Created Wetlands—Sustainable Landscapes

-Created Wetlands in Denmark and Skåne: An Analysis of Impacts on Nutrient Retention and Biodiversity

By

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Abstract

Differing wetland construction methodologies in Denmark and Skåne have been studied, and impacts on nutrient retention and biodiversity analyzed. Skåne wetland projects were 6 times more effective at removing nitrogen, exhibiting average retentions of 1,700 kg N ha^{-1} yr^{-1} compared to 270 kg N ha^{-1} yr^{-1} for Danish projects. Increased retention was attributed to two factors: better placement in the landscape relative to eutrophication sources, and the opting for construction of pond-like wetlands which function as more efficient nutrient traps. Given the overall scale of national restoration plans, Skåne wetlands will be 3 times more effective in combating eutrophication, removing 8,500 metric tons of nitrogen annually compared to 2,700 metric tons in Denmark. Biodiversity in both regions quickly increased following a post-construction stabilization period. Created wetlands substantially increased species richness and diversity while simultaneously increasing habitat diversity. Wetland creation additionally resulted in occurrences of numerous rare and threatened species which otherwise would not be present. Danish goals of decreasing eutrophication can significantly benefit by incorporating methodology from Skåne. Simultaneously, conflicts between newly created biodiversity and pre-existing biological values can be reduced. Skåne nutrient trap effectiveness will not benefit by integrating Danish methodologies. Regional biodiversity might, however, marginally benefit from such integration. Numerous political obstacles prevent this from being an implementable option, however, and the additional benefits to regional biodiversity—over those already exhibited—are not expected to be substantial. This last finding is in contrast to study expectations. Constructing wetlands increases and benefits sustainable development of agriculture in these landscapes.

Keywords: Constructed wetlands; Wetland restoration; Nutrient trap; Nitrogen retention, Biodiversity; Agricultural landscape; Sustainable development

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Additional thanks to the numerous individuals who have helped with constructive criticism and editing efforts.

Dedication

This thesis is dedicated to my mother and father, two of the most honest, hard-working and loving individuals any son can have the fortune of calling his parents. To them I dedicate this thesis, and thereby say thank you for introducing me to that infinitely-faceted jewel which is nature and Her myriad of aquatic environments.

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1 Introduction

Denmark and Sweden have carried out large-scale wetland restoration programs within the last decade. In both countries, large portions of the landscape were drained and channelized to benefit agriculture. These human actions drastically changed the hydrologic conditions in these landscapes, impoverishing the habitat, biotic diversity and composition of the landscape. Concurrent with the loss of natural wetlands is a parallel loss of biodiversity in streams, rivers and near-coast environments.

Eutrophication of waters and loss of wetland habitats are the primary cause of this biological impoverishment, and are a result both of increased input nutrients into watercourses, and decreased nutrient retention in the open landscape. As wetlands were drained and converted to agricultural land, their natural water purification functions have disappeared. Restoration of wetlands has largely been an attempt for Denmark and Skåne to re-establish these purifying qualities of wetlands in order to combat what is now known to be the key source of these nutrients—agricultural non-point source pollution.

Despite similar histories of wetland drainage, however, restoration programs in the two countries rely largely upon different processes and methodology. The focus of these projects also differ. In Skåne, efforts have stressed creating small pond-like wetlands for the primary purpose of reducing nutrient transport to downstream areas. This generally occurs within the confines of the present water table, and does not involve large hydrologic changes within the landscape. In Denmark, restoration efforts revolve around creating new wetlands by raising water levels in the landscape, thus rewetting substantial areas and creating wetlands typified by wet meadows and fens. Concurrent with this are numerous nature restoration projects which seek to restore the former natural physical habitat of stream and riparian areas by re-meandering them, thus restoring the hydrologic contact of river systems with their former floodplains. These projects involve substantial changes of the river and riparian regimes in the landscape, and are employed for the dual purposes of reducing eutrophication, and for promoting and restoring biological diversity.

It is apparent that these different approaches have differing implications for both the reduction of nutrients and increasing biodiversity in the agriculturally dominated landscapes where wetlands are restored.

This particular study is timely for several reasons. Firstly, it is well documented that created wetlands can serve as cost-efficient nutrient traps. Additionally, the ability of new wetland areas to increase biodiversity has also been examined. Prior examinations and studies have examined aspects of this in both Denmark and Skåne, with weight upon nutrient retention functions in Skåne, and effects upon biodiversity in Denmark. To date, however, there exists no systematic comparison of the growing body of knowledge within these two neighboring areas. Additionally, and although the situation is improving, an apparent ignorance of neighboring practices, experiences and general knowledge—beyond a basal level—hinders optimization of the (mutual—yet with varying emphasis) goals of wetland restoration efforts in both countries. This is especially interesting in light of statements indicating that some people from Skåne consider Danish wetland restoration methodology as a role-model (Swedish Environmental Protection Agency, 2001, p. 93 & p. 96).

1.1 Objectives of the Study

The general objective of the study is to examine the core question: how do the differing wetland creation and restoration methodologies in Denmark and Skåne impact nutrient reduction and biodiversity in these agriculturally dominated landscapes. In addition to assembling the various fragments of knowledge and providing a coordinated overview of some of the most recent wetland restoration efforts, this will allow an analysis of why, and to what extent the impacts of these methodologies differ. There are several specific objectives as follows:

1. Quantitatively compare the nitrogen reduction service of created wetlands in Denmark and Skåne.

2. Qualitatively evaluate and compare changes in biological diversity as a result of re-establishing wetlands.

3. Analyze how, and to what extent any observed differences in nutrient retention and changes in biodiversity are the result of methodological differences.

4. Provide recommendations for how methodologies in the one country can effectively augment practices in the other in order to decrease eutrophication of rivers and near-shore coastal environments, and also to increase regional biodiversity. In a larger context, to explain how created wetlands can better contribute to sustainable development within these areas.

1.2 Hypothesis

It is hypothesized that the differing wetland implementation strategies will be mirrored in differences both as concerns both the reduction of nutrients, but also regarding the biodiversity of the landscapes in which wetlands are restored. It is expected that created wetlands in Skåne will exhibit increased nutrient trap efficiency relative to Danish wetlands. It is further expected that Danish wetlands will better function to increase biodiversity in the landscape.

2 Study Area, Definition, Methods and Limitations

2.1 Study Area

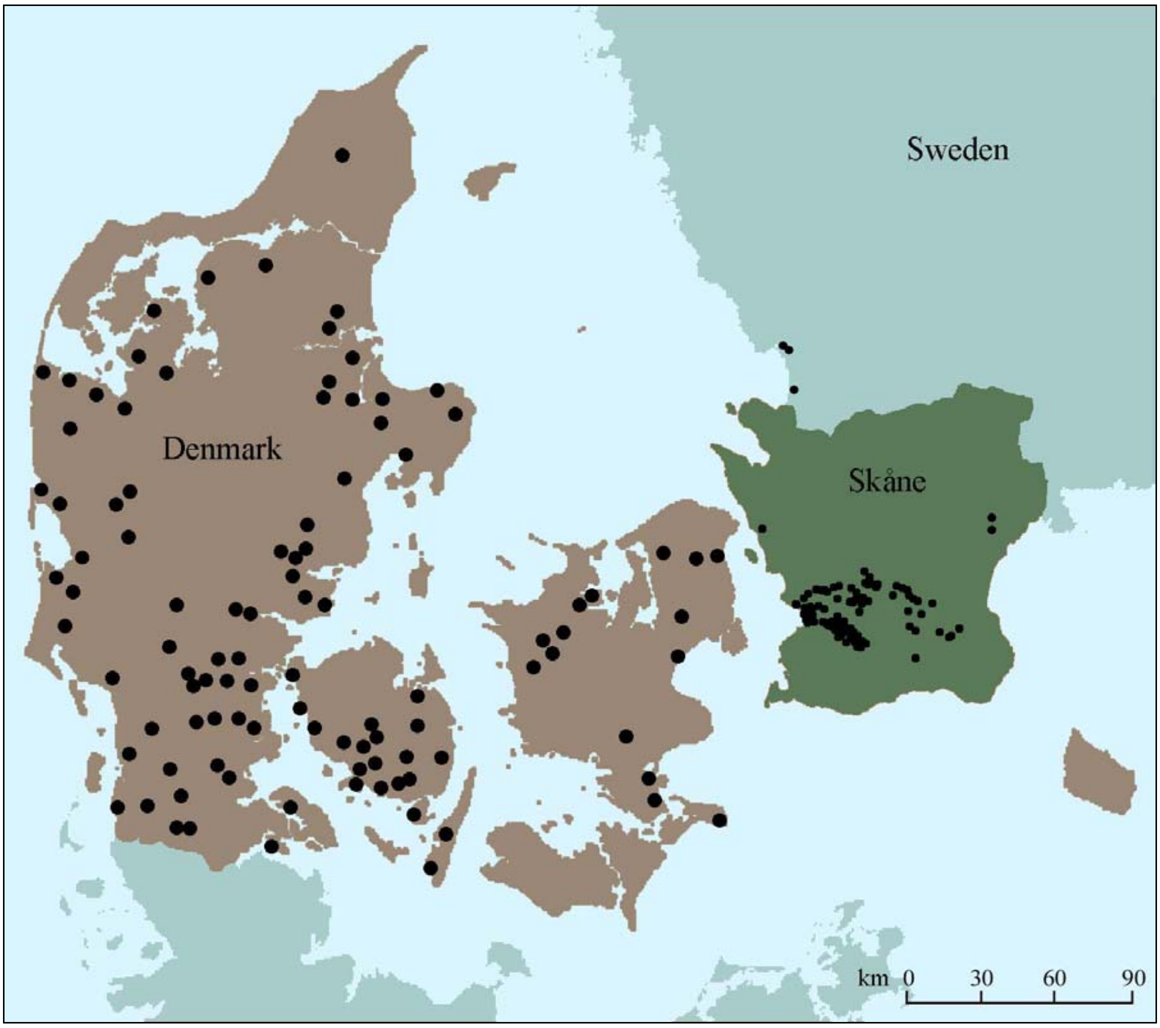

Figure 1. Map of the study area, with locations of selected wetland projects examined in this study.

The region studied includes the country Denmark which is located in the northernmost part of the contiguous European continent above Germany, and Skåne, the southernmost region of the country of Sweden located immediately to the east of Denmark (**Figure 1**). Several wetlands have additionally been investigated in the small area immediately to the northwest of Skåne in Halland kommune, on the west coast. As the geographical and political conditions surrounding wetland implementation in this region are very similar to Skåne, inclusion of these wetlands is a logical method of increasing the size of the wetland data set, while still preserving the focus on Skåne.

2.2 Wetland Definition

This study employs the definition of wetlands as described in the RAMSAR Wetland Convention of 1971. A wetland is here described as:

"areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres" (RAMSAR, 2002a). Additionally, this *"may incorporate riparian* […] *zones adjacent to the wetlands"* (RAMSAR, 2002a).

2.3 Methods

Scientific literature from both countries has been examined and augmented with other foreign studies where their findings were deemed relevant. Creation methodologies of numerous wetland restoration projects have been analyzed, and several restored wetlands were visited. Especially helpful has been personal communications with workers, researchers and state entities directly involved with wetland restoration, giving greater scope and perspective to the findings.

2.4 Scope and Limitations

This study examines the variables of nutrient reduction and biodiversity within the boundaries of wetland creation projects in Denmark and Skåne. Although there are many nutrients contributing to eutrophication, this study focuses upon nitrogen, but recognizes that phosphorus, among others, is also an important element to consider in an overall perspective. In terms of biodiversity, this study examines habitat diversity at the regional and landscape scale, as well as organismal diversity—i.e. species richness and diversity. Genetic diversity of species is also an important consideration when discussing overall biological diversity, but is also outside the scope of this study.

Additionally, the economical aspects of wetland construction are also largely omitted. While they are briefly mentioned, to the extent necessary to give further clarifying background to certain discussions, a meaningfully thorough socio-economic analysis is deemed worthy of a thesis or two of its own, and is thus outside the scope of this study.

It is also taken as a given that wetland construction methodologies generally differ between Denmark and Skåne. This is a matter of historical perspective, and the deeper sociological and political reasons underlying these differences are not the focus of this study. In that they are, however, linked to societal decisions upon which it has been decided to create these wetlands, these background reasonings are lightly touched upon within the context of wetland creation, nutrient retention and biodiversity.

Lastly, it may be argued that an analysis of this type, by comparing methodologies of such a varying nature, presupposes representative and comparative conclusions. The author has, however, endeavored to remove, and otherwise account for, confounding factors as much as possible.

3 Wetlands in Retrospect – A (Mutually) Draining Story

Denmark and Skåne both share a quite common wetlands background within the last 200 years. Wetlands have greatly decreased in both these areas as a result of wetland drainage and stream and river channelization. The primary reason for draining wetland areas was to increase the area of land available for agriculture—a business whose increasing profitability was not to be ignored (Rasmussen, 1999).

An example from the Hindsholm Peninsula on the island Fyn in Denmark illustrates this. Here, wetland area decreased by 72% (from 18.9km2 to 5.3km2) since 1800 (BERNET, 2000, p. 22). This mirrors also the overall status of wetlands on the entire island, where overall decreases have been almost 75% in the last 100 years (Fyns Amt, 2001, p. 26). Wetlands used to cover 25% of the country 200 years ago. (COWI, 1997). Less than one-third remain. One of the last—and biggest—reclamation projects occurred as recently as 1962-1968, where around 4,000 hectares were drained in the Skjern River Valley. At the same time, "more than 90% of Danish streams have been channeled, straightened and deepened during the past 100 years with most changes occurring between 1920 and 1970" (Riis and Sand-Jensen, 2001, p. 270; see also Brookes, 1987). Habitats have thus been "considerably deteriorated" for plants and animals in over 90% of the nations rivers, streams, and associated wetlands according to Bach et al. (2002, p. 195).

The situation is nearly identical, while greater in scale on the other side of Øresund in Skåne. One example is in the county immediately to the north, in the Laholm Bay drainage basin, where wetland loss in the coastal zone "has been almost total" (BERNET, 2000, p. 22). This is, albeit, a drastic example, yet it highlights the slightly worse situation of wetlands in the Skåne region. Here, over the last 200 years, and especially in the last 100 years, channelization of streams and drainage of wetlands has decreased wetland area by 90% (Swedish EPA, 2001, p. 13; Ekologgruppen, 2000, p.3).

4 Arable land/Wetlands/Biodiversity/Eutrophication: One System

"Eutrophication of shallow coastal waters represents an unintended, well replicated, large-scale manipulation experiment" (Borum, 1997, p. 112).

Wetland depletion is often found at the nexus where human activities interact with terrestrial and aquatic systems. Disturbances and changes within either of these components lead to subsequent changes in biological and chemical systems according to the conceptual map (Figure 2).

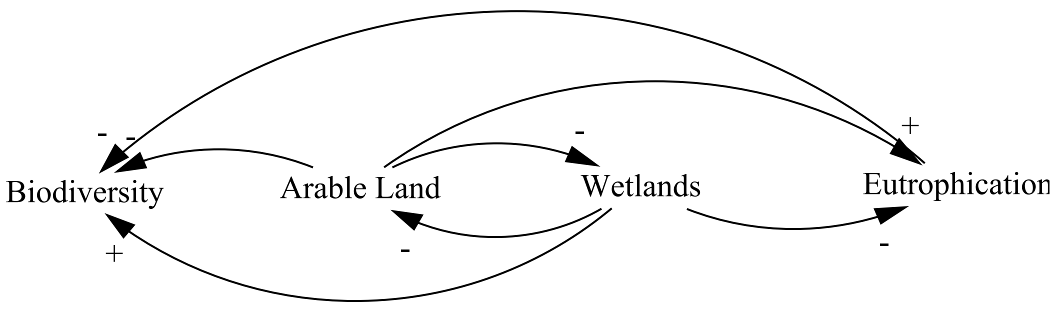

Figure 2. Terrestrial, Aquatic, Chemical & Biological Interactions

Historically, drainage ("reclamation") of wetland areas allowed for wide-spread expansion of agricultural activities. This has a recognized triple impact upon eutrophication. First, reduction of wetland areas eliminates their natural nutrient filtering function in the watershed. This increases the total load of nutrients in local surface waters and near-shore coastal ecosystems. Secondly, as drained areas were transformed into agricultural land, there is an additional leakage of nutrients from the subsequently formed agricultural areas in the form of unused fertilizers. This too increases eutrophication. Finally, draining these areas introduced oxygen into formerly anoxic environments, causing the release of minerals and chemicals until then bound within the soil substrate. In Denmark and Skåne, the vast majority of eutrophication in general, and the watercourse nitrate load specifically, can be attributed to high-intensity agricultural practices (Bøgestrand 2001; Arheimer and Brandt 2000; Eriksson, 2001). This trend is not unique to these areas, but is mirrored in other countries with extensive tracts of high-intensity agriculture, the U.S.A. being one example. (Hey, 2002).

At the same time, two other factors influence biodiversity in these areas. Replacement of varied landscape forms with uniform, bio-manipulated crops leads to a direct impoverishment of habitats for plants and animals. This occurs both via direct, physical areal effects, and through the chemical constraints placed upon non-desirable species through applied pesticides and herbicides. Second, the chemical regime imposed by eutrophication (without even considering the now water-born synthetic crop additives) physiologically limits the diversity of species capable of living within nutrient-rich environments (Bach et al., 2002; Riis and Sand-Jensen, 2001).

Restoring and creating wetlands in these areas of agricultural lands built on drained wetlands generally leads to increases in both species richness and abundance. This is an effect of both a general increase of habitat variety in the landscape matrix, and especially via the reintroduction of **specifically** this type of ecosystem, as:

> *"globally and regionally wetlands harbour significantly high biodiversity disproportionate to their geographical area"* (Gopal and Junk, 2001, p. 278).

Conflicts in interpretation can arise with respect to the new biological regime made possible by these changes and others created on the periphery, or even within the agricultural land. This especially seems to be the case when wetlands are restored in non-agricultural areas, i.e. areas with some prior existing and established non-cropland-related biodiversity. This will be discussed later.

5 Eutrophication Sources: transports through (former) wetland areas

5.1 Overall Areal Comparisons

Denmark has an overall area of 43,037 km^2, of which approximately 67 % is currently agricultural land. This percentage makes Denmark the European country with the greatest

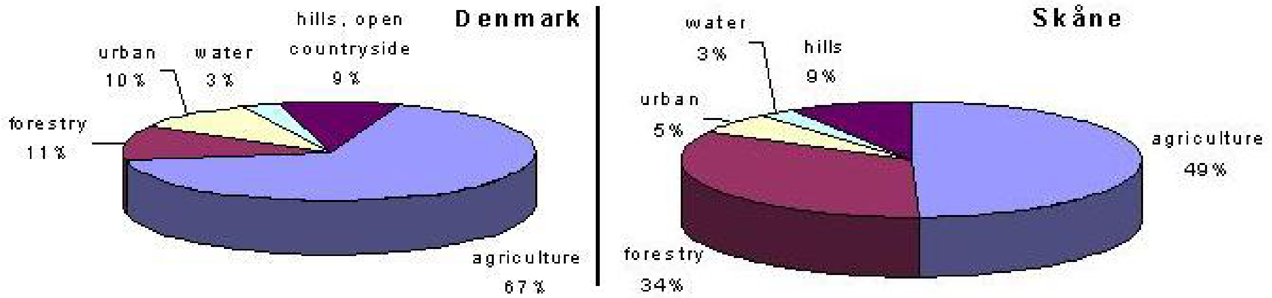

Figure 3. Land use in Denmark and Skåne. Source: data from Bach et al., 2002; Swedish Board of Agriculture, 2002; Skåne länsstyrelsen, 2001a.

percentage of arable land (Bach et al., 2002, p. 245). Skåne's land area is 11,346 km2, and while this only represents approximately 2.5% of Sweden's overall area, it accounts for 17% of Sweden's arable land (Swedish Board of Agriculture, 2002). Additionally, Sweden's best agricultural land (from a production standpoint) is predominantly found only in Skåne (Skåne länsstyrelsen, 2001).

In 2000, the total input[1] of nitrogen to Denmark's near-shore marine environments via watercourses and point-sources was 83,000 metric tons (Bøgestrand, 2001); see Figure 4. Of this amount, nationwide measurements confirmed that diffuse leakage from agricultural land is by far the greatest source of nitrogen, contributing almost 74,000 metric tons of the total in 2000 (Bøgestrand, 2001); see Figure 5

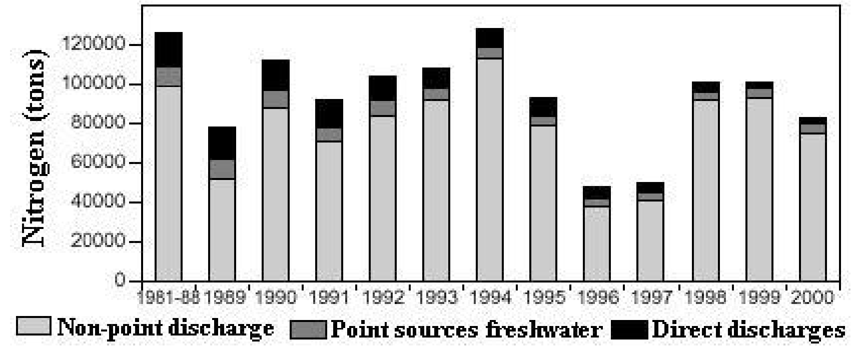

Figure 4. Total Riverine Nitrogen Discharge to Coastal Environments. Source: modified from Bøgestrand, 2001, p. 79.

While there is a natural background contribution from the environment, findings in the National Aquatic Monitoring Program found that "concentrations of total N are highest in rivers that drain upstream arable land [...] this is typically 4-5 times greater than in rivers draining natural environments" (Bøgestrand, 2001, p.21) It is this immense nutrient runoff which "makes the Danish coastal waters, like other north-temperate coastal waters[...]some of the most strongly nutrient-subsidized ecosystems" (Borum, 1997, p. 102)

The waters surrounding Southern Sweden provide a similar example. Modeling by Johnsson and Hoffman (1998) calculated the total gross load of agriculturally derived N to be 55,000 metric tons in 1994. Subsequent modeling by Arheimer and Brandt (2000) reported losses from arable land of 64,500 metric tons/yr, with a net transport to the sea of 33,500 metric tons/year. They concluded that losses from arable land constituted 45% of the total load. In this study's area, in 2000 in Skåne, the transport of nitrogen from Skåne's 11 largest watercourses to coastal areas was 11,000 metric tons (Skåne länsstyrelsen, 2001a). The majority of this was agriculturally related non-point discharges (Eriksson, 2001). In the southwest region of Skåne, this contribution of agriculture was 88% (Vought & Lacoursière, 2001). Additionally, Skåne, on the Swedish side of Øresund, is responsible for approximately 70% of the water-born nitrogen discharge to this boundary water (Eriksson, 2001).

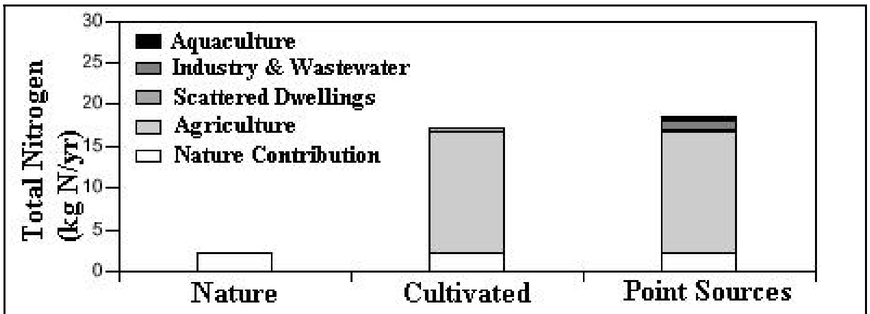

Figure 5. Sources of total riverine nitrogen transport in 3 different headland types. Source: modified from Bøgestrand, 2001, p. 22.

[1] Not including atmospheric deposition.

5.2 Eutrophication Sources & Scales Discussion

Generally, then, anthropogenic (figure 4), agriculturally-dominated (figure 5) leakage of nutrients are the dominant and prevailing source of eutrophication of freshwaters river courses and the near-coast marine environments of both Denmark and Skåne. The overall transport from Skåne and Denmark in 2000 is seen in Figure 6. For a given land area (remember that Denmark is roughly four times of Skåne), Denmark pollutes near-shore marine environments roughly twice as much as Skåne. Of course, there can be substantial regional and catchment variability. This can be illustrated by losses from the Laholm Bay drainage area (located immediately north of northwest Skåne), where "total-N losses are of about the same magnitude in forests and agriculture" (BERNET 2000, p. 11). However, here we find that the lower general contribution of forested areas to eutrophication is compounded and multiplied by the substantially greater total area they cover. Local action plans to minimize eutrophication by employing created and restored wetlands need to consider prevailing conditions in order to locate wetlands where they will be most beneficial.

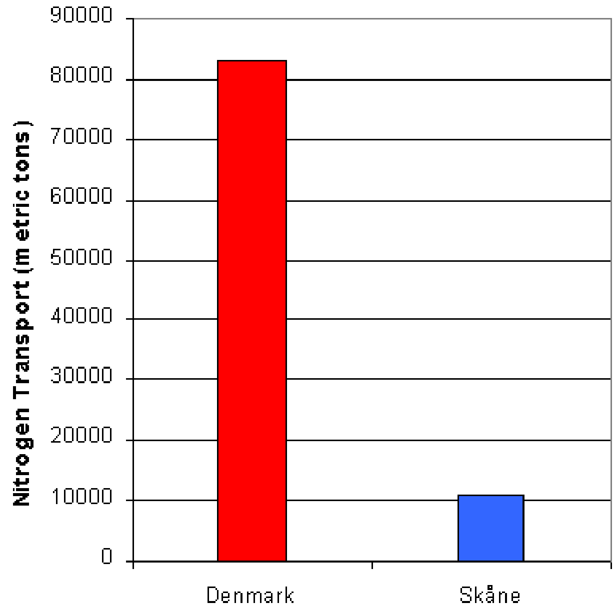

Figure 6. Nitrogen Transport to coastal waters in 2000. Source: Data from Bøgestrand, 2001; Skåne länsstyrelsen, 2001.

6 National Plans for Wetland Establishment: Sweden and Denmark

Both Denmark and Sweden have acknowledged wetlands as nationally important. Both are signatories of the RAMSAR convention on wetlands; Denmark has 27 Ramsar listed wetlands totaling in all almost 7,400 km^2, while Skåne has 5 listed areas totaling almost 229 km^2 (RAMSAR, (2002b).

National legislation was adopted in 1998 and 1999, respectively, in these two countries to reestablish and create wetlands on a national scale. These plans seek to address, and indeed were made possible by the increasing knowledge of the extent of wetland drainage, and its negative effects upon aquatic environments. These will be briefly examined here to provide a framework for subsequent recommendations.

6.1 Thriving Wetlands in Sweden

Myllrande Våtmarker [Thriving Wetlands] is one of 15 environmental goals adopted by the Swedish government in April 1999 in order to reach an ecologically sustainable Sweden by the year 2020 (Swedish EPA, 2001). The government, through this goal, recognized that wetlands are important for plants, animals, water quality and people. In short, it acknowledges that wetlands are vital elements of healthy ecosystems, which form part of the foundations for our societies. A preliminary evaluation by the Swedish Environmental Protection Agency (2001) two years later indicated that the goal of establishing at least 12,000 hectares in farming areas by 2010 (5,000 hectares of which would be located in Skåne) seemed reachable, albeit with certain possibilities and constraints.

They concluded that the strongest motive underlying restoration and creation of wetlands in the 1990s was the desire to control eutrophication of the surrounding seas; biological diversity (and intrinsic values) and ecological importance of wetlands in any landscape were not the main reasons (Swedish EPA, 2001). This view has affected how wetland re-establishment and creation has proceeded.

Thriving Wetlands works in conjunction another one of the 15 goals, namely one entitled Zero Eutrophication. These two goals are meant to work in conjunction to help achieve sustainable development of landuse and agriculture.

The primary constraints and problems they identified were varying views on the values of wetlands, and conflicts of interest between simultaneously striving for both economic development and ecological sustainability. They recognized that re-establishing wetlands that have disappeared in regions now dominated by agriculture would be "one of the most important and most resource intensive measures" to achieve the goal of thriving wetlands (Swedish EPA, 2001, p. 52). This was especially the case in southern Sweden, where less than 10% of original wetlands remain (Swedish EPA, 2001, p. 13; Ekologgruppen, 2000, p.3), and where agriculture dominates the landscape.

6.1.1 Wetland Projects in Skåne: Generalizations

In Skåne, the primary types of wetlands constructed are excavated small ponds, often axillary to a stream or river, and of approximately 1-2 hectares (Ekologgruppen, 2000; Vought and Lacoursière 2001). Agricultural drainage runoff was usually led into these created ponds (Ekologgruppen, 2000).

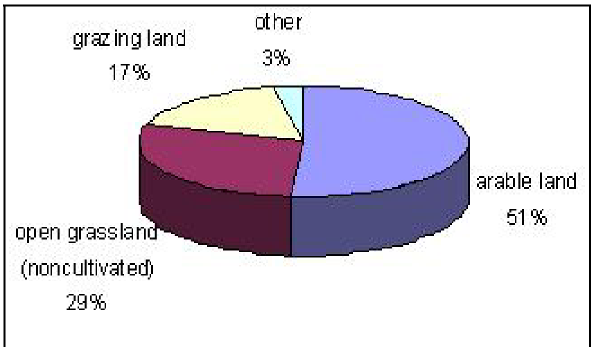

Figure 7. Former landuse of the sites where 65 wetlands were constructed. Source: modified from Ekologgruppen, (2000), p. 17.

As regards placement within the landscape, wetlands creation measures "have largely been carried out in areas with arable land" (Ekologgruppen, 2000, p.5) see also Figure 7, although there is some variation.

Ekologgruppen (2000, p. 16) found that, although there were some exception, 5,000 m^2 (half a hectare) was considered the lower boundary for creating cost-effective wetlands by. In contrast, in an area just to the north in Halland County, and in other areas where construction costs are not as high as in these two watersheds[2], lower construction costs can dictate a different logic for lower boundaries of wetland size.

[2] Several local sources indicated an 'artificial' inflation of overall wetland construction costs associated with both increasing project scale and complexity, but also in association with increases of non-local funding (generally EU) becoming available (Åkerman, July 19 2002).

The numerous wetland projects in the Höje and Kävlinge catchments estimated nitrogen reduction to be on an average of 1 metric ton N ha^{-1} yr^{-1} (Ekologgruppen, 2000). The 17 wetlands examine by Vought and Lacoursière (2001) had an average retention of 1,770 kg N ha^{-1} yr^{-1}.

An underlying principle is that wetland creation should aim to create natural systems, and that later "management should be avoided as much as possible" (Fleischer, Gustafson, Joelsson, Pansar, Stibe, 1994). The creation of numerous small wetlands (as opposed to fewer, larger wetlands of the same area) in this manner is the result of several factors, but dominating them is the underlying influence of dikningsföretaget—an entity of up to hundreds of landowners with interests in water tables and water extractions, who have strong legal influences. Raising water table levels, as would be incurred by stopping drainage networks and culverts, would require the (hard to acquire) assent of all the interested parties. Thus,

> *"restoration of wetlands by simply raising the water level is not often accomplished"* (Ekologgruppen, 2000, p. 13).

Additionally, as expropriation of land to facilitate wetland creation is not an option in Sweden, negotiations with this entity could be long and protracted, if not impossible. So for political reasons, small wetlands created within the framework of the present existing water table, are necessitated, or are more easily implementable (see also Fleischer et al., 1994). Also, wetland projects are based upon voluntary participation of landowners, and these individuals were generally more positive about pond-like wetlands than larger more stereotypical wet-meadow wetlands (Eriksson, 2001). Other considerations include the high costs associated with the excavation-intensive methods employed here, and that the government does not have a 'pool' of land which it can use to exchange with landowners.

6.2 Multiple Context Wetlands: Wetlands in Denmark

Wetland creation and re-establishment on a national level in Denmark has developed along two parallel, yet somewhat differing paths. The first is the creation of wetlands under Vandmiljøplan II [the national Action Plan on the Aquatic Environment II], while the second path is that of wetlands created under nature-restoration projects. Common to both is the objective of ecologically restoring aquatic environments to their former appearances and functions.

6.2.1 Wetlands under the Second Action Plan on the Aquatic Environment

The aim of the Action Plan on the Aquatic Environment II adopted in February 1998 (Andersen, 2000, V.1, p. 5) [hereafter referred to as the Action Plan II] is to protect Danish aquatic environments from nutrient pollution and subsequent oxygen depletion. The Action Plan, based upon its predecessor—Action Plan I—was quickly adopted by a majority in Parliament after two nearly simultaneous events. First, hypoxia in several near-shore coastal waters was quite severe and secondly, the EU Commission informed Denmark that its current plans and actions were not sufficient to fulfill the Commission's Water Framework Directive's rules concerning nitrogen leakage from agricultural areas (Tind et al., 2000, 20-21).

The Action Plan's goal is to reduce the leaching of nitrogen from cultivated lands by 100,000 tons with various measures implemented by 2003 (Iversen et al., 1998). One of these complementary measures was the creation of 16,000 hectares of wetlands by the end of 2003, which would achieve a calculated reduction of 5,600 tons per year. This was based on an understanding that wetlands function as nutrient traps, removing nitrogen in water flowing through them, with a presumed average nitrogen retention of 200-500 kg N ha^{-1} yr^{-1} (Iversen et al., 1998).

As in Sweden, an evaluation was conducted after two years (Midtvejsevaluering—but here it was a halfway evaluation) with the disappointing conclusion that only 6,000 hectares would probably be re-established by the deadline (Grant et al., 2000, p.11). Based upon this evaluation, the goal was downgraded to 8,000-12,500 ha.

As of October 9 2002, 9 projects totaling 332 hectares have been created, while funding has been granted for implementation of a further 4,041 hectares. Additional funding has also been granted to an additional 54 projects for suitability studies which total 7,360 hectares (Larsen & Stamphøj, 9 October 2002). The Danish Forest and Nature Agency estimates that (as of October 9, 2002) 900 hectares will be completed before the end of 2002. They additionally anticipate that 2,000 hectares will be completed by the end of 2003, and that an additional 5,000 hectares will, at that time, either be in the construction phase, or will have been granted funds and permission for final completion (ibid.).

Therefore, although implementation of the 8,000-12,500 wetland hectares is not expected to be fulfilled by 2003, it is estimated that "the right initiatives will already have been implemented" (Secretary of the Environment, 2002) in order to attain this goal.

6.2.2 Nature Restoration Projects

Many aquatic restoration projects have been completed in Denmark in the last twenty years. This is directly linked to the adoption of The New Watercourse Act of 1982 (Madsen, 1995) which made it possible to implement river restoration projects. While the scale and scope of these numerous projects varies greatly, their overall objective is largely the same, namely to create a naturally functioning—and self maintaining system—as far as possible, which strengthens river self-purification capacity. The act recognized that clean water in and of itself is not enough to base an overall improvement of aquatic and riparian nature quality upon. Physical conditions and hydrological considerations, in other words habitat heterogeneity, are just as important to considerations of biotic diversity.

The flagship, and best known, of these projects is in the Skjern Å River Valley. This is Denmark's largest nature restoration project, and as one of Europe's largest, represents the spirit of river restoration and of what is possible. The scale on a national level is shown by the implementation of this project on Denmark's largest river in terms of discharge. Approximately 250 million Danish kroner are being used to return 2,200 ha of cultivated meadow into a wetlands area (Rasmussen, 1999).

6.2.3 Wetland Implementation in Denmark: Generalizations

Drawing useful generalizations about wetland construction in Denmark is not easy, as wetlands created under various programs and at differing regional levels vary greatly in size, scale and form. Additionally, wetlands created under the Action Plan and under nature restoration projects do not then necessarily have the same primary goal, although increasing biodiversity and decreasing nutrient transport in watercourses are common to both. Wetland creation in both of these programs, however, is accomplished in much the same way and with the same orientations.

To fulfill the goal of restoring nature to a pre-regulatory state, emphasis is placed upon raising of groundwater levels by re-meandering channeled streams and rivers, blocking drainage pipes and channels, and by discontinuing drainage pumpings. Among those wetland projects approved for completion, or already completed under the Action Plan as of 20 September 2002, at least 33 involve blockage of drainage pipes and/or canals. This number increases to at least 42 if we include projects created by cessation of pumping (my calculations: data from Larsen & Stamphøj, 9 October 2002). These are thus the primary 'tools' employed to re-establish flooded meadows while simultaneously re-establishing hydraulic contact between waterways and their former floodplains.

As the exact physical results of these actions can be difficult be predict, created wetlands in Denmark take on a myriad of forms, where fens and wet meadows "are the most important types of wetlands created in Denmark" (BERNET 2000, p. 15). Another implication of heightened water levels, is that (generally) larger areas of land are affected. Wetland creation projects are thus often quite large, as is evidenced by the average size of established wetlands under the Action Plan being about 37 hectares, and even this probably represents the lower possible estimate for average project size, as if we include those projects already granted funding for completion, then the average size increases to 87.5 hectares (Larsen & Stamphøj, 9 October 2002).

At the lower end of the scale, the smallest completed Action Plan project was 13 hectares (Ulleruplund project; Larsen & Stamphøj, 9 October 2002). The 2 smallest project applicants of 4 and 6 hectares were rejected on the overall basis of a "too small project size" (ibid.).

As concerns placement within the landscape, wetland creation measures exhibit large variation as to where new wetlands are constructed. As Abildtrup indicates, some wetland projects are implemented entirely on arable land, while others are constructed solely upon meadows and existing natural areas (Abildtrup, 2001).

The Danish government also commonly employs land exchanges to facilitate wetland implementation. Here, substitute areas are given to landowners in exchange for plots where wetlands will be created.

Unlike Sweden, the Danish government has the legislative ability to expropriate land to facilitate wetland creation. This option, while rarely used, facilitates the potential for implementing larger projects where numerous land owners are impacted, although wetland creation still hinges upon voluntary landowner participation. Expropriation should not be viewed, however, as universally beneficial for wetland implementation; it has the drawback that it does not foster mutual good will. As Ledskov (2001) related about this, the potential for employing it fosters a hostile environment where "it is like negotiating with someone who has a gun in their back pocket" (p. 63).

7 Nitrogen reduction and Nutrient trap efficiency studies – Swedish Case Studies

Numerous wetlands have been successfully created in southern Sweden for the purposes of increasing water quality and reducing eutrophication. Vought and Lacoursière put this number at around 200, created over the 10-year period from 1990 to 2000 (Vought and Lacoursière, 2001). Ongoing measurements of nutrient retention in some of these wetlands has occurred. A review is presented here to give an overview of how created wetlands function in the southern-Swedish landscape in terms of their ability to function as natural nutrient filters, and what kinds of effects we can expect from created wetlands.[3] Findings from modeling the impacts of watershed construction of nutrient removal will also be examined.

- Nutrient retention in a newly created pond east of Lund was examined over a three-year period by Dellien and Wedding (1997). Their findings revealed nitrogen reduction occurred with an average of 1,000 kg N ha^{-1} yr^{-1} in a year with normal runoff. Large variation occurred both from year to year, and from season to season in this 0.72 ha pond.

- A pond studied on the Rååån revealed that the 1.5 hectare pond removed "about the same amount of nitrogen as the whole river [15 km] upstream of the pond" (Jansson, Andersson, Berggren, Leonardson, 1994, p. 322), with a specific removal of 3,000 kg N ha^{-1} yr^{-1}.

- Three created ponds in the Höje and Kävlinge watershed were reported upon in *Nutrient Reduction in Newly Created Ponds* (Wedding, 2001). The largest pond at 1 hectare, Slogstorp, was also the newest of the three studied and has been examined in the four years since it was created. Nitrogen reduction over this period averaged 3,156 kg N ha^{-1} yr^{-1}. The 0.65 ha pond Genarp, studied for three years exhibited nitrogen reductions of 365 kg N ha^{-1} yr^{-1}. Råbytorp, the final pond with 0.75 ha area had an average of 746 kg N ha^{-1} yr^{-1}. The data for this pond had been collected for over 8 years.

- The consultant group, Ekologgruppen, who had examined the three earlier ponds, also included one more pond in the same area in their report (Ekologgruppen, 2000). Lomma was a relatively large (7.9 ha) wetland created near the end of the Höje river watercourse in an abandoned pit left over from clay mining. Their four year investigation revealed a nitrogen reduction of 1,080 kg N ha^{-1} yr^{-1}.

- Nutrient retention for the four aforementioned ponds averaged 1,700 kg N ha^{-1} yr^{-1} in Ekologgruppen's Final Report (Ekologgruppen, 2000).

- The report *Constructed wetlands for treatment of polluted water: Swedish experiences* (Vought & Lacoursière, 2001) examined 17 ponds in southern Sweden for nutrient retention. Average nitrogen retention for these ponds was 1,770 kg N ha^{-1} yr^{-1}.[4]

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[3] The predominant type of wetland created in these projects in southern Sweden takes the form of a small pond. When referring to created wetlands in this area, I freely interchange the word 'pond' with 'created wetland'; the meaning is synonymous unless otherwise indicated. – see text for further information.

[4] Included among these 17 examined wetlands was one also included in Ekologgruppen's study, (2000), namely the wetland Råbytorp. Subtracting this pond from their figures increases the average retention by approximately 100 kg N ha^{-1} yr^{-1} .

- Examining nitrogen removal in created farmland ponds, Fleischer et al. found annual net retention to vary between 73 and 7,000 kg N ha^{-1} yr^{-1}. Higher retention values were linked to ponds receiving higher nitrogen loading (Fleischer et al., 1994).

- Purely hypothetical modeling by Arheimer and Wittgren (1994) in southeastern Sweden estimated nitrogen removal was normally less than 100 kg N ha^{-1} yr^{-1} (1994). Stronger modeling, which incorporated and was calibrated with actual data from eight created surface-flow wetlands, examined the creation of 40 potential wetlands in a coastal catchment located immediately north of Skåne. Average N removal averaged 198 kg N ha^{-1} yr^{-1} for the 40 sites (Arheimer and Wittgren, 2002).

- Long term retention capacity was examined by Wedding (2001) to see if significant changes occurred over the examined periods in the ability of the wetlands to assimilate and transform nutrients. The three wetlands examined did not exhibit either substantial increases or decreases in their retention capacity over time, although there was some slight variability.

7.1 Discussion of studies

These created wetlands exhibited an average nitrogen retention of 1,960 kg N ha^{-1} yr^{-1}. Arheimer and Wittgren's 2002 modeling results were substantially below this at 198 kg N ha^{-1} yr^{-1}, although their average findings were depressed due to inclusion of findings from all 40 ponds. Several of these ponds, as a function of their hypothetical—albeit potentially realistic—siting, exhibited very low nutrient removal, party as a result of short retention times, and insufficient nutrient loading. Continuous and frequent sampling over longer time periods in the Dellien and Wedding (1997) study and by Ekologgruppen (2000) allows an interpretation of these examinations as both reliable and accurate 'from-the-field' results, unlike random or single event testing which is subsequently extrapolated to larger results. It is worth noting here that the majority of these results were obtained through people/groups with vested interests in the establishment of wetlands. This does not negate the accuracy of their findings, just implies that closer attention needs to be paid to their studies and methods to confirm data validity.

These findings of average nutrient retention fall within the 0-4,500 kg N ha^{-1} yr^{-1} reported for constructed ponds by Leonardson (1994).

A common factor among all the results was a high variability of nutrient retention both from year to year, and season to season. Modeling studies exhibited fluctuations of removal rates within a range of 57 to 466 kg N ha^{-1} yr^{-1} (Arheimer and Wittgren, 2002). The pond studied by Dellien and Wedding (1997) exhibited variability in nitrogen retention from 299 to 1,017 kg N ha^{-1} yr^{-1}. The 17 study wetlands of Vought and Lacoursière (2001) similarly exhibited large fluctuation from negative 6,900 to positive 8,650 kg N ha^{-1} yr^{-1} (the large negative value occurred for only two of the sampled wetlands, and was a result of, among other things, extreme wintertime hydrologic loading). This is a factor of hydrology, and as nutrient retention and denitrification are largely dependent upon nutrient load, then seasonal and yearly variability in precipitation will obviously be a determining factor in what level of 'raw-goods' are delivered to these natural purification plants, and thus their performance. So variability is a natural phenomenon to be expected.

But what about variability from area to area? Are these results typical for all of Skåne? Yes and no. First, almost all of the studied wetlands are relatively small. Additionally, a large portion of these results come from the southwestern portion of the Skåne region, an area which, as earlier indicated, is extensively dominated by agricultural land. Also, the priority for siting these projects was in or near agricultural areas to maximize their efficiency as nutrient traps. In that the majority of land use is agriculturally dominated (section 5.1) then we can say that these results are typical for Skåne.

Yet there are areas of Skåne not covered with agricultural fields, and these findings would not, then be immediately translatable to wetlands created in areas with other types of land use, unless we could expect similar levels of nitrogen loading. Even this prerequisite, however, leaves too many unaccounted factors to generalize from. Not all wetland restoration efforts in Skåne employ the predominant methods, i.e. excavating new ponds below the existing water table, and directly introducing agricultural runoff into the created wetlands, which are nearly universally employed in southwestern Skåne. A minority of wetlands have been created here by blocking of drainage pipes and re-meandering of waterways (Lindström, 8 October 2002). As, however, we are examining these wetlands within the context of their goals, i.e. effectiveness as natural nutrient traps, and as the majority are primarily placed within agricultural areas, then, this does not reduce the validity of the findings. Wedding supported this analysis:

> *"It is very difficult to predict* […] *how large nitrogen retention will be in any one pond. The results, however, do constitute a good basis for a more general evaluation of the nitrogen reducing effects of created ponds"* (2001)

Weighing the above studies, the evaluation of how effective constructed wetlands in southern Sweden are in removing nutrients and helping prevent eutrophication of downstream water bodies is thus a positive one. A quote from Vought and Lacoursière illustrates this:

"*The construction of wetlands to combat freshwater and marine eutrophication has proven to be a successful measure in the agricultural and urban landscape of Southern Sweden"* (2001)

8 The Nitrogen reduction question in Denmark: multi-vectoral approaches

Wetland creation in Denmark is strongly influenced by the construction methods employed. This means that wetland recreation is guided by restoration concepts, i.e. that restoration should be for the purpose of returning these areas to a natural, unregulated 'wild' state. So it is appropriate to examine the nitrogen removal efficiency of the environments which recreated wetlands are supposed to mimic, in order to gain an idea of (potential) typical reference behavior.

8.1 'Background' nitrogen removal in natural wetlands

Several studies have been done of un-drained meadows and associated riparian areas in Denmark, predominantly in areas where groundwater came to the surface and overflooded surrounding meadows. Findings of nitrogen removal are summarized in Table 1.

Location	Retention (kg N ha^{-1} yr^{-1})	Reference
Stevns Å, meadow	57	Hoffmann, 1998
Rabis brook, meadow	340-398	Ambus & Hoffmann, 1990; Brüsch & Nilsson, 1990
Rabis brook	130	Færge et al., 2000 (recalculation of Brüsch & Nilsson 1990)
River Gjern: 7 different measures		
Site A, meadow	140	Hoffmann, 1998
Site B, fen (1993)	2,100	ibid.
Site B, meadow (5 years)	1,079	Andersen, 2000; V. 2
Site C, meadow	541	Hoffmann, 1998
Site D, meadow	398	ibid.
River Gjern, fen[5]	1,137	Kronvang et al., 1999
River Gjern, meadow4	340	ibid.
Langevad Å	300	Ambus & Hoffmann, 1990

Table 1 Nitrogen removal in Danish natural wetlands and riparian areas[6]

It is reasonable to question how representative these results really are. Sampled areas are situated in all the major parts of Denmark and were the result of both mass-balances and acetylene blocking, i.e. both field and laboratory studies. Nitrogen retention findings show large variability, although this is not surprising considering the extremely site-specific dependency of nutrient retention. Clearly, however, these sites confirm that different types of wetlands in Denmark do promote nitrogen removal.

Whether or not these studies make a good scientific foundation for presumption that an 'average' restored wetland can remove—on average—350 kg N ha^{-1} yr^{-1}, as is the foundation for estimations of the efficiency of wetland creation under VMP II, has been examined by Færge et at. (1998). They concluded, after reviewing the majority of the above projects, that for all of the studies employing mass-balance methods, that it

> *"was possible on one or more points to question the validity of these estimations"* (Færge et al, 1998, p. 42).

Additionally, these graduate students in agronomy went further to conclude(!) that;

> *"There is not a solid scientific basis for presuming that re-established wetlands will be able to remove 200-500 kg N/ha/yr"* (p. 43).

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[5] Not included in Færge et al.'s 1998 study.

[6] Not all the study findings reported nitrogen removal in kg N ha^{-1} yr^{-1}. A few reported actual denitrification with units of mg N m^{-2} day^{-1}. I have converted the latter to kg N ha^{-1} yr^{-1} to present a standardized format with the simple conversion factor [1 mg N m^{-2} day^{-1} = 3.65 kg N ha^{-1} yr^{-1}].

The former statement was later reworded to say that the doubt involved studies indicating nitrate removal greater than 100 kg N ha^{-1} yr^{-1} (Færge et al., 2000).

Their findings from these studies does not negate the projects' general worth. Færge et al. call attention to the danger of extrapolating yearly, or other long term figures, from short term results. Furthermore, groundwater intrusions must carefully be considered in mass balances. Additionally, many of the field tests could be, and were not, backed up by other investigations (they refer to the use of acetylene blocking tests to confirm that denitrification was the source of nitrate removal in these wetlands). However, there is a shortcoming in placing so much weight on a lack of supportive laboratory results, and subsequently using that lack of supportive evidence to draw such far-reaching negative conclusions. The problem could also be looked at in a retrospective fashion, where we could question whether laboratory studies have been confirmed by (thorough) mass-balance tests. This seems especially the case with wetlands system analysis, as they are, despite their often lentic or slow moving aquatic environments, **dynamic systems** whose analysis must, therefore at a minimum incorporate in-situ studies to best quantify nitrogen transformations. A further exploration of this is, however, outside of the scope of this study.

In the end, though, as they have not supplied us with their evaluation of what they believe retention capabilities are[7], we are left questioning what magnitude of nitrogen we can expect to be removed from created wetlands, and thus must use the available figures, albeit with the limitations they indicate in mind.

8.2 Remeandered rivers, Re-established Lakes and Restored Floodplains: Nitrogen Retention

Krongvang et al. (1994) examined nitrogen removal following the re-meandering of the river Gelså. Mass balances comparing the restored reach and an upstream reference section indicated a decrease in nitrate loss to the river of 80 kg N per hectare of created wet meadow (Kronvang et al. 1994).

Studies of the re-meandering and restoration of the river Brede indicated nitrogen retention in the restored floodplain to be 92 kg N ha^{-1} yr^{-1}. Due, however to extremely dry climatic conditions starting immediately after restoration efforts, it was concluded that there were no actual (significant) differences in nitrate-N concentration between pre- and post-restoration (Hoffmann et al., 1998).

The creation of the first three of six shallow lakes, Alsønderup Engsø, Solbjerg Engsø and Strødam Engsø (52, 33, and 20 hectares respectively) since the end of the 1980s along Pøleå creek in order to, among other things, reduce downstream eutrophication, has had a "large purifying effect" (Olsen, 2002, p. 246), and has "markedly affected the water chemistry" (Lindhardtsen, 2002, p. 86). Yearly retention in Solbjerg Engsø is calculated at 242 kg N ha^{-1} yr^{-1}, equivalent to 20% of the amount of nitrogen input into the lake on a "normal" hydrologic year (Grünfeld & Lindhardtsen, 1999, p. 26).[8]

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[7] This was not their goal, so it should not reflect negatively upon their study.

[8] Retention on a per hectare yearly basis is my own calculation, from their estimate of 8 tons/year for the lakes surface area.

Nitrogen concentrations in Solbjerg Engsø dropped again, nearly by half in 1998 in association with decreased concentrations in lake input levels from 1994-1998 (Grünfeld & Lindhardtsen, 1999). This decrease was attributed to the creation of a wetland area, Strødam Engsø, further upstream on Pøleå creek in 1996 (ibid., pp. 33). Additionally, increased nutrient retention in the newly created wetland areas led to decreases in downstream nitrogen concentrations of more than 50%, partly as a result of increased nitrogen retention in Solbjerg Engsø (Grünfeld & Lindhardtsen, 1999). Average yearly concentrations in 1993 were 7.5 mg/l and in 1994-1998 have remained around 3.3 – 3.8 mg/l (ibid).

A scenario analysis simulating restoration of the river Gjern was reported upon by Kronvang et al. (1999). Employing the TRANS-model (Transport, Removal and Accumulation of Nutrients in waterSheds), they calculated the effects on nutrient retention of restoring the entire river system, including watercourses, riparian areas and a single lake, to a situation mirroring that recorded on old 1870s area maps. Restoration increased nutrient retention from 38.8 tons N to 81.4 tons per year (Kronvang et al., 1999). This substantial increase reduced nitrogen export from the catchment by 25% (ibid).

8.2.1 Restoration Contemplations

Restorations of streams and adjacent floodplain ecosystems bring about increases in nitrogen retention. The rivers Brede and Gudenå both yielded, however, results that are difficult to draw substantial conclusions from owing to their short overall time perspective combined with abnormally dry climatic conditions (Hoffmann et al., 1998; Pedersen et al., 1998). We would expect that with increasing post-restoration time, perhaps in the 2-3 years range, that macrophytes and other biota in the reconstructed stream and surrounding wet meadows would be better established, and that subsequently observed nutrient removal rates would increase.

A more representative picture, and a significant indication of the powerful potential for restored wetlands to decrease eutrophication can be seen in the form of the shallow 'pearl-string' of lakes created along Pøleå creek. Here, each of these successive nutrient traps contribute to purifying the downstream inputs to the next 'pearl' in the river system. Two of these have now existed for at least 9 years and thus can be expected to be more or less functioning as relatively "natural" (here implying a high level of ecosystem stabilization has been reached) environments.

Nutrient modeling on the river Gjern[9] reveal some similarly interesting implications concerning the potential for nature restoration programs to increase nutrient retention on a catchment scale. The Gjern river drains a catchment of 113.5 km2, of which almost 8% is riparian areas. Of this 8%, less than 5% is today wetlands in the forms of fens and wet meadows. This gives a wetland coverage of 0.39% of the catchment—a very small fraction at 1/250th of the catchment. In the 1870s, however, wetland coverage was 33% which equates to about 1/38th of the catchment area. Restoration of what amounts to basically a relatively small percentage of the catchment area yields substantial decreases in the nutrient export from the basin. In addition, this is also considering that they assumed a "conservative" (their wording; Kronvang et al., 1999, p.33) denitrification rate of 100 kg N ha^{-1} yr^{-1}. If decreasing eutrophication is the goal, large-scale wetland restoration projects—like the massive Skjern river restoration—are, disregarding their

[9] Data from: *Retention of nutrients in river basins*, by Kronvang et al., (1999). The fractional calculations are my own.

logistical feasibility/unfeasibility, project types whose beneficial aspects in interception and transforming leaked nutrients should not be immediately discounted.

The nutrient retention capacity of created wetlands, then, has shown to have positive but varying effects on the transport of nitrogen to downstream areas. Additionally, nutrient retention is intrinsically linked to several major wetland characteristics, not least of which is the biotic composition of the wetland area (Gopal and Junk 2001, 290-291). Thus, we now explore the biological diversity of some of the created wetlands in Denmark and Skåne.

9 Biodiversity in Constructed Wetlands: Skåne

This section will examine how, and to what extent created wetlands have impacted biological diversity in southern Sweden, with primary statistical weight upon Skåne. Over 70 ponds are examined in the studies presented here, examining birds, benthic macroinvertebrates, emergent and submerged vegetation and fish.

9.1 Bird Inventories

The consultant agency, [Ekologgruppen], examined 51 created wetlands in the period from 1994-2001 in the Höje and Kävlinge catchments with the purpose of assessing their importance on bird diversity and composition. A total of 141 wetland inventories were carried out throughout this period. Their last examination (Hammar, 2002) recorded a total of 29 different species in 31 of the ponds. A total of 12 redlisted species were recorded, and they were discovered in 20 of the 31 ponds. As many as 18 pairs of breeding pairs were counted in one of the youngest ponds completed in 1999.

The highest number of species were recorded in the largest wetlands (Ekologgruppen, 2000). The largest increase in species richness seemed to occur after an individual wetland area exceeded 1.5 ha. (Hammar, 2002, Figure 4), although smaller ponds also showed significant and stable colonization patterns.

9.2 Benthic macroinvertebrates inventories

Over four years from 1998-2001, 36 created wetlands were surveyed for aquatic insects and other associated macroinvertebrates by Ekologgruppen. Here, also, the primary study purpose was an assessment of the biological diversity. A total of 58 investigations is included in these findings. They recorded 222 different species (Torle, 2002). This included 4 redlisted species and 19 classified as rare, which were found in all but one of the surveyed ponds. Other key findings included:

- Wetland age was a factor of "significant importance" in species composition (Torle, 2002, p.17).
- Area and form of individual wetlands did not, however, affect species composition.
- Differing types of inflows did not, similarly, affect species composition.

Studies of 20 created wetlands in Skåne reported on by Vought et al. (2001) also indicated similar levels of invertebrates in created ponds. Additionally, they reported that wetland location in relation to other water bodies was important to macroinvertebrate composition; wetlands in direct contact or in the vicinity of other wetlands exhibited a larger number of species.

9.3 Aquatic Macrophytes – Vegetation Inventories

Ekologgruppen also examined a total of 26 ponds in 1998 and 2000 to determine the biodiversity of aquatic and emergent vegetation. 109 different wetland species were recorded in the 2000 survey, with an average of 33 species per wetland (Reuterskiöld, 2001). Overall, both species richness and composition between 1998 and 2000 was very similar. As in the macroinvertebrate surveys, wetland age was also a key factor in species composition. In this case, however, differing inflows did affect species richness:

> *"the highest number of species occurred in wetlands receiving water from main streams, followed by open tributaries, while the lowest number of species were found in wetlands with a water supply from piped drainage systems"* (Ekologgruppen, 2000, p. 32).

Differences in wetland vegetation between constructed and natural/semi-natural wetlands were reported on by Kiehl & Weisner (1998). They surveyed 26 ponds—13 constructed and 13 natural or semi-natural. They found that both species richness and diversity was generally lower in the constructed wetlands compared to the reference systems (p. 12). Additionally, they recorded the presence of 3 red book species in 2 of the wetlands, although it should be noted that one of them had been planted and was not, thus, naturally established. They concluded, though, that although the plant species diversity was lower in the constructed wetlands, that

> "*plant species diversity in agricultural landscapes can be increased by wetland construction"* (p.17).

9.4 Fish and Constructed Wetlands

A study by Olsson (1998) revealed high mortality (81.5%) of downstream-migrating anadromous fish forced to migrate through constructed wetlands, although he concluded that more follow-up work was necessary to draw further and larger conclusions from his study.

9.5 Increased & Improved Biological Diversity in Constructed Wetlands

If a broad generalization can be made from these studies, it is that within the created wetlands of Skåne and a small region immediate to the north in Halland County, that overall species biodiversity quickly and rapidly increased. An examination of the studies is called for to see how they might be applied and how much we can extrapolate from them.

The foundation for which these studies findings can be broadly generalized is the type of created wetland they represent. The surveyed wetlands are generally small (average size of the wetlands created in the Höje and Kävlinge catchments was 1.1 hectares—from Ekologgruppen, 2000, p.16), created in agricultural areas, and predominantly constructed by excavation of ponds below the existing man-made watertable. Scientifically, sampling techniques and schedules for the examined species were adequate, thorough and systematic.

Two common themes can be built around these findings of increased biodiversity in constructed wetlands. First, created wetlands are quickly colonized and exhibit both species richness and diversity already from the first year after creation. Torle's summary about invertebrates, can also be applied to all of the species examined in these created wetlands:

> *"There are not many biotopes which mankind can recreate, and achieve such a high level of biodiversity in such a short time*[…]*"* (Torle, 2002, p. 20).

That the highest number of species was associated with increasing area is to be expected; this is what we would expect from the ecological area effect concept (Wilson, 1992, 221-227).

Such rapid species colonization is not surprising. Owing in part to extensive excavation and other earth-moving practices inherent in construction practices here, these created wetlands initially represent a nearly textbook area of 'virgin' territory where rapid colonization is a matter of course, in the absence of confounding factors. The indicated ecological succession within the invertebrates and macrophytes is also predictable. Within the initial years of creation two factors are at work here: the physical aspects are in a state of flux before reaching equilibrium, and the biological organisms are colonizing the area according to their nature as weak/strong colonizers and then subsequently being out competed by stronger species.

The second theme is that of biological interconnectivity. Individual species richness and complexity was confirmed here. All of these species, however, ecologically interact to make each others lives possible. The invertebrates require the presence of aquatic macrophytes for both food and cover, and subsequently constitute one part of the food chain for birds. But the chain is more complex as birds are also contributors to the dispersal of both vegetation and invertebrates in these areas (Torle, 2002, p. 16). These ecological webs are further explored by Vought et al. (1999).

In the case of biodiversity in constructed wetlands in Skåne, it is a very much a holistic case of the whole being larger than the sum of its parts. Small constructed wetlands are a part of a "larger habitat mosaic" (Fischer, 2002, p.133). It is not just the (studied) species which determine wetland influence upon biodiversity; this is supported by the (not studied) species that are reliant upon wetlands, but which may not necessarily be wetland dependant directly. One example of this is in the Ekologgruppen report (2000, p. 30), where it is indicated that the birds which employ these wetlands for foraging and resting may be transitive and not necessarily breeding and nesting in the area. This was supported by Fischer and Lindenmayer's (2002) studies of small habitat patches which found that "the vast majority of bird species[…]were found to use small [habitat] patches" (p. 132). Gopal and Junk, in a similar discussion, argue that those species dependent upon wetland species and habitat "must also be considered among wetland organisms" (2001, p. 279). Many unexamined species thus contribute to the overall biological diversity within these small wetlands.

Findings of less plant biodiversity—both as regards richness and diversity—in created wetlands versus natural wetlands need similarly to be considered in light of a few factors. First, of the thirteen constructed wetlands, 5 were quite young (less than or equal to 5 years old; Kiehl & Weisner, 1998, p.6), and thus could probably be expected to be still undergoing biotic and hydrological changes before reaching some manner of stability in their representative biodiversity. This was the delineation time period identified in a French river restoration study necessary for the state of the ecosystem to become "stable and self-sustainable" (Henry et al., 2002, p. 552). This is, of course, a generalization that would vary in created wetlands depending upon area-specific factors, but seems anyway to be a logical generalization. Also, an additional 2 of the ponds were constructed as urban stormwater reservoirs, and not in agricultural areas.

Additionally, it is definitely not the case that creation of these biotopes universally improves biodiversity. As can be seen from the study by Olsson (1998), wetland creation involving stream widening can definitely have negative effects on species in transit through the area.

In the context of extrapolating these biodiversity findings to other wetlands, the generally small wetland size needs to be considered. Studies of small isolated wetlands on reptile and amphibian diversity in the United States revealed

> *"*[these] *wetlands are focal points of herpetofaunal richness and abundance…and contribute more to regional biodiversity than is implied by their small size"* (Russell et al., 2002)

These findings are just as applicable here even though the wetlands studied were not constructed ones, as the typical wetland creation pattern in Skåne has largely been that of small wetlands, which are relatively isolated in an agricultural landscape.

Additionally, it is increasingly being recognized that the island biogeography principle "seems to have limitations in its application to ponds" (Oertli, 2002, p.66). As indicated by the biotic diversity in these—and other (Oertli, 2002; Russell et al., 2002) small wetland areas, we can conclude that restored and constructed wetlands do not have to be large to have a significant impact on regional and local biodiversity.

In a broader perspective, the small habitat areas of the constructed ponds in Skåne help to "soften the landscape matrix and make it[…]less hostile for biota" (Fischer, 2002, p. 133). Wetland creation in Skåne, then, establishes biodiversity oases in the otherwise biologically impoverished and homogeneous landscape resulting from the modern, high-intensity agricultural practices used here.

10 Constructed Wetlands and Biodiversity: Denmark

The establishment of new wetland areas in Denmark is supposed to have a "positive effect on the wild plant and animal life in the project areas" (Andersen 2000; V.1, p.7). Clearly, there has been progress in the creation of wetlands. Re-established wetlands, including lakes, fens and freshwater meadows "make up, respectively, 0.9%, 0.9% and 0.7% of the existing types of nature in DK" (Agger et al., 1999 in Tind, 2000, p. 24). But what about the biological diversity in these new wetland areas? The current state of knowledge—or perhaps its lack—is described by the Danish Nature Council in the Wetland Strategy of the Aquatic Environment Action Plan II– Consequences and Possibilities for Nature: "an overview of the state of biological conditions in these re-established wetlands is lacking" (Tind et al., 2000, p.24), and again and more specifically

> *"to the best of our knowledge, a comprehensive, consolidated evaluation of the influence of created wetlands influence on fauna has not been made"* (Tind et al, 2000, p.66).

With this as our starting point, we will here examine what is known about how wetlands influence biodiversity in Denmark.

10.1 Plant Diversity and Wetlands

10.1.1 Aquatic Vegetation and Wetland Drainage – Arriving Where We Are

Declining lowland stream area, and hence their associated wetland area, in Denmark is linked to changes in species richness and composition among stream vegetation. Riis and Sand-Jensen, (2001) performed a broad historical analysis of Danish stream plants, examining the period around 1896 to 1996, and comparing data from 208 stream sites in 1996 with archival information from 27 sites in 1896. Of the 208 modern data sites, 13 were included in the earlier information.

Their research calls attention to two interlinked findings. First, species richness of submerged plants has declined "profoundly" over this period. This was evident both historically (by viewing streams present in both periods), and from comparison of all the other streams (p. 269). Second was a directional pressure favoring species both resistant to frequent disturbance and those adapted to eutrophic conditions. This decline was especially notable among the Potamogeton species, and was so striking that:

> *"seven of the 16 species previously observed in [Danish] streams were not found recently,* ***even though the total number of localities studied was eight times higher"***
> (Riis and Sand-Jensen, 2001, p. 276; my emphasis).

10.1.2 Botanical Implication of Raised Water Levels and Increased Flooding

We now have a retrospective look at the current situation. What changes plant composition and richness in and around created wetlands will now subsequently undergo—or can be expected to undergo—due to heightened water levels is now examined.

Terrestrial vegetation was surplanted by wetland species after raised water levels re-established hydrologic conditions in wet meadows. Additionally, the resulting vegetation both differed from that existing before drainage 6 years earlier, and was dominated by fewer species (Hald and Petersen, 1992).

With the assumption that the Action Plan II will impose certain hydrologic conditions in created wetlands due to elevated water levels, Anna Hald examined (1998) terrestrial, emergent and aquatic species in Denmark to see how they would be impacted. Database cross-referencing of species and their habitat types allowed examination of which species would best be promoted by "moist to wet or water covered, eutrophic and oxygen poor" environments typical of created wetlands (Hald, 1998, p. 115). She identified 208 species which would, potentially, be "easily" negatively affected. In contrast, she found 149 species expected to be positively affected. Overall, though, she says that nature restoration projects that raise water levels by reopening subterranean drainage pipe networks (i.e. "more or less aquatic habitats in and by canals, watercourses, streams and lakes") can be seen as beneficial. (Hald, 1998, p. 119). Here, a "marked" advance among normally occurring plants can be expected (ibid.).

In this same train of thought, Baatrup-Pedersen and Friberg (2000) examined how re-established natural watercourse dynamics and the increased inherent flooding events this would incur, would impact plant richness and diversity. They found that:

> *"plant communities along unregulated watercourses do not just exhibit greater species diversity, but also have a **higher quality** than plant communities along regulated rivers"* (Baatrup-Pedersen and Friberg, 2000, p. 72; my emphasis).

Plant species richness quickly recovered in 1-2 years following restoration of the river Brede (Biggs et al., 1998). Purely aquatic plants reached pre-restoration levels, while emergent species richness reached and exceeded initial levels (pp. 246-247). Vegetation abundance, as measured by coverage, had returned to approximately half of pre-restoration levels after 2 years, but indicated strongly increasing growth trends (pp. 250-251).

Almost all submerged vegetation underwent an ecological collapse in Solbjerg Engsø from 1997-1998 (Grünfeld & Lindhardtsen, 1999), following a nearly universal "hostile takeover" of thread algae, predominantly Cladophora. Biological surveys indicated, however, that submerged plants are again returning (ibid.).

The large wetland restoration project in West Stadil Fjord similarly examined effects before and after restoration. Restoration work was completed in 1998 (Søndergaard et al., 2001). Terrestrial vegetation, as would be expected, showed a decline from 187 total species in 1998 to 172 in 2000 (p. 20). Average coverage of underwater plants in the large downstream lake increased "significantly" from 8% in 1998 to 31% in 2000, with an increase of species from 6 to 9 (p. 14). Linked to this was the increase in visibility from 0.2m to 0.6 m, due to a decrease in overall phytoplankton (p. 11).

10.2 Macroinvertebrates

There is substantial evidence in the scientific literature that invertebrates are rapid colonizers of virgin, restored and newly created habitats (for example, see Wilson, 1992). Here we examine a few of the newly created wetland areas.

Macroinvertebrate surveys before and after river re-meandering on the river Brede revealed rapid recolonization by aquatic macroinvertebrates. After 1 year species richness had almost reached pre-restoration values (Biggs et al., 1998). Additionally, "species richness in the restored sites was not significantly different to that in the control site" (ibid, p. 246). Despite this, however, they concluded that their study showed "little evidence of net [biological] benefits in the short term" (ibid., p. 253).

Fyns Amt found that the Danish Watercourse Faunal Index (an index employing aquatic macroinvertebrates to indicate levels of water pollution – hereafter also referred to as DVFI) was not just dependent upon water quality, but also the physical variation of the watercourse (Fyns Amt 2001).

In the West Stadil Fjord wetland restoration reported upon by Søndergaard et al. (2001), zooplankton biomass in the lake in the heightened water area exhibited a 50% increase from 1999-2000, although the short nature of this study limits its value. In the large lake immediately downstream of this area, there was, despite large yearly variations in the average zooplankton biomass, a general change in zooplankton composition towards greater numbers of larger animals.

Re-meandering of sections of Pøleå creek has been examined since project completion in 1987. Although there was substantial sectional variation, the Watercourse Faunal Index in the restored section improved from 3 & 4, to generally 5 (Gørtz, 2001). There was additionally reported a finding of a total of 107 macroinvertebrate taxa.

10.3 Restoration - Waterfowl and other birds

Following establishment of three separate shallow (average depths approximately 0.7m) lakes on Pøleå creek in Sjælland, an extensive number of waterfowl, migratory birds and raptors subsequently immigrated into the area (Olsen, 2002).[10]

The first restored lake, Alsønderup Engsø, is 52 hectares and was restored in 1987. Solbjerg Engsø (33 hectares) was then restored a few kilometers upstream in 1993, followed by Strødam Engsø in 1996. In this last lake, there were 5 bird species present shortly after restoration. In 1997 fifteen, 16 in 1998 and 19 in 1999. Common to all of these lakes is that they have "large populations of migratory birds outside of their breeding seasons" (Olsen, 2002, pp. 246-247), along with raptors and substantial numbers of wetland species.

10.4 Restored hydrological conditions – Impact on Fish

Fish have long been recognized and used as indicators of overall aquatic and riparian ecosystem stability and health. Stream re-meandering, associated heightening and/or elevation of streambed and water levels and other inherent changes aim to increase habitat diversity and hence biodiversity among fish. As findings regarding fish biodiversity were generally unanimous, a small representative sampling is given here.

Holmehave brook was remeandered in 1988, with an increase in watercourse length from 790 to 910 meters. Following a two year stabilization period after re-meandering, trout populations were growing rapidly and were "considerably greater" than before (Hansen, 1996, pp.73-75).

A portion of Idom Stream was remeandered in 1990 from 280 to 568 meters. Three stream sections were examined, one downstream and non-channelized, one in the restored area, and one upstream and channelized. The trout population in the stretch downstream of the study area roughly doubled following the upstream restoration. In the remeandered area, trout populations increased from 25 in 1989 to 225 in 1993. In the stretch above the re-meandering, trout populations also increased, here from 25 to just under 150 (Hanson, 1996, pp. 30-31). See Figure 8.

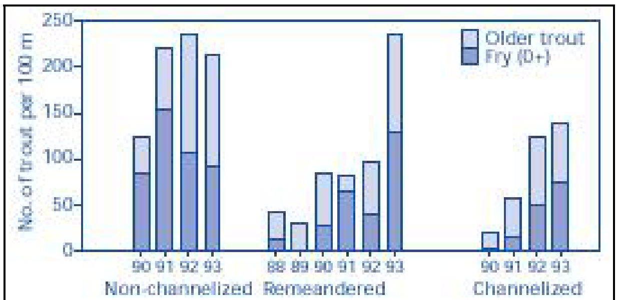

Figure 8. Evolution of Trout Populations in Idom Stream. Source: Hansen, 1996

Fish species composition in the large downstream lake in West Stadil Fjord were largely unchanged after water levels were raised 1 meter immediately north of the lake in its headwaters. There was a slight decrease in both total sampled numbers and weights from 1998 to 2000, but

[10] Olsen (2002) is also the information source for the following paragraph.

significant insecurity inherent in their sampling methods led them to conclude that these changes "were not necessarily significant" (Søndergaard, 2001, p. 14).

10.5 Biological Diversity in Re-established Wetlands

Wetland drainage in Denmark resulted in the "loss of suitable habitats" and the reinforcing factor of "strong anthropogenic impacts" which led to the current state of aquatic stream vegetation (Riis and Sand-Jensen, 2001, p. 269). Many other species were affected by these changes. The general impoverished state of biodiversity in Denmark is in large measure due to the lack of wetlands areas.

This is not to say that Danish wetlands exhibit lower biodiversity than other countries, just that biodiversity has been diminished due to the loss of wetland areas. It can be hard to think of the current state as impoverished without an adequate time perspective. A longer view also allows us to examine how wetland restoration in Denmark—whose goal can be described as restoring conditions existing 50, 100 or even 200 years in the past—is linked to biodiversity through the subcomponents of: stream re-meandering, raising river beds, increasing hydraulic contact of the river with its former floodplain, and raising ground water levels.

A closer look at the Idom Stream re-meandering study will help elucidate how these concepts are linked. This study includes many of the principles that wetland creation and biodiversity hinge upon. In addition, since in-stream spawning areas were not augmented by the addition of spawning gravel (a practice common in some restoration projects aimed at rebuilding in-stream fish habitat), we can better evaluate the area-related effects of the project on biodiversity.

Before restoration began, the river area had been placed under a preservation order, meaning that no river maintenance (dredging, weed removal) had occurred for five years in the study area. Thus, the stream had naturally begun to re-establish its former meandered course. Downstream of the study area, the stream had never been channelized, and the upstream stretch was still channelized, albeit with the aforementioned self-restoration in progress. As part of restoration, several large and small ponds were created in the remeandered section to increase habitat diversity and area.

Biodiversity, as here indicated by trout density and richness, strongly increased as a result of the project. Restoring the formerly channeled river section improved biodiversity both in the restored section, where changes were associated with increases in habitat, and also in downstream sections, where changes were probably more closely linked to increased water quality. Re-meandering the stream increased its hydraulic contact with surrounding meadows and riparian areas. In this project, this was also linked to the building of small ponds and lakes in the area. These new wetland areas provided new and better habitat, and increased biodiversity. This is supported by Jensen's conclusions that the observed increases in trout in the remeandered and the upstream stretch were "chiefly attributable to the development of physical conditions at the two stations" (Jensen, 1996, p. 31).

The link between greater habitat diversity and increased biodiversity is seen in Fyn Amt's aquatic macroinvertebrate findings, where both improved water quality and increased physical habitat variation led to greater macroinvertebrate diversity. However, as the Pøleå creek invertebrate study showed, improving physical habitat through meandering alone is not necessarily enough to ensure increased biodiversity, if not combined with efforts to increase water quality.

Although the DVFI did, here, improve in certain areas sufficiently to meet the goal of reaching DFVI level 5 (a goal which in 1999 had not been met in "the last several decades [Grünfeld & Lindhardtsen, 1999, p. 64]), project shortsightings inhibited larger positive influences on biodiversity (Gørtz, 2001). For example, the restored conditions did not lead to better contact with the riparian area—excessively deep meanders "effectively prevented any flooding" of the floodplain. Evidently, re-meandering projects whose primary aim is to increase biodiversity should establish conditions that aid reintegration of the riverine channel into the natural floodplain

Considering the large open-water wetland areas created on Pøleå creek, the reappearance of so many waterfowl and other types of transitory bird species is hardly surprising. The extent of this positive effect was thus described;

> *"all together, bird richness and composition has **markedly evolved** from a state before restoration which was typified by species impoverishment*[…]*to the current **very diverse** status with several rare and red-listed species"* (Grünfeld & Lindhardtsen, 1999, p. 50; my emphasis).

In this way, then, the anthropogenic influences in the form of re-meandering has improved biodiversity. Another strength of this project is the ability to examine the **extra value added** to biodiversity via—admittedly large—human intervention, as compared with letting nature self-restore itself. Findings revealed that total "trout population in the restored stretch is 3-4 fold greater than what could be expected had the reach only been allowed to undergo self-restoration to the same degree as[the upstream section]" (Hansen, 1996, p. 31). There is **an enhanced time aspect of restoration efforts on biodiversity**; although plants and animals quickly recolonize recreated wetland areas, human intervention creates a larger template, thus speeding up the process by augmenting its scale.

It is appropriate to ask whether nature restoration projects with species-specific goals also work for the common good of the rest of the biotic community. The reports agree that fish have almost unanimously benefited by wetland restoration in Denmark, but it can considered a very species-specific view. Indeed, it need not be fish, as various interest groups will each point out their own preferred biotic type which may be positively or negatively affected: waterfowl, orchids, otters etc. Studies in Finland showed that river restoration programs "performed for the sole purpose of fisheries enhancement, with little consideration for other stream biota or ecosystem processes" also benefited benthic invertebrate communities (Muotka et al., 2002, p. 251). With the tightly linked trophic and ecological processes in wetland environments, we would expect a web-like response, where actions influencing one area of the environment (for better or worse) are quickly manifested in influences upon other areas and species. Wetland creation in Denmark seems to work in this way, increasing biological diversity, in its myriad forms, for a majority of species.

The finding that most species benefit, does not preclude negative impacts upon some species. There is an ecobiological trade-off inherent with recreating wetland ecosystems which primarily affects biota favoring dry (drained in this case) terrestrial habitats. Some types of strictly terrestrial vegetation are the most obvious biota surplanted (Hald, 1998; Hald & Petersen, 1992). The professional evaluation of the Second Action Plan also acknowledged this, yet weighed in favor of wetland flora which "have been in decline for many years" (Iversen et al., 1998, p.22).

Adequate long time studies are essential to establishing any relation between wetland restoration efforts and biodiversity. In the River Brede re-meandering, it was concluded that little evidence of short term benefits could be found (Biggs et al, 1998). Obviously, with too short a sampling period this would seem to be the expected outcome. Their study of invertebrates examined post-restoration effects for just one year, and included only four sampling periods—the first one just one month after the work was completed. While this is an adequate horizon for first recognizing recolonization patterns, it is inadequate for generalizations about effects of restoration on biodiversity.[11] Similarly, in the new lakes along the Pøleå creek system, we would expected that the high initial colonization rates of bird species exhibits a typical pre-stabilization pattern where the increasing numbers will also undergo a typical modified bell-curve before stabilizing (Olsen, 2002, p. 246). The meadows studied by Hald (1992) also exhibited a status different from that before the former wetlands were drained. Again we see the too-short-examination time horizon. Only long-term monitoring will reveal what type of baseline system might be expected after restoration.

10.6 Increased Biodiversity amid Biotope Uncertainty

In summary, recreated wetlands increase overall biodiversity, but not universally. This includes not just species richness and diversity, but also habitat richness and diversity. However, despite the large scale of many recent nature restoration projects—or perhaps especially because of it—uncertainties remain as to what extent biodiversity will increase, and whether or not subsequent ecological surprises might still occur. The ecological take-over of algae in the created shallow lake Solbjerg Engsø is one example. In hindsight, one might have foreseen this happening, as the shallow eutrophic conditions favor the algal growth, but it still represents one unplanned surprise.[12] As we cannot foresee all the effects such ecological engineering projects will have, raising water tables, restoring river meanders in a river valley and creating conditions which favor more frequent flooding of adjacent floodplains is still, then, an imprecise science. Careful planning and investigation will be needed if significant biological good is to be realized from new wetland projects that supplant pre-existing diversity. The implications on biodiversity are that:

> *"biologically, it can be difficult in certain circumstances to precisely predict which type of wetland will be created after a restoration, even though the drained areas history is well-known via old maps and drainage plans"* (Hoffmann et al., 2002, p. 12).

This biological uncertainty at the biotope level exists, however, within the larger framework of an increasing body of knowledge on how specific biotic communities respond and react to wetland creation.

[11] This is not to slight Bigg et al.'s study, it is just to point out the need for an increased number of long-term studies. As their study's focus was aimed at examining short-term effects, their conclusion seem justified.

[12] An interesting bio-ecological tangent to this is that it sets the stage for experiments to see if biomanipulation can restore the lakes water clarity. Exploration of this is outside the scope of this study, but further information can be obtained in Grünfeld & Lindhardtsen, 1999.

11 Discussion A: New wetlands & nutrient reduction: a trans-boundary Danish and Scanien analysis

Despite differences in implementation of new and restored wetlands, nutrient retention has thus been shown to increase following wetland establishment in both Denmark and Skåne. The extent, scale and associated impact on riverine and near-shore coastal aquatic environment is now discussed.

11.1 Nutrient retention summary

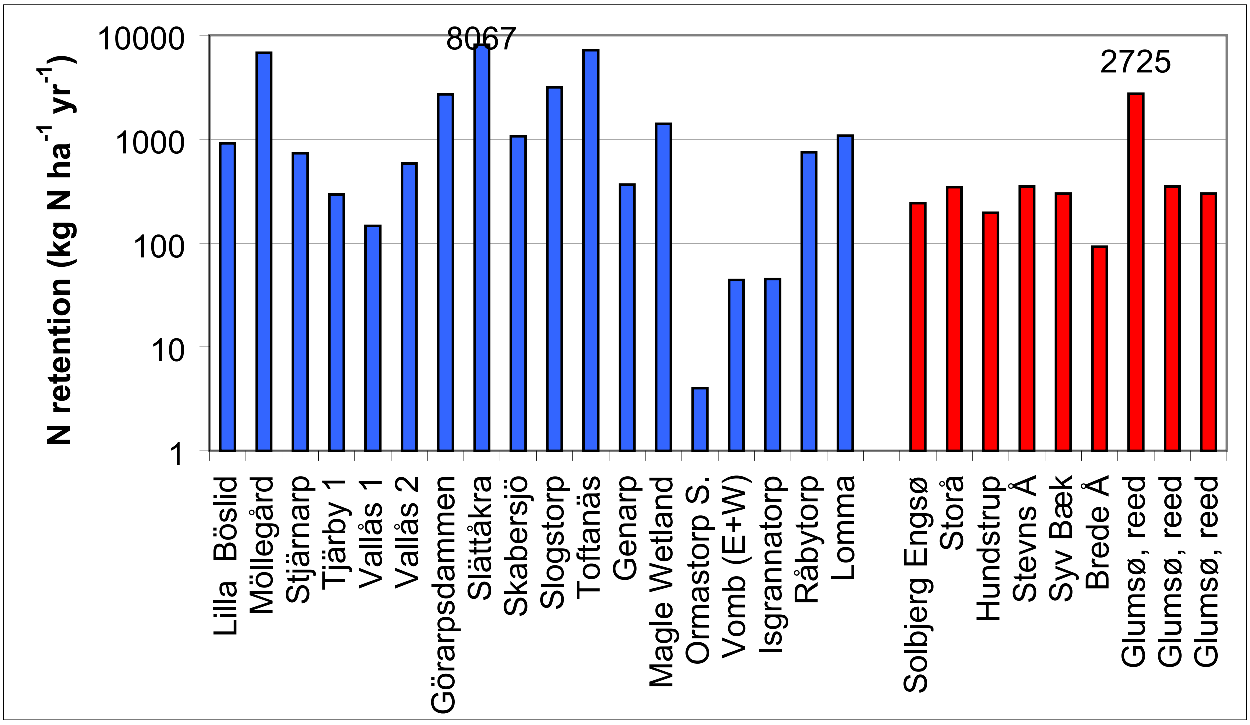

Figure 9. Nitrogen retention in constructed wetlands. Blue bars indicate Swedish wetlands, red bars indicate Danish wetlands. The two maximum values for each region are indicated. Source: Ekologgruppen, 2000; Hoffmann, 1998; Vought and Lacoursière, 2001; Grünfeld and Lindhardtsen, 1999; Leonardson, 1994.

Figure 9 summarizes nutrient retention data from sections 6 and 7, showing to what extent created wetlands function in these landscapes as nutrient traps.

The overall nitrogen retention in the examined wetlands created in Sweden averaged approximately 1,960 kg N ha^{-1} yr^{-1}, while in Denmark the average was 490 kg N ha^{-1} yr^{-1}. Subtracting the wetlands with the highest and lowest retentions from each country to help standardize the data, yields average nitrogen retention of, respectively, **1,700 kg N ha^{-1} yr^{-1}** and **270 kg N ha^{-1} yr^{-1}**.[13]

If we employ these averages over the wetland areas each country expects to establish, (5,000 ha. and 10,000 ha.[14] respectively), we see what effect these national plans for wetland restoration will have:

- wetlands in Skåne will remove **8,500 metric tons of nitrogen per year**.
- Danish wetlands will remove **2,700 metric tons on nitrogen per year.**

11.2 Discussion of nutrient retention findings

These **constructed wetlands in Skåne retain, as a per-project average, slightly more than 6 times the amount of nitrogen as wetlands (re)created in Denmark, and on a national/regional scale, wetland restoration projects in Skåne exhibit an approximately 3-fold greater total removal of nitrogen.** This seems mostly a result of differing priorities, as manifested by wetland implementation in the landscape, and not necessarily as reflected by stated goals and aims for all of these projects. While nutrient retention was one of the two top priorities for wetlands created in both Denmark and Skåne, differences in two related key areas, namely construction practices and placement in the landscape (spatial factors), largely explain the substantial difference between the two countries.

Differing restoration/construction practices—here synonymous with manipulation of hydrologic factors—can be thought of in two ways: one either brings a new wetland to the water (the Swedish examples), or else one brings the water to a new wetland (the Danish practice).

11.2.1 Bringing a new wetland to the water…

Bringing a new wetland to the water, as a metaphor for construction of wetlands within the system boundary of a fixed water table, is an intensive and commensurately expensive practice as large amounts of earth excavation and moving are generally involved. However, one benefit of this practice is greater assurance in produced results. Wetland creation is an in-the-field ecological manipulation experiment, and as with any experiment, the more closely variables can be manipulated, the greater security there is that results will fulfill and reflect project goals. That nitrogen retention in created wetlands in Skåne is substantially higher than in Denmark is not, then,

[13] Unless otherwise mentioned, the standardized retention rates will be those discussed in the following section. This standardization was deemed necessary to show the most representative results possible. This method was employed as only one project in Denmark (indicated in figure 11 with a retention of 2725 kg N ha^{-1} yr^{-1}) exhibited **substantially** higher retention than all the other Danish projects, while one project in Skåne (seen in figure 11 with a retention of 4 kg N ha^{-1} yr^{-1}) in an inverse fashion exhibited retention on an order of approximately 480 times lower than the average. This does not call into question the validity of these studies, but rather attempts to illustrate the most representative picture by accounting for these outlying and unrepresentative findings.

[14] Not including the approximately 2,000 hectares of the Skjern Å project. This seems justified as it is hard to generalize overall average nitrogen reduction from the myriad of micro-scale patchy wetlands habitats which will be produced by this project. Where they to be included, however, the total removal in Denmark would be 3,240 metric tons.

surprising; it is merely the result of a more carefully controlled experiment. Leonardson (18 November, 2002) supported this idea that Swedish wetlands are more closely controlled experiments.

This is not to say that high nutrient retention is a guaranteed outcome, or even entirely predictable—remember here Wedding's statement (Section 7.1) that "it is very difficult to predict with a high level of confidence how large nitrogen retention will be in any one pond." (2001). With increasing complexity of manipulated variables and other system components, like depths, slopes and catchment/wetland ratios for example, there is an increasing uncertainty. The numerous small pond-like wetlands in Skåne help to counteract this uncertainty. They (paradoxically, as their construction methods are usually more involved than 'simpler' Danish methods), in some ways, better embody the KISS concept[15], as the biogeochemical consequences of their small size on nutrient retention are more easily manipulatible and thus predictable.

11.2.2 Bringing the water to a new wetland…

Danish wetland creation operates under an umbrella of nature restoration. Within this dogma is the idea that the prior intrusions of mankind on the natural landscape should be reversed, with subsequent restoration of the lost purification functions of natural wetlands. In the Danish context, this implies that drained wetland areas should be restored to resemble and function like natural systems—in short, to return to and not just mimic natural ecosystems.

On one level this can be a simple process involving a cessation of activities that artificially maintain "unnatural" conditions. This is exemplified by the stopping of drainage pumps. On another level, however, this can imply a slightly more active approach, for example raising water levels by filling in drainage channels and trenches. The highest, and most vigorous incursion is when habitats need to be restored to pre-regulated forms. This refers to the re-meandering of streams to allow and facilitate semi-controlled flooding of stream and rivers, and to permit these same entities to recapture their former floodplains.

One result of these actions—which bring water to a new level and thus wet a new larger surface area—is that there is a greater likelihood of unexpected results. In the Danish examples of these ecomanipulation projects, uncertainty works on several levels that increases the chances that nutrient retention will be lower than in projects in Skåne. In the first place, there is uncertainty when dealing with new and higher water levels, as to what specific type of biotope will be created. This can be seen in the numerous different types of wetlands which are created in Denmark. Compounding this is the knowledge that varying wetland types exhibit different types and scales of chemical transformations, and that regardless of which type is created in Denmark, it usually is a wet meadow or fen—project types with substantially lower potentials for nitrogen removal.

Although many investigations have clarified what background levels of nutrient retentions occur in natural wetland systems (see Table 1 for a small sampling), there is less literature examining the time span necessary for restored wetlands to asymptotically approach or even become this model. With enough time, of course, and neglecting unforeseeable mitigating factors,

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[15] KISS is an acronym for **K**eep **I**t **S**imple **S**tupid. An adage often quoted in many disciplines, but one perhaps especially suited to wetlands system analysis; in other words, employ the simplest possible model (i.e. project) which adequately explains project requirements.

we expect that the two systems will approach each other in performances. This does not imply, however, that the nearly six-fold gap in nutrient retention between Skåne and Danish wetlands will decrease with time. With passing time, and the ecological stability that subsequently ensues, Danish wetlands will approach levels typified by natural systems. But it is critical to note at the outset that those levels are substantially lower than those for wetland ponds in Skåne—which are more specifically designed for nitrogen retention.

We must also note that many of these background investigations are micro-scale experiments (for example the majority of the irrigation experiments) whose results have been scaled up to extrapolate the performance of larger areas. While this does not reduce their validity, it must be closely scrutinized as a basis for interpreting nutrient retention on a larger scale. Nutrient reduction in wetlands operates as an amalgam of a large number of micro-scale processes and can be expected to show micro-scale variability (for example, the one, substantially higher at 2725 kg N ha^{-1} yr^{-1}, nitrogen retention finding of Hoffmann 1998; see Figure 9); this seems especially true when groundwater flows are the primary agent of nitrogen transformation and removal.

Danish construction methods more readily create conditions for which it is more difficult to make conclusions of final nutrient retention. A greater proportion of sub-surface flow wetlands (an example being seasonally flooded meadows) versus a majority of surface-flow wetlands in Skåne make it harder to draw comparisons. This is another possible explanation for the doubts raised by Færge et al. (1998 and 2000) about the ability of restored wetlands in Denmark to remove an average of 350 kg N ha^{-1} yr^{-1}.

11.2.3 Similar Means – Different Created Wetlands – Different Results

There is a certain similarity between the Skåne "piped system" wetlands and the Danish wet meadows. Both involve diverting agricultural drainage water into holding areas to either increase retention time and/or divert the inflow into a larger area. In Sweden, to generalize, this area becomes the wetland, whose outflow—with an associated decrease of nutrients—is discharged into creeks, rivers and canals. In Denmark, the wet meadow is more often a riparian meadow strip located between this holding area and an adjacent watercourse.

The means used, i.e. the disruption and plugging of drainage networks, or the simple diversion of their outflows into a new wetland, determines whether or not water levels are raised in the project area. Here we can compare the 42 projects under the Action Plan II where drainage pipes were either blocked or otherwise rendered inoperative, and where pumping actions were stopped in order to transfer drainage water to new wetland areas, to the 23 projects in Skåne in the Höje and Kävlinge catchments. The former projects generally involve heightened water levels, while the latter do not. The result is the creation of two different types of wetlands: wet riparian meadows in Denmark, and pond-like wetlands in Skåne.

Furthermore, while denitrification in wet meadow areas has been reported to be substantial in many micro-scale area experiments (see Hoffmann, 1998), overall nitrogen retention is higher in created ponds than in wet meadow areas—(from 0-4,000 kg N ha^{-1} yr^{-1} in the ponds to 0-3,000 kg N ha^{-1} yr^{-1} in the wet meadows: Leonardson, 1994). The nearly six-fold increase in nitrogen retention in constructed wetland systems between Skåne and Denmark illustrates this.

The implication of this is that, if combating eutrophication were the only, or primary, consideration, then created wetlands should generally be formed as shallow ponds. This would facilitate their strategic placement in the landscape where high nutrient loading would be guaranteed. Increased nutrient retention would follow as a result. Of course, this is too simplistic a standpoint. Local site conditions, topography, hydrology, and sociological factors like landowner and other multiple-use interests are also an integral part of project formation (Ekologgruppen, 2000, p. 16).

11.2.4 Nutrient Retention and Smart Weaponry

Placement of wetland projects within a landscape is a key component determining their effectiveness as nutrient traps. Regardless of the type of wetland constructed, and the manner in which it is ultimately created, situation in the landscape will be the main factor determining what nutrient loads will be subsequently input.

In both Denmark and Skåne contributions from agricultural land are the overwhelming source of downstream eutrophication problems as seen in section 5. Therefore, the placement of wetland creation projects has emphasized areas close to, in or around cultivated land. This is especially true in Scanien projects directly employing inputs of agricultural water. In Denmark, however, wetlands under the Second Action Plan II can be created (basically) only in those areas previously selected by the various counties and compiled into the national registry of areas potentially suitable for wetland restoration. While the counties primary reasons for identifying these areas was their potential for nitrogen removal (Tind et al., 2000, p. 39), with such a large potential area indicated on a national level, it can be difficult to predict whether wetlands will be re-established in the places they are most needed (Tind et al., 2000, pp. 41-42).

From a nutrient reduction standpoint, multiple smaller projects in a catchment—as exemplified in the Höje and Kävlinge projects in Skåne and the shallow lakes being re-established in the uplands of Arresø in Denmark—then seem to be one ideal manner to use wetlands purification capacities. This is in contrast to Jansson et al.'s recommendations to not create wetlands in the headwaters of a lake, as the lake is a better net remover of nitrogen (1994, p. 325). Here, however, the purpose is to reduce the inflowing nutrient load, so this is an ideal siting. The benefits are that numerous smaller projects can be sited in the landscape where they will do the greatest good. They can reinforce each other, if the nutrient concentrations exceed the capacity of larger but fewer projects. A topical, yet somewhat unrelated, comparison can be made to attacking military targets with conventional bombs versus with "smart" weapons. Both generally accomplish the mission, although the more surgical nature of the one implies more specific area-related results with fewer resources. Smaller, more effective wetland projects are, here, the smarter weapon to employ against eutrophication.

11.2.5 Nutrient Retention: Hydrologic & Area Factors

Nutrient retention is, then a function of both creation methodology and areal-spatial factors i.e. placement within the landscape. Both factors show a greater variability in the wetlands in Denmark, so as expected, we see less nutrient reduction in Danish wetland restoration projects. Admittedly, the many different approaches are difficult to compare: stream re-meandering projects, excavated ponds and wet meadows established through water level raising are three distinct entities. However, all their components exist within terrestrial-aquatic ecotones—all are wetlands of sorts—and as such, their varying success at nutrient reduction can be validly compared.

In comparing constructed pond-like wetlands and wet meadows to stream re-meandering projects, we have seen that the former promote substantially greater nutrient reductions. Jansson et al. went so far as to say that

> *"reconstruction of channelized streams to the original meandering courses will…have little effect on the total nitrogen removal"* (Jansson, Andersson, Berggren, Leonardson, 1994, p. 322).

This broad statement, while valid in a very narrow context, seems to discount the effects that stream meandering projects have in creating new nutrient traps other than just those in the stream course. Here, for example, we can consider seasonally flooded areas in adjacent riparian meadows in Denmark which also show some level of nitrogen transformation. As Hoffmann et al. indicate, there are numerous other effects linked to river re-meandering:

> *"stream-land interactions increase, as does the groundwater level and the extension of the riparian wetlands and wet meadows"* (Hoffmann, Pedersen, Kronvang, Øvig, 1998, p. 224),

and these associated effects have been proven to decrease nutrient transport in the aquatic environment, even during short-term flooding events (Hoffmann, 1998, p. 43). These restoration projects therefore, exhibit greater net nutrient removal than that which would be suggested by just examining retention in the stream channel. Stream re-meandering does help ameliorate and reduce nutrient concentrations, although the nutrient reduction component it carries is not as high as that incurred by the creation of shallow wetland ponds.

Additionally, while nutrient retention is not completely predictable in every wetland, we can foster the best conditions to maximize the potential that nutrient reduction will function as predicted. The smaller created wetlands in Skåne are better projects because they are take advantage of this. They tend to be situated immediately below, or in immediate hydrologic connection with, non-point source agriculturally derived pollutants.

11.2.6 Nutrient Traps: Sustainable Development and Social Responsibility

Recreating wetlands in Denmark and Skåne is a type of ecosystem-level replumbing of the landscape with multiple benefits directly linked to sustainable development of these areas. Insofar as nutrient reduction has been examined in this study, creating wetlands function to reduce nitrogen transports and thus reduce eutrophication of riverine and near-coast marine environments. As the source of these pollutants is primarily agricultural non-point based, they thus primarily address and mitigate the negative anthropogenic impacts of agriculture.

Industry has already taken steps to reduce their contribution to the eutrophication problem (Eriksson, 2001; Bøgestrand et al., 2001), but they are but a small contributor to the eutrophication problem. Why should agricultural interests not also be required to exhibit the same responsibility for their effluents and by-products? Granted, they are forced to take consideration of this indirectly through the taxes they pay for nitrogen fertilizers, but this defensive approach to environmental protection is a far cry from the pro-active, conscious action plan which creating wetlands represents. It is a way, then, of acknowledging social responsibility, and is one of the complementary measures which can be a key element promoting sustainable development within agriculture.

Additionally, the approximate six-fold increases in nitrogen retention, and especially the substantially higher total effectiveness of Skåne's wetland restoration plans, shows that substantially greater gains could be made in Denmark. This does not imply that agriculture needs to be substantially undermined by large scale restoration of all former wetlands. This would be as unrealistic as it would be undesirable, given the importance of agricultural production both economically, and in terms of food production. Swedish projects demonstrated that quite small areas of land converted to wetlands are sufficient for this purpose. The increasing body of information (a representative sampling can be found in Ekologgruppen, 2000; Brix, 1998; Campbell & Ogden, 1999), and this study, indicate that constructed wetlands, as those created in the Höje and Kävlinge catchments, are ideal decentralized natural resources to use to combat anthropogenic wastes at their sources.

Additionally, as we are discussing sustainable development of the landscape, it is appropriate to inquire about the societal costs of these projects. Are they cost-effective compared to traditional, established methodology involving construction of centralized downstream treatment facilities? Substantial scientific evidence exists indicating that constructed wetlands "may achieve the same treatment at a lower cost and maintenance level" (Sundblad, 1998, p. 251; also: Byström et al., 2000; Ekologgruppen, 2000; Brix, 1998). Also this cost-effective attractiveness of wetland projects does not incorporate the numerous other benefits of wetlands upon society: recreational aspects, restoration of a cultural-landscape identity, and the potential for increasing and restoring the lost and impoverished biodiversity of the landscape.

12 Discussion B: New Wetlands & Biodiversity: a trans-boundary Danish and Scanien analysis

Constructed wetlands in Denmark and Skåne both create and improve wildlife habitat. Danish methods which re-establish natural hydrogeomorphic processes, and the smaller Skåne pond-like wetlands operate, spatially, at two different levels in the landscape matrix. We can further explore this by examining the impacts on biodiversity through the theory of habitat island geography. This is here appropriate as fulfilling one of the mutual priorities of these wetlands, namely increasing and aiding biodiversity, is achieved by purposefully **increasing** landscape fragmentation, i.e. by increasing the varieties of habitats in these regions. Additionally, this approach will enlighten the analysis, owing to the otherwise extreme difficulty of drawing generalizations about biodiversity via quantitative comparisons of the studied biota—the extreme variety of wetland habitat types confounded simple analysis between project sites and areas.

12.1 Wetland Habitat Island Biogeography: SLOSS

SLOSS is the acronym for Single Large Or Several Small, and refers to the ecological question often arising when discussing conservation and habitat areas. The new habitat areas which created wetlands produce, are created within the boundaries of socio-economic constraints earlier discussed; currently in Skåne, these logistics dictate that establishing substantially large wetlands is not logistically possible, while in Denmark the opposite is true. Regardless, however, restoring wetlands here involves dealing with what amount to habitat fragments.

The substantial biodiversity seen in Skåne wetlands illustrates the benefits of small wetland habitats (see section 9.5). As examined earlier, there are several reasons why several small habitat reserves can be beneficial for biodiversity. Whittaker (1998) examined some additional reasons for why several small habitats may be just as, or more, beneficial as fewer but larger ones: several small reserves may incorporate more varied habitat varieties, that there is less competitive pressure excluding species of similar niches, that there is less risk inherent in several spatially distributed areas, and that some species require small habitat islands (p. 207).

These reasons are applicable here, and are reinforced by the **lack** of any significant large obligatory wetland species in both Denmark and Skåne. The top, non-migratory, obligate wetland inhabitants in Denmark are the otter and the beaver. And even animals of this modest size are not present in Skåne wetlands. As the argument for larger habitat areas is often linked to the large spatial requirement of animals higher up the trophic chain, the lack, then,[16] of any such species implies that smaller wetland areas can also be highly effective.

Zedler (2000) suggests that "efforts to restore biodiversity should be based on knowledge of factors that led to species loss[…]" (p. 311). In acknowledging, addressing and undoing these factors, Danish efforts are then more directly focused towards increasing biodiversity. Also, as Danish restored wetlands are not necessarily designed to provide only one specific service (i.e. nutrient reduction as is the primary weighted focus in Skåne), there is a greater potential that the varied habitats resulting from Danish efforts will better support non-generic ecosystems. And indeed, we see that there is a greater variety of wetlands created in Denmark.

To what extent, however, does this greater habitat heterogeneity translate to greater and better biodiversity? There was no substantial overall differences in examined biodiversity between the two regions, although this is partially explained by the depth of the biodiversity comparisons. Closer species-by-species comparison might reveal greater variation. Additionally, the impacts upon biodiversity of re-establishing very large habitat areas, for example on the scale of the Skjern River project in Denmark, remain to be proven. It is too early to draw meaningful conclusions as to whether biodiversity will be increased **to a greater extent** by wetland projects of this magnitude.

It is an obvious fact that biodiversity in either of these regions is not going to become an Amazonian basin of biodiversity. This does not imply, however, that broadening restoration efforts in Skåne—to some extent—would be misplaced. This is especially the case in terms of re-meandering streams in Skåne which could increase anadromous and catadromous fish populations as seen in Denmark. This is, however, more a factor of improved stream habitats and cleaner water than a direct result of creating new wetland areas, and thus can not meaningly contribute to argumentation for re-meandering streams for the primary purpose of creating riparian wetlands. However, the already mentioned political, social and economic factors in Skåne are factors limiting how extensively Danish methodology could in any event be adopted and implemented.

Both Skåne and Denmark are regions where societal growth patterns have dictated that the majority of land usage is devoted to agriculture. If a region can be characterized by a lack of natural wetlands—whether or not as a result of anthropogenic habitat alterations, although in these regions the former is especially the case—then the created-versus-natural counterargument is a moot point. We can see from the historical scale of wetland loss that biodiversity is impoverished; this is as regards both species directly dependent upon wetland habitats, and those indirectly

[16] Here, I think of the larger total space requirements of such top trophic wetland species found in foreign wetlands, such as the hippopotamus or the crocodile and alligator—all three of which are conspicuous here by their absence.

dependent. Recreating wetlands also involves the re-establishment of wetland species. The latter cannot exist without the former.

Here it is then appropriate to discuss the biodiversity in these created wetlands versus natural ones. This is an important topic, as numerous studies abroad (Gopal et al., 2001; Gopal et al., 2000) find that biodiversity in created wetlands is neither as rich nor as diverse as that in natural wetlands. Findings in both Denmark and Skåne (Hald, 1998; Kiehl & Weismer, 1998) supported this. Nevertheless, whether or not the biodiversity we can restore mirrors that of pre-restoration and pre-wetland draining should not be the standard by which to judge project effectiveness. The ability of new wetlands to increase biodiversity in the modern landscape—which here has been documented—is by far a better departure point for discussion. The findings of several hundred different taxa—many of which would otherwise not be present in the landscape—illustrates this potential of wetlands to increase habitat diversity and biotic diversity within these two regions' landscapes.

If the more numerous but smaller wetlands in Skåne are then biodiversity oases as I believe, then regarding Denmark's fewer but larger created wetlands as hotspots of biodiversity seems appropriate. The former is a more focused project, while the latter involves a larger regional scale. Both methodologies increase ecosystem diversity. The larger habitat mosaic created by the numerous small wetlands' overall spatial interconnectivity, may, however, contribute just as efficiently to overall regional biodiversity. Thus:

> *"a set of ponds of small size has more species and has a higher conservation value than a single large pond of the same total are.* [However,] *large ponds* [can] *harbour species missing in the smaller ponds"* (Oertli, 2002, p. 59).

Whigham (1999) also indicated the importance of small isolated wetlands on biodiversity. Also, as explained above, the lack of large wetland species reduces the weight of the argument necessitating larger habitat areas

This is not to say, however, that establishing wetlands on smaller local scales, as has been done in Skåne, does not presuppose conflicts between pre-existing flora and fauna values. This problem has received more attention in Denmark, and thus has higher visibility, but is also a factor concerning wetland implementation in Skåne. Regardless of the methods used, such biodiversity conflicts are inevitable. Negative effects, however, can be minimized, especially when adopting the more rigorous locating of wetlands near eutrophication sources in Skåne.

13 Discussion C: Biodiversity—Nutrient Retention: To what extent a trade-off?

All of the examined projects, except for a few of the smaller stream meandering projects created solely for the purpose of increasing in-stream fish habitat, include as their goals the promotion of biodiversity and elevation of the nutrient removal potential. The projects have **demonstrated their ability** to accomplish both of these goals, albeit to differing extents and scales. In light of these differences, we can pose two related questions:

1. Is biodiversity being traded-off to some extent for increased nutrient retention?

2. Is nutrient retention being traded-off to some extent to improve biodiversity?

The first question asks whether, and if so to what extent, there is a biological price of creating wetlands in the Swedish manner—i.e. gaining an average 6-fold increase in nutrient retention—rather than using Danish methods? There appeared to be no significant small-scale biological price for this increase, although there are many factors implicit in such a generalization. There may be several explanations. First, higher nutrient retentions in Skåne wetlands are only achieved by virtue of their specific location within a catchment where nutrient loading from agricultural water is introduced to the wetlands. These areas generally do not support high levels of flora and fauna, as compared with areas outside of the anthropogenically heightened influence of fertilizers and other nutrient additives. These wetlands have also been designed with specific catchment:wetland ratios in mind to avoid nutritionally overloading them to the detriment of biodiversity. There is, then, a type of built in consideration for biodiversity values. Additionally there is the counterbalancing benefit of Skåne methodology, in that it tends to decrease the potential for conflicts with pre-existing biodiversity. Other reasons were discussed in Sections 10.5, 10.6 and 12. The biological price, then, does not seem significant when viewed at smaller, local scales.

The second question asks whether greater nutrient reduction is 'sacrificed' by prioritizing improved biodiversity. This study shows a clear yes. Created wetlands in Denmark function at substantially lower levels as nutrient traps. This is both as regards average nutrient retention—which is approximately 6 times less, and total regional effectiveness—which is roughly 3 times smaller. Given the findings that biodiversity did not exhibit substantial increases with Danish methods relative to Skåne, this study questions the underlying logic of not employing wetland systems as they are implemented in Skåne, on the basis of improved biodiversity arguments.

14 Recommendations

Swedish regional efforts to enhance biodiversity with created wetlands could be improved by adopting some of the Danish methodology employing water level raising and stream re-meandering, with the subsequent inundation of larger areas. This would have the effect of increasing the scale of wetland habitat fragments, and habitat diversity in the landscape. Given the numerous logistical difficulties of establishing large wetland areas (i.e. Dikningsföretaget, little possibility for land exchange, the increasing saturation of areas available and suitable for wetland restoration…), however, we must ask ourselves if the marginally increased biodiversity benefits would be commensurate with the costs, given that Skåne is a smaller region than Denmark, and has certain production responsibilities on a national scale.

The lack of findings of substantial differences in biodiversity between Denmark and Skåne supports the conclusion that creating wetlands in Skåne under the current schemes has perhaps benefited biodiversity nearly to the extent to which it will be possible to reasonably establish, given the largely immutable extent and importance of agricultural land use in the area. Biologically, then, and within the current system boundaries, the evidenced increases in biodiversity already achieved through wetland creation might be reaching a point of diminishing returns. Adoption of Danish creation methodologies will not, then, significantly improve biodiversity.

Danish adoption of the Scanien background approach to achieving higher nutrient retention would, on the other hand, have significant positive implications on especially nutrient retention, but also biodiversity. Tind et al. (2000) argue that the requirement for an average nitrogen removal of 350 kg N ha^{-1} yr^{-1} are too high and should be reduced to achieve greater nature quality in Denmark. This is, however, only the case within the current system boundaries. Using experiences from wetland creation in Skåne, **raising the requirement**, not lowering it, could aid both efforts to increase biodiversity and increase net gains of nutrient reduction. The basic points of this reasoning are:

- Raising the nitrogen removal project requirement would imply that less areas could potentially be restored, as there as less areas with suitable nutrient concentrations.

- Identification of project sites would then refocus attention to those areas where nitrogen trapping projects could achieve the greatest benefits. This would mean smaller projects placed more strategically on agricultural land—the primary source of the nutrient leakage these wetlands are attempting to reduce.

- This means that overall project efficiency in terms of nutrient retention would increase. A smaller area of wetlands then achieves the same effect as a larger area under the former conditions.

- A smaller effected area, and greater net nutrient reduction, would be attractive to a majority of landowners as fewer would be impacted by land-use changes.

- This also means fewer conflicts arising from large projects enveloping large areas with pre-existing natural (biodiversity) values. Smaller projects situated immediately on or near intensively cultivated arable land, which has (comparatively) a lower pre-existing nature biodiversity value, would better serve to increase biodiversity. This can generally be prescribed to the overall paucity of wetland biotopes in these modern agriculturally dominated landscape.

Alternatively, the effect of restored wetlands on decreasing eutrophication of streams and near-shore coastal environments could be tripled, quadrupled, or even more, by establishing the originally planned coverage under the new formatting. Better placement within the landscape would help overcome concerns (see Section 8.1) that wetlands won't actually decrease eutrophication much.

15 Conclusions

Wetland construction methodology and subsequent impacts on nutrient retention and biodiversity have been studied in Denmark and in Skåne, the southernmost region of Sweden.

Analyzed projects revealed that average nitrogen retentions vary from 1,700 kg N ha^{-1} yr^{-1} for Skåne and 270 kg N ha^{-1} yr^{-1} for Denmark. Constructed wetlands in Skåne retain, then, on average approximately 6 times the amounts of nutrients on a per hectare basis. Despite having national restoration plans which are approximately half the size of those in Denmark, overall effectiveness of national wetland creation plans in combating the nitrogen component of eutrophication is approximately 3 times greater in Skåne than in Denmark, with total nitrogen removals of 8,500 metric tons and 2,700 metric tons, respectively. This increase was attributed to two factors: better placement in the landscape relative to those nutrients constructed wetlands were supposed to ameliorate, and the opting for constructing wetland types which function as more efficient nutrient traps.

National plans employing wetland creation to decrease eutrophication will be particularly effective in Skåne, while Danish plans—in their current forms—will have limited impacts on decreasing eutrophication. Both regions still have a long way to go in order to substantially decrease the main source of this eutrophication problem, agricultural non-point pollution. This study has highlighted the potential of created wetlands to function as one component for effectively combating eutrophication. Other complementary measures will still, however, be needed to significantly and further reduce eutrophication, as employing wetlands alone, in the proposed scales, will not sufficiently reduce eutrophication.

Constructed wetlands have effectively helped restore some of the biodiversity lost due to wetland draining in the past 150 years. Biodiversity in both study areas was documented to quickly increase following a post-construction stabilization period. Created wetlands generally increased both species richness and diversity while simultaneously increasing habitat diversity in the otherwise agriculturally dominated landscapes typical for these regions. Their creation has resulted in occurrences of numerous species which otherwise would not be present, concurrent with findings of several endangered and threatened species in both Denmark and Skåne.

Danish construction methodology generally involved substantial changes of the hydrological regimes in project areas, created a greater variety of wetland types typified by fens and wet meadows. The great variety of project and habitat types thus produced confounded and prohibited the drawing of precise qualitative comparisons of biodiversity between the two regions.

The objectives of increased nutrient retention and biodiversity are not mutually exclusive, and project methodology can be altered to optimize effectiveness of either component. In the case of Denmark, it is found that nutrient trap and project effectiveness can be beneficially augmented with incorporation of methodology from Skåne into the present system. Additionally, conflicts between newly created biodiversity and pre-existing biological values can be reduced. Skåne nutrient trap effectiveness, on the other hand, will not be increased by using Danish methodology, but goals of increasing biodiversity in Skåne could, however, be aided by the adopting of Danish water level raising techniques, creating larger wetlands more typified by fens and wet meadows than pond-like wetlands. There are substantial political obstacles to this being an implementable option, however, and the additional benefits to regional biodiversity—over those already exhibited—might not be that substantial. This last finding is in contrast to one of the expectations of this study.

Constructing wetlands to combat eutrophication and increase biodiversity has been proven to be an effective, cost efficient method in these areas. Additionally, this is an environmentally friendly manner helping to promote sustainable development of landuse in these areas. Findings here substantiate the statement that, “as wetlands flourish and landscapes emulate the natural prototype, wildlife will proliferate and many […] environmental problems will be solved” (Hey, D., Philippi, N.S., 1999, 26-27). It additionally represents a modern way of approaching the issue of social responsibility regarding addressing the impacts of our methods of production.

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