Horizontal distribution of organic matter, nitrogen and sulfur in the sediments of an eutrophic lake; Årungen, Norway.

Horisontal fordeling av organisk materiale, nitrogen og svovel i sedimentene til en eutrof innsjø; Årungen, Norge.

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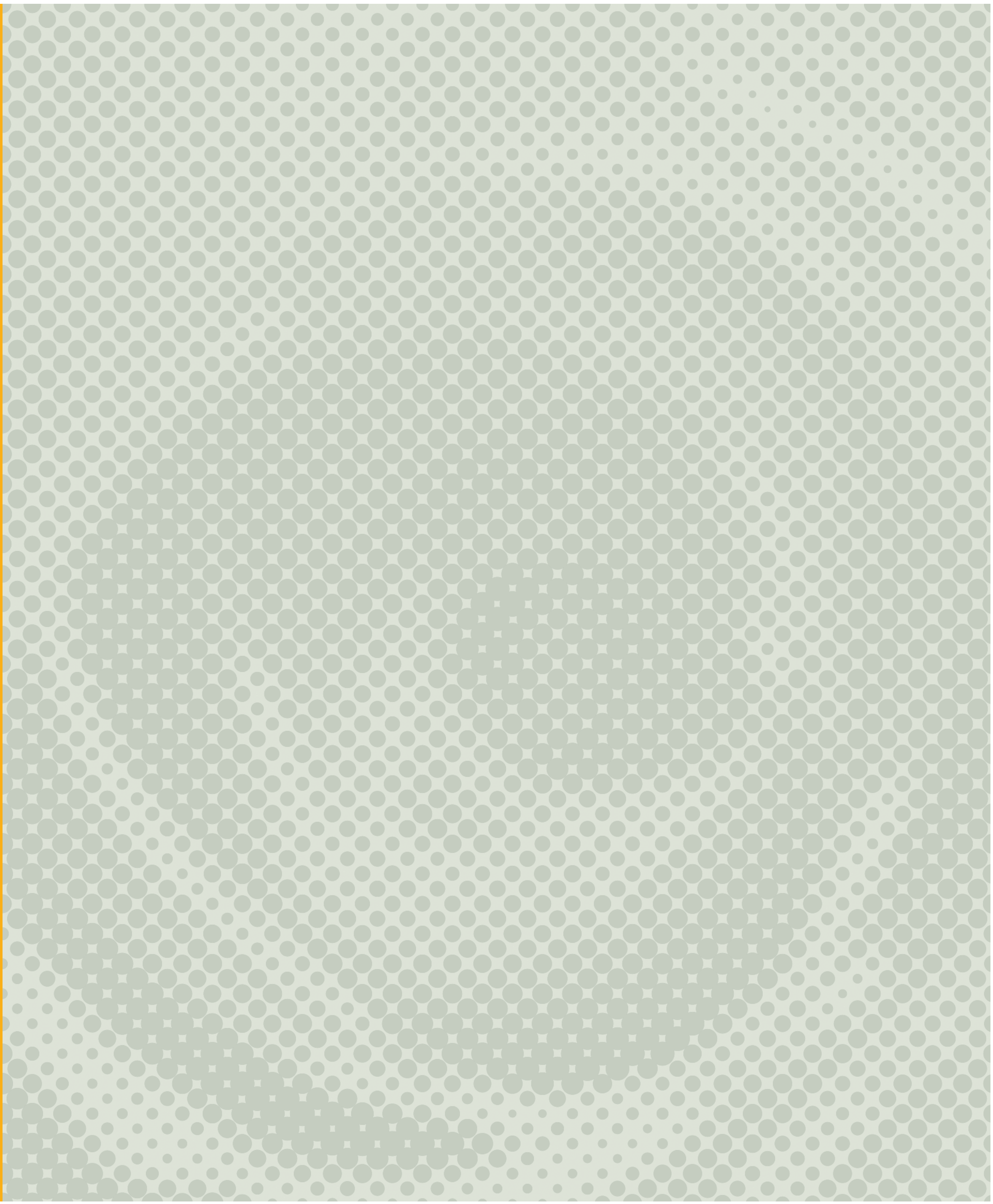
Master Thesis 30 credits 2010



Preface

This master thesis is associated with the project "Water area Bunnefjorden with the Årungen and Gjersjøen water courses" (PURA), an inter-municipal organization whose main goal is to secure and improve the water quality of the reservoirs, rivers, lakes, and fjords in the area.

I want to thank the group of advisors: Gunnhild Riise and Tore Krogstad (main advisors), Inggard A. Blakar, Ståle Haaland, and Alexandra T. Romarheim. Thank you for good discussions and valuable comments during this semester. Johnny Kristiansen has been a great resource during field-work and in the laboratory. Irene Eriksen Dahl has also been very helpful at the laboratory.

I want to thank in particular the other students on the sediment-project for interesting discussions, the exchange of knowledge and cooperation. In addition, a lot of the data here have been provided because these people have spent a lot of time in the laboratory. Sara Brækhus Zambon and Torgeir Reierstad have done the preparation to tot-S and tot-P analyses. Johnson Rutsinda has done the grain size distribution analyses.

Ski and Frogn municipalities have been helpful with providing layers to use in GIS. Vegard Lien and Nadja Thieme have been helpful with difficulties with ArcVIEW.

I want to thank my best friend, Hilde, for sharing her experience in writing a master thesis with me, proof-reading, and for good memories both in Trondheim and here at Ås. Astrid, Gina and Ragnhild, thank you for proof-reading, mental support, and good laughs during this process of writing the master thesis. And last, but not least, all the other students at the study-room at INA for making this an unforgettable semester.

Ås, 18.15.2010

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Abstract

The sediments are an important part of the total lake system that is traditionally underestimated in water management. Knowledge about the lake sediments can give important information on processes in the lake, and the distribution of substances in time and space. Most sediment studies focus on vertical distribution of parameters in the sediments, to reveal historical development in the lake, or to compare between lakes. The complexity of sediment processes arise a need for research on horizontal distribution in the lake. The horizontal distribution of organic matter, tot-N (nitrogen) and tot-S (sulfur) in the sediments in Lake Årungen has thus been mapped in this study. The stochiometry and relation to sediment characteristics have also been investigated.

There has been a decrease in the content of all parameters in the last 30 years. From historical distribution in the sediments, it seems like the content of the sediments today is similar to the content back in the 1950s and 1960s. In other words, this could indicate that the supplies have decreased significantly.

All parameters showed more variation in the littoral zone than in the rest of the lake. Based on C:S ratio, it seems to have been more anoxic episodes in the profundal. Organic matter seems to be a good predictor for tot-N, however does not explain the tot-S content quite as much. The clay content does not explain the distribution of any of the parameters.

This study is one of four on the sediments of Lake Årungen. The findings of these four studies will give a good basis for further research on the sediment processes in Lake Årungen. Hopefully, these studies will enhance the understanding of important lake processes, and improve the management of lakes.

Sammendrag

Sedimentene er en viktig del av det totale innsjøsystemet. De er imidlertid tradisjonelt sett undervurdert i forvaltning av vannressurser. Kunnskap om innsjøsedimentene kan gi viktig informasjon om prosesser i innsjøen, og om fordelingen av stoffer i tid og rom. De fleste sedimentstudier som er gjort fokuserer på vertikal fordeling i sedimentet eller sammenligner en eller noen få kjerner mellom innsjøer. Det er imidlertid viktig å kjenne den horisontale fordelingen i innsjøen fordi sedimentprosessene er så komplekse. Den horisontale fordelingen av organisk materiale, nitrogen (tot-N) og svovel (tot-S) i sedimenter i innsjøen Årungen i Akershus, har derfor blitt kartlagt i denne studien. I tillegg har støkiometriske forhold og betydningen av sedimentegenskaper for fordelingen av næringsstoffer blitt undersøkt.

Det ble funnet en nedgang i innholdet av alle undersøkte parametre i løpet av de siste 30 år. Sammenlignet med den historiske utviklingen i Årungen kan dette tilsvare tilstanden på 1950 og -60 tallet. Med andre ord kan det tyde på at det har vært en tilbakegang i tilførslene fra 1980-tallet.

Det ble også funnet at innholdet av organisk materiale, nitrogen og svovel varierte mye mer i littoralsonen enn i resten av innsjøen. Organisk materiale ser ut til å være en bestemmende faktor for tot-N. Når det gjelder tot-S, blir en mindre del av fordelingen i innsjøen forklart gjennom tilstedeværelsen av organisk materiale. Innholdet av leire viser seg ikke å være noen god forklaringsfaktor for noen av variablene.

Denne studien er en av fire som undersøker ulike problemstillinger i forbindelse med den horisontale fordelingen av sedimentene i Årungen. Funnene fra disse studiene, vil gi et godt grunnlag for videre forskning på sedimentprosesser i Årungen. Det vil forhåpentlig også være et bidrag til å øke forståelsen for viktige innsjøprosesser og dermed bedre forvaltningen.

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1. Introduction

The sediment reservoir is an important part of the total lake system (Jones & Bowser 1978; Håkanson & Jansson 2002). In water management, the sediments have traditionally been viewed as a sink for nutrients outside the lake system (Jones & Bowser 1978), and not as an interactive part, being both a sink and a source of nutrients (Mortimer 1941; Mortimer 1942).

Knowledge about the lake sediments can give important information on processes in the lake, and the distribution of substances in time and space (Jones & Bowser 1978; Håkanson & Jansson 2002). This is especially valuable in understanding processes of eutrophication (Mackeret 1966). In Lake Trummen, Sweden, removing of sediments was conducted to reduce the internal loading of phosphorus. After restoration, it was found that the nutrient content of the water and the nutrient release from the sediments had decreased (Gelin & Ripl 1977).

Most sediment studies focus on vertical distribution of parameters in the sediments, to reveal the historical development in the lake (e.g. Skogheim & Erlandsen 1984; Mitchell et al. 1985; Khim et al. 2005; Rosenbauer et al. 2009), or to compare lakes using a single or a few cores from each lake (e.g. Norwegian institute for water research (NIVA) 2008; Trolle et al. 2008). Investigation in the vertical variations is important in order to know the historical deposition patterns and to determine the natural state of the lake. Comparison of different lakes gives important information on regional differences. However, because of the complex sediment processes in the lake, one, or a few cores are not enough to represent the whole lake (Håkanson 1981a; Xu et al. 2003).

Thus, I want to investigate the horizontal distribution of organic matter, nitrogen, sulfur and stoichiometry in the sediments of Lake Årungen, how this has changed over time, and how the sediment characteristics control the distribution of the nutrients.

The main objectives of the thesis are to:

1) quantify the horizontal distribution and the variation of the parameters with water depth.
2) quantify the stoichiometric relationships (C:N, C:P, N:P and C:S ratios) and how these are distributed horizontally in the lake.

3) quantify how the nutrients are distributed in relation to organic matter and grain size distribution.
4) put the findings of this study into a historical context by comparing with previous studies of the lake.

In order to investigate this, sediment samples equally distributed in a grid-net were collected in Lake Årungen. Organic matter, represented by loss-on-ignition (LOI) and total carbon (tot-C)), total nitrogen (tot-N) and total sulfur (tot-S) were determined using chemical analyses. The horizontal distribution was mapped using interpolation with a geographical information system (GIS) tool, and statistical tests were used to find differences between the layers (t-test) and relationships between the parameters (correlation). The ratios between the parameters were calculated on weight basis.

The findings are discussed in relation to previous findings in the lake (Skogheim 1978; Skogheim & Erlandsen 1984), and in other lakes. The main focus of the discussion is on the horizontal distribution of parameters and the stoichiometric relationships. The linear relationship between organic matter, clay and the nutrients are presented, however, only briefly discussed.

The findings in this study will add to the knowledge of Lake Årungen, and, in combination with already existing data on the lake, enhance the understanding of important processes in the lake. In addition, since there already is data on the vertical distribution in the sediments (Skogheim 1978; Skogheim & Erlandsen 1984), and thus historical development, this study can tell something about where the lake is heading and how far from its natural condition in water quality, the lake is.

2. Theoretical background

2.1. Sediment processes

The sediments in a lake are under strong influence of different physical processes (Håkanson 1977; Sly 1978), and are a product of lake characteristics such as water depth, orientation of the lake and local climatic variation. The physical inputs that initiate these processes are wind, river inflow and atmospheric heating. These inputs, in addition to controlling factors, will in combination produce different hydrological patterns (Sly 1978).

The distribution of the sediments depends on the water depth. There is a larger variation in the near-shore areas, which decreases with water depth (Håkanson 1981a). The particle size is also important. Finer particles are distributed all over the lake, while larger ones will preferably settle in littoral areas (Davis & Brubaker 1973).

The lake basin can be divided into different zones of sedimentation (Håkanson & Jansson 2002): (i) The *zone of accumulation* is a zone of high turbulence where the finer particles accumulate. (ii) In the *zone of transportation,* the accumulation of finer particles is discontinuous. This is a transition zone where accumulation takes place during stratification, and transportation during circulation periods. (iii) In the *zone of erosion,* no accumulation takes place.

Information about a lake's origin can also be an important guide to sediment processes in lakes (Sly 1978). Hutchinson (1957; referred to in Håkanson 1981b) distinguishes between 11 major lake types based on morphology, origin and distribution on earth. The origin is a result of different natural processes, such as tectonic processes, landslides, volcanism, glacial activity, and so forth. In Scandinavia, practically all lakes originate from activity related to the last glacial era (Håkanson 1981b).

2.2. Organic matter, nitrogen and sulfur

Organic matter is a complex system (Aiken et al. 1985) and an important part of the sediments (Meyers & Teranes 2001). Organic colloids have great adsorption capacity to nutrients (Ohle 1935; referred to in Steinberg & Muenster 1985). Organic matter can also form complex structures with trace metals, and this leads to, among others, decreased toxicity and availability of metals (Steinberg & Muenster 1985).

For simplification, a separation into two categories can be made: nonhumic and humic substances (Aiken et al. 1985). Humic substances are quantitatively important parts of detritus, and make up the majority of organic carbon, including all organisms, independent of water type (Steinberg & Muenster 1985; Steinberg et al. 2008), and consist of about 50 % carbon (Meyers & Teranes 2001).

Organic matter can also be separated according to whether it is dissolved in water (dissolved organic carbon, DOC) or whether it occurs in particulate form (particulate organic matter – POC) (Thurman 1985). POC not decomposed in water, will eventually become part of the sediments. DOC will sediment if it becomes part of inorganic particulate matter, such as clay (Wetzel 2001). Further biological degradation may occur in the sediments (Håkanson & Jansson 2002).

Sources of organic matter are either from production outside the lake (allocthonous) or production within the lake (autochtonous) (Friedman & Sanders 1978; Meyers 1997). Where the sources come from, can be determined from the C:N ratio. Autocthonously derived organic matter usually have a C:N ratio between 4 and 10 (atom based), and allochtonous organic matter have C:N ratios above 20 (Meyers & Teranes 2001).

Even though phosphorus is considered the limiting nutrient for algal growth, and hence eutrophication (Schindler 1977; Schindler et al. 2008), the importance of nitrogen is not inconsiderable (Wetzel 2001). In the marine environment, nitrogen is found to be the limiting nutrient (Granéli et al. 1990). This is especially important when considering coastal areas and the fjords, as the nutrients escaping the lakes, eventually ends up here (Garrison 2007). Knowledge of nitrogen in freshwater sediments is thus also important. Sources of nitrogen are, among others, precipitation, nitrogen fixation in the water and in the sediments, and external input from the watershed. Most of the contributions of reactive nitrogen to lakes are anthropogenic in origin (Wetzel 2001).

Sulfur can exist in either organic or inorganic forms and both forms are essential as nutrients for all living organisms (Mitchell et al. 1984). There has been a major focus on sulfur in the last 30 years because it is a key agent in acidification (TVLF 2002). The atmospheric loading of sulfur has decreased in later years (Tørseth & Semb 1998). Sulfur in lake sediments originates from sedimented organic matter or sulfate in the water coloumn (Fry 1986; Wetzel 2001). The precipitation of sulfur from water to the sediments is mostly helped by biological activity (Mackeret 1966). When there are aerobic conditions in the lake, phosphate (PO_4^{3-}) will bind to iron (III) (Fe^{3+}) and form ironphosphate ($FePO_4$). However, when conditions are anaerobic, the iron will reduce to iron (II) (Fe^{2+}), and reacts with sulphide to ironsulfide (FeS) (Wetzel 2001). Thus, phosphorus is released from the sediments when sulfur is withheld and vice versa.

3. Materials and methods

3.1 Study area

Figure 1. Lake Årungen is a highly eutrophic lake. Seasonal algae blooms colors the lake green. The picture is taken in late May, 2003 (Norge i bilder: Geovekst 2003).

Lake Årungen (Figure 1; Figure 2) is situated in Ås and Frogn municipalities, in Akershus County (59° 40' N, 10° 44' E), 25 km south of Oslo, Norway. The drainage area (Figure 2) is located in Ås, Frogn and Ski municipalities. The lowest point in the drainage area is Lake Årungen, at 33 m.a.s.l., and the highest point is 166 m.a.s.l. The lake area is 1.18 km^2 (Hexum 1963) which is about 2,3 % of the 51 km^2 drainage area (Skogheim 1978). The drainage area has areas with different objectives: agriculture (53%), forest and other outfields (34%), open water surfaces (3 %), and densely populated areas (10%) (Borch et al. 2007). The most densely populated areas are situated in the centre of Ås and Ski, and the Norwegian University of Life Sciences, UMB. These areas can be categorized as partly urban and with a relatively high percentage of sealed surfaces. There are also some scattered towns and villages in the drainage area. The rest of the human activity is near the farms. Most of the industry is in Ski, with the exception of Ski and Ås municipal waste disposal, which lies in the Bølstadbekken drainage area (Borch et al. 2007). The highway, E6, passes closely west of the lake.

Lake Årungen originates from glacial activities (Hexum 1963). All of the drainage area is below the highest post-glacial marine limit, thus the soil consists mainly of calcium-rich quaternary marine clay and moraine. It lies on south-eastern Norwegian bedrock areas that are largely dominated by gneisses and granite rocks (Skogheim 1978; Borch et al. 2007).

The climate type of the area is a cool forest climate with warm summers (Johannessen 1969). The area is in the boreonemoral vegetation zone, a transition zone between deciduous forest and coniferous forest areas. The climate zone is weakly oceanic (Moen 1998). The normal yearly precipitation for the area is between 700-1000 mm(The Norwegian Meteorological Institute 2010a). The normal yearly mean temperature is 5-6°C. In 2009 the maximum temperature was 33°C and minimum was -17.5°C (The Norwegian Meteorological Institute 2010b). The maximum discharge is in spring, and has one, sometimes two, peaks (Johannessen 1969).

There are six (seven) inlet rivers to Lake Årungen (Figure 3): Syverudbekken[1], Bølstadbekken, Norderåsbekken, Vollebekken and Brønnerudbekken (meets and become one inlet before reaching Lake Årungen), Smebølbekken, and Storgrava. Of these, accounts for more than half of the discharge from these inlets (Table 1). The outlet, Årungselva, is north of the lake and drains down to Bunnefjorden, an arm of the Oslofjord.

Table 1. Main inlet rivers to Lake Årungen.

Stream/watershed	Watershed area (km^2)	Discharge (million m^3 yr^{-1})
Bølstadbekken	25.5	12.6
Storgrava	8,4	4.2
Smedbølbekken	7.3	3.6
Vollebekken	2.1	1.0
Nordreåsbekken	2.7	1.3
Brønnerudbekken	0.8	0.4
Sum	46.8	23.1

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[1] No information on discharge available. Part of the Bølstadbekken drainage area.

Figure 2. Lake Årungen, situated in Ås and Frogn municipalities, Akershus county, Norway. The lake's drainage area is located in Ås, Ski and Frogn municipalities (Borch et al. 2007).

Lake Årungen is a dimictic lake (Romarheim & Riise 2009), with two full circulation periods, during spring and autumn, and two stagnation periods, during winter and summer. In the summer, the lake is thermally stratified, and in the winter the lake is usually ice-covered. The lake's maximum depth (Figure 3) is 13 meters and average depth is about 8 meters (Borch et al. 2007). The maximum length is 3 km, and maximum width is 0.6 km (Skogheim 1978). The mean width is 450 meters. The main axis is North-South, which corresponds with the main wind direction. Thus, there is a good circulation in Lake Årungen. The theoretical retention time is about 4.5 months (Borch et al. 2007). Mean sedimentation rate for the period 1900-1950 was 3.4 mm/year in the deepest part of the lake. The sedimentation rate could vary in different parts of the lake (Skogheim 1978; Skogheim & Erlandsen 1984). There have not been calculated any sedimentation rates after that.

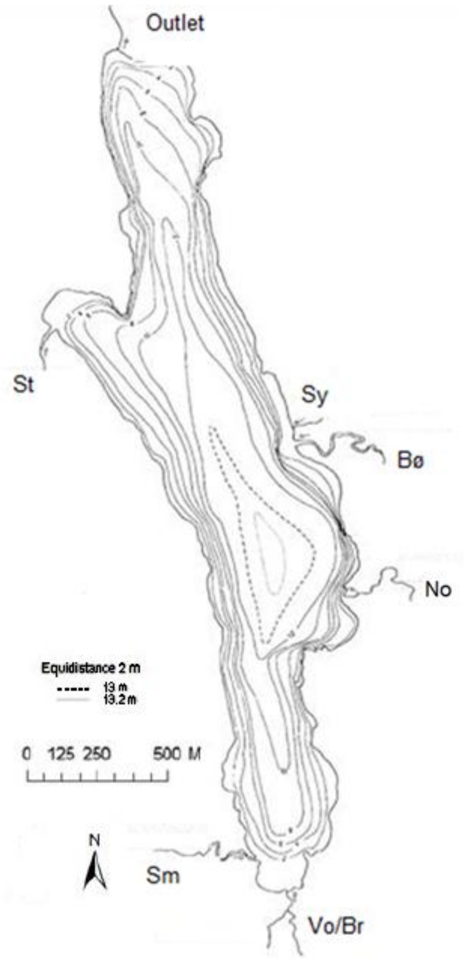

Figure 3. The morphometry (depth) of Lake Årungen. In- and outlets (modified from Skogheim & Abrahamsen 1979).

Condition

Lake Årungen has always been a nutrient rich lake. The natural state, when human influence was neglible, is considered from historical data to be mesotrophic. In the 1950s, the loading of nutrients to the lake increased drastically, as untreated wastewater and runoff from agricultural activities in the area was let directly into the lake. The lake then became highly eutrophic (Skogheim & Erlandsen 1984). Measures have been put forward to decrease the runoff and the condition was better for some years. However, in recent years it has become worse again. It has been suggested that natural variations in climate might be the reason (Borch et al. 2007).

In summer, blooms of cyanobacteria, a bluegreen algae that is able to fix nitrogen from the atmosphere and produces toxins, are dominating (Løvstad & Krogstad 1995).

The concentration of total organic carbon (TOC) at 13 meters water depth was 6.49 mg/l in April, 2009. The content in the water measured at the outlet was 5.86 mg/l.

For total nitrogen (tot-N) the concentration at 13 meters water depth was 2.24 mg/l, and 2.14 mg/l in the outlet (personal comment, Alexandra T. Romarheim[2] 2010).

3.2 Field work

The field work was conducted in week 13 and 14 in 2009 on an ice-covered Lake Årungen. The locations of the sample spots (Appendix 1) were distributed evenly in a grid-net pattern, 100x100 meters. Each location was located with a Garmin Colorado GPS which contained the pre-plotted coordinates (Appendix 2). The GPS' accuracy varied between 1 and 5 meters. A sediment collector (Uwitec Corer), with total pipe length 60 centimeters and inside diameter 5.95 centimeters, was used. The sediment cores were divided into two layers: 0 – 2.5 centimeter and 2.5 – 5.0 centimeters. The splitting was done *in situ.* The samples were brought back to the laboratory and stored in a refrigerated storage room (2-4°C), pending further analyzes.

3.3 Chemical analyses

Dry weight

First, surplus water at the sediment surface was removed. The samples were then homogenized with a plastic spoon to enhance the representativeness of the subsamples.
In preparation for LOI, tot-C and tot-N analysis, subsamples were weighed with an accuracy of 1 mg (Sartorius LC 32101D). About 15 grams were taken out from the samples collected in the littoral zone (four meters or shallower), and about 13.5 grams from areas deeper than 4 meters. The samples were then dried at 105°C over night, and then cooled off in a deciccator. The samples were weighted again, and the dry weight percentage was calculated (Appendix 3).

The dried samples were further homogenized with a Retsch Agamorter (RMO, Germany). The samples were then kept at 40^0C to avoid moisture from the air in the dry sediment.

Loss-on-ignition (LOI)

The method for determining LOI is described in Wageningen (1976). About 1 gram of dry weight from each sample was weighed with an accuracy of 1 mg (Sartorius LC

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[2] PhD student, University of life Sciences (UMB), Plant and environmental sciences

32101D) and put in small ceramic bowls. The samples were then ignited at 550°C, over night. Some empty bowls were ignited as reference or blank samples to check that the weight loss from the bowls did not contribute to the LOI. The samples were weighted again after ignition. Percentage ignition loss is calculated with the formula (Heiri et al. 2001):

$$LOI_{550}\ (\%) = ((DW_{105} - DW_{550})/DW_{105}) \times 100$$

LOI_{550} is loss-on-ignition at 550°C, DW_{105} is weight after drying at 105°C, and DW_{550} is weight after ignition at 550°C.

Correction for clay-content

The method of determining organic matter from LOI is highly debated (Ball 1964; Heiri et al. 2001; Beaudoin 2003; Boyle 2004; Sun et al. 2009). Clay content may lead to structural water loss (SWL) that also gives a false representation of the organic matter content (Ball 1964). The SWL varies according to both the amount and the mineralogical features of the sediment (Grim 1953; referred to in Ball 1964; De Leenheer et al. 1957; referred to in Ball 1964).

Data on clay content are available for about half of the samples in layer B (Rutsinda 2010). The clay content varies from 14.6 – 74.1 %, with mean value 57.1 (±1.7 SE mean) (Appendix 6). Data on clay content was used to correct the loss-on-ignition. In lack of knowledge of the mineralogy of the clay, a correction based on intervals of clay content in the sample was done. The correction (Table 2) is based on a study of Scandinavian soil, a young soil with high content of low-weathered minerals (Ekström 1926).

Table 2. Correction for clay content (Ekström 1926).

Clay-content (%)	Correction factor
5-10	1
10-25	2
25-40	3.5
40-60	3.5
> 60	4.5

Total carbon (tot-C) and nitrogen (tot-N).

The analysis was done by trained staff at the institute's laboratory. Both parameters were analyzed on the same instrument, LECO CHN 1000. The analyses of tot-C was done after the *dry combustion* method suggested by Allison and described in Nelson & Sommers (1982). About 200 mg of each sample was weighed in a tinfoil. During the analysis there is a complete combustion which leads to the oxidation of all the carbon monoxide (CO) to carbon dioxide (CO_2). The concentration of the CO_2 gas is then measured with infrared light, an IR cell.

Tot-N analysis was done according to the *Dumas* method (Bremmer & Mulvaney 1982). The method is the same as for total carbon, in principle, however, the nitrogenoxide-compounds (NO_X) is being reduced with the help of copper to N_2. The nitrogen gas concentration is measured by thermal conductivity (TC cell).

Total sulfur (tot-S) and total phosphorus (tot-P)

The tot-S was determined by trained staff on ICP-OES. The preparation was done by other students at the project, as part of the determination of a large number of elements. The details of the preparational work can be found in Zambon (2010) and Reierstad (2010). The analysis was conducted by trained staff at the institute's laboratory. Certified reference material (CRM) for tot-S in Appendix 4. CRM for tot-P in Reierstad (2010).

Grain size distribution

The data on grain size distribution is provided by Rutsinda (2010). The method is described there.

3.4 Statistical analyses

An interpolation between the sample locations were done with the program ESRI © ArcVIEW™ 9.3. The interpolation was done with the spatial analyst tool *Spline with barriers* (ESRI Inc. 1999-2009).

Scatterplots and simple linear regressions were conducted in Microsoft Office Excel. The remaining statistical tests and figures were conducted in Minitab®. A paired t-test was conducted initially to see whether there were any differences between the two layers, and thus make a decision about whether to include both layers in the analysis or not. The paired t-test is used when the samples are dependent. Changes are tested for pairs of observations (i.e. a before-and-after test) (Snedecor & Cochran 1980). The strength of the t-test is that it is often valid, even when the assumption of normality is not fulfilled. In addition, the paired t-test does not assume equal variance of the observations (Minitab inc. 2007).

Pearson correlations were run in order to check whether there were any linear relationships between the variables. The data were ranked according to Spearman (Snedecor & Cochran 1980) before running the correlation, in order to avoid the problem of influencing outliers.

Ratios can be calculated based both on atom mass and weight, and the literature differs in what kind that is used (Meyers & Teranes 2001). In this thesis, weight based ratios are used. When comparing with data that are based on atom mass ratios, these values are divided by 1.17 for C:N, 2.58 for C:P, 2.21 for N:P and 2.67 for C:S.

Data

Because of extremely high values in a couple of samples (numbers 7 and 33), that had notes about sources of errors (Appendix 7) it was decided to leave them out of the study. The data material is considered big enough. Two samples (numbers 69 and 98) were not analyzed for tot-S in the lower layer (2.5-5.0 centimeters), because there was not enough sediment left.

The lake was separated into four different zones (Table 3), each comprising ¼ of the lake's surface area. The division was done according to the bathygraphical curve made as part of an earlier master thesis on Lake Årungen (Hexum 1963).

Table 3. Zoning of the Lake Årungen according to water depth.

Depth zone	Water depth (m)
1	< 4
2	4 - 8.5
3	8.5 - 11.3
4	11.3 - 13.4

3.5 Variable selection

A paired t-test gave significant differences between the two layers, however only small differences (Table 4). Thus it was decided to present data from only one of the layers. The lower layer (2.5-5.0 cm) was chosen because it is available data on clay from the deepest layer. Further, the top layer (0-2.5 cm) is in contact with the water surface and is exposed to disturbance and sediment to water exchange.

Table 4. A t-test conducted to measure differences between the two layers (0-2.5 and 2.5-5.0).

Parameter ($g\ kg^{-1}$ dw)	**Mean (± SE) 0-2.5 cm**	**Mean (± SE) 2.5-5.0 cm**	**Difference**	**Significance (p)**
Tot-C	42.06 ± 1.87	39.51 ± 1.75	2.55 ± 0.71	< 0.001
(n)	*(120)*	*(120)*	*(120)*	
LOI	110.24 ± 3.32	105.10 ± 3.14	5.14 ± 1.63	< 0.01
(n)	*(120)*	*(120)*	*(120)*	
Tot-N	4.87 ± 0.13	4.51 ± 0.14	0.36 ± 0.087	< 0,001
(n)	*(120)*	*(120)*	*(120)*	
Tot-S	1.12 ± 0.10	1.53 ± 0.14	-0.40 ± 0.07	< 0,001
(n)	*(118)*	*(118)*	*(118)*	

There was a good correlation between both uncorrected and corrected LOI (LOI_{corr}), and tot-C. The uncorrected LOI was thus used in the visual presentation of the parameters, because the correction was only done on half of the data collected. Further, it was decided to use tot-C as a measure of organic matter in the further analyses. Tot-C made up about 60 % of LOI_{corr} and around 50 % of LOI (Figure 4). This is in accordance with findings that carbon makes up 50-60 % of organic matter (Meyers & Teranes 2001) (Broadbent 1953). On this background an assumption can be made that the tot-C in the sediment are practically all organic.

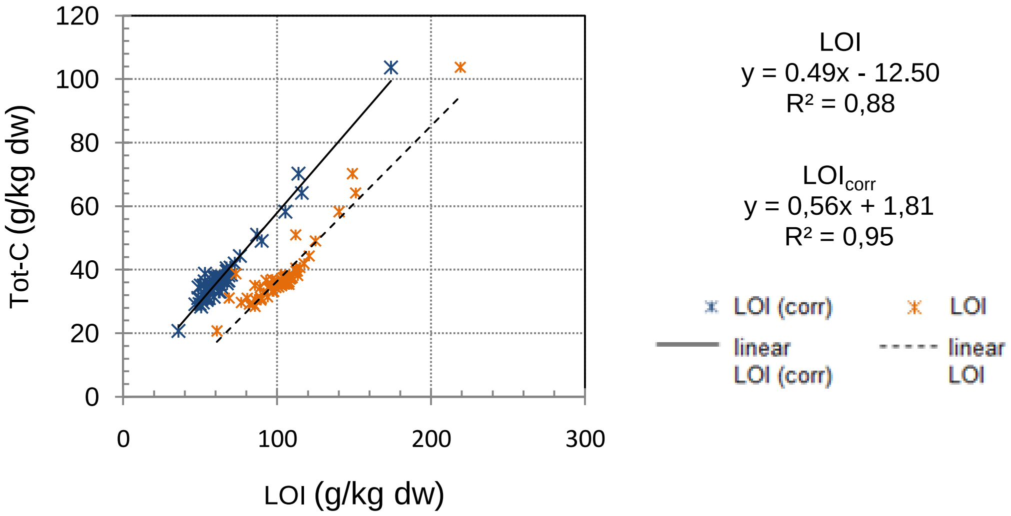


Figure 4. Scatterplot with linear regression line. LOI and LOI_{corr} vs tot-C (N=60).

Table 5. Pearsons correlation coefficients (r) for correlations between LOI, LOI_{corr} and tot-C. * = p < 0.001. ** = p < 0.01. *** = p < 0.05. x = not significant.

		Tot-C	(n)	LOI	
All data	LOI	0.887*	(120)		
	LOI_{corr}	0.810*	(60)	0.862*	(60)
1	LOI	0.945*	(120)		
	LOI_{corr}	0.827*	(60)	0.955*	(60)
2	LOI	0.750*	(120)		
	LOI_{corr}	0.697**	(60)	0.807*	(60)
3	LOI	0.870**	(120)		
	LOI_{corr}	0.802*	(60)	0.855*	(60)
4	LOI	0.834*	(120)		
	LOI_{corr}	0.770**	(60)	0.900*	(60)

4. Results

4.2 Horizontal distribution

Organic matter (LOI and tot-C)

The mean content of organic LOI (Figure 5) in Lake Årungen was 105 g/kg dw. The horizontal distribution of LOI shows that there were three locations with much higher accumulation than in the rest of the lake. One of those locations is south in the lake, near the inlet Vollebekken/Brønnerudbekken. The other two are in the northern part of the lake, in the littoral zone west and east in the lake. The lowest values are found in the south part of the lake, and in the littoral. Thus, it seems to be more variation in the littoral than in the deeper parts of the lake. When dividing into different depth zones, this is confirmed. When running correlation with depth, this is significant and positive, however, weak ($r = 0.238$, $p<0.01$).

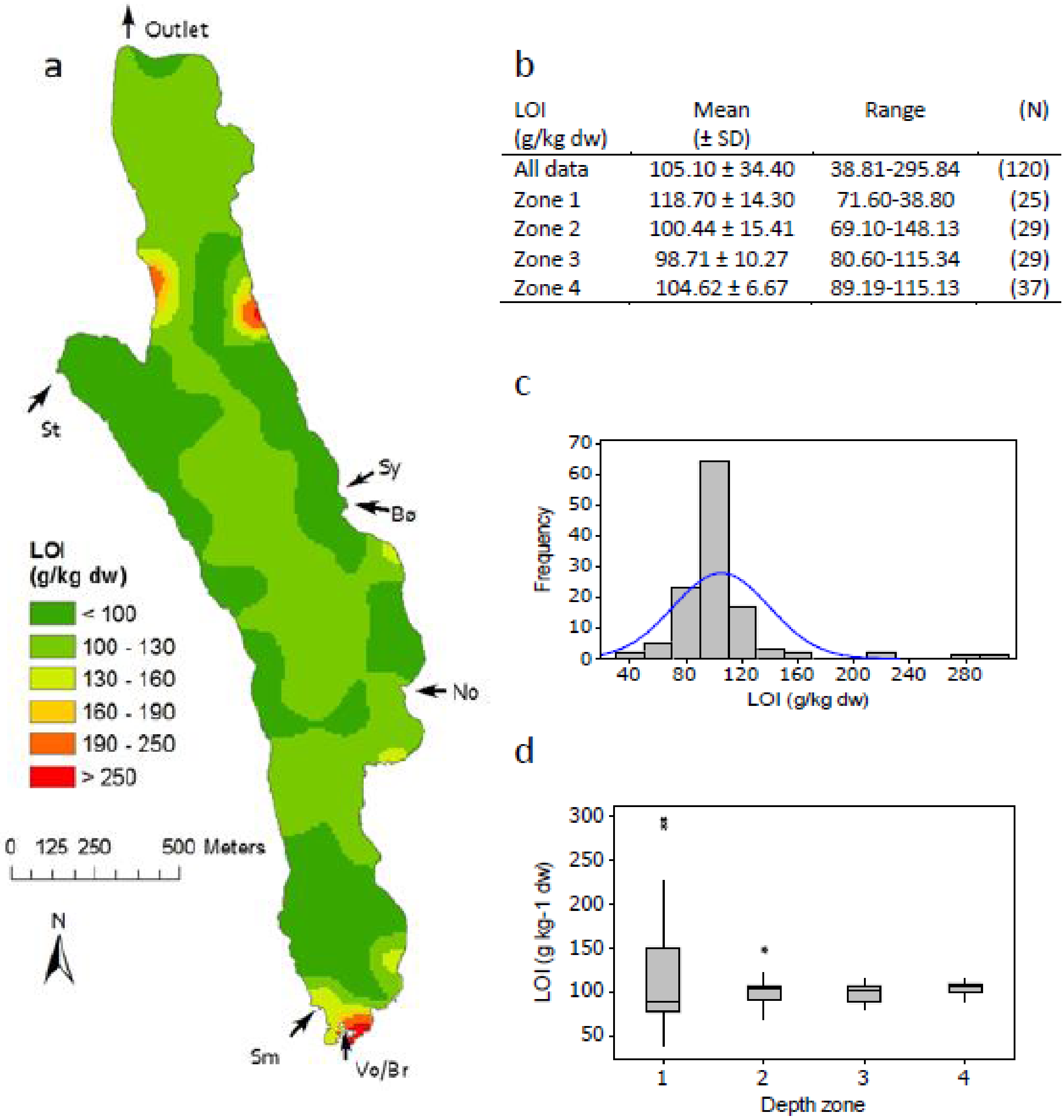
The mean content of tot-C (Figure 6) was 39.51 g/kg dw. The horizontal distributional patterns were similar to those of LOI, with the same locations of higher accumulation. The rest of the distribution seems more homogenous than for LOI. Some variation can be detected in the littoral, and this is confirmed when distinguishing between depth zones. In addition, there is an area of medium high accumulation in the deepest part of the lake. As for LOI, the correlation with depth is weakly positive ($r = 0.209$, $p<0.05$).

Nitrogen (tot-N)

The mean content of organic tot-N (Figure 7) in Lake Årungen is 4.51 g/kg dw. The horizontal distribution of tot-N shows that there are three locations where there is much higher accumulation than the rest of the lake. One of those locations is south in the lake, near the inlet Vollebekken/Brønnerudbekken. The other two are in the northern part of the lake, in the littoral zone west and east in the lake. The lowest values are found in the south part of the lake, and in the littoral. Thus, it seems to be more variation in the littoral than in the deeper parts of the lake. When dividing into different depth zones, this is confirmed. When running correlation with depth, this is significant and positive, however, weak ($r = 0.185$, $p<0.05$).

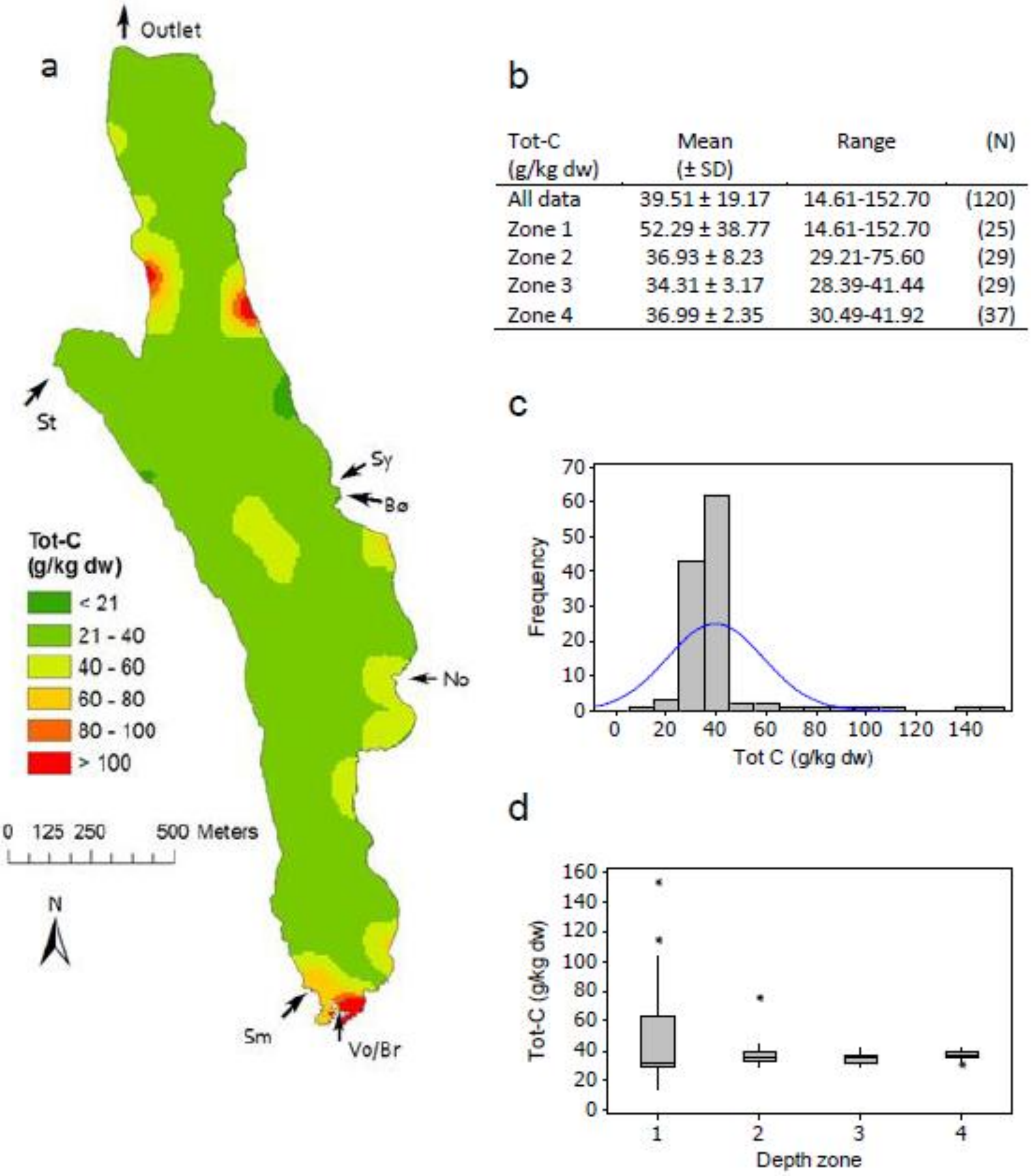
Sulfur (tot-S)

The mean content of tot-S (Figure 8) is 1.52 g/kg dw. Three locations with high accumulation (>5 g/kg dw) are seen on the map. One is in the south, near Vollebekken/Brønnerudbekken, and the others are located in the north end of the lake, in the littoral zone on the west and east side of the lake. This is concurrent with the other parameters. There is, however, a more obvious increase towards the profoundal zone of the lake, when leaving out the highest accumulation in the littoral. This is only vaguely detected in the boxplot. The correlation between depth and tot-S reveals a stronger positive correlation ($r = 0.467$, $p<0{,}001$) than for the other parameters.



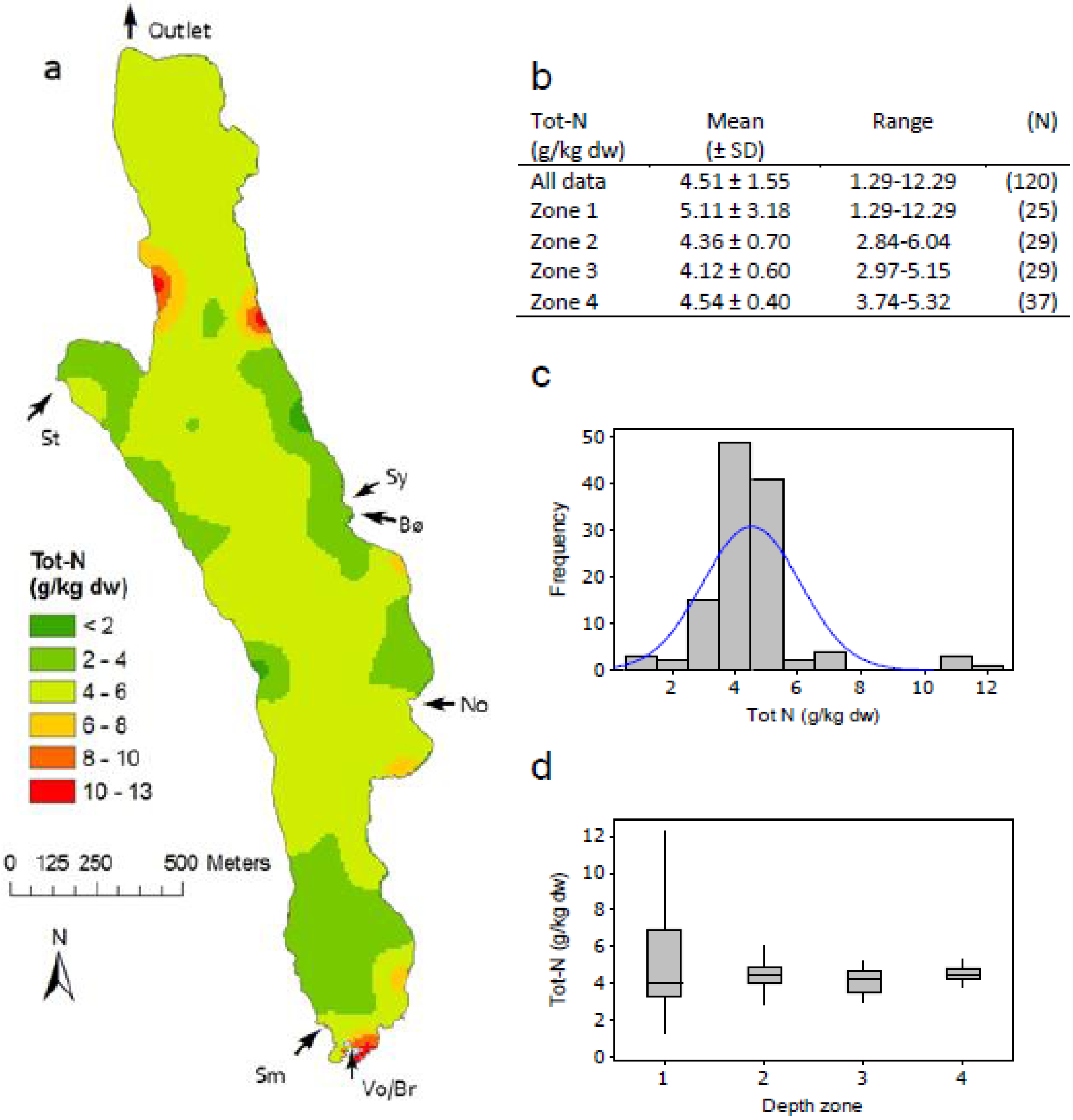
LOI (g/kg dw)	Mean (± SD)	Range	(N)
All data	105.10 ± 34.40	38.81-295.84	(120)
Zone 1	118.70 ± 14.30	71.60-38.80	(25)
Zone 2	100.44 ± 15.41	69.10-148.13	(29)
Zone 3	98.71 ± 10.27	80.60-115.34	(29)
Zone 4	104.62 ± 6.67	89.19-115.13	(37)

Figure 5. Graphical summary of the distributional patterns of the LOI in Lake Årungen. a) Visual presentation of the horizontal distribution. b) Descriptive statistics. c) Frequency distribution. d) Boxplot with the ratios grouped according to depth zones. The box represents the middle 50 % of the data (interquartile range box). Horizontal lines represent first quartile (bottom line of box) median (midline) and third quartile (top line). Vertical lines (whiskers) represent minimum and maximum data point within 1.5 box heights from the bottom of the box. The outliers are represented by dots and are datapoints that fall beyond the upper or lower whisker (Minitab inc. 2007).



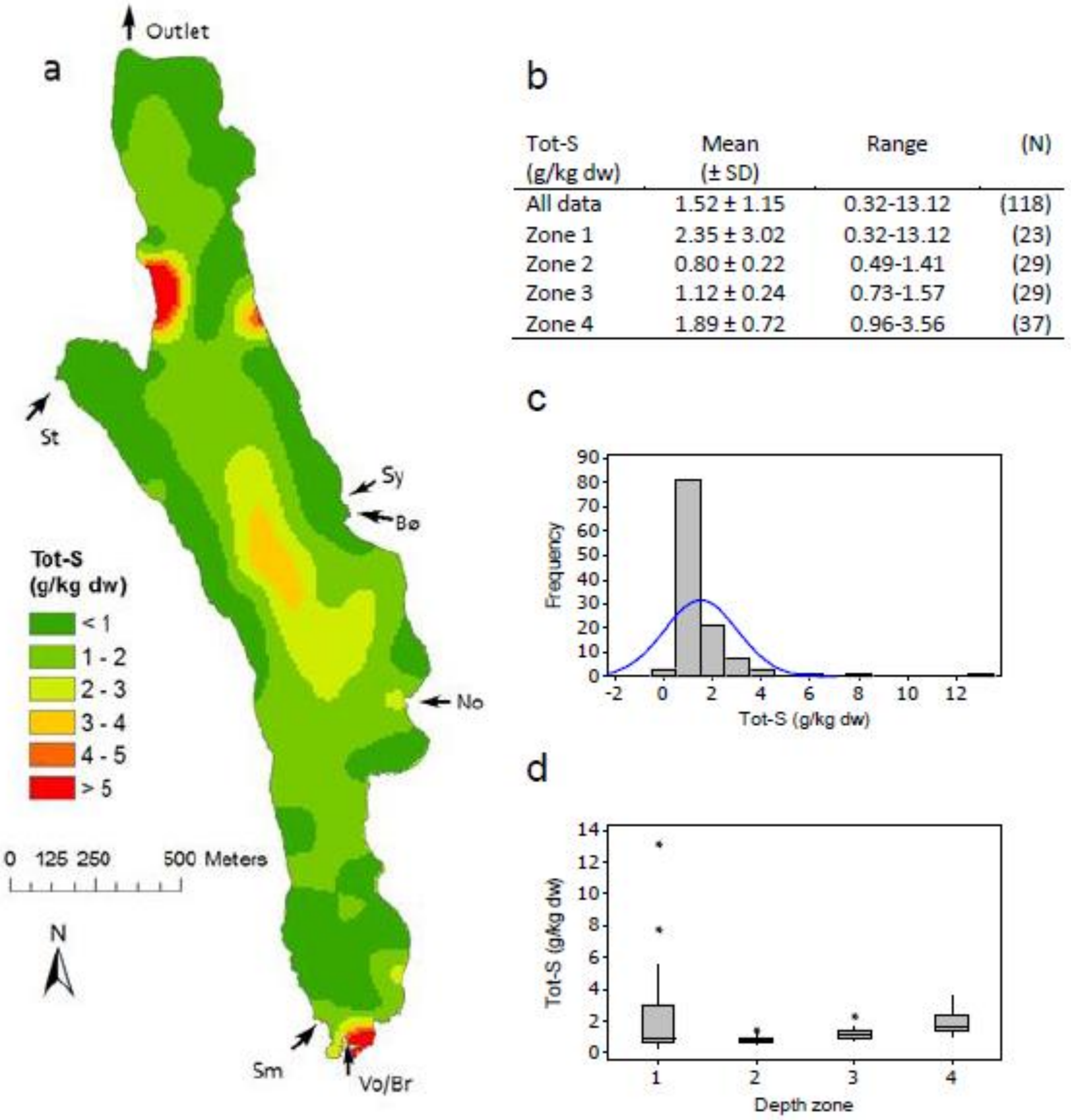
Tot-C (g/kg dw)	Mean (± SD)	Range	(N)
All data	39.51 ± 19.17	14.61-152.70	(120)
Zone 1	52.29 ± 38.77	14.61-152.70	(25)
Zone 2	36.93 ± 8.23	29.21-75.60	(29)
Zone 3	34.31 ± 3.17	28.39-41.44	(29)
Zone 4	36.99 ± 2.35	30.49-41.92	(37)

Figure 6. Graphical summary of the distributional patterns of the tot-C in Lake Årungen. a) Visual presentation of the horizontal distribution. b) Descriptive statistics. c) Frequency distribution. d) Boxplot with the ratios grouped according to depth zones. The box represents the middle 50 % of the data (interquartile range box). Horizontal lines represent first quartile (bottom line of box) median (midline) and third quartile (top line). Vertical lines (whiskers) represent minimum and maximum data point within 1.5 box heights from the bottom of the box. The outliers are represented by dots and are datapoints that fall beyond the upper or lower whisker (Minitab inc. 2007).



Tot-N (g/kg dw)	Mean (± SD)	Range	(N)
All data	4.51 ± 1.55	1.29-12.29	(120)
Zone 1	5.11 ± 3.18	1.29-12.29	(25)
Zone 2	4.36 ± 0.70	2.84-6.04	(29)
Zone 3	4.12 ± 0.60	2.97-5.15	(29)
Zone 4	4.54 ± 0.40	3.74-5.32	(37)

Figure 7. Graphical summary of the distributional patterns of the tot-N in Lake Årungen. a) Visual presentation of the horizontal distribution. b) Descriptive statistics. c) Frequency distribution. d) Boxplot with the ratios grouped according to depth zones. The box represents the middle 50 % of the data (interquartile range box). Horizontal lines represent first quartile (bottom line of box) median (midline) and third quartile (top line). Vertical lines (whiskers) represent minimum and maximum data point within 1.5 box heights from the bottom of the box (Minitab inc. 2007).



Tot-S (g/kg dw)	Mean (± SD)	Range	(N)
All data	1.52 ± 1.15	0.32-13.12	(118)
Zone 1	2.35 ± 3.02	0.32-13.12	(23)
Zone 2	0.80 ± 0.22	0.49-1.41	(29)
Zone 3	1.12 ± 0.24	0.73-1.57	(29)
Zone 4	1.89 ± 0.72	0.96-3.56	(37)

Figure 8. Graphical summary of the distributional patterns of the tot-S ratios in Lake Årungen. a) Visual presentation of the horizontal distribution. b) Descriptive statistics. c) Frequency distribution. d) Boxplot with the ratios grouped according to depth zones. The box represents the middle 50 % of the data (interquartile range box). Horizontal lines represent first quartile (bottom line of box) median (midline) and third quartile (top line). Vertical lines (whiskers) represent minimum and maximum data point within 1.5 box heights from the bottom of the box. The outliers are represented by dots and are datapoints that fall beyond the upper or lower whisker (Minitab inc. 2007).

4.2 Relative horizontal distribution

Carbon:nitrogen (C:N) ratios

C:N ratios (Figure 9) below 8 was mostly found in the northern part of the lake. In the littoral (depth zone 1), only one location had C:N ratio above 20 (sample location 85, C:N ratio 20.13). Near the inlets Smebølbekken and Vollebekken/Brønnerudbekken, the C:N ratio was quite high as well. Some locations of medium high C:N ratios were distributed in the littoral zone, near inlets (Syverudbekken, Bølstadbekken and Norderåsbekken). The rest of the lake had C:N ratios between 8 and 10. Mean values in the littoral (depth zone 1) was higher than the remaining (C:N ratio of 10) and in the variation around the median in the boxplot. The correlation between C:N and depth was negative, however not very strong ($r = -0.331$, $p < 0.001$).

Carbon:phosphorus (C:P) ratios

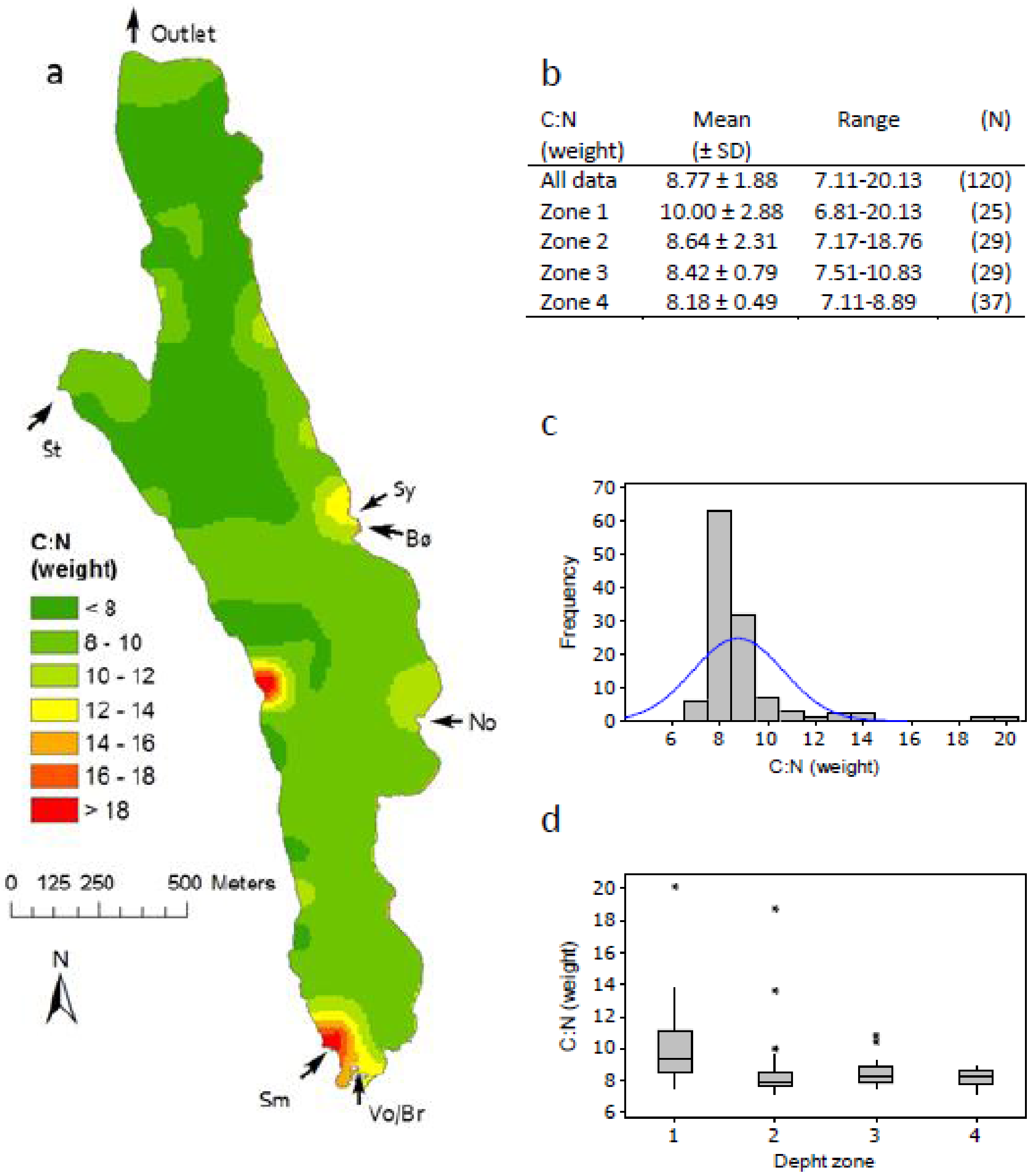
The C:P ratios (Figure 10) were below 25 (mean values 24.97) in the whole lake, except the littoral, where it was more variation. This is confirmed by higher mean values (42.81), and variation around the median in depth zone 1. The locations with higher ratios were mostly near inlets, however the highest ratios were found in the northern part of the lake. The correlation between C:P and depth suggest a decreasing C:P ratio with increasing depth ($r = -0.643$, $p<0.001$).

Nitrogen:phosphorus (N:P) ratios

The N:P ratios (Figure 11) were mostly between 2-4 (mean ratio 2.77) for the whole lake. There were some locations with lower ratios in the profundal. In the littoral, there were locations with both higher and lower ratios. There are no immediate visible differences near inlets, although near a couple of inlets, the ratio was higher (Vollebekken/Brønnerudbekken and Norderåsbekken). The locations with highest ratios were in the northern part of the lake, in the littoral. Grouped according to water depth zones, the variation around the median were larger in zone 1. Even though not visible in the boxplot, the correlation between N:P and depth indicates a decreasing trend ($r = -0.550$, $p<0.001$).

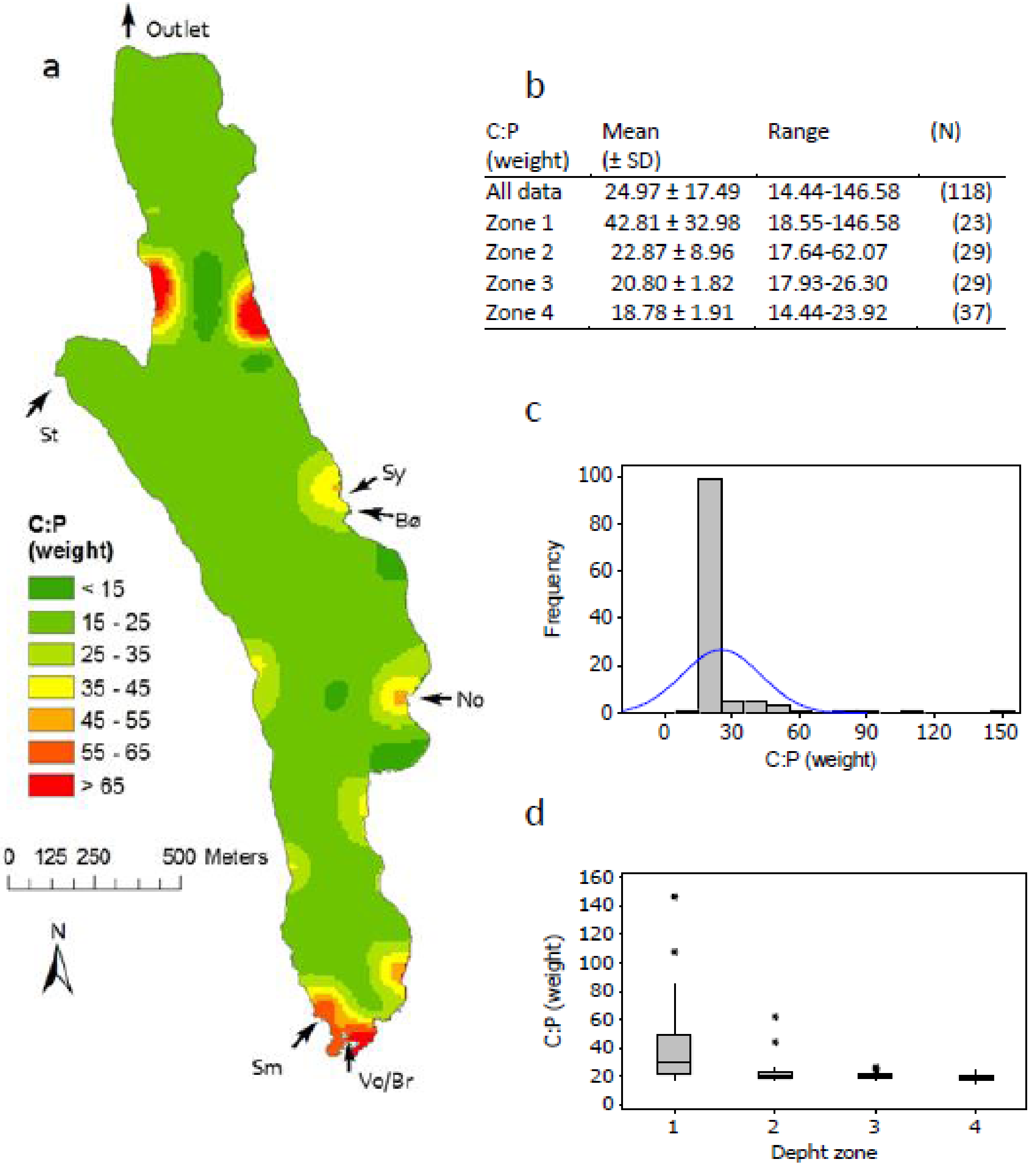
Carbon:sulfur (C:S) ratios

The C:S ratios (Figure 12) were not as uniform across the lake as the above mentioned. At first glance it seems to be a decreasing trend from the littoral to the profoundal, although there was more variation in the littoral. Looking at the distribution according to depth zones, this is confirmed, at least for the three deeper zones. The littoral zone (depth zone 1) had larger variation around the median, and the mean was lower (33.63) than for depth zone 2 (47.52). From the grouped data, it is apparent that the decreasing trend applies, when excluding zone 1. Running correlation confirmed a decreasing trend with depth ($r = -0.540$, $p<0.001$).



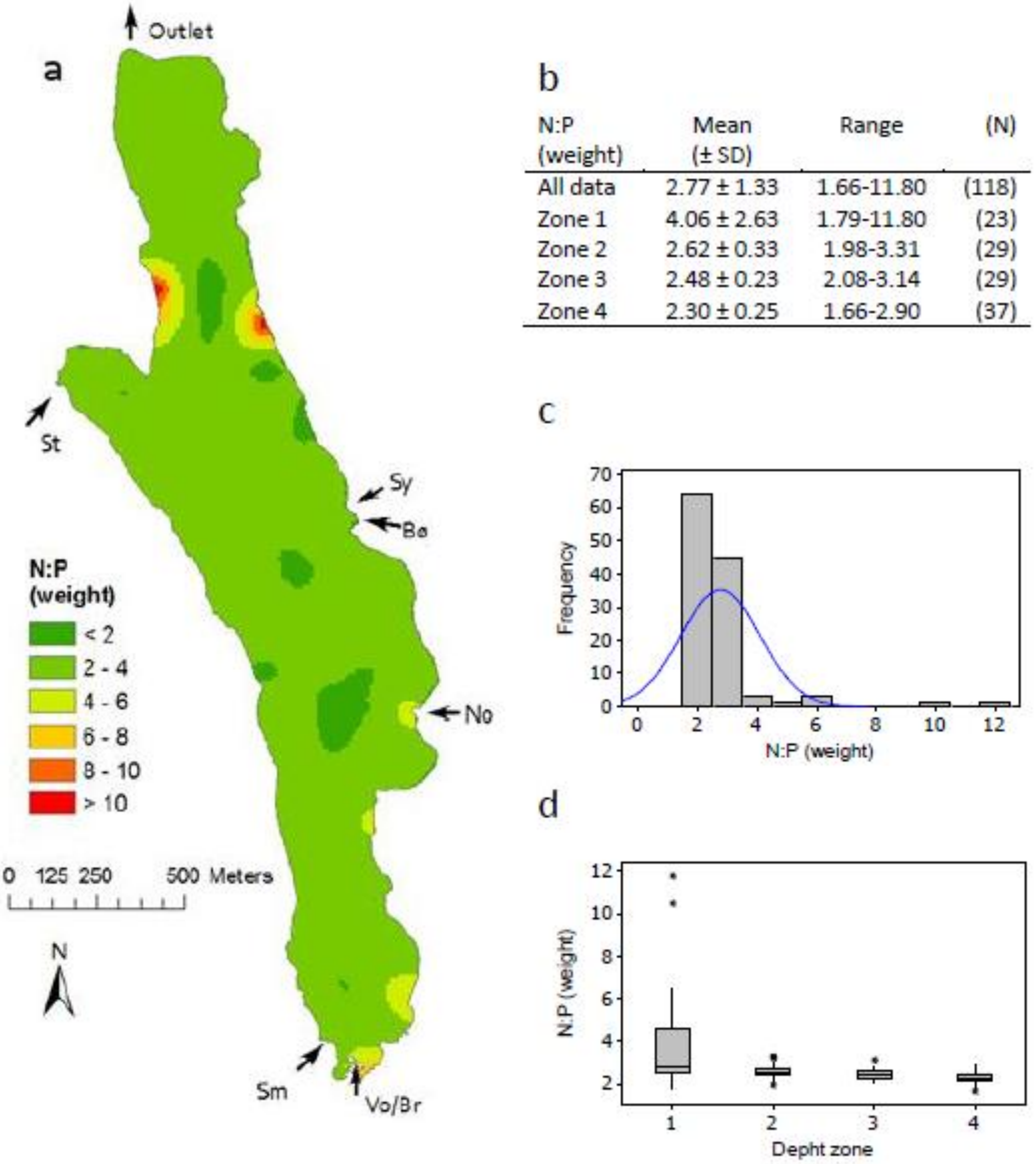
C:N (weight)	Mean (± SD)	Range	(N)
All data	8.77 ± 1.88	7.11-20.13	(120)
Zone 1	10.00 ± 2.88	6.81-20.13	(25)
Zone 2	8.64 ± 2.31	7.17-18.76	(29)
Zone 3	8.42 ± 0.79	7.51-10.83	(29)
Zone 4	8.18 ± 0.49	7.11-8.89	(37)

Figure 9. Graphical summary of the distributional patterns of the C:N ratios in Lake Årungen. a) Visual presentation of the horizontal distribution. b) Descriptive statistics. c) Frequency distribution. d) Boxplot with the ratios grouped according to depth zones. The box represents the middle 50 % of the data (interquartile range box). Horizontal lines represent first quartile (bottom line of box) median (midline) and third quartile (top line). Vertical lines (whiskers) represent minimum and maximum data point within 1.5 box heights from the bottom of the box. The outliers are represented by dots and are datapoints that fall beyond the upper or lower whisker (Minitab inc. 2007).



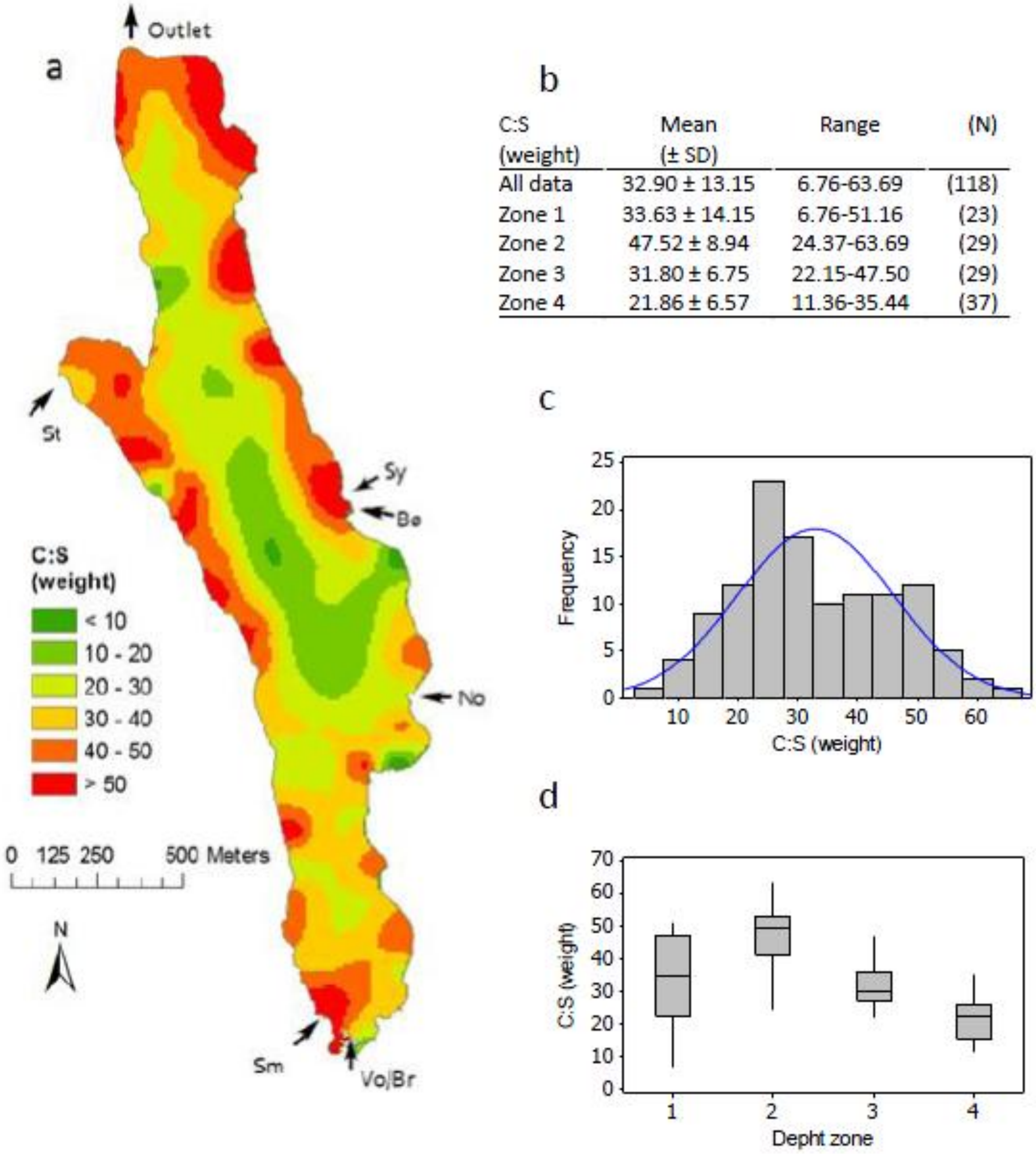
C:P (weight)	Mean (± SD)	Range	(N)
All data	24.97 ± 17.49	14.44-146.58	(118)
Zone 1	42.81 ± 32.98	18.55-146.58	(23)
Zone 2	22.87 ± 8.96	17.64-62.07	(29)
Zone 3	20.80 ± 1.82	17.93-26.30	(29)
Zone 4	18.78 ± 1.91	14.44-23.92	(37)

Figure 10. Graphical summary of the distributional patterns of the C:P ratios in Lake Årungen. a) Visual presentation of the horizontal distribution. b) Descriptive statistics. c) Frequency distribution. d) Boxplot with the ratios grouped according to depth zones. The box represents the middle 50 % of the data (interquartile range box). Horizontal lines represent first quartile (bottom line of box) median (midline) and third quartile (top line). Vertical lines (whiskers) represent minimum and maximum data point within 1.5 box heights from the bottom of the box. The outliers are represented by dots and are datapoints that fall beyond the upper or lower whisker (Minitab inc. 2007).



N:P (weight)	Mean (± SD)	Range	(N)
All data	2.77 ± 1.33	1.66-11.80	(118)
Zone 1	4.06 ± 2.63	1.79-11.80	(23)
Zone 2	2.62 ± 0.33	1.98-3.31	(29)
Zone 3	2.48 ± 0.23	2.08-3.14	(29)
Zone 4	2.30 ± 0.25	1.66-2.90	(37)

Figure 11. Graphical summary of the distributional patterns of the N:P ratios in Lake Årungen. a) Visual presentation of the horizontal distribution. b) Descriptive statistics. c) Frequency distribution. d) Boxplot with the ratios grouped according to depth zones. The box represents the middle 50 % of the data (interquartile range box). Horizontal lines represent first quartile (bottom line of box) median (midline) and third quartile (top line). Vertical lines (whiskers) represent minimum and maximum data point within 1.5 box heights from the bottom of the box. The outliers are represented by dots and are datapoints that fall beyond the upper or lower whisker (Minitab inc. 2007).



C:S (weight)	Mean (± SD)	Range	(N)
All data	32.90 ± 13.15	6.76-63.69	(118)
Zone 1	33.63 ± 14.15	6.76-51.16	(23)
Zone 2	47.52 ± 8.94	24.37-63.69	(29)
Zone 3	31.80 ± 6.75	22.15-47.50	(29)
Zone 4	21.86 ± 6.57	11.36-35.44	(37)

Figure 12. Graphical summary of the distributional patterns of the C:S ratios in Lake Årungen. a) Visual presentation of the horizontal distribution. b) Descriptive statistics. c) Frequency distribution. d) Boxplot with the ratios grouped according to depth zones. The box represents the middle 50 % of the data (interquartile range box). Horizontal lines represent first quartile (bottom line of box) median (midline) and third quartile (top line). Vertical lines (whiskers) represent minimum and maximum data point within 1.5 box heights from the bottom of the box (Minitab inc. 2007).

4.3 The relationship between organic matter and nutrients

Tot-C explained a great deal of tot-N (R^2 = 82 %) (Figure 13) when considering the whole lake. The correlation between tot-C and tot-N was positive, and quite strong for the whole lake, and even stronger in depth zone one (Table 6). In zone three, the correlation was similar to the whole lake. The correlation was weakest in zone two.

The linear relationship between tot-C and tot-S is not as strong (R^2 = 58 %) (Figure 14). Correlations revealed the same pattern (Table 6). The correlation for the whole lake was medium strong, and a little higher in the different depth zones, except for zone three, where the correlation was not significant.

The presence of tot-N explains little more than half of the distribution of tot-S (R^2 = 55 %) (Figure 15). The correlation between the two was best in depth zone 1 (r = 0.767, $p < 0.001$). In depth zone three, the correlation was not significant.

Table 6. Pearsons correlation coefficient (r) for correlations between tot-N, tot-S and tot-C for the whole lake, and differentiated between different depth zones. * = p < 0.001. ** = p < 0.01. *** = p < 0.05. x = not significant.

Depth zone	**Parameter**	**Tot-C**	**Tot-S**
All	**Tot-N**	0.830*	0.896*
	Tot-S	0.559*	
1	**Tot-N**	0.945*	0,692*
	Tot-S	0.767*	
2	**Tot-N**	0.598*	0,465***
	Tot-S	0.605*	
3	**Tot-N**	0.812*	0,445***
	Tot-S	0.282x	
4	**Tot-N**	0,721*	0,595*
	Tot-S	0,698*	

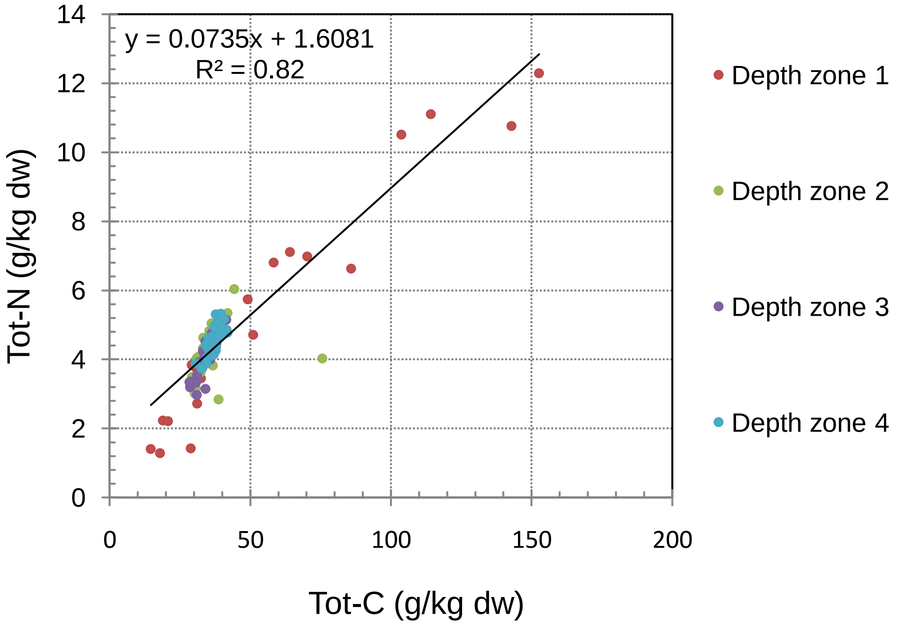


Figure 13. Scatterplot of the relationship between tot-C and tot-N in the different depth zones. Linear regression line is based on data from the whole lake.

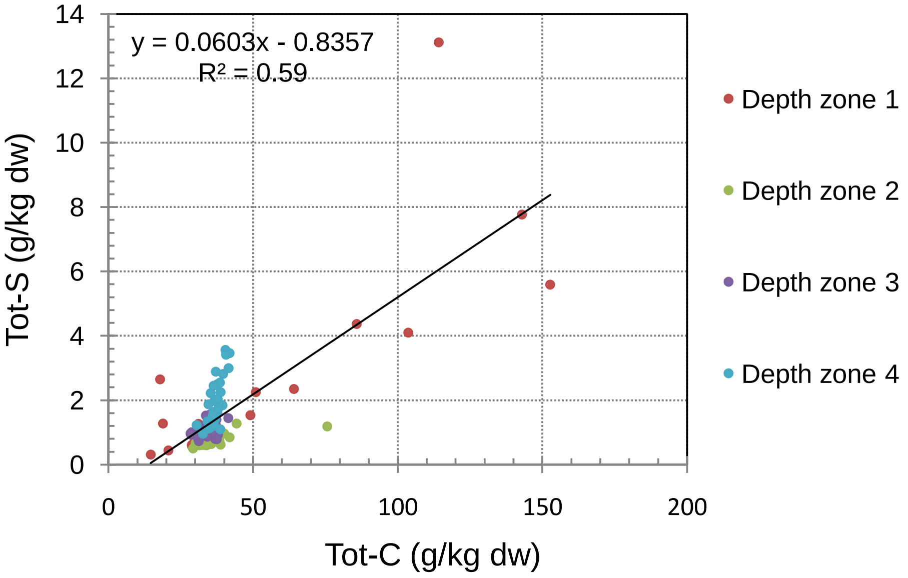


Figure 14. Scatterplot of the relationship between tot-C and tot-S in the different depth zones. Linear regression line is based on data from the whole lake.

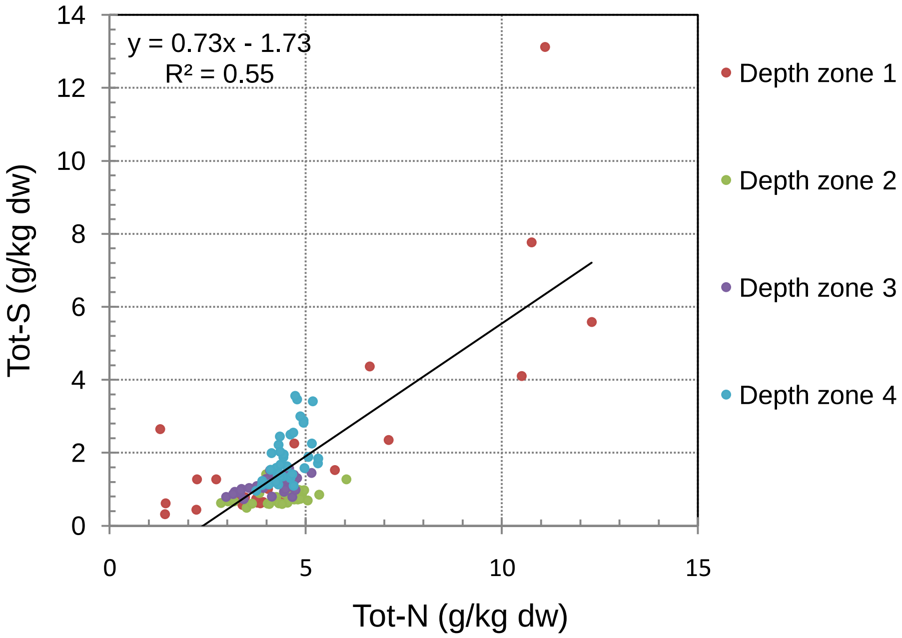


Figure 15. Scatterplot of the relationship between tot-N and tot-S in the different depth zones. Linear regression line is based on data from the whole lake.

4.4 The relationship between grain size, organic matter and nutrients

The content of tot-C, when grouped after clay content, showed a slight increase with increasing clay content (Figure 16). It was more variation around the median in the groups with the least clay content. Correlations between tot-C and clay content was medium strong and positive for the whole lake (Table 7). It was not significant in depth zones 1 and 2, however positive and stronger than for the whole lake, in zones 3 and 4. The scatterplot (Figure 17) with linear regression line show that clay explains very little of the distribution of tot.-C (R^2 = 2 %).

The distribution of tot-N grouped according to clay content showed a slight positive relationship (Figure 18). The variation around the median was largest in the clay group with less than 50 % clay. The correlation between tot-N and clay was positive and medium strong for the whole lake (Table 7). In the different depth zones, there was strong and positive correlation between tot-N and clay in the three first zones, and medium strong correlation in depth zone 4. However, clay explains very little of tot-N when running a simple linear regression (R^2 = 20 %, Figure 19).

The distribution of tot-S according to groups of clay content shows an increase from the first two groups (<50 and 50-68 % clay) to the third (60-68 % clay), and then a slight decrease (Figure 20). The variation around the median was largest in the two groups containing the most clay (60-69 and >68 % clay). The correlation between tot-S and clay were medium strong and positive for the whole lake (Table 7). When distinguishing between different depth zones, it was revealed that the correlations in the first two depth zones failed the significance test, and the correlations in the remaining were positive and stronger than for the whole lake. Clay explains 16 % of the tot-S distribution (Figure 21).

Table 7. Pearsons correlation coefficient (r) for correlations between tot-N, tot-S and tot-C for the whole lake, and differentiated between different depth zones. * = $p < 0.001$. ** = $p < 0.01$. *** = $p < 0.05$. x = not significant.

Depth zone	*All*	*1*	*2*	*3*	*4*
Parameter			**Clay**		
Tot-N	0.654*	0.809**	0.925*	0.837*	0.535***
Tot-S	0.499*	0.436x	0.477x	0.556***	0.419x
Tot-C	0.520*	0.509x	0.415x	0.666**	0.716*

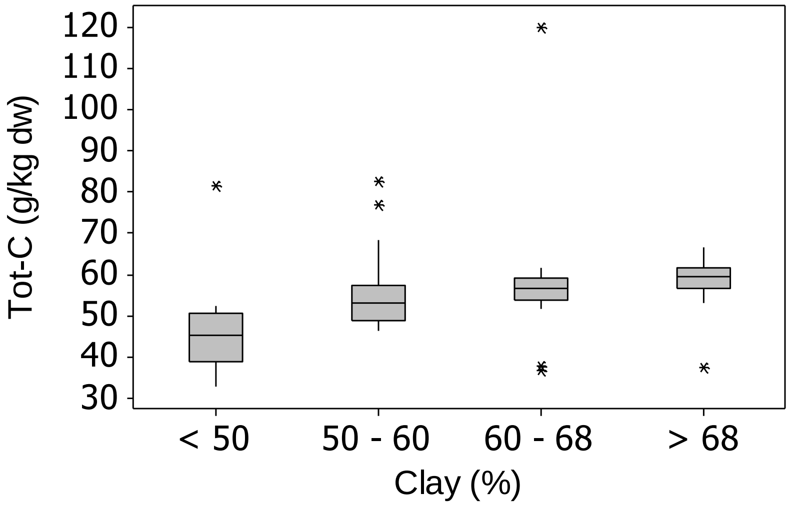


Figure 16. Boxplot of the distribution of tot-C (g/kg dw) according to different groups of clay (%). The box represents the middle 50 % of the data (interquartile range box). Horizontal lines represent first quartile (bottom line of box) median (midline) and third quartile (top line). Vertical lines (whiskers) represent minimum and maximum data point within 1.5 box heights from the bottom of the box. The outliers are represented by dots and are datapoints that falls beyond the upper or lower whisker (Minitab inc. 2007).

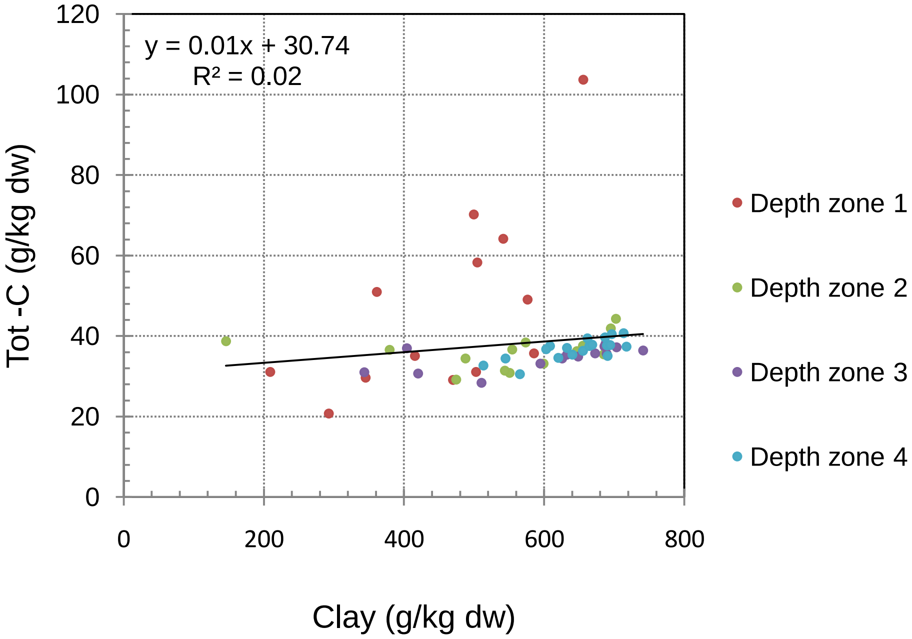


Figure 17. Scatterplot showing the relationship between clay and tot-C in the different depth zones. The regression line is for the whole lake.

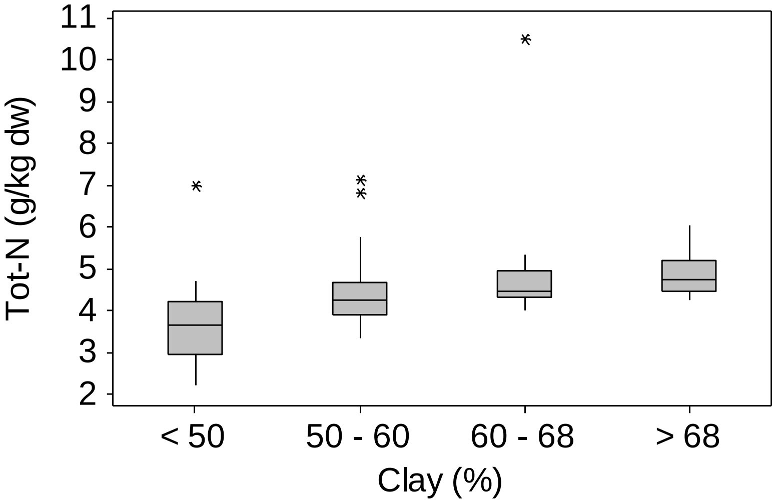


Figure 18. Boxplot of the distribution of tot-N (g/kg dw) according to different groups of clay (%).The box represents the middle 50 % of the data (interquartile range box). Horizontal lines represent first quartile (bottom line of box) median (midline) and third quartile (top line). Vertical lines (whiskers) represent minimum and maximum data point within 1.5 box heights from the bottom of the box. The outliers are represented by dots and are datapoints that falls beyond the upper or lower whisker (Minitab inc. 2007).

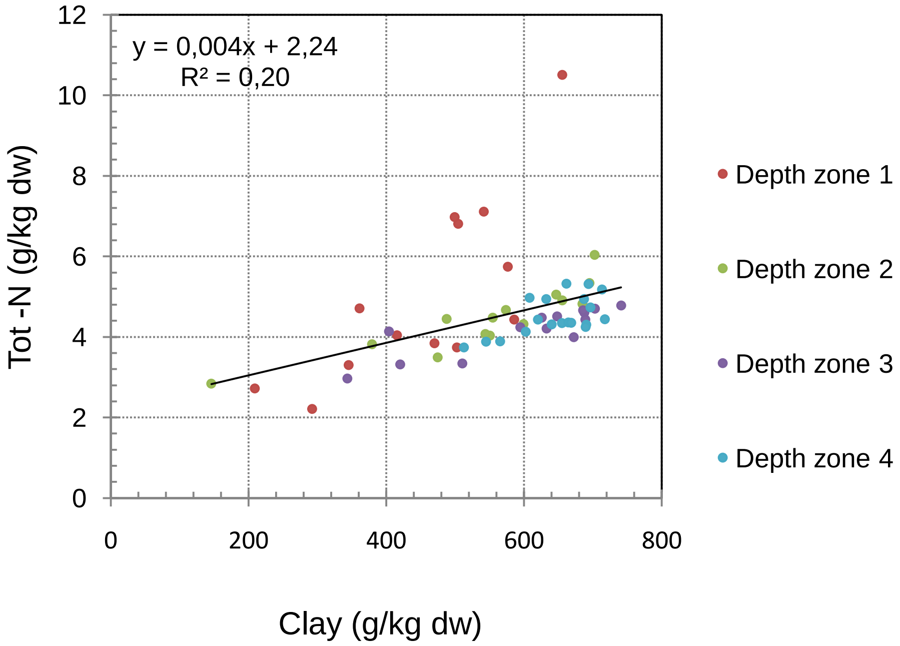


Figure 19. Scatterplot showing the relationship between clay and tot-N in the different depth zones. The regression line is for the whole lake.

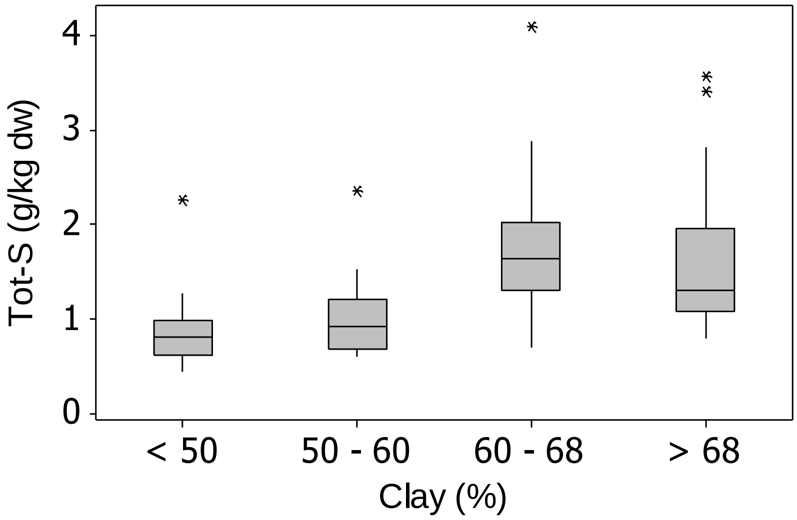


Figure 20. Boxplot of the distribution of tot-S (g/kg dw) according to different groups of clay (%).The box represents the middle 50 % of the data (interquartile range box). Horizontal lines represent first quartile (bottom line of box) median (midline) and third quartile (top line). Vertical lines (whiskers) represent minimum and maximum data point within 1.5 box heights from the bottom of the box. The outliers are represented by dots and are datapoints that falls beyond the upper or lower whisker (Minitab inc. 2007).

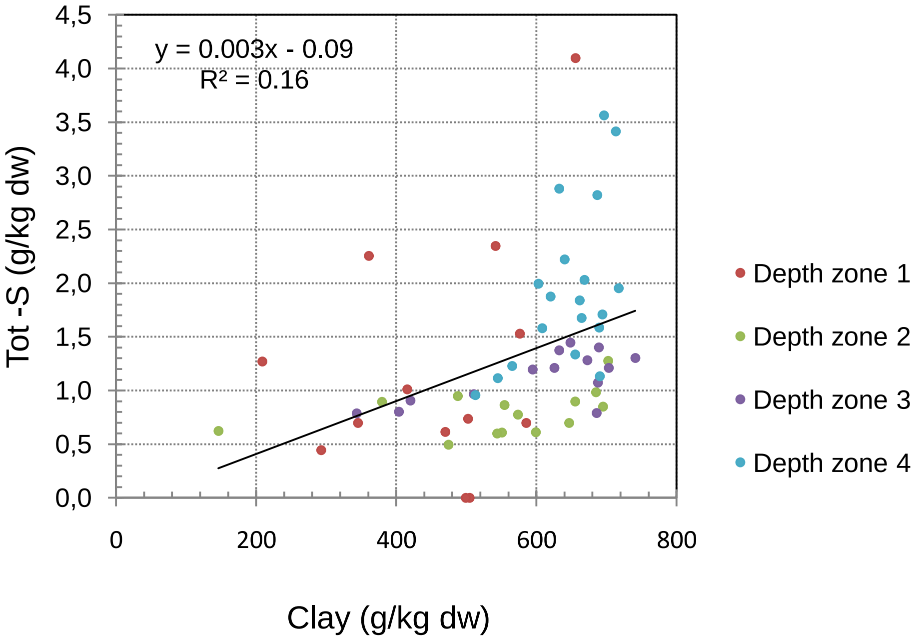


Figure 21. Scatterplot showing the relationship between clay and tot-S in the different depth zones. The regression line is for the whole lake.

5. Discussion

5.1 Horizontal distribution

All parameters show larger variation around the mean in the littoral zone (Figure 5, Figure 6, Figure 7, Figure 8). This is in accordance with findings in Swedish lakes (Håkanson 1981a), where the variation in shallow areas was found to be related to the variation of sediment processes in these areas. Erosion, transportation and accumulation of fine sediments can occur there. The relatively similar distribution between the parameters can be attributed to the sedimentation of so called 'carrier-particles' (Håkanson 1977, referred by Håkanson 1981a). This means that a lot of contaminants (e.g. nutrients) are bound to particles and follow the sedimentation patterns of those.

There was a location of higher accumulation of all parameters near the inlet Vollebekken/Brønnerudbekken in the south part of the lake. This is probably related to the wetland with high production south of the lake.

The locations of higher accumulation in the northern part of the lake are not as easily explained. It could be related to features in the drainage area, or that these locations are on very shallow water depths (numbers 36 and 39 1.50 and 1.76 meters, accordingly). This, perhaps in combination with area use in immediate surroundings, could contribute to the high accumulation of the parameters there. Flow patterns could also explain differentiated accumulation (Sly 1978). There is no such information available for Lake Årungen. Thus, lack of information makes it difficult to conclude on the reason for the higher accumulation locations in the northern part.

5.2 Relative horizontal distribution

The mean C:N ratio (Figure 9) is 8.7 and most of the lake, when excluding the littoral, has a C:N ratio below 10. In the northern part of the lake, the ratio is below 8 and the rest is between 8 and 10. Organic matter that originates from autochtonous production are found to have C:N ratios between 3 and 9 (based on weight) and organic matter with allochtonous origin have C:N ratios above 17 (based on weight) (Meyers & Teranes 2001). This is to be expected, since Lake Årungen is an eutrophic lake and thus high production within the lake. The higher C:N ratios near shore are probably related to runoff from land. Most of the points of medium to high accumulation are near inlets (except number 85). Of those, only the one near Smebølbekken is above 17.5. The surrounding area is wetland with high production, and thus the sediments near the inlet will be dominated by allochtonous organic matter. The other locations that are near inlets are probably more diluted by organic matter from within the lake, but still, one can see that the allocthonous element is higher near inlets, than in the rest of the lake. The reason for the high accumulation near sample location 85 is unknown.

The N:P ratio in the sediments is much lower than what has been found in the water. In the period 1980-2000 it was measured N:P ratios between 40 and 80 (Romarheim & Riise 2009). This could perhaps be due to sediment processes of denitrification that is not investigated in this study.

The Redfield ratio in plankton are found to be C:N:P = 106:16:1 (by mass) (Redfield 1958). The recalculated weight based ratio is 41:7:1. In the sediments of Lake Årungen, this is lower (25:3:1, Figure 10; Figure 11). What this means has not been investigated further in this study.

The C:S ratio (Figure 12) of Lake Årungen is much more variable than the other ratios. The C:S ratio can tell something about the oxic conditions at the sediment water interface. Elevated tot-S content and low C:S values are found in locations that have had anoxic episodes (Rosenbauer et al. 2009).

From the map, it seems like the correlation between C:S and depth should be higher than it was. This is probably because of the variation in zone 1. A new correlation was thus conducted, leaving out zone 1. The correlations between C:S and depth increased considerable ($r = 0.869$, $p<0.001$). Thus, it can be concluded that it is a strong negative correlation between C:S and lake water depth, when leaving out the littoral zone, represented here by zone 1.

5.3 The importance of organic matter and sediment characteristics

Organic matter seems to explain more of the tot-N distribution than the tot-S distribution. Thus, there is probably not as much organic S in the sediments as organic N. The content of organic matter are not at all explained by the content of clay (R^2 = 2 %, Figure 17). From the correlations there seems to be more relationship between organic matter and clay in the profundal (zone 3 and 4). There are often most clay in the profundal (Davis & Brubaker 1973), that might be the reason for the significant correlation here.

5.4 Changes in the last 30 years

The mean content of tot-C (Figure 6) was found to be 36.99 g/kg dw in the deepest part of the lake (zone 4). The lake mean was 39.51 g/kg dw. Around 1980, the content of the upper three centimeters were circa 65 g/kg dw. Thus, the content of organic matter has decreased considerably since then.

The decrease in organic matter could be caused by the decreased algal production in the lake, and thus production of less organic matter, or less organic matter supplies to the lake. The C:N ratio (Figure 9) in the deepest part of the lake was around 8.13 (weight), 30 years ago (Skogheim & Erlandsen 1984). This is similar to what is found in the deepest part of the lake (zone 4) today (8.18 based on weight). The organic matter was thus mostly autochtonous in origin 30 years ago as well, and this could suggest that the decrease in organic matter is caused by decreased algal growth.

The mean variation content of tot-N (Figure 7) was found to be 4.54 g/kg dw in the deepest part of the lake (depth zone four), which corresponds to the lake's mean value (4.51 g/kg dw). The content of tot-N in 1984 (Skogheim & Erlandsen 1984) was found to be about 8 g/kg dw in the upper three centimeters. The lower content today corresponds to the tot-N content back in the 1960s, according to dating using the ^{137}Cs-activity in the sediments (Skogheim & Erlandsen 1984). This could reflect that the measures in the drainage area have been successful in decreasing the loadings of N to the lake. The N:P ratio of the lake sediments in the deepest part of the lake (zone 4) today (2.30, based on weight) is smaller than 30 years ago (about 4, based on weight). This means that there is less N relative to P now than before. Thus, there must have been a decrease of nitrogen supply to the lake's sediments relative to the supplies of phosphorus.

The content of tot-S (Figure 8) show similar development as the other parameters. The mean content in depth zone four was 1.89 g/kg dw, just a little more than the lake's mean of 1.52 g/kg dw. Thirty years ago, this was about 11 g/kg dw in the top three centimeters of the lake. The tot-S content of today corresponds to the content around 1950. The decrease could reflect better conditions in the lake, i.e. fewer episodes of anoxic conditions. The decrease of atmospheric loading of S is probably also a reason for the decrease, or a combination of both.

The values from 30 years ago are based on two cores at 13 meters water depth, while the values from this study are based on several cores (n = 37). This might make the comparison uncertain. Another uncertainty is differences in analyzing methods (Skogheim 1978; Skogheim & Erlandsen 1984). However, since similar values are found in two studies around 1980s, one of them using several cores (Skogheim 1978), it is fairly reasonable to conclude that it has been a decrease in the content of organic matter, tot-N and tot-S in the last 30 years.

5.5 Evaluation of methods and fieldwork

In retrospect there are some issues that could make the results better, or that could be a source of errors. During fieldwork, some locations, especially in the littoral zone, had to be moved because it was almost impossible to collect samples (Appendix 7). This was due to two things, either too shallow water depth, or rocks at the bottom instead of sediment. In addition, some of the samples had living creatures or other non-sediment objects (Appendix 7). Some of these were deleted (7 and 33), and some were not. The higher values made such big impact on the maps that some of the variation got lost. This may or may not have been a good decision. However, the high number of samples makes it possible to delete samples without decreasing the prediction value.

In the chemical analyses, there is always a chance of contamination. This is, however, not as an important source of error in analyses sediment as in analyses of water. The reason for this is that in a water sample, most substances are dissolved in the water. In the sediments, most of the substances are incorporated into the mineral structures, and contamination that leads to changes in concentration is not as easily attained (personal comment, Tore Krogstad[3] 2010).

Regarding the maps, there are numerous ways to divide the different classes of values. This affects to some degree how the impression of the distribution is to the viewer. This is especially true for the variation. Some variation may not be visible because of an unfortunate division. The categories are to some degree chosen to get as much of the variation as possible. However, there is always room for improvement.

The variables used in the statistics were more or less normally distributed (Figure 5; Figure 6; Figure 7; Figure 8). Because of the variation in accumulation in the

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lake sediments, there were a lot of outliers that potentially could influence the results. This is avoided in the correlation because the data was ranked. The paired t-test is often valid, even when the assumption of normality is not fulfilled. However, the simple linear regression that was conducted in Microsoft Office Excel, are probably influenced by the fact that the outliers get too much influence on the model. The findings here can thus only be used to see trends, and regression models should be fitted that deletes variables with high leverage and deviating residuals to secure an adequate model (Montgomery et al. 2006).

The zonation of the lake is based on the bathygraphical curve and does not take into consideration the sediment processes in the lake, because those have not been mapped. This could be a source of error in that the division probably does not correspond to the zones of sediment processes in the lake.

6. Conclusion

In this study the sediments of Lake Årungen has been mapped in terms of the content of organic matter, nitrogen and sulfur and the relative distribution patterns of those. This thesis has a limited scope, and thus it is not room for making strong conclusions. There are however, some trends that are worth mentioning. The most important finding is that there seems to have been a decrease in the content of all parameters. This could indicate that measures in the drainage area to reduce the supplies of nutrients and erosion products have been, to some degree, successful.

There can be great variation between and within different depth zones. There seems to be consistently more variation in the littoral zone. The C:S ratio increases with increased depth, and this is probably due to anoxic episodes being more common in the profundal zone. Organic matter seems to explain a great deal of the distribution of tot-N, and only a part of the distribution of tot-S. The correlations between organic matter and the nutrients are similar in strength to the regression line, which confirms the relationship between organic matter and the nutrients. There is, however, variation in the different zones, for tot-S in particular. The relationship between clay and the parameters are highly variable in different zones and consistently poor in explanation power (R^2).

The zonation of the lake revealed differences, sometimes huge, between different depth zones. The next step would be to find the zones of accumulation, erosion and transportation according to Håkanson & Jansson (Håkanson & Jansson 2002) and further research should explore relationships between parameters in the different zones. Especially is the organic matter a key agent in binding nutrients and toxics. The binding capacity to toxic is further explored in Zambon (2010).

The findings could be put into a bigger context by relating to information on parameters in the water and additional information about the drainage area. Lake Årungen is one of the most studied lakes in Norway, and a PhD-student (Romarheim 2010) systematizes at the time of writing these studies and samples done over decades. In addition to the already existing data on Lake Årungen, a mapping of the flow patterns could be valuable to better understand the sediment processes in the lake.

The implication for management is enhanced knowledge about accumulation patterns and locations that should be investigated further. For example could the C:S ratio distribution give important information about locations were there might be more phosphorus leakage than other locations. Also, the C:N ratio plotted against tot-N content, as done by Mackereth (1966) and Hendricks & Silvey (1973) could give information on the correlation between tot-N and organic matter and to suggest if the relative content of ammonia is large or small (Hendricks & Silvey 1973).

This study is only one small part of the mapping of the sediments of Lake Årungen. The findings from this study combined with the findings of the other students (Reierstad 2010; Rutsinda 2010; Zambon 2010), will give a good basis to further investigations on the processes of the sediments in Lake Årungen.

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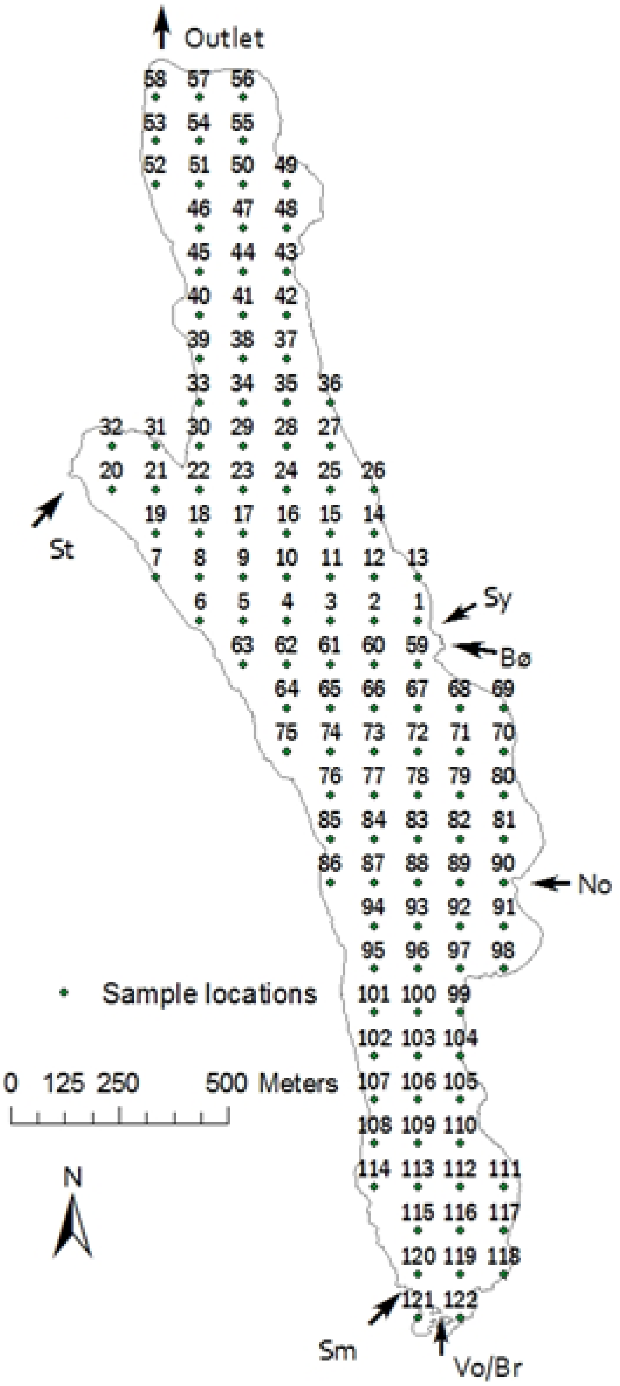
Appendices

Appendix 1. The distribution of the sample locations.



Appendix 2. The coordinates of the sample locations

Nr.	Coordinates	*Nr.*	Coordinates	*Nr.*	Coordinates
1	32 V 598420 6618155	*44*	32 V 598020 6618955	*87*	32 V 598320 6617555
2	32 V 598320 6618155	*45*	32 V 597920 6618955	*88*	32 V 598420 6617555
3	32 V 598220 6618155	*46*	32 V 597920 6619055	*89*	32 V 598520 6617555
4	32 V 598120 6618155	*47*	32 V 598020 6619055	*90*	32 V 598620 6617555
5	32 V 598020 6618155	*48*	32 V 598120 6619055	*91*	32 V 598620 6617455
6	32 V 597920 6618155	*49*	32 V 598120 6619155	*92*	32 V 598520 6617455
7	32 V 597820 6618255	*50*	32 V 598020 6619155	*93*	32 V 598420 6617455
8	32 V 597920 6618255	*51*	32 V 597920 6619155	*94*	32 V 598320 6617455
9	32 V 598020 6618255	*52*	32 V 597820 6619155	*95*	32 V 598320 6617355
10	32 V 598120 6618255	*53*	32 V 597820 6619255	*96*	32 V 598420 6617355
11	32 V 598220 6618255	*54*	32 V 597920 6619255	*97*	32 V 598520 6617355
12	32 V 598320 6618255	*55*	32 V 598020 6619255	*98*	32 V 598620 6617355
13	32 V 598420 6618255	*56*	32 V 598020 6619355	*99*	32 V 598520 6617255
14	32 V 598320 6618355	*57*	32 V 597920 6619355	*100*	32 V 598420 6617255
15	32 V 598220 6618355	*58*	32 V 597820 6619355	*101*	32 V 598320 6617255
16	32 V 598120 6618355	*59*	32 V 598420 6618055	*102*	32 V 598320 6617155
17	32 V 598020 6618355	*60*	32 V 598320 6618055	*103*	32 V 598420 6617155
18	32 V 597920 6618355	*61*	32 V 598220 6618055	*104*	32 V 598520 6617155
19	32 V 597820 6618355	*62*	32 V 598120 6618055	*105*	32 V 598520 6617055
20	32 V 597720 6618455	*63*	32 V 598020 6618055	*106*	32 V 598420 6617055
21	32 V 597820 6618455	*64*	32 V 598120 6617955	*107*	32 V 598320 6617055
22	32 V 597920 6618455	*65*	32 V 598220 6617955	*108*	32 V 598320 6616955
23	32 V 598020 6618455	*66*	32 V 598320 6617955	*109*	32 V 598420 6616955
24	32 V 598120 6618455	*67*	32 V 598420 6617955	*110*	32 V 598520 6616955
25	32 V 598220 6618455	*68*	32 V 598520 6617955	*111*	32 V 598620 6616855
26	32 V 598320 6618455	*69*	32 V 598620 6617955	*112*	32 V 598520 6616855
27	32 V 598220 6618555	*70*	32 V 598620 6617855	*113*	32 V 598420 6616855
28	32 V 598120 6618555	*71*	32 V 598520 6617855	*114*	32 V 598320 6616855
29	32 V 598020 6618555	*72*	32 V 598420 6617855	*115*	32 V 598420 6616755
30	32 V 597920 6618555	*73*	32 V 598320 6617855	*116*	32 V 598520 6616755
31	32 V 597820 6618555	*74*	32 V 598220 6617855	*117*	32 V 598620 6616755
32	32 V 597720 6618555	*75*	32 V 598120 6617855	*118*	32 V 598620 6616655
33	32 V 597920 6618655	*76*	32 V 598220 6617755	*119*	32 V 598520 6616655
34	32 V 598020 6618655	*77*	32 V 598320 6617755	*120*	32 V 598420 6616655
35	32 V 598120 6618655	*78*	32 V 598420 6617755	*121*	32 V 598420 6616555
36	32 V 598220 6618655	*79*	32 V 598520 6617755	*122*	32 V 598520 6616555
37	32 V 598120 6618755	*80*	32 V 598620 6617755		
38	32 V 598020 6618755	*81*	32 V 598620 6617655		
39	32 V 597920 6618755	*82*	32 V 598520 6617655		
40	32 V 597920 6618855	*83*	32 V 598420 6617655		
41	32 V 598020 6618855	*84*	32 V 598320 6617655		
42	32 V 598120 6618855	*85*	32 V 598220 6617655		
43	32 V 598120 6618955	*86*	32 V 598220 6617555		

Appendix 3. Dry weight (%)

Nr.	Dry weight (%)	*Nr.*	Dry weight (%)	*Nr.*	Dry weight (%)
1	43.37	*44*	24.91	*87*	26.41
2	30.59	*45*	21.59	*88*	27.14
3	28.06	*46*	22.18	*89*	34.24
4	28.58	*47*	23.64	*90*	28.22
5	23.98	*48*	20.08	*91*	23.36
6	23.86	*49*	19.87	*92*	27.90
7	13.47	*50*	22.4	*93*	28.20
8	24.76	*51*	23.37	*94*	26.05
9	26.53	*52*	20.23	*95*	25.03
10	27.34	*53*	20.62	*96*	27.58
11	28.69	*54*	22.8	*97*	23.11
12	29.98	*55*	20.54	*98*	21.35
13	35.92	*56*	21.04	*99*	21.08
14	41.82	*57*	21.23	*100*	31.08
15	29.56	*58*	21.51	*101*	23.54
16	28.24	*59*	30.25	*102*	20.99
17	26.99	*60*	28.67	*103*	31.29
18	26.39	*61*	28.75	*104*	21.78
19	25.77	*62*	24.37	*105*	22.87
20	26.09	*63*	24.02	*106*	32.54
21	30.6	*64*	22.86	*107*	24.93
22	25.86	*65*	27.99	*108*	22.09
23	26.81	*66*	27.7	*109*	31.62
24	28.79	*67*	29.17	*110*	31.48
25	28.28	*68*	27.63	*111*	24.15
26	28.89	*69*	17.68	*112*	37.95
27	26.74	*70*	25.5	*113*	30.09
28	27.87	*71*	28.22	*114*	23.62
29	24.17	*72*	27.82	*115*	37.80
30	23.02	*73*	26.59	*116*	36.24
31	29.24	*74*	28.05	*117*	17.13
32	34.95	*75*	21.89	*118*	20.94
33	24.82	*76*	23.99	*119*	26.78
34	26.05	*77*	26.21	*120*	22.80
35	26.02	*78*	28.21	*121*	8.93
36	15.06	*79*	29.78	*122*	11.49
37	23.85	*80*	31.13		
38	26.24	*81*	38.75		
39	14.57	*82*	28.94		
40	19.31	*83*	26.78		
41	24.61	*84*	26.44		
42	23.15	*85*	49.82		
43	21.34	*86*	24.44		

Appendix 4. Table with the values for the Certified reference material. **Green**: the values that are within the value of the CRM and its uncertainty (good accuracy); **yellow**: the values that differs with x 2 the uncertainty (satisfying); **red**: values that are within the value were the uncertainty is x 3 or more (not satisfying). **white:** no reference available

CRM	sediment	S (g/kg dw)
River Sediment	Average (n=5)	3.70 ± 0.89
	CRM content	
Estuarine Sediment	Average (n=2)	10.3
	CRM content	
Mess 1	Average (n=2)	7.41
	CRM content	7.2 ± 0.5
Best 1	Average (n=2)	1.84
Bcss 1	Amount (n=1)	4.01
	CRM content	3.6 ± 0.5

Appendix 5. Descriptive statistics depth, tot-N, tot-S, tot-C and LOI. The whole lake and different depth zones.

Depth zone	**Var.**		**Sed. depth (cm)**	**N**	**Mean**	**SE mean**	**St. dev.**	**Min.**	**Max.**
All	Depth	(m)	-	120	8.25	0.35	3.85	0.75	13.42
	Tot-N	(g kg^{-1} dw)	0.0-2.5	120	4.87	0.13	1.39	1.88	11.24
	Tot-N	(g kg^{-1} dw)	2.5-5.0	120	4.51	0.14	1.55	1.29	12.29
	Tot-S	(g kg^{-1} dw)	0.0-2.5	120	1.15	0.10	1.11	0.39	7.69
	Tot-S	(g kg^{-1} dw)	2.5-5.0	118	1.52	0.14	1.15	0.32	13.12
	Tot-C	(g kg^{-1} dw)	0.0-2.5	120	42.06	1.87	20.49	20.93	157.90
	Tot-C	(g kg^{-1} dw)	2.5-5.0	120	39.51	1.75	19.17	14.61	152.70
	LOI	(g kg^{-1} dw)	0.0-2.5	120	110.24	3.32	36.42	52.00	286.66
	LOI	(g kg^{-1} dw)	2.5-5.0	120	105.10	3.14	34.40	38.81	295.84
1	Depth	(m)	-	25	2.44	0.18	0.92	0.75	3.98
	Tot-N	(g kg^{-1} dw)	0.0-2.5	25	5.70	0.49	2.45	1.88	11.24
	Tot-N	(g kg^{-1} dw)	2.5-5.0	25	5.11	0.64	3.18	1.29	12.29
	Tot-S	(g kg^{-1} dw)	0.0-2.5	25	2.13	0.43	2.13	0.39	7.69
	Tot-S	(g kg^{-1} dw)	2.5-5.0	23	2.35	0.63	3.02	0.32	13.12
	Tot-C	(g kg^{-1} dw)	0.0-2.5	25	58.75	7.45	37.27	20.93	157.90
	Tot-C	(g kg^{-1} dw)	2.5-5.0	25	52.29	7.75	38.77	14.61	152.70
	LOI	(g kg^{-1} dw)	0.0-2.5	25	130.80	13.10	65.50	52.00	283.90
	LOI	(g kg^{-1} dw)	2.5-5.0	25	118.7	14.30	71.60	38.80	295.80
2	Depth	(m)	-	29	6.32	0.24	1.29	4.06	8.44
	Tot-N	(g kg^{-1} dw)	0.0-2.5	29	4.72	0.15	0.78	3.22	6.73
	Tot-N	(g kg^{-1} dw)	2.5-5.0	29	4.36	0.13	0.70	2.84	6.04
	Tot-S	(g kg^{-1} dw)	0.0-2.5	29	0.77	0.05	0.26	0.56	1.98
	Tot-S	(g kg^{-1} dw)	2.5-5.0	29	0.80	0.04	0.22	0.49	1.41
	Tot-C	(g kg^{-1} dw)	0.0-2.5	29	40.65	2.99	16.10	31.08	121.10
	Tot-C	(g kg^{-1} dw)	2.5-5.0	29	36.93	1.53	8.23	29.21	75.60
	LOI	(g kg^{-1} dw)	0.0-2.5	29	108.36	6.71	36.13	74.56	286.66
	LOI	(g kg^{-1} dw)	2.5-5.0	29	100.44	2.86	15.41	69.10	148.13
3	Depth	(m)	-	29	9.90	0.16	0.86	8.51	11.27
	Tot-N	(g kg^{-1} dw)	0.0-2.5	29	4.56	0.20	1.79	3.00	7.33
	Tot-N	(g kg^{-1} dw)	2.5-5.0	29	4.12	0.11	0.60	2.97	5.15
	Tot-S	(g kg^{-1} dw)	0.0-2.5	29	0.72	0.02	0.10	0.55	0.98
	Tot-S	(g kg^{-1} dw)	2.5-5.0	29	1.12	0.04	0.24	0.73	1.57
	Tot-C	(g kg^{-1} dw)	0.0-2.5	29	35.97	0.62	3.34	29.46	41.23
	Tot-C	(g kg^{-1} dw)	2.5-5.0	29	34.31	0.59	3.17	28.39	41.44
	LOI	(g kg^{-1} dw)	0.0-2.5	29	100.98	2.02	10.89	77.99	118.60
	LOI	(g kg^{-1} dw)	2.5-5.0	29	98.71	1.91	10.27	80.60	115.34
4	Depth	(m)	-	37	12.39	0.10	0.59	11.35	13.42
	Tot-N	(g kg^{-1} dw)	0.0-2.5	37	4.67	0.10	0.63	3.65	6.98
	Tot-N	(g kg^{-1} dw)	2.5-5.0	37	4.54	0.07	0.40	3.74	5.32
	Tot-S	(g kg^{-1} dw)	0.0-2.5	37	1.12	0.05	0.27	0.74	1.75
	Tot-S	(g kg^{-1} dw)	2.5-5.0	37	1.89	0.12	0.72	0.96	3.56
	Tot-C	(g kg^{-1} dw)	0.0-2.5	37	37.10	0.28	1.71	32.52	39.79
	Tot-C	(g kg^{-1} dw)	2.5-5.0	37	36.99	0.39	2.35	30.49	41.92
	LOI	(g kg^{-1} dw)	0.0-2.5	37	105.10	0.86	5.24	94.81	115.23
	LOI	(g kg^{-1} dw)	2.5-5.0	37	104.62	1.10	6.67	89.19	115.13

Appendix 6. Descriptive statistics, reduced dataset. LOI_{corr}, clay, tot-N, tot-S, and tot-C

Depth Zone	**Parameter**		**Layer (cm)**	**N**	**Mean**	**SE mean**	**St. dev.**	**Min.**	**Max.**
All	LOI^{corr}	(g kg^{-1} dw)	0-2.5	60	68.59	2.95	22.85	45.89	201.08
	LOI^{corr}	(g kg^{-1} dw)	2.5-5.0	60	65.01	2.61	20.25	35.92	61.70
	Clay	(%)	-	60	57.1	1.7	13.3	14.6	74.1
	Tot-N	(g kg^{-1} dw)	0.0-2.5	60	4.86	0.16	1.25	3.00	11.24
	Tot-N	(g kg^{-1} dw)	2.5-5.0	60	4.54	0.16	1.20	2.21	10.51
	Tot-S	(g kg^{-1} dw)	0.0-2.5	60	1.04	0.09	0.69	0.56	5.19
	Tot-S	(g kg^{-1} dw)	2.5-5.0	58	1.37	0.10	0.79	0.44	4.10
	Tot-C	(g kg^{-1} dw)	0.0-2.5	60	40.17	1.68	13.00	28.11	115.50
	Tot-C	(g kg^{-1} dw)	2.5-5.0	60	38.29	1.50	11.63	20.71	103.70
1	LOI^{corr}	(g kg^{-1} dw)	0.0-2.5	13	90.70	11.50	41.60	50.50	201.1
	LOI^{corr}	(g kg^{-1} dw)	2.5-5.0	13	80.10	10.93	39.30	35.90	174
	Clay	(%)	-	13	45.8	3.5	12.8	20.9	65.6
	Tot-N	(g kg^{-1} dw)	0.0-2.5	13	5.71	0.57	2.05	3.92	11.24
	Tot-N	(g kg^{-1} dw)	2.5-5.0	13	5.09	0.63	2.28	2.21	10.51
	Tot-S	(g kg^{-1} dw)	0.0-2.5	13	1.56	0.36	1.29	0.56	5.19
	Tot-S	(g kg^{-1} dw)	2.5-5.0	11	1.43	0.33	1.10	0.44	4.10
	Tot-C	(g kg^{-1} dw)	0.0-2.5	13	51.68	6.86	24.72	28.11	115.50
	Tot-C	(g kg^{-1} dw)	2.5-5.0	13	46.83	6.35	22.88	20.71	103.70
2	LOI^{corr}	(g kg^{-1} dw)	0.0-2.5	14	65.70	2.01	7.54	52.18	76.64
	LOI^{corr}	(g kg^{-1} dw)	2.5-5.0	14	62.49	2.11	7.88	49.54	75.79
	Clay	(%)	-	14	55.0	4.0	14.9	14.6	70.3
	Tot-N	(g kg^{-1} dw)	0.0-2.5	14	4.66	0.17	0.62	3.28	5.66
	Tot-N	(g kg^{-1} dw)	2.5-5.0	14	4.45	0.21	0.80	2.84	6.04
	Tot-S	(g kg^{-1} dw)	0.0-2.5	14	0.76	0.04	0.14	0.56	1.11
	Tot-S	(g kg^{-1} dw)	2.5-5.0	14	0.79	0.06	0.21	0.49	1.28
	Tot-C	(g kg^{-1} dw)	0.0-2.5	14	38.05	1.09	4.08	31.70	47.05
	Tot-C	(g kg^{-1} dw)	2.5-5.0	14	36.06	1.11	4.17	29.21	44.31
3	LOI^{corr}	(g kg^{-1} dw)	0.0-2.5	14	60.97	1.89	7.06	45.89	71.10
	LOI^{corr}	(g kg^{-1} dw)	2.5-5.0	14	59.11	1.54	5.76	49.00	68.35
	Clay	(%)	-	14	59.7	3.4	12.6	34.4	74.1
	Tot-N	(g kg^{-1} dw)	0.0-2.5	14	4.54	0.29	1.10	3.00	7.05
	Tot-N	(g kg^{-1} dw)	2.5-5.0	14	4.17	0.15	0.57	2.97	4.78
	Tot-S	(g kg^{-1} dw)	0.0-2.5	14	0.70	0.02	0.07	0.58	0.82
	Tot-S	(g kg^{-1} dw)	2.5-5.0	14	1.12	0.06	0.23	0.79	1.45
	Tot-C	(g kg^{-1} dw)	0.0-2.5	14	36.03	0.88	3.30	29.46	39.26
	Tot-C	(g kg^{-1} dw)	2.5-5.0	14	34.67	0.77	2.89	28.39	38.19
4	LOI^{corr}	(g kg^{-1} dw)	0.0-2.5	19	61.22	0.97	4.22	54.48	68.75
	LOI^{corr}	(g kg^{-1} dw)	2.5-5.0	19	60.85	1.21	5.28	52.25	69.66
	Clay	(%)	-	19	64.6	1.3	5.8	51.3	71.8
	Tot-N	(g kg^{-1} dw)	0.0-2.5	19	4.66	0.15	0.67	3.78	6.98
	Tot-N	(g kg^{-1} dw)	2.5-5.0	19	4.52	0.11	0.48	3.74	5.32
	Tot-S	(g kg^{-1} dw)	0.0-2.5	19	1.13	0.07	0.31	0.74	1.75
	Tot-S	(g kg^{-1} dw)	2.5-5.0	19	1.94	0.17	0.75	0,96	3.56
	Tot-C	(g kg^{-1} dw)	0.0-2.5	19	36.90	0.37	1.63	32.78	39.30
	Tot-C	(g kg^{-1} dw)	2.5-5.0	19	36.77	0.59	2.59	30.49	40.67

Appendix 7. Notes on sources of error from fieldwork

Nr.	**Water depth (m)**	**Note**
6	2.54	Shell in sediment
7	1.10	Moved ten meters towards sample location 8
13	2.32	Clam (alive) moved ten meters towards sample location 12
14	3.07	Moved five meters towards sample location 26
26	2.93	Moved 20 meters towards sample location 25
30	6.06	Moved 20 meters towards sample location 29
33	1.31	Roots and stones
42	7.84	Hard bottom
58	5.01	Fluffy at the surface of sediment
107	2.60	Shell in sediment