Master's thesis

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Possibilities of rewetting agricultural land for decreasing greenhouse gas emission and sustainable adaptation to flooding

-A case study from two sites in Sweden

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Abstract

The consequence of climate change will be more flooding in some areas and problems with sea-level rise. Drained wetlands and lakes that today are used for agriculture in the future may need to be rewetted because it might be unsustainable to continue to drain them. Rewetting these lands will have many positive effects like for instance decreased greenhouse gas emissions since these lands due to their high organic matter content are emitting a lot of CO_2 and N_2O.

In this study two sites that could become candidates for rewetting have been studied and compared for their CO_2 and N_2O emissions. This was done by using a method for sampling gases both from a closed chamber and directly from soil. The emission rates were higher for Ramsjön compared to Vesan for both gases that could probably be an effect of season. A strong covariation between the two gases was shown for Ramsjön and the relationship was fairly strong for Vesan this indicates a common process for releasing the two gases. Rewetting these areas would probably have a high potential for saving greenhouse gas emissions and possibly also serve as flood adaptation areas with a high biodiversity and recreational value.

Keywords: Climate change, Carbon dioxide emission, Nitrous oxide emission, Flood Adaptation, Rewetting drained wetlands, Room for the river

Preface

First of all, I would like to thank Si institute for giving me this amazing opportunity of studying in Sweden, without Si scholarship I wouldn't be able to go after my dream.

There are a number of people who were essential to the successful completion of this thesis. Their contribution, as well as my learning experience, is of inordinate value to me. I am indebted to each of them.

I am greatly thankful to my supervisor Marie Mattsson, Associate Professor, School of Business, Engineering and Science, Halmstad University, Sweden for providing the definite direction, designing the project concept with professional guidance and constant encouragement from the beginning of the work and moral support in many ways during study period.

It was an honour to work under the supreme guidance, excellent suggestions and scholarly notes to Professor Siegfried Fleischer, School of Business, Engineering and Science, Halmstad University, Sweden during the thesis work.

I would also like to thank my four elder sisters for their never-ending support throughout the project report. I am extremely delighted to extend my special to my mother, Mrs. Suraiya Begum for her divine blessings throughout the period of this work. I am also thankful to my friend Richard Chamberlain for his endless support.

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1. Introduction

Climate change will lead to a lot of changes in weather conditions and sea level. It is expected to cause major changes in precipitation patterns with increased frequency of large rainfall events (IPCC, 2007). During the last decade, summer floods occurred more often in Europe than before. Severe summer and late-spring floods have occurred in the major rivers (Kundzewicz et al., 2005). In another study Christensen et al. (2003) explains how climate change may cause heavy precipitation in Europe in summer, which may lead to intense frequent flooding.

In order to avoid severe effects of climate change it is important that we both decrease greenhouse gas emissions and adapt to new conditions. In many parts of northern Europe since more than a hundred years wetlands and lakes have been drained and rivers have been straitened in order to gain more agricultural land. These soils also emit huge amounts of greenhouse gases due to being high in organic, matter and nutrient content. Rewetting these soils to what they used to be; shallow lakes and wetlands even wet meadows, could lead to multiple benefits. Drained peat-lands emit some 20 (grassland) to 30 (cropland) tons CO_2 $ha^{-1}year^{-1}$, whereas N_2O emissions add another 3 tons CO_2 equivalents (IPCC, 2006) and thus constitute severe emission hotspots. These lands also lose up to several centimeters of height per year through peat oxidation (Berglund and Berglund, 2010). To transform agriculture on organic soils into a more sustainable land use, different approaches have been suggested in several countries.

Nitrous oxide (N_2O) is an important greenhouse gas, which contributes to stratospheric ozone destruction. Despite its low concentration in the atmosphere of about 316 ppm, its global warming potential is about 298 times higher than that of CO_2 in a 100-year time frame (Lindgren and Lundblad, 2014). Considerable amounts of N_2O gas are emitted from natural and cultivated soils through microbial processes (Xing, 1998). According to the study Hernandez and Mitsch, (2006) soil–water system can be a main source or a sink for atmospheric N_2O depending on microbial activity. Another study by Yan et al. (2000) reported that the main pathway of N_2O emission from rice–soil system depended on the status of soil water. Changes in land use patterns will cause alterations in the soil organic matter status and the soil nitrogen mineralization rates and therefore will also influence N_2O emissions (Lu et al. 2014).

Now due to heavy rainfall and sea-level rise there have been cases of severe flooding across Europe in many areas. The traditional approach to flood control has been to build dikes and embankments. For example, in the Netherlands and in Germany there are now ideas of more sustainable solutions. With increasing climate change the question is: how long can the water be kept out of the cities and agricultural land? There may be more cost-effective strategies for adapting to flooding by sacrificing agricultural land but also gaining other values like decreased greenhouse gas emissions and increasing biodiversity. Water system planners and managers in the city of Kristianstad which is in southern Sweden have begun to explore these ideas of an "adaptive river management" (Johannessen, 2015). Rewetting is the process through which lands are flooded artificially that have previously been drained for anthropogenic activities, in order to re-establish and maintain water saturated conditions, this can be done by blocking drainage ditches, construction of bunds or disabling drainage pump facilities. (Wilson et al., 2016b)

The aim of this study is divided into two parts. A Literature review was done to find out if there are any positive effects of rewetting and how rewetting can be a potential effective solution for both reducing greenhouse gas emission and flood adaptation. Fieldwork provided the greenhouse gas emission rates from a few drained agricultural lands. This thesis presents two cases of former wetlands, (Ramsjön and Vesan) that are situated in Sweden, used for agricultural practices today. These lands have high soil organic content that also emits large amounts of CO_2 and N_2O and would therefore be good candidates for rewetting. Both sites have been studied and compared for their CO_2 and N_2O emissions and analyzed if there is any correlation between them. A strong correlation will indicate a common process for releasing the two gases. Rewetting these areas would probably have a high potential for saving CO_2 and N_2O gas emissions and possibly also serve as flood adaptation areas with a high biodiversity and recreational value.

2. Methods

2.1 Literature review

A literature search was done using the Web of Science-SCI EXPANDED (www.webofscience.com) and Compendex database on the 2nd April 2015. Four searches were performed using the following search term combinations with no restriction on years (i.e. 1985-2015)

These were the specific search terms that were used for the literature search:

1. Wetland, greenhouse gas emissions, flooding (Topic search), (62 results)

2. Flood mitigation, climate change, wetland (Topic search), (36 results)

3. Rewetting, biodiversity, floodplain areas (Topic search), (3 results)

4. "Room for the river" (Topic search), (25 results)

The title and abstract of each result were inspected and articles that focused on greenhouse gas emission and flood adaptation were short-listed. After this sorting process papers were chosen. The final step in the selection process involved an evaluation of the entire paper and selection was made based upon the following criteria:

(1) The study area was related to reducing greenhouse emission.
(2) Direct relation to climate change and sustainable flood adaptation.
(3) Related to rewetting and increased biodiversity.

Those papers that fulfilled these specific criteria and provided different standpoints on how rewetting and flood adaptation strategies can reduce the emissions of greenhouse gases were chosen. Moreover, websites and other scientific reports that were relevant to the mentioned criteria were used as well as references.

2.2 Fieldwork

Study area of drained wetlands

Two sites, Ramsjön and Vesan were chosen for this particular study. Both of them were wetlands before (approximately 100 years ago) but now are used as agricultural land. Data from Ramsjön was taken in 18th September 2014 and data from Vesan was taken in 11th of May 2015. In both of the sites carbon dioxide and nitrous oxide emissions were measured.

The upper 10 cm of the soil was chosen for measuring greenhouse gas concentration in the soil atmosphere.

A stainless-steel ring (51cm width and 17cm height) was used to block the greenhouse gas emission from going to the atmosphere. This ring comes with a cover, which is equipped with a fan that keeps moving for avoiding stratification of the gas inside the chamber. There is also a battery outside for powering up the fans inside the closed chambers.

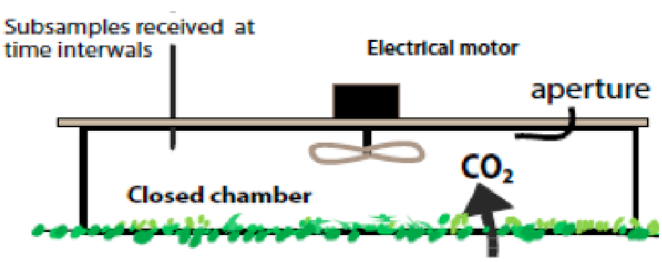

Figure 1- Closed chamber with an electrical fan for taking greenhouse gas samples.

Samples from the closed chamber

For taking gas samples straight from the chamber a hand pump was also connected to an exetainer with a tube and needle for taking samples. While doing that, the inside pressure was equilibrated by the use of an aperture (Figure 1). Five or six samples were taken at different time intervals starting from 0 to about 60 minutes and the exact sampling times were noted for later plotting. The increase in plotted greenhouse gases concentrations levels off until an equilibrium with the superficial soil concentration was attained (Figures 2-5 and 6-9). These procedures are in accordance with the suggestions by (Matson and Harriss, 1995)

In both Ramsjön and Vesan, two chambers were used simultaneously to measure the concentrations of carbon dioxide and nitrous oxide (Figure 2-5 and 6-9). Concentrations inside the chambers were measured from time 0 and concentrations were then obtained as ppm when analyzed with gas chromatograph. These concentrations were used for calculating carbon dioxide and nitrous oxide emissions using the plotted curves and the formula shown below (Calculations). The concentration increase rates were derived from the derivative at time 0. Temperature of the soil was also necessary to measure because it is related to greenhouse gas emission. Higher temperature triggers high production of greenhouse gases in the soil.

Soil atmosphere sampling

Soil atmosphere samples were also taken at 25 m transects across the fields. A stainless-steel tube (diameter 6 mm) with a perpendicular hole near the closed bottom side was used for taking soil atmosphere samples every meter at 10 cm depth. For pumping the air out of the soil, a hand air pump was attached to a 12 ml exetainer. Moreover, these samples were analyzed with gas chromatography.

Additional soil sampling

Soil samples were also taken to the laboratory for measuring the water, mineral and organic content. At the beginning weight of the soil sample was measured. For getting rid of the water content soil sample were dried at 100° C for 24 hours, then again weight was measured after cooling. In order to measure the organic content samples were treated at 550° C at least for 5 hours. Again, weights of the sample were measured after cooling. The soil sample from Vesan was unsieved but the soil sample from Ramsjön was sieved using 2 mm mesh size.

Calculations of emission rates:

In order to calculate the gas emission rates from the concentration increase at time zero the following variables were needed:

Surface of the chamber = 0.20418 m^2

Volume of the chamber = 34.3021 liter

Gas at 0° C = 22.414 liter per mole

0° C= 273K

Molar mass of nitrous oxide and carbon dioxide = 44 g/mol

The formula used for calculations of emission rates is shown below.

(Concentration increase (ppm/hr) X volume of the chamber X molar mass of the gas X temperature in K at 0°C) / (10^6 X 22.414 (liter gas per mole at 0°C) X surface of the chamber X temperature in K).

Calculations are based on the ideal law of gases. At the end, the unit of gas emission will be

$gm^{-2}hr^{-1}$.

Since nitrous oxide is 298 times stronger as a greenhouse gas than carbon dioxide in a hundred-year perspective (Lindgren and Lundblad, 2014) the nitrous oxide gas emissions need to be multiplied by 298, which gave the CO_2 equivalents for nitrous oxide.

For measuring the relative impact of the gas, these measurements of nitrous oxide emissions were divided by the sum of the readings of carbon dioxide and nitrous oxide measurements from the chamber, which indicated the share of total climate impact (Lindgren and Lundblad, 2014).

The soil atmosphere samples taken at these two sites were used for plotting nitrous oxide concentrations against carbon dioxide concentrations in order to reveal if a covariation existed along the transects.

3. Results

3.1 Literature study

Climate change is a burning issue, effects of the climate change are visible in almost every part of the world but this is only the beginning. Extreme climatic event is going to take place. Some parts will face extreme heat waves and some parts will face flooding due to unexpected heavy rainfall. In case of northern Europe, it's going to endure a lot of rainfall in the upcoming future. In order to deal with this problem different flood adaptation strategies are necessary.

Different strategies like lowering floodplains, moving dikes further, deepening riverbeds are main steps for accomplishing controlled flooding in empty lands when it is necessary. Moreover, developed countries like Australia, UK and America are also coming forward to implement different projects for achieving sustainable flood adaptation (Making Room for the River, 2015). In Quebec (Canada) there is another project going on which follows the same principle with different approach, they are calling it "freedom space". This idea of freedom space is divided into three levels; first level of freedom space covers those areas of the river that are vulnerable to floods for next 50 years, second level includes space for larger magnitude of flood and the final level covers exceptional magnitude of flood. To make it more sustainable and environment friendly, areas designated for freedom space will be completely based upon hydro-geomorphic assessment (Biron et al. 2014).

Several flood adaptation strategies are basically indicating towards rewetting the lands. Rewetting procedure comes with added advantages. Good examples would be flood adaptation, reducing greenhouse gas emission, increased biodiversity and so on.

Flood adaptation

Numbers of flood events have increased worldwide and climate change is likely to make it worse by speeding up in the future. Europe suffered more than one hundred major floods between 1998 and 2004. When the rivers Danube and Elbe overflowed their banks in 2002 there were 700 fatalities and 250,000 people left homeless. The extent of the damage stood at around € 25 billion (Room for the River Programme, 2015). Factors like global population growth and socio-economic activities going on in the banks of the rivers are making flood protection and drainage infrastructure way more important than they should be. For the sake of safety of all these people around the world a sustainable flood adaptation system is not just a requirement but also a necessity (Herk et al., 2014).

Globally, flood adaptation is going through a transition period. Flood adaptation these days are shifting towards implementing flood protection by following the idea of ‘living with water’. Hence, land use is one of the key factors while managing exposure and vulnerability to floods. It is visible that engineering measures won’t be able to handle the future abundance and impacts of flooding (Herk et al., 2014). With the course of time, effectiveness of levees becomes less and affects the natural abilities of the river. However, spending the same amount of money in implementing flood plain reconnection could provide better safety, diverse biodiversity and a healthy environment (Guida et al., 2014). Adding up to that, floodplain reconnection is way more sustainable and more applicable than other conventional flood management system. It is beneficial for factors like sediment transport, channel planform adjustment, ecosystem processes, biogeochemical cycling, and the services rivers provide to society (Opperman et al., 2010).

At the moment, a project called “Room for the river” is going on in Netherlands, in which the basic concept is to go for controlled flooding in some predestined areas by sacrificing some lands to save others (Making Room for the River, 2015). In Quebec (Canada) there is another project going on which follows the same principle with different approach, they are calling it “freedom space”. They are giving the river 1.7 times more space than the channel width as the preventive measure of flood (Biron et al. 2014). Moreover, Germany and Sweden are also implementing projects following the similar concept as mentioned above. In Germany the system of “paludiculture” revitalize traditional forms of land use, paludiculture (‘palus’– latin for ‘swamp’) is the productive use of wet peat-land in a way that the peat body is preserved (Paludiculture, 2012). In Sweden an “adaptive river management” is suggested for the Kristianstad area, which is very sensitive to flooding. From a broader perspective EU flood directive is dealing with how to deal with upcoming environmental issues of flooding. The Swedish Civil Contingency Agency (Myndigheten för samhällsskydd och beredskap, or MSB) in collaboration with county administration is implementing EU Floods Directive in Sweden. The work has been going on since 2009–2015. Initiatives like identifying areas vulnerable to flood, building up maps to implement flood risk management plans are the basic concepts of this particular project. In addition, Water Framework Directive and government agencies will coordinate plans for creating public awareness in the preparation of these plans (Johannessen, 2015).

In a nutshell, most of the developed countries are adapting to their vulnerability of flood by implementing new flood adaptation strategy to deal with the consequences of climate change.

Reducing greenhouse gas emissions

In recent years, due to abrupt climate change knowledge concerning emissions became significantly important. As a result, factors that affect emission rates are looked into way more than before. Based on this new knowledge, there are different kinds of vegetation, which could be the potential option for rewetting, like forest, grassland, agricultural land and peat-lands. However, rewetting is one of the most effective options in terms of reducing greenhouse gas emission if it is done in drained wetlands. Soil from agricultural land is generally low in organic matter, but if it was a drained wetland in the past then these are high in organic matter naturally. This high organic matter breaks down the soil and results high emission (Lindgren and Lundblad, 2014). Draining different kinds of wetland was a common practice in Sweden for increasing agricultural practices. In the Swedish climate report, they calculated release of carbon dioxide and nitrous oxide from drained peat-lands amounted to 11.4 million tons of carbon dioxide equivalent in 2012.This is almost 20 percent of Sweden's total greenhouse gas emissions, which is approximately 57.6 million tons (Naturvårdsverket, 2014).

Rewetting or recreating pre drainage conditions and turning the land into wetlands can decrease the emissions of carbon dioxide and nitrous oxide but could increase emissions of methane. However, the decrease in carbon dioxide and nitrous oxide emission is larger, and consequently there is a net decrease of greenhouse gas emissions. (Wilson et al., 2016b)

When land is drained the water table and the soil is oxygenated. This means that methane emissions from the soil decreases because microorganisms produce methane under anaerobic conditions. Meanwhile, the organic material stored in land available for other microorganisms degrade it to carbon dioxide. This increases the carbon dioxide emission from the soil. In addition, nitrogen in the soil is made available to nitrifying and denitrifying microorganisms, which means that drained peat-lands also can be great sources of nitrous oxide (Berglund and Berglund, 2010). Conventional peat-land utilization requires a lowering of the water table. As peat largely consists of water, this water removal leads to compaction and subsidence of the peat. Drainage furthermore leads to oxidation of the peat that is no longer water-saturated, resulting in huge emissions of greenhouse gases (CO_2 and N_2O) to the atmosphere and additional losses of carbon and nitrate to adjacent surface waters and the groundwater (Berglund & Berglund 2010).

In Sweden there are a lot of agricultural lands on drained peat-lands that are no longer used for agricultural production. Most of the area is probably afforested today while a lot of the area taken out of production in recent times is probably not used at all, neither for growing crops, for grazing or forestry.

The reason behind land taken out of production maybe they are wet therefore it is not very productive (Wilson, 1999). Moreover, this phenomenon is not just taking place in Sweden, it is happening all over the world. Most peat-lands in agricultural landscapes have lost the capacity to provide their original ecosystem services. At a global scale, 16% of the former peat-land area has been strongly degraded due to anthropogenic activities, in North America 5%, in Europe more than half (52%). Once multi-functional wetlands, they have become mono- functional crop and grasslands (Joosten & Clarke 2002).

Paludiculture ('palus'– latin for 'swamp') is the productive use of wet peat-land in a way that the peat body is preserved. This unique idea can provide us biomass from wet peat-lands, which can be used as biofuel. In many cases even new peat is formed and the aboveground biomass is harvested and the belowground biomass forms new peat. Rewetting and paludiculture got many positive outcomes. Like climate change mitigation, halt to soil degradation, potential habitats for rare species and provides raw materials for energy and industry. Oxidation of peat and the associated release of greenhouse gases are stopped. There are good chances of carbon getting accumulated as peat. While using the cultivated biomass as fossil fuels and raw materials, further carbon emissions are avoided. The wet peat-lands furthermore cool the local and regional climate through increased evapotranspiration (Paludiculture, 2012).

Rewetting these lands can be used for sustainable flood management as well, at the same time greenhouse gas emissions will be less. There are certain ideas, which should be followed while implementing rewetting. If a wetland is to be constructed on drained peat-lands in order to reduce greenhouse gas emissions, water table constantly needs to be near the ground level. The general concept of this is to recreate past environmental conditions. If there is a swamp that has been drained, the measure should be focused recreating a swamp. If a lake has been drained then design of the measure should focus on the water level that covers the land through the whole year. To reduce the risk of high methane release immediately after installation, caused by the fact that easily degradable organic material is broken down. Due to this reason plants should be removed before the soil is restored to wetland. This applies particularly to agricultural land as compared to forest (Couwenberg et al., 2011).

Biodiversity

Increased biodiversity is also another outcome of rewetting. Planned river restoration and flood adaptation measures are needed to restore healthy and diverse floodplain landscapes (Schaich et al., 2010). The re-establishment of natural river conditions is the key factor for enhancing floodplain ecology and functionality and room for the river project is exactly focusing on that. Flooding an area has its down side but it is also known as a positive factor for plant distribution and species richness in terms of biodiversity (Bissels et al., 2004).

Wetlands and active floodplains are some of the most productive vegetations in terms of species richness, biological activity, and ecological system, yet they continue to be disconnected and altered due to increased demand of land and especially agricultural practices (Opperman et al., 2009). Moreover, using floodplain for grazing is a great idea. It can be a really important factor for vegetation and the structure of the topsoil. In this way it is very much possible to achieve a higher biodiversity competitive interaction between animal and species (Moran et al., 2008).

On the other hand, for maintaining high biodiversity in flooded areas some preventive measures are necessary in long run. Flood plain management strategy called Cyclic Floodplain Rejuvenation (CFR) focuses on measures like removal of soft wood forest, lowering flood plains and construction of secondary channel which are proven to be effective in terms of maintaining high biodiversity (Baptist et al. 2003)

3.2 Results from field work

The table below depicts Organic matter content of the soil from both sites, the soil at Ramsjön showed a slightly higher percentage (Table 2).

Table 1. Composition of the soil samples.

Sites	Organic material (Percent of dry matter)	Mineral content (Percent of dry matter)
Vesan	23.1%	76.9 %
Ramsjön	30.5%	69.5%

Results from Vesan

The results from chamber A from Vesan for both carbon dioxide (Figure 2) and nitrous oxide (Figure 3) shows increasing gas emissions which levels off with time. Both gases differ in terms of emission rate and time.

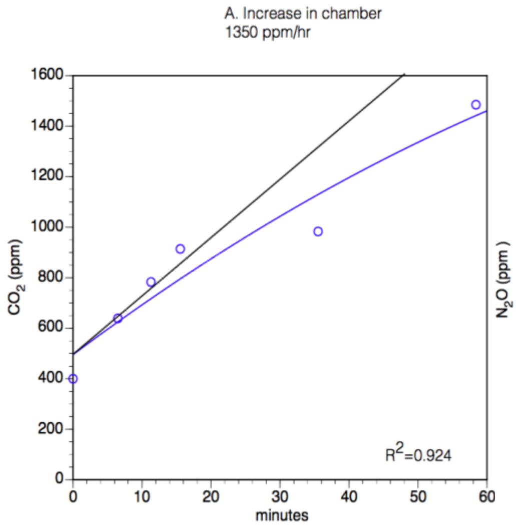

Figure 2- CO_2 from Vesan(A)

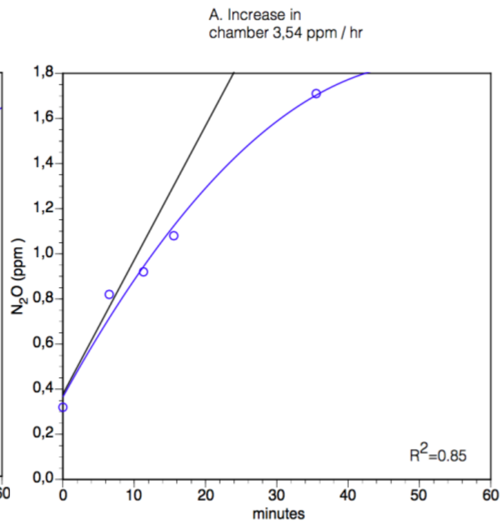

Figure 3- N_2O from Vesan(A)

Similar results were obtained from CO_2 and N_2O in Chamber B(Figure 4 and Figure 5). See also Figure 2 and 3.

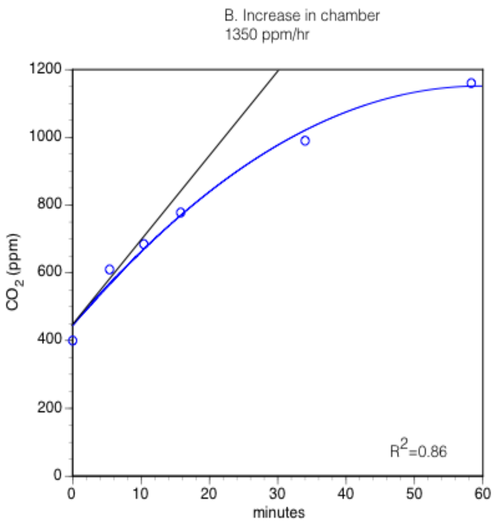

Figure 4- CO_2 from Vesan(B)

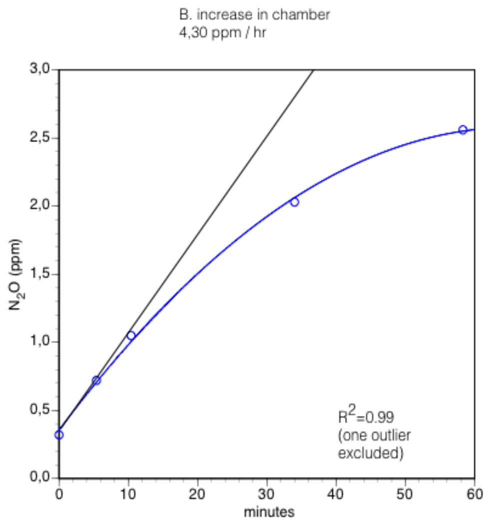

Figure 5- N_2O from Vesan(B)

Based on the figures 2-5, the table 3 was derived after calculations. The two chambers showed similar emission rates for both CO_2, N_2O respectively and relative impact of the two gases it was shown that 44-48% of the climate impact at the site was from nitrous oxide (Table 3)

Table 2- Measurements in two closed Chamber (A and B) at Vesan.

Chambers	Carbon dioxide g $m^{-2}hr^{-1}$	Nitrous oxide g $m^{-2}hr^{-1}$	Climate forcing effect of Nitrous oxide (Emission x 298)	Nitrous oxide's share of total climate impact at the site (%)
A	0.420	0.0011	0.3278	43.8%
B	0.420	0.0013	0.3874	48.0%

Figure 6 shows that, in Vesan nitrous oxide versus carbon dioxide concentrations at 10cm soil depth showed only a fairly strong relationship to each other, analyzing measurements from each meter in a 25 m transect (R^2 = 0.35, Fig. 6). This indicates that the origin of the gases could be found in the same process."

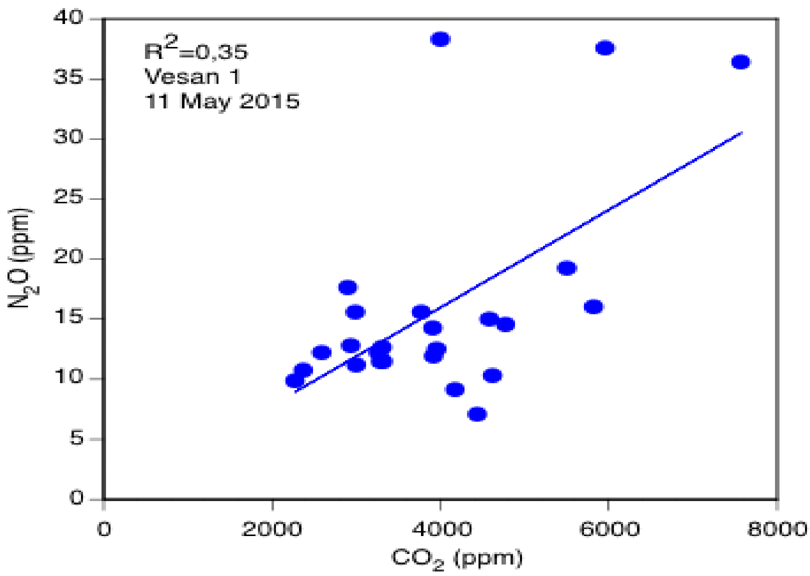

Figure 6- Nitrous oxide versus carbon dioxide at each meter in a 25 meter transect in former lake of Vesan at 10 cm dept

Results from former lake Ramsjön

Figure 7 and Figure 8 shows results from chamber C from Ramsjön for both carbon dioxide and nitrous oxide. Both gases differ in terms of emission rate and time.

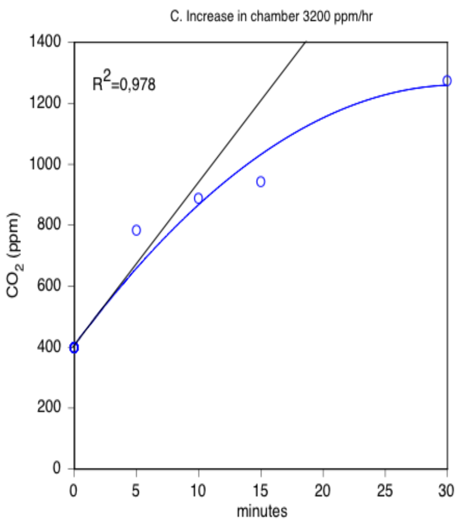

Figure 7- CO_2 from Ramsjön(C)

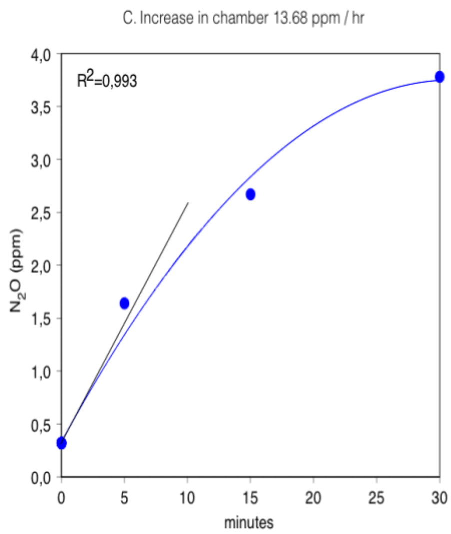

Figure 8- N_2O from Ramsjön (C)

Increase of CO_2 and N_2O in Chamber D from Ramsjön (Figure 9 and Figure 10). See also Figure 7 and 8 for Chamber C.

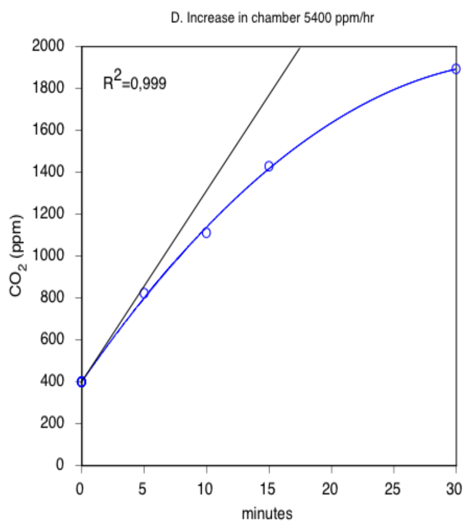

Figure 9- CO_2 from Ramsjön (D)

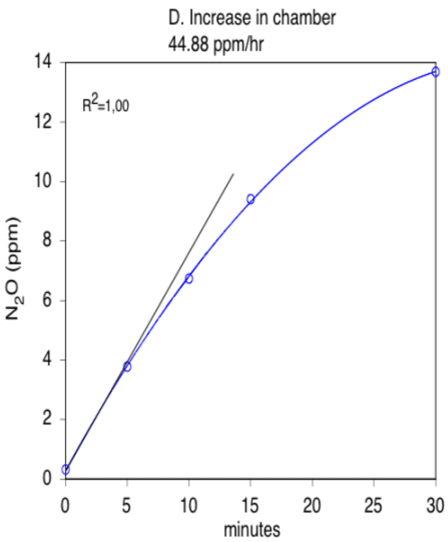

Figure 10- N_2O from Ramsjön (D)

Based on the figures 7-10, the Table 4 results were derived. Emission rates of the two chambers were a bit different in Ramsjön and the share of the total climate impact was higher for nitrous oxide in Ramsjön (Table 4) compared to Vesan(Table 3).

Table 3- Measurements in two closed Chambers (C and D) at Ramsjön.

Chambers	Carbon dioxide g $m^{-2}hr^{-1}$	Nitrous oxide g $m^{-2}hr^{-1}$	Climate forcing effect of Nitrous oxide (Emission x 298)	Nitrous oxide's share of total climate impact at the site (%)
C	0.997	0.0044	1.3112	56.8%
D	1.682	0.0144	4.2912	71.8%

Figure 11 is showing, there was a strong correlation between nitrous oxide and carbon dioxide concentration in the soil at lake Ramsjön, analyzing measurements from each meter in a 25 m transect $R^2 = 0.79$, Fig. 11). This indicates that the origin of the gases could be found in the same process.

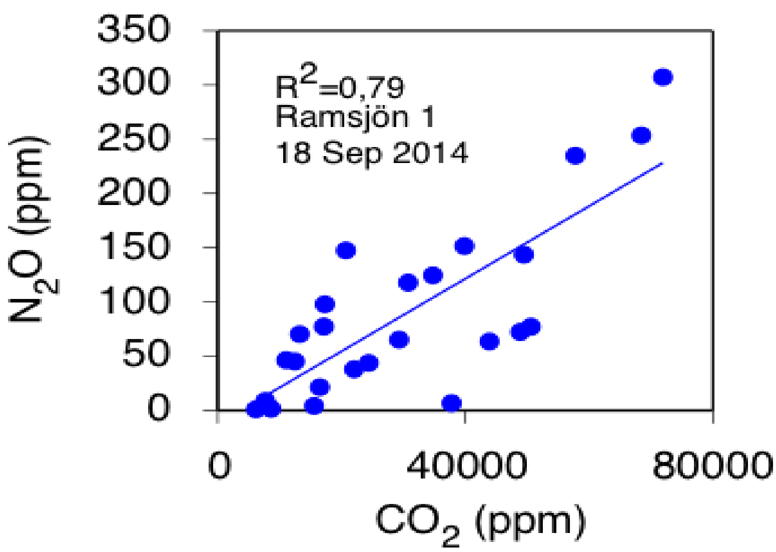

Figure 11- Covariation between nitrous oxide versus carbon dioxide at each meter in a 25 meter transect in the former lake of Ramsjön at 10 cm depth.

4. Discussion

A small change in perspective can bring wondrous changes like unique flood adaptation strategies of "Room for the river" and "Paludiculture" which are just indicating a way towards finding the acceptable balance between human and the environment. From the beginning our strategies have been only about serving us, how it is going to affect the nature was not the main concern. However, now-a-days we are realizing our activities should be beneficial for both environment and ourselves. By strengthening nature, it's only going to give us more in return. Advantages of these flood adaptation strategies in terms of nature are perfect example of this. Rewetting these areas will reduce floods, greenhouse gas emissions and will provide higher biodiversity.

Greenhouse gas emissions are controlled by several factors, such as; soil moisture content, temperature and concentration of mineral nitrogen (IPCC, 2014). Emissions of these gases are often erratic, and large bursts have been recorded after large rain events, freezing, thawing or after nutrient application. Moreover, factors like temperature; changes of season, sunlight, and fertilization also affect the data. Furthermore, one-meter distance between samples can differ significantly in terms of emission rates as dictated by concentrations in the soil probably (Figure 11).

The emission of carbon dioxide from the soil surface usually shows a strong correlation with the concentration of carbon dioxide in the superficial soil atmosphere (Fleischer, 2003 & 2010). That's why also taking samples directly from the soil should reflect the real scenario. Only two chambers were used at both of the sites and additional chambers may have resulted in less uncertain emission results. This might be especially important as the concentrations (of both CO_2 and N_2O) in the 25 m transect varied considerable at this sampling occasion (Figure 11). There is almost generally a covariation between carbon dioxide and nitrous oxide in different types of soils including drained wetland soils, including Vesan. This covariation has not been found in unfertilized forest soils (Fleischer, S.personal com). The reason for this covariation could be a common process for the emission of N_2O in soil. A possible process could be denitrification, which is known to be an important process for N_2O emission (Klemedtsson et al. 2005). In comparison with the mean annual global carbon emission, the emission of CO_2 from Vesan since it was drained was about twice as high. It was estimated that 1180000 metric tons CO_2 was lost 80 years ago (Fleischer, 2010). In this particular study, in both sites there was high loss of CO_2 to the atmosphere and there also has been a high emission of N_2O from the drained soils, which significantly added to the total climate forcing (Table 3 and 4).

The study of Yu et al. (2008) states, in different kinds of vegetations the rate of greenhouse gas emissions was almost double in the warm season compared to cold season. Data from Ramsjön were measured in the autumn season due to that it was indicating possibly higher emission rates than Vesan in the spring season. The reason behind emission rate being lower in Vesan could be that after the long winter, it takes a long time for the soil organisms to become active after the cold period. In the autumn season, the emission rate is higher because after the summer the soil organisms are active and has built a large population in the soil. This might be the reason why in Ramsjön emission rates were higher than in Vesan (Table 3 and 4). Moreover, annual temperature changes in the ground vs. air affects microbial activity of soil organisms. Microbial activity is slow until late spring and highest in late summer and in early autumn. In Vesan the highest carbon dioxide emission was measured in the middle of September (Fleischer, 2010). In a study by Hernandez et al. (2007) they show a strong influence of temperature on N_2O emissions were indicated. The effect of temperature on nitrous oxide fluxes is not always clear; but high fluxes from temperate soils during the winter and early spring have been spotted probably due to specific freeze/thaw phenomena. The large variability in N_2O emissions observed in this study also has been visible in the fieldwork. Such variability might be caused by non-uniform distribution of inorganic nitrogen within the soil (Figure 12).

In this study soil samples from the two sites were very high in organic matter, which is natural since they were both, drained wetlands/lakes (Table 2). The soil organic matter when used in agriculture gets broken down more rapidly compared to when it is not cultivated. This is why we see high emission rates of greenhouse gases from both sites. Emissions can be different in different areas depending on varying soil conditions and texture (organic soils, moraine, clay soils) and intensive agricultural areas such as the Vesan goes through annual processing and fertilization of the soil. According to Lloyd and Taylor (1994) aerobic soil microorganisms breaking down or transforming organic matter into greenhouse gas require substrate, moisture and oxygen. It indicates soil with high organic matter should have higher emission rates. In Ramsjön soil organic matter was higher than in Vesan, which could also have explained emission rate differences between two sites. Klemedtsson et al. (2005) states N_2O emissions are especially sensitive to nutrient status and fertilization. Another study (Kroon et al., 2010) shows that the use of fertilizers in agricultural fields often causes bursts of emissions during a short period after application.

Rewetting can reduce significant amount of greenhouse gases emitted. All over the world substantial number of rewetting projects are going on (Zerbe et al., 2013). Another study (Couwenberg et al., 2011) focuses on how to rewet peat-lands for reducing emission of greenhouse gases. So, rewetting should be done in land where emission rates are higher than on other types of land. Drained wetland soils that are used for agricultural practices emit a lot of greenhouse gases due to being rich in organic content. To show how alarming it can be; measuring emission rates from drained wetland soils are nothing but necessary. In a german study (Paludiculture, 2012) the possibility for decreasing greenhouse gas emission by rewetting drained peat-soils focused on CO_2 and CH_4 but not N_2O. N_2O is way more potential as greenhouse gas than CO_2 and CH_4. There are also other studies like Regina et al. (2006) that focuses only on the global emission rates of CH_4 in arable soils. Another study Koebsch et al. (2013) deals with how different vegetation can affect methane emissions but ignores the importance of N_2O. Huang et al.

(2007) shows how irrigation activities on paddy soils affect the emission rates of N_2O. In order to find the effect on N_2O soil column experiments were conducted with three irrigation regimes. The irrigation regimes are flooding, intermittent and natural drying. Natural drying had the most contribution to N_2O emissions, which supports the hypothesis of high emission rates from drained agricultural lands. On the other hand, flooding irrigation regime had the least contribution. This result clearly supports the hypothesis of how rewetting or flooding can change the scenario of N_2O emission from the agricultural fields.

While running these projects like “Room for the river” and “Paludiculture” shows that simple efforts can result in flood adaptation, decreased greenhouse gas emissions and increased biodiversity over the flood plain areas. As an example, Cyclic Floodplain Rejuvenation (CFR) is a strategy that ensures biodiversity and flood adaptation are not contradicting each other. Other facilities like refuge for endangered species of birds and new grazing areas for cattle are bonus features of these projects. Species that are especially suitable for these floodplain areas can be introduced to avoid erosion and increase biodiversity (Baptist et al. 2003). This process is applicable for Vesan, Ramsjön and probably many other wetlands used for agriculture. After rewetting the area, through this strategic planning Vesan would be able to achieve diverse biodiversity (Björk, 2010).

5. Conclusion

Our measurements show amount of N_2O and CO_2 are emitted from the soils at both sites of drained agricultural land and that N_2O shows a large contribution to the total impact. The emission rates were higher for Ramsjön compared to Vesan for both gases, which could probably be an effect of season. A strong co variation between the two gases was shown for Ramsjön and fairly strong relationship was weaker for Vesan but could anyhow indicate a common process for releasing the two gases. Both these sites could become strong candidates for rewetting and restoring wetlands, which would also have a positive influence on the greenhouse gas emission from these sites.

The idea of rewetting drained wetlands comes with a lot of positive outcomes, for dealing with climate change in Europe, sustainable flood adaptation is necessary and in order to achieve that rewetting is a great option. Ongoing projects like “room for the river” and “paludiculture” are good example of that. Projects like these can play a vital role in terms of reducing greenhouse gas emission. Furthermore, increased biodiversity and potential future tourism sites these are just added benefit that comes naturally with the rewetting process. Now, it is time to change our approach towards environment, living with the nature should be the focus rather than living against it. Rewetting agricultural land can be the very first step towards changing our perspective, which will lead us towards an innovative future with new possibilities.

6. References

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