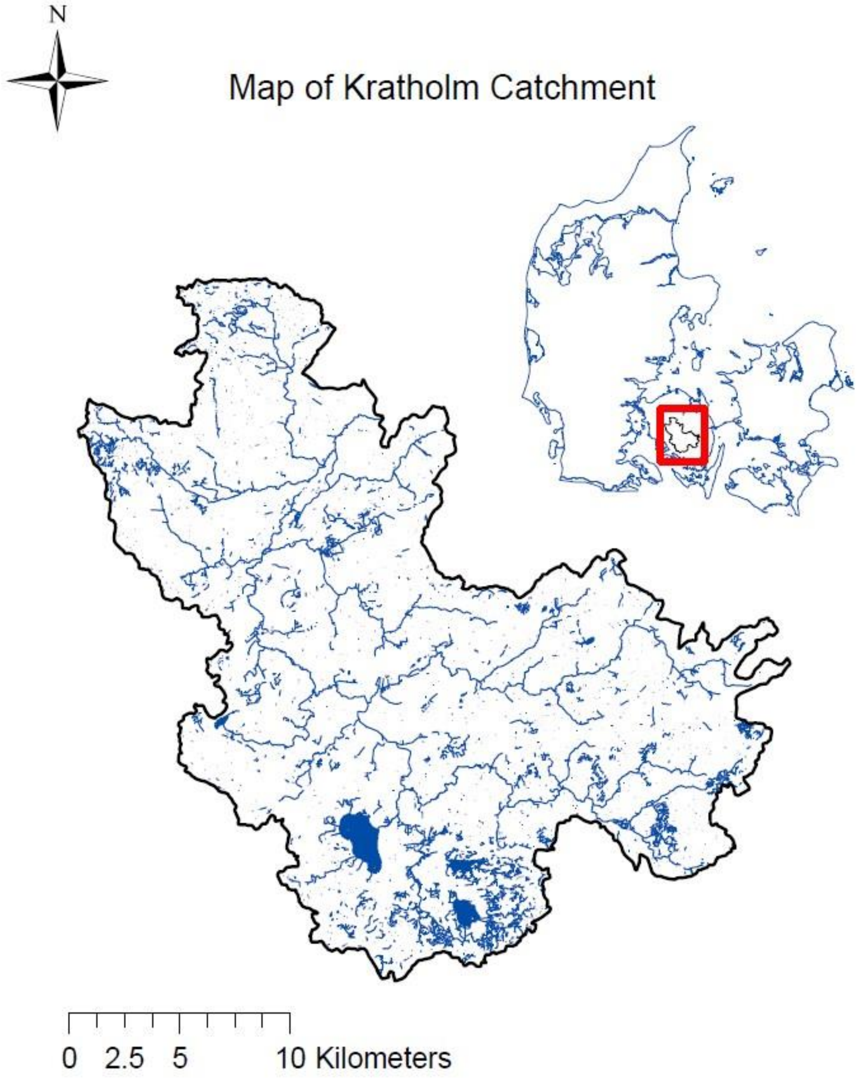


Figure 1. Map of Kratholm catchment.

The total area of the catchment is 486 km^2. The catchment is characterized by a temperate and humid climate (Hashemi et al., 2018). The average annual precipitation in the catchment is 740 mm. The landscape is dominated by moraine plains, covered with moraine clay deposits, which were left by the base of the ice sheet that was formed during the Weichsel glaciation period. The most common soil types found in the area are loamy sandy soils, represented in 40% of the catchment, as well as sandy clay soils, found in 36% of the area. The dominant type of the land use is agricultural land in 71% of the area, while 15% are forested areas and 8% - urban areas (Kronvang et al., 2012).

Kratholm is one of the Danish catchments where the wetland restoration has been very popular, thus large areas of wetlands have been restored. The restoration work in the catchment has been done since the year 2000 (Windolf et al., 2016). The studied area consists of ten restored sites with a total area of 858.9 ha (Figure 2, Table 1). The wetland restoration work in the research areas has been done as part of The Action Plan for the Aquatic Environment II, except Posens Mose, where the restoration was carried out under The Action Plan for the Aquatic Environment III.

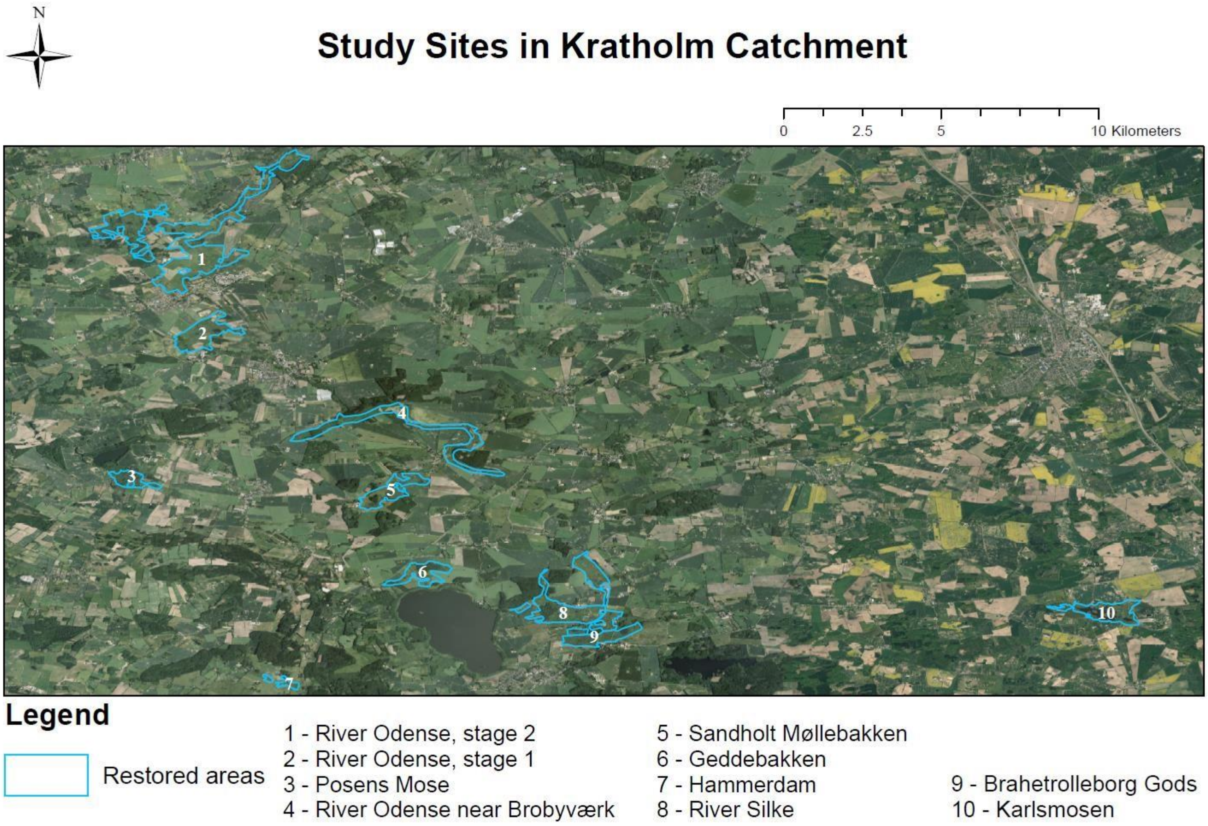


Figure 2. Map of studied wetland restoration sites in Kratholm catchment.

Table 1. Studied sites, year of the restoration and size of the area.

Restored site	Year restored	Area, ha	Type of restoration
River Odense, stage 2	2010	295.7	Re-meandering and tile drain cut
River Odense, stage 1	2009	68.8	Re-meandering and tile drain cut
Posens Mose	2009	26.1	Tile drain cut
River Odense near Brobyværk	2003	104.4	Re-meandering and tile drain cut
Sandholt Møllebakken	2003	54.7	Re-meandering and tile drain cut
Geddebakken	2003	44.1	Tile drain cut
Hammerdam	2005	9.8	Re-meandering and tile drain cut
River Silke	2011	146.9	Re-meandering and tile drain cut
Brahetrolleborg Gods	2008	45.6	Re-meandering and tile drain cut
Karlsmosen	2001	62.5	Re-meandering and tile drain cut

The first stage of River Odense restoration project was finished in 2009. The area of the restored stretch of the river is 68.8 ha. **The second stage** was accomplished a year later – in 2010. It is also the largest of all 10 study sites with the total area of 295.7 ha. The wetland restoration activities in both projects included tile drain cut and remeandering River Odense.

Posens Mose was restored in 2009 with the total area of 26.1 ha. The main restoration activity was cutting tile drains.

River Odense near Brobyværk was restored in 2003, the total area where the restoration project was implemented is 104.4 ha. The restoration aim for the area was to re-create wet and dry meadows as well as reducing the nitrogen input from agricultural lands to the stream. During the project, a 3.6 km long stretch of the stream was re-meandered and the river bed raised (Madsen and Debois, 2006). Additionally, tile drains were cut in the area.

Sandholt Møllebakken wetland restoration was finished in 2003. During the restoration, River Odense was re-meandered and tile drains cut. The total area of the site is 54.7 ha.

Geddebakken is a 44.1 ha large area near lake Arreskov. The wetland was restored in 2003 by disconnecting drains that were draining the wetland. As a result, several small shallow lakes were formed that are currently surrounded by wet meadows (Windolf et al., 2016).

Hammerdam is the smallest of the research sites with the total area of 9.8 ha. Wetland restoration in Hammerdam was done in 2005. The main restoration activities included re-meandering of River Odense and drainage tile cutting in the area.

River Silke restoration was done in 2011. The area of the restored site is 146.9 ha. During the project, River Silke was re-meandered and tile drains cut.

North from River Silke occurs **Brahetrolleborg Gods** wetland restoration project area, which was implemented in 2008. The area of the restored wetland is 45.6 ha. The main restoration activities in the area were stream re-meandering and tile drain cutting.

Karlsmosen is the eldest restored site, where the restoration work was done in 2001. The total area of the site is 62.5 ha. During the restoration, 18 tile drains that were draining the adjacent agricultural lands were cut. During the restoration of the area, River Hågerup was re-menadered so the stream water floods the reestablished riparian fen (Hoffmann et al., 2011).

2.2. Vegetation Descriptions

The vegetation descriptions in the research areas were done in June 2018. The size of the vegetation plots was 4 m^2 (2 by 2 m or 1 by 4 m in case the plot occurred right at a stream). In total, 172 vegetation plots were described (Table 2). The location of the vegetation plots was chosen randomly. Vegetation descriptions were done according to Braun-Blanquet cover - abundance scale (Braun-Blanquet and Pavillard, 1930). The scale used in the field work is shown in Table 3. In the vegetation plots, all vascular plant and bryophyte species were determined by using field guides (Atherton et al., 2010; Mossberg and Stenberg, 2014). A map of described vegetation plots is shown in Figure 3.

Table 2. Number of vegetation plots described in the study sites.

Restored site	Year restored	Number of vegetation plots described	Number of aboveground biomass samples collected
River Odense, stage 2	2010	70	18
River Odense, stage 1	2009	9	2
Posens Mose	2009	8	4
River Odense near Brobyværk	2003	25	4
Sandholt Møllebakken	2003	7	4
Geddebakken	2003	7	4
Hammerdam	2005	5	5
River Silke	2011	25	3
Brahetrolleborg Gods	2008	6	1
Karlsmosen	2001	10	5

Table 3. Braun-Blanquet cover – abundance scale used for vegetation descriptions (Braun-Blanquet and Pavillard, 1930).

Scale	Range of cover
+	<1%, few individuals
1	1-5%
2	5-25%
3	25-50%
4	50-75%
5	75-100%

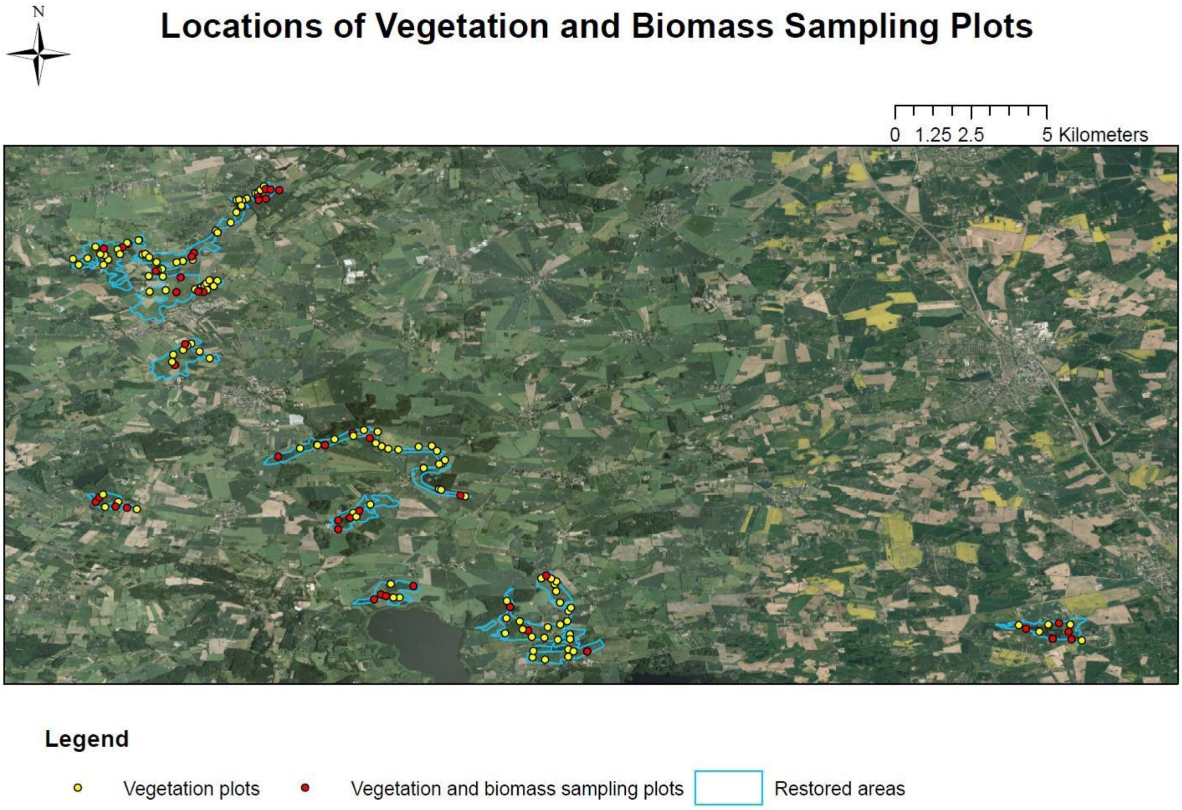


Figure 3. Map of study sites, vegetation plots and biomass sampling plots in Kratholm catchment.

2.3. Plant Nutrient Stock Analysis and Nutrient Leaching Experiment

To assess the plant uptake of phosphorus and nitrogen, as well as nutrient leaching, biomass samples were collected from 50 vegetation plots (Figure 3). The plots were chosen randomly, the number of biomass samples collected in each of the restored sites is shown in Figure 3. The biomass was harvested from a 0.1 m^2 large square in the centre of the vegetation plot.

The harvested biomass was dried at the room temperature for eight weeks and cut in 5 cm long pieces, then the sampled material was homogenised in a fine-grain mill. The total phosphorus content in the samples was determined as soluble reactive phosphorus. Molybdenum blue method was used after an acid digestion procedure, where 10 mg of dry sample was mixed with 2 ml 10 M Sulphuric acid H_2SO_4, 4 ml 30% Hydrogen peroxide H_2O_2, and 20 ml de-ionised water at 160°C for two hours

(Murphy and Riley, 1962). Nitrogen content in the samples was determined by using a CN elemental analyzer (Vario EL; Elementar, Mt. Laurel, New Jersey, USA). The net uptake of phosphorus and nitrogen was calculated by using the nutrient concentrations and biomass data (Zak et al., 2014).

In addition, nutrient leaching experiment was performed by using collected, dried and cut biomass samples. To estimate phosphorus, and nitrogen leaching, 5 g of the plant material were inserted in 250 ml large dark glass bottles. The bottles were filled with 200 mg L^{-1} Natrium chloride NaCl solution which acted as a leaching solution to imitate ionic strength that occurs in groundwater and avoid osmotic stress for microorganisms. The bottles were covered with caps left on a on a 100 RPM platform shaker in dark climatic chambers for 24 hours. In the next step, the solution was filtered through 0.45 µm pre-rinsed glucose-acetate filters and the amount of soluble reactive phosphorus and dissolved nitrogen was measured. The soluble reactive phosphorus concentrations were determined by using the molybdenum blue method, developed by J. Murphy and J.P. Riley (1962), at a spectrophotometer (Cary 60 UVVis; Agilent Technologies, USA). Dissolved nitrogen was analysed in a CN elemental analyzer (TOC-L, Shimadzu, Kyoto, Japan). To calculate the nutrient leaching rates during the growing season, the share of water leached nitrogen and phosphorus was calculated based on the results of leaching experiment and using the data available on net nitrogen and phosphorus uptake by plants per growing season (Meuleman et al., 2002; Zak et al., 2014). The estimated length of growing season was 150 days from May till September.

2.4. Data Analysis

Vegetation, plant nutrient stock and nutrient leaching data was analysed by using statistical program R version 3.5.3. as well as R Studio (R Studio, 2019; The R Foundation, 2019).

To study the plant communities, a report on Grassland and Mire Plant Communities in Denmark was used (Nygaard et al., 2009). The database created based on the report is called DANVEG. The dataset consists of more than 13000 vegetation plot descriptions, analysed with DECORANA and then plotted. To ensure that data is comparable, the vegetation data from Kratholm catchment was modified. Following modifications were done – the cover of bryophytes in the plots was deleted entirely as there is no information on bryophytes in DANVEG. Most of the vascular plants that were determined till genus were deleted as the database has full species names with rare exceptions, for example, Dandelions *Taraxacum sp*. The values of axis of the described vegetation plots from Kratholm catchment were plotted together with the DANVEG dataset. The plot of the DANVEG dataset is shown in Figure 4.

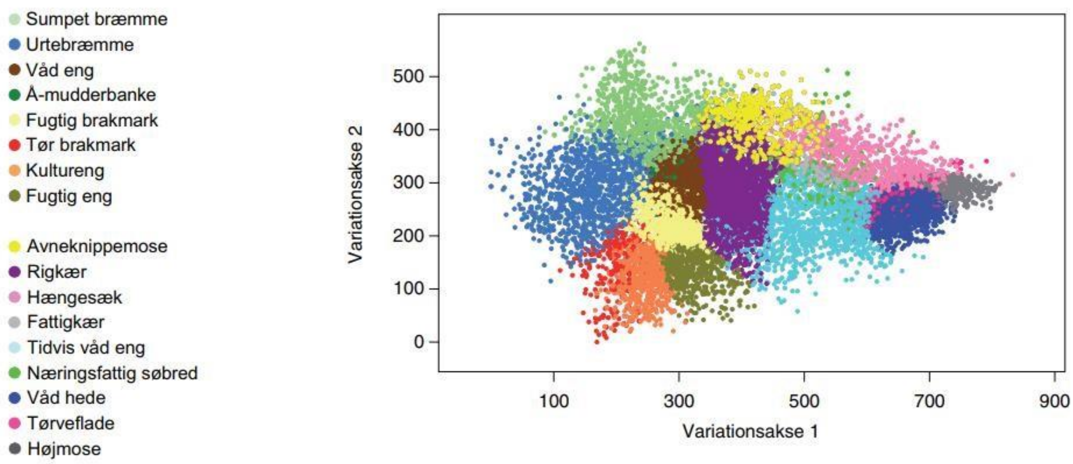


Figure 4. A plot of DANVEG dataset for mire and grassland plant communities in Denmark (Nygaard et al., 2009). Variationsakse 1 – axis 1, variationsakse 2 – axis 2. Sumpet bremme – reed beds, urtebræmme - Humid tall herb fringes, våd eng – humid grasslands, å-mudderbanke - river mud banks, fugtig brakmark - moist fallow fields, tør brakmark - dry fallow fields, kultureng – improved grasslands, fugtig eng – Mesophile grasslands, avneknippemose - fen-sedge beds, rigkær – rich fen, hængesæk - transition mires, fattigkær – acidic fens, tidvis våd eng - Purple moorgrass meadows *Molinia caerulea* and related communities, næringsfattig søbred – vegetation along nutrient poor lakes, våd hede - Northern wet heaths, tørveflade - White beak-sedge *Rhynchospora alba* communities, højmose – near natural raised bogs.

Shannon species diversity index, also known as Shannon-Wiener index, was used to describe plant species diversity in plant communities (Shannon, 1948). To describe whether parameters such as species richness, nitrogen content in biomass samples etc. from restored wetlands with a different wetland age are statistically significantly different, analysis of variance ANOVA and pairwise t-test was used (Kabacoff, 2012; ETH Zurich, 2019). In order to be able to run the pairwise t-test in program R, the data on aboveground biomass, nutrient stock and leaching from wetlands restored in 2008 had to be eliminated as there was only one biomass sample representing this wetland age class.

To evaluate abiotic factors, Ellenberg indicator values were used for vascular plant species, if the values were available (Ellenberg et al., 1991). Species that were determined till genus were deleted from dataset. For this study, the indicator values of light, moisture, and soil fertility were used. If indifferent values were present, the species were also eliminated from dataset. To calculate the indicator values per each plot or community, community weighted mean was used. The calculations were done by multiplying indicator value by abundance, summing it up for all species and dividing it by sum of abundance.

Maps were created in ArcMap 10.4.1.

3. Results

3.1. General Description of Vegetation

During the field work in Kratholm catchment, 172 vegetation plots were described. The size of the plot used for the vegetation descriptions was 4 m^2. The total number of species registered in plots was 180, where 172 of all species were vascular plants and eight were bryophytes (Appendix 1). The plants that were not possible to determine till species were noted down as genus, for example *Rosa sp*., eight in total.

Species richness in the vegetation plots is shown in Figure 5. The average number of species per plot was 9.5, which leads to average species richness of 2.4 species per m^2. The number of species ranged from one to 36 species per plot. The largest group of plots, 24 in total, had seven species. The second largest class was formed by 21 plots with 11 species. From all plots that were described, 131 plots or 76% had five to 12 species. Only three vegetation plots had more than 20 species registered.

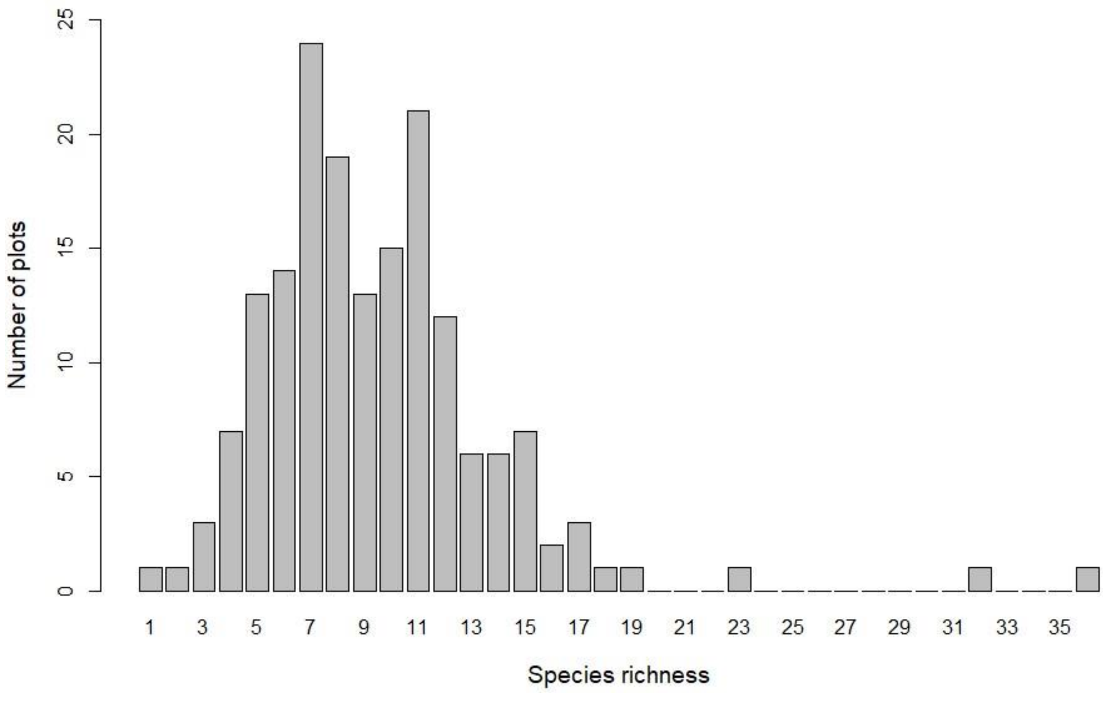


Figure 5. Species richness in vegetation plots from restored wetlands in Kratholm catchment. The size of the plot – 4m^2.

The species recorded in the highest number of plots was Common nettle *Urtica dioca*, 88 plots in total. Other commonly found species were Field thistle *Cirsium arvense* in 57 plots, Great willow herb *Epilobium hirsutum* in 63 plots, and Reed canary grass *Phalaris arundinacea* in 74 plots. However, 137 species or 77% of all species were registered up to 10 times. In total, 50 species were recorded only one time (Figure 6).

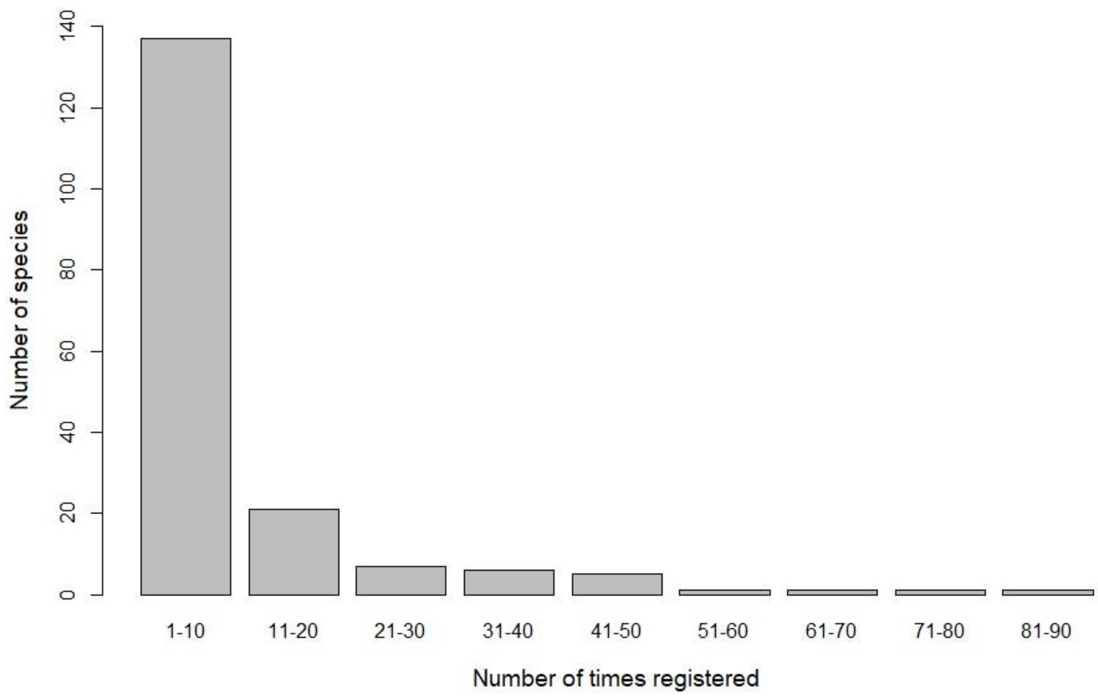


Figure 6. Frequency of species registered in vegetation plots from restored wetlands in Kratholm catchment. The size of the plot – $4m^2$.

Regarding rare and protected species, two orchids were found and determined as Marsh orchid *Dactylorhiza sp*. as only leaves of the plants were present. In Denmark, 11 species from *Dactylorhiza* genus are found in the nature. According to The Danish Red List, conservation status of the *Dactylorhiza* species is evaluated from least concerned up to the category endangered (Moeslund, 2019).

Plant diversity in the vegetation plots was characterized by using Shannon index. The average diversity in all plots was 1.2, ranging from 0 to 2.2 (Figure 7). The most common values of the index were in the interval from 1.2 to 1.4, 17 plots in total were representing this interval. The largest share of plots, 80 plots or 47%, are representing the indicator values in the interval from 1.0 to 1.6. The smallest group of plots were formed by five plots or 3%, describing values 2.0-2.2.

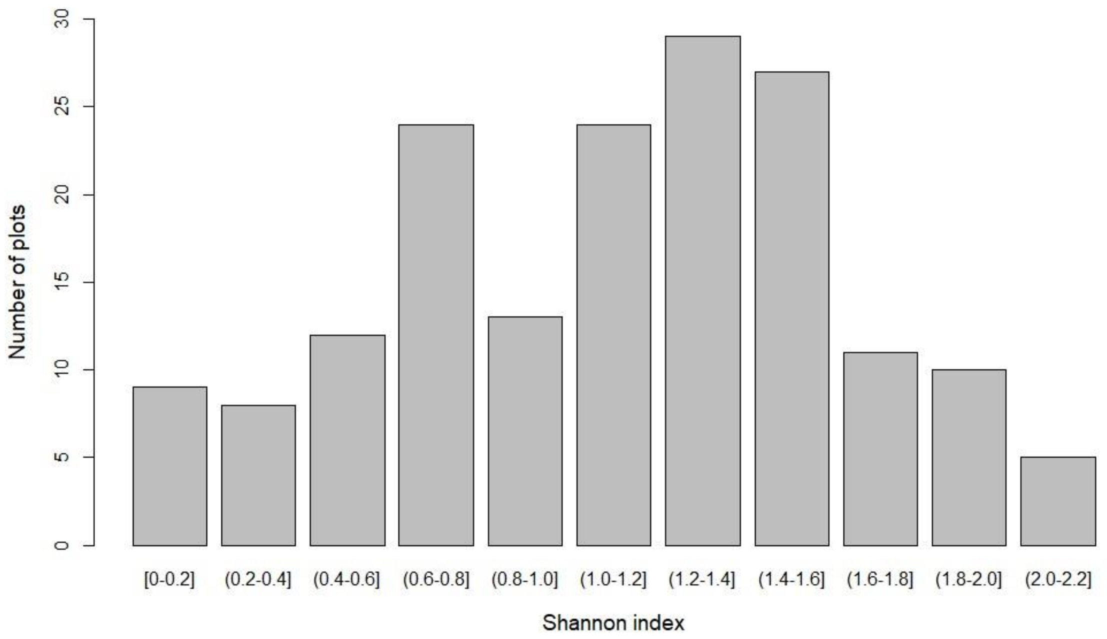


Figure 7. Frequencies of Shannon index in vegetation plots from restored wetlands in Kratholm catchment. The size of the plot – 4m^2.

To evaluate the environmental factors that are characteristic to the vascular plant species described in the vegetation plots, Ellenberg indicator values for light, moisture, and soil fertility were assessed (Ellenberg et al., 1991). Species that were determined till genus were not included in the analysis. Indicator values were available for 164 species in total. However, some species had indifferent indicator values. For example, in case of light, four species were represented by indifferent value. The average indicator value for light was 7.0, representing half-light plants. The largest share of all vascular plant species registered - 84 species or 51% were described with the indicator value 7. In general, the values ranged from 2, characterizing plants that are between deep shade plants and shade plants, to 9, which describes full light plants (Figure 8).

Regarding moisture, 19 plant species had indifferent indicator values. The average indicator value for all species was 7.0, describing plants that are preferring humidity. The values varied from 3, representing damp soil plants, to 11 - aquatic plants rooted under water. The largest amount of species – 29 species or 18%, were indicating wetness and representing indicator value 9. The next largest group was formed by 26 species or 16% that are fresh soil plants with indicator value 5 (Figure 8).

When Ellenberg values for soil fertility were analysed, 20 species had indifferent preferences for soil fertility. The average indicator value was 6.1, showing species that occur between moderately nutrient rich sites and nutrient rich sites. The values ranged from 1 - species found in nutrient poorest sites, to 9 - species representing very nutrient rich sites. The largest share – 29 species or 18% were found in nutrient rich sites, representing indicator value 7 (Figure 8).

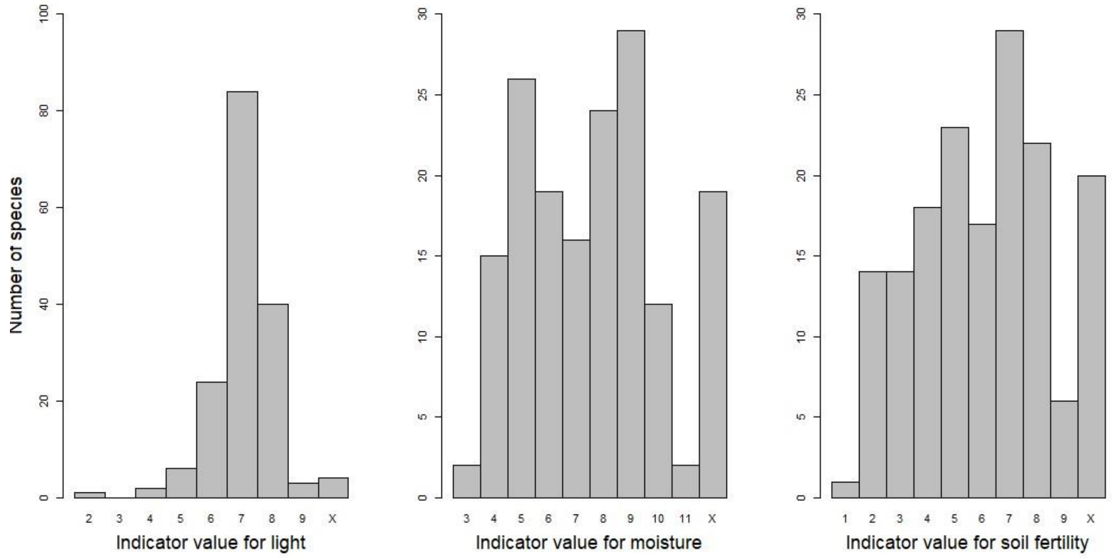


Figure 8. Ellenberg indicatorvalues for light, moisture and soil fertility for species registered in vegetation plots from restored wetlands in Kratholm catchment. The size of the plot – 4m^2. Indicator values for light: 2 – between 1 (deep shade plants) and 3, 3 – shade plants, 4 – between 3 and 5, 5 - semi-shade plants, 6 – between 5 and 7, 7 – half-light plants, 8 – light plants, 9 - full light plants. Indicator values for moisture: 3 – damp soil, 4 – between 3 and 5, 5 – fresh soils, 6 – between 5 and 7, 7 – humidity indicator, 8 – between 7 and 9, 9 – wetness indicator, 10 – aquatic plants that can survive for long periods without flooding, 11- aquatic plants rooted under water. Indicator values for soil fertility: 1- nutrient poorest sites, 2 – between 1 and 3, 3 – nutrient poor sites, 4 – between 3 and 5, 5 – moderately nutrient rich sites, 6 – between 5 and 7, 7 – nutrient rich sites, 8 – pronounced nutrient indicator, 9 – very nutrient rich sites. X – indifferent indicator value (Ellenberg et al., 1991).

To evaluate the Ellenberg indicator values for each plot, the average community weighted mean was calculated. Species with indifferent indicator value were not included in the calculations. The average community weighted indicator value for light for all vegetation plots was 7.2, representing half-light plants. The largest share of the vegetation plots – 118 plots or 69% had an indicator value of 7, while 40 plots or 23% had the indicator value of 8, which represents plants that grow at almost full light. In general, the indicator values ranged from 5, semi-shade plants, to 9, full light plants (Figure 9).

The average community weighted indicator value for moisture for all plots was 7.3, representing plants that prefer humidity. The values varied from 3 for damp soil plants, up to 10 for aquatic plants that can survive for long periods without flooding. The largest amount of vegetation plots – 48 plots or 28% had the indicator value of 8, which describes plants that occur between humid and wet conditions. The next largest group was formed by 45 plots or 26% of all plots with the indicator value of 7 – plants that are humidity indicators (Figure 9).

Regarding soil fertility, the average community weighted indicator value for all plots was 6.4, representing sites that have the indicator value between moderately nutrient rich and nutrient rich soils. The lowest registered value was 3 for plants growing in nutrient poor sites, while the highest was 9 for plants preferring nutrient rich sites. The largest share - 65 plots or 38% had the average weighted indicator value of 7 – nutrient rich sites (Figure 9).

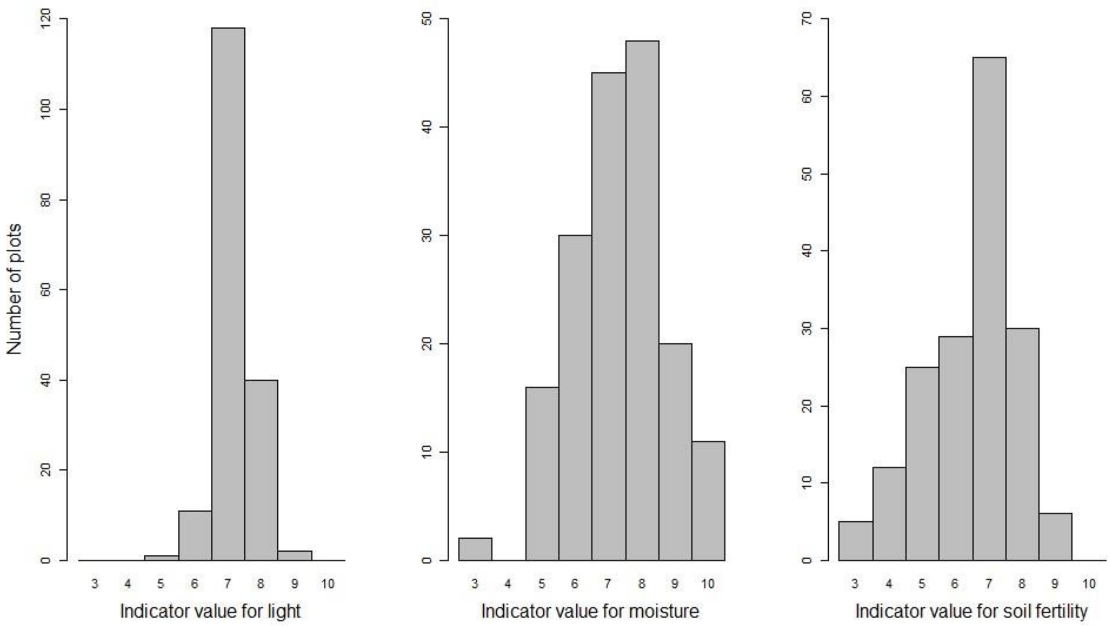


Figure 9. The average community weighted value of Ellenberg indicatorvalues for light, moisture and soil fertility for species registered in vegetation plots from restored wetlands in Kratholm catchment. The size of the plot – $4m^2$. Indicator values for light: 3 – shade plants, 4 – between 3 and 5, 5 - semi-shade plants, 6 – between 5 and 7, 7 – half-light plants, 8 – light plants, 9 - full light plants. Indicator values for moisture: 3 – damp soil, 4 – between 3 and 5, 5 – fresh soils, 6 – between 5 and 7, 7 – humidity indicator, 8 – between 7 and 9, 9 – wetness indicator, 10 – aquatic plants that can survive for long periods without flooding. Indicator values for soil fertility: 3 – nutrient poor sites, 4 – between 3 and 5, 5 – moderately nutrient rich sites, 6 – between 5 and 7, 7 – nutrient rich sites, 8 – pronounced nutrient indicator, 9 – very nutrient rich sites. (Ellenberg et al., 1991).

3.2. Plant Communities

To describe the plant communities in restored sites in Kratholm catchment, 172 vegetation plots were compared to DANVEG dataset from the report on Grassland and Mire Plant Communities in Denmark. The results of DCA ordination for the vegetation plots were plotted together with the DANVEG dataset (Figure 10). Most of the points are located on the left side of the plot, where different types of fringe, fen, fallow field and meadow plant communities are represented. The full DCA ordination with eight grassland and nine mire plant communities that have been defined within DANVEG model is shown in Figure 4 under Chapter 2.4.

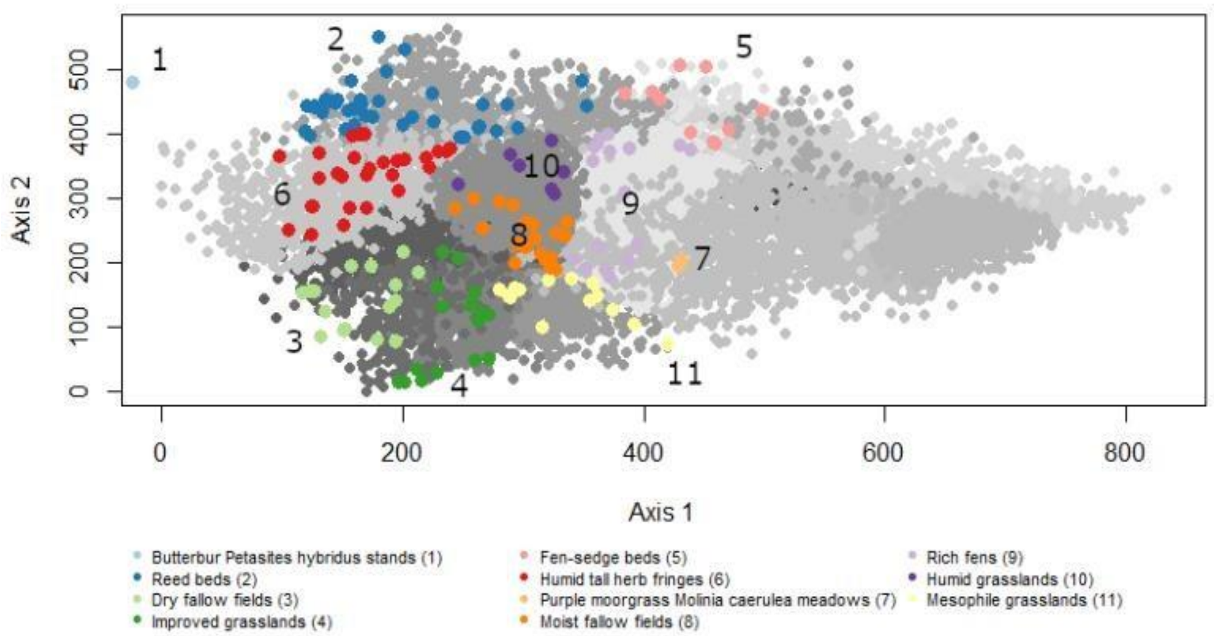


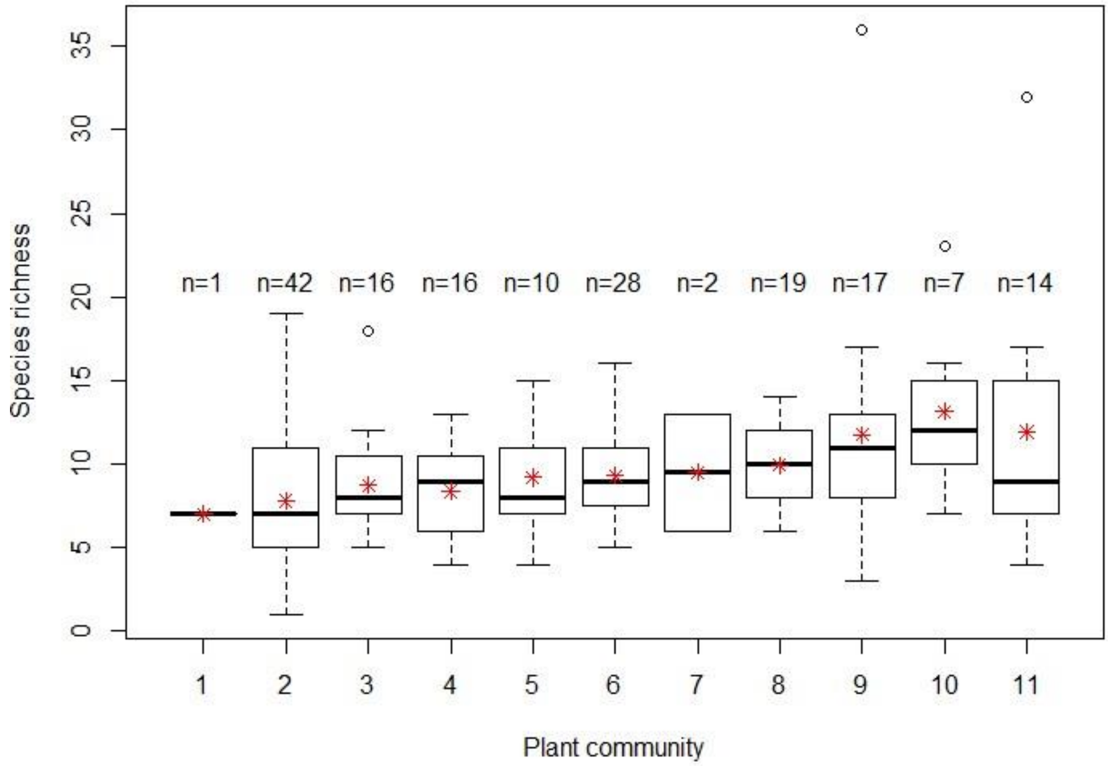
Figure 10. DCA ordination of described vegetation plots from restored wetlands in Kratholm catchment compared to DANVEG dataset for mire and grassland plant communities (gray dots) (Nygaard et al., 2009). Numbers from 1 to 11 describe each of the plant communities.

The plant communities and the number of plots that are representing the communities in the restored sites are shown in Table 4. From all vegetation plots that were described in Kratholm catchment, the largest group is formed by 42 plots or 24% of all plots, representing reed beds. The second largest group was 28 plots or 16%, describing humid tall herb fringe communities. Moist fallow fields and rich fens were described in 19 and 17 plots, while dry fallow fields, and improved grasslands 16 plots each. Four plant communities were described in less than 15 plots. A point in the Figure 10 located in the upper left corner of the plot, far from the rest of the dataset, is a plot with Butterbur *Petasites hybridus*, further described as *Petasites hybrydus* stands.

Table 4. Described plant communities in restored wetlands in Kratholm catchment according to the report on Grassland and Mire Plant Communities in Denmark (Nygaard et al., 2009). Plant community number used according to Figure 10.

Plant community	Number of plots	%
Reed beds (2)	42	24
Humid tall herb fringes (6)	28	16
Moist fallow fields (8)	19	11
Rich fens (9)	17	10
Dry fallow fields (3)	16	9
Improved grasslands (4)	16	9
Mesophile grasslands (11)	14	8
Fen-sedge beds (5)	10	6
Humid grasslands (10)	7	4
Purple moorgrass *Molinia caerulea* meadows and related communities (7)	2	1
Butterbur *Petasites hybridus* stands (1)	1	1
In total	172	100

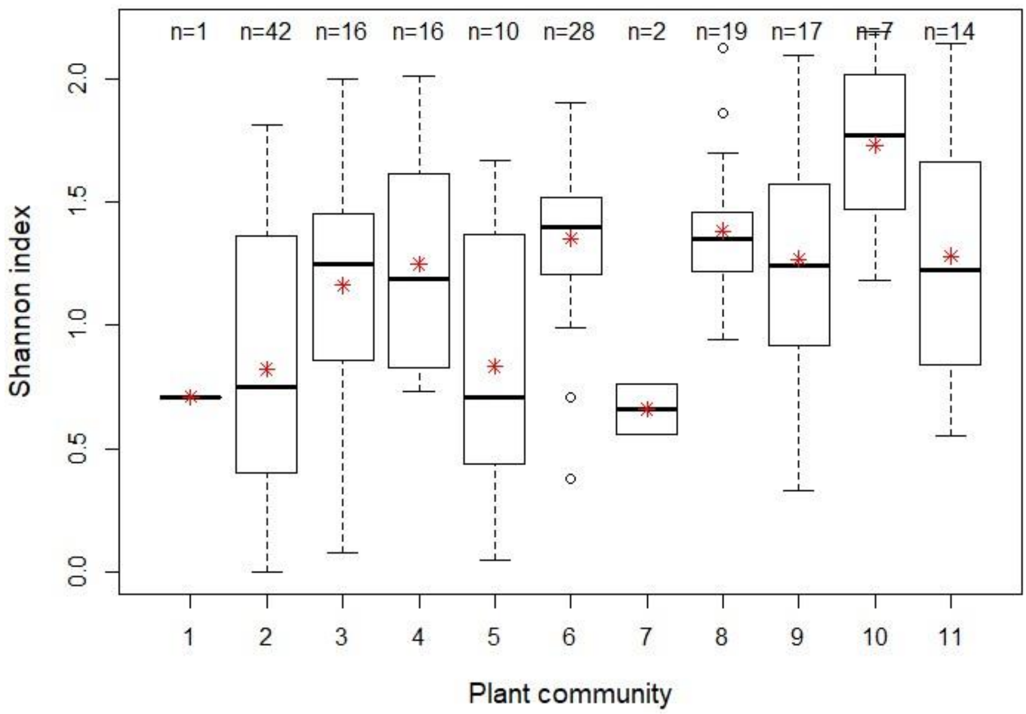
When the average number of species per plot is compared within all registered plant communities, the highest number of species was found in humid grasslands 13.1 species per 4 m^2 large plot or 3.3 species per m^2 (Figure 11). The second highest value had mesophile grasslands 11.9 species per 4 m^2 large plot or 3.0 species per m^2. The lowest average number of species per plot had *P.hybrydus* stands – seven species per 4 m^2 large plot or 1.8 species per m^2. However, there is only one plot described with such vegetation. As mentioned previously, the average number of species per 4 m^2 plot from all plant communities together is 9.5 species, which leads to average species richness of 2.4 species per m^2. The widest range of species richness was recorded in reed beds. Three outliers occurred in the described plots from rich fens, humid grasslands, as well as mesophile grasslands.



1	Butterbur *Petasites hybridus* stands	5	Fen-sedge beds	9	Rich fens
2	Reed beds	6	Humid tall herb fringes	10	Humid grasslands
3	Dry fallow fields	7	Purple moorgrass *Molinia caerulea* meadows	11	Mesophile grasslands
4	Improved grasslands	8	Moist fallow fields		

Figure 11. Species richness in plant communities from restored wetlands in Kratholm catchment. The size of a plot - 4 m^2. In the box plots, the bottom and top of the box are describing the 25th and 75th percentiles, the band near the middle of the box is the 50th percentile (the median); the ends of the whiskers represent the minimum and maximum of the data. The circles show outliers, while red stars describe the mean values. The sample size is shown above each box.

For Shannon index, the highest average value was in the plots representing humid grasslands - 1.7. The second highest average value was registered in humid tall herb fringes and moist fallow fields - 1.4 in both. Mesophile grasslands, rich fens, improved grasslands, and dry fallow fields had very similar results - the average value for Shannon index was 1.3 and 1.2. The lowest average value was 0.7, representing Butterbur *Petasites hybridus* stands as well as Purple moorgrass *Molinia caerulea* meadows and related communities (Figure 12).



1	Butterbur *Petasites hybridus* stands	5	Fen-sedge beds	9	Rich fens
2	Reed beds	6	Humid tall herb fringes	10	Humid grasslands
3	Dry fallow fields	7	Purple moorgrass *Molinia caerulea* meadows	11	Mesophile grasslands

4 Improved 8 Moist fallow fields grasslands

Figure 12. The average value of Shannon index in each plant community registered in restored wetlands in Kratholm catchment. In the box plots, the bottom and top of the box are describing the 25th and 75th percentiles, the band near the middle of the box is the 50th percentile (the median); the ends of the whiskers represent the minimum and maximum of the data. The circles show outliers, while red stars describe the mean values. The sample size is shown above each box.

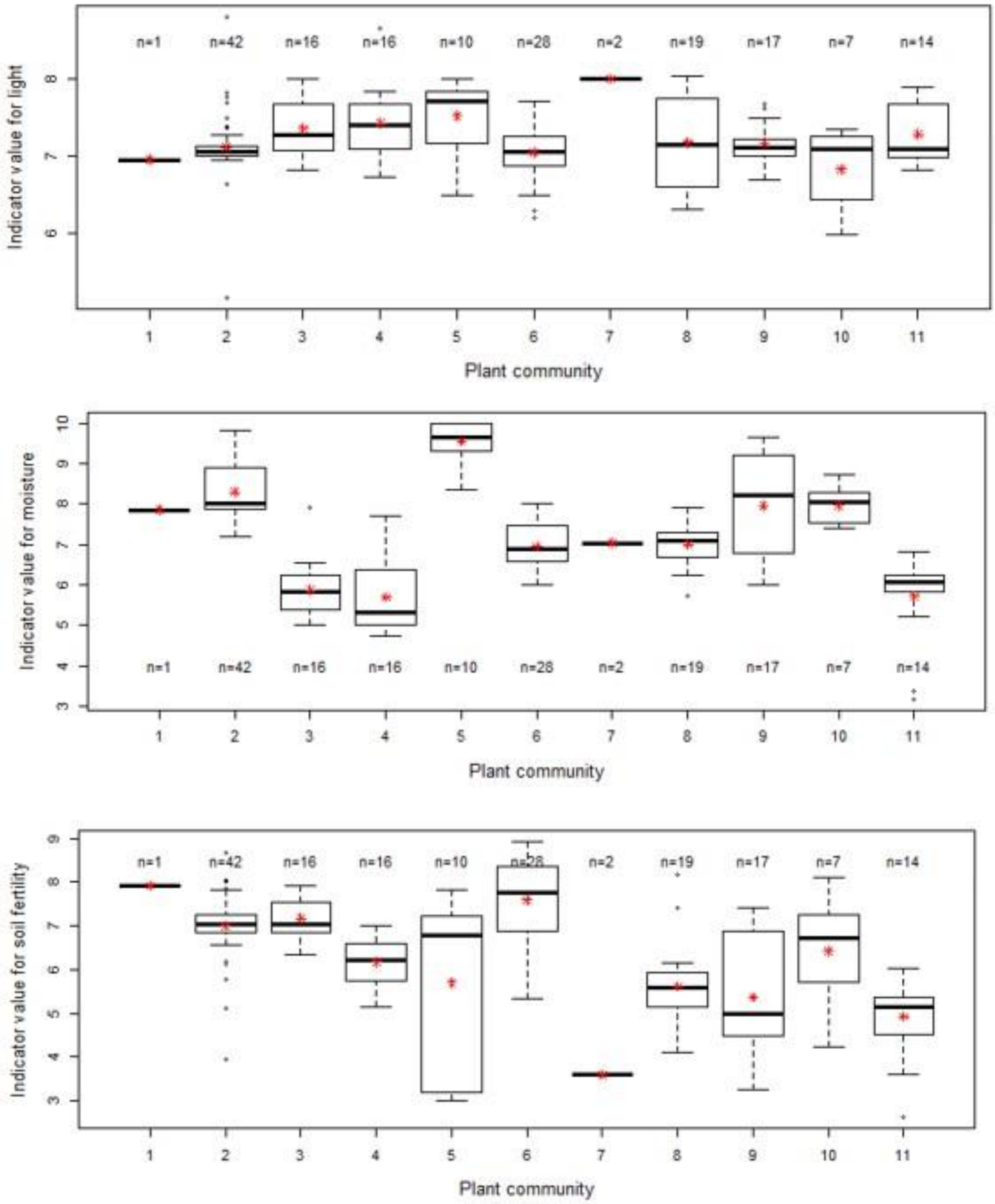
When the results of species ordination were plotted, the species that are characteristic for humid and wet conditions, such as Woody nightshade *Solanum dulcamara*, Broadleaf cattail *Typha latifolia*, Large bitter-cressare *Cardamine amara* etc., were located in the upper part of the ordination plot (Appendix 2). According to the Figure 10, in this area such plant communities as reed beds, fen-sedge beds were represented.

In contrast, species characteristic to more dry conditions such as Couch grass Elytrigia repens, White clover Trifolium repens, and Spear thistle Cirsium vulgare occurred in the lower part of the ordination, where improved grasslands, dry fallow fields, and other plant communities are located.

To evaluate the environmental factors that are characteristic to the plant communities from restored wetlands in Kratholm catchment, the average community weighted Ellenberg indicator values for vascular plant species were calculated (Ellenberg et al., 1991). Regarding light, the values were very similar, ranging from 6.8 for humid grasslands to 8.0 for Purple moorgrass *Molinia caerulea* meadows (Figure 13). Indicator value 7 describes half-light plants, while indicator value 8 is characteristic to light plants. The widest range of values were presented in moist fallow fields.

The highest average community weighted value for moisture had fen-sedge beds – 9.5, indicating aquatic plants that can survive for long periods without flooding, while the lowest average value was 5.7, which describes the state between fresh soils and humidity, representing mesophile grasslands (Figure 13). The widest range of indicator values was shown in rich fens.

When each of the plant communities are analysed regarding the soil fertility, the highest average community weighted value had Butterbur *Petasites hybridus* stands with indicator value of 7.9, however only one plot was recorded with this species. The second largest value 7.7 was showed by humid tall herb fringe communities. Indicator value 8 represents species that are pronounced nutrient indicators. The lowest community weighted average of 3.6 had Purple moorgrass *Molinia caerulea* meadows, describing nutrient levels between nutrient poor and moderately nutrientrich sites (Figure 13). The highest range of values were represented in fen-sedge beds.



1	Butterbur *Petasites hybridus* stands	5	Fen-sedge beds	9	Rich fens
2	Reed beds	6	Humid tall herb fringes	10	Humid grasslands
3	Dry fallow fields	7	Purple moorgrass *Molinia caerulea* meadows	11	Mesophile grasslands

4 Improved 8 Moist fallow fields grasslands

Figure 13. The average community weighted Ellenberg indicator values for light, moisture, and soil fertility in different plant communities from restored wetlands in Kratholm catchment. The size of a plot - 4 m^2. Indicator values for light: 1- deep shade plants, 2 – between 1 and 3, 3 – shade plants, 4 – between 3 and 5, 5 - semi-

shade plants, 6 – between 5 and 7, 7 – half-light plants, 8 – light plants, 9 - full light plants. Indicator values for moisture: 1- strong drought indicator, 2 – between 1 and 3, 3 – damp soil, 4 – between 3 and 5, 5 – fresh soils, 6 – between 5 and 7, 7 – humidity indicator, 8 – between 7 and 9, 9 – wetness indicator, 10 – aquatic plants that can survive for long periods without flooding, 11- aquatic plants rooted under water, 12 – permanently or almost permanently submerged aquatic plants. Indicator values for soil fertility: 1- nutrient poorest sites, 2 – between 1 and 3, 3 – nutrient poor sites, 4 – between 3 and 5, 5 – moderately nutrient rich sites, 6 – between 5 and 7, 7 – nutrient rich sites, 8 – pronounced nutrient indicator, 9 – very nutrient rich sites (Ellenberg et al., 1991). In the box plots, the bottom and top of the box are describing the 25th and 75th percentiles, the band near the middle of the box is the 50th percentile (the median); the ends of the whiskers represent the minimum and maximum of the data.

The circles show outliers, while red stars describe the mean values. The sample size is shown above or under each box.

3.3. Vegetation and Wetland Age

When the wetland age was taken into consideration, as well as the number of species registered per plot, the average species richness varied from 8.7 species per 4 m^2 large plot in sites that were restored in 2008 to 10.1 per 4 m^2 in sites restored in 2001 (Figure 14). The largest distribution of values was seen in the plots described in the wetlands restored in 2010, the values ranged from one to 36 species per plot. Two outliers occurred in the samples from 2010 and one outlier from 2011. When the analysis of variance ANOVA was performed, no statistically significant differences were found among the groups as p-value was 0.93. The same results were acquired in the pairwise test – all p-values were higher than the confidence level 0.05.

Table 5. Results of pairwise t-test for species richness in restored wetlands with a different wetland age.

Year	2011	2010	2009	2008	2005	2003
2010	0.30	-	-	-	-	-
2009	0.75	0.61	-	-	-	-
2008	0.93	0.51	0.77	-	-	-
2005	0.94	0.66	0.90	0.90	-	-
2003	0.79	0.39	0.92	0.81	0.94	-
2001	0.46	0.91	0.66	0.54	0.66	0.56

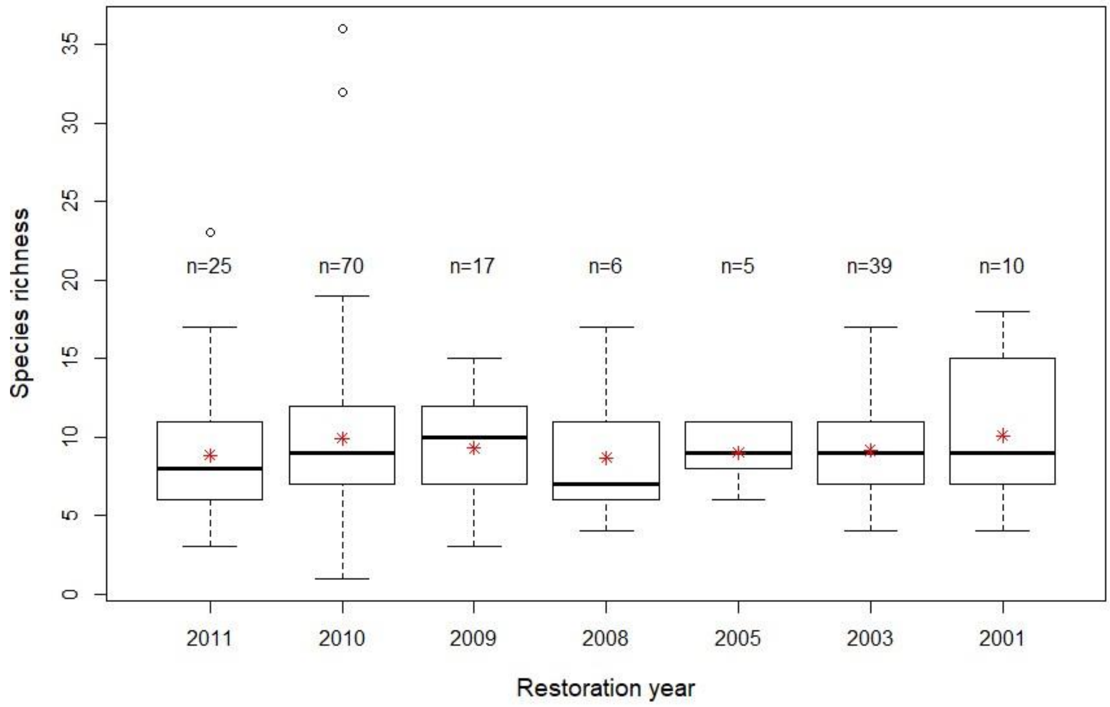


Figure 14. Species richness in wetlands with a different wetland age in Kratholm catchment. The size of a vegetation plot was 4 m^2. In the box plots, the bottom and top of the box are describing the 25^{th} and 75^{th} percentiles, the band near the middle of the box is the 50^{th} percentile (the median); the ends of the whiskers represent the minimum and maximum of the data. The circles show outliers, while red stars describe the mean values. The sample size is shown above each box.

When the Shannon species diversity index was analysed for the vegetation plots according to the restoration year, the average values varied from 1.1 for plots restored in 2008, 2010, and 2011, to 1.3 for the plots restored in 2003, and 2005 (Figure 15). The largest variation of the values was recorded in plots from 2010, as well as 2011. An outlier occurs in a plot from 2005, while two outliers were found in the plots from 2003. According to ANOVA analysis, no statistically significant difference was found between the values of Shannon index and restoration years as p-value was 0.47. However, in the pairwise t-test a statistically significant difference was found between the Sahannon diversity index values from plots restored in 2010 and 2003 as p-values was 0.045 (Table 6).

Table 6. Results of pairwise t-test for Shannon species diversity index in restored wetlands with a different wetland age.

Year	2011	2010	2009	2008	2005	2003
2010	0.863	-	-	-	-	-
2009	0.411	0.270	-	-	-	-
2008	0.932	0.853	0.644	-	-	-
2005	0.371	0.302	0.723	0.509	-	-
2003	0.158	0.045	0.719	0.461	0.873	-
2001	0.434	0.325	0.931	0.623	0.790	0.844

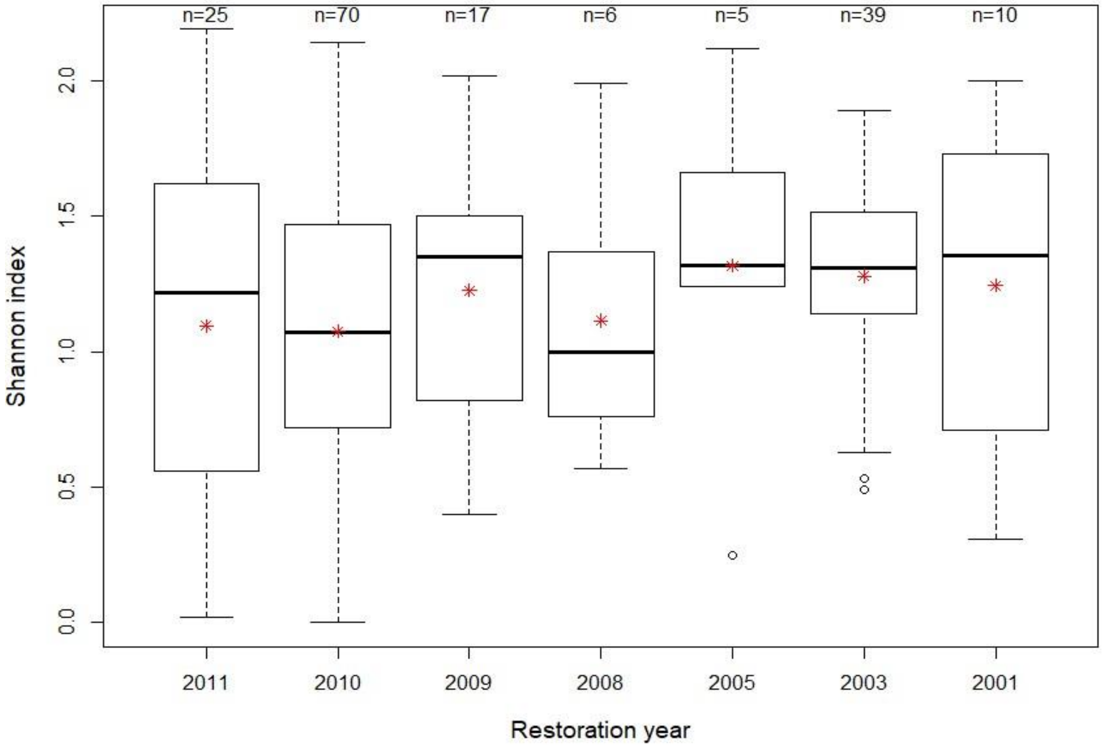


Figure 15. Shannon species diversity index for vegetation plots described in restored wetlands located in Kratholm catchment. The size of a plot was 4 m^2. In the box plots, the bottom and top of the box are describing the 25^{th} and 75^{th} percentiles, the band near the middle of the box is the 50^{th} percentile (the median); the ends of the whiskers represent the minimum and maximum of the data. The circles show outliers, while red stars describe the mean values. The sample size is shown above each box.

Percentage diagram with plant communities according to the restoration year is showed in Figure 16. In the plots restored in 2011, the dominant communities were improved grasslands, and reed beds, 24% each. In plots from 2010, reed beds were dominant in 30% of the total amount of plots, while in the plots from 2009, humid tall herb fringes, and rich fens both were described in 24% of the plots. A clear dominance of fen-sedge beds was seen in the plots from 2008, half of the plots represented this plant community. For the year 2005, only five plots were described and each of them were from a different plant community. In the plots restored in 2003, reed beds, and humid tall herb fringes were described in 28% of the plots each. Finally, in the plots restored in 2001, dominant plant communities were dry fallow fields, improved grasslands, and humid tall fringes, each 20%.

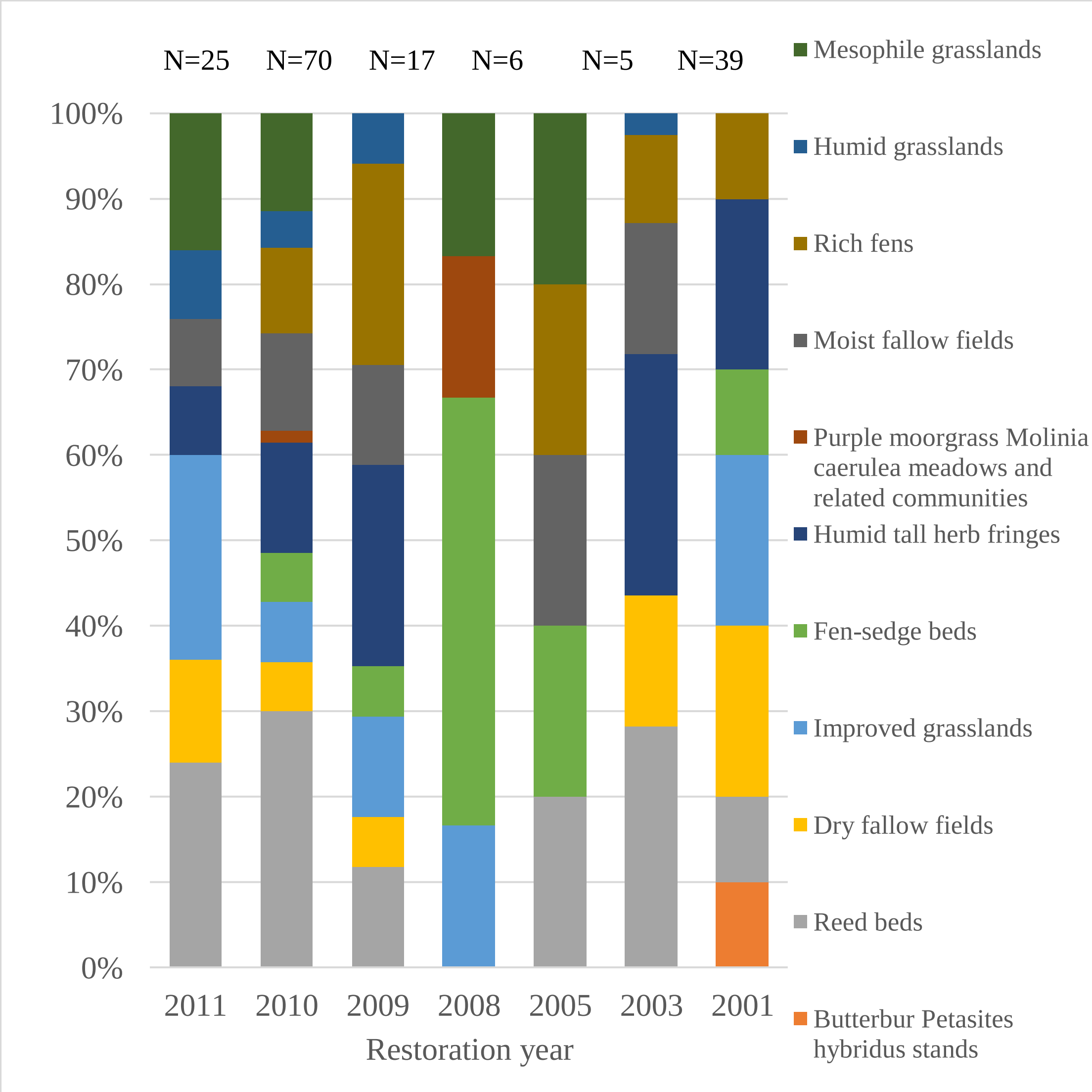


Figure 16. Percentage diagram of plant communities in restored wetlands from Kratholm catchment according to the year of restoration. The younger sites are displayed on the left side of the x-axis, while the eldest – on the right side of x-axis. The sample size is shown above each bar.

3.4. Biomass, Nutrient Stock and Leaching

Aboveground plant biomass samples were collected from 50 vegetation plots. The frequencies of the dry weight of biomass from sampling plots are shown in Figure 17. The dry weight ranged from 0.3 to 2.3 kg of dry mass (DM)/m^2, while the average weight was 1.1 kg DM/m^2. The largest share of the plots, 9 plots or 18% represented the weight category 0.8 to 1.0 kg DM/m^2.

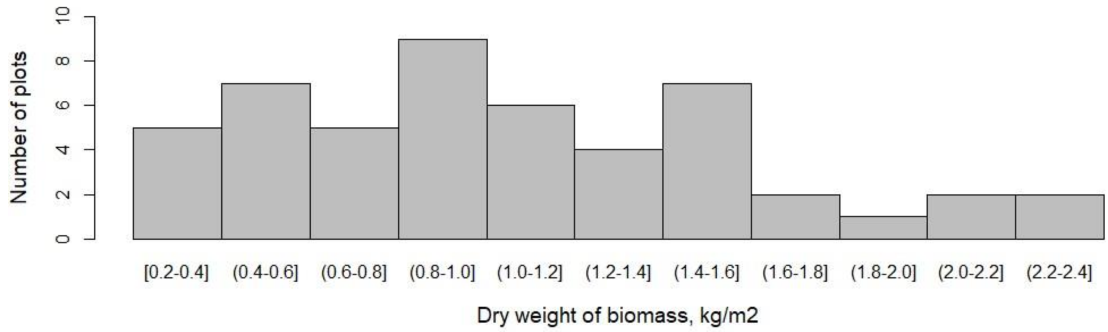


Figure 17. Dry weight of aboveground plant biomass, kg DM/m^2 for samples collected in restored wetlands in Kratholm catchment.

The values of nitrogen stock in the sampled biomass varied from 3.3 up to 29.5 g N/m^2. The average nitrogen stock was 14.6 g N/m^2. The largest share of plots, 16 plots or 32% represented the values between 11.0 and 15.0 g N/m^2 (Figure 18).

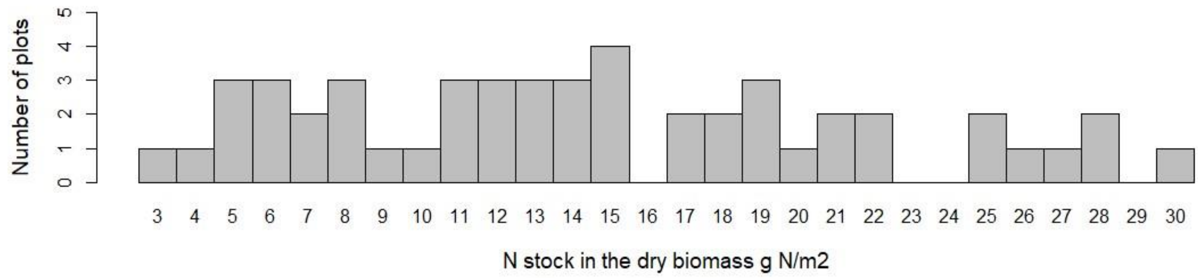


Figure 18. Nitrogen stock g N/m^2 in dry aboveground plant biomass samples collected in restored wetlands in Kratholm catchment.

The results from the leaching experiment showed that the average nitrogen leaching loss from aboveground biomass samples was 20.5 kg N/ha, ranging from 2.9 to 85.2

kg N/ha. The largest share of plots represented the leaching rates up to 10 kg N/ha and 20 to 30 kg N/ha, 15 plots or 30% for each of the groups (Figure 19).

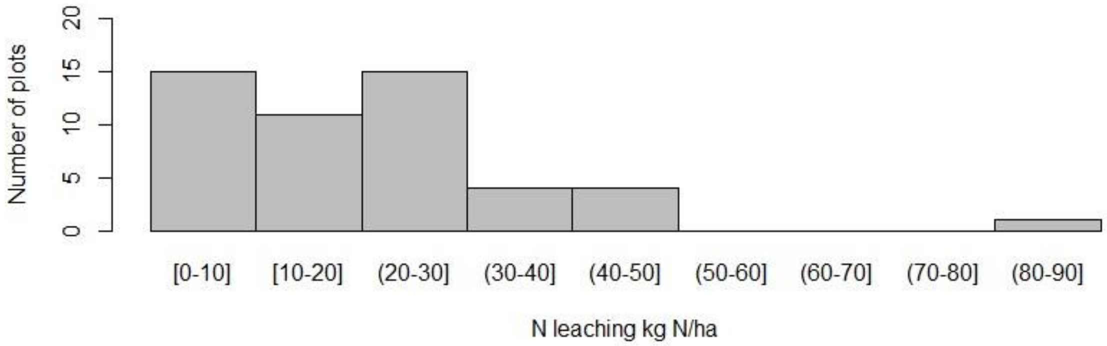


Figure 19. Nitrogen leaching loss kg N/ha from aboveground plant biomass samples in restored wetlands in Kratholm catchment.

Regarding the phosphorus stock in the dry aboveground biomass, the average value was 2.1 g P/m^2.The values ranged from 0.4 to 4.7 g P/m^2. The most frequently represented values occurred in the interval from 0.5 to 2.0 g P/m^2, 26 plots in total or 52% of all plots (Figure 20).

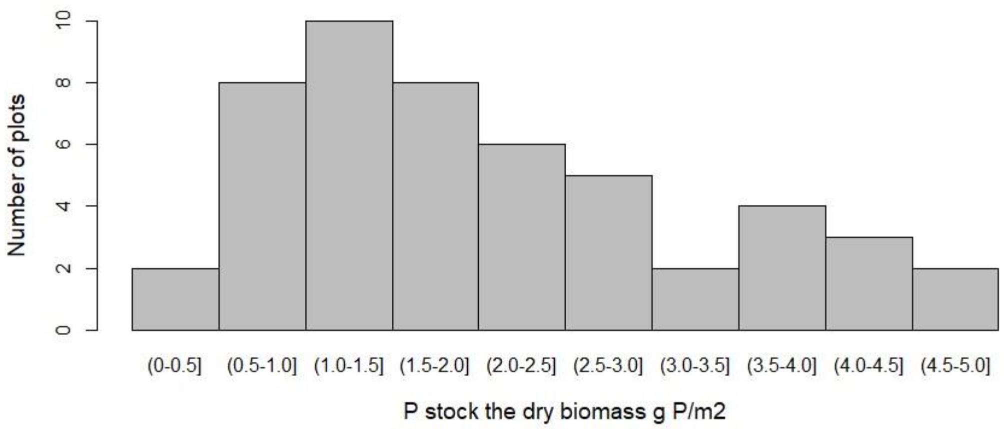


Figure 20. Phosphorus stock g P/m^2 in dry aboveground plant biomass samples in restored wetlands in Kratholm catchment.

The average phosphorus leaching loss per hectare was 7.8 kg P/ha, varying from 1.5 to 22.4 kg P/ha. The two largest groups of plots, 30 plots or 15% had the leaching rates of 4 and 5 kg P/ha (Figure 21).

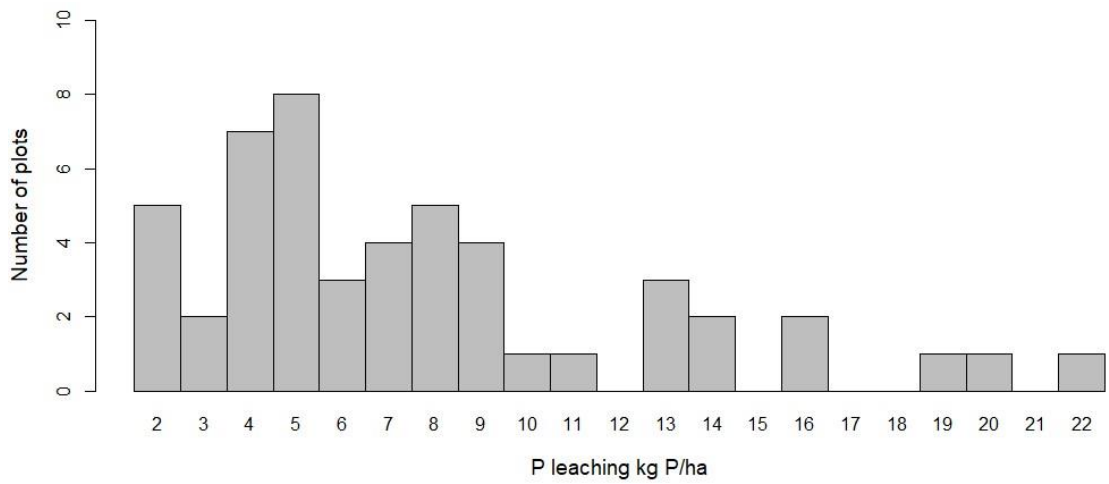
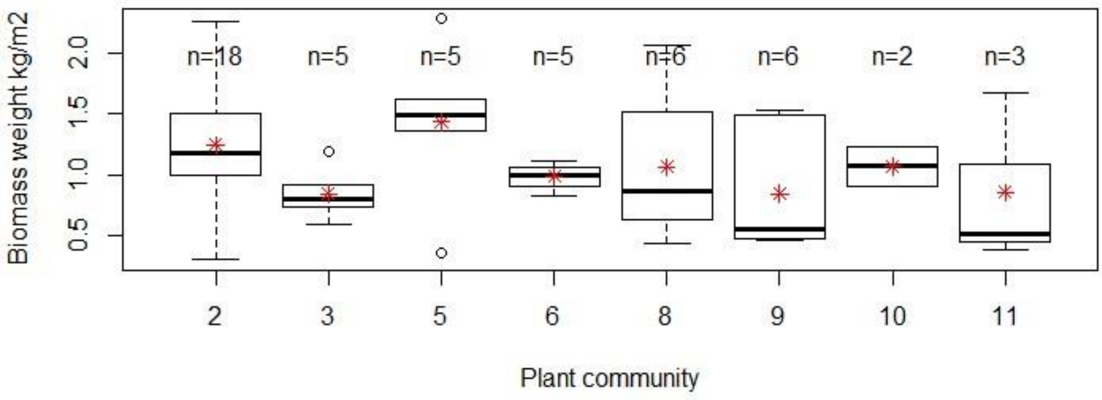


Figure 21. Phosphorus leaching loss kg P/ha from aboveground plant biomass samples in restored wetlands in Kratholm catchment.

In total, eight plant communities were represented in the biomass sampling plots: reed beds, dry fallow fields, fen-sedge beds, humid tall herb fringes, moist fallow fields, rich fens, humid grasslands, as well as mesophile grasslands. The largest share - 18 plots or 36% were sampled in reed beds, while the rest of the plant communities were represented in two to six samples. Thus, the conclusions regarding dry biomass weight, nutrient stock and leaching in different plant communities should be drawn carefully.

The average dry biomass weight in plant communities ranged from 0.9 kg DM/m^2 in dry fallow fields, humid tall herb fringes, and mesophile grasslands to 1.4 kg DM/m^2 in fen-sedge beds. However, only five biomass samples were collected in fen-sedge beds, among the values, two outliers occurred. The next highest average value was represented by reed beds – 1.2 kg DM/m^2. The widest range of values were recorded in reed beds, while dry fallow fields also had an outlier (Figure 22).



2 Reed beds 6 Humid tall herb fringes 10 Humid grasslands
3 Dry fallow fields 8 Moist fallow fields 11 Mesophile grasslands
5 Fen-sedge beds 9 Rich fens

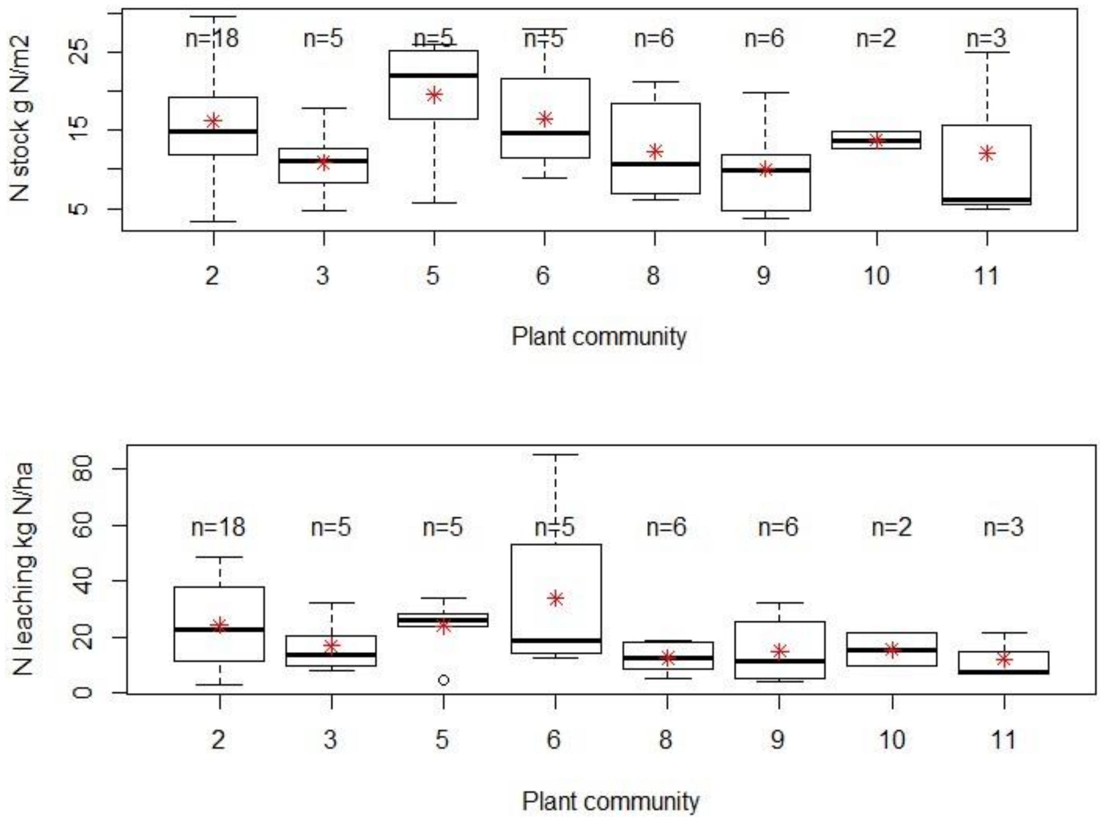
Figure 22. Dry aboveground biomass weight kg DM/m^2 in plant communities from restored wetlands in Kratholm catchment. In the box plots, the bottom and top of the box are describing the 25th and 75th percentiles, the band near the middle of the box is the 50th percentile (the median); the ends of the whiskers represent the minimum and maximum of the data. The circles show outliers, while red stars describe the mean values. The sample size is shown above each box.

Nitrogen stock in dry biomass samples from different plant communities is shown in Figure 23. The lowest average value was 10.0 g N/m^2 in rich fens, while the highest average value was 19.5 g N/m^2 in fen-sedge beds. The largest range of values was represented in reed beds, as shown in Figure 23.

Regarding the nitrogen leaching loss, the highest average value occurred in humid tall herb fringes – 33.6 kg N/ha, while the lowest leaching was recorded in mesophile grasslands – 12.0 kg/ha. The widest range of values occurred in humid tall herb fringes and reed bed plant communities, while fen-sedge beds had an outlier (Figure 23).

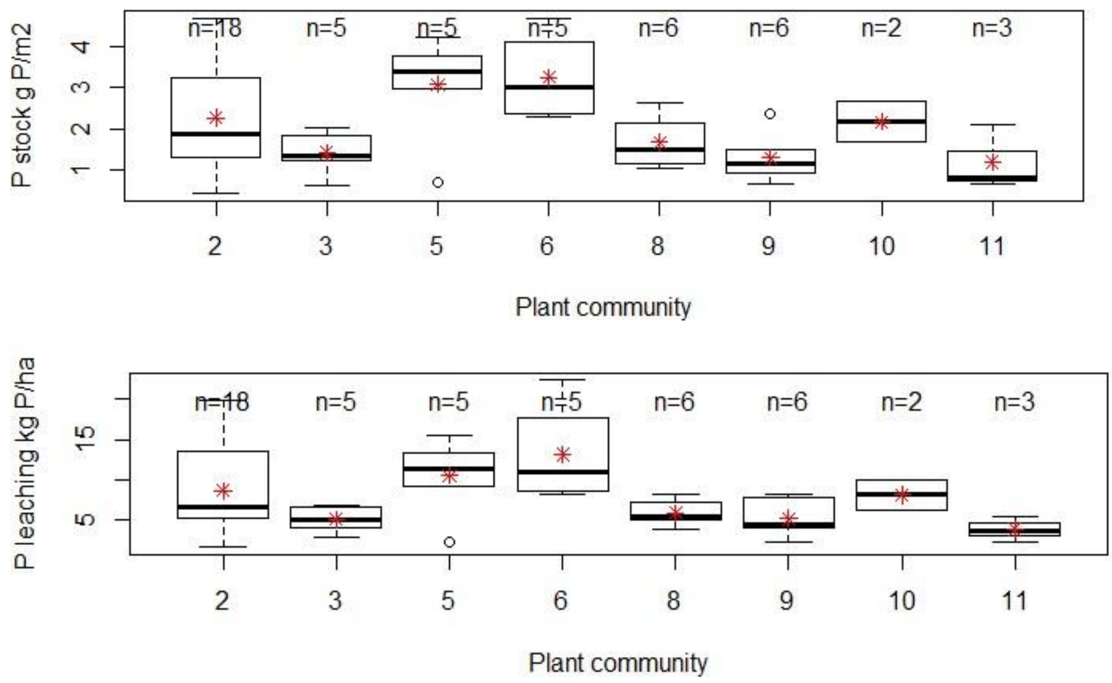
Phosphorus content in biomass samples in different plant communities from restored wetlands in Kratholm catchment is shown in Figure 24. The average values varied from 1.2 g P/m^2 in mesophile grasslands to 3.3 g P/m^2 in humid tall herb fringes. Again, the widest range of values is shown in reed beds. An outlier occurred in rich fens and fen-sedge beds.

Regarding the phosphorus leaching rates, the highest average leaching was recorded in humid tall herb fringes – 13.1 kg P/ha, while the lowest – 3.8 kg P/ha in mesophile grasslands. The widest range of values were recorded in reed beds, an outlier occurred among the samples from fen-sedge beds (Figure 24).



2	Reed beds	6	Humid tall herb fringes	10	Humid grasslands
3	Dry fallow fields	8	Moist fallow fields	11	Mesophile grasslands
5	Fen-sedge beds	9	Rich fens		

Figure 23. Total nitrogen stock in dry aboveground biomass samples g N/m^2 and biomass nitrogen leaching loss kg N/ha in plant communities from restored wetlands in Kratholm catchment. In the box plots, the bottom and top of the box are describing the 25th and 75th percentiles, the band near the middle of the box is the 50th percentile (the median); the ends of the whiskers represent the minimum and maximum of the data. The circles show outliers, while red stars describe the mean values. The sample size is shown above each box.



2 Reed beds 6 Humid tall herb fringes 10 Humid grasslands
3 Dry fallow fields 8 Moist fallow fields 11 Mesophile gra sslands
5 Fen-sedge beds 9 Rich fens

Figure 24. Total phosphorus stock in dry biomass samples g P/m^2 and biomass phosphorus leaching loss kg P/ha in plant communities from restored wetlands in Kratholm catchment. In the box plots, the bottom and top of the box are describing the 25th and 75th percentiles, the band near the middle of the box is the 50th percentile (the median); the ends of the whiskers represent the minimum and maximum of the data. The circles show outliers, while red stars describe the mean values. The sample size is shown above each box.

When the aboveground biomass weight, nutrient stock and leaching rates were compared within the biomass samples from wetlands with a different wetland age, the two largest groups were formed by 18 and 12 samples from wetlands restored in 2010 and 2003. The rest of the years were represented in six or less samples. As described under the section 2.4 Data Analysis, in order to run the pairwise t-test, the data on aboveground biomass, nutrient stock and leaching from the wetland restored in 2008 was eliminated from the dataset.

Comparing the dry aboveground biomass weight within biomass samples from wetlands with a different wetland age, the highest average weight was recorded from samples from wetlands restored in 2008 – 2.3 kg DM/m^2. However, only one sample represents this year. The second highest average value was 1.2 kg DM/m^2 from years 2011, 2010, and 2005. The lowest average weight was recorded in samples from wetlands restored in 2003 – 0.9 kg DM/m^2. The widest range of values were registered in samples from 2010, and 2005. An outlier occurred among the values from 2003 (Figure 25). According to ANOVA analysis, there is no statistically significant difference between the biomass weight in samples from wetlands with a different age as p-values was 0.2. Also, for pairwise t-test, no values were lower than the confidence level 0.05 (Table 7).

Table 7. Results of pairwise t-test for dry aboveground biomass weight in restored wetlands with a different wetland age.

Year	2011	2010	2009	2005	2003
2010	0.84	-	-	-	-
2009	0.67	0.71	-	-	-
2005	0.91	0.93	0.72	-	-
2003	0.28	0.13	0.43	0.25	-
2001	0.58	0.58	0.86	0.61	0.58

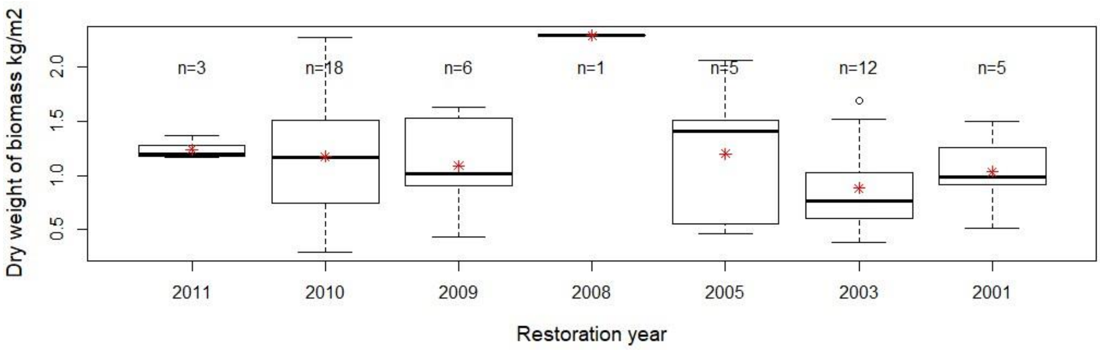


Figure 25. Dry aboveground biomass weight kg DM/m^2 from restored wetlands in Kratholm catchment with a different wetland age. In the box plots, the bottom and top of the box are describing the 25th and 75th percentiles, the band near the middle of the box is the 50th percentile (the median); the ends of the whiskers represent the minimum and maximum of the data. The circles show outliers, while red stars describe the mean values. The sample size is shown above each box.

The nitrogen stock in dry aboveground biomass samples ranged from 8.5 g N/m^2 in 2001 to 25.1 g N/m^2 in 2008. As there was only one sample from 2008, the next highest value was from 2011 – 18.3 g N/m^2. The widest range of values were recorded from wetlands restored in 2010. An outlier occured among the samples from 2001 (Figure 26). According to ANOVA analysis, there is a statistically significant difference between nitrogen stocks in samples from wetlands with a different age as p-value was 0.03. According to the results of pairwise t-test, there is a significant difference between the values from the wetlands restored 2001 and 2011 (p=0.049), 2003 and 2010 (p=0.008), as well as 2001 and 2010 (p=0.009) as shown in Table 8.

Table 8. Results of pairwise t-test for nitrogen stock in dry aboveground biomass in restored wetlands with a different wetland age.

Year	2011	2010	2009	2005	2003
2010	0.8723	-	-	-	-
2009	0.4872	0.4070	-	-	-
2005	0.3609	0.2628	0.7692	-	-
2003	0.0828	0.0075	0.1999	0.3800	-
2001	0.0487	0.0091	0.1107	0.2085	0.5320

When the nitrogen leaching losses from aboveground biomass per hectare are calculated, the highest average leaching – 27.6 kg N/ha represented plots restored in 2010. The lowest mean value is shown in plots restored in 2001 – 12.4 kg N/ha. The widest range of values were present in samples from wetlands restored in 2010, while an outlier was registered within the plots from 2001 (Figure 26). In general, the leaching rates were not statistically significantly different as p-value in ANOVA analysis was 0.2. However, pairwise t-test shows a difference between the nitrogen leaching rates from wetlands restored in 2003 and 2010 (Table 9).

Table 9. Results of pairwise t-test for biomass nitrogen leaching loss in restored wetlands with a different wetland age.

Year	2011	2010	2009	2005	2003
2010	0.775	-	-	-	-
2009	0.543	0.200	-	-	-
2005	0.471	0.167	0.873	-	-
2003	0.281	0.022	0.591	0.747	-
2001	0.258	0.051	0.509	0.632	0.805

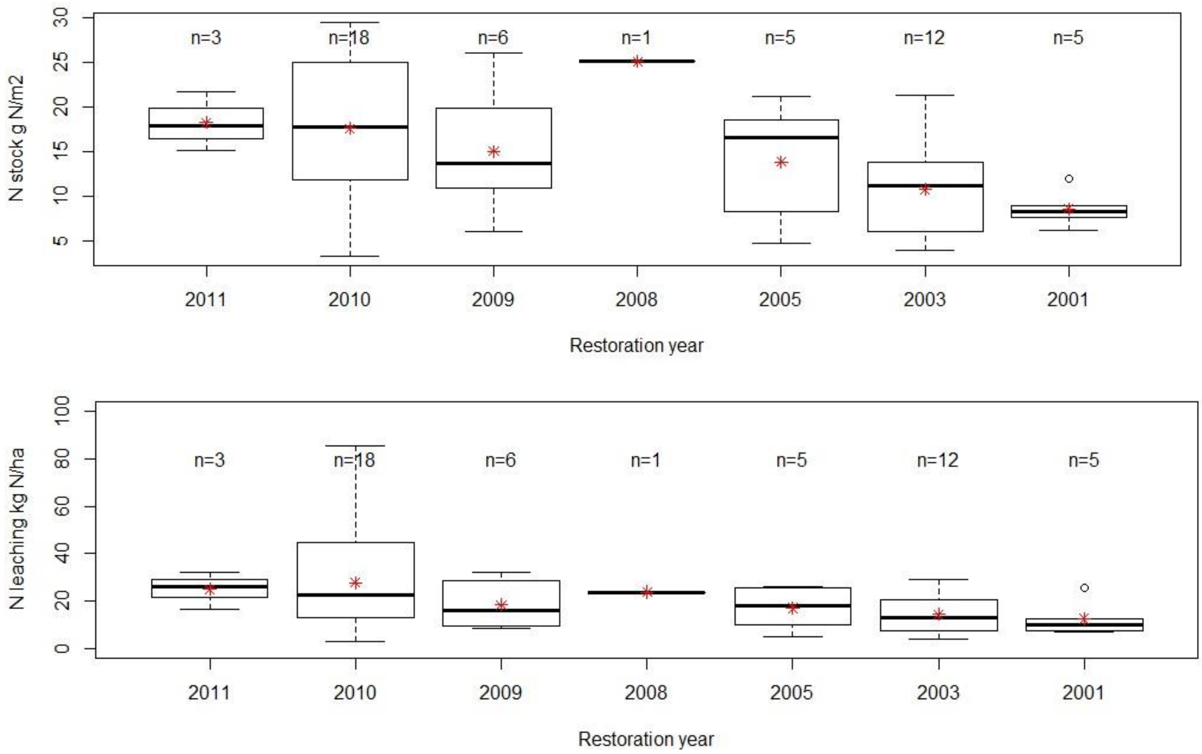


Figure 26. Total nitrogen stock in dry aboveground biomass samples g N/m^2 and biomass nitrogen leaching loss kg N/ha from restored wetlands in Kratholm catchment with a different wetland age. In the box plots, the bottom and top of the box are describing the 25th and 75th percentiles, the band near the middle of the box is the 50th percentile (the median); the ends of the whiskers represent the minimum and maximum of the data. The circles show outliers, while red stars describe the mean values. The sample size is shown above each box.

Phosphorus stock in dry aboveground biomass from plots with a different wetland restoration age ranged from 1.4 g P/m^2 in wetlands that were restored in 2003 to 3.8 g P/m^2 restored in 2008. As there was only one sample from 2008, the next highest value was 2.7 g P/m^2 from wetlands restored in 2010. The widest range of values occurred in plots from 2010 (Figure 27). However, there is no statistically significant difference between the years as p-value in ANOVA analysis was 0.06. According to pairwise t-test, there is a significant difference between the phosphorus stock in dry aboveground biomass sampled from wetlands restored in 2003 and 2010 (Table 10).

Table 10. Results of pairwise t-test for phosphorus stock in dry aboveground biomass in restored wetlands with a different wetland age.

Year	2011	2010	2009	2005	2003
2010	0.8979	-	-	-	-
2009	0.4591	0.2035	-	-	-
2005	0.3726	0.1513	0.8313	-	-
2003	0.1115	0.0041	0.3035	0.4667	-
2001	0.2372	0.0654	0.5695	0.7328	0.7460

When leaching loss of phosphorus from sampled biomass was calculated, the highest average leaching occurred in plots from 2010 – 10.2 kg P/ha as shown in Figure 27. The lowest average value recorded was 5.3 kg P/ha from plots restored in 2003. The widest range of values were registered in plots that were restored in 2010. Outliers occurred in the plots restored in 2009, 2005, and 2001. ANOVA analysis showed that there is no statistically significant difference among the phosphorus leaching rates in different years as p-value was 0.2. When the pairwise comparison is done, there was a significant difference between the phosphorus leaching values from wetlands restored in 2003 and 2010 as p-value was 0.007 (Table 11).

Table 11. Results of pairwise t-test for biomass phosphorus leaching loss in restored wetlands with a different wetland age.

Year	2011	2010	2009	2005	2003
2010	0.5569	-	-	-	-
2009	0.7040	0.1819	-	-	-
2005	0.5162	0.1010	0.7334	-	-
2003	0.2902	0.0068	0.4047	0.6907	-
2001	0.5112	0.0988	0.7263	0.9927	0.6987

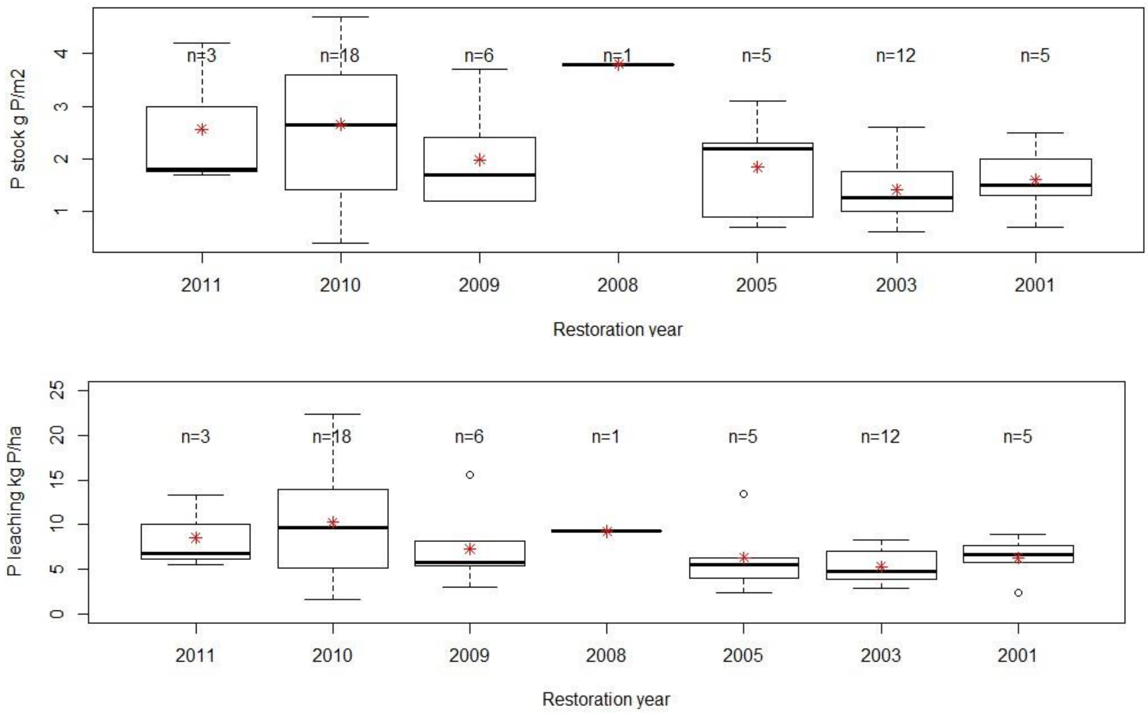


Figure 27. Total phosphorus stock in dry aboveground biomass samples g P/m^2 and biomass phosphorus leaching loss kg P/ha from restored wetlands in Kratholm catchment with a different wetland age. In the box plots, the bottom and top of the box are describing the 25th and 75th percentiles, the band near the middle of the box is the 50th percentile (the median); the ends of the whiskers represent the minimum and maximum of the data. The circles show outliers, while red stars describe the mean values. The sample size is shown above each box.

4. Discussion

4.1. General Vegetation Parameters

According to the sampled data during the field work in 10 restored wetlands in Kratholm catchment, it was found that the average species richness in the vegetation plots was 2.4 species per m^2. The highest amount of species recorded was 36 species per 4 m^2 large plot or 9 species per m^2. Audet et al. (2015) have done a study in wetlands that are part of six naturally meandering streams, which are considered among the least disturbed stream ecosystems in Denmark. In the studied sites, the species richness varied from 6.4 to 40.8 species/m^2. According to the study, the average species richness in the plots with fen vegetation, which is target vegetation for restored wetlands in Denmark, was 24 species/m^2. In a monitoring report on wetland restoration success, the average amount of species richness in calcareous fens in River Sønderå in Southern Jutland was 26.0 species/m^2, while in River Hellegårdå in Central Jutland was 15.1 species/m^2 (Hoffmann et al., 2005).

The significant difference between the species richness in restored wetlands and the target vegetation can be explained with hydrology, high phosphorus and nitrogen input as well as wetland age. Species richness is higher in areas with high ground water level and low nutrient input (Zedler, 2000; Güsewell et al., 2005; Audet et al., 2015). Restoration of natural or close to natural hydrological regime is among the main aims of wetland restoration projects, showing that wetland habitats cannot exist without water (Zedler, 2000). In riparian wetlands, higher species richness is found in groundwater discharge areas, which also tend to be more resistant to human induced regulation of hydrological regime, thus allowing to form larger and more stable wetland plant populations (Jansson et al., 2007).

As the wetlands are restored with the aim to reduce nitrogen and phosphorus losses from agricultural lands, the areas receive large amounts of nutrients. Therefore, species richness as well as species diversity is low in highly productive plant communities such as reed beds or humid tall herb fringes, which were the most commonly described plant communities in the studied sites. Similar results regarding decrease in species richness with an increased productivity were also observed in wetlands in Poland, Belgium and The Netherlands (Olde Venterink et al., 2003).

Regarding wetland age, the results for species richness and diversity from wetlands restored in different years were rather similar. For example, in the plots from 2010, the average species richness was 9.9 species per 4 m^2, while for wetlands restored in 2003, the average species richness was 9.1 species per 4 m^2. However, Shannon species diversity index tend to increase with an increase of wetland age. For example, for the vegetation plots from 2010 the index was 1.1, while for the plots from 2003 the index was 1.3. In general, the species rich plant communities in restored wetlands develop over several decades. Even 100 years after the restoration, the species richness can be lower than in natural wetlands (Moreno-Mateos et al., 2012). In comparison, the oldest restored wetland included in this study was Karlsmossen, which was restored in 2001. Therefore, a long-term monitoring of species composition and richness would be useful to follow the development of vegetation in restored wetlands. An increase of the value of Shannon index, thus a higher diversity in the plant communities can be also reached by increasing the discharge in the restored sites, thus increasing flooding and creating new, more variable habitats (Göthe et al., 2016).

In addition, seed banks occurring in the soil in the restored areas are an important criterion for a successful restoration of a species rich wetland plant communities (Stroh et al., 2012). Regarding fen restoration, seed banks and long distance seed dispersal should be considered as a crucial factor (Malson et al., 2008). It has been found that large share of fen grassland species have a long-term persistent seed banks, which possibly might be restored if the conditions and management is suitable (Jensen, 2004). However, the streams in Kratholm catchment have been straightened since 1940s and most of the adjacent areas have been used for agriculture until the implementation of restoration projects. Thus, the wetland plant seed bank in the areas might be rather poor. On the other hand, if there is an inundation taking place, a considerable amount of viable seeds might be deposited in the restored area. In a study on seed germination from deposited sediments during high winter flow in riparian areas in Denmark it was found that the inundated areas receive species rich and diverse seed deposits. A significantly high richness and diversity was registered in the samples taken 16 m from the stream (Riis et al., 2014).

Regarding the Ellenberg indicator values for light, moisture, and soil fertility, the results applying community weighted mean show that plants preferring half-light conditions, humidity as well as the soil fertility between moderate nutrient rich and nutrient rich are dominating in the restored wetlands. A detailed discussion about Ellenberg indicator values and plant communities is given in the next section of the thesis.

4.2. Plant Communities

The most common plant communities represented in the vegetation plots from studied wetlands were reed beds and humid tall herb fringes. Both plant communities were described in 40% of all vegetation plots. In Danish riparian wetlands, reed beds dominate in areas where there is a high input of nitrogen via groundwater (BaattrupPedersen et al., 2014). Regarding the ecology of both plant communities, it is rather similar, both are located at nutrient rich river banks (Nygaard et al., 2009). As the wetlands are restored with the aim to reduce the amount of nitrogen and phosphorus entering the streams, plant communities that are highly productive would be expected to dominate in the area. Data on plant community distribution in the areas is needed for further research.

Regarding species richness, reed beds had one of the lowest average values - 7.8 species per 4 m^2 vegetation plot, while the highest values were above 12 species per 4 m^2 for rich fens, humid and mesophile grasslands. Shannon species diversity index showed the same results – the index was lower in reed beds, while higher in fen and grassland plant communities. In contrast, the average Shannon index in humid tall herb fringe plant communities was also rather high – 1.4, almost twice as high as in reed beds. Regarding reed beds, grasslands and rich fens, Baattrup-Pedersen et al. (2014) drew a similar conclusion in a research on vegetation in riparian wetlands in agricultural catchments in Denmark. The highest species richness was registered in rich fens, compared to grasslands and reed beds. According to Danish wetland and grassland plant community descriptions, one of the typical characteristics of reed beds is a dominance of one tall herb species, for example, Great manna grass *Glyceria maxima,* Reed canary grass *Phalaris arundinacea,* Great willow herb *Epilobium hirsutum,* Lesser water-parsnip *Berula erecta,* as well as Common nettle *Urtica dioca* (Nygaard et al., 2009). In this study, all previously mentioned species, except *B.erecta* were among the most abundant species.

In comparison, a high species richness is characteristic to rich fens. Many rare species can be found in these plant communities (Nygaard et al., 2009). In this study, 17 vegetation plots or 10% of all plots described were classified as rich fens, the average species richness of 11.8 species per 4 m^2 large plot can be considered as low, comparing to the potential species richness described in the section 4.1. of this thesis.

When Ellenberg indicator values for light were analysed among different plant communities, the average values were rather similar in all communities, ranging from 6.8 to 8.0, describing half-light and light plants that are related to open habitats. The results align with the plant community descriptions of Danish grassland and mire plant communities (Nygaard et al., 2009).

Regarding average Ellenberg indicator values for moisture, a large difference was shown among described plant communities, ranging from 5.7 in mesophile grasslands up to 9.5 for fen-sedge beds. Indicator value 6 describes fresh to humid soils, while values 9 and 10 indicate wetness and aquatic plants that can survive for long periods without flooding. Both plant communities also occur in different ends of the spectrum regarding the plant community descriptions – the indicator value for mesophile grasslands is 5 to 6, while for fen-sedge beds it is 7 to 9 (Nygaard et al., 2009). When the two most commonly registered plant communities in the vegetation plots are compared regarding the wetness, the average indicator value for reed beds was 8.2 – a state between humidity and wetness, while humid tall herb fringe communities had the average value of 7.0, indicating humidity. This also fits rather good with the values described by Nygaard et al. (2009), where plants found in reed beds are characterized by wetness indicator values from 8 to 10, and humid tall herb fringes with values 6 to 7. Thus, it shows that plants preferring more wet conditions can be found in reed beds, while drier river banks are occupied by humid tall fringes.

For soil fertility, two main groups of plant communities can be described – the first with average values in the interval from 6 to 8, for example, reed beds, dry fallow fields, and the second with values below 6 – rich fens, and mesophile grasslands. Indicator value 6 describes moderate nutrient rich to nutrient rich soils, while value 8 indicates pronounced levels of nutrients. Also, this description fits very well with findings of Nygaard et al. (2009) regarding grassland and mire communities. Reed beds and humid tall herb fringes occur among the plant communities that prefer moderate to nutrient rich soils, thus approving the fact that the restored areas are receiving large amount of nutrients from adjacent agricultural lands.

Comparing plant communities registered in the vegetation plots from wetlands restored in 2003 and 2010, as well as 2011, a decrease in number of vegetation plots representing improved and mesophile grasslands can be seen with an increase of wetland age. This can be explained with a fact that most of the restored areas have previously been used as agricultural lands or meadow-lands (Hoffmann and BaattrupPedersen, 2007). Thus, it can be expected that the representation of improved grasslands in the restored areas will decrease over the time**.** Contrarily, the representation of plots with humid tall herb fringe communities tend to increase with the wetland age. In fact, it takes time to establish these stream bank plant communities after the restoration has been finished. Often, wetland restoration includes excavation work and river re-meandering.

The target plant community for restored wetlands – rich fens was represented in 10% of all plots described and was present in wetlands restored in 2010 and 2003. However, the species richness was rather low, which is atypical for fens. In fact, due to high nutrient input to the wetland areas, the wetland vegetation might reflect it - reeds as well as large sedges can become dominant instead of the characteristic fen vegetation (Pfadenhauer and Grootjans, 1999). Thus, the quality of the rich fens might decrease over the time, however additional research on this topic is needed.

4.3. Biomass, Nutrient Stock and Leaching

The average aboveground plant biomass weight from restored wetlands in Kratholm catchment was 1.1 kg dry mass (DM)/m^2. Regarding the plant communities, the highest average biomass weight had fen-sedge beds – 1.4 kg DM/m^2 and reed beds – 1.2 kg DM/m^2. In a study from Denmark where the dry aboveground biomass weight was measured in a riparian wetland, which is close to a natural state, the average weight was 0.9 kg DM/m^2, which was considered as high (Andersen, 2004). As mentioned before, the restored wetlands are established for nutrient removal, thus their productivity is expected to be higher than in the natural wetlands. In two restored riparian wetlands in Denmark, Storå and Egeskov, the dry aboveground biomass weight was 0.7 kg DM/m^2 and 0.5 kg DM/ m^2 (Hoffmann et al., 2012). In wastewater treatment wetlands in Estonia, which are even more productive than

Danish restored wetlands, the two most common species were Common reed *Phragmites australis* and Common cattail *Typha latifolia,* the results showed that the average aboveground biomass varied from 0.6 to 1.2 kg DM/m^2 for *P.australis* and from 0.3 to 1.8 kg DM/m^2 for *T.latifolia* (Maddison et al., 2009). In restored peatlands in Germany, the average dry aboveground biomass for such helophyte species as *P.australis*, *T.latifolia*, Great manna grass *Glyceria maxima,* The greater pond sedge *Carex riparia*, The acute sedge *Carex acuta*, and *P.arundinacea* was between 0.6 and 1.6 kg DM/m^2. The highest values were recorded in the *P.australis* samples where the dry aboveground biomass weight varied from 1.3 to 2.4 kg DM/m^2. The average weight for *P.arundinacea* was 0.6 kg DM/m^2 (Zerbe et al., 2013). All four species were recorded in the vegetation plots in Kratholm catchment, while *P.arundinacea* was among the most abundant species. Regarding wetland age and aboveground biomass weight, no statistically significant difference was found within the samples from wetlands with a different wetland age.

The average nitrogen stock in dry aboveground biomass was 14.6 g N/m^2. In comparison, in two restored riparian wetlands – Storå and Egeskov, the nitrogen stocks were 12.7 g N/m^2 and 10.8 g N/m^2 (Hoffmann et al., 2012). In a seasonally inundated wetland, which is located in the floodplain of River Gjern in Jutland, the nitrogen uptake by plants was 10.3 g N/m^2 and the values was characterized as high (Andersen, 2004).

Regarding plant communities, reed beds and humid tall herb fringes stored the largest amount of nitrogen, the nitrogen stocks were 16.2 g N/m^2 and 16.5 g N/m^2, however the leaching rates also were rather high – 24.1 and 33.6 kg N/ha. In comparison, the average nitrogen leaching from all biomass samples was 20.5 kg N/ha. As mentioned before, *P.arundinacea* was one of the most abundant species in the vegetation plots, often being the dominant species in reed beds and humid tall herb fringes. In rewetted peatlands in Germany, *P.arundinacea* stored only 6.6 g N/m^2 (Zerbe et al., 2013). Kao et al. (2003) has measured the nitrogen content in the tissues of *P.arundinacea,* the average value was 15 mg N/g of dry matter. However, the species has a low capacity to retain nutrients – only 28% of nitrogen remained in litter after a fivemonth long decomposition period. Wetland plant species found in restored peatlands with a high nitrogen stock are *P.australis* 19.1 g N/m^2, *T.latifolia* 18.7 g N/m^2, *G.maxima* 12.3 g N/m^2 (Zerbe et al., 2013). All previously mentioned species were among the most abundant species in restored wetlands in Kratholm catchment and characteristic to reed bed or humid tall herb fringe plant communities.

For average nitrogen stock in wetlands with a different wetland age, more nitrogen was stored in the biomass from wetlands restored in 2011 and 2010, where nitrogen stock was 18.3 and 17.6 g N/m^2 and can be considered as high compared to samples from 2003 and 2001 with average values 10.7 and 8.5 g N/m^2. In addition, average nitrogen leaching was also higher in more recently restored wetlands 27.6 kg N/ha in 2010, compared to 14.4 kg N/ha in 2003.

The average phosphorus stock in the samples was 2.1 g P/m^2. The stock values from Storå and Egeskov riparian wetlands were slightly lower – 1.7 g P/m^2 and 1.0 g P/m^2 (Hoffmann et al., 2012). The highest phosphorus stock among the plant communities was in humid tall herb fringes – 3.3 g P/m^2, however the leaching rates were also the highest – 13.1 kg P/ha. In comparison the average leaching rates for all vegetation plots were 7.8 kg P/ha. It has been found that phosphorus content in aboveground biomass for *P.arundinacea*, which is one of the most characteristic species for humid tall herb fringes, was 1.8 mg P/g DM, while after five months of decay only 18% of phosphorus remained (Kao et al., 2003). According to Nygaard et.al (2009), along the *P.arundinacea*, another characteristic species for tall herb fringes is *G.maxima*. In rewetted peatlands the species in aboveground biomass stored 2.8 g P/m^2 , while *P.arundinacea* stored 1.2 g P/m^2 (Zerbe et al., 2013). Regarding phosphorus leaching, in a study on phosphorus retention in riparian buffer zones in Denmark, the plant uptake was up to 1.5 g P/ m^2, per year (Hoffmann et al., 2009).

For phosphorus stock, there was a statistically significant difference between the values from wetlands restored in 2010 with the average value 2.7 g P/m^2 and 2003 with average value 1.4 g P/m^2. The same years also statistically significantly differ regarding the phosphorus leaching rates – the average leaching in the samples from wetlands restored in 2010 was 10.3 kg P/ha, while 5.3 kg P/ha from the areas restored in 2003. Thus, the phosphorus uptake and leaching tend to decrease with an increase of wetland age.

The results show that the reed bed and humid tall herb fringe plant communities where such species as *P.arundinacea*, *P.australis* and *G.maxima* are dominant can be a significant source for phosphorus and nitrogen leaching - nutrients that are taken up by plants are removed only temporally and can be released through leaching and ongoing mineralisation. In a research from Denmark, four restored wetlands removed between 52 and 337 kg N/ha per year and retained phosphorus between 0.1 and 10.0 kg P/ha per year (Hoffmann et al., 2011). Karlsmossen, which is one of the research areas, in periods when discharge and nutrient load is high, removes from 3.0 to 3.7 kg N/ha per day (Hoffmann and Baattrup-Pedersen, 2007). Thus, the nutrient stock in wetland plants is a significant measure for nutrient balance calculations, especially regarding phosphorus. For example, the phosphorus that was taken up by plants in restored riparian wetlands was up to 136 times higher than annual phosphorus load for the wetland, therefore biomass harvesting is highly recommended in such areas (Hoffmann et al., 2012). It has also been found that plant uptake forms from 12% up to 73% of the total nitrogen retention in herbaceous wetland buffer zones (Hefting et al., 2005).

4.4. Management Recommendations

During the field work, it was observed that the areas differ a lot regarding the management. For example, some areas were managed by mowing, grazing by sheep, cattle, horses, or both - mowing and grazing. On the other hand, there were also areas that have not been managed at all for a longer period of time and had a dense litter layer, as it was in the case of Gedebakken. It would be advisable for land owners in Kratholm catchment to manage the restored wetlands, however, management in restored areas after the implementation of the projects is not obliged (Carl Christian Hoffmann 2019c, personal communication). However, in some areas tree and shrub cutting must be done (Miljø- og Fødevareministriet, 2019d). Vegetation mapping in the areas would provide a useful information for planning further management.

Reed beds and humid tall herb fringes were the two most common plant communities recorded in the vegetation plots. Both communities are rather productive; therefore, it would be recommended to harvest the biomass several times during the growing season, thus also removing the nutrients. For example, in a research on herbaceous wetland buffer zones along streams, it was found that a periodic harvesting can significantly contribute to nitrogen removal - in The Netherlands in unmanaged sites nitrogen that was taken up by plants formed 13% of the annual nitrogen retention, while in mown sites it was 30% (Hefting et al., 2005). In a study on reed management, it was found that regular harvesting of reeds increased species richness by 90% in freshwater wetlands (Valkama et al., 2008). Thus, plant biomass harvesting should be also considered as a way to increase re-oligotrophication of restored wetlands (Zerbe et al., 2013). In general, moderate grazing and moving in restored wetlands reduces dominance by few species and increases species richness (Zedler, 2000).

In case of River Skjern, which is one of the largest riparian wetland restoration projects in Denmark, a management plan is developed for the area. The main target for the management plan is to keep the river valley managed, otherwise *P.australis* along with alder *Alnus* sp. and willow *Salix* sp. will become the dominant species. However, some areas are left without any management, where the natural colonisation of tall grasses, bushes and trees occurs. The most common type of management in the area is cattle grazing (Pedersen et al., 2007).

In general, grazing and mowing would be the most recommended type of management of the restored areas in Kratholm catchment. Mowing with a biomass removal should be done several times during the growing season. In some of the studied wetlands, removal of tree and shrub layer would be needed.

4.5. Restoration Success and Restoration Goals

Regarding the success of the implementation of restoration projects in Kratholm catchment when focusing on plant species and plant communities, the conclusion can be drawn that it takes a lot more time for development of species rich plant communities which would be more valuable from the botanical perspective. In addition, the nutrient input must be lower in order to improve the species richness in the restored wetland areas (Zedler, 2000; Güsewell et al., 2005; Audet et al., 2015). However, mowing of reed beds and humid tall herb fringes that are characterised with low species richness, often dominated by one species, can be used as an effective tool to increase the nutrient removal capacity of restored wetlands (Hefting et al., 2005; Hoffmann et al., 2012).

To be able to evaluate the success of a wetland restoration project regarding plant communities, it is important to define parameters that will be monitored on a yearly basis or for example once in every three years. Species composition and cover are significant measures for plant communities, thus allowing to calculate species richness, Shannon diversity index and other significant parameters. Also, vegetation mapping should be done in the restored areas, for example, before restoration and then every fifth, tenth etc. year after the restoration. A management plan should be developed for each area, setting goals regarding plant species, plant communities, habitats, bird species etc. For each goal, certain management activities should be assigned and described detally.

5. Conclusions

1. The average species richness in vegetation plots in restored wetlands in Kratholm catchment was low – 2.4 species per m^2. Species preferring halflight conditions, humidity and soil fertility between moderate nutrient rich and nutrient rich soils are dominating in the restored wetlands. Species diversity tends to increase with a wetland age. In total, 10 plant communities were described in the studied wetlands. The most commonly recorded plant communities in vegetation plots were reed beds and humid tall herb fringes, preferring light conditions, as well as wet and fertile soils. Both plant communities were characterized by low species richness.
2. The average weight of aboveground plant biomass and nutrient stock was high - 1.1 kg DM/m^2, 14.6 g N/m^2 and 2.1 g P/m^2. Nitrogen and phosphorus stock and leaching rates tend to decrease with an increase of wetland age. Reed beds represent high aboveground biomass weight, high nitrogen stock and nitrogen leaching values, while humid tall herb fringes store and leach high amounts of nitrogen and phosphorus.
3. The best-case scenario for management of restored wetlands in Kratholm catchment would be grazing and periodical mowing during the growing season with a biomass removal from the area, thus also removing nutrients from the system.
4. It is difficult to rate the success of restoration projects. Even though the species richness is low, the most productive plant communities, such as reed beds and humid tall herb fringes can be used for increasing the nutrient removal rates of the wetlands. Regarding restoration goals, each area should be evaluated separately, a monitoring plan and a management plan should be developed.

The hypothesis was partially confirmed, the species diversity increases with an increase of wetland age, however there was no statistically significant difference in species richness among the wetlands with different wetland age. Nutrient stock and leaching tend to decrease with an increase of wetland age.

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Appendices

List of vascular plant and bryophyte species registered in the vegetation plots in restored wetlands in Kratholm catchment.

Vascular plants			
Species name	**Species name**	**Species name**	**Species name**
Achilea millefolium	*Chenopodium rubrum*	*Equisetum fluviatile*	*Mentha aquatica*
Acorus calamus	*Cirsium arvense*	*Equisetum palustre*	*Mentha arvensis*
Aegopodium podagraria	*Cirsium oleraceum*	*Equisetum pratense*	*Mercurialis perennis*
Agrostis capillaris	*Cirsium palustre*	*Eupatorium cannabinum*	*Myosotis arvensis*
Agrostis gigantea	*Cirsium vulgare*	*Festuca arundinacea*	*Myosotis scorpioides*
Agrostis stolonifera	*Crataegus sp.*	*Festuca brevipila*	*Persicaria amphibia*
Alisma plantagoaquatica	*Cynosurus cristatus*	*Festuca pratensis*	*Persicaria hydropiper*
Alnus glutinosa	*Dactylis glomerata*	*Festuca rubra*	*Persicaria lapathifolia*
Alopecurus geniculatus	*Dactylorhiza sp.*	*Filipendula ulmaria*	*Petasites hybridus*
Alopecurus pratensis	*Deschampsia cespitosa*	*Galeopsis speciosa*	*Peucedanum palustre*
Angelica sylvestris	*Eleocharis palustris*	*Galium album*	*Phalaris arundinacea*
Anisantha sterilis	*Elytrigia repens*	*Galium aparine*	*Phleum pratense*
Anthemis arvensis	*Epilobium hirsutum*	*Galium palustre*	*Phragmites australis*
Anthoxanthum odoratum	*Epilobium palustre*	*Galium uliginosum*	*Pilosella officinarum*
Anthriscus sylvestris	*Epilobium parviflorum*	*Geranium pusillum*	*Plantago lanceolata*
Argentina anserina	*Epilobium roseum*	*Geranium sp.*	*Plantago major*
Arrhenatherum elatius	*Equisetum arvense*	*Geum rivale*	*Poa angustifolia*
Artemisia vulgaris	*Equisetum fluviatile*	*Geum urbanum*	*Poa pratensis*
Berula erecta	*Equisetum palustre*	*Glechoma hederacea*	*Poa trivialis*
Betula pendula	*Equisetum pratense*	*Glyceria fluitans*	*Populus tremula*
Betula pubescens	*Eupatorium cannabinum*	*Glyceria maxima*	*Prunella vulgaris*
Bidens cernua	*Festuca arundinacea*	*Heracleum sphondylium*	*Quercus robur*
Bidens tripartita	*Festuca brevipila*	*Holcus lanatus*	*Ranunculus acris*
Briza media	*Festuca pratensis*	*Hypericum maculatum*	*Ranunculus auricomus*
Butomus umbellatus	*Festuca rubra*	*Hypericum perforatum*	*Ranunculus flammula*
Calamagrostis canescens	*Filipendula ulmaria*	*Hypochoeris radicata*	*Ranunculus repens*
Calystegia sepium	*Galeopsis speciosa*	*Iris pseudacorus*	*Rhinanthus minor*
Cardamine amara	*Chenopodium rubrum*	*Juncus alpino-articulatus*	*Rorippa palustris*
Carex acuta	*Cirsium arvense*	*Juncus articulatus*	*Rosa sp.*
Carex acutiformis	*Cirsium oleraceum*	*Juncus conglomeratus*	*Rubus caesius*
Carex disticha	*Cirsium palustre*	*Juncus effusus*	*Rubus idaeus*
Carex hirta	*Cirsium vulgare*	*Lactuca serriola*	*Rumex acetosa*
Carex nigra	*Crataegus sp.*	*Lapsana communis*	*Rumex acetosella*
Carex ovalis	*Cynosurus cristatus*	*Lemna minor*	*Rumex conglomeratus*
Carex pairaei	*Dactylis glomerata*	*Leontodon autumnale*	*Rumex crispus*
Carex panicea	*Dactylorhiza sp.*	*Leucanthemum vulgare*	*Rumex obtusifolius*
Carex paniculata	*Deschampsia cespitosa*	*Lolium perenne*	*Rumex palustris*
Carex pseudocyperus	*Eleocharis palustris*	*Lotus corniculatus*	*Rumex sp.*
Carex riparia	*Elytrigia repens*	*Lychnis flos-cuculi*	*Salix cinerea*
Carex rostrata	*Epilobium hirsutum*	*Lycopus europaeus*	*Salix sp.*
Carex spicata	*Epilobium palustre*	*Lysimachia vulgaris*	*Salix triandra*
Carex vesicaria	*Epilobium parviflorum*	*Lythrum salicaria*	*Scirpus sylvaticus*
Cerastium fontanum	*Epilobium roseum*	*Matricaria matricarioides*	*Scrophularia nodosa*
Chenopodium album	*Equisetum arvense*	*Medicago lupulina*	*Scutellaria galericulata*

List of vascular plant and bryophyte species registered in the vegetation plots in restored wetlands in Kratholm catchment.

Vascular plants			
Species name	**Species name**	**Species name**	**Species name**
Senecio jacobaea	*Stachys palustris*	*Trifolium campestre*	*Valeriana officinalis*
Senecio vulgaris	*Stellaria graminea*	*Trifolium pratense*	*Veronica chamaedrys*
Sium latifolium	*Stellaria media*	*Trifolium repens*	*Veronica sp.*
Solanum dulcamara	*Stellaria palustris*	*Triglochin palustris*	*Vicia cracca*
Sonchus asper	*Taraxacum officinale*	*Typha latifolia*	*Vicia sp.*
Sparganium erectum	*Thalictrum flavum*	*Urtica dioica*	
Bryophytes			
Species name	**Species name**	**Species name**	**Species name**
Brachytheciastrum velutinum	*Brachythecium salebrosum*	*Pleurozium schreberi*	*Rhytidiadelphus squarrosus*
Brachythecium rutabulum	*Calliergonella cuspidata*	*Pseudoscleropodium purum*	*Sciuro-hypnum oedipodium*

DCA ordination for species described in vegetation plots from Kratholm catchment (red dots) compared to DANVEG dataset for mire and grassland plant communities (gray dots). Species presented have been registered in more than five vegetation plots (Nygaard et al., 2009).