Swedish University of Agricultural Sciences
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Relation and change over time of CN-ratios throughout Swedish peatlands and in seven fertility classes

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Master's Thesis in Environmental Science

Institutionen för mark och miljö, SLU
Examensarbeten 2012:07

Uppsala 2012

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EX0431, Independent Project in Environmental Science - Master´s thesis, 30 credits, A2E

Institutionen för mark och miljö, SLU, Examensarbeten 2012:07
Uppsala 2012

Keywords: CN-ratios, peat, peatlands, mires, Sweden

Online publication: http://stud.epsilon.slu.se

Cover: photo by Lars Lundin

Abstract

Peat covered areas makes up about one quarter of the total Swedish land area and are composed of accumulated organic material that can reach great depths. Nowadays, they are a valuable resource for man due to its many applications and functions. In Europe they are disappearing at an accelerated rate due to the increasing demands for energy, agriculture, horticulture and forestry.

The purpose of this work was to observe the CN-ratio proprieties and trends for peatlands during the last 30 years and throughout different regions of Sweden. Included were C/N values observed within a specific fertility classification to see how they correlated with the different fertility classes. For the purpose, three soil datasets (1983-87; 1993-98; 2003-08) were used.

It was observed as expected that the CN-ratios were low in the more fertile classes and high on the less fertile ones. However, there were no noticeable CN-ratio trends throughout the years. Within the different regions of Sweden the results were contradicting the expectations, since the C/N values were lower in the north than in the south of Sweden, as opposed to the N deposition values, which are much higher in the south than in the north.

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1 Introduction

Peatlands cover about one quarter (ca. 10 million hectares) of the total Swedish land area (Fredriksson et al., 1993). These peatlands are composed of accumulated organic material that can reach great depths, and are nowadays a valuable resource for man due to its many applications and functions (Rydin and Jeglum, 2006). According to Joosten and Clarke (2002), peatland areas are disappearing at an accelerated rate due to the increasing demands for energy, agriculture, horticulture and forestry. Peatlands are considered to contribute to high biodiversity and are wildlife habitats that store approximately the same amount of carbon as the atmosphere, which is a higher amount than the one contained throughout the forests in the world (Joosten and Clarke, 2002). This is why there must be an intelligent use of this resource, supported by thorough scientific investigation in a way that future generations can also benefit from.

According to Hånell (1988), there has been an increase in the use of wetlands for forestry purposes which is why he proposed a new classification system that is based on postdrainage forest productivity of peatlands and its relation to previous site vegetation.

In this thesis, using the Swedish Forest Soil Inventory database (SFSI, 2010), the fertility classes are related to soil chemical proprieties and especially CN-ratios, considered along with other indicators.

The hypotheses are that:

- The CN-ratios should be lower on the most fertile classes and vice versa;
- There should be a trend for the decreasing C/N throughout a time span (ca. 30 years), which could be explained by the increased nitrogen atmospheric deposition originated through the recent industrialization practices or from the increasing temperatures that accelerate mineralization;
- The CN-ratios should be lower in the south of Sweden due to the higher nitrogen deposition values and warmer temperatures.

2 Objectives

The main objective of this thesis is to find out if there is a change over time of the CN-ratios in Swedish peatlands. This is achieved through the utilization of the Swedish Forest Soil Inventory database (SFSI, 2010), together with a previously elaborated peatland classification system that comprehends 7 fertility classes.

The specific objectives were:

- To see if there is a relation between CN-ratios and peatland fertility classes.
- To show the geographical distribution of peatlands fertility in relation to CN-ratios.
- To find out if there is a change over time (c.a. 30 years) of the CN-ratios throughout Sweden.

3 Background

3.1 Peat and carbon

Peatlands are originated through a process where the organic matter cycle is incomplete, which results in an increased accumulation of carbon. This occurs due to the particularly wet conditions that the site is exposed to, which allow plant production to surpass decomposition. The large heat capacity of the water induces reduced temperatures, and also there's low oxygen content in peatlands due to the limited gas diffusion rates in a waterlogged environment. This results in a lower activity of the decomposition associated organisms and hence peat is accumulated. Another factor that influences the decomposition rates is the plant chemical and structural composition, which can vary according to the different plant species and its constituting parts and substances, because some are easier to decompose then others (Joosten and Clarke, 2002).

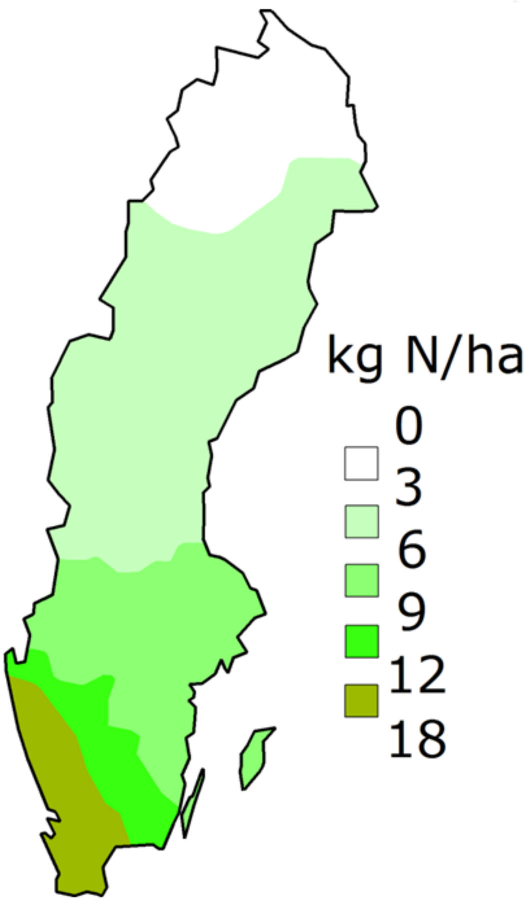
According to Heathwaite and Göttlich (1993), peat has been excavated since a long time ago, but it was only during the last century that it became a large scale practice, which happened due to its changes in land use, where mires became pastures, cultivated land, or even just a source of peat to be used as fuel or horticultural substrate.

Nowadays, and with the growing environmental conscience, peatlands are becoming of very high importance because they provide not only wildlife habitat, but they are also seen as an important freshwater resource, and as carbon storage deposits they play an important role in climate change mitigation. Since it takes such a long time for the development of peat layers, there is a necessity to do a better and sustainable use of it so future generations can also take advantage of its benefits and functions (Joosten and Clarke, 2002).

3.2 Nitrogen deposition in Sweden

Nitrogen from atmospheric deposition is a relevant nutrient input for the earth´s ecosystems. After the Second World War period there have been strong trends for economic growth, and the emissions of nitrogen have been increasing in pair with the usage of fossil fuels (Bertills and Näsholm, 2000).

The deposition of nitrogen in Sweden has a wide variation between the southern and northernmost regions. In southwest Sweden the deposition values can achieve around 15 kg N ha^{-1} yr^{-1}. Lower values are found in the north and east parts of the country. The high deposition values occur due to the local and long-range influence of the nitrogen emissions that come mostly from the transport sector and cultivated land. In the north the deposition occurs near the hemispheric background and has a much lower value of about 2 kg N ha^{-1} yr^{-1} (Akselsson et al, 2010).



Figur 1. Nitrogen deposition throughout Sweden (Fröberg et al., 2012).

3.3 Swedish Climate

There is a wide climate variation in Sweden as a result of its latitudinal extension. In general, Sweden has precipitation values in the range between 600 and 900 mm per year, although there are some locations where these values can be quite higher such as on the west coast inlands, where it can reach up to 1300 mm, and also in the northwestern mountains where it sometimes reaches 2000 mm. As for the temperatures, in the north the annual mean is around 0 °C, whereas in the southern region it is about 8 °C (Raab and Vedin, 1995).

3.4 CN-ratios

The CN-ratios have a certain importance because they can give us useful information about the nutrient content, and quality of the humified organic matter in the soil. Also, the CN-ratios should be able to give us information about the state of decomposition of the organic matter, since according to Heathwaite and Göttlich (1993), there is a correlation between CN-ratios and the humification degree, whereas a low CN-ratio is usually equivalent to a high humification degree, and vice versa.

Another factor that can contribute to the reduction of the CN-ratios is also the nitrogen atmospheric deposition that occurs due to the industrial pollution (Rydin and Jeglum, 2006), which is much more intense in the southern regions of Sweden (see section 3.2).

In the top of the peat soil, it is also frequent to find very high C/N values, and this happens due to the litterfall that occurs from plants and trees, since they take up the nitrogen from their leaves during the wilting process. Then in the soil the reverse process begins, because organisms will slowly consume the carbon and recirculate the nitrogen, and thus resulting in a gradual reduction of the C/N values (Rydin and Jeglum, 2006). In the northern regions and due to its colder temperatures, the decomposition activity should be even lower since the organisms should have a reduced activity, which should further inhibit the reduction of the CN-ratios.

3.5 pH

The accumulation of peat usually results in an increase of the acidity, which is the consequence of the constant addition in organic matter content, and also due to the abundance of Sphagnum peat, which produces protons and thus further reducing it´s pH levels. The soil reaction is also related with the peat electrical conductivity, Ca content and base richness, which is why it is a good site indicator. Bogs, as ombrotrophic mires (water supply from precipitation), are usually characterized by low pH values and poor site conditions, whereas in fens, which are minerotrophic (water supply also comes from the surrounding mineral soil), while pH is usually higher, it can also vary on a much wider range (Rydin and Jeglum, 2006). According to the fertility classifications used in this thesis, the pH values should then be higher in the most fertile classes as opposed to the poorest ones.

3.6 Humification

The humification degree gives an approximate idea of how decomposed the peat is. With a low humification degree, the plant material is still in a shape similar to its original aspect, which correlates with a high fiber content in the organic material, whereas a high degree means that the organic material should already be in an advanced state of decomposition which has low fiber content (Rydin and Jeglum, 2006).

There are a wide number of factors that affect the rate of decomposition and may also interact among themselves, such as temperature, moisture, oxygen content, plant material composition, and quantity and combination of organisms in the peat. In mires, there is a positive balance of organic matter, which is mostly the result of low decomposition rates due to the anoxic conditions that induce a low microorganism activity, hence, drainage of the site will result in a faster mineralization of the organic material and thus increasing the inorganic nitrogen production and the release of stored base cations (Heathwaite and Göttlich, 1993).

4 Materials and methods

4.1 Fertility Classes

The fertility classification that is used in this work, is an adaptation between the classification used by the Swedish National Forest Inventory (SE NFI, 2012), which comprehends 16 fertility classes that were elaborated with the purpose of classifying mineral soils. There is also Hånell´s fertility classification, which comprehends 8 fertility classes that were elaborated through a process of evaluating post-drainage forest productivity of peatlands in Sweden (Hånell, 1988). To be able to use the NFI classification, there had to be a compilation of classes to reasonably harmonise with the Hånell classification. The outcome, which was also the work of a different report developed by Hånell (2009), is a classification that comprehends 7 fertility classes, and that was achieved by reallocating some of the vegetation species groups that characterize each of the fertility classes.

4.1.1 Swedish National Forest Inventory classification (Anon., 2012)

01 – Tall herbs without shrubs
02 – Tall herbs with shrubs/blueberry
03 – Tall herbs with shrubs/lingonberry
04 – Low herbs without shrubs
05 – Low herbs with shrubs/blueberry
06 – Low herbs with shrubs/lingonberry
07 – Without field layer (no plants, just mosses)
08 – Broad grasses
09 – Narrow grasses
10 – Tall carex

11 – Low carex
12 – Horsetail
13 – Blueberry
14 – Lingonberry
15 – Crowberry/calluna
16 – Poor shrubs

4.1.2 Adapted classification by Hånell (2009)

1 – Tall herb type (01, 02, 03)
2 – Low herb type (04, 05, 06, 07, 08, 09)
3 – Blueberry-horsetail type (12, 13)
4 – Tall sedge type (10)
5 – Dwarf shrub type (14, 16)
6 – Low sedge type (11)
7 – Marsh andromeda-cranberry type (15)

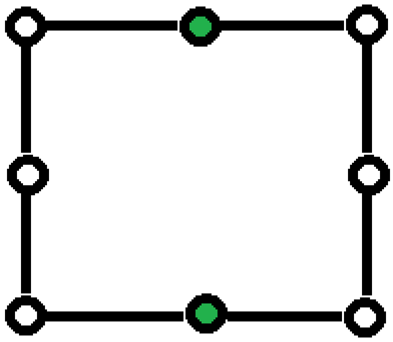
As it is shown, each of the classes was put together by reallocating the respective different species groups from the mineral soil classification, throughout the 7 fertility classes. However, in this work a species group (16) was moved from class 5 to 7 in order to balance the fertility classes. The intent was only to move 2 out of the 4 species, but since they were already grouped together in the Swedish National Forest Inventory classification it was not possible to separate them.

4.2 Swedish Forest Soil Inventory database (SFSI, 2010)

The Swedish Forest Soil Inventory comprehends a large amount of permanent sample plots that are scattered throughout almost the entire country, out of which long term monitoring is carried out year after year and thus providing a good statistical representation of Sweden. This inventory includes a general site characterization and several soil measures regarding each different plot and its location, and then some of the variables that were measured were used as indicators in the assessment presented for this thesis. The inventories are carried out in 5 or 10 year periods and the ones used in this investigation are 1983-87, 1993-98 and 2003-08. In the trend analysis the same reinvented plots were compared.

4.2.1 Plot delimitation

In the Swedish Forest Soil Inventory (SFSI, 2010) the plot delimitation is carried out for each tract according to the figure bellow, whereas the samples are taken from the mid-top and mid-bottom circles.



Figur 2. Sampling plots (green) from each tract.

4.3 Variables used

4.3.1 Soil indicators

Some of the main indicators that are used within this work which were provided by the Swedish Forest Soil Inventory database (SFSI, 2010) are:

- The CN-ratios, which were simply calculated from the separate C and N values that were measured on material from peat soil layers of 0-30 and 30-50 cm depth, respectively;
- The pH, which was also measured in these layers;
- And the humification degree, which comprehends classes 1 through 5, where 1 stands for the lowest humification degree, and 5 is the highest, and these were measured in the same layers. The five classes was a grouping of the ten original classes on humification degree (von Post and Granlund, 1926)

For the purpose of simplification, from now on the peat soil layers of 0-30 and 30-50 cm depth will be designated as peat 3 and peat 5 respectively.

4.3.2 Regions

For the purpose of this work, Sweden was divided into 3 regions due to its climate differences, such as temperature and precipitation, and also deposition conditions and physical geography. These regions constitute the southwest, southeast and north part of Sweden (Fig. 3). Whereas region one is the north (BD, AC, Z, Y, X), region two is southeast (H, I, E, D, AB, C, U, T, W), and region three is southwest (S, O, F, G, K, M, N). The letters used relate to the common designation of the Swedish counties.

Figur 3. Swedish map and its counties divided in 3 regions (Wikipedia, 2012)

4.3.3 Land use

It is important to mention that the peatland areas covered in this thesis can be either mires or forest productive land. And the difference between these two is the productive forest land area has forest productivity over 1 m^3 fo ha^{-1} $year^{-1}$ being the total volume over bark. When the productivity is lower they are then considered mires, which barely have any trees.

4.4 Procedure

In order to analyze the CN-ratio trends over the different peatland fertility classes and throughout Sweden, a data analysis was carried out. This was achieved through the use of the Swedish Forest Soil Inventory database (SFSI, 2010) together with a data analysis tool.

For the purpose, the data was related to 3 periods (1983-87; 1993-98; 2003-08), and to study the relation between the CN-ratios and the fertility classes together with its geographical distribution, only the data from the last period was used (2003-08) since there were more samples for the assessment. To study the CN-ratio trends throughout Sweden and over time (c.a. 30 years), the data from all 3 periods were obviously used.

5 Results and Discussion

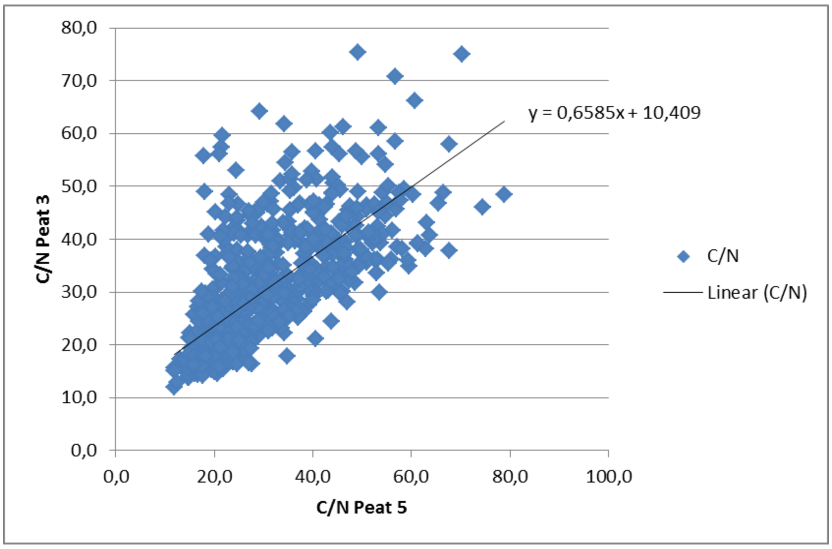
5.1 Period 3 analysis (2003-2008)

5.1.1 Depth difference

According to a paired t-test, the CN-ratios were not significantly different ($P > 0,05$) between peat 3 and peat 5 (Table 1), which was the reason why from here on, the work was based on the measures collected from peat 3. And this preference was also due to the fact that there was more availiable data for peat 3, since the deeper samples (peat 5) only started to be gathered much later.

	Peat 3	Peat 5
Mean	30,0	29,7
Median	27,7	25,8
Confidence interval (95 %)	0,83	0,89

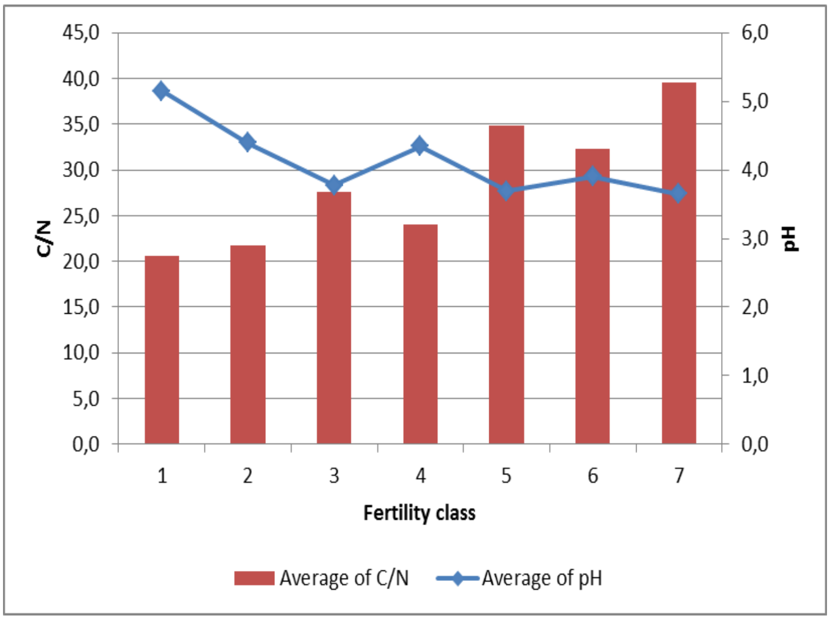
Tabell 1. Mean, median and Confidence intervals (95 %) for both peat 3 and peat 5 datasets.



Figur 4. Comparison of CN-ratios between peat 3 and peat 5.

Although the measures were not significantly different when comparing CN-ratios between peat 3 and 5, it seemed that with the higher CN-ratios there was a wider variation between the two depths (Fig. 4).

5.1.2 Fertility classes

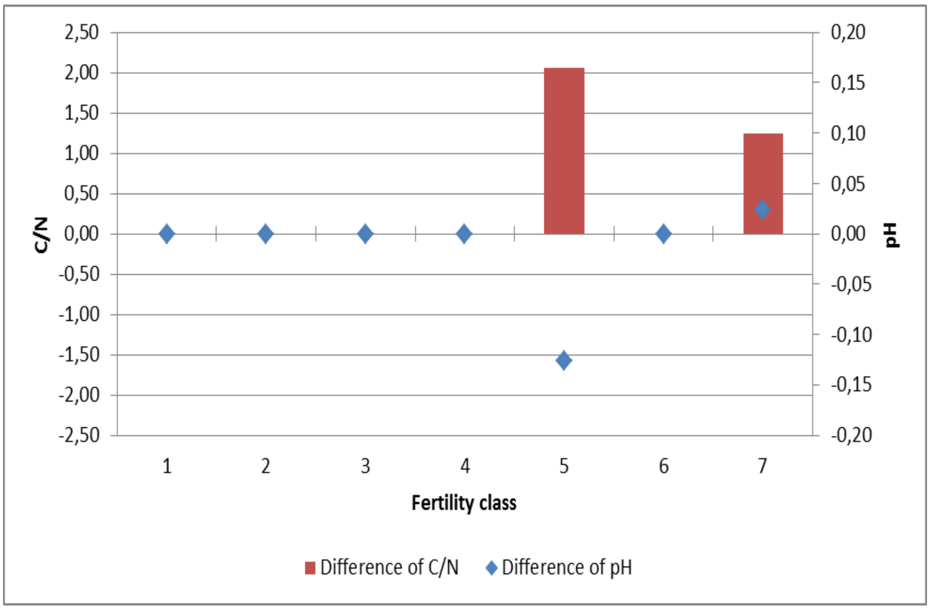


Figur 5. C/N and pH per fertility class according to the original fertility classification.

There was a relation between pH and CN-ratios on each of the different fertility classes, based on site vegetation (Fig. 5). As it was expected, the CN-ratios were lower on the more fertile classes and higher on the poor ones, from which it was considered that the CN-ratios might be a good site fertility indicator.

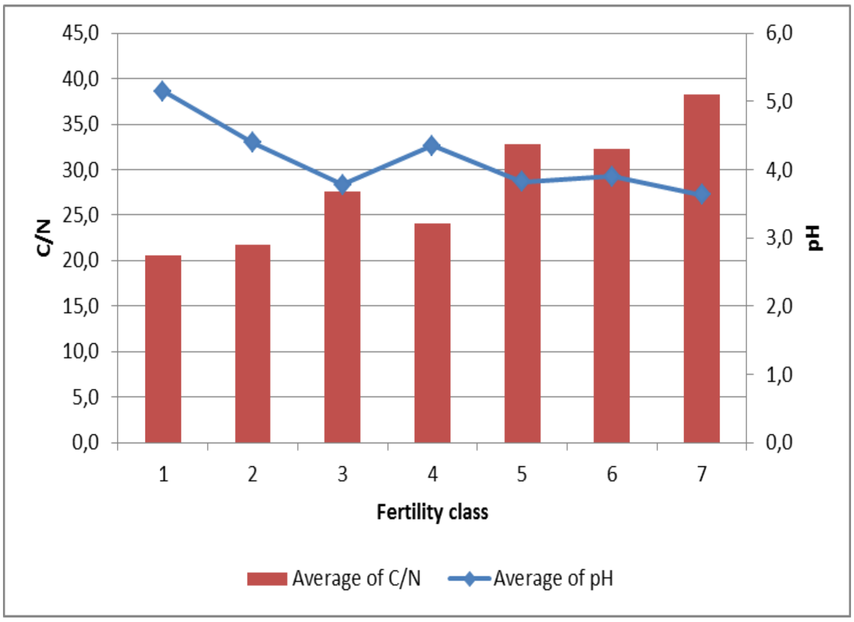
Even though there was a correlation between the CN-ratios and the fertility classes, there were still some irregularities that could be observed, such as fertility class 5 CN-ratios, which were too high if we would compare them with classes 4 and 6. And this is the reason there were some changes made on these fertility classes, where four species groups have been moved from fertility class 5 to 7.

Another relevant observation could be made regarding the pH values, which clearly had an opposite relation with the CN-ratios, since low C/N meant high pH values and vice versa.



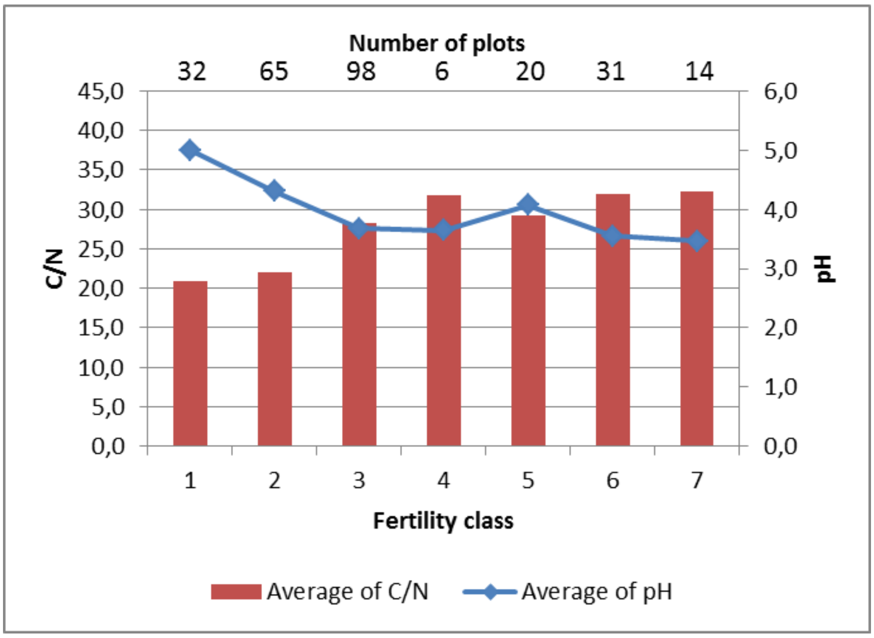
Figur 6. Difference between the original and new classification.

Due to the changes on class 5, from which were taken plots designated by 4 plant species (Vaccinium uliginosum, Ledum palustre, Andromeda polifolia and Vaccinium oxycoccos) and then moved to class 7, there was a slight reduction in the CN-ratios regarding class 5 (Fig. 6).

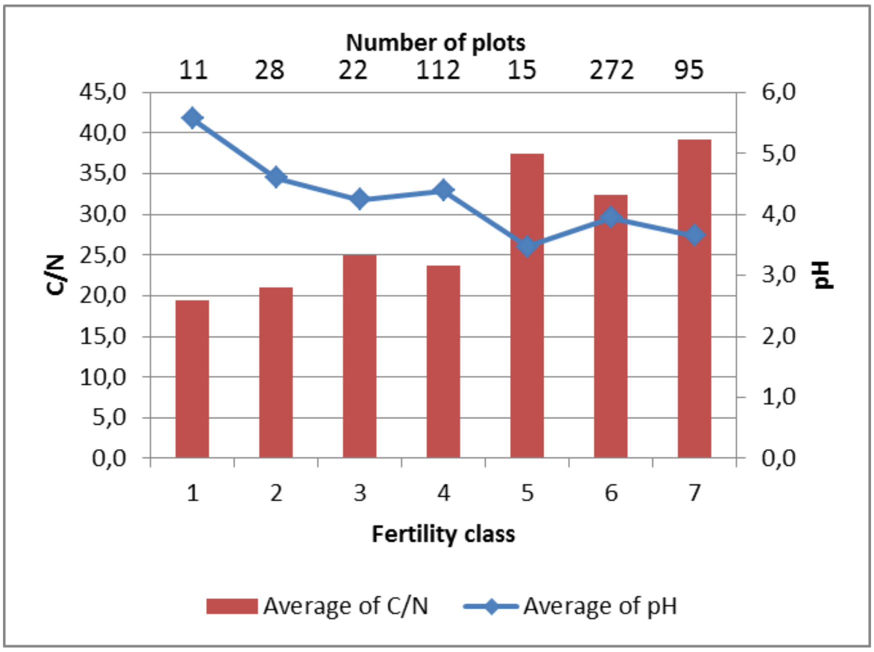


Figur 7. C/N and pH per fertility classes according to the new classification.

Regarding the preceded alterations, fertility class 5 did then present itself more balanced when compared to its adjacent classes (Fig. 7), which is why from here on in this thesis the new fertility classification was used. However, these were very small changes because the ideal would be to move only the plots designated by the most fertile 2 (Vaccinium uliginosum and Ledum palustre) out of the 4 species. This was not possible since all 4 species belonged to species group 16 of the mineral classification (see section 4.1), hence it was only possible to move them all together.



Figur 8. C/N, pH and number of plots per fertility class regarding productive forest land.



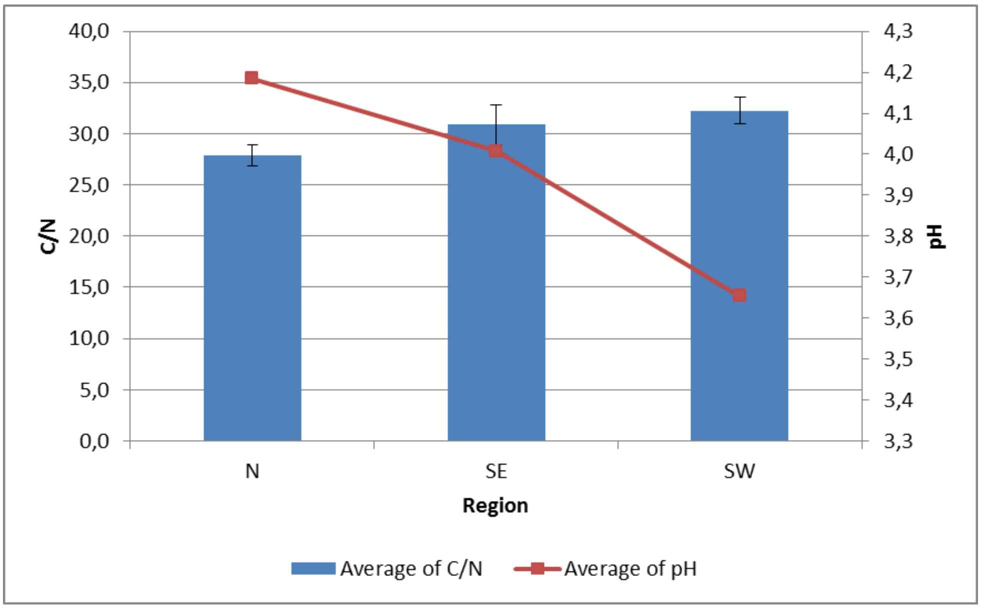
Figur 9. C/N, pH and number of plots per fertility class regarding mires.

Since it was expected a different behavior between productive forest land and mires, the data was then split into these two categories in order to observe the differences. And to help in this analysis, the numbers of plots per fertility class were added on top of the respective charts (Fig. 8 and Fig. 9).

It was noticeable here that the productive forest land took up the most fertile classes (1, 2 and 3) while the mires were mostly located in the poorest ones (4, 6 and 7). One explanation for these differences to occur could be that, when drainage practices are used on mires, it is obvious that there will be an increase in the rate at which mineralization occurs, since the fluctuations of the water table will allow the oxygen to accelerate decomposition (Heathwaite and Göttlich, 1993) and thus providing better conditions for tree growth, such as increased nutrient uptake and oxygen availability for the roots. These differences mainly occur in fertility class 4 (tall sedge type), which is almost only represented by mires, and it is possible that these class 4 sites, when drained, are turning into class 3 (blueberry-horsetail type) together with a forest productivity increase. It is also so, that the foresters understand that the yield outcome will be better with higher fertility, so the rich classes have attracted most interest for drainage. However, with nature conservation considerations, these classes now attract the highest protection. Earlier (ca. 100 years ago), nature conservation was not such a high priority as currently, which is why we now face a situation with so many rich sites drained.

Another observation to take notice is that fertility class 6 has much more plots then all of the other classes, but this is due to the fact that this is the most common mire type in Sweden.

5.1.3 Regions

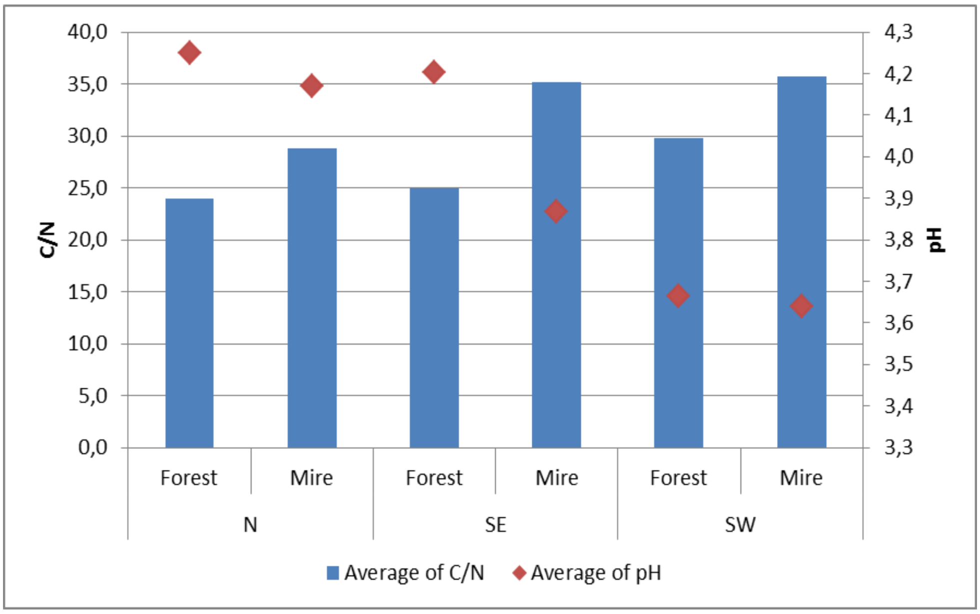


Figur 10. C/N and pH per region with confidence intervals (95 %) on CN-ratios.

Due to the different climate and nitrogen deposition trends throughout Sweden, it was also necessary to split the data on the three different regions in order to observe the geographical differences in the CN-ratios.

Unlike it was expected, the CN-ratios were much lower in the northern region, followed by the southeast, and the highest CN-ratios were then associated with the southwestern region. These results were a bit unexpected since they show the exact opposite of the nitrogen deposition trends in the different parts of Sweden, which are around 2 kg N ha^{-1} yr^{-1} for the north, and achieving its maximum values of about 15 kg N ha^{-1} yr^{-1} in the southwestern region (Akselsson et al, 2010).

One possible explanation for this could be that, according to Hyvönen et al. (2007) and Berg and Matzner (1997), there is evidence regarding different effects of N deposition on decomposition, whereas low N deposition values can increase decomposition rates, and the opposite happens for high values of N deposition, which can actually mitigate decomposition. This could help to understand the high CN-ratios in the south when compared to the north, since there is such a big difference in the N deposition values, which are very low in the north and could be accelerating the decomposition process. On the other hand, decomposition in the south should be restricted since N deposition can achieve very high values.

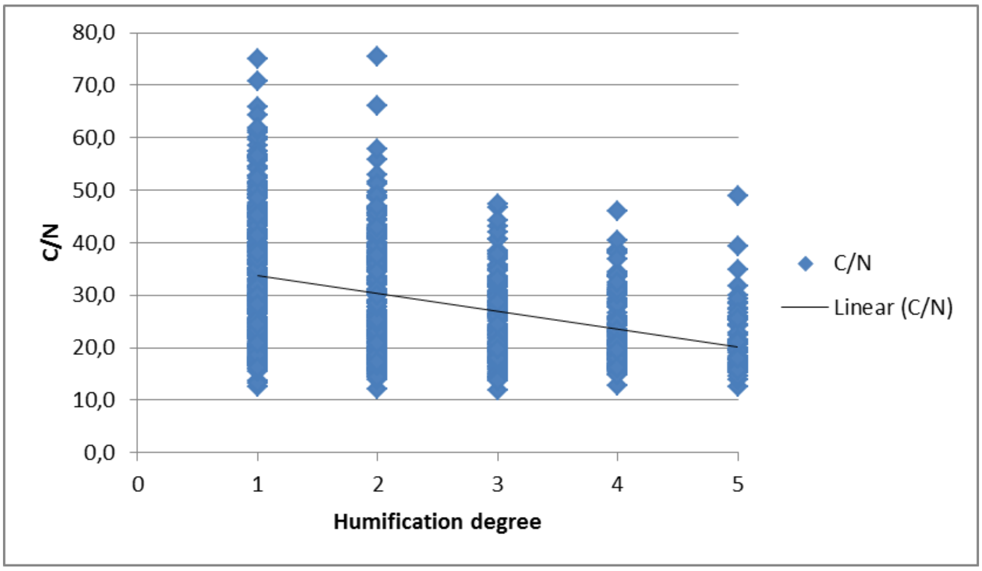


Figur 11. C/N and pH per region and land use.

There was a noticeable difference in the CN-ratios between the productive forest land and the mires within the different regions (Fig. 11), whereas the productive forest land presented lower CN-ratios in all of them. Like it was pointed out before, this could be explained due to the fact that trees require more fertile land to grow than the usually short peatland vegetation, hence the lower CN-ratio values.

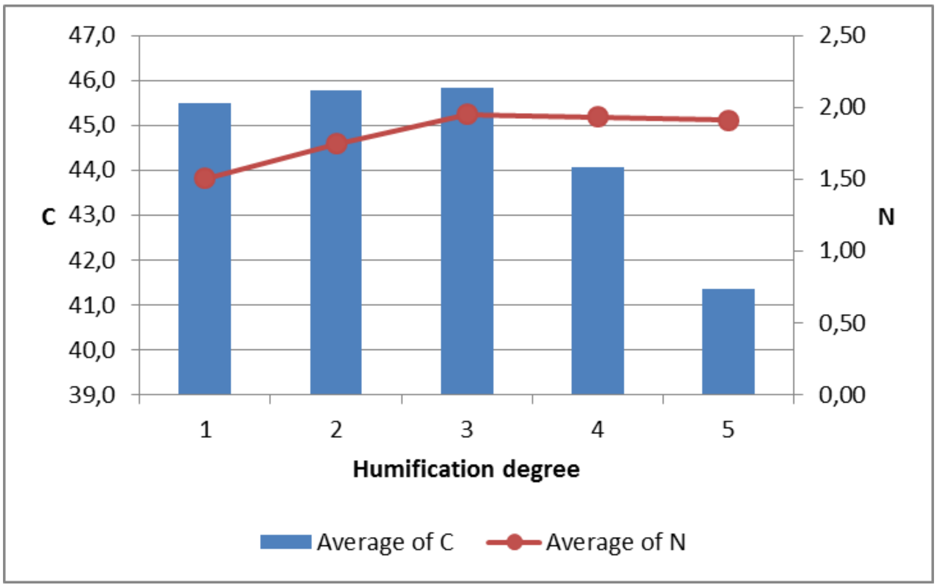
Also, the difference between the SE and SW seemed to be mostly on productive forest land, because the mire C/N values were very similar even though there were small changes in the soil reaction. The fact is that there is a relatively high occurrence of bogs with forested marginal slopes in the SW region, which could explain resulting higher CN-ratios.

5.1.4 Humification degree



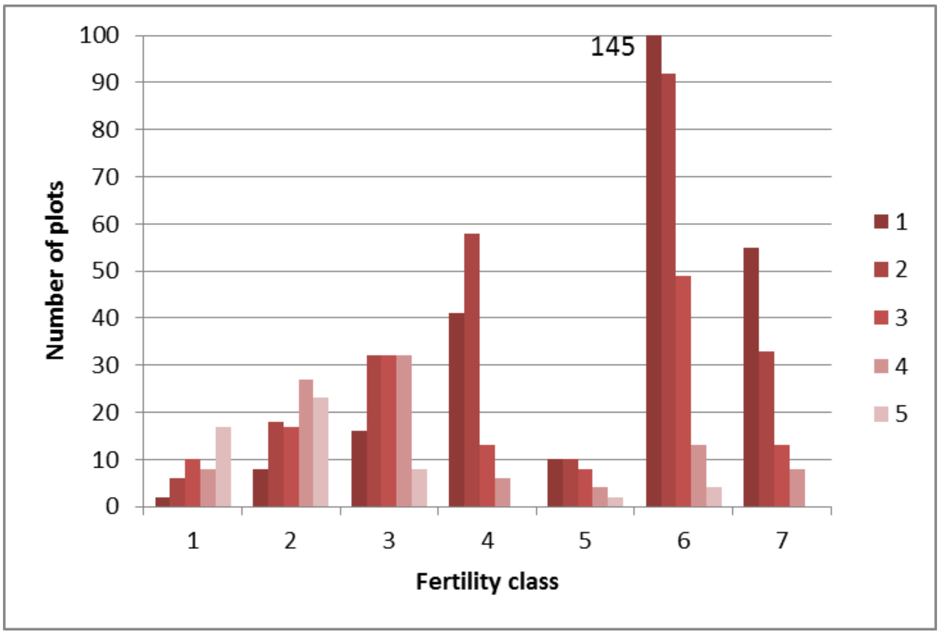
Figur 12. CN-ratios and humification degree.

Since decomposition is a key factor in peatlands, it was also important to observe if there was a relation between the CN-ratios and the humification degree. As expected according to Heathwaite and Göttlich (1993), it could be seen that there was a clear relation between both indicators, whereas the highest CN-ratios corresponded to a low humification degree and vice versa (Fig. 12).



Figur 13. C, N and humification degree.

It could also be observed (Fig. 13) that the reduction of the CN-ratios from humification degree 1 to 5, happened due to an increase in the nitrogen values on the least humified sites (1, 2 and 3), but the reason CN-ratios kept decreasing on the most humified sites (4 and 5) was due to a decrease in the carbon values, since the nitrogen barely changed.

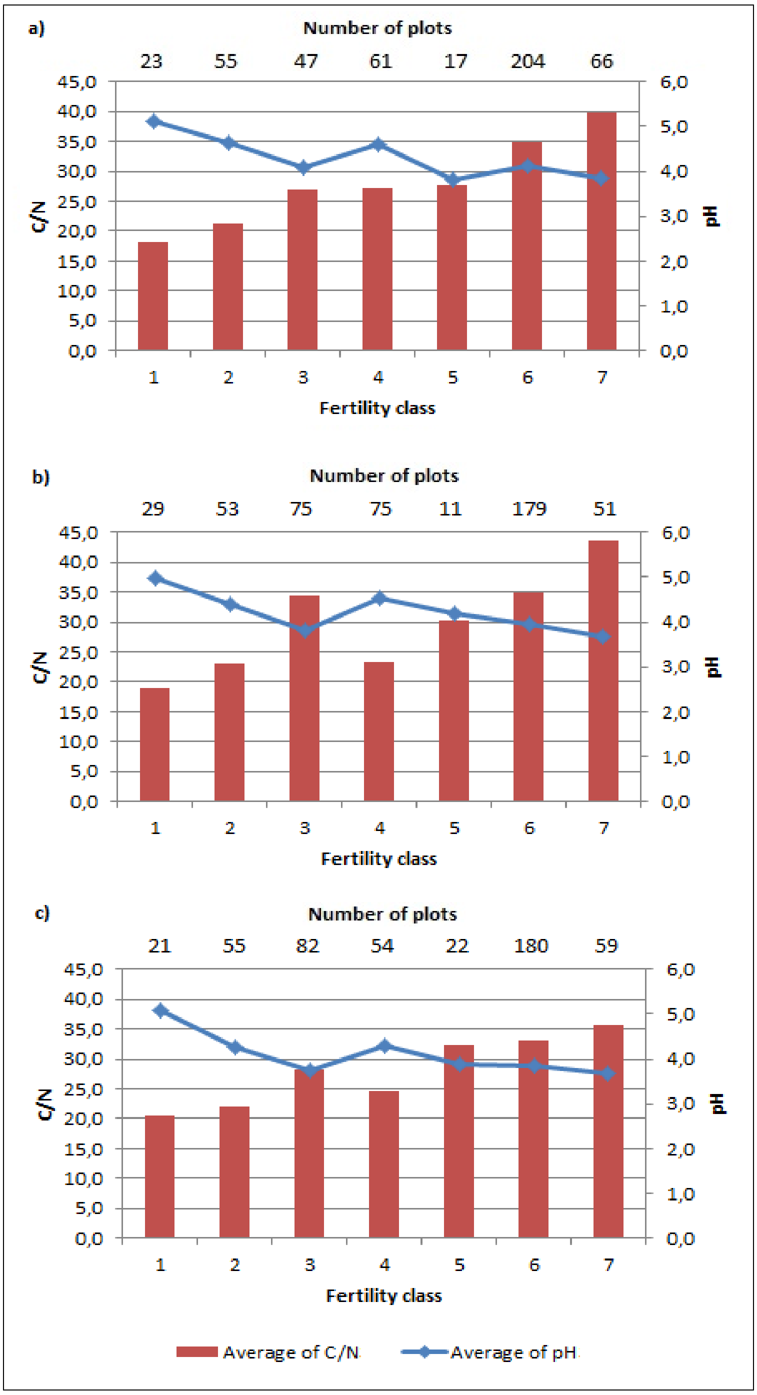


Figur 14. Humification degree per fertility class.

The humification degree was then associated with the fertility classes (Fig. 14), and it became easy to understand that the richest classes (1, 2 and 3) held the largest number of plots with a high humification degree, as opposed to the poorest ones (4, 5, 6 and 7), which mostly presented a large number of plots with low humification degree. Once again this could be associated with the drainage practices, since the most fertile classes were productive forest land where ditching is common, and thus accelerating the humification process.

5.2 Trend analysis over three periods

5.2.1 Fertility classes

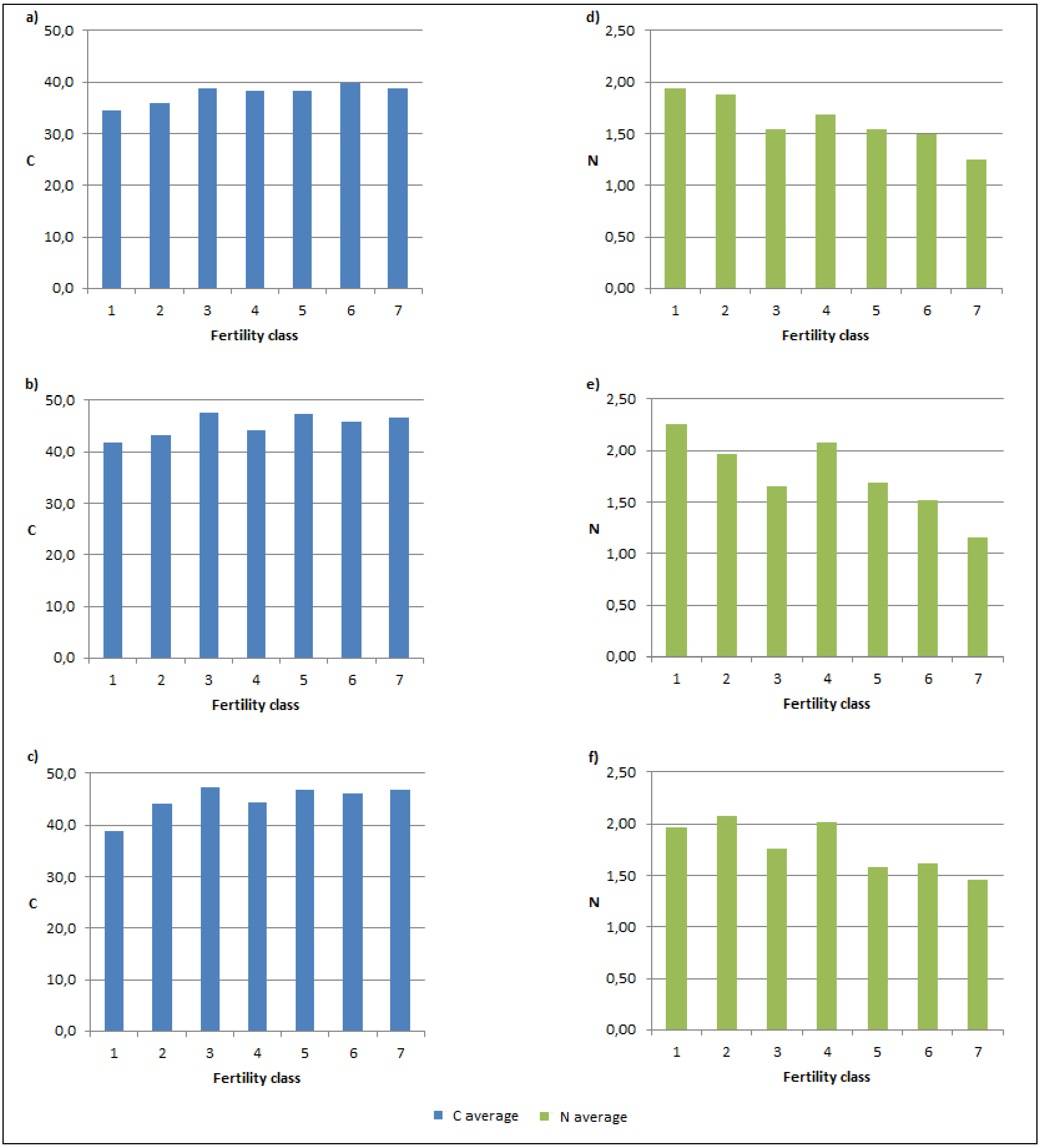


Figur 15. C/N and pH per fertility class in: (a) period 1; (b) period 2; (c) period 3.

In the analysis of all 3 periods (1983-87; 1993-98; 2003-08), the CN-ratios were compared in order to show if there were any important trends. For the purpose, fertility classes were partly still used so it could be seen if there were also any particular trends regarding the range from rich to poor sites.

The C/N values from each different period and regarding the different classes were also a bit unexpected (Fig. 15), because the nitrogen deposition values have been increasing over time due to industrial and traffic pollution (Bertills and Näsholm, 2000) and this should have led to a reduction of the CN-ratios. Instead, the C/N values oscillated between the 3 periods, which could be seen in some fertility classes where the CN-ratios increased from period 1 to period 2 but decreased again in period 3. Therefore, there were no signs of an overall decrease in the ratios which might not have happened due to the insufficient duration of the periods, because even though it is a total of about 30 years, changes take time to occur in peatlands, where the lack of oxygen slows down the soil processes. Also, as mentioned before the influence of N deposition on organic matter decomposition can be contradictory, since high levels of N deposition can inhibit decomposition (Hyvönen et al., 2007; Berg and Matzner, 1997). Hence, the several factors working in different ways, such as increased temperatures over time accelerating decomposition and high N deposition values reducing it, could explain the reason for the oscillating CN-ratios without any specific trends.

5.2.2 Carbon and nitrogen



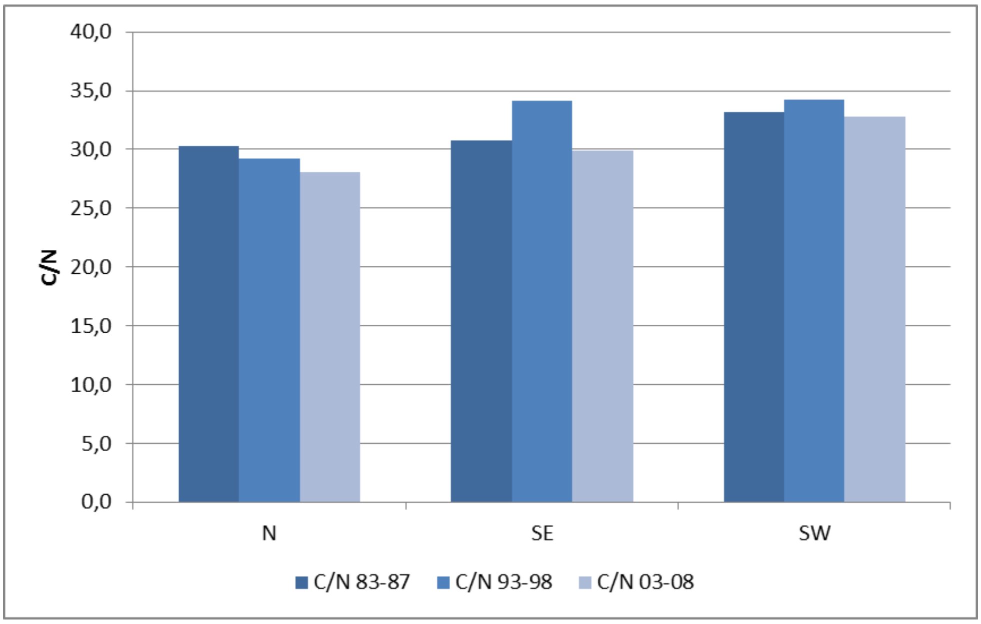
Figur 16. Carbon in periods 1 (a), 2 (b) and 3 (c); and nitrogen in periods 1 (d), 2 (e) and 3 (f) for the seven fertility classes.

After all the analysis with the CN-ratios, it was also important to separate the carbon from the nitrogen and see how their independent behavior was (Fig. 16), since the fluctuations in the C/N could be explained from either separate or both of the indicators together.

Overall, in each of the different periods carbon had more or less the same values with the exception of the two most fertile classes, which presented slightly lower values. However, carbon values from period 1 were lower than in period 2 and 3, which most likely happened due to differences in the way sampling and measurements were taken. In the first period, the chemical analysis was made with a wet analysis method, however, in periods 2 and 3 the dry combustion method was used, which has been found to result in higher carbon values.

As for the nitrogen values, as it was expected, they were high in the most fertile classes while gradually reducing towards the poor ones. These results led to believe that most of the variations in CN-ratios were caused by changes in the nitrogen values, since there didn’t seem to be many changes regarding carbon content in the peat.

5.2.3 Regions



Figur 17. C/N trends in all 3 periods and regions.

To better understand the trends over time throughout the different regions of Sweden, the work was assessed without splitting the data among the fertility classes.

In the southeast and southwestern region, instead of a trend there was an increase of the CN-ratios in period 2 (Fig. 17), but these values decreased again in period 3, in which there were similar CN-ratios obtained as for period 1. However, in the north of Sweden there was a gradual decrease in the CN-ratios throughout the 3 periods, which was the expected to happen in all 3 periods. Instead, only in the north where the least N deposition occurs (Akselsson et al, 2010) there seemed to be a trend.

According to previous explanations, the reasons that possibly caused this to happen were the fact that the low N deposition values might actually increase the decomposition process. On the other hand, another cause for these reductions in the CN-values could be the warming temperatures, but this factor should also have influenced the southern regions so it doesn´t really explain the C/N differences throughout Sweden.

6 Conclusion

- As it was expected, the CN-ratios were lower on the more fertile classes and higher on the poor ones (as opposed to the pH), from which it was considered that the CN-ratios were a good site fertility indicator and correlated accordingly with the fertility classification.

- It was observed that many of the richest mires have been drained and now have high forest productivity. Also, the richest mires have a much higher humification degree.

- The CN-ratios were much lower in the north than in the south of Sweden, which contradicted the N deposition values that are much lower in the north than in the south. This was explained due to the fact that high N deposition values can have a mitigating effect on decomposition.

- There were no signs of CN-ratio trends throughout the three different periods, which was also possibly explained due to the mitigating effects of high N deposition on decomposition. Or perhaps the timespan was not enough for trends to take place since all processes are very slow in peat soil due to its anaerobic conditions.

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Acknowledgement

I would like to thank my supervisor, Lars Lundin, for giving me the opportunity to work on this project, and also for his availability and constructive criticism during the time being.

I would like to thank Ola Löfgren, for all the help working with the database. Also my thanks to my co-supervisor Johan Stendahl for his help when I needed.

Thanks to Maria Helena Almeida and Paula Malveiro at Instituto Superior de Agronomia back in Portugal, for making it possible for me to come to Sweden work on my project.

Last but not least, thanks a lot to all my family and friends here and back at home for all the support and good times!