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Mercury, lead and cadmium in fish from Lake Norsjø, Southern Norway

Clara Enedina Moreno Vicente

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Universidad Autonoma de Madrid

Mälardalen University Sweden

Arts and Sciences
Hallvard Eikas plass, 3800 Bø

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Authors:	Clara Enedina Moreno Vicente
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Telemark University College
Faculty of Arts and Sciences
Department of Environment and Health Studies
Hallvard Eikas plass
3800 Bø i Telemark

http://www.hit.no

Content

Abstract

Concentrations of mercury (Hg), cadmium (Cd) and lead (Pb) have been investigated in whitefish *(Coregonus lavaretus*, n = 41*)*, European smelt *(Osmerus eperlanus*, n = 29*)*, Arctic char *(Salvelinus alpinus*, n = 27*)*, perch *(Perca fluviatilis*, n = 26), brown trout *(Salmo trutta*, n = 22*)*, Atlantic salmon *(Salmo salar*, n = 14*)*, northern pike *(Esox lucius*, n = 11), tench *(Tinca tinca*, n = 4*)* and crucian carp *(Carassius carassius*, n = 2*)*, in Lake Norsjø, southern Norway. In addition, the stable isotope ratios $\delta^{15}N$ and $\delta^{13}C$ have been analysed to reveal variations in trophic position and carbon source, both within and between fish species. The concentrations of Cd and Pb were far below the consumption limits in Norway, i.e. 0,2 µg Cd/L; 1 µg Pb/L). Only 5,6 % of the analyzed individuals had Pb-concentrations > the detection limit for Pb (0,1 mg Pb/kg ww), while none of the individuals exceeded the detection limits for Cd (0,005 mg Cd/kg ww). The Hg levels varied within and between the fish species. Totally 9 fish had Hg-concentrations above the consumption limit of 0,5 µg Hg/L, 5 pikes, 2 Arctic char, 1 brown trout and 1 European smelt. The highest concentration, 1,44 mg Hg/kg ww, was both measured in a brown trout and a northern pike. The $\delta^{15}N$ and $\delta^{13}C$ values varied from 7,2 ‰ to 13,6 ‰ and -20,2 ‰ to -33,5 ‰ respectively. The results on $\delta^{15}N$ indicate a food web consisting of 4 consumer levels. The $\delta^{13}C$ signatures indicate that Arctic char, European smelt and sub-populations of whitefish primarily feed in the pelagic zone ($\delta^{13}C$ between -28 and -34), while the $\delta^{13}C$ in perch, brown trout and the other sub-population of whitefish had heavier $\delta^{13}C$ signatures, indicating fish feeding in the littoral zone of the lake. All fish species (except Atlantic salmon) exhibit significant correlations ($p < 0,05$) between Hg and age, weight and length. Only adult individuals of Atlantic salmon, returned from the sea to River Skienselva for spawning, were incorporated in the study. Low concentrations and minor variations in the Hg-levels (0,07 – 0,14 mg Hg/kg ww) in this marine derived individuals, are the main reasons for no correlation between Hg and age, weight and length for this species. Within each species, no significant correlations were found between Hg and $\delta^{15}N$, but a weak but significant ($r^2 = 0,074$, $p < 0,001$) positive linear relationship was found when plotting all the fish species together, indicating biomagnification along the food web. The high $\delta^{15}N$ signature in the dwarf population of Arctic char is likely a consequence of low condition factor, as transamination and deamination normally occur during starvation. These processes imply isotope fractionation of nitrogen and consequently a heavier $\delta^{15}N$ signature.

Key words: *heavy metals, $\delta^{15}N$, $\delta^{13}C$, bioaccumulation, fish, lakes, Norway*

Preface

This master thesis is part of the Joint Degree Master Program of Inland Water Quality Assessment, coordinated by the Autonomous University of Madrid (Spain) and Mälardalen University (Sweden). The project has been carried out from September 2008 to August 2009, in Telemark University College (HiT), in the department of Environment and Health Studies, in Bø (Norway).

I am grateful to the supervisor of my thesis, professor Espen Lydersen (HiT), who was abundantly helpful and provided assistance in numerous ways throughout the whole development of the project. Next, I wish to express my gratitude to Bjørn Steen (HiT) for his help and invaluable assistance during the laboratory work of the project, showing countless patience. I would also like to thank professor Jan Heggenes (HiT) for his help with the age measurement of fish.

Finally, I would like to express my greatest thanks to my family, who have always supported me during my years of study abroad, and for their encouragement to continue. Special thanks to my friends and colleagues for their help and understanding through the duration of the project.

I especially dedicate this thesis to my beloved grandfather, Luciano Jesús Vicente Vicente.

Bø, September 1st, 2009

Clara Enedina Moreno Vicente

Main goals

The main goal of this study is to investigate various fish species in Lake Norsjø, Southern Norway and the assessment of health status, trophic position, sources of energy, and content of heavy metals (Hg, Pb and Cd). A sub goal is to compare the heavy metal levels and trophic position data with other lakes, particularly in Norway.

Abbreviations

AMAP	Arctic Monitoring and Assessment Programme
Asl	Above sea level
BAF	Bioaccumulation Factor
BCF	Bioconcentration Factor
EEA	European Economic Area
FAO	Food and Agriculture Organization
IFE	Institute for Energy Technique
JAMP	Joint Assessment and Monitoring Programme
NIVA	Norwegian Institute for Water Research
OSPAR-convention	Convention for the protection of the marine environment of the North-East Atlantic
PDB	Pee Dee Belemnite
Pers. comm.	Personal communication
RID	Riverine inputs and direct discharges to Norwegian coastal water
SFT	Norwegian Pollution Control Authority
TOC	Total Organic Carbon
USEPA	United States Environmental Protection Agency
VPDB	Vienna Pee Dee Belemnite
WFD	Water Framework Directive
WHO	World Health Organization

1 Introduction

1.1 The Water Framework Directive

The Water Framework Directive (WFD) is one of the major directives concerning water management that has been developed in Europe. After years of preparation it finally came to force on December 22nd, 2000. The WFD establishes a legal framework for a common European strategy to protect, maintain or improve the quality of inland surface water, transitional waters, groundwaters and coastal waters throughout Europe, including Norway. The WFD was taken into Norwegian law through the Water Management Regulation Act which is the base for the implementation of the directive.

The main goal of the WFD is to achieve a "good ecological status" across all bodies of water in Europe by 2015. When the Directive is entirely implemented, no water body that is not exempted under the Directive terms will be allowed to deteriorate in terms of quality, quantity or ecological status. Consequently, measures must be adopted to protect the waters and achieve these goals.

The WFD indicates in its text that the purpose of the Directive is to *establish a framework for the protection of inland surface waters which prevents further deterioration and protects and enhances the status of aquatic ecosystems.* The selected metals for this study (Hg, Cd and Pb) and many of the most harmful organic micro-pollutants are included in the list that is given in the Annex VIII of the WFD (Indicative List of the Main Pollutants), which must be analyzed in the waters, and which all Member States shall collect and maintain the information of the type and magnitude.

The Norwegian framework regulation on water management was adopted on December 15th 2006, and it incorporates the WFD into Norwegian law. The Norwegian Parliament approved the incorporation of the WFD into the EEA-agreement on February 12th 2009. (www.vannportalen.no, read April 9th, 2009)

In 2008, important developments were done regarding the Norwegian implementation progress, such as the creation of the Norwegian Water Information System, called Vann-Nett. This tool systematizes and shows updated information on the current state and the development of the ecological status in groundwater, rivers, lakes and coastal water. It was established with the purpose of helping the authorities to manage the water resources in a more holistic way by presenting the data to all stakeholders. Vann-Nett makes it easy to see different pressures in relation to each other. (http://vann-nett.nve.no/, read April 9th, 2009)

1.2 Study area

This master thesis is based on data from Lake Norsjø, located in the county of Telemark, Southern Norway (Figure 1-1). The lake is located a few km from the ocean, 15,3 m asl. It has an elongated shape and it is approximately 30 km long. The lake area is 55,24 km^2 and the catchment area is 10 377,63 km^2. Total volume of the lake is 5 100 m^3, with a mean depth of 87 m and a maximum depth of 171 m.

Figure 1-1. *Location of Lake Norsjø in Southern Norway. (Source: Google Earth)*

The lake is located in the water region of Mid-Telemark, which comprises an area of 4 249,61 km^2, and belongs to the River Basin District of Vest-Viken. Three main rivers enter into the lake, the Gvarv River and Sauar River from the north, and River Eid from west. All the three rivers drain large high mountain areas basically in the Telemark County. The outlet River of Lake Norsjø is the River Skienselva. Lake Norsjø is part of the Telemark Canal, which is a canal that stretches 105 km from Skien to Dalen and it flows through existing lakes in the area, such as Norsjø and this canal is a very popular tourist object.

The stable and good climate around Lake Norsjø is important for fruit production in Telemark, and the production has been important for development of this area. The municipalities around this lake want to maintain and hopefully increase the fruit growing within sustainable ecological frames. Accordingly, a general reduction of environmental pollution and future risk of environmental pollution to the Lake Norsjø should be focused on to secure sustainable ecological status in this water body.

Lake Norsjø is surrounded by agriculture areas in the west and the north, and by forest and mountainous areas in the east. Besides being the major irrigation and recipient source for fruit farmers in the area, Lake Norsjø is the main drinking water source for 2 municipalities (Skien and Nome), and a ground water source located very close the lake act as drinking water for another municipality (Sauherad). Since Lake Norsjø is among the 20 largest lakes in Norway the lake is also a very important recreation area (outdoor life, fishing, hunting, tourism etc) for thousands of people in the region.

The most important towns and villages within the Lake Norsjø catchment are Rjukan, Notodden, Gvarv, Seljord and Ulefoss, while the cities Skien and Porsgrunn, are located downstream the lake outlet.

The beginning of modern industry in Norway started in Telemark, where they converted the power of the waterways in the region into electricity at the beginning of the 19^{th} century. Accordingly the first large industrial area in Norway was established in this area. Most internationally reputed is likely Norsk Hydro, which started the production of artificial fertilizers in the area already in 1905, followed by light metal production (such as aluminium and magnesium). Other industries such as mining, ironworks and brickworks have been of importance in the area of Ulefoss for long time.
(http://en.visittelemark.com/om_telemark/industri_telemark, April 15th 2009).

At least two main local Hg emitters have been located in the nearby area of the lake. Tinfoss paper mill, located in Notodden city about 30 km north from Lake Norsjø, used mercury as fungicide, but the paper mill activity was closed in 1972. Similarly, farmers used the anti-fungal properties of Hg on seed grains, especially for cereal crops, but due to the poisoning hazard, this has been forbidden for decades.

Some studies made in this region indicate that there might be more than one type of pressure registered for the lakes in the area, such as pollution, physical encroachments and biological pressure (Figure 1-2). Regarding water acidification, many lakes in the region have been classified as poor status (Figure 1-3), but Lake Norsjø is not among these lakes with pH > 6,5 (Borgvang et al., 2007) . Regarding physical-chemical and biological quality criteria, the lakes in the area were classified as high and good status, respectively (Figure 1-4). (http://vann-nett.nve.no/ read April 22nd, 2009)

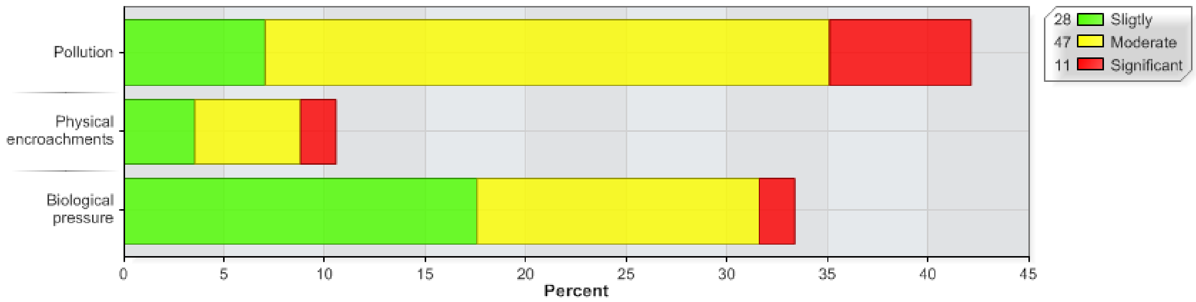


Figure 1-2. *Percentage of pressures (pollution, physical encroachments and biological pressures) for lakes in the Mid-Telemark water region.*

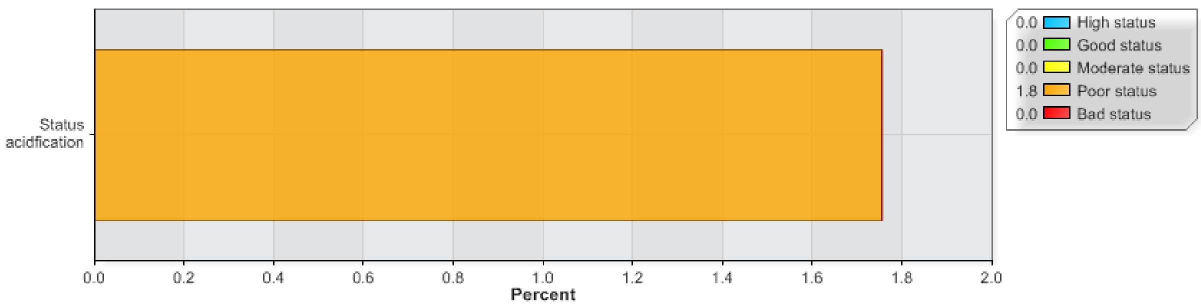


Figure 1-3. *Classification of status, regarding acidification, for the lakes in the Mid-Telemark water region.*

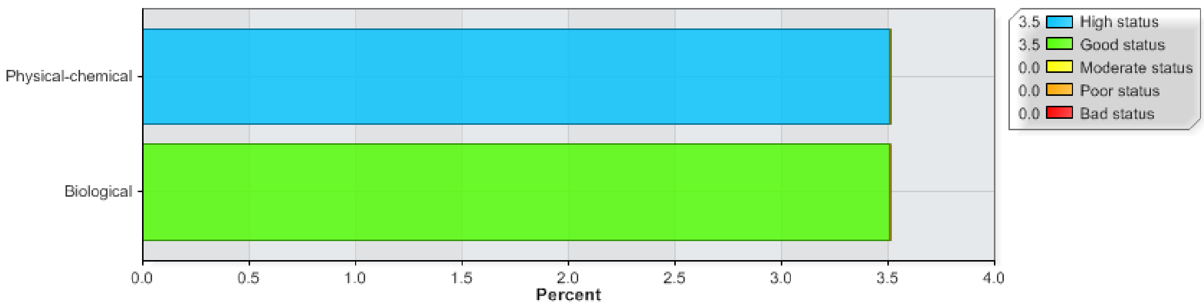


Figure 1-4. *Classification of the lakes in the Mid-Telemark water region according to physical-chemical and biological status.*

1.3 Pollutants involved in the study

In aquatic systems, the natural concentrations of metal ions are principally dependent on their distribution within the environment, the weathering and subsequent leaching of these elements from the catchment. Also, erosion or volcanic activity may contribute to natural supply of metals into aquatic systems. Today, the major sources of metals to aquatic systems derive from anthropogenic sources, metal industry, combustion of various hydrocarbons and industrial waste. Besides local sources, almost all areas on the globe receive long range transported air pollutants where heavy metals constitute an important part. However in the western world, a significant decrease in atmospheric inputs of heavy metals as Cd, Pb and Zn have occurred at least during the last two decades (Figure 1-6).

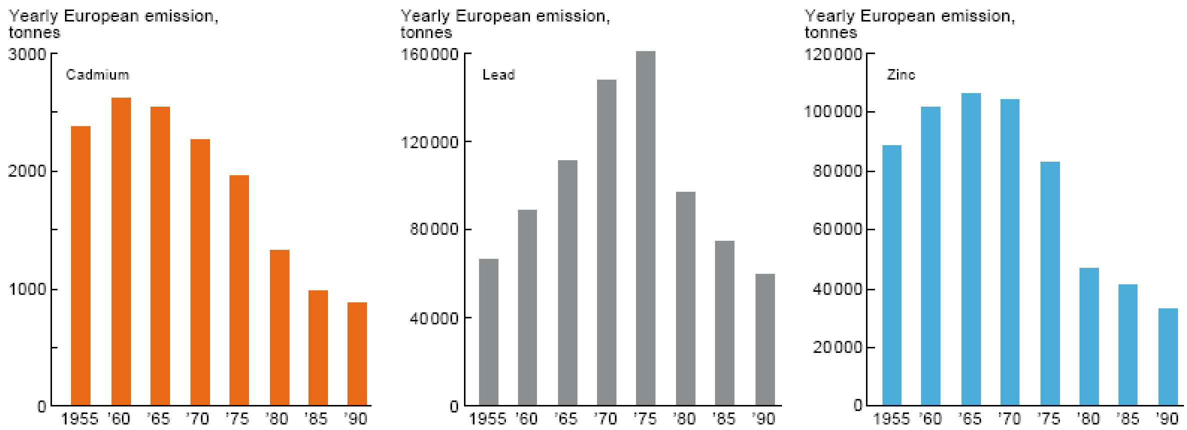


Figure 1-6. *Time trend in European atmospheric emissions of cadmium, lead and zinc (AMAP, 1997).*

Lake Norsjø is surrounded by agricultural areas. Most of the pesticides used end up in the water and sediments of the lake. In addition, a few km south of the lake is the most industrialized area in Norway, and because of predominant winds from the south and southwest, local air pollutants may impact the lake and its surroundings.

In freshwater systems, fish are usually on the top of the food chain, and therefore vulnerable to many inorganic and organic toxicants. Normally, aquatic organisms have higher concentrations of heavy metals in their body compared with the concentration in their surrounding water body. The ratio between concentration of a compound in water and concentration in the organism (or specific organs as liver, kidney, spleen or muscle) is often named as bioaccumulation factor (BAF) or bioconcentration factor (BCF). Some metals as methyl-Hg, also biomagnify through the aquatic food web, a phenomenon most often described for many persistent organic pollutants as PCB, DDT etc. Biomagnification means an upconcentration of a substance through each trophic position, which means that predators on the top of long food webs may reach very high concentration of toxicants, compared with top predator of shorter food webs.

Biomagnification and bioaccumulation of pollutants often cause various chronic effects, while for many heavy metals, the inorganic aqueous cations (i.e. as Cd^{2+}, Pb^{2+}, Al^{3+}) have acute toxic effects on gill-breathing aquatic organisms, due to their direct effect on gill surfaces (Lydersen et al., 2002).

It is well known that metal uptake and the effects of metal exposure are highly dependent on the form of metal available to the organism (Lydersen et al., 2002). Thus, the complex relationship between metal chemistry and metal toxicity in different organisms, makes metal contamination of natural waters a difficult environmental problem both for regulators that try to preserve fisheries and ecosystem integrity, and for industry that have to go through costly procedures to reclaim metals from discharges, thus, reducing environmental contamination.

1.3.1 Mercury

Production, use and sources

Globally, mercury (Hg) has been used in dentistry, measuring and control equipment, batteries and lamps. The chloro-alkaline industry is also known to use large amounts. Hg has also been used as a pesticide and biocide on grain and in paper industry. In Norway, today's use of Hg is almost totally banned or restricted. Currently, Hg is found in old electrical appliances, amalgam in teeth and in lights (tubes, energy saving light bulbs and headlamps on cars). Human activities can mobilize Hg, either through mining and subsequent use of Hg in a range of products, or by burning fossil fuels.

Emissions and discharges

Atmospheric Hg emission is an international problem as the troposphere provides effective global transport of this element. The ratio of anthropogenic to natural Hg in the atmosphere has been stated to be about 1,4:1 or about 2 900 tonnes from human activity and 2 100 tonnes from natural sources on an annual basis. Approximately 98 % of the estimated 5 000 tonnes of Hg in the atmosphere is Hg^0 vapour, emitted from human activities, contaminated soils and water, as well as natural sources. This gas is readily transported and has a mean atmospheric residence time of about one year to one and a half years. The transformation of insoluble Hg^0

to its more reactive and water-soluble form, Hg^{2+}, is thought to provide the mechanism for the deposition of Hg emissions to land and water. (http://www.ec.gc.ca/MERCURY/EH/EN/eh-t.cfm?SELECT=EH, read June 24th, 2009)

A recent comprehensive study of anthropogenic mercury emissions in China (Streets et al., 2005) yielded a figure of 536 t of Hg for the year 1999 with coal combustion (all types) accounting for 38 % of the total. Although the estimates vary, China produces about three times more Hg per ton of coal burnt than the USA, because of the lack of modern pollution technology and limited use of cleaned coal (desulphured coal).

Asian emissions of 1179 metric tons, excluding Russia, accounted for more than half the global anthropogenic Hg emissions of 2190 metric tons in 2000 (Pacyna et al., 2006 and Pacyna et al., 2009, in press).

According to SFT (Norwegian Pollution Control Authority), 1100 kg of Hg was emitted in Norway in 2003. Main emissions were from land based industry (31%), transport (20%), amalgam (14%), waste management – incineration and landfills (27%), oil and gas industry (3%) and other (6%). From 1995 to 2003, the Norwegian releases have been reduced by about 60 %.

The amount of Hg transported from central and eastern Europe to Scandinavia has declined during the past few years. However, this decline may only be temporary. What happens in the future depends to a large extent on how fast industrial production recovers from the economic slump of the early 1990s and the ongoing crisis. The potential for long-term lower emissions from Western Europe and North America is better, because the technology to clean sulphur from industrial emissions also removes Hg and other heavy metals associated with sulphur. Efforts to decrease metal emission are on the agenda in current political negotiations about long-range transboundary pollution. Despite so, the most important factor in the years to come regarding Hg-load in Norway, and all over the globe, is the willingness to invest in best available cleaning technology (BAT technology) in smelters and coal-based power plant, and the willingness to use coal with lower sulphur content and thereby lower Hg content. At present, the main challenges are in Asia and, particularly, in China (Streets et al., 2005).

Monitoring

Monitoring of Hg in Norway has, since 1981, been part of JAMP (Joint Assessment and Monitoring Programme) and RID (Riverine inputs and direct discharges to Norwegian coastal waters), both programmes part of the OSPAR-convention which is the current legal instrument guiding international cooperation on the protection of the marine environment of the North-East Atlantic. Work under the Convention is managed by the OSPAR Commission, made up of representatives of the Governments of 15 Contracting Parties and the European Commission, representing the European Community.

Air and precipitation chemistry in Norway is determined through various monitoring international programmes at several sites located in the rural areas of Norway. At 7 sites heavy metals are monitored, but monitoring of Hg is only implemented at 2 sites (Aas et al., 2003).

Monitoring of heavy metals in Norwegian surface waters is only conducted every 10^{th} year by the Norwegian institute for water research (Brit Lisa Skjelkvaale, NIVA, pers. comm.).NIVA also carries a monitoring programme on Hg in water, sediment and fish (Sigurd Rognerud, NIVA, pers. comm.)

According to the document "*A study f the priority substances of the WFD"*, there is no further need for screening of Hg. However, certain localities should be further investigated. As levels are high and long range transport contribution significant, Hg should be continuously monitored.

<u>Mercury cycle</u>

Two main types of reactions convert Hg through its various forms, i.e. oxidation-reduction and methylation-demethylation. In oxidation-reduction reactions, Hg is either oxidized to a higher valence state (e.g. from relatively inert Hg^0 to the more reactive Hg^{2+}) through the loss of electrons, or mercury is reduced, the reverse of being oxidized, to a lower valence state (Lucotte et al., 1999).

Oxidation of elemental Hg^0 in the atmosphere is an important mechanism involved in the deposition of Hg on land and water. Hg^0 can volatilize relatively easily and be emitted to the atmosphere, where it may be transported by wind currents for a year or more and be re-deposited in the environment for further cycling. In contrast, Hg^{2+} has an atmospheric residence time < 2 weeks due to its solubility in water, low volatility and reactive properties. Thus, when Hg^0 is converted to Hg^{2+}, it can be rapidly taken up in rain water, snow, or adsorbed onto small particles, and subsequently deposit in the environment through "wet" or "dry" deposition.

If methyl groups are present (CH_3^-) in the environment, Hg^{2+} might be transformed into methyl-Hg. The methylation of Hg^{2+} is primarily a natural, biological process resulting in the production of highly toxic methyl-Hg compounds ($MeHg^{+}$) that accumulate in organisms and increase its concentration through the food web, from microorganisms like plankton, to small fish, to piscivorous fish, and piscivorous birds and mammals, including humans.

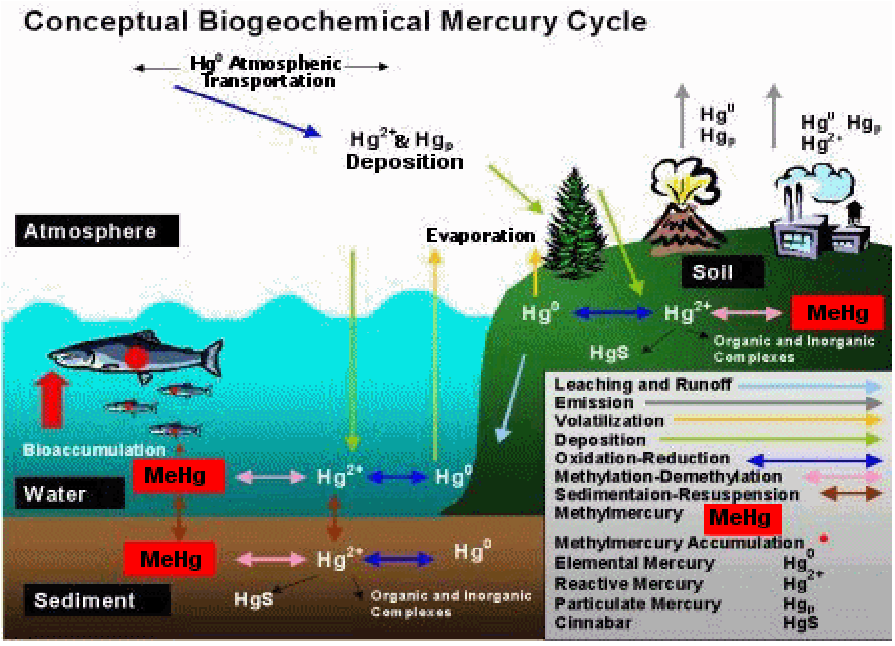


Figure 1-7. *Conceptual biogeochemical mercury cycle. (Source: www.ec.gc.ca, read May 17th, 2009)*

A variety of microorganisms, particularly methanogenic (methane producing) and sulfate-dependant bacteria, are involved in the conversion of Hg^{2+} to methyl-Hg under anaerobic (oxygen poor) conditions, often present in wetlands, sediments, and certain soil types. Methylation occurs primarily in aquatic, low pH (acidic) environments with high concentrations of organic matter. Biomethylation increases by increasing temperatures when biological productivity is high, and decreases by declining temperature during the winter (Ullrich et al., 2001). (See Jensen & Jernelöv, 1969; Compeau & Bartha, 1985, Lucotte et al., 1999, Ullrich et al., 2001)

Land use changes affecting some of the above mentioned factors, might increase the rate of Hg-methylation (Munthe & Hultberg, 2004). For example, the construction of hydroelectric dams can mobilize Hg stored in the submerged forest floor and vegetation. The presence of organic matter (in the form of newly submerged vegetation) in combination with anaerobic conditions can stimulate microbial growth and lead to elevated methyl-Hg levels (Lucotte et al., 1999).

The exact mechanisms by which Hg enters the food chain remain largely unknown and may vary among ecosystems. Certain bacteria play an important early role. Bacteria that process sulfate (SO_4^{2-}) in the environment, take up Hg in its inorganic form and convert it to methyl-Hg through metabolic processes. The conversion of inorganic Hg to methyl-Hg is important because its toxicity is greater and because organisms require considerably longer time to eliminate methyl-Hg. These methyl-Hg-containing bacteria may be consumed by the next level in the food chain, or the bacteria may excrete the methyl-Hg to the water where it can quickly be adsorbed to plankton, which subsequently can be consumed by other organisms within the next level in the food chain. Because animals accumulate methyl-Hg faster than they eliminate it, Hg successively increases up the food web (bioaccumulation). Thus, even low environmental concentrations of methyl-Hg can easily accumulate to potentially harmful concentrations in fish, fish-eating wildlife and people (Figure 1-8). Even at very low atmospheric deposition rates in areas far from point sources, biomagnification of Hg can result in toxic effects in top predators in these aquatic food webs. (Mercury in the Environment. Fact Sheet 146-00, October, 2000)

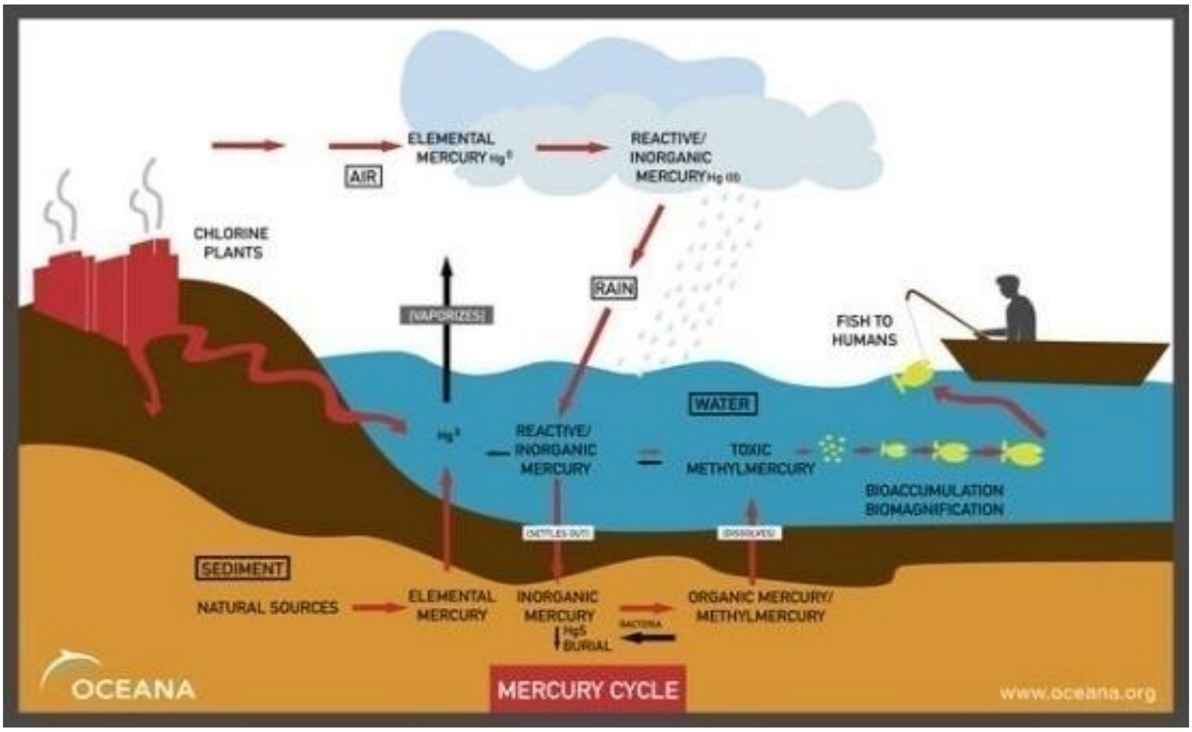


Figure 1-8. *The mercury cycle. (Source: www.oceana.org)*

Yet, it is not possible to fully explain the bioaccumulation mechanism of methyl-Hg in biota and, particularly, why differences exist between different freshwater ecosystems. Consequently, it is necessary to determine food web dynamics at the base of the food chain, since in higher trophic levels we can measure, but not account for, the accumulation of methyl-Hg (Montgomery et al., 2000).

One major mechanism for demethylation of methyl-Hg (CH_3-Hg^+) is by sunlight (Sellers et al., 1996; Mason & Benoit, 2003). In boreal areas, typically for eastern Norway, many lakes have high concentrations of humic material (brown lakes) causing low penetration of light. This implies low demethylation rates and, accordingly, high concentration of methyl-Hg in fish compared with clearwater lakes.

Contamination of freshwater fish by Hg remains an environmental problem of concern in the Nordic countries. Regarding the geographical patterns of Hg-concentrations, the main tendency is decreasing levels from south to north with the highest concentrations also found in central Sweden and along the Swedish coast of the Gulf of Bothnia. (Munthe et al., 2004) (Figure 1-9). Hg-concentrations in reference lake sediments and surface sediments in Norway is shown in figure 1-10.

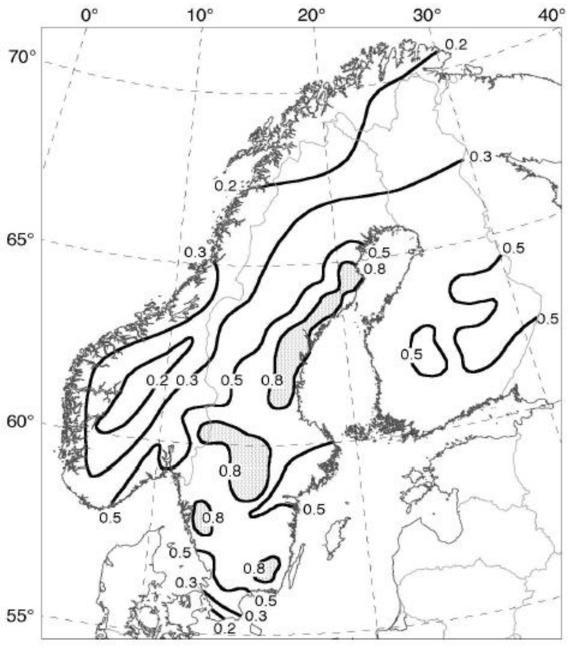


***Figure 1-9**. Mercury concentrations in freshwater fish in the Nordic countries. Preliminary map based on data from >1500 lakes and referring to the concentration (mg/kg fw) in a 1-kg pike (Esox lucius) (Source: Munthe et al. 2004)*

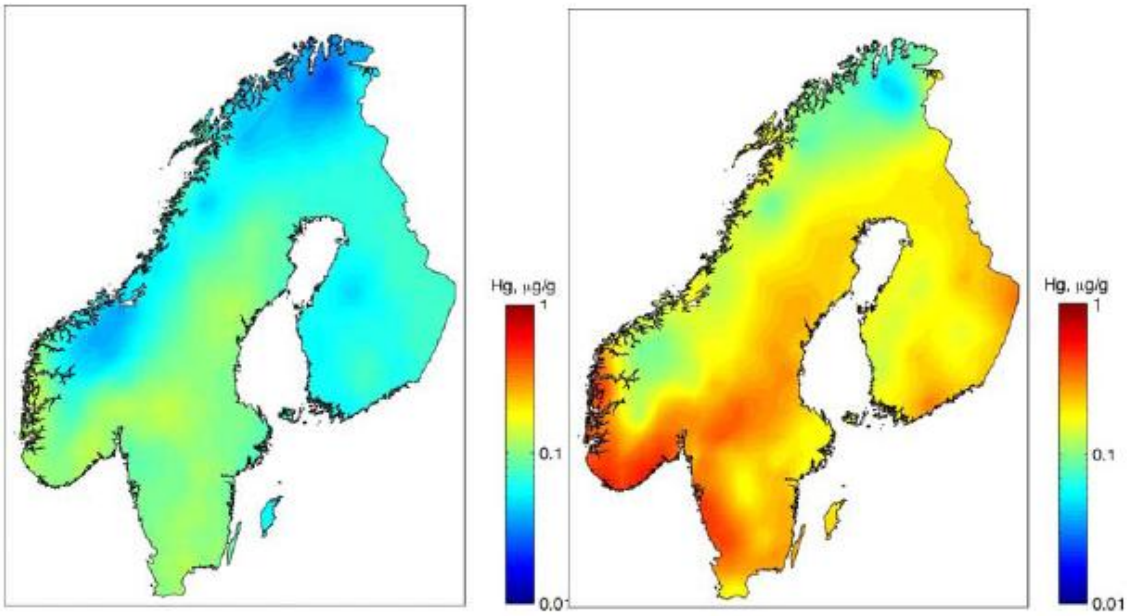


Figure 1-10*. Mercury concentrations (mg kg^{-1} dw) in reference lake sediments (left panel) and surface sediments (right panel) presented as kriged maps (spatially interpolated) (Munthe et al. 2007).*

1.3.2 Lead

Production, use and sources

Lead (Pb) occurs in a wide variety of minerals, and substantial amounts have been distributed into the environment from mine and metal smelters. Furthermore, Pb has globally been used in construction, ceramics, ammunition, pigments and petrol additives, in fishing lures, cables, sail boat keels, cars, batteries/accumulators, plastics, paints, sand blasting, etc.

Today, Pb is banned in a lot of products in many countries and, consequently, the emission of Pb into the environment has been significantly reduced during the last decades.

Emissions and discharges

Total Norwegian emissions of Pb have decreased from 598 tons in 1995 to 455 tons in 2003, while discharges to water in the same period have dropped from 181 tons to 73 tons during the same period (Økland et al., 2005). A drop in Pb emissions from oil and gas and industrial sources has been reversed by increased emissions from Pb in products.

Deposition of long range transported air pollutants have decreased significantly in Norway during the latest years, i.e. from 20 tons in 1991 to approximately 5 tons in 2002. In products, almost no change is detected between 1985 and 2002. The Norwegian annual use is approximately 20 000 tons. The ban on use of Pb pellets in shotguns from 2005 will cause a drop in emissions as this is the single largest source in Norway. 15 000 tons of Pb are estimated to be located in firing ranges. Lost fishing lures may also cause large discharges at popular locations for fishing (Økland et al., 2005).

Monitoring

In Norway, heavy metals (like Pb, Cd, Zn) in air and preciptation have been continously monitored at 7 Norwegian sites, some of them back to 1975-1980 (Aas et al., 2003).

Monitoring of heavy metals in Norwegian surface waters is only conducted every 10th year by the Norwegian institute for water research (Skjelkvåle et al., 2008).

According to SFT, no further screening is considered necessary but monitoring of Pb concentrations should continue, both because environmental levels are high and in order to evaluate measures and policies for lead reduction, such as the banning of Pb in shotgun ammunition (Økland et al., 2005).

Toxicity

In fish, Pb accumulates primarily in the gill, liver, kidney and bone. In juvenile fish, Pb causes a blackening of the tail followed by damage to the spine.

Lead in the environment is strongly adsorbed by sediments and soil particles, and it is therefore, largely unavailable to plants and animals. Many of the salts of lead (lead oxides and sulfides) are not readily soluble in water and are sequestered in sediments. In aquatic systems, uptake is influenced by various environmental factors such as temperature, salinity, pH, and the presence of organic matter (AMAP, 1997).

Lead in surface water systems

Borg (1987) found that higher concentrations of Pb are normally present during winter time compared to summer time, and explained this by higher sedimentation rates during the summer.

Many studies have shown that Pb is strongly accumulated in the topsoil, often causing an insignificant contribution from the watershed to the surface water (Bergkvist, 1987; Blais & Kalff, 1993; Brännvall et al., 1997). Thus, the major source is atmospheric inputs directly onto the lake surface (Brezonik et al., 1993; Renberg et al., 1994). Mobilisation of Pb from the watershed is also found to be minimal even under severe acidification (Vesely and Majer 1996).

The Swedish and Norwegian lake survey in 1995 shows relatively clear relationships between Pb in surface waters and both pH and TOC. Pb-concentrations were found to increase by decreasing pH in surface waters. The strong pH-relationship with Pb is primarily due to the close link between atmospheric inputs of strong acids and Pb. This means that the negative relationship between Pb and pH in lakes is not casual. A positive and expected relationship was found between Pb and TOC (Lydersen et al., 2002).

1.3.3 Cadmium

Production, use and sources

Cadmium (Cd) is associated with zinc (Zn) and non ferrous ores, and usually present in cement and phosphate fertilizer, as well as in fossil fuels. Cadmium has been widely used, in pigments and is still in widespread use in electronics metallurgy and for corrosive protection. In Norway, main use by 2002 was in batteries.

Cadmium is a relatively rare metal. Like other metals, Cd occurs naturally and it is also released by human activity. Cadmium is a toxic heavy metal, but it is not found in pure state in nature.

Emissions and discharges

The main Cd-emissions come from products, industrial sources, and the oil and gas sector, but 29 % of the Norwegian emissions in 2002 are diffuse or from other sources. According to SFT almost 2/3 of the annual Cd-pollutions come from sources outside Norway. The Cd-emissions in Norway have dropped from 43 tons in 1985, via 5 tons in 1995 to 1 ton in 2003. Discharges of Cd to water in the same period have dropped from about 3,5 tons to about 600 kg (Økland et al., 2005).

Monitoring

In Norway, heavy metals (like Pb, Cd, Zn) in air and precipitation have been continuously monitored at 7 Norwegian sites, some of them back to 1975-1980 (Aas et al., 2003).

Monitoring of heavy metals in Norwegian surface waters is only conducted every 10th year by the Norwegian institute for water research (Skjelkvåle et al., 2008).

According to the document "*A study of the priority substances of the WFD"*, produced on behalf of the Norwegian Pollution Control Authority (SFT), no further screening is considered necessary, but monitoring of the metal should continue in order to estimate health risks and effectiveness of policies and measures regarding use and waste management.

Toxicity

As for many other metals, salmonids seem to be the most sensitive taxonomic group to Cd in freshwater, but data are not sufficient to rank other taxa. When the concentration of aqueous Cd is high and acute toxicity occurs, the toxic mechanism is gill damage. Cadmium, however, has a systemic mode of action at lower Cd-concentrations, producing hyperactivity and eventual muscle tetanus (Benoit et al., 1976; Roch & Maly, 1979).

The bioconcentration factor (BCF) of Cd in fish typically increases with increasing exposure concentration in water. Under conditions of low Cd-concentrations and prolonged exposure, the concentration of Cd on liver and kidney is shown to gradually increase. (Lydersen et al., 2002)

Cadmium in surface water systems

Borg (1987) found that higher concentrations of Cd are normally present during winter time compared to summer time, and explained this by higher sedimentation rates during the summer.

By dividing the 1995 surveyed Nordic lakes into TOC- and pH-classes, it is clear that pH plays an important role for the concentration of Cd in surface waters, most likely due to the link between high atmospheric inputs of strong acids and Cd, and low surface water pH. For Norwegian and Swedish lakes with pH < 5.4, median Cd-concentration is 0,030 µg Cd L^{-1}, while the corresponding concentrations in pH-class: 5,4-6,0 and pH-class > 6 are 0,014 and 0,010 µg Cd L^{-1}, respectively. Thus, since Norway has the highest number of acidic lakes and also the largest area of strong acid rain impact in Scandinavia, it is expected that Norwegian lakes will have the highest Cd-concentrations (Lydersen et al., 2002).

1.4 Stable isotopes

Isotopes are atoms of the same chemical element, each having the same number of protons, but a different number of neutrons. There are two types of isotopes, the stable isotopes, which persist in nature, and the radioactive isotopes, which spontaneously degrade. Despite minor mass difference between stable isotopes, the tiny variation between isotopes is enough to behave slightly different in various physical, chemical and biological processes. Generally, the lightest isotope (^{12}C or ^{14}N) tends to form weaker bonds and react faster than the heavier isotopes (^{13}C or ^{15}N). As a consequence of these bond energy and reaction rate differences, the abundance of stable isotopes of an element will vary between chemical species. The change in isotopic abundance between chemical species, due to physical or chemical processes, is termed isotope fractionation (Gannes et al., 1998).

The isotopic composition is expressed in terms of δ values, and expresses the ratio of a sample to a standard (in per mil, ‰):

$$\delta X = \left(\frac{R_{sample}}{R_{standard}} - 1\right) * 1000$$

where X is ^{13}C or ^{15}N, and R is the corresponding ratio between the heavy and light isotope, $^{13}C/^{12}C$ or $^{15}N/^{14}N$, in the sample and the standard respectively. The δ values are measures of the ratio between heavy and light isotopes in a sample. Increases in these values denote increases in the amount of the heavy isotope components. Conversely, decreases in δ values denote decreases in the heavy isotope content, and a reciprocal increase in the light isotope component (Peterson & Fry, 1987).

<u>Carbon $\delta^{13}C$</u>

Two natural stable carbon isotopes exist: ^{12}C (98,89 %) and ^{13}C (1,11 %), with a natural ratio $^{13}C/^{12}C$ ($\delta^{13}C$) of 0,112 ‰ (1,11/98,89). The $\delta^{13}C$-ratio is expressed in per mil (‰), where the isotope ratio is compared to a reference standard. For carbon a PDB carbonate standard is used. This standard consists of a Cretaceous belemnite from the Peedee Formation in South Carolina (Craig, 1953). The nomenclature has been changed to VPDB (Coplen, 1994). Accordingly, $\delta^{13}C$ can be calculated as follows:

$$\delta^{13}C = \left(\frac{R_{sample}}{R_{standard}} - 1\right) * 1000$$

The degree of ^{12}C enrichment is measured with the $\delta^{13}C$ method, which expresses the deviation related to the standard reference material (PDB or VPDB). More negative $\delta^{13}C$ means more ^{12}C enrichment in relation to ^{13}C.

Nitrogen $\delta^{15}N$

Two natural stable nitrogen isotopes exist: ^{14}N (99,64 %) and ^{15}N (0,36 %), with a natural ratio $^{15}N/^{14}N$ ($\delta^{15}N$) of 3,61 ‰ (0,36/99,64). The $\delta^{15}N$-ratio is expressed in per thousand (‰), where the isotope ratio in a sample is compared to the standard nitrogen ratio in air (Mariotti, 1983). Accordingly, $\delta^{15}N$ can be calculated as follows:

$$\delta^{15}\mathrm{N} = \left(\frac{R_{sample}}{R_{standard}} - 1\right) * 1000$$

The use of stable isotopes, especially carbon and nitrogen, to provide time-integrated information about feeding relationships and energy flow through food webs, has been widely studied (Peterson & Fry, 1987; Kling et al., 1992; Cabana & Rasmussen, 1996). The use of these techniques requires a priori estimates of the enrichment or depletion in $\delta^{15}N$ and $\delta^{13}C$ values between prey and predator, known as trophic fractionation (Vander Zanden & Rasmussen, 2001). One of the advantages of using stable isotopes techniques to evaluate the structure and dynamics of ecological communities is that they combine benefits of both the trophic level and food webs paradigms in food web ecology (Post, 2002).

Stable isotope fractionation

Enrichment of $\delta^{15}N$ occurs at successive levels, therefore allowing estimates of consumer trophic position within a food web (Cabana and Rasmussen, 1996; Vander Zanden and Rasmussen, 1999). Regarding stable carbon isotopes, there is very little fractionation from prey to predator, thus indicating feeding and carbon flow pathways (Fry & Sherr, 1984; Peterson & Fry, 1987).

Consumers become enriched in ^{15}N relative to their diet by 3,4 ‰ per trophic level (Minagawa & Wada, 1984). In contrast, the isotope fractionation of carbon through the food web is relatively conserved in each trophic level transfer, only about 0,8 ‰ (Vander Zanden & Rasmussen, 2001). The $\delta^{13}C$ signature can provide information on the basal energy sources assimilated in higher order consumers (Post, 2002). The $\delta\ ^{15}N$ values can be converted into trophic position estimates by interpreting the $\delta^{15}N$ of the higher consumers relative to a representative baseline $\delta^{15}N$ value (Cabana & Rasmussen, 1996). Some stable carbon isotope ratio data from different carbon sources is shown in Table 1-4-1.

Table 1-4-1. *$\delta^{13}C$ values from different carbon sources.*
Source: (http://www.c14dating.com/isotope.html, read May 17th, 2009).

Material	**$\delta^{13}C$ (‰)**
PDB $\delta^{13}C$ standard	0
C4 photosynthesis plants	-13
Atmospheric CO_2	(-9 ± 2)
C3 photosynthesis plants	-28
Freshwater macrophytes (submerged)	-16 ± 4
Small plankton algae	-36 - -30
Periphyton	-22 - -18
Turf, humus	-27 ± 3

Due to the effects of water turbulence on reducing boundary layer diffusion resistance and promoting ^{13}C discrimination in riverine and epiphytic attached algae, it may often be impossible to distinguish between aquatic (autochthonous) and watershed (allochthonous) food dependency for freshwater consumers. This is primarily due to the overlap that occurs in the carbon isotope ratios of terrestrial vegetation and benthic algae (France, 1996).

Starving animals exhibit elevated $\delta^{15}N$ enrichment (Hobson et al., 1993), presumably because animals catabolize their own bodily proteins, producing isotopic enrichment analogous to that for ingested food (Gannes et al., 1998).

In general, the $\delta^{15}N$ signature becomes heavier as the $\delta^{13}C$ signature becomes lighter. This is caused by a change in N-sources for primary producers as the importance of other carbon sources changes (Rognerud et al., 2008).

Figure 1-4-1 illustrates the theoretical assumption that consumers become enriched in $\delta^{15}N$ in relation to their diet by 3,4 ‰ per trophic level. Examples of organisms at different consumer levels are:

- Primary consumers: *Lymnea peregra*, zooplankton (*Daphnia spp.*) and small planktonic crustaceans (*Eurycercus lamelatus*).
- Secondary consumes: Larger crustaceans (*Gammarus lacustris*, *Lepidurus arcticus*) and young fish feeding on zooplankton, insects and invertebrates.
- Tertiary consumers: fish-eating fish, but also invertebrates (*Mysis relicta*).

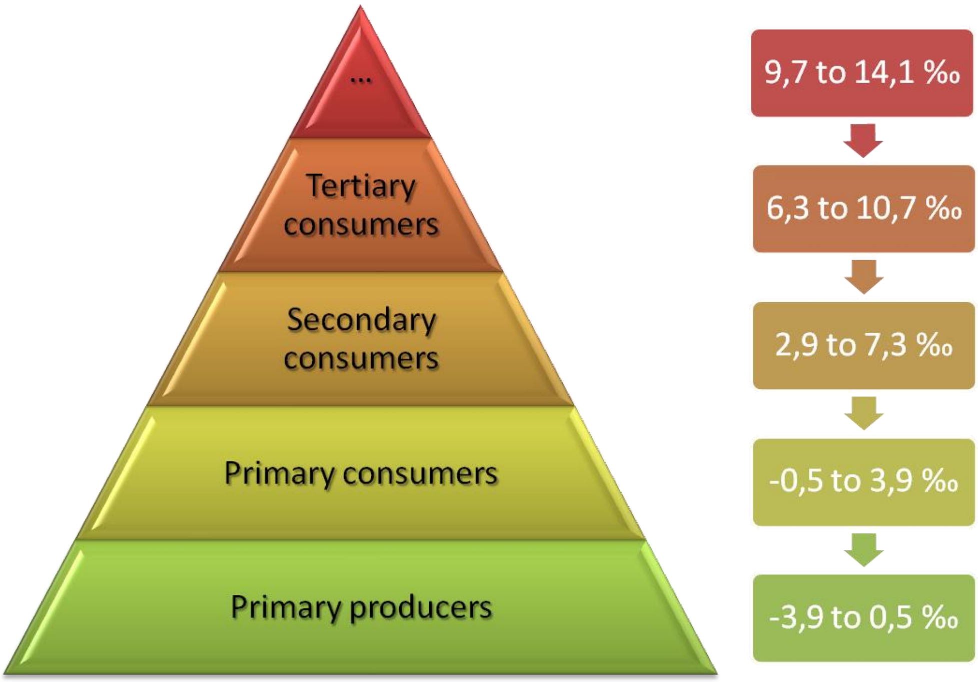


Figure 1-4-1. *$\delta^{15}N$ (‰) enrichment per trophic level based on data taken from Rognerud et al., 2003, except for $\delta^{15}N$ in primary producers, which is based on the fact that consumers become enriched in ^{15}N relative to their diet by 3,4 ‰ per trophic level (Minagawa & Wada, 1984).*

Sources of C and N

In aquatic ecosystems, $\delta^{13}C$ is useful for differentiating between two major sources of available energy, littoral (near shore) primary production from attached algae (periphytes) and detritus, and pelagic (open water) primary production from phytoplankton, because the $\delta^{13}C$ signature of the littoral food web tends to be enriched in ^{13}C (less negative $\delta^{13}C$) relative to the signature of the pelagic food web (France, 1995). The $\delta^{13}C$ signature is generally somewhat lighter in plants by increasing water depth, because of increased incorporation of respired CO_2 by depth (Rognerud et al., 2003).

There are primarily three energy sources in aquatic ecosystems, which ideally have various $\delta^{13}C$ signatures: plankton algae carbon, periphyton carbon and terrestrial carbon (Figure 1-4-2).

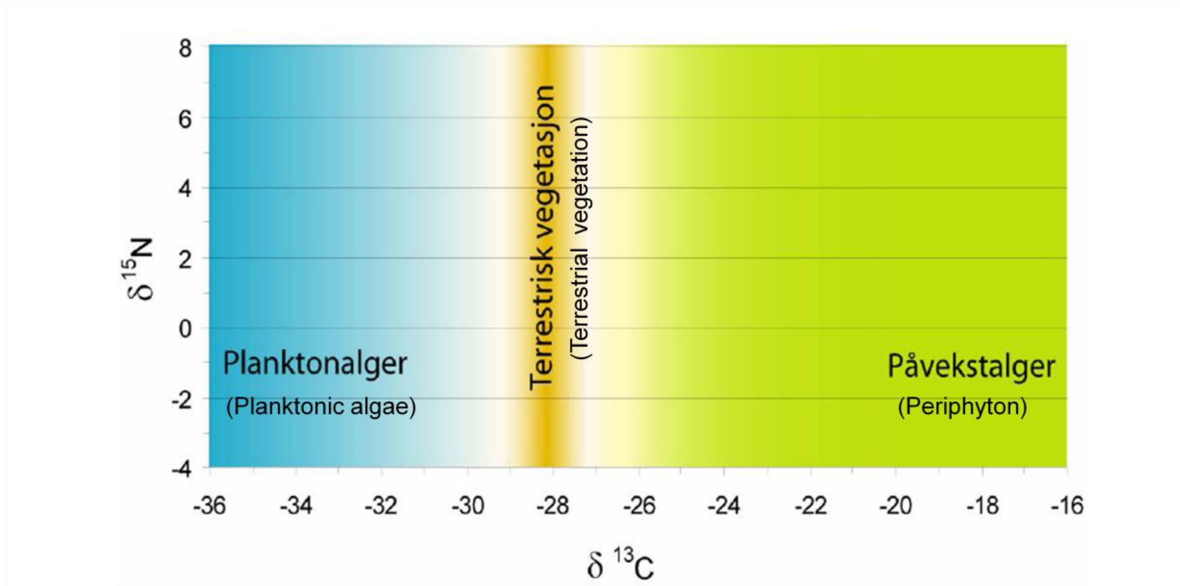


Figure 1-4-2. *Principal energy sources in an aquatic ecosystem. (Source: Sigurd Rognerud, NIVA)*

In terrestrial ecosystems, $\delta^{13}C$ is often used to differentiate between diets based on plants with different photosynthetic pathways, i.e. C_3 vs. C_4 (Peterson & Fry, 1987). That is, the processes of C_3 and C_4 photosynthesis result in different $\delta^{13}C$ values. In Norway there are only C_3 plants, while the C_4 plants are specialized for hot/dry climates. The C_3 plant photosynthesis depends completely on open stomata for its supply of CO_2. When the weather gets hot and dry, the stomata close to conserve the water. Unfortunately, this also keeps out the CO_2, i.e. much photosynthetic efficiency is lost in C_3 plants this way. C_4 plants have chemical mechanisms to scavenge CO_2, which means that photosynthesis occurs even when the stomata are closed and CO_2 is low.

Regarding the nitrogen sources and their $\delta^{15}N$ signatures in the food web, human wastewater and livestock waste nitrogen (NH_3/NH_4^+) are enriched in $\delta^{15}N$ (10-20 ‰), while synthetic fertilizers and atmospheric nitrogen typically have low $\delta^{15}N$ values (atmospheric, 2-8 ‰; inorganic fertilizer, -3 to 3 ‰) (Valiela et al., 2000).

Primary producers show different degree of nitrogen isotope fractionation (diatoms > flagellates), but normally a certain preference for $^{14}NO_3^-$ compared with $^{15}NO_3^-$ is documented. A $\delta^{15}N$ of 5-9 ‰ in relation to inorganic NO_3^- is often documented in marine environments (Altabet & Francois, 1994).

The identification of nutrient sources and pathways within aquatic ecosystems is of great importance in order to achieve nutrient reduction, and there is a need for reliable indicators of anthropogenic nutrient source. Stable nitrogen isotope values ($\delta^{15}N$) in aquatic biota are thought to reflect anthropogenic nutrient inputs, and they may be a promising tool for tracing nutrient sources in watershed (Vander Zanden et al., 2005).

Cabana & Rasmussen (1996) found that primary consumer $\delta^{15}N$ in lakes increased with human population density in the watershed, although linkages between biota $\delta^{15}N$ and specific nutrient sources or land uses were not assessed. However, according to Vander Zanden et al. (2005), both agricultural and urban nitrogen inputs are linked to elevated $\delta^{15}N$ in the biota.

Furthermore, other studies such as Harrington et al. (1998) reported positive correlation between $\delta^{15}N$ values of stream water nitrate and percent of agricultural land-use within a given catchment. This is important because agricultural nitrogen sources may vary widely in isotopic signatures and will be subjected to fractionation associated with biogeochemical transformations (Vander Zanden et al., 2005).

Gut-content and stable isotopes

Many studies have used gut-content analysis to provide information about the diet of animals in an ecosystem. However, gut-content is only a snapshot of the diet (i.e. providing point-in-time information), being a major disadvantage because many animals are opportunistic foragers and their diet may vary considerably over time. As well, stomach analysis is also important for a more detailed presentation of the food web and energy fluxes in the aquatic systems (Rognerud et al., 2008). Stable isotopes of nitrogen and carbon in animal's tissues integrate dietary components over a much longer period of time (Hesslein et al., 1993) and they provide an average estimate of an organism's preferred diet which is much less subjected to temporal bias (Pinnegar & Polunin, 1999). Therefore, a combined use of both analyses (gut-content and stable isotopes) can provide more complete and improved information.

Nevertheless, certain points must be taken into account when attempting to reconstruct animal diets from the isotopic composition of their tissues (Gannes et al., 1998):

- The dietary components of interest must have isotopically distinct signatures.
- The appropriate animal tissue must be cautiously chosen by researchers, since different tissues may reflect the isotopic composition of different dietary constituents.

According to DeNiro & Epstein (1981), different individuals of a species raised on the same diet can have significantly different $\delta^{15}N$ values. The variability of the relationship between the $\delta^{15}N$ values of animals and their diets is greater for different species raised on the same diet than for the same species raised on different diets.

Bottom-line correction

For comparison of stable isotopes in food webs from different lakes, it is necessary that different corrections related to trophic positions are made: bottom-line correction for trophic position ($\delta^{15}N$) and enrichment correction for trophic position ($\delta^{13}C$). When the bottom-line correction is made, it is very likely that the slope of the curve decreases and very nearly becoming a parallel line to the x axis in a $\delta^{13}C$, $\delta^{15}N$ plot.

Investigations have shown the importance of adjusting $\delta^{15}N$ in fish and pray animals to a common bottom-line when doing comparisons between lakes. The variations in $\delta^{15}N$ at the bottom of the food web may be due to several causes, but in areas with minor impacts from anthropogenic sources, the proportion of algae fixating nitrogen and the degree of denitrification in sediments are important factors (Fjeld, 2003).

The $\delta^{15}N$ values may reveal temporal fluctuations due to seasonal variation in N-source input to lakes. Thus, gastropods (snail) and bivalves (mussels) are suitable organisms for bottom line corrections because gastropods feed on periphyton and bacteria, the lowest trophic level in the bottom-near food web, and bivalves feed on seston (algae and bacteria), the lowest trophic level of the pelagic food web. Both groups live relatively long and therefore reduce seasonal fluctuations typical from short-lived organisms. Both groups are therefore suitable for bottom-line corrections for benthic and pelagic food web respectively (Post, 2002).

In oligotrophic clear water lakes, bottom-near invertebrates (benthos) are important prey for many fish species. In such case the periphyton-feeding gastropod *Lymnea peregra* has been used in Norwegian lakes and the corrections made are as follows (Rognerud et al., 2003):

1) $\delta^{15}N\text{-k}$ (‰) = $\delta^{15}N$ (‰) (prey animal) – $\delta^{15}N$(‰) (*Lymnea peregra*)
2) $\delta^{13}C\text{-k}$ (‰) = $\delta^{13}C$ (‰) – [$\delta^{15}N\text{-k}$ (‰) / 3,4] x 0,5

For fish feeding on plankton, the seston-feeding bivalve (mussels) should be used for these corrections, i.e., like the “pondmussels” as *Anadonta piscinalis* if present.

Thus, isotopic signatures of higher trophic level consumers, if corrected for baseline $\delta^{15}N$ variation as indicated by long-lived primary consumers, will provide a measure of food-chain length related to bottom-up mass transfer that can be compared between lakes (Cabana & Rasmussen, 1996).

Stable isotope fractionation in fish

In freshwater ecosystems, fish are important consumers in aquatic food webs and they are usually on the top of the food chain. Therefore, fish are widely used in the evaluation and understanding of trophic interactions in aquatic food webs (Havelange et al., 1997).

When analyzing individual tissues of a single fish, differential fractionations might occur. Frequently, dorsal white muscle, bone collagen or fish livers are sampled, and the whole fish has been utilized when it is too small for any individual tissue to be sampled (Pinnegar & Polunin, 1999).

According to Pinnegar & Polunin (1999), white muscle is found to be less variable in $\delta^{13}C$ and $\delta^{15}N$ than all other tissues, and it is probably the best tissue for use in ecological work. However, red muscle, which is often closely associated with white muscle, is more variable in $\delta^{13}C$ and may constitute a source of significant error in source material identification and dietary overlap. As well, the effect of removal of lipid in the samples was studied by these authors, concluding that there were slight $\delta^{15}N$ enrichments in white muscle and liver of 0,78 ‰ and 0,61 ‰, respectively. Tissues that contain large amounts of lipids tend to be more depleted in ^{13}C than other tissues. They support the idea that variation among tissues is due to some other factor, such as the structural-protein amino acids.

The extraction of lipid prior to stable isotope analysis can produce significantly different $\delta^{13}C$ values for freshwater and marine fishes and invertebrates (Søreide et al., 2006). This variability makes it difficult to compare results from studies that have used different extraction methods. Differences in the amount of lipid removed by different extraction methods probably cause variability in the $\delta^{13}C$ values obtained, with more negative $\delta^{13}C$ values produced by less exhaustive methods than by methods with higher lipid yields. (Logan & Lutcavage, 2008)

Mercury and stable isotopes

Mercury is known to have elevated values in fish and many other species from lakes in northern Europe and elsewhere. Most of the mercury found in the biota occurs as methylmercury, a bioaccumulative environmental toxicant. Therefore, Hg concentrations are known to increase towards higher trophic levels in body tissues, such as liver, muscle and kidney (Dietz et al., 1996).

Analysis of stable isotopes of nitrogen is a commonly used method to determine the trophic relationships. Thus, the measure of relative trophic position within a food web may be correlated with contaminants in organisms and, therefore, it could be possible to estimate the biomagnification rates (Power et al., 2002).

As mentioned before, pelagic and benthic algae in freshwater lakes show different carbon signatures as a result of differential fractionation during carbon fixation. The carbon signatures of consumers at multiple trophic levels may be used to differentiate between the relative dependence of organisms on food webs of pelagic and benthic origin (Hecky & Hesslein 1995). Accordingly, the combined analyses of carbon and nitrogen isotopes may be of importance in understanding the details of contaminant impacts on fish communities as influenced by habitat use and/or food web dependencies (Power et al., 2002).

2 Material and methods

2.1 Sampling

The fish individuals of this study were collected from different sites in Lake Norsjø (Figure 2-1), sampled during the period September 2008 - February 2009. The majority was collected by gill net of different mesh sizes in order cover different age, weight and length classes. This gill net material was collected from the Northern part, Årnesbukta (Figure 2-1).

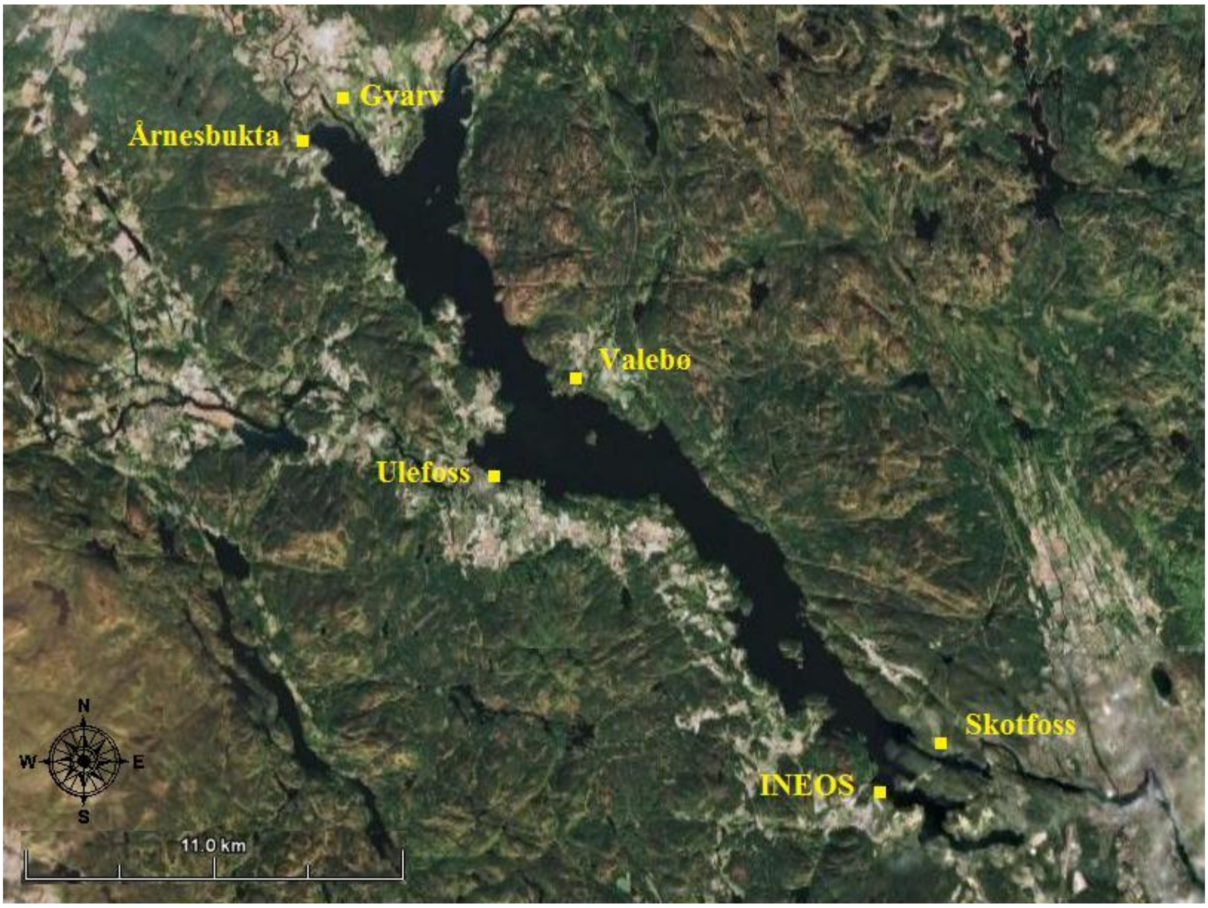


Figure 2-1. *Sampling sites where the fish individuals were caught (Source: Google maps)*

The Arctic char (*Salvelinus alpinus*) primarily derives from the southern part of the lake, where the water intake of Ineos Industries is located (Figure 2-1). This intake is located at a depth of 46-60 m, about 40-80 m from the shore. The fish trapped on the grate installed in front of the submerged water pipeline, were collected and frozen by Ineos Industries workers.

The Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) were collected by local fishermen and by a local hatchery located at the outlet of Lake Norsjø, at the Skotfoss waterfall (Figure 2-1).

Totally 173 fish were incorporated in this investigations. The distribution between fish species were as follows: 41 white fish (*Coregonus lavaretus*), 29 European smelt (*Osmerus eperlanus*), 27 Arctic char (*Salvelinus alpinus*), 26 perch (*Perca fluviatilis)*, 22 brown trout (*Salmo trutta*), 14 Atlantic salmon (*Salmo salar*), 11 northern pike (*Esox lucius)*, 4 tench (*Tinca tinca*) and 2 crucian carp (*Carassius carassius*). All data is presented in Appendix 1.

All fish were investigated regarding length and weight, and all otoliths were taken for age determination. Also, scales, pterygoid and other gill bones were collected from a subgroup of the various species, as useful support in age determination. All fish were individually labelled and stored in a freezer in separate plastic bags. Otoliths from each individual were stored together in separate paper envelopes.

2.2 Age measurement

Fish age determination is mainly performed by use of otoliths. The otoliths are calcified structures located near the fish brain, behind each fish eye, growing throughout the whole life. Since freshwater fishes in this region of the world have significantly higher growth rates during summer compared with winter, seasonal growth zones will be manifested as light growth zones and dark stagnation zones in the otoliths. Accordingly, number zones can be directly transferred to fish age. To better distinguish between light and dark zones, the otolith was heat up with a butane lighter, until it became light brown. Afterwards, the otolith was transversally sectioned into two pieces and the number of zones were investigated in a microscope (Figure 2-2).

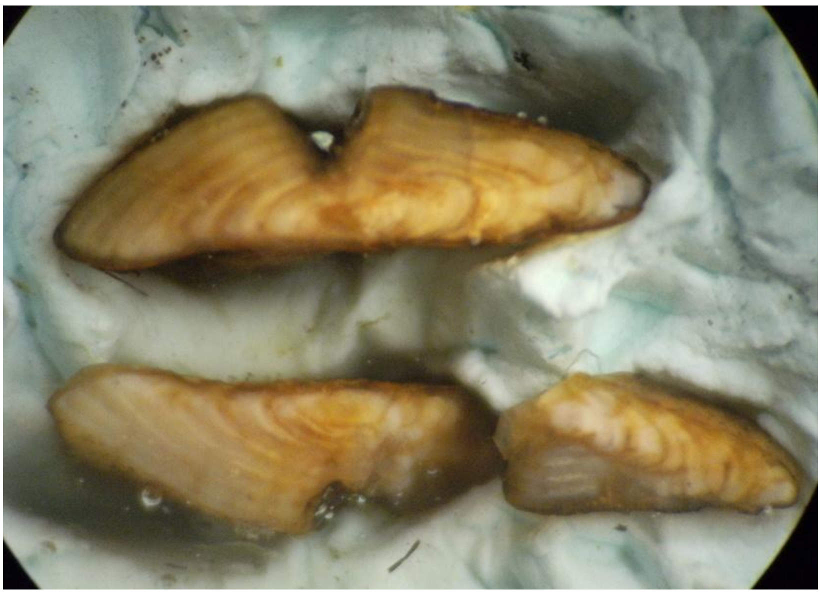


Figure 2-2. *Otolith from a brown trout (4x magnifier)*

Since the otoliths of the Arctic char were very small, the whole otolith was initially immersed in glycerol for several days in order to obtain enhanced appearance of the growth zones or rings. These otoliths were not sectioned in two, but directly examined in the microscope. The otoliths were different in shape and size for the different fish species (Figure 2-3).

Figure 2-3. *Otoliths for whitefish, northern pike, European smelt, brown trout, tench, crucian carp, Atlantic salmon, perch and Arctic char, respectively.*

Individual scales were also used for determination of age. They were collected from an area between the second dorsal fin and the lateral line. Similar to the otoliths, scales grow proportionally to the fish, and the evidence of this growth can be seen in the circuli or concentric light and dark growth lines laid down on a scale. The spacing between circuli is an indication of the environmental conditions present in the waterway. During periods of environmental stress or decreased metabolism, fish growth will be slow and the circuli will be very close together. These lines are often so close that they appear as a heavy, dark line on the scale. These dark lines are called annuli and generally formed during the growth stagnation winter months. By counting the number of annuli on a scale, the age of the fish can be determined (http://creekconnections.allegheny.edu, read June 15th, 2009) (Figure 2-4). Several scales from the same individual were placed in crystal slides and observed in a microfiche reader.

Figure 2-4. *Scale from a brown trout in a microfiche reader.*

2.3 Analysis of the samples

2.3.1 Heavy metals

The concentration of Hg, Cd and Pb was measured in skinless fillets taken from the mid-dorsal muscle of the investigated fishes. Approximately 1 g of fillet was sampled from each fish and then, the samples were transferred into a digestion bomb. All bombs were previously rinsed with 7M HNO_3 for several hours, then treated with an EDTA solution (50 g/L) and finally rinsed twice with distilled water. The intention of this procedure is to prevent heavy metal contamination. Into the rinsed bombs with fish fillet, 4 ml of concentrated nitric acid (HNO_3) and 1 ml of 30 % hydrogen peroxide (H_2O_2) were added, before the bombs were heated up in a microwave oven for approximately 25 minutes. Then, the fillet should be totally digested. After cooling the bombs in cold water for approximately 20 minutes, the digested solutions were filtered into volumetric flasks and diluted up to 100 ml with distilled water. For each set of digestions (10 samples), one blank solution was done.

The Hg-analysis was performed by Atomic Fluorescence, with a PS Analytical (Millenium System) device. In every analysis, a 10 ppb Hg control was performed previous to the first sample analysis.

The analysis for Cd and Pb was performed by Graphite Furnace Atomic Absorption Spectrometry, using a Perkin Elmer HGA 900 instrument. For the measurement of Cd and Pb matrix modifiers were used, in order to prevent evaporation because of the high temperatures used during the analysis. For Cd, two modifiers were used: 2µl of $Mg(NO_3)_2$ and 2µl of $Pd(NO_3)_2 \cdot 2H_2O$, while $NH_4H_2PO_4$, was used as modifier for Pb.

2.3.2 Stable isotopes

About 50-100 mg of fish fillet from the mid-dorsal muscle of each fish was used for preparation of samples for stable isotope analyses of carbon and nitrogen. The samples were dried in the oven between 60-80 ºC over night before grinded in a mortar and dried again for some more hours at 60-80 ºC. Approximately 1 mg of each dried sample was then weighed and put into 9x15 mm tin capsules, which was sent to the Norwegian Institute for Energy Technique (IFE) for stable isotope analyses. Totally 173 samples were analyzed for stable carbon isotopes, ^{12}C and ^{13}C, and stable nitrogen isotopes ^{14}N and ^{15}N.

At IFE, the dried and grinded samples were subjected to combustion in the presence of O_2 and Cr_2O_3 at 1700 ºC in an Eurovector element analyzer. Reduction of NO_x to N_2 was done in a Cu oven at 650 ºC. H_2O was removed in a chemical trap of $KMnO_4$ before separation of N_2 and CO_2 on a 2 m Poraplot Q GC column. The C/N ratio was quantified on the basis of the mass 44 peak areas. N_2 and CO_2 were directly injected on-line to a Nu Horizon Stable Isotope Ratio Mass Spectrometer for determination of $\delta^{13}C$ and $\delta^{15}N$.

All isotope values are referring to primary standards. For C the reference standard, PDB, is marine carbonate, Pee Dee Belemnite (Craigh, 1953). Peedee is a place in South Carolina where the Cretaceous formation is located. This nomenclature has now been changed to VPDB (Coplen, 1994). For N the reference standard is atmospheric nitrogen (Mariotti, 1983).

The accuracy and precision of $\delta^{13}C$ and $\delta^{15}N$ analyses have been measured by replicate analysis of IFE internal standard (IFE trout) and international standards IAEA-N-1 and IAEA-N-2 ($\delta^{15}N$) and USGS-24 ($\delta^{13}C$). The house standard at IFE was prepared by Soxhlet extraction with CH_2Cl_2:7% CH_3OH for approximately 2 hours, cleansed with 2N HCl and rinsed with distilled water to neutral pH. Average results with one standard deviation for 18 analyses of the IFE trout standard analyzed together with the samples were:

$$\delta^{15}N_{AIR}\text{: } 11{,}49‰ \pm 0{,}16, \quad \delta^{13}C_{VPDB}\text{: } -20{,}14\ ‰ \pm 0{,}07$$

The relationships between stabile isotopes of C and N ($^{13}C/^{12}C$ and $^{15}N/^{14}N$) are reported in ‰ and the δ is expressed according to the following equation:

$$\delta^{15}N \text{ or } \delta^{13}C = \left(\frac{R_{sample}}{R_{standard}} - 1 \right) * 1000$$

where R represent the ratio between the heavy and light isotope ($^{13}C/^{12}C$ or $^{15}N/^{14}N$).

3 Results

In order to make comparisons between lakes, correlations with weight, length and age is useful to express growth rates, which furthermore is an indication of food and nutrient status in the lake. Since some metals as methyl-Hg biomagnify through the aquatic food web, fish weight is a good predictor of Hg-concentration in fish (Gilmour and Riedel, 1999).

3.1 Whitefish (Coregonus lavaretus)

Totally 41 whitefish were analyzed in this study. Average weight for the analyzed population of whitefish was 247 ± 100 g, varying from a minimum of 90 g to a maximum of 470 g. The average length was 29,8 ± 4,1 cm, varying from a minimum of 22 cm to a maximum of 37 cm. There was no weight or length group of individuals that prevailed in the studied material. The age groups comprise a variety of whitefish from 3 up to 13 year old, with an average value of 6,6 ± 2,6 yrs.

Based on the whitefish analyzed, the population seems to be in good condition, with a k-factor (K_f = Weight (g)*100/Length ^{3}(cm)) varying from 0,70 to 1,11, with an average of 0,88 ± 0,10. The studied whitefish population showed a significant quadratic relationship between weight and length (Figure 3-1-2d).

The average Hg-concentration in whitefish was 0,12 ± 0,04 mg Hg/kg ww, varying from 0,04 to 0,22 mg Hg/kg ww (Table 3-1-1). No significant relationships were found between Hg-concentration in fish and weight, length or age (Figure 3-1-2). As an example, 7 year old whitefishes varied in Hg-concentrations from 0,040 to 0,220 mg Hg/kg ww, i.e. the minimum and maximum values among all our data (Figure 3-1-2c). Furthermore, the biggest whitefish (weight: 470 g, length: 36 cm) had similar Hg-concentration as the smallest fishes in the investigated material (Figure 3-1-2a).

Pb- and Cd-concentrations in the whitefish (n = 22) were in general very low, with Cd-levels below the detection limit (< 0,005 mg Cd/kg ww) for all investigated whitefish, and only one whitefish had Pb-concentrations above detection limit (< 0,1 mg Pb/kg ww), i.e. 0,67 mg Pb/kg ww.

The stable nitrogen isotope ratio ($\delta^{15}N$) in whitefish (n = 41) varied from 7,60 ‰ to 11,88 ‰ (Figure 3-1-1, Table 3-1-1), with an average value of 9,59 ± 0,98 ‰. A significant ($p < 0,001$) linear relationship was found between $\delta^{15}N$ and weight (r^2 = 0,71), length (r^2 = 0,71) and age (r^2 = 0,63), but no significant relationship was found between $\delta^{15}N$ and Hg-concentration (Appendix 2, Figure 3-1-3).

The stable carbon isotope ratio ($\delta^{13}C$) in whitefish (n = 41) varied from -29,44 ‰ to -20,16 ‰, with an average of -25,61 ± 2,71 ‰ (Table 3-1-1). A significant ($p < 0,001$) linear relationship was found between $\delta^{13}C$ and weight ($r^2 = 0,77$), length ($r^2 = 0,74$) and age ($r^2 = 0,41$), whilst a weak, but significant ($p < 0,05$) linear relationship was found between $\delta^{13}C$ and Hg-concentration. No significant relationship was found between $\delta^{13}C$ and k-factor (Appendix 2, Figure 3-1-4).

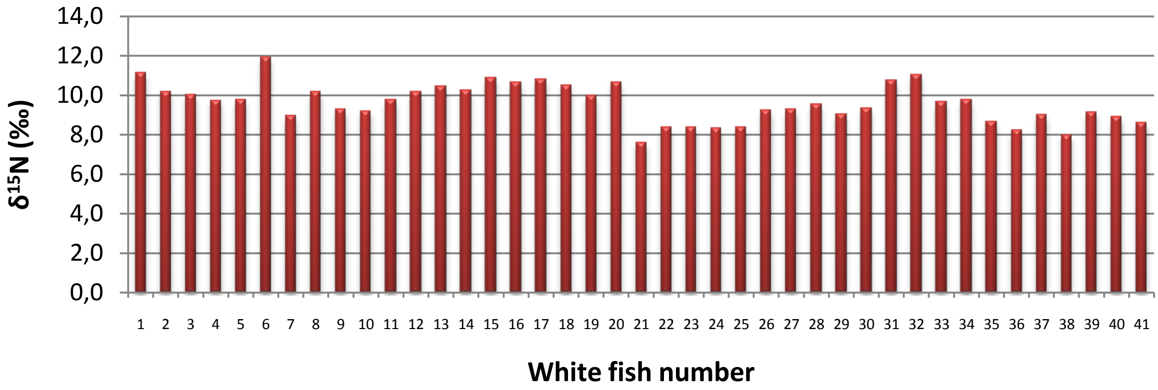
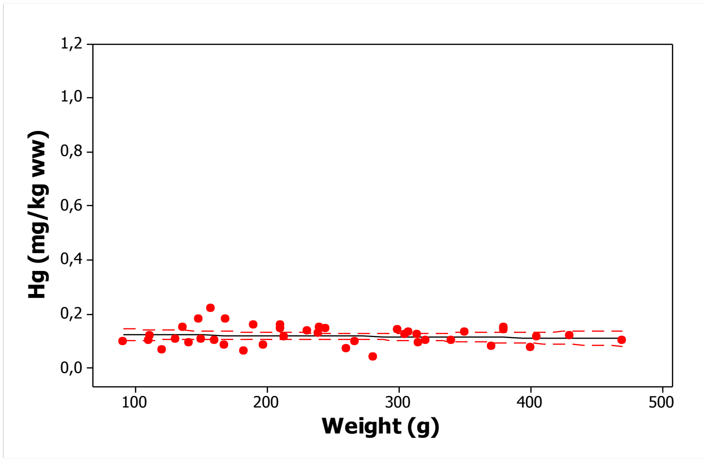


Figure 3-1-1. *$\delta^{15}N$ values in whitefish from Lake Norsjø*

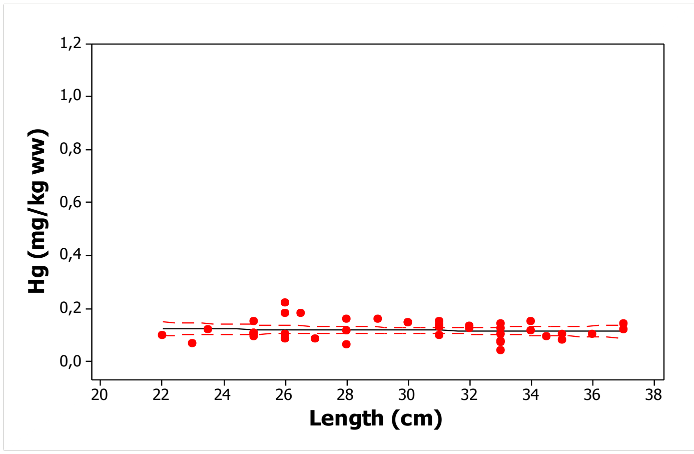
Table 3-1-1. *Morphological data, age, stable N and C isotope ratio and concentrations of Pb, Cd, and Hg in whitefish from Lake Norsjø.*

Species	Variable	Units	Number	Average	Median	SD	Min.	Max.
White fish	Length	cm	41	29,84	31,00	4,13	22,00	37,00
	Weight	g	41	247,16	239,00	100,56	90,00	470,00
	Age	years	41	6,63	7,00	2,57	3,00	13,00
	K-factor		41	0,88	0,87	0,10	0,70	1,11
	$\delta^{15}N$	‰	41	9,59	9,64	0,98	7,60	11,88
	$\delta^{13}C$	‰	41	-25,61	-25,59	2,71	-29,44	-20,16
	Hg	(mg/kg ww)	41	0,12	0,12	0,04	0,04	0,22
	Pb	(mg/kg ww)	41	0,10			0,10	0,67
	Cd	(mg/kg ww)	41	0,005				

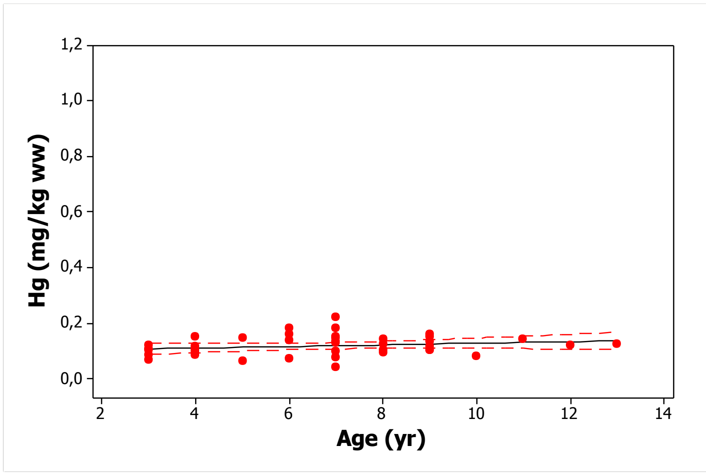
a) Hg in fish versus weight in whitefish



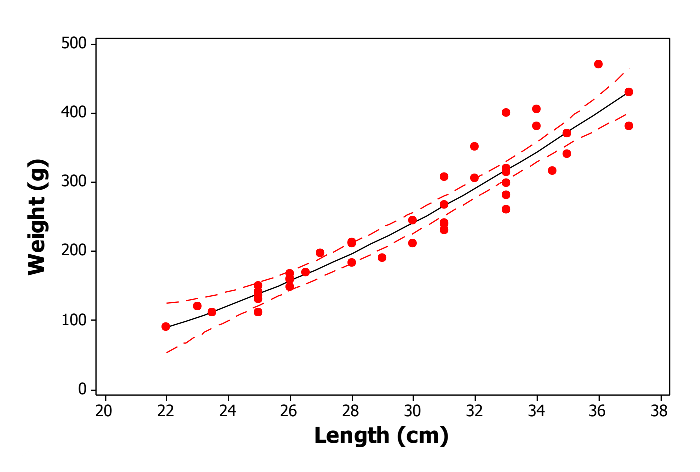
b) Hg in fish versus length in whitefish



c) Hg in fish versus age in whitefish



d) Weight versus length in whitefish



a) Hg = 0,1267 - 0,000037 Weight
r^2 = 0,00 p = 0,526

b) Hg = 0,1387 - 0,000702 Length
r^2 = 0,00 p = 0,617

c) Hg = 0,09824 + 0,002934 Age
r^2 = 0,02 p = 0,190

d) Weight = 21,9 - 8,74 Length + 0,5358 Length^2
r^2 = 0,89 p = 0,000

Figure 3-1-2. *Relationship between Hg-concentration and weight (a), length (b) and age (c) in whitefish from Lake Norsjø. The curves are based on linear regression. The relationship between weight and length (d) is based on quadratic regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*

3.2 European smelt (*Osmerus eperlanus*)

Average weight of the European smelt (*Osmerus eperlanus*) was 7,9 ± 10,3g (n = 29), varying from 3 g to 60 g. Average length was 10,6 ± 2,3 cm, varying from 9 to 22 cm (Table 3-2-1). Except for one big individual (22 cm and 60 g), the remaining population investigated, were basically between 3-10 g, with lengths between 9-11 cm. Average age of the studied individuals was 6 ± 2,1 yrs (n = 29), varying from 2 to 14 yrs (Table 3-2-1), but the investigated population were predominated by 5-7 year old European smelts.

The k-factor (K_f = Weight (g)*100/Length ^{3}(cm)) varied from 0,40 to 0,75, with an average of 0,55 ± 0,10 (n= 29). Since use of K_f as a condition measure, is principally used on salmonids, primarily brown trout and Arctic char, this low K_f in the European smelt is not necessarily an expression of a population in bad condition. European smelts, naturally have an elongated shape and are rather thin. A very significant quadratic relationship (r^2 = 0,99) was found between weight and length of the European smelts (Figure 3-2-2d).

The average Hg-concentration in European smelt was 0,24 ± 0,16 mg Hg/kg ww (n = 29), varying from a minimum of 0,07 mg Hg/kg ww to a maximum of 0,94 mg Hg/kg ww (Table 3-2-1). The individual with the highest Hg-concentration was the biggest (weight: 60 g, length: 22 cm) and eldest (14 yrs). However, the lowest Hg-concentration was recorded in the second biggest European smelt (weight: 14,5 g, length: 12,5 cm, age: 7 yrs).

Significant linear relationships ($p < 0,001$) were found between Hg-concentrations and weight (r^2 = 0,63), length (r^2 = 0,65) and age (r^2 = 0,60) (Figure 3-2-2). However, if the analysis is done without the extreme point, the results obtained vary significantly, so much so that the correlations are weaker and not significant anymore.

Pb- and Cd-concentrations were analyzed in European smelt (n = 18), and they all had Pb-levels < 0,1 mg Pb/kg ww. On the other hand, the Cd-concentrations were the highest among all the fish species analyzed. Average Cd-concentration was 0,055 ± 0,029 mg Cd/kg ww, varying from 0,005 to 0,126 mg Cd/kg ww. No linear relationship was found between Cd-concentration and weight, length nor age.

The stable nitrogen isotope ratio ($\delta^{15}N$), varied from 7,54 ‰ to 12,02 ‰, with an average of 10,81 ± 0,88 ‰ (n = 28) (Table 3-2-1). No significant relationships were found between $\delta^{15}N$ and weight, length, age nor Hg-concentration (Appendix 2, Figure 3-2-3). However, if the analysis is done without the extreme points, the relationships change. The correlation between weight and $\delta^{15}N$ changes to a negative and significant (r^2 = 0,24, $p < 0,05$) relationship, while the relation of length and age with $\delta^{15}N$ does not improve. As well, Hg-concentration versus $\delta^{15}N$ becomes a significant (r^2 = 0,38, p = 0,001) positive correlation.

However, the oldest and biggest European smelt had a higher $\delta^{15}N$ signature compared to the other individuals.

The stable carbon isotope ratio ($\delta^{13}C$) in European smelt varied from a minimum of -30,30 ‰ to a maximum of -27,77 ‰ (Table 3-2-1), with an average of -29,03 ± 0,64 ‰ (n= 28). No significant relationships were found between $\delta^{13}C$ and weight, length age nor Hg-concentration (Appendix 2, Figure 3-2-3).

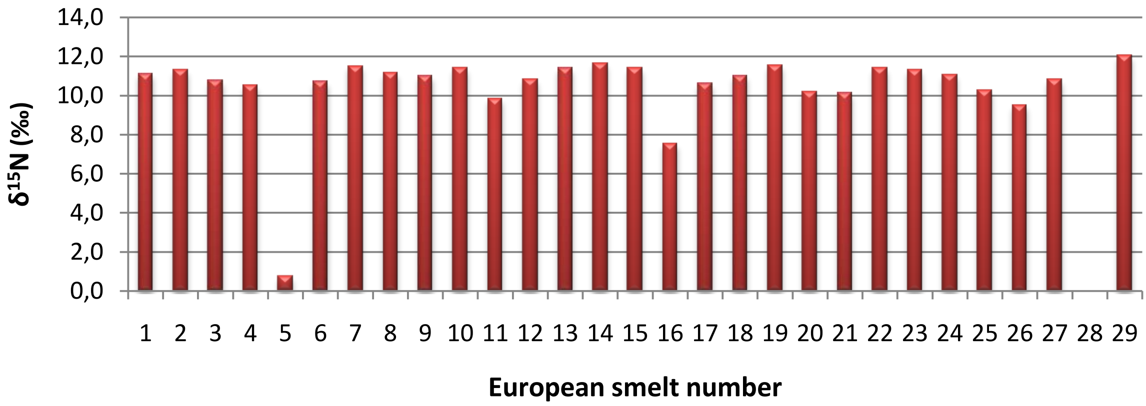
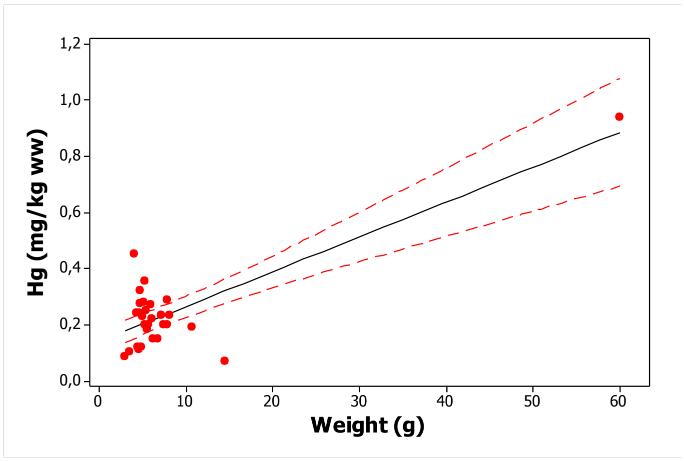


Figure 3-2-1. *$\delta^{15}N$ values in European smelt from lake Norsjø*

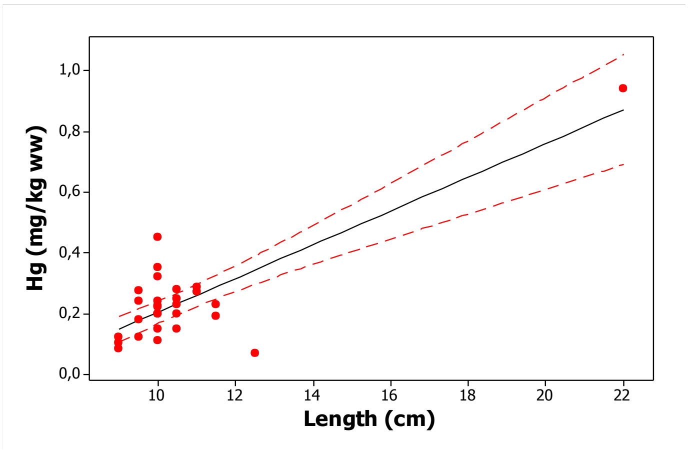
Table 3-2-1. *Average (± stdev), median, maximum and minimum values of morphological parameters, age, Hg-concentration and K-factor from European smelt (n = 29) in Lake Norsjø and $\delta^{15}N$ (n = 27), $\delta^{13}C$ (n = 28), Pb- and Cd-concentrations (n = 18).*

Species	Variable	Units	Number	Average	Median	SD	Min.	Max.
E. smelt	Length	cm	29	10,59	10,00	2,33	9,00	22,00
	Weight	g	29	7,87	5,32	10,28	3,00	60,00
	Age	years	29	6,03	6,00	2,10	2,00	14,00
	K-factor		29	0,55	0,54	0,10	0,40	0,75
	$\delta^{15}N$	‰	27	10,81	11,01	0,88	7,54	12,02
	$\delta^{13}C$	‰	28	-29,03	-28,95	0,64	-30,30	-27,77
	Hg	(mg/kg ww)	29	0,24	0,22	0,16	0,07	0,94
	Pb	(mg/kg ww)	18				0,10	0,10
	Cd	(mg/kg ww)	18	0,055	0,059	0,029	0,005	0,126

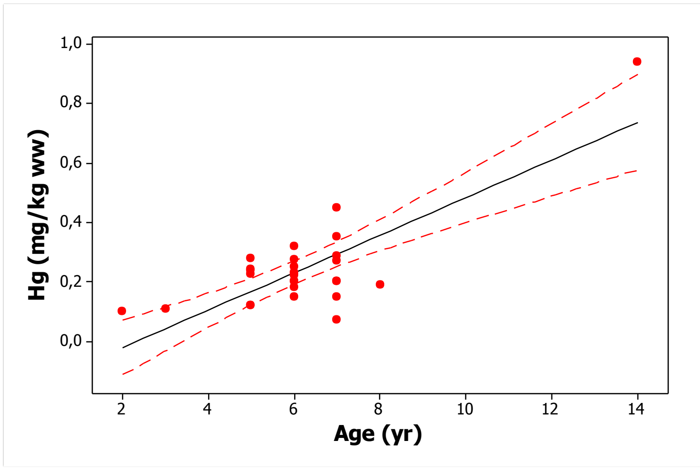
a)Hg in fish versus weight in European smelt



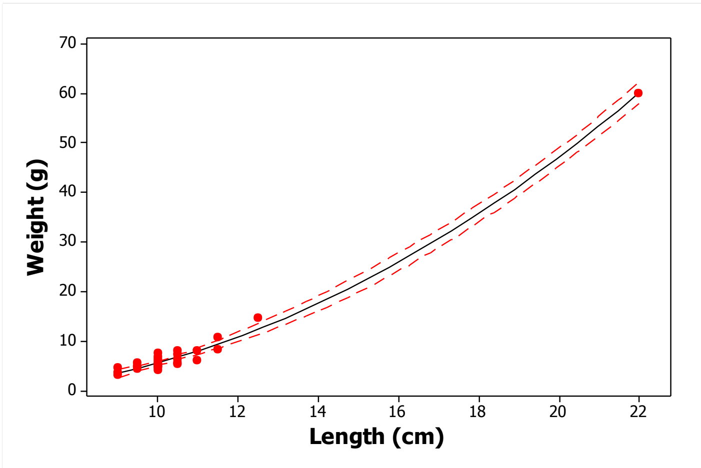
b) Hg in fish versus length in European smelt



c) Hg in fish versus age in European smelt



d) Weight versus length in European smelt



a) Hg = 0,1393 + 0,01244 Weight
r^2 = 0,63 p = 0,000

b) Hg = - 0,3514 + 0,05560 Length
r^2 = 0,65 p = 0,000

c) Hg = - 0,1480 + 0,06324 Age
r^2 = 0,61 p = 0,000

d) Weight = 1,780 - 1,531 Length + 0,1900 Length^2
r^2 = 0,99 p = 0,000

Figure 3-2-2. *Relationship between Hg-concentration and weight (a), length (b) and age (c) in European smelt from Lake Norsjø. The curves are based on linear regression. The relationship between weight and length (d) is based on quadratic regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*

3.3 Arctic char (*Salvelinus alpinus*)

Of the 53 Arctic char (*Salvelinus alpinus*) incorporated in this study, only 27 were analyzed with respect to age, $\delta^{13}C$, $\delta^{15}N$, Hg, Pb and Cd.

Average weight of the Arctic char was 30 ± 34 g (n = 53), varying from 3,8 g to 164 g. Average length was 13,8 ± 5,6 cm (n =53), varying from 8-38 cm (Table 3-3-1). The majority of the investigated individuals varied between 5-25 g in weight and between 8-15 cm in length. Average age of the investigated population was 8,8 ± 3,4 yrs, varying from 5-20 yr.

The k-factor (K_f = Weight (g)*100/Length ^{3}(cm)) varied from 0,30 to 1,19, with an average of 0,84 ± 0,13). These values indicate a population with relatively low condition, well illustrated with the biggest and oldest one (164 g and 18,5 cm) having a K_f as low as 0,30. However, there was a very significant relationship (Figure 3-3-2d) between weight and length (r^2= 0,95, $p < 0,001$). Moreover, a weak but significant ($p < 0,05$) negative linear relationship was found between K_f and Hg-concentration.

The investigated Arctic char were in general very small, old and with a low k-factor. This reflects an Arctic char population in bad condition. Likely the investigated population belongs to a "dwarf population" in the lake. It is not uncommon to have two separate populations of Arctic char in large, deep lakes in Norway, one population consisting of big and healthy individuals, separated from a population of small and often less healthy individuals (dwarfs) located in the deeper parts of the lake (Jonsson & Semb-Johansson, 1992; Hindar & Jonsson, 1982).

The average Hg-concentrations in Arctic char (n = 27) was 0,24 ± 0,24 mg Hg/kg ww (Table 3-3-1), varying from 0,08 to 1,11 mg Hg/kg ww. The highest Hg-concentrations (0,46- 1,1 mg Hg/kg ww) were found in Arctic char between 8-20 yrs.

A weak, but significant linear relationship ($p < 0,05$) was found between Hg-concentrations in fish and weight (r^2 = 0,30), length (r^2 = 0,37) and age (r^2 = 0,22) (Figure 3-3-2). However, these relationships become stronger and more significant ($p < 0,001$) if the extreme point is not taken into account on the analysis (r^2 = 0,74, r^2 = 0,73 and r^2 = 0,61 respectively).

Pb- and Cd-concentrations in the Arctic char (n = 27) were in general very low, and only 2 individuals had Pb-concentrations > the detection limit of 0,1 mg/kg ww, i.e. 0,2 and 0,3 mg Pb /kg ww. 18 of the 27 investigated individuals had Cd-levels > detection limit of 0,005 mg Cd/kg ww, and the highest measured concentration (0,064 mg Cd/kg ww) was recorded in one of the youngest and smallest individuals (age: 5 yr, weight: 5,80 g, length: 16 cm). However, even this concentration is very low.

The average stable nitrogen isotope ratio ($\delta^{15}N$) in Arctic char was 12,68 ± 0,51 ‰ (n = 27), varying from 11, 47 ‰ to 13,63 ‰ (Figure 3-3-1). No significant relationships were found between $\delta^{15}N$ and weight, length, age or Hg-concentrations in the Arctic char investigated (Appendix 2, Figure 3-3-3). If the extreme point is removed in the Hg-concentration versus $\delta^{15}N$ correlation, the result does not improve.

Average stable carbon isotope ratio ($\delta^{13}C$) in Arctic char was -30,20 ± 1,31 ‰ (n = 27), varying from -33,68 ‰ to -27,88 ‰ (Table 3-3-1). A weak, but significant ($p < 0,05$) linear relation was found between $\delta^{13}C$ and weight ($r^2 = 0,12$) and Hg-concentration ($r^2 = 0,14$). No significant relationship was found between $\delta^{13}C$ and length or age (Appendix 2, Figure 3-3-4).

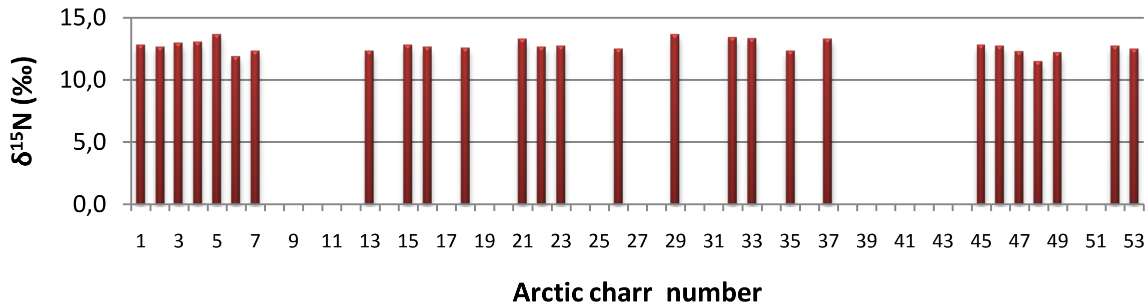
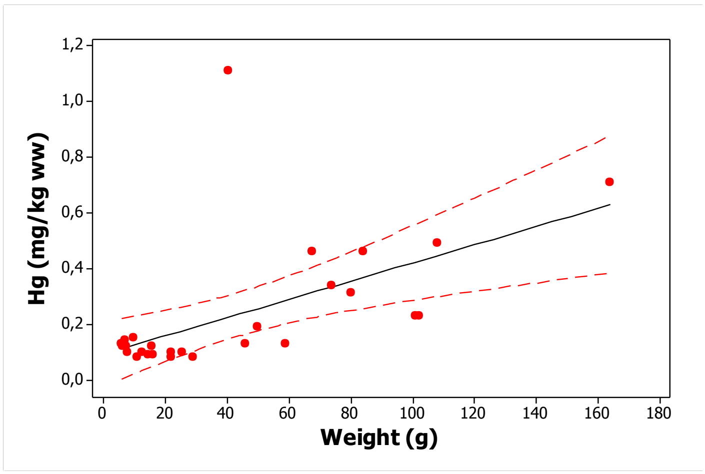


Figure 3-3-1. *$\delta^{15}N$ values in Arctic char from Lake Norsjø*

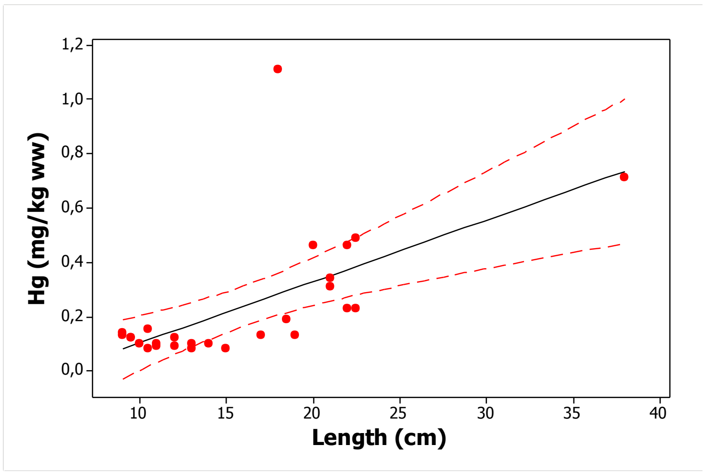
Table 3-3-1. *Average (± stdev), median, maximum and minimum values of morphological parameters and K-factor from Arctic char (n = 53) in Lake Norsjø and age of fish and $\delta^{15}N$, $\delta^{13}C$, Hg, Pb, Cd in fish fillet from 27 of the same group of fish.*

Species	Variable	Units	Number	Average	Median	SD	Min.	Max.
Arctic char	Length	cm	53	30,25	12,00	5,60	8,00	38,00
	Weight	g	53	75,85	14,50	33,91	3,80	164,00
	Age	years	27	8,81	8,00	3,43	5,00	20,00
	K-factor		53	0,84	0,85	0,13	0,30	1,19
	$\delta^{15}N$	‰	27	12,68	12,70	0,51	11,47	13,63
	$\delta^{13}C$	‰	27	-30,20	-29,95	1,31	-33,68	-27,88
	Hg	(mg/kg ww)	27	0,24	0,13	0,24	0,08	1,11
	Pb	(mg/kg ww)	27				0,10	0,30
	Cd	(mg/kg ww)	27				0,005	0,064

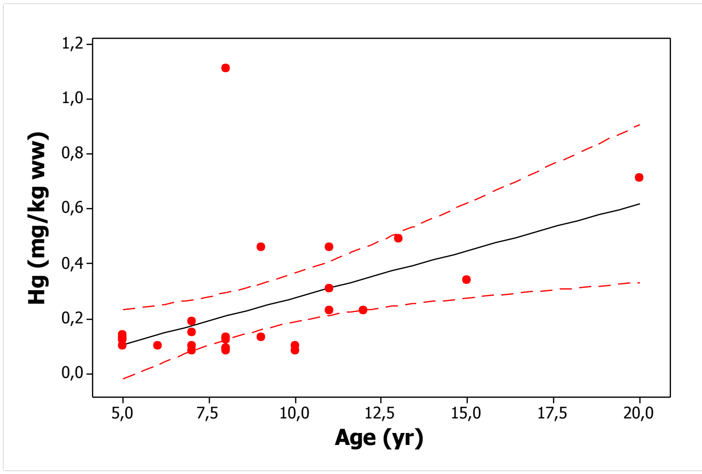
a) Hg in fish versus weight in Arctic char



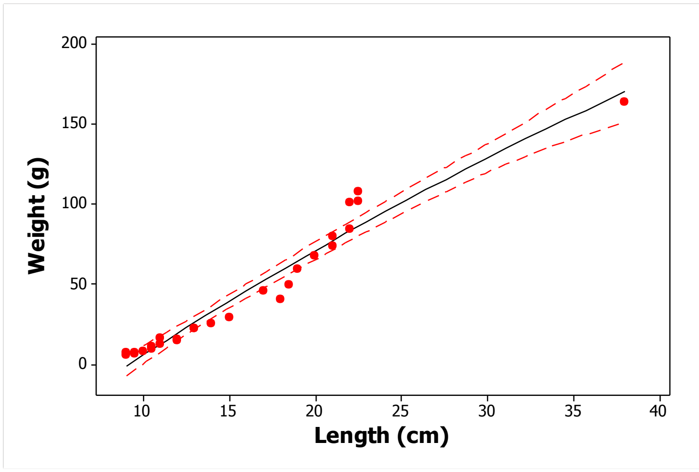
b) Hg in fish versus length in Arctic char



c) Hg in fish versus age in Arctic char



d) Weight versus length of Arctic char



a) Hg = 0,09270 + 0,003275 Weight
r^2 = 0,30 p = 0,002

b) Hg = - 0,1247 + 0,02267 Length
r^2 = 0,37 p = 0,000

c) Hg = - 0,0647 + 0,03419 Age
r^2 = 0,22 p = 0,008

d) Weight = - 66,56 + 7,596 Length - 0,03587 Length^2
r^2 = 0,95 p = 0,000

Figure 3-3-2. *Relationship between Hg-concentration and weight (a), length (b) and age (c) in Arctic char from Lake Norsjø. The curves a, b, and c are based on linear regression, while the relationship between weight and length, curve (d), is based on quadratic regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*

3.4 Perch (*Perca fluviatilis*)

Totally 26 perches were analyzed in this study. Average weight of the investigated perch (*Perca fluviatilis)* was 156,64 ± 115,14 g (n = 26), varying from 1,52 g to 516 g (Table 3-4-1). Average length was 22,40 ± 6,40 cm, varying from 5,5 cm to 34 cm. Most of the individuals included were between 100-150 g in weight and between 20-25 cm in length. The age varied from 1 to 7 years, with an average of 4,2 ± 1,2 yrs (n = 26). 4-5 year old individuals predominated in the investigated material.

The k-factor values for the analyzed perches indicated that they were in rather good condition. The average was 1,12 ± 0,11, varying from 0,91 to 1,33, but as mentioned earlier the k-factor is primarily used for salmonids. Perch normally change to a more circular shape as they grow bigger, which means that the K-factor (K_f = Weight (g)*100/Length ^{3}(cm)) will easily reach values > 1, since the ratio between weight and length is very different from salmonids as brown trout and Arctic char.

Average Hg-concentrations in perch was 0,13 ± 0,07 mg Hg/kg ww (n = 26), varying from 0,07 mg Hg/kg ww to 0,40 mg Hg/kg ww. The highest Hg-concentration was found in a 5 yr old perch, whilst the lowest concentration was found in a 4 yr old perch, but this concentration was very close to that found in the youngest perches investigated (1 year old).

A weak, but significant linear relationship ($p < 0,05$) was found between Hg-concentration in perch and weight ($r^2 = 0,39$), length ($r^2 = 0,29$) and age ($r^2 = 0,22$), while a very significant quadratic relationship ($p < 0,001$) existed between weight and length ($r^2 = 0,98$) (Figure 3-4-2).

Pb- and Cd-concentrations in the perch (n = 26) were generally very low (Table 3-4-1), and only 3 individuals had Pb-concentrations > detection limit of 0,1 mg Pb/kg ww, i.e. 0,16, 0,12 and 0,11 mg Pb/kg ww. Except for one individual (0,007 mg Cd/kg ww), the Cd-concentrations in perch were < detection limit of 0,005 mg Cd/kg ww.

Stable nitrogen isotope ratio ($\delta^{15}N$) in perch (n = 26), varied from 7,81 ‰ to 11,25 ‰ (Figure 3-4-1), with an average of 10,24 ± 0,94 ‰ (Table 3-4-1). No significant relationships were found between $\delta^{15}N$ and weight or Hg-concentrations, but a weak relationship ($p < 0,05$) was found between $\delta^{15}N$ and length ($r^2 = 0,13$) and age ($r^2 = 0,15$) (Appendix 2, Figure 3-4-3).

Stable carbon isotope ratio ($\delta^{13}C$), for the analyzed perch (n = 26), varied from -26,89 ‰ to -21,27 ‰, with an average of -24,21 ± 1,36 ‰ (Table 3-4-1). No significant relationships were found between $\delta^{13}C$ and weight, length or Hg-concentrations, but a weak relationship ($p < 0,05$) was found between $\delta^{13}C$ and age ($r^2 = 0,13$) (Appendix 2, Figure 3-4-4).

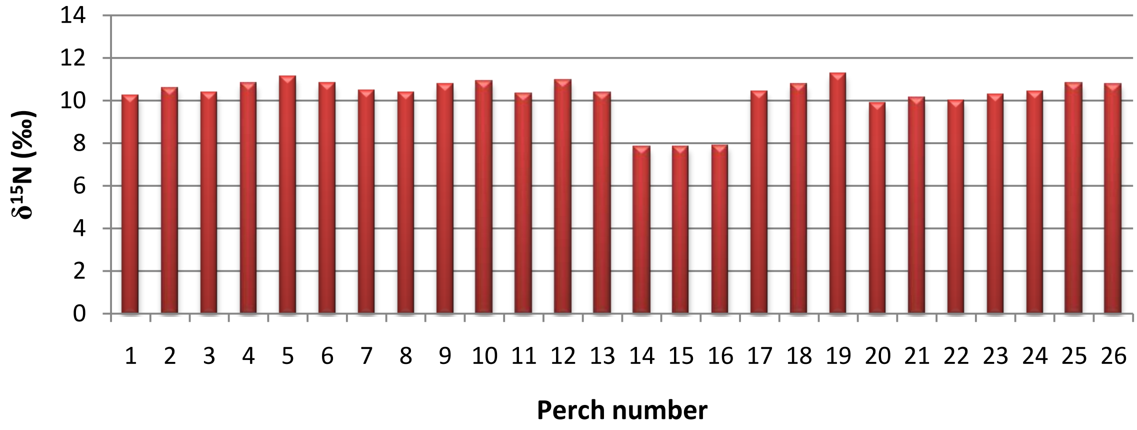
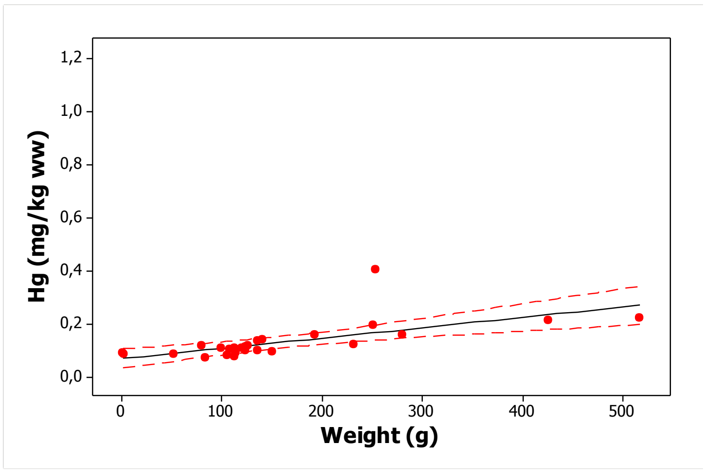


Figure 3-4-1. *δ^{15}N values in perch from lake Norsjø*

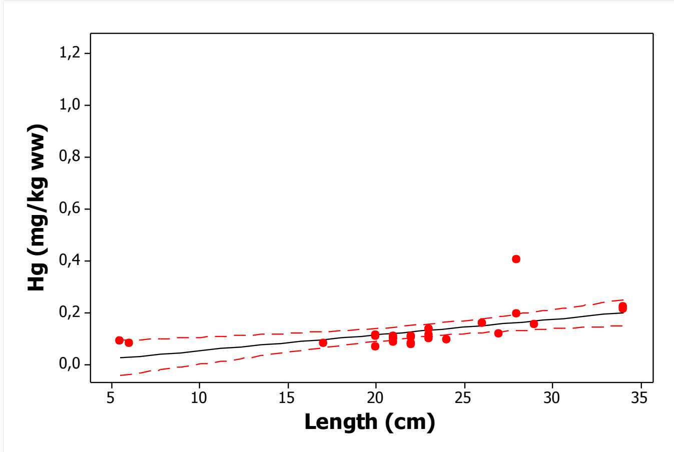
Table 3-4-1. *Morphological data, age, stable N and C isotope ratio and concentrations of Pb, Cd, and Hg in perch from Lake Norsjø.*

Species	Variable	Units	Number	Average	Median	SD	Min.	Max.
Perch	Length	cm	26	22,40	22,00	6,40	5,50	34,00
	Weight	g	26	156,64	123,50	115,14	1,52	516,00
	Age	years	26	4,23	4,00	1,24	1,00	7,00
	K-factor		26	1,12	1,12	0,11	0,91	1,33
	δ^{15}N	‰	26	10,24	10,40	0,94	7,81	11,25
	δ^{13}C	‰	26	-24,21	-23,92	1,36	-26,89	-21,27
	Hg	(mg/kg ww)	26	0,13	0,11	0,07	0,07	0,40
	Pb	(mg/kg ww)	26				0,10	0,16
	Cd	(mg/kg ww)	26				0,005	0,007

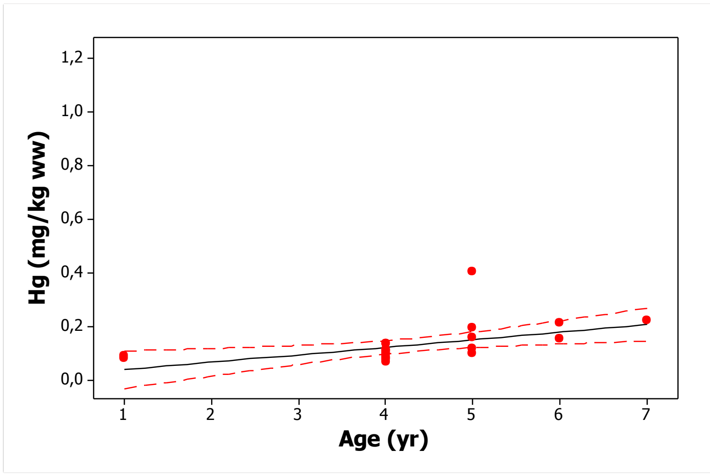
a) Hg in fish versus weight in perch



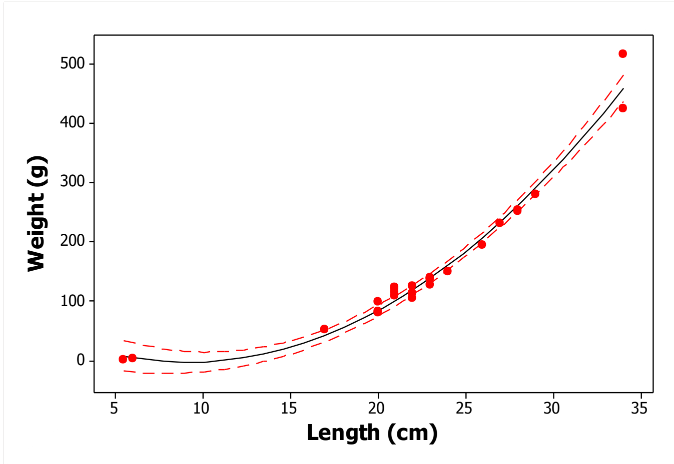
b) Hg in fish versus length in perch



c) Hg in fish versus age in perch



d) Weight versus length in perch



a) Hg = 0,06696 + 0,000389 Weight
r^2 = 0,39 p = 0,000

b) Hg = - 0,00855 + 0,006090 Length
r^2 = 0,29 p = 0,003

c) Hg = 0,00970 + 0,02793 Age
r^2 = 0,22 p = 0,009

d) Weight = 61,53 - 13,98 Length + 0,7543 Length^2
r^2 = 0,98 p = 0,000

Figure 3-4-2. *Relationship between Hg-concentration and weight (a), length (b) and age (c) in perch from Lake Norsjø. The curves a, b, and c are based on linear regression, while the relationship between weight and length, curve (d), is based on quadratic regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*

3.5 Brown trout (*Salmo trutta*)

The average weight of the investigated brown trout was 611 ± 336 g (n = 22), varying from a minimum of 180 g to a maximum of 1580 g (Table 3-5-1). The average length was 38,8 ± 6,8 cm, varying from 28 cm to 53 cm. The material was dominated by individuals between 200-800 g. The age varied between 4-14 years, with an average of 7,7 ± 2,3 yrs.

The average k-factor was 0,97 ± 0,13, varying from 0,75 to 1,31 (Table 3-5-1). Since a k-factor of 1 ((K_f = Weight (g)*100/Length ^{3}(cm) = 1) reflects a brown trout population in good condition, the brown trout in Lake Norsjø accordingly should be in good condition. A strong quadratic relationship ($p < 0,001$, $r^2 = 0,92$) was found between weight and length in the investigated brown trout material (Figure 3-5-2). However, no linear relationship was found between K_f and Hg-concentration.

The average Hg-concentration in brown trout was 0,19 ± 0,29 mg Hg/kg ww (n = 22), varying from 0,04 - 1,44 mg Hg/kg ww. The highest Hg-concentration (1,44 mg Hg/kg ww) was found in the eldest individual (14 year, weight: 1200 g, length: 53 cm) caught during spawning time in October 25th, 2008. It was a tendency that the smallest brown trout also had the lowest Hg-concentrations. This was further confirmed by a strong quadratic relationship ($p < 0,001$, $r^2 = 0,84$) between Hg-concentration and age, and weak, but significant ($p < 0,05$) linear relationships between Hg-concentration and weight ($r^2 = 0,16$) and length ($r^2 = 0,22$) (Figure 3-5-2). However, if the extreme point is removed to do the regression analysis, all these correlations become weaker.

Pb- and Cd-concentrations in all the brown trout analyzed (n = 22) were < detection limits, i.e. < 0,005 mg Cd/kg ww and < 0,1 mg Pb/kg ww.

The average stable nitrogen isotope ratio ($\delta^{15}N$) in brown trout was 10,14 ± 1,45 ‰ (n = 22), varying from a minimum of 7,20 ‰ to a maximum of 12,19 ‰ (Figure 3-5-1, Table 3-5-1). No significant relationship was found between $\delta^{15}N$ and weight, length, age and Hg-concentrations in fish (Appendix 2, Figure 3-5-3). However, the correlation between Hg-concentration and $\delta^{15}N$ became strong and significant ($r^2 = 0,44$, $p = 0,001$) when removing the extreme point from the analysis.

The average stable carbon isotope ratio ($\delta^{13}C$) in brown trout was -25,01 ± 2,54 ‰ (n = 22), varying from -29,69 ‰ to -20,71 ‰ (Table 3-5-1). No significant relationship was found between $\delta^{13}C$ and weight, length, age and Hg-concentration (Appendix 2, Figure 3-5-4).

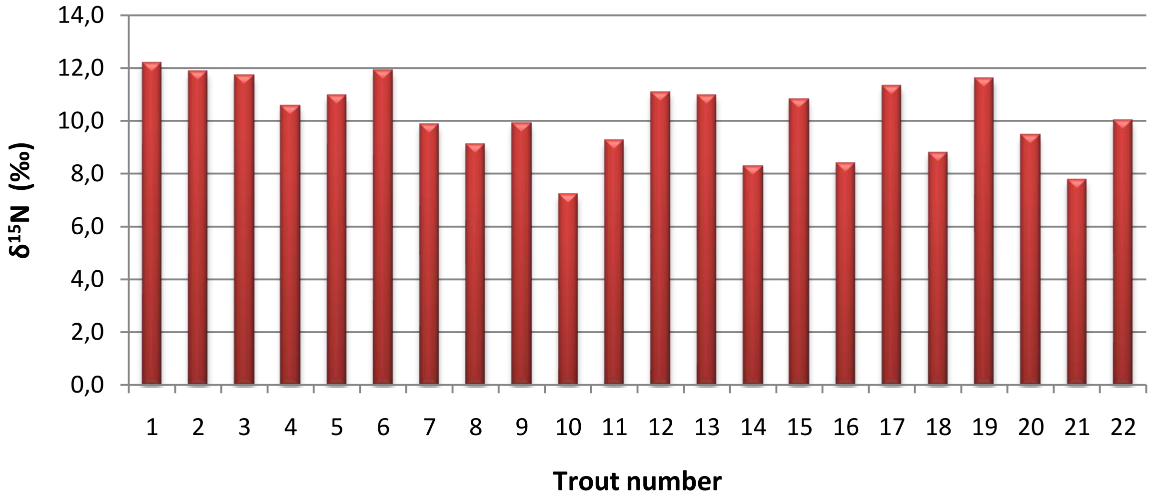
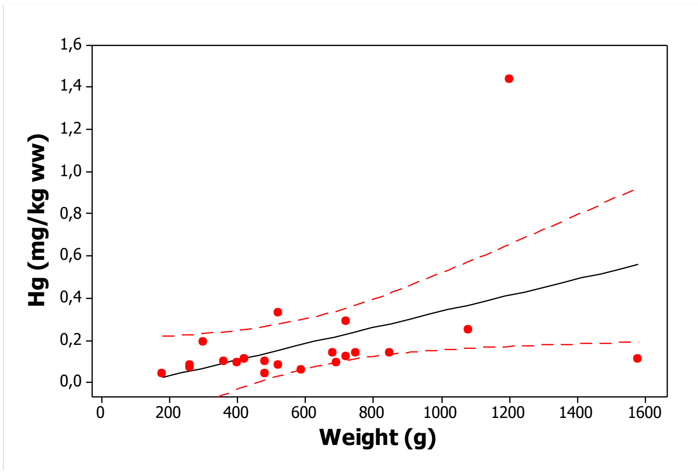


Figure 3-5-1. *δ^{15}N values in brown trout from Lake Norsjø*

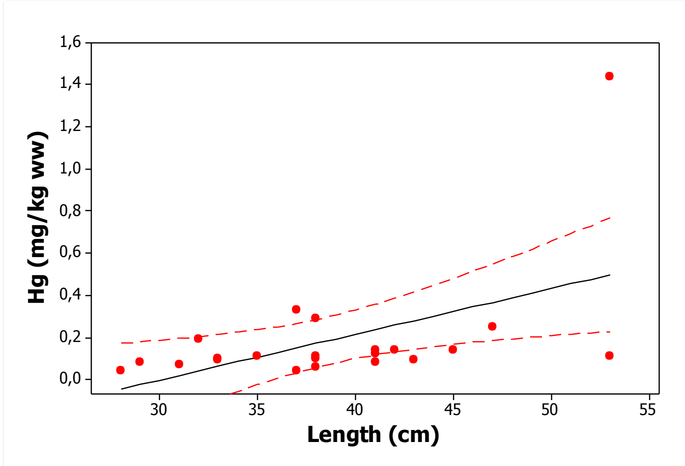
Table 3-5-1. *Morphological data, age, stable N and C isotope ratio and concentrations of Pb, Cd, and Hg in brown trout from Lake Norsjø.*

Species	Variable	Units	Number	Average	Median	SD	Min.	Max.
Trout	Length	cm	22	38,77	38,00	6,77	28,00	53,00
	Weight	g	22	611,82	520,00	336,49	180,00	1580,00
	Age	years	22	7,68	8,00	2,30	4,00	14,00
	K-factor		22	0,97	0,98	0,13	0,75	1,31
	δ^{15}N	‰	22	10,14	10,30	1,45	7,20	12,19
	δ^{13}C	‰	22	-25,01	-25,18	2,54	-29,69	-20,71
	Hg	(mg/kg ww)	22	0,19	0,11	0,29	0,04	1,44
	Pb	(mg/kg ww)	22	0,10				
	Cd	(mg/kg ww)	22	0,005				

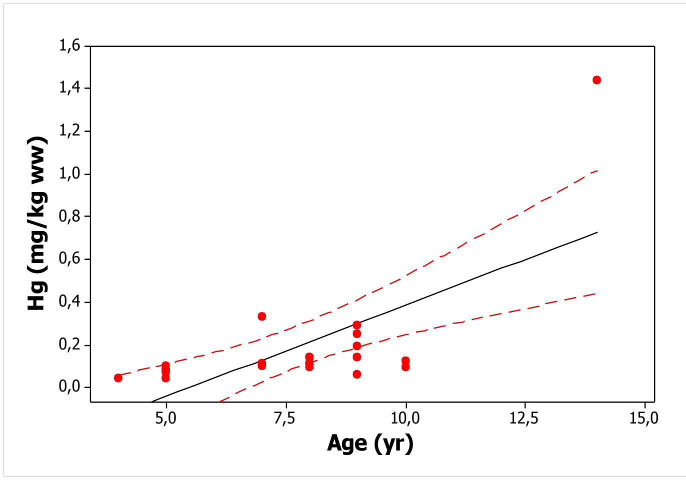
a) Hg in fish versus weight in brown trout



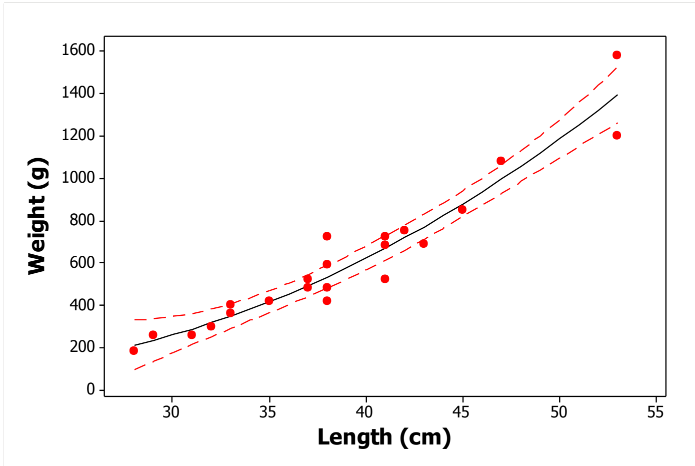
b) Hg in fish versus length in brown trout



c) Hg in fish versus age in brown trout



d) Weight versus length in brown trout



a) Hg = - 0,0471 + 0,000383 Weight
r^2 = 0,16 p = 0,038

b) Hg = - 0,6563 + 0,02176 Length
r^2 = 0,22 p = 0,016

c) Hg = - 0,4709 + 0,08568 Age
r^2 = 0,43 p = 0,001

d) Weight= 374,3 - 33,75 Length + 0,9993 Length^2
r^2 = 0,92 p = 0,000

Figure 3-5-2. *Relationship between Hg-concentration and weight (a), length (b) and age (c) in brown trout from Lake Norsjø. The curves a, b and c are based on linear regression, while the relationship between weight and length, curve (d), is based on quadratic regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*

3.6 Atlantic salmon (*Salmo salar*)

The average weight of the Atlantic salmon (*Salmo salar*) was 3189 ± 2085 g (n = 14), varying from 1670 g to 9200 g. The average length was 79,6 ± 9,8 cm, varying from 70 cm to 107 cm. (Table 3-6-1). Predominant size was about 2200 g and 75 cm. The age varied from 6 to 13 year old individuals, with an average age of 8,9 ± 1,8 yrs. 8 and 9 year old salmon predominated.

The k-factor varied from 0,43 to 0,75, with an average of 0,57 ± 0,11. These values indicate rather thin and skinny individuals, but it is not representative because they had been kept at the local hatchery for a long time and had recently spawned. A healthy salmon should have a k-factor of about 0,9-1,0 (Lydersen, pers. comm.). Despite this fact, there was a significant ($p < 0,001$) quadratic relation between the weight and length of Atlantic salmons ($r^2 = 0,96$) (Figure 3-6-2d). Moreover, a significant ($p < 0,001$) linear relationship was found between K_f and $\delta^{15}N$ ($r^2 = 0,55$).

The Hg-concentration varied from 0,07 mg Hg/kg ww to 0,14 mg Hg/kg ww, with an average value of 0,10 ± 0,02 mg Hg/kg ww (n = 14) (Table 3-6-1). The low concentration of Hg is likely because these salmon have fed in the ocean for years, and thus lower Hg-concentrations should be expected compared with piscivorous fresh water fish. No significant relationships were found between Hg-concentration in Atlantic salmon and weight, length and age.

The Pb- and Cd-concentrations in the Atlantic salmon investigated were all < detection limits, i.e. < 0,005 mg Cd/kg ww and < 0,1 mg Pb/kg ww.

The average stable nitrogen isotope ratio ($\delta^{15}N$) in Atlantic salmon was 12,74 ± 0,45 ‰ (n = 14), varying from 12,09 ‰ to a maximum of 13,62 ‰ (Figure 3-6-1, Table 3-6-1). No significant relationships were found between $\delta^{15}N$ and weight, length, age or mercury concentrations (Appendix 2, Figure 3-6-3).

Stable carbon isotope ratio ($\delta^{13}C$) in analyzed Atlantic salmon (n = 14), varied from -21,52 ‰ to -19,64 ‰, with an average of -20,58 ± 0,40 ‰ (Table 3-6-1). Significant ($p < 0,05$) linear relationships were found between $\delta^{13}C$ and length ($r^2 = 0,32$), weight ($r^2 = 0,30$) and age ($r^2 = 0,26$), but no relationship was found between $\delta^{13}C$ and Hg-concentration (Appendix 2, Figure 3-6-4).

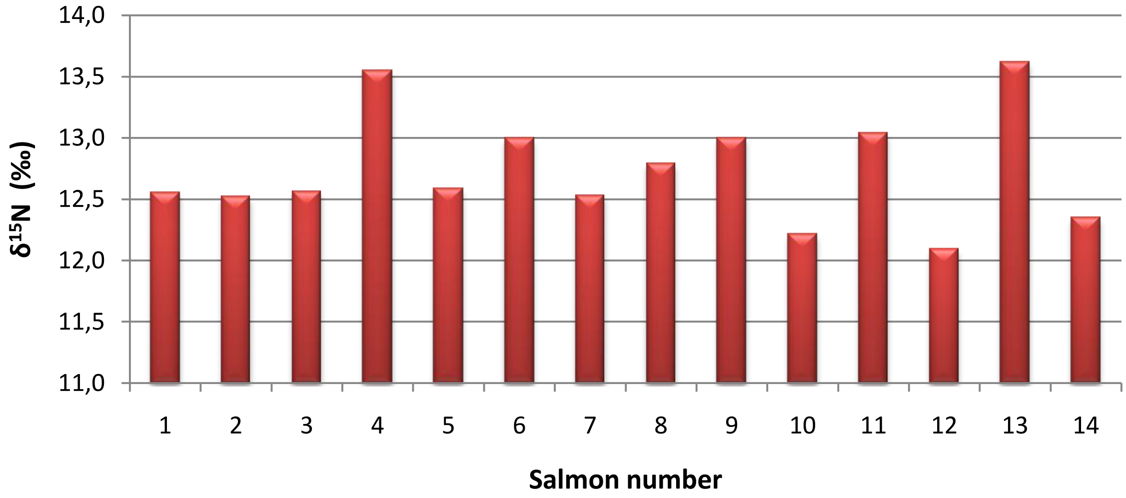
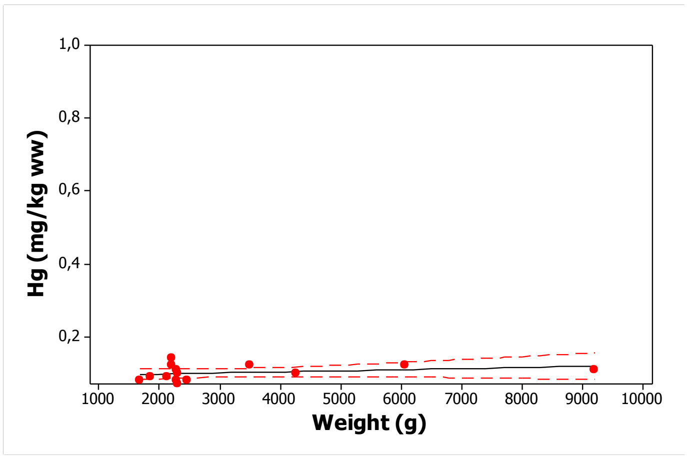


Figure 3-6-1. *δ^{15}N values in Atlantic salmon from Skienselva, the river outlet from Lake Norsjø*

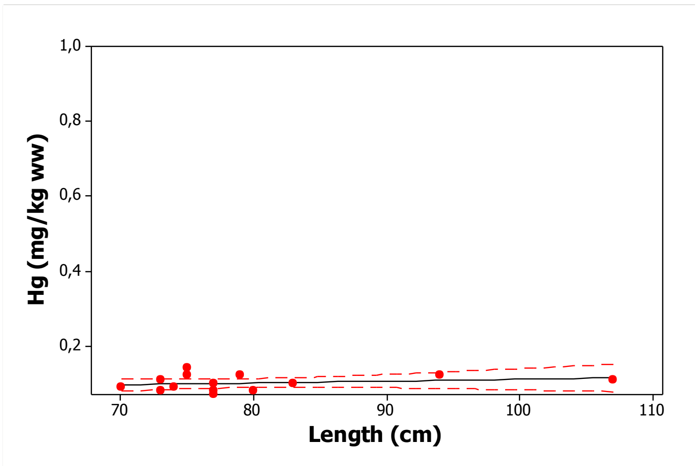
Table 3-6-1. *Morphological data, age, stable N and C isotope ratio and concentrations of Pb, Cd, and Hg in Atlantic salmon from Skienselva, the river outlet from Lake Norsjø.*

Species	Variable	Units	Number	Average	Median	SD	Min.	Max.
Salmon	Length	cm	14	79,57	77,00	9,78	70,00	107,00
	Weight	g	14	3189,29	2285,00	2085,02	1670,00	9200,00
	Age	years	14	8,86	8,50	1,83	6,00	13,00
	K-factor		14	0,57	0,52	0,11	0,43	0,75
	δ^{15}N	‰	14	12,74	12,58	0,45	12,09	13,62
	δ^{13}C	‰	14	-20,58	-20,63	0,40	-21,52	-19,64
	Hg	(mg/kg ww)	14	0,10	0,10	0,02	0,07	0,14
	Pb	(mg/kg ww)	14	0,10				
	Cd	(mg/kg ww)	14	0,005				

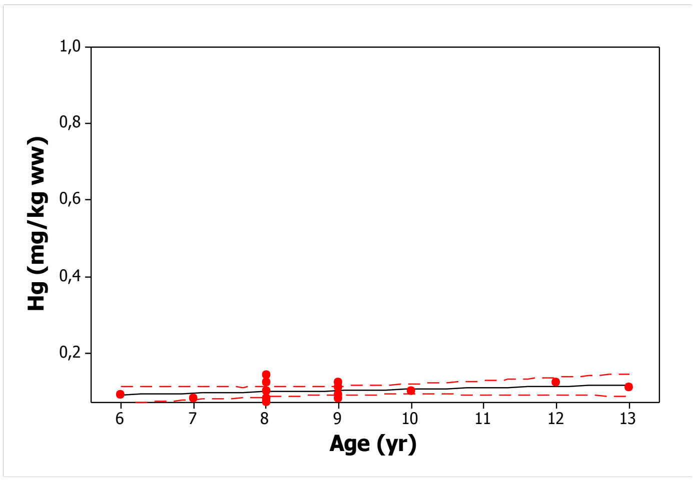
a) Hg in fish versus weight in Atlantic salmon



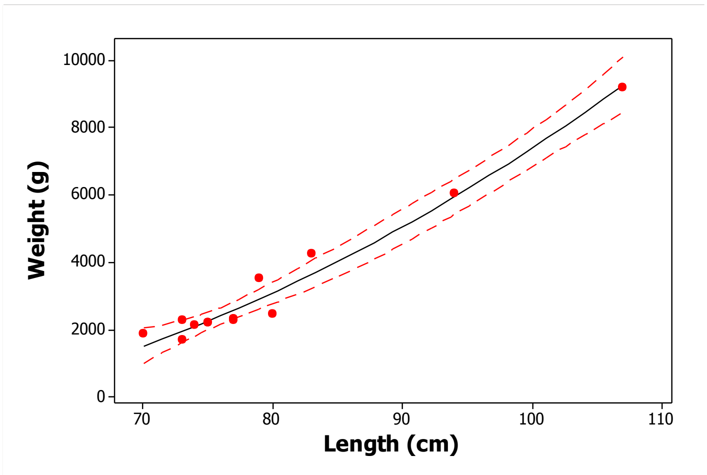
b) Hg in fish versus length in Atlantic salmon



c) Hg in fish versus age in Atlantic salmon



d) Weight versus length in Atlantic salmon



a) Hg = 0,09115 + 0,000003 Weight
r^2 = 0,02 p = 0,281

b) Hg = 0,06140 + 0,000494 Length
r^2 = 0,00 p = 0,410

c) Hg = 0,06801 + 0,003693 Age
r^2 = 0,04 p = 0,241

d) Weight = 1150 - 128,5 Length + 1,911 Length^2
r^2 = 0,96 p = 0,000

Figure 3-6-2. *Relationship between Hg-concentration and weight (a), length (b) and age (c) in Atlantic salmon from Skienselva, the river outlet from Lake Norsjø. The curves a, b, and c are based on linear regression, while the relationship between weight and length, curve (d), is based on quadratic regression. The dotted lines represent a 95% confidence interval. The regression equations,* r^2 *and p-values are shown on the panel above.*

3.7 Northern pike (*Esox lucius*)

The analyzed material includes 10 northern pike *(Esox lucius)*. The average weight of the pikes was 2565,30 ± 2725,39 g, varying from a minimum of 428 g to a maximum of 9250 g. Average length was 64 ± 19 cm, varying from 41 cm to 97 cm. Average age of the investigated population was 7 ± 2,8 yrs, varying from a minimum of 3 yrs to a maximum of 13 yrs. The studied northern pikes were of a wide variety.

Average condition factor (K_f) for the analyzed northern pike was 0,70 ± 0,13, varying from 0,54 to 1,01. Significant quadratic relationships were found between K_f and age (r^2 = 0,85, p = 0,001) (Figure 3-7-1) and between weight and length of the pike (r^2 = 0,98), p < 0,001) (Figure 3-7-3d). Moreover, a significant linear relationship was found between K_f and $\delta^{15}N$ (r^2 = 0,41, p < 0,05).

The Hg-concentrations in pike varied from 0,10 mg Hg/kg ww to 1,44 mg Hg/kg, with an average of 0,64 ± 0,51 mg Hg/kg ww (Table 3-7-1). Pikes with highest Hg-concentrations were between 7 to 13 years, respectively, but one 7 year old individual had a relatively low Hg-concentration of 0,30 mg Hg/kg ww.

A weak, but significant linear relationship (p < 0,05) was found between Hg-concentrations in fish and weight (r^2 = 0,35), length (r^2 = 0,50) and age (r^2 = 0,41) (Figure 3-7-3).

The Pb- and Cd-concentrations in the analyzed pike were all < detection limits, i.e. < 0,005 mg Cd/kg ww and < 0,1 mg Pb/kg ww.

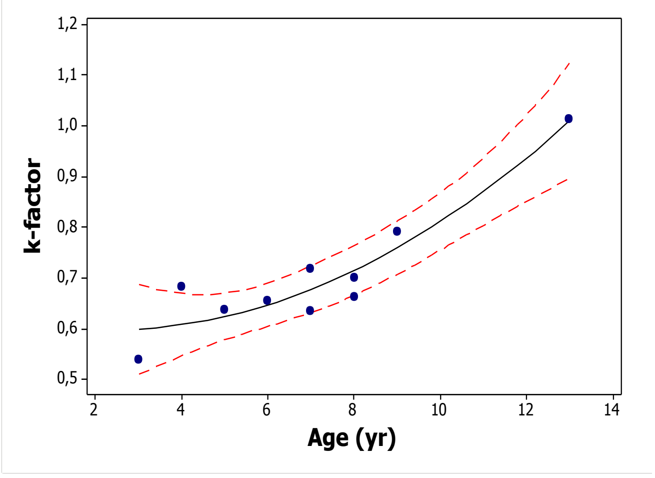


Figure 3-7-1. *Relationship between condition factor (K_f) and age in northern pike from Lake Norsjø. r^2 = 0,85, p = 0,001.*

Stable nitrogen isotope ratio ($\delta^{15}N$) in pike varied from 9,96 ‰ to 12,51 ‰ (Figure 3-7-1), with an average value of 11,05 ± 0,93 ‰ (n = 10). No significant relationships were found between $\delta^{15}N$ and weight, length, age or Hg-concentrations (Appendix 2, Figure 3-7-4).

Stable carbon isotope ratio ($\delta^{13}C$) in pike varied from -26,89 ‰ to -25,27 ‰, with an average of -26,24 ± 0,44 ‰ (n = 10) (Table 3-7-1). No significant relationships were found between $\delta^{13}C$ and weight, length or age. However, a significant ($p < 0{,}05$) linear relationship was found between $\delta^{13}C$ and Hg-concentration (Appendix 2, Figure 3-7-5).

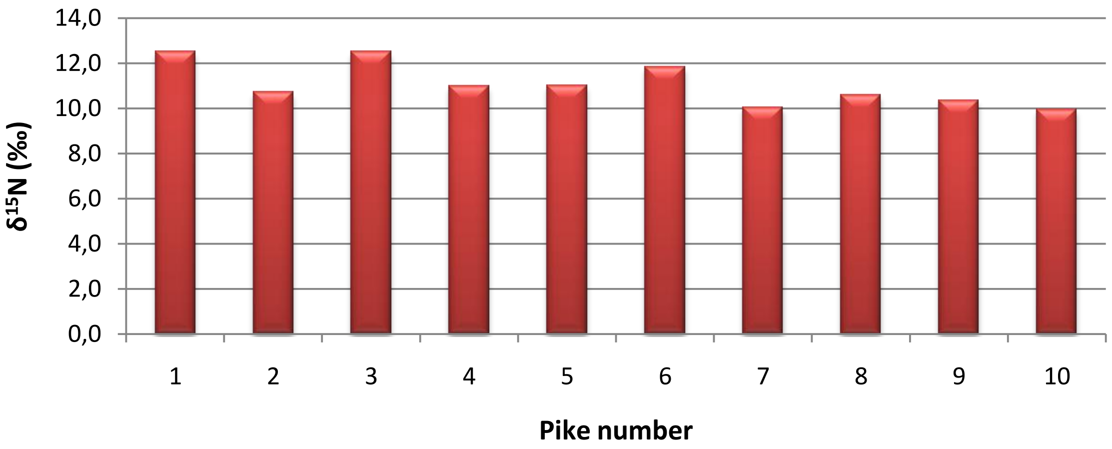
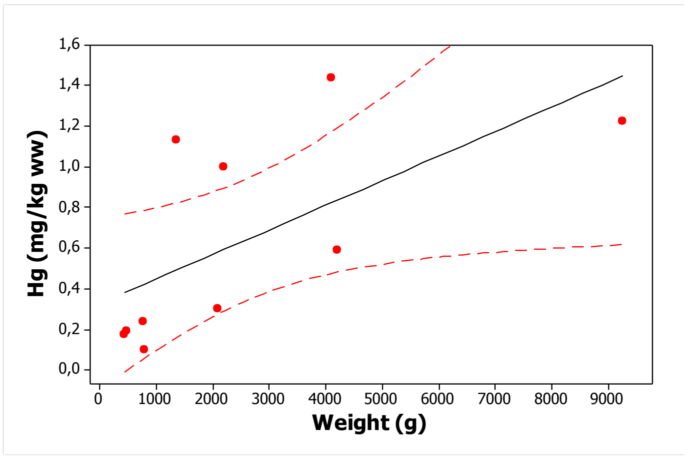


Figure 3-7-2. *$\delta^{15}N$ values in northern pike from lake Norsjø*

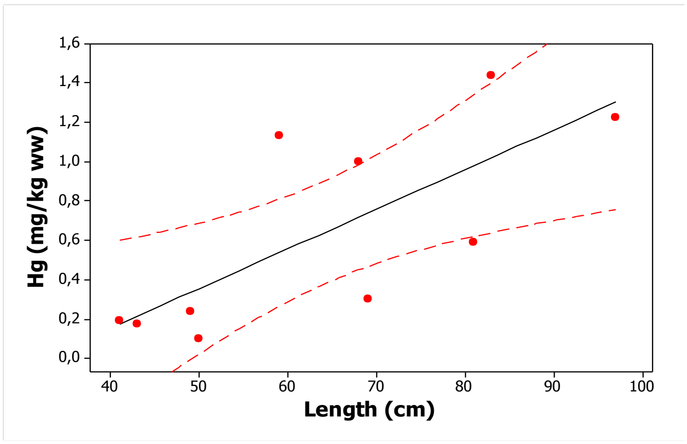
Table 3-7-1. *Morphological data, age, stable N and C isotope ratio and concentrations of Pb, Cd, and Hg in northern pike from Lake Norsjø.*

Species	Variable	Units	Number	Average	Median	SD	Min.	Max.
Pike	Length	cm	10	64,00	63,50	18,84	41,00	97,00
	Weight	g	10	2565,30	1720,00	2725,39	428,00	9250,00
	Age	years	10	7,00	7,00	2,83	3,00	13,00
	K-factor		10	0,70	0,67	0,13	0,54	1,01
	$\delta^{15}N$	‰	10	11,05	10,84	0,93	9,96	12,51
	$\delta^{13}C$	‰	10	-26,24	-26,24	0,44	-26,89	-25,27
	Hg	(mg/kg ww)	10	0,64	0,45	0,51	0,10	1,44
	Pb	(mg/kg ww)	10	0,10				
	Cd	(mg/kg ww)	10	0,005				

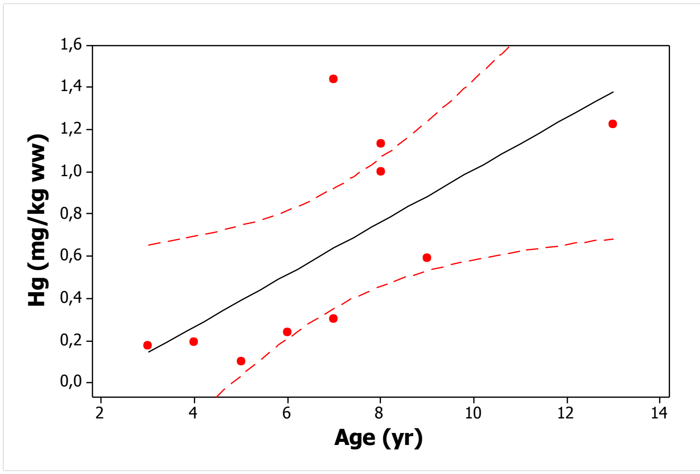
a) Hg in fish versus weight in northern pike



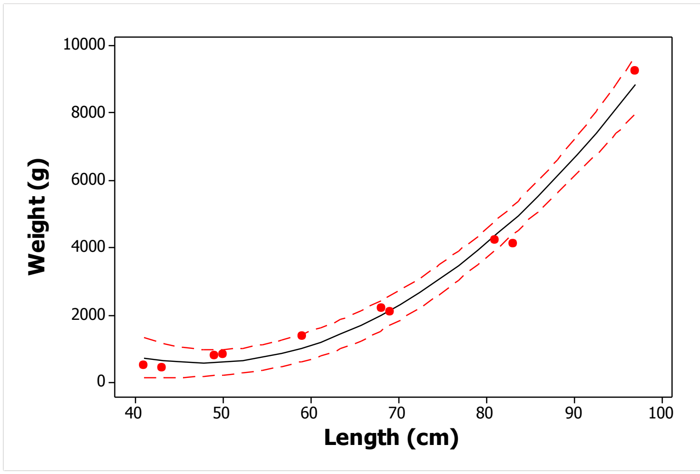
b) Hg in fish versus length in northern pike



c) Hg in fish versus age in northern pike



d) Weight versus length in northern pike



a) Hg = 0,3273 + 0,000121 Weight
r^2 = 0,35 p = 0,043

b) Hg = - 0,6538 + 0,02018 Length
r^2 = 0,50 p = 0,013

c) Hg = - 0,2311 + 0,1241 Age
r^2 = 0,41 p = 0,027

d) Weight = 8273 - 323,6 Length + 3,398 Length^2
r^2 = 0,98 p = 0,000

Figure 3-7-3. *Relationship between Hg-concentration and weight (a), length (b) and age (c) in pike from Lake Norsjø. The curves a, b, and c are based on linear regression, while the relationship between weight and length, curve (d), is based on quadratic regression.. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*

3.8 Tench (*Tinca tinca*)

Only 4 tench were included in this investigation. Average weight was 1550 ± 470 g, varying from 1275 g to 2250 g (Table 3-8-1). The average length was 44,75 ± 3,59 cm, varying from 42 cm to 50 cm. The tench were between 6 and 10 year old, with an average of 7,3 ± 1,9 yrs.

The average k-factor was 1,69 ± 0,14, varying from 1,50 to 1,80, indicating a stocky fish species compared with the more torpedo shaped salmonids where this k-factor primarily is applied. No significant relationship was found between weight and length ($r^2 = 0,94$, $p = 0,137$) (Figure 3-8-2d), but the number of individuals were very few.

The average Hg-concentration was 0,17 ± 0,11 mg Hg/kg ww (n = 4), varying from a minimum of 0,10 mg Hg/kg ww to a maximum of 0,34 mg Hg/kg ww (Table 3-8-1). The biggest and oldest tench (weight: 2250 g, length: 50 cm, age: 10 yrs,) had the highest Hg-concentration, while the smallest and youngest tench (age: 6 yrs, weight: 1275 g, length: 40cm) exhibited the lowest Hg-concentration.

Even though only 4 individuals were incorporated, very significant relationships were found between Hg-concentrations and weight ($r^2 = 1$, $p < 0,001$), length ($r^2 = 0,90$, $p < 0,05$), and age ($r^2 = 0,97$, $p < 0,05$) (Figure 3-8-2).

Regarding Pb- and Cd-concentrations, they were all < detection limits, i.e. < 0,005 mg Cd/kg ww and < 0,1 mg Pb/kg ww.

Average stable nitrogen isotope ratio ($\delta^{15}N$) in tench varied from 9,03 ‰ to 10,74 ‰ (Figure 3-8-1), with an average of 9,95 ± 0,70 ‰ (n = 4) (Table 3-8-1). No significant relationships were found between $\delta^{15}N$ and weight, length, age or mercury concentrations (Appendix 2, Figure 3-8-3).

Average stable carbon isotope ratio ($\delta^{13}C$) in tench varied from -26,27 ‰ to -23,98 ‰, with an average of -25,29 ± 1,14 ‰ (n = 4), (Table 3-8-4). No significant relationships were found between $\delta^{13}C$ and weight, length, age or mercury concentrations (Appendix 2, Figure 3-8-4).

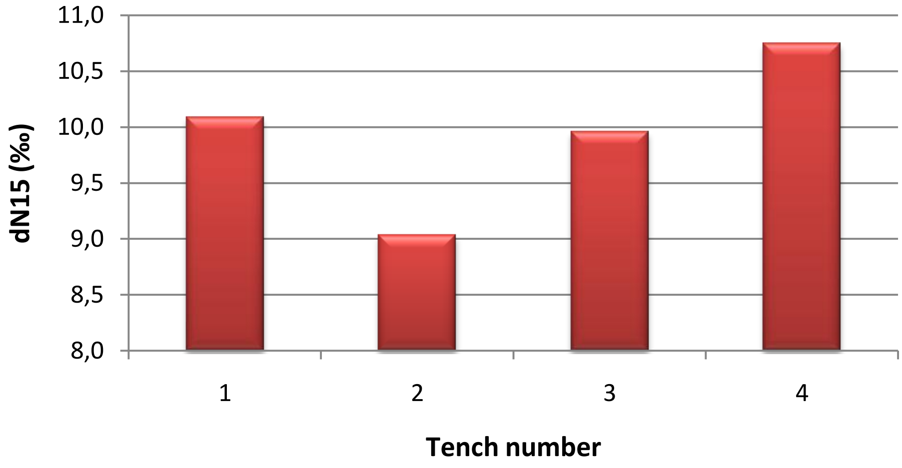
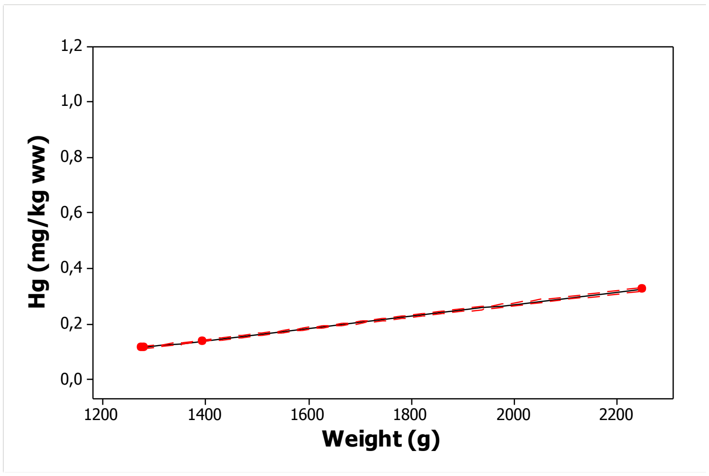


Figure 3-8-1. *δ^{15}N values in tench from lake Norsjø*

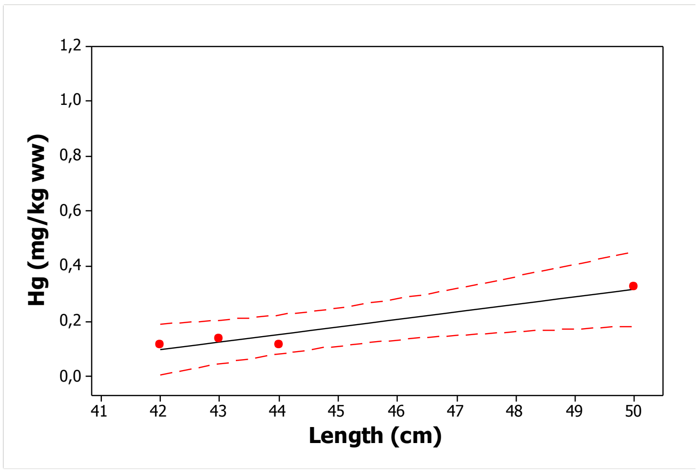
Table 3-8-1. *Morphological data, age, stable N and C isotope ratio and concentrations of Pb, Cd, and Hg in tench from Lake Norsjø*

Species	Variable	Units	Number	Average	Median	SD	Min.	Max.
Tench	Length	cm	4	44,75	43,50	3,59	42,00	50,00
	Weight	g	4	1550,00	1337,50	469,95	1275,00	2250,00
	Age	years	4	7,25	6,50	1,89	6,00	10,00
	K-factor		4	1,69	1,74	0,14	1,50	1,80
	d15N	‰	4	9,95	10,02	0,70	9,03	10,74
	d13C	‰	4	-25,20	-25,29	1,14	-26,27	-23,98
	Hg	(mg/kg ww)	4	0,17	0,12	0,11	0,10	0,34
	Pb	(mg/kg ww)	4	0,10				
	Cd	(mg/kg ww)	4	0,005				

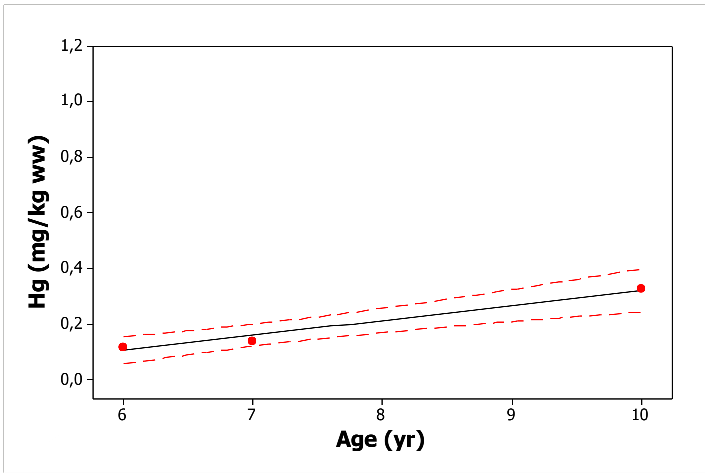
a) Hg in fish versus weight in tench



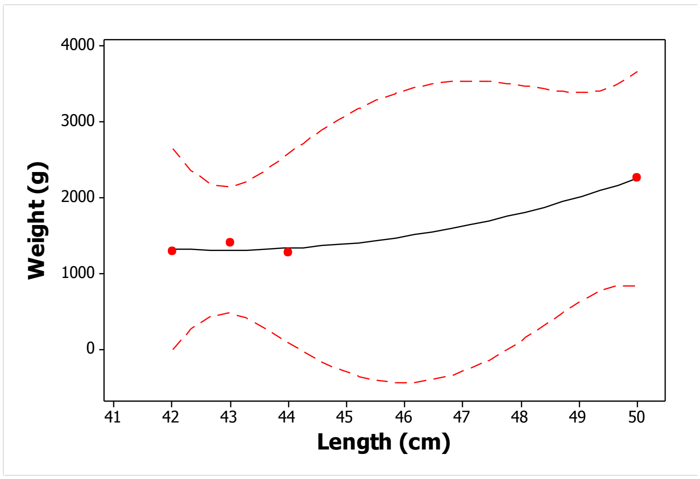
b) Hg in fish versus length in tench



c) Hg in fish versus age in tench



d) Weight versus length in tench



a) Hg = - 0,1661 + 0,000219 Weight
r^2 = 1 p = 0,000

b) Hg = - 1,064 + 0,02763 Length
r^2 = 0,90 p = 0,033

c) Hg = - 0,2166 + 0,05370 Age
r^2 = 0,97 p = 0,011

d) Weight = 35648 - 1601 Length + 18,67 Length^2
r^2 = 0,94 p = 0,137

Figure 3-8-2. *Relationship between Hg-concentration and weight (a), length (b) and age (c) in tench from Lake Norsjø. The curves a, b, and c are based on linear regression, while the relationship between weight and length, curve (d), is based on quadratic regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*

3.9 Crucian carp (*Carassius carassius*)

Only two Crucian carp (*Carassius carassius)* were included in this investigation, one big and one small. The big one weighted 1474 g and was 41 cm long, while the small one was 132 g and 19 cm. The age measurements showed that they were 19 and 5 year old, respectively.

The K_f values for the youngest fish was 1,92 and 2,14 for the biggest, reflecting the disc shaped body of crucian carps and the fact that they grow relatively more in height than in length contrary the salmonids.

The Hg-concentrations in the crucian carp was 0,041 mg Hg/kg ww and 0,218 mg Hg/kg ww in the youngest and eldest, respectively.

Pb- and Cd-concentrations in the crucian carp were < detection limits (< 0,1 mg Pb/kg ww and < 0,005 mg Cd/kg ww).

Stable nitrogen isotope ratio ($\delta^{15}N$) in the two crucian carp was 8,02 ‰ and 10,30 ‰ (eldest). Stable carbon isotope ratio ($\delta^{13}C$) was -27,08 ‰ in the eldest and -30,36 ‰ in the youngest.

4 Discussion

The present study provides data (Appendix 1) about the contamination by heavy metals (Hg, Cd and Pb) in different fish species from Lake Norsjø, Southern Norway.

The concentrations of Pb and Cd is generally below the detection limits (0,1 mg Pb/kg ww and 0,005 mg Cd/kg ww). Only 5,6 % of the analyzed individuals in this study exceeded the detection limit for Pb, while none of the individuals exceeded the detection limits for Cd. The classification system of Norwegian freshwaters (primarily related to salmonids), assess no effects on biota or no limitations for human consumption of fish at concentrations < 0.2 µg Cd/L or < 1 µg Pb/L (UN-ECE 1997b) (Lydersen et al., 2002). The low concentrations of these elements in fish from lake Norsjø is a natural consequence of the reduced local and long range transported emissions of heavy metals in Scandinavia and Europe during the last decades. Further discussions of these elements are therefore omitted.

For the nine fish species investigated, the Hg-concentration level was highest in northern pike (mean 0,64 mg/kg ww, range 0,10-1,44), followed by European smelt (mean 0,24 mg/kg ww, range 0,07-0,94); Arctic char (mean 0,24 mg/kg ww, range 0,13-0,24); brown trout (mean 0,19 mg/kg ww, range 0,04-1,44); tench (mean 0,17 mg/kg ww, range 0,10-0,34); perch (mean 0,13 mg/kg ww, range 0,07-0,40); crucian carp (mean 0,13 mg/kg ww, range 0,04-0,22); whitefish (mean 0,12 mg/kg ww, range 0,04-0,22); and last, by Atlantic salmon (mean 0,10 mg/kg ww, range 0,07-0,14). Totally, 9 individuals had levels above the consumption limit of 0,5 mg Hg/kg, 5 pikes, 2 Arctic char, 1 trout and 1 European smelt (Figure 4-5).

There is no known direct input of Hg into Lake Norsjø, so it is very likely that the Hg reaches the lake via long distance atmospheric transport, directly through the lake surface and indirectly by river inputs and by biogeochemical processes in the lake sediments and the surrounding catchment soils.

If we compare the Hg-data in fish from Lake Norsjø with data from Lake Heddalsvannet (Wårås, 2007), a lake located a few km upstream from Lake Norsjø, the data are very similar (Table 4-1), regarding morphological data and Hg-concentration. The higher Hg-concentrations reported in perch, brown trout and Arctic char in Lake Heddalsvannet might be easily explained by the fact that the investigated material in the Lake Heddalsvannet consisted of bigger and older individuals. Thus, a higher bioconcentration factor for Hg should be expected because bigger individuals of these fish species feed at higher trophic levels.

Table 4-1. *Hg-concentration, length, weight and age of fish from Lake Norsjø and from Lake Heddalsvannet (Wårås, 2007.)*

	Heddalsvannet				Norsjø			
	Average Hg-conc. mg/kg ww	Length (cm)	Weight (g)	Age (yr)	Average Hg-conc. mg/kg ww	Length (cm)	Weight (g)	Age (yr)
Northern pike	0,60	66,40	2604	6,2	0,64	64,00	2565,30	7,0
Perch	0,56	27,50	337	6,8	0,13	22,40	156,64	4,2
Brown trout	0,60	48,80	1870	8,9	0,19	38,77	611,82	7,7
Arctic char	0,73	36,91	643	--	0,24	30,25	75,85	8,8
Whitefish	0,13	30,00	263	7,1	0,12	29,84	247,16	6,6

We can compare the data obtained in this study with Hg-concentrations in fish from the Nordic countries (Table 4-2). The mean values obtained in this study are very similar to the mean values from the summary data collected from 1965-2004 (Munthe et al., 2007). The main differences are the much higher maximum Hg-concentration values in Munthe et al. (2007), compared with the data from Lake Norsjø. For example, while maximum Hg-concentration for northern pike was 6,02 mg/kg ww in the database, it was 1,44 mg/kg ww in our study. Much higher values in the report by Munthe et al. (2007) are expected as their database cover the Nordic countries, and contain Hg-analyses in 24 520 pikes compared with only 10 individuals analyzed in our study.

Table 4-2. *Summary statistics of the fish mercury concentrations from the Nordic countries (all data from 1965-2004) (Source: Munthe et al. 2007).*

Hg	Lake counts (n)	Fish counts (n)	Mean mg/kg ww	Median mg/kg ww	Min. mg/kg ww	Max. mg/kg ww
Pike	2517	24520	0,73	0,65	0,01	6,02
Perch	157	4778	0,40	0,30	0,01	4,16
Trout	136	2422	0,13	0,08	0,01	3,14
Char	40	829	0,11	0,075	0,01	1,04
Whitefish sp.[a]	46	563	0,12	0,10	0,01	0,57

[a)] Whitefish species containing mainly of powan (*Coregonus lavaretus*) and vendace (*Coregonus albula*).

In Southern Norway, for a standard fish (1-kg pike or 0,3-kg perch or 3,2-kg trout or 1,4-kg char), the median Hg-concentration is 0,45 mg Hg/kg fw (for lakes < 800 m asl) and 0,14 mg/kg (for lakes > 800 m asl) (Table 4-3). Our study area is located within the group of lakes < 800 m asl. The median value obtained in our study for pike, perch, brown trout and Arctic char individuals is 0,12 mg/kg ww, which is much lower than the 0,45 mg Hg/kg fw obtained in the database containing data from 1965 to 2004.

Table 4-3. *Summary of fish Hg-concentrations collected 1965-2004 in different regions of Norway, and fractions of lakes with levels exceeding different guidelines in a standard fish (1-kg pike or 0,3-kg perch or 3,2-kg trout or 1,4-kg char) (Source: Munthe et al. 2007).*

Region	Number of lakes n	Median HgStd mg/kg fw	Fraction of lakes with HgStd > 1.0a mg/kg fw	Fraction of lakes with HgStd > 0.5b mg/kg fw	Fraction of lakes with HgStd > 0.3c mg/kg fw
All	200	0,34	4%	30%	59%
North	33	0,23	3%	5%	17%
Central < 800m	31	0,31	3%	20%	49%
South < 800m	107	0,45	7%	42%	75%
Central > 800m	12	0,15	0%	2%	15%
South > 800m	17	0,14	0%	2%	10%

[a)] EU maximum concentration for marketing of specified predatory fish, e.g. pike.
[b)] EU general maximum concentration for marketing of fish
[c)] USEPA criterion for methyl mercury in fish

Based on the guideline levels established by Codex Alimentarius Comission (Joint FAO/WHO food standard programme) in 1991, the European consumption limits for Hg in fish is 0,5 mg Hg/kg (0,5 ppm), except for certain larger predatory species having a consumption limit of 1.0 mg Hg/kg. Based on the data from Lake Norsjø, only 4 % of the fish individuals exceeded the limit of 0,5 mg Hg/kg, and 2,9 % exceeded the limit of 1 mg Hg/kg. The fish species that exceeded 1 mg/kg limit were mainly pikes and one brown trout. The stomach of this brown trout (Ø-16) was full of European melt, confirming a piscivorous individual. The pikes (G-1, G-4, G-8, and G-11) with Hg-concentrations > 1 mg Hg/kg were among the biggest and oldest individuals of these species. Pike is a piscivorous species since they are very young individuals. Thus, it is expected that the eldest (biggest) fish also has the highest Hg-concentrations, because Hg accumulates in fish both by age and weight.

Correlations between fish length or weight and Hg-concentration can be used to predict the average size where Hg-concentration may exceed tissue levels above the recommended consumption levels of 0,5 mg Hg/kg. Based on these correlations, the average critical size for various fish species in Lake Norsjø are:

- Brown trout: 1428 g and 53 cm
- Perch: 1113 g and 83 cm
- Northern pike: 1427 g and 57 cm
- Arctic char: 124 g and 28 cm
- European smelt: 29 g and 15 cm.

The low weight at which Arctic char exceed the Hg-consumption limit, differ from the other species investigated. The reasons for this is likely because the population of Arctic char investigated are generally very small, very old and in bad condition. This will also be commented on later in this chapter.

For most fish species investigated, significant and positive correlations were found between Hg-concentration in fish and age or length. Exceptions were, white fish, Atlantic salmon and crucian carp (Table 4-4).

The $\delta^{15}N$ values in the investigated fish varied from 7,2 to 13,6 ‰. According to the $\delta^{15}N$ values obtained in this investigation and the link between $\delta^{15}N$ and trophic position presented in Figure 1-4-1, the lowest trophic level of fish in Lake Norsjø is secondary consumers, while many fish feed at trophic levels 1-2 trophic position higher ($\delta^{15}N$: 3,4 – 6,8 ‰ higher). According to $\delta^{15}N$, Arctic char ($\delta^{15}N$: 11,5-13,6‰) and Atlantic salmon ($\delta^{15}N$: 12,1-13,6 ‰) are located at the highest trophic position observed in Lake Norsjø, while whitefish in general is located at a somewhat lower trophic position ($\delta^{15}N$: 7,6-11,9 ‰) .

The reason why no correlation was found between weight/length and Hg-concentration in Arctic char might be several. The investigated fish consists of relatively old individuals (5-20 yrs); they are generally very small and in bad conditions. Starvation and subsequent deamination and transamination (internal rearrangement of N) are isotope fractionation processes, and might be the reason for the high $\delta^{15}N$ status of this population, because small Arctic char are not piscivorous. Generally, small and old individuals with low condition factor and low variation in $\delta^{15}N$ might be the reasons why no significant correlations were found between Hg in Arctic char and weight/length.

The reason why no correlation was found between weight/length and Hg-concentration in Atlantic salmon might also have several explanations. Atlantic salmon is an anadromous species, and all the individuals incorporated in this investigation are adults being out in the ocean for one or several years, feeding on fish from many places in the Northern Atlantic. In addition, they are all in spawning modus. This might be the reasons for lack of correlation between Hg concentration in fish and weight/length. The high $\delta^{15}N$ (12,1 – 13.6 ‰) but low Hg concentration is not unexepcted, because the level of Hg (methyl-Hg) in the ocean is lower compared with Hg-concentrations in fish in Scandinavian lakes.

The reason why no correlation was found between weight/length and Hg-concentration in whitefish might be due to the fact that whitefish probably consist of two sub-populations, one primarily living in the pelagic zone feeding on zooplankton and small planktonic crustaceans (lower $\delta^{15}N$), and the other one living in the littoral zone feeding on invertebrates and bottom fauna in the shallow areas (higher $\delta^{15}N$). The $\delta^{15}N$ values in Figure 4-1 show the possibility of two sub-populations, taking into account the 3,4‰ enrichment between trophic levels. The mixture of two sub-populations of white fish in the invetsigated material might be the reason why no significant correlation was found between Hg in whitefish and weight/length.

Brown trout mainly feed in the littoral zone of lakes, but in Lake Norsjø, bigger brown trouts are piscivorous, feeding on European smelts, which predominantly live in the pelagic zone. When they start feeding on European smelts their $\delta^{13}C$ signature changes to more pelagic derived carbon sources, as illustrated in Figure 4-1. However, most of the analyzed individuals were small trouts, mainly feeding in the littoral zone, where the main carbon source derives from periphyton in the near-shore zone. This is also reported from other lakes higher up in this water system (Rognerud et al., 2003, 2008). The $\delta^{15}N$ values clearly indicate brown trout individuals feeding at different trophic positions, not unexpected because this species exhibits a large degree of omnivory, where only a few start feeding on fish and thus obtain a growth potential of being really big (> 2 kg).

Perch mainly feed on invertebrates and insects in the littoral zone (Jonsson & Semb-Johansson, 1992), but bigger individuals are piscivorous, similar to brown trouts. The $\delta^{15}N$ signatures in the two young and small perch in the investigated material (Figure 4-1) show that small perch feed at least one trophic level below the other elder individuals. The $\delta^{15}N$ values in perch indicate none piscivorous individuals in the investigated materials. This might be due to lack of big individuals (> 500 g).

Pike normally feed in shallow areas in the littoral zone, even though they might look up in the pelagic area if a lot of fish are present in this area (Jonsson & Semb-Johansson, 1992). Pikes start eating other fish since they are very young individuals. According to $\delta^{15}N$, the oldest and biggest pike is generally situated about one trophic level higher compared with the youngest individuals (Figure 1-4-1 and Figure 4-1). In shallow areas of lakes the carbon source might derive from both terrestrial plants or from primary production by periphyton. According to the $\delta^{13}C$ in the pike investigated, the carbon source seems to be influenced by terrestrial plants (Figure 4-1). On the other hand, it might reflect that pike feed on all kinds of fish feeding on carbon sources deriving from both plankton and periphyton sources.

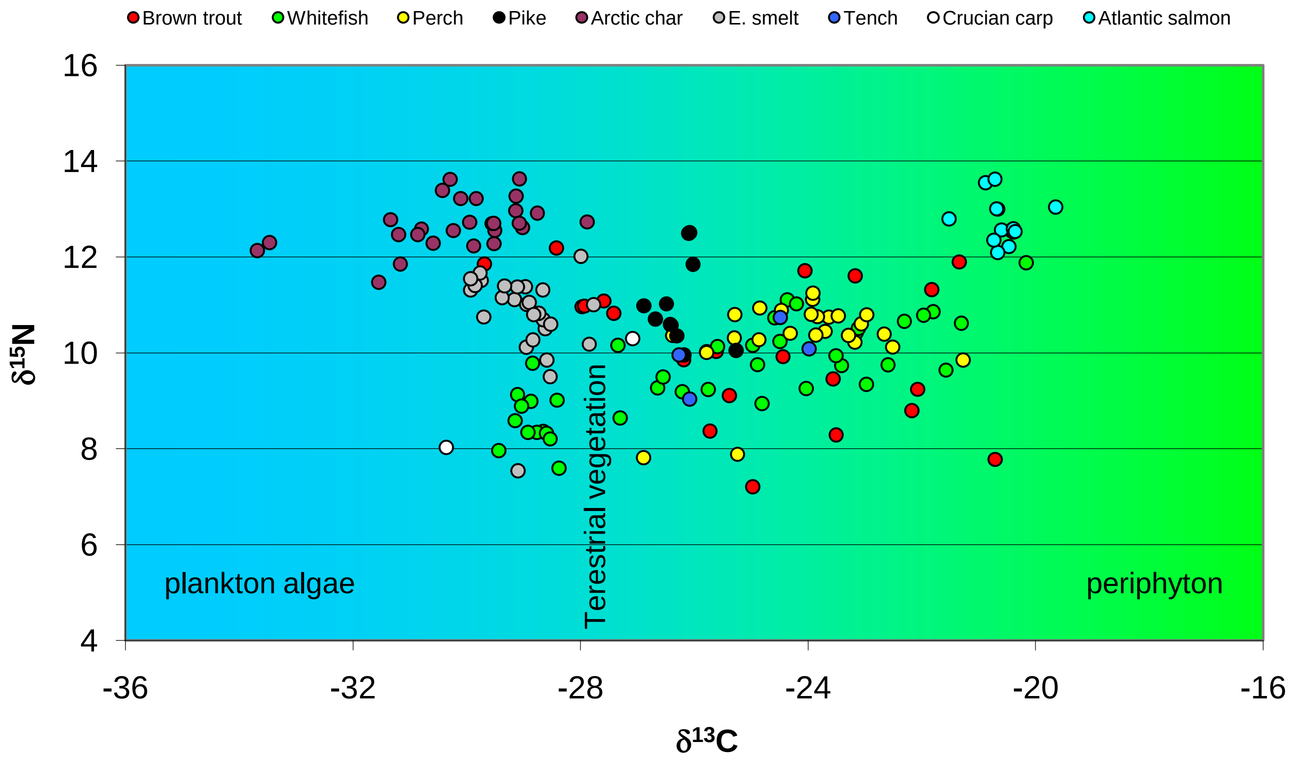


Figure 4-1. *Relation between trophic position ($\delta^{15}N$) and energy sources ($\delta^{13}C$) of fish from Lake Norsjø.*

The Arctic char population occurs mainly in the open waters, as we can clearly see in the $\delta^{13}C$ values in Figure 4-1. In this area they likely feed on zooplankton, small pelagic crustaceans and invertebrates from the deeper parts of the lake. Thus, the very high $\delta^{15}N$ values (Figure 4-1) are unexpected since they are obviously not piscivorous. The main reason for this is likely the fact that they are generally in bad condition (k-factor = 0,84 ± 0,13), indicating a population of starving individuals (Hobson et al., 1993). Starvation might cause internal deamination and transamination when proteins are broken down. These processes do isotope fractionate nitrogen (Gannes et al., 1998), and accordingly might be the reason for the high

$\delta^{15}N$ signature in the Arctic char. Relatively high $\delta^{15}N$ values were also reported in Arctic char from Lake Heddalsvannet (Wårås, 2007), but not as high as in Lake Norsjø. As mentioned in the results chapter, the investigated Arctic char probably belongs to a dwarf population with low condition factor, living in the deeper parts of the lake. Lower $\delta^{15}N$ values will be expected in the healthier population feeding in the littoral zone of Lake Norsjø. Only further investigation of the Arctic char populations in Lake Norsjø will confirm these assumptions.

European smelt is the main prey for piscivorous brown trout in Lake Norsjø. Based on the $\delta^{13}C$ signature of European smelt, they primarily seem to be located in the pelagic zone of the lake, similar to the Arctic char. They mostly feed on zooplankton and planktonic crustaceans, but big individuals might be piscivorous, feeding on smaller individuals of their own species (Jonsson & Semb-Johansson, 1992). The biggest European smelt in this investigation (60 g) exhibits far the highest Hg concentrations among the investigated individuals (0,94 mg Hg/kg). This individual also had the highest $\delta^{15}N$ (12,0 ‰). This individual obviously had fish on its diet.

The four tench in the investigations are all big individual (1275 - 2250 g). According to Jonsson & Semb-Johansson (1992) they live on soft sediments with water vegetation, feeding on snails, mussels, insects and plant fragments, and seldom reach weights > 1 kg in Norway. Thus, our individuals are unexpectedly big. Based on the $\delta^{13}C$ values (Figure 4-1), they seem to feed on carbon sources deriving from the littoral zone (terrestrial and periphytic carbon), and their $\delta^{15}N$ signature (about 10 ‰) reflects a diet similar to what described by Jonsson & Semb-Johansson (1992).

Only two crucian carp were incorporated in this study. According to Jonsson & Semb-Johansson (1992) this species primarily feed on copepods (zooplankton), worms, insects and decomposing vegetation. Based on the $\delta^{15}N$ values in Figure 4-1, the biggest carp feed on organisms at higher trophic levels compared with the small individual, as expected. The different $\delta^{13}C$ signatures in the two individuals, indicating the smallest feeding on more planktonic carbon sources, might be real, but only two individuals is not enough to conclude.

All the Atlantic salmon in this investigation were caught in River Skienselva, at Skotfoss waterfall, and kept in a local hatchery for breeding purposes. They are adult individuals who have returned from the sea to the river to spawn (anadromous). Out in the ocean, Northern Atlantic, they are piscivorous, which is well illustrated with the high $\delta^{15}N$ signatures (Figure 4-1). The specially high $\delta^{13}C$ values compared to the other freshwater fish species might reflect a different carbon source or a difference in $\delta^{13}C$ signature in sea water compared to freshwater.

Based on the investigated material, no linear relationships were found between Hg-levels and trophic position ($\delta^{15}N$) within each single fish species investigated (Table 4-4). However, a weak but significant ($r^2 = 0,074$, $p < 0,001$) positive linear relationship was found when plotting all the fish species together (Figure 4-2). The general tendency of Hg to increase as a function of trophic position indicates biomagnification. Typically pike, which is predominantly piscivorous, have highest Hg levels, especially the biggest and eldest, as well as one big trout, where the stomach was filled with European smelt. The high $\delta^{15}N$ in Arctic char can, as discussed earlier, not be related to a high trophic position, because small Arctic char are not piscivorous.

Weak, but significant, positive linear relationships were found between Hg levels and $\delta^{13}C$ in Arctic char, northern pike and whitefish (Table 4-4). However, the Hg-concentrations were significantly ($r^2 = 0,078$, $p < 0,001$), and negatively related to $\delta^{13}C$, when all fish data is evaluated (Figure 4-3), nominally indicating that fish feeding in the littoral zone have lower Hg-concentrations than fish feeding in the pelagic zone. The amount of data and the weak correlation are, however, not enough to draw this general conclusion.

Table 4-4*. Coefficient of determination (r^2) values measuring the proportion of variation in Hg-concentration explained by changes in length, weight, age and isotope signatures of the different species sampled in Lake Norsjø. All regressions were significant ($p < 0,05$) except when marked with an asterisk (*).*

Species	Length (cm)	Weight (g)	Age (yr)	$\delta^{15}N$	$\delta^{13}C$
Arctic char	0,369	0,298	0,216	0,000*	0,145
European smelt	0,652	0,635	0,607	0,016*	0,000*
Perch	0,288	0,394	0,220	0,087*	0,000*
Northern pike	0,502	0,347	0,410	0,061*	0,338
Atlantic salmon	0,000*	0,021*	0,039*	0,211*	0,000*
Tench	0,901	1,000	0,968	0,431*	0,000*
Brown trout	0,221	0,158	0,434	0,000*	0,000*
Whitefish	0,000*	0,000*	0,019*	0,000*	0,081

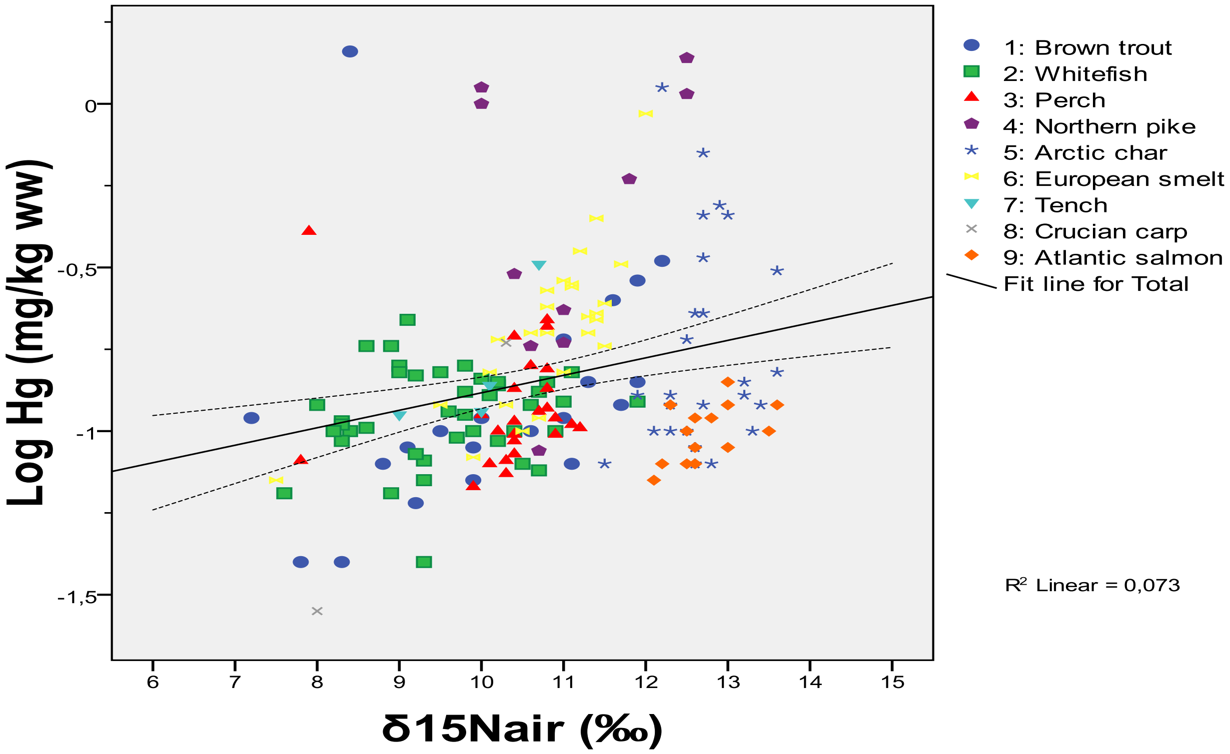


Figure 4-2. *Estimated linear relationship between trophic position (δ^{15}N) and the logarithm of Hg-concentration for all the investigated fish in this study.*
(y = 0,0537x – 1,4202; r^2 = 0,073; p = 0,000)

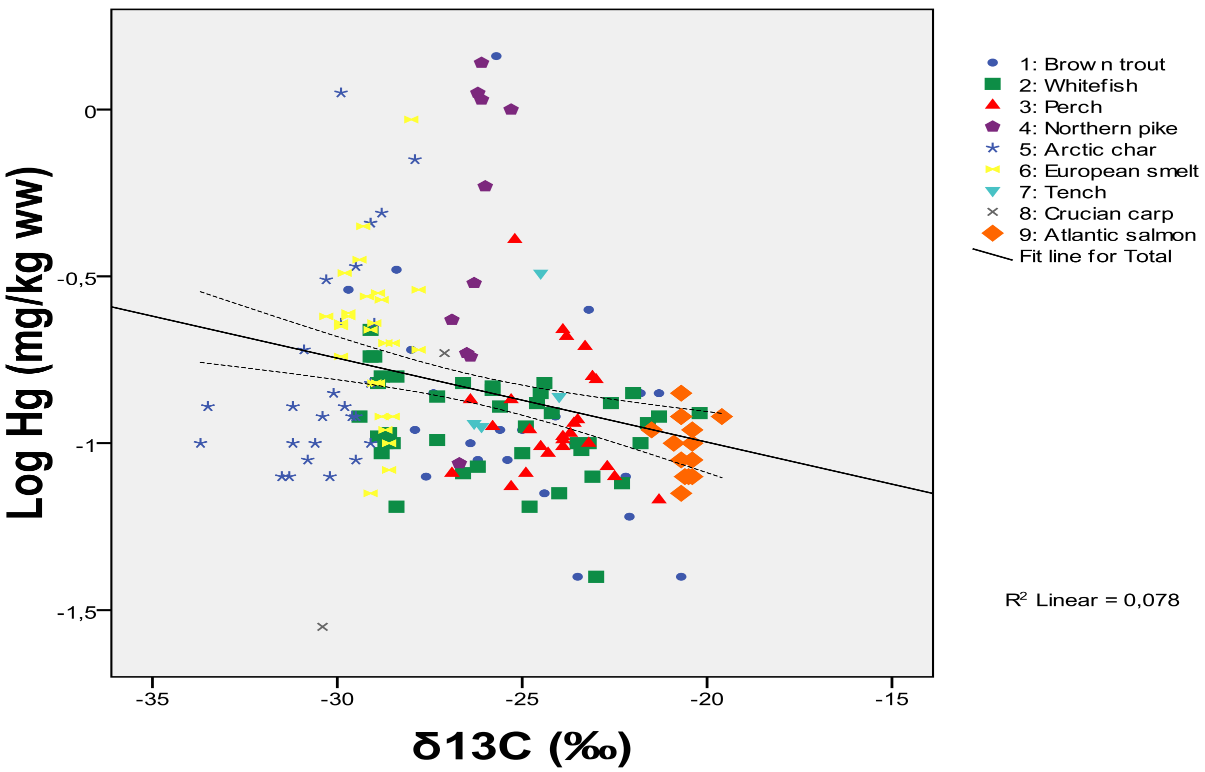


Figure 4-3. *Estimated linear relationship between δ^{13}C and the logarithm of Hg-concentration for all the investigated fish in this study.*
(y = -0,0251 – 1,4993; r^2 = 0,078; p = 0,000)

The variations observed between Hg-concentrations in the different species could be due to their feeding habits or the seasonal variation, but they also depend on the Hg content in food and on the bioconcentration capacity of each species. The diet of these fish species is therefore critical in determining observed Hg levels (Lindqvist et al. 1991).

As mentioned in the introduction chapter, when comparing stable isotopes in food web from different lakes, it is necessary that different corrections related to trophic positions are made: bottom-line correction for trophic position ($\delta^{15}N$) and enrichment correction for trophic position ($\delta^{13}C$). In this investigation we have not collected snails or zooplankton for bottom-line corrections.

The analysis of trophic interactions at lower trophic levels is complicated. Very often gut-content is used in fish studies, but this will only provide a snapshot of the fish's diet. Many of the problems that arise with gut-content analysis can be avoided with the application of stable isotopes to food web studies (DeNiro & Epstein, 1981). Thus, $\delta^{15}N$ serves as a more accurate alternative to diet data as measure of trophic position, as long as variation in primary producer (baseline) $\delta^{15}N$ can be taken into consideration (Toda and Wada, 1990). Figure 4-4 shows all the $\delta^{15}N$ values obtained for the different fish species in the study, indicating the variations in trophic positions within and between fish species in Lake Norsjø.

All $\delta^{13}C$ values (Figure 4-1) obtained in this study indicate that the fish's diet derives from C_3 plants (ranging from -35 ‰ to -20 ‰), as it is typical for northern countries

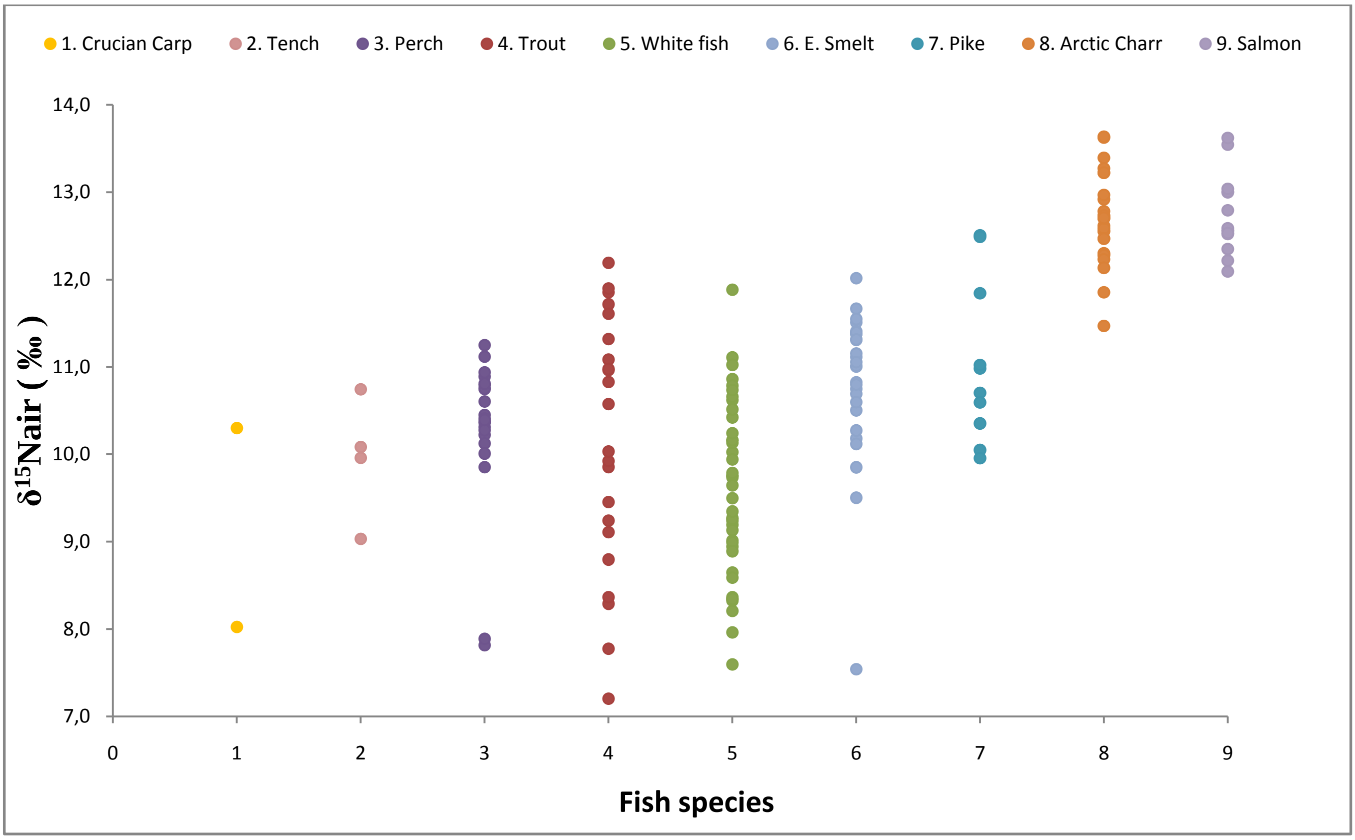


Figure 4-4. *δ^{15}N values in the studied species from Lake Norsjø*

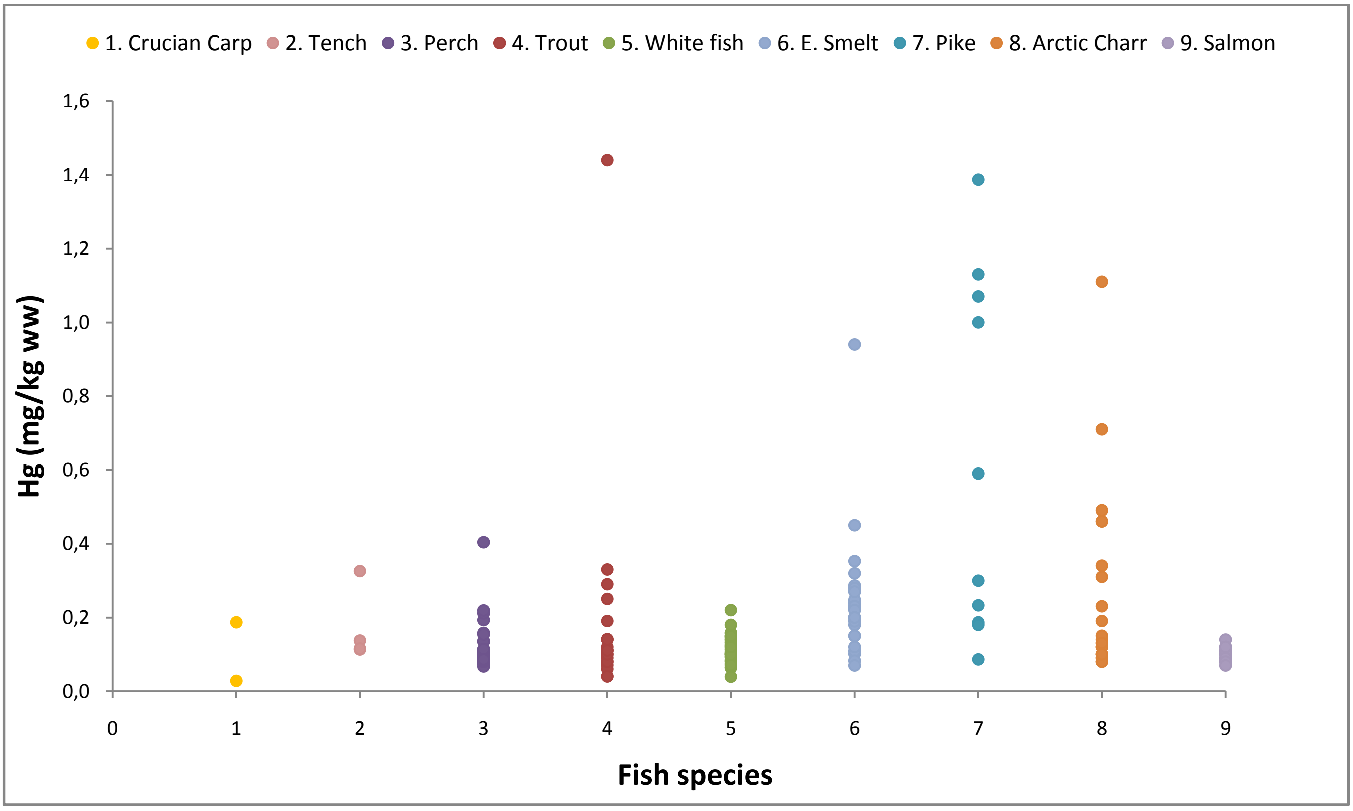


Figure 4-5. *Hg-concentration values in the studied species from Lake Norsjø*

5 Conclusions

The heavy metal (Hg, Cd and Pb) concentrations documented in the nine fish species (Arctic char, European smelt, perch, northern pike, Atlantic salmon, tench, brown trout, whitefish and crucian carp) from Lake Norsjø can be considered low, since they appear to be mostly within the ranges reported by the European Community. The Cd and Pb-concentrations were both below detection limits. The concentrations of Hg varied widely both within and between the fish species analyzed in this study. The variation is partly explained by age, weight and length, trophic position and source of carbon. A total of nine individuals had levels above the consumption limit in Norway of 0,5 mg Hg/kg in fish: five pikes, two Arctic char, one trout and one European smelt.

The $\delta^{15}N$ and $\delta^{13}C$ values obtained for the nine fish species investigated, varied from 7,2 ‰ to 13,6 ‰ and -20,2 ‰ to -33,5 ‰ respectively.

Assuming each trophic level representing an increase in $\delta^{15}N$ of 3,4‰, the food web in Lake Norsjø consists of 4 consumer levels. The $\delta^{13}C$ values document that Arctic char, European smelt and a population of whitefish primarily feed in the pelagic zone of the lake, while perch, brown trout and other population of whitefish are found in the littoral zone. To improve the knowledge about the trophic positions in Lake Norsjø, $\delta^{15}N$ and $\delta^{13}C$ should be investigated in other prey animals such as the snail *Lymnea peregra* and zooplankton. It is necessary if we are going to compare data between lakes.

All fish species (except Atlantic salmon) exhibit significant correlations ($p < 0,05$) between Hg and age, weight and length. Only adult individuals of Atlantic salmon, returned from the sea to River Skienselva for spawning, were incorporated in the study. Low concentrations and minor variations in the Hg-levels (0,07 – 0,14 mg Hg/kg ww) in this marine derived individuals, are the main reasons for no correlation between Hg and age, weight and length. Within each species, no significant correlations were found between Hg and $\delta^{15}N$; but a weak and significant ($r^2 = 0,074$, $p < 0,001$) positive linear relationship was found when plotting all the fish species together, indicating biomagnifications along the food web. The high $\delta^{15}N$ signature in the dwarf population of Arctic char is likely a consequence of low condition factor, as transamination and deamination normally occur during starvation. These processes imply isotope fractionation of nitrogen and, consequently, a heavier $\delta^{15}N$ signature. More investigations should be performed on the Arctic char populations in the lake to better assess the unexpected high $\delta^{15}N$ signature of this species in Lake Norsjø.

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Appendix

Appendix 1: Fish data from Lake Norsjø

Marked	Species	Location	Caught	Length	Weight	Age	K-factor	Hg	Pb	Cd	$\delta^{13}C_{VPDB}$	$\delta^{15}N_{AIR}$	W% C/N
			Date	cm	g	yr		mg/kg ww	ppm	ppm	‰	‰	
R-1	Arctic char	Industries	24/02/2009	22,5	102,00	11	0,90	0,23	< 0,1	< 0,005	-29,9	12,7	2,59
R-2	Arctic char	Industries	24/02/2009	22	101,00	12	0,95	0,23	< 0,1	< 0,005	-29,0	12,6	2,58
R-3	Arctic char	Industries	24/02/2009	22,5	108,00	13	0,95	0,49	< 0,1	< 0,005	-28,8	12,9	2,51
R-4	Arctic char	Industries	24/02/2009	22	84,00	11	0,79	0,46	< 0,1	0,007	-29,1	13,0	2,45
R-5	Arctic char	Industries	24/02/2009	21	80,00	11	0,86	0,31	< 0,1	0,019	-30,3	13,6	2,69
R-6	Arctic char	Industries	24/02/2009	19	59,00	9	0,86	0,13	< 0,1	< 0,005	-31,2	11,9	2,71
R-7	Arctic char	Industries	24/02/2009	17	46,00	8	0,94	0,13	< 0,1	< 0,005	-33,5	12,3	2,67
R-8	Arctic char	Industries	24/02/2009	14,5	29,00		0,95						
R-9	Arctic char	Industries	24/02/2009	16	38,00		0,93						
R-10	Arctic char	Industries	24/02/2009	17	33,00		0,67						
R-11	Arctic char	Industries	24/02/2009	17	22,00		0,45						
R-12	Arctic char	Industries	24/02/2009	16	33,00		0,81						
R-13	Arctic char	Industries	24/02/2009	13	22,00	7	1,00	0,10	< 0,1	0,006	-30,6	12,3	2,64
R-14	Arctic char	Industries	24/02/2009	10,5	9,05		0,78						
R-15	Arctic char	Industries	24/02/2009	10,5	10,80	7	0,93	0,08	< 0,1	0,015	-31,3	12,8	2,77
R-16	Arctic char	Industries	07/01/2009	11	15,80	8	1,19	0,09	< 0,1	0,028	-29,5	12,6	2,56
R-17	Arctic char	Industries	07/01/2009	12,5	17,50		0,90						
R-18	Arctic char	Industries	07/01/2009	13	22,00	8	1,00	0,08	< 0,1	0,036	-30,2	12,6	2,60
R-19	Arctic char	Industries	23/12/2008	11	11,40		0,86						
R-20	Arctic char	Industries	23/12/2008	11	11,75		0,88						
R-21	Arctic char	Industries	23/12/2008	9	7,00	5	0,96	0,14	< 0,1	0,05	-30,1	13,2	2,61
R-22	Arctic char	Industries	23/12/2008	12	14,45	8	0,84	0,09	< 0,1	0,03	-30,8	12,6	2,50
R-23	Arctic char	Industries	23/12/2008	12	15,45	8	0,89	0,12	< 0,1	0,033	-29,6	12,7	2,57
R-24	Arctic char	Industries	23/12/2008	12	14,50		0,84						
R-25	Arctic char	Industries	23/12/2008	11	11,20		0,84						
R-26	Arctic char	Industries	23/12/2008	11	12,25	6	0,92	0,10	0,2	0,023	-31,2	12,5	2,42
R-27	Arctic char	Industries	23/12/2008	10,5	8,50		0,73						
R-28	Arctic char	Industries	23/12/2008	10	8,02		0,80						

Marked	Species	Location	Caught	Length	Weight	Age	K-factor	Hg	Pb	Cd	$\delta^{13}C_{VPDB}$	$\delta^{15}N_{AIR}$	W% C/N
			Date	cm	g	yr		mg/kg ww	ppm	ppm	‰	‰	
R-29	Arctic char	Industries	23/12/2008	10,5	9,60	7	0,83	0,15	< 0,1	0,045	-29,1	13,6	2,58
R-30	Arctic char	Industries	23/12/2008	10	8,50		0,85						
R-31	Arctic char	Industries	23/12/2008	9,5	8,45		0,99						
R-32	Arctic char	Industries	23/12/2008	9,5	6,30	5	0,73	0,12	< 0,1	0,036	-30,4	13,4	2,70
R-33	Arctic char	Industries	23/12/2008	10	7,70	5	0,77	0,10	< 0,1	0,016	-29,1	13,3	2,50
R-34	Arctic char	Industries	23/12/2008	9	6,75		0,93						
R-35	Arctic char	Industries	23/12/2008	9,5	7,30	5	0,85	0,12	0,3	0,021	-29,5	12,3	2,44
R-36	Arctic char	Industries	23/12/2008	9	5,90		0,81						
R-37	Arctic char	Industries	23/12/2008	9	5,80	5	0,80	0,13	< 0,1	0,064	-29,8	13,2	2,46
R-38	Arctic char	Industries	23/12/2008	9	5,25		0,72						
R-39	Arctic char	Industries	23/12/2008	9,5	6,60		0,77						
R-40	Arctic char	Industries	23/12/2008	8	3,80		0,74						
R-41	Arctic char	Industries	23/12/2008	8,5	4,80		0,78						
R-42	Arctic char	Industries	23/12/2008	8,5	5,00		0,81						
R-43	Arctic char	Industries	23/12/2008	9	5,50		0,75						
R-44	Arctic char	Industries	23/12/2008	8	4,40		0,86						
R-45	Arctic char	Industries	23/12/2008	38	164,00	20	0,30	0,71	< 0,1	0,014	-27,9	12,7	2,38
R-46	Arctic char	Industries	23/12/2008	21	74,00	15	0,80	0,34	< 0,1	< 0,005	-29,5	12,7	2,55
R-47	Arctic char	Industries	23/12/2008	18	40,50	8	0,69	1,11	< 0,1	0,029	-29,9	12,2	2,78
R-48	Arctic char	Industries	23/12/2008	15	29,15	10	0,86	0,08	< 0,1	< 0,005	-31,5	11,5	2,43
R-49	Arctic char	Industries	23/12/2008	14	25,50	10	0,93	0,10	< 0,1	0,037	-33,7	12,1	2,88
R-50	Arctic char	Industries	23/12/2008	18	60,25		1,03						
R-51	Arctic char	Industries	23/12/2008	17,5	46,90		0,88						
R-52	Arctic char	Industries	23/12/2008	20	67,50	9	0,84	0,46	< 0,1	< 0,005	-29,1	12,7	2,57
R-53	Arctic char	Industries	23/12/2008	18,5	49,70	7	0,78	0,19	< 0,1	< 0,005	-30,9	12,5	2,52

Marked	Species	Location	Caught	Length	Weight	Age	K-factor	Hg	Hg	Hg	Hg	Hg	Pb	Cd
			Date	cm	g	yr		mg/kg ww	mg/kg ww	mg/kg ww	mg/kg ww	average	ppm	ppm
C-1	Crucian carp	Årnesbukta	06/09/2008	41	1474	19	2,14	0,133	0,154	0,272	0,311	0,218	< 0,1	< 0,005
C-2	Crucian carp	Årnesbukta	06/09/2008	19	132	5	1,92	0,028	0,054			0,041	< 0,1	< 0,005

Marked	Species	Location	Caught	W% C/N	$\delta^{13}C_{VPDB}$	$\delta^{15}N_{AIR}$
			Date	‰	‰	
C-1	Crucian carp	Årnesbukta	06/09/2008	3,17	-27,1	10,3
C-2	Crucian carp	Årnesbukta	06/09/2008	3,14	-30,4	8,0

Marked	Species	Location	Caught	Length	Weight	Age	K-factor	Hg	Pb	Cd	$\delta^{13}C_{VPDB}$	$\delta^{15}N_{AIR}$	W% C/N
			Date	cm	g	yr		average	ppm	ppm	‰	‰	
S-1	White fish	Årnesbukta	06/09/2008	34	380	9	0,97	0,151	< 0,1	< 0,005	-24,4	11,1	3,26
S-2	White fish	Årnesbukta	06/09/2008	31	230	6	0,77	0,139	< 0,1	< 0,005	-27,3	10,2	3,28
S-3	White fish	Årnesbukta	14/09/2008	30	244	7	0,90	0,146	< 0,1	< 0,005	-25,8	10,0	3,11
S-4	White fish	Årnesbukta	14/09/2008	31	267	7	0,90	0,096	< 0,1	< 0,005	-23,4	9,7	3,12
S-5	White fish	Årnesbukta	14/09/2008	28	213	4	0,97	0,113	< 0,1	< 0,005	-24,9	9,8	3,20
S-6	White fish	Årnesbukta	14/09/2008	33	314	8	0,87	0,124	< 0,1	< 0,005	-20,2	11,9	2,95
S-7	White fish	Årnesbukta	14/09/2008	28	182	5	0,83	0,064	< 0,1	< 0,005	-24,8	8,9	3,27
S-8	White fish	Årnesbukta	14/09/2008	31	239	7	0,80	0,128	< 0,1	< 0,005	-25,6	10,1	3,31
S-9	White fish	Årnesbukta	14/09/2008	27	197	4	1,00	0,082	< 0,1	< 0,005	-26,6	9,3	3,13
S-10	White fish	Årnesbukta	14/09/2008	26	167	3	0,95	0,085	< 0,1	< 0,005	-26,2	9,2	3,13
S-11	White fish	Årnesbukta	14/09/2008	31	307	7	1,03	0,133	< 0,1	< 0,005	-22,6	9,8	3,12
S-12	White fish	Årnesbukta	24/09/2008	34,5	315	8	0,77	0,093	< 0,1	< 0,005	-25,0	10,2	3,14
S-13	White fish	Årnesbukta	24/09/2008	35	340	9	0,79	0,100	< 0,1	< 0,005	-23,2	10,4	3,21
S-14	White fish	Årnesbukta	24/09/2008	33	299	8	0,83	0,142	< 0,1	< 0,005	-24,5	10,2	3,20
S-15	White fish	Årnesbukta	03/12/2008	36	470	9	1,01	0,100	< 0,1	< 0,005	-21,8	10,9	2,44
S-16	White fish	Årnesbukta	03/12/2008	37	430	12	0,85	0,120	< 0,1	< 0,005	-21,3	10,6	2,23

Marked	Species	Location	Caught Date	Length cm	Weight g	Age yr	K-factor	Hg average	Pb ppm	Cd ppm	$\delta^{13}C_{VPDB}$ ‰	$\delta^{15}N_{AIR}$ ‰	W% C/N
S-17	White fish	Årnesbukta	03/12/2008	37	380	11	0,75	0,140	< 0,1	< 0,005	-22,0	10,8	2,19
S-18	White fish	Årnesbukta	03/12/2008	35	370	10	0,86	0,080	< 0,1	< 0,005	-23,1	10,5	2,24
S-19	White fish	Årnesbukta	03/12/2008	33	320	8	0,89	0,100	< 0,1	< 0,005	-23,5	9,9	2,23
S-20	White fish	Årnesbukta	03/12/2008	33	400	7	1,11	0,075	< 0,1	< 0,005	-22,3	10,7	2,21
S-21	White fish	Årnesbukta	03/12/2008	23	120	3	0,99	0,065	< 0,1	< 0,005	-28,4	7,6	2,27
S-22	White fish	Årnesbukta	03/12/2008	26	160	4	0,91	0,101	< 0,1	< 0,005	-28,7	8,4	2,24
S-23	White fish	Årnesbukta	03/12/2008	25	140	4	0,90	0,093	0,670	< 0,005	-28,8	8,3	2,23
S-24	White fish	Årnesbukta	03/12/2008	25	150	4	0,96	0,107	< 0,1	< 0,005	-28,6	8,3	2,27
S-25	White fish	Årnesbukta	03/12/2008	25	130	3	0,83	0,104	< 0,1	< 0,005	-28,9	8,3	2,25
S-26	White fish	Årnesbukta	03/12/2008	30	210	5	0,78	0,147	< 0,1	< 0,005	-25,8	9,2	2,19
S-27	White fish	Årnesbukta	03/12/2008	33	260	6	0,72	0,071	< 0,1	< 0,005	-24,0	9,3	2,24
S-28	White fish	Årnesbukta	03/12/2008	31	240	7	0,81	0,150	0,110	< 0,005	-26,6	9,5	2,23
S-29	White fish	Årnesbukta	03/12/2008	29	190	6	0,78	0,158	< 0,1	< 0,005	-28,4	9,0	2,21
S-30	White fish	Årnesbukta	03/12/2008	33	280	7	0,78	0,040	< 0,1	< 0,005	-23,0	9,3	2,27
S-31	White fish	Årnesbukta	24/12/2008	32	350	9	1,07	0,133	< 0,1	< 0,005	-24,6	10,7	2,29
S-32	White fish	Årnesbukta	24/12/2008	32	305	13	0,93	0,124	< 0,1	< 0,005	-24,2	11,0	2,33
S-33	White fish	Årnesbukta	24/12/2008	34	405	9	1,03	0,115	< 0,1	< 0,005	-21,6	9,6	2,26
S-34	White fish	Årnesbukta	24/12/2008	28	210	9	0,96	0,158	< 0,1	< 0,005	-28,8	9,8	2,29
S-35	White fish	Årnesbukta	24/12/2008	25	110	3	0,70	0,103	< 0,1	< 0,005	-27,3	8,6	2,30
S-36	White fish	Årnesbukta	24/12/2008	22	90	4	0,85	0,099	< 0,1	< 0,005	-28,5	8,2	2,35
S-37	White fish	Industries	07/01/2009	25	136	4	0,87	0,15	< 0,1	< 0,005	-28,9	9,0	2,38
S-38	White fish	Industries	07/01/2009	23,5	110,5	3	0,85	0,12	< 0,1	< 0,005	-29,4	8,0	2,44
S-39	White fish	Industries	07/01/2009	26	157,25	7	0,89	0,22	< 0,1	< 0,005	-29,1	9,1	2,35
S-40	White fish	Industries	07/01/2009	26,5	168	6	0,90	0,18	< 0,1	< 0,005	-29,0	8,9	2,34
S-41	White fish	Industries	07/01/2009	26	148	7	0,84	0,18	< 0,1	< 0,005	-29,1	8,6	2,39

Marked	Species	Location	Caught Date	Length cm	Weight g	Age yr	K-factor	Hg mg/kg ww	Pb ppm	Cd ppm	$\delta^{13}C_{VPDB}$ ‰	$\delta^{15}N_{AIR}$ ‰	W% C/N
K-1	European smelt	Gvarvelva	30/05/2008	9,5	4,68	6	0,55	0,273			-29,2	11,1	3,30
K-2	European smelt	Gvarvelva	30/05/2008	10	5,02	5	0,50	0,226			-29,9	11,3	3,24
K-3	European smelt	Gvarvelva	30/05/2008	10	4,63	5	0,46	0,240			-29,7	10,8	3,34
K-4	European smelt	Gvarvelva	30/05/2008	9	3,51	2	0,48	0,101			-28,6	10,5	3,22
K-5	European smelt	Gvarvelva	30/05/2008	9,5	4,23	5	0,49	0,239			-30,3	0,7	3,63
K-6	European smelt	Gvarvelva	30/05/2008	10	4,55	3	0,46	0,109			-28,7	10,7	3,22
K-7	European smelt	Gvarvelva	30/05/2008	10,5	5,32	6	0,46	0,248			-29,7	11,5	3,22
K-8	European smelt	Gvarvelva	30/05/2008	10	5,26	7	0,53	0,353			-29,4	11,2	3,33
K-9	European smelt	Gvarvelva	30/05/2008	11	7,77	7	0,58	0,287			-27,8	11,0	3,28
K-10	European smelt	Gvarvelva	30/05/2008	11,5	8,08	6	0,53	0,230			-29,0	11,4	3,25
K-11	European smelt	Årnesbukta	24/09/2008	9	3,00	---	0,41	0,083			-28,6	9,9	3,16
K-12	European smelt	Industries	24/02/2009	10,5	7,80	6	0,67	0,20	< 0,1	0,068	-28,7	10,8	2,49
K-13	European smelt	Industries	24/02/2009	10,5	7,20	6	0,62	0,23	< 0,1	0,067	-29,9	11,4	2,47
K-14	European smelt	Industries	24/02/2009	10	4,70	6	0,47	0,32	< 0,1	0,062	-29,8	11,7	2,51
K-15	European smelt	Industries	24/02/2009	10	6,10	6	0,61	0,22	< 0,1	0,032	-29,1	11,4	2,50
K-16	European smelt	Industries	07/01/2009	12,5	14,50	7?	0,74	0,07	< 0,1	< 0,005	-29,1	7,5	2,62
K-17	European smelt	Industries	07/01/2009	10	7,45	7	0,75	0,20	< 0,1	0,073	-28,5	10,6	2,46
K-18	European smelt	Industries	07/01/2009	10	6,70	7	0,67	0,15	< 0,1	0,062	-28,9	11,0	2,54
K-19	European smelt	Industries	07/01/2009	9,5	5,50	6	0,64	0,18	< 0,1	0,126	-29,9	11,5	2,56
K-20	European smelt	Industries	23/12/2009	11,5	10,70	8	0,70	0,19	< 0,1	0,027	-27,8	10,2	2,44
K-21	European smelt	Industries	23/12/2009	10,5	6,25	6	0,54	0,15	< 0,1	0,067	-29,0	10,1	2,46
K-22	European smelt	Industries	23/12/2009	10	4,00	7	0,40	0,45	< 0,1	0,026	-29,3	11,4	2,48
K-23	European smelt	Industries	23/12/2009	10	5,30	7	0,53	0,20	< 0,1	0,096	-28,7	11,3	2,49
K-24	European smelt	Industries	23/12/2009	10,5	5,15	5	0,44	0,28	< 0,1	0,055	-28,9	11,1	2,50
K-25	European smelt	Industries	23/12/2009	9,5	4,80	5?	0,56	0,12	< 0,1	0,023	-28,8	10,3	2,46
K-26	European smelt	Industries	23/12/2009	9	4,50	5?	0,62	0,12	< 0,1	0,038	-28,5	9,5	2,45
K-27	European smelt	Industries	23/12/2009	11	5,95	7	0,45	0,27	< 0,1	0,041	-28,8	10,8	2,48
K-28	European smelt	Industries	23/12/2009	10	5,60	6	0,56	0,20	< 0,1	0,018	---	---	---
K-29	European smelt	Industries	23/12/2009	22	60,00	14	0,56	0,94	< 0,1	< 0,005	-28,0	12,0	2,49

Marked	Species	Location	Caught Date	Length cm	Weight g	Age yr	K-factor	Hg average	Pb ppm	Cd ppm	$\delta^{13}C_{VPDB}$ ‰	$\delta^{15}N_{AIR}$ ‰	W% C/N
A-1	Perch	Årnesbukta	04/09/2008	21	108	4	1,17	0,098	< 0,1	< 0,005	-23,2	10,2	3,14
A-2	Perch	Årnesbukta	04/09/2008	26	193	5	1,10	0,158	< 0,1	< 0,005	-23,1	10,6	3,14
A-3	Perch	Årnesbukta	04/09/2008	23	136	4+	1,12	0,134	< 0,1	< 0,005	-26,4	10,4	3,13
A-4	Perch	Årnesbukta	04/09/2008	23	140	4	1,15	0,136	< 0,1	< 0,005	-25,3	10,8	3,08
A-5	Perch	Årnesbukta	04/09/2008	20	99	4	1,24	0,106	< 0,1	< 0,005	-23,9	11,1	3,06
A-6	Perch	Årnesbukta	04/09/2008	29	280	6	1,15	0,154	< 0,1	< 0,005	-23,0	10,8	3,19
A-7	Perch	Årnesbukta	04/09/2008	21	120	4	1,30	0,107	< 0,1	< 0,005	-23,7	10,4	3,21
A-8	Perch	Årnesbukta	04/09/2008	28	251	5+	1,14	0,193	< 0,1	< 0,005	-23,3	10,4	3,13
A-9	Perch	Årnesbukta	04/09/2008	23	126	4	1,04	0,114	< 0,1	< 0,005	-23,6	10,7	3,08
A-10	Perch	Årnesbukta	04/09/2008	21	123	4	1,33	0,098	0,160	< 0,005	-24,5	10,9	3,07
A-11	Perch	Årnesbukta	04/09/2008	22	112	4	1,05	0,074	0,108	< 0,005	-25,3	10,3	3,11
A-12	Perch	Årnesbukta	04/09/2008	22	124	4	1,16	0,110	< 0,1	< 0,005	-24,8	10,9	3,10
A-13	Perch	Årnesbukta	04/09/2008	23	136	5	1,12	0,097	0,122	< 0,005	-23,9	10,4	3,13
A-14	Perch	Årnesbukta	24/09/2008	6	2,07	1+	0,96	0,082	< 0,1	< 0,005	-26,9	7,8	2,66
A-15	Perch	Årnesbukta	24/09/2008	5,5	1,52	1+	0,91	0,088	< 0,1	< 0,005	---	---	---
A-16	Perch	Årnesbukta	24/09/2008	28	253	5	1,15	0,404	< 0,1	< 0,005	-25,2	7,9	3,32
A-17	Perch	Årnesbukta	24/09/2008	24	150	4	1,09	0,094	< 0,1	< 0,005	-24,3	10,4	3,14
A-18	Perch	Årnesbukta	24/09/2008	34	425	6	1,08	0,211	< 0,1	< 0,005	-23,8	10,8	3,25
A-19	Perch	Årnesbukta	24/09/2008	22	112	4	1,05	0,104	< 0,1	< 0,005	-23,9	11,2	3,05
A-20	Perch	Årnesbukta	24/09/2008	20	83	4	1,04	0,067	< 0,1	0,007	-21,3	9,9	3,15
A-21	Perch	Årnesbukta	24/09/2008	22	105	4	0,99	0,080	< 0,1	< 0,005	-22,5	10,1	3,17
A-22	Perch	Årnesbukta	24/09/2008	20	80	4	1,00	0,114	< 0,1	< 0,005	-25,8	10,0	3,46
A-23	Perch	Årnesbukta	24/09/2008	17	52	4	1,06	0,082	< 0,1	< 0,005	-24,9	10,3	3,14
A-24	Perch	Årnesbukta	24/09/2008	21	114	4	1,23	0,086	< 0,1	< 0,005	-22,7	10,4	3,11
A-25	Perch	Årnesbukta	24/09/2008	34	516	7	1,31	0,219	< 0,1	< 0,005	-23,9	10,8	3,15
A-26	Perch	Årnesbukta	24/09/2008	27	231	5	1,17	0,118	< 0,1	< 0,005	-23,5	10,8	3,09

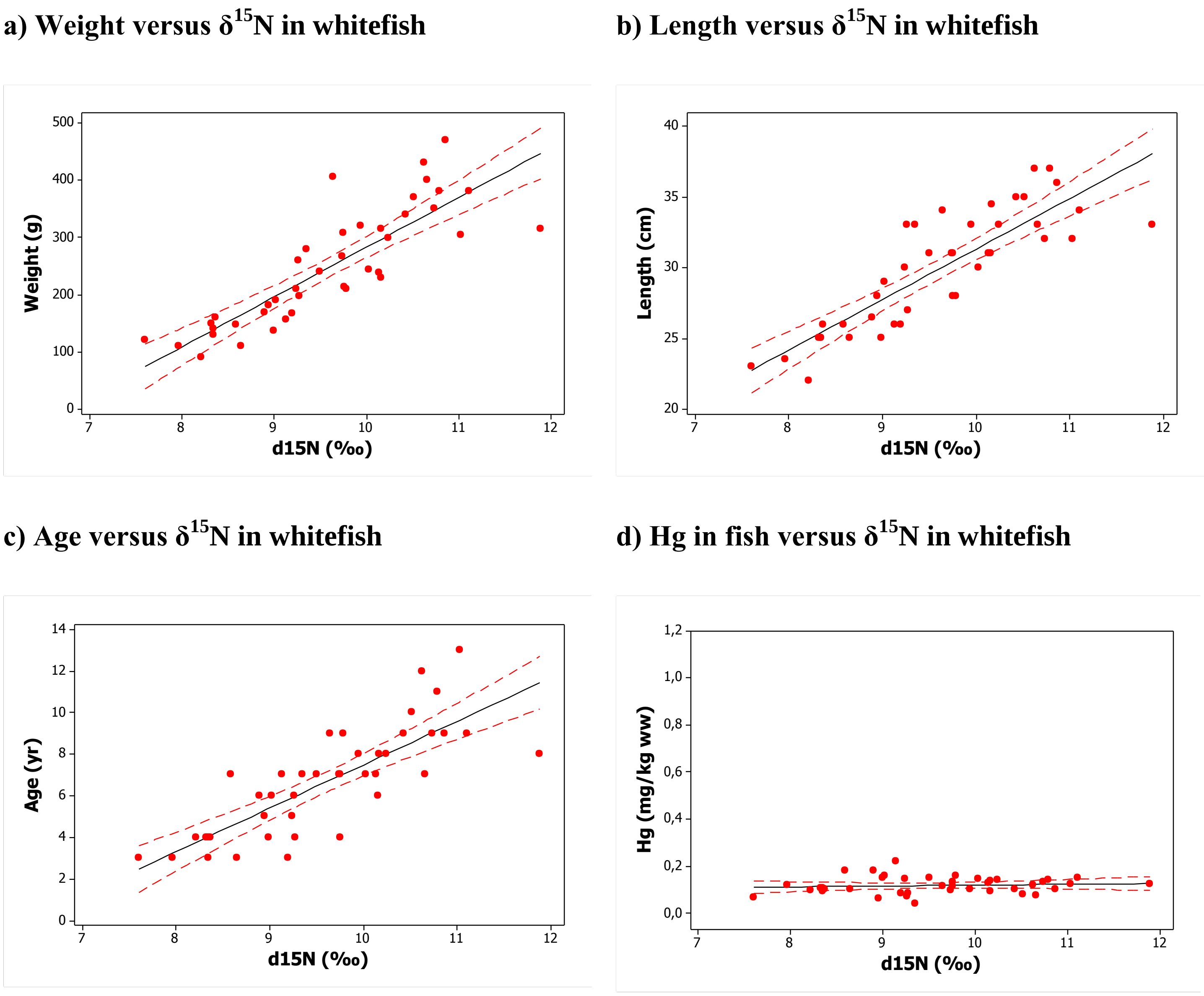
Marked	Species	Location	Caught Date	Length cm	Weight g	Age yr	K-factor	Hg average	Pb ppm	Cd ppm	$\delta^{13}C_{VPDB}$ ‰	$\delta^{15}N_{AIR}$ ‰	W% C/N
G-1	N. Pike	Årnesbukta	28/06/2008	83	4100	7	0,72	1,44	< 0,1	< 0,005	-26,1	12,5	3,07
G-3	N. Pike	Årnesbukta	04/09/2008	50	795	5	0,64	0,10	< 0,1	< 0,005	-26,7	10,7	3,00
G-4	N. Pike	Årnesbukta	04/09/2008	97	9250	13	1,01	1,22	< 0,1	< 0,005	-26,1	12,5	3,32
G-5	N. Pike	Årnesbukta	06/09/2008	49	770	6	0,65	0,24	< 0,1	< 0,005	-26,9	11,0	3,07
G-6	N. Pike	Årnesbukta	06/09/2008	41	470	4	0,68	0,19	< 0,1	< 0,005	-26,5	11,0	3,02
G-7	N. Pike	Årnesbukta	14/09/2008	81	4200	9	0,79	0,59	< 0,1	< 0,005	-26,0	11,8	3,07
G-8	N. Pike	Gvarv	20/08/2007	68	2200	8	0,70	1,00	0,16	< 0,005	-25,3	10,0	3,09
G-9	N. Pike	Årnesbukta	24/09/2008	43	428	3	0,54	0,18	< 0,1	< 0,005	-26,4	10,6	3,07
G-10	N. Pike	Årnesbukta	24/12/2008	69	2080	7	0,63	0,30	< 0,1	< 0,005	-26,3	10,4	2,51
G-11	N. Pike	Årnesbukta	24/12/2008	59	1360	8	0,66	1,13	< 0,1	< 0,005	-26,2	10,0	2,42

Marked	Species	Location	Caught Date	Length cm	Weight g	Age yr	K-factor	Hg mg/kg ww	Pb ppm	Cd ppm	$\delta^{13}C_{VPDB}$ ‰	$\delta^{15}N_{AIR}$ ‰	W% C/N
LA-1	A. Salmon	Skotfoss	Nov. 2008	74	2130	9	0,53	0,09	< 0,1	< 0,005	-20,4	12,6	2,29
LA-2	A. Salmon	Skotfoss	Nov. 2008	77	2280	9	0,50	0,08	< 0,1	< 0,005	-20,4	12,5	2,42
LA-3	A. Salmon	Skotfoss	Nov. 2008	80	2450	8	0,48	0,08	< 0,1	< 0,005	-20,6	12,6	2,40
LA-4	A. Salmon	Skotfoss	Nov. 2008	83	4250	10	0,74	0,10	< 0,1	< 0,005	-20,9	13,5	2,61
LA-5	A. Salmon	Skotfoss	Nov. 2008	73	2280	9	0,59	0,11	< 0,1	< 0,005	-20,4	12,6	2,41
LA-6	A. Salmon	Skotfoss	Nov. 2008	75	2200	8	0,52	0,14	< 0,1	< 0,005	-20,7	13,0	2,51
LA-7	A. Salmon	Skotfoss	Nov. 2008	77	2300	8	0,50	0,10	< 0,1	< 0,005	-20,4	12,5	2,27
LA-8	A. Salmon	Skotfoss	Nov. 2008	107	9200	13	0,75	0,11	< 0,1	< 0,005	-21,5	12,8	2,96
LA-9	A. Salmon	Skotfoss	Nov. 2008	70	1850	6	0,54	0,09	< 0,1	< 0,005	-20,7	13,0	2,38
LA-10	A. Salmon	Skotfoss	Nov. 2008	73	1670	7	0,43	0,08	< 0,1	< 0,005	-20,5	12,2	2,37
LA-11	A. Salmon	Skotfoss	Nov. 2008	79	3500	8	0,71	0,12	< 0,1	< 0,005	-19,6	13,0	2,42
LA-12	A. Salmon	Skotfoss	Nov. 2008	77	2290	8	0,50	0,07	< 0,1	< 0,005	-20,7	12,1	2,32
LA-13	A. Salmon	Skotfoss	Nov. 2008	94	6050	12	0,73	0,12	< 0,1	< 0,005	-20,7	13,6	2,57
LA-14	A. Salmon	Skotfoss	Nov. 2008	75	2200	9	0,52	0,12	< 0,1	< 0,005	-20,7	12,3	2,33

Marked	Species	Location	Caught Date	Length cm	Weight g	Age yr	K-factor	Hg average	Pb ppm	Cd ppm	$\delta^{13}C_{VPDB}$ ‰	$\delta^{15}N_{AIR}$ ‰	W% C/N
SU-1	Tench	Årnesbukta	06/09/2008	43	1395	7	1,75	0,137	< 0,1	< 0,005	-24,0	10,1	3,07
SU-2	Tench	Årnesbukta	06/09/2008	44	1275	6	1,50	0,104	< 0,1	< 0,005	-26,1	9,0	2,51
SU-3	Tench	Årnesbukta	06/09/2008	42	1280	6	1,73	0,110	< 0,1	< 0,005	-26,3	10,0	2,33
SU-4	Tench	Årnesbukta	24/09/2008	50	2250	10	1,80	0,341	< 0,1	< 0,005	-24,5	10,7	2,69

Marked	Species	Location	Caught Date	Length cm	Weight g	Age yr	K-factor	Hg mg/kg ww	Pb ppm	Cd ppm	$\delta^{13}C_{VPDB}$ ‰	$\delta^{15}N_{AIR}$ ‰	W% C/N
Ø-1	Trout	Nesodden	14/10/2008	37	520	7	1,03	0,33	< 0,1	< 0,005	-28,4	12,2	2,51
Ø-2	Trout			38	720	9	1,31	0,29	< 0,1	< 0,005	-29,7	11,9	3,00
Ø-3	Trout	Omdalsbekken Skotfoss	13/10/2008	41	720	10	1,04	0,12	< 0,1	< 0,005	-24,1	11,7	2,33
Ø-4	Trout	Omdalsbekken Skotfoss	13/10/2008	33	360	7	1,00	0,10	< 0,1	< 0,005	-26,4	10,6	2,25
Ø-5	Trout	Omdalsbekken Skotfoss	13/10/2008	32	300	9	0,92	0,19	< 0,1	< 0,005	-28,0	11,0	2,24
Ø-6	Trout	Omdalsbekken Skotfoss	13/10/2008	41	680	8	0,99	0,14	< 0,1	< 0,005	-21,3	11,9	2,34
Ø-7	Trout		13/10/2008	43	690	10	0,87	0,09	0,12	< 0,005	-26,2	9,9	2,37
Ø-8	Trout	Mastdalsbekken	13/10/2008	33	400	8	1,11	0,09	< 0,1	< 0,005	-25,4	9,1	2,30
Ø-9	Trout	Gravabekken Valebø	13/10/2008	31	260	5	0,87	0,07	< 0,1	< 0,005	-24,4	9,9	2,32
Ø-10	Trout	Mastdalsbekken Valebø	13/10/2008	38	420	7	0,77	0,11	< 0,1	< 0,005	-25,0	7,2	2,25
Ø-11	Trout	Mastdalsbekken Valebø	13/10/2008	38	590	9	1,08	0,06	< 0,1	< 0,005	-22,1	9,2	2,33
Ø-12	Trout	Omdals bek. Skotfoss	13/10/2008	29	260	5	1,07	0,08	< 0,1	< 0,005	-27,6	11,1	2,32
Ø-13	Trout	Omdals bek. Skotfoss	13/10/2008	35	420	8	0,98	0,11	< 0,1	< 0,005	-27,9	11,0	2,28
Ø-14	Trout	Gravabekken Valebø	13/10/2008	28	180	4	0,82	0,04	< 0,1	< 0,005	-23,5	8,3	2,30
Ø-15	Trout	Mastdalen Bekken	13/10/2008	45	850	8	0,93	0,14	< 0,1	< 0,005	-27,4	10,8	2,39
Ø-16	Trout	Bekk til Sanar elva	25/10/2008	53	1200	14	0,81	1,44	< 0,1	< 0,005	-25,7	8,4	2,41
Ø-17	Trout	Omdalsbekken Skotfoss	13/10/2008	42	750	9	1,01	0,14	< 0,1	< 0,005	-21,8	11,3	2,31
Ø-18	Trout	Gravabekken Valebø	13/10/2008	41	520	5	0,75	0,08	< 0,1	< 0,005	-22,2	8,8	2,30
Ø-19	Trout	Omdalsbekken Skotfoss	13/10/2008	47	1080	9	1,04	0,25	< 0,1	< 0,005	-23,2	11,6	2,36
Ø-20	Trout	Gravabekken Valebø	13/10/2008	38	480	5	0,87	0,10	< 0,1	< 0,005	-23,6	9,5	2,23
Ø-21	Trout	Gravabekken Valebø	13/10/2008	37	480	5	0,95	0,04	< 0,1	< 0,005	-20,7	7,8	2,30
Ø-22	Trout	Gravabekken Valebø	13/10/2008	53	1580	8	1,06	0,11	< 0,1	< 0,005	-25,6	10,0	2,41

Appendix 2: Results



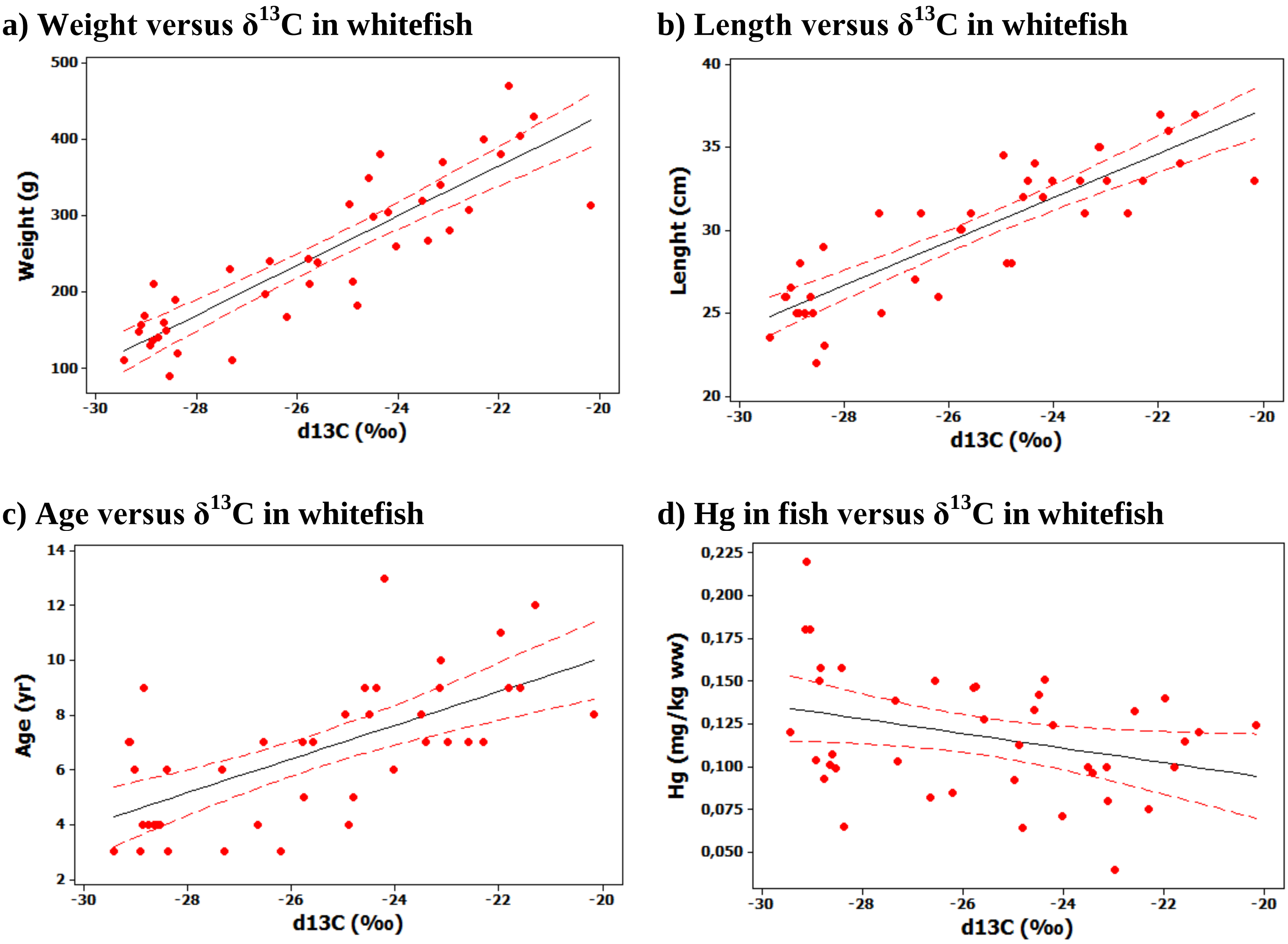
a) Weight = - 586,3 + 86,92 $\delta^{15}N$
$r^2 = 0,71$ $p = 0,000$

b) Length = - 4,414 + 3,572 $\delta^{15}N$
$r^2 = 0,71$ $p = 0,000$

c) Age = - 13,44 + 2,093 $\delta^{15}N$
$r^2 = 0,63$ $p = 0,000$

d) Hg = 0,08235 + 0,003688 $\delta^{15}N$
$r^2 = 0,00$ $p = 0,532$

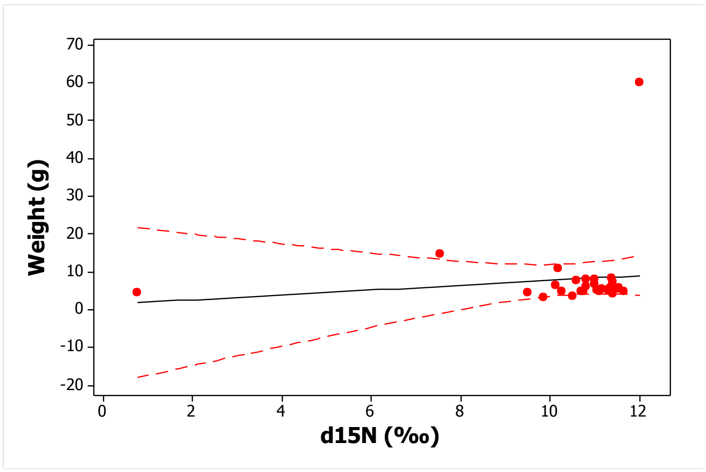
Figure 3-1-3. *Relationship between stable nitrogen isotope ($\delta^{15}N$) and weight (a), length (b), age (c) and Hg-concentration (d) in whitefish from Lake Norsjø. The curves are based on linear regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*



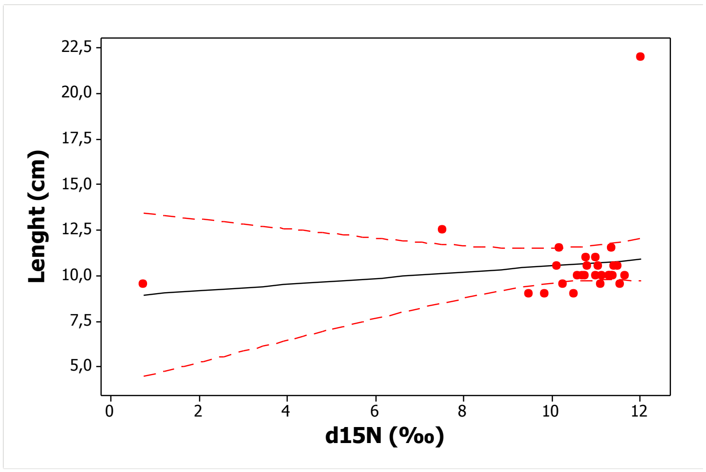
a) Weight = 1082 + 32,60 d13C r^2 = 0,77 p = 0,000	b) Length = 63,52 + 1,315 d13C r^2 = 0,74 p = 0,000
c) Age = 22,38 + 0,6148 d13C r^2 = 0,41 p = 0,000	d) Hg = 0,00825 - 0,004274 d13C r^2 = 0,08 p = 0,040

Figure 3-1-4. *Relationship between stable carbon isotope ($\delta^{13}C$) and weight (a), length (b), age (c) and Hg-concentration (d) in whitefish from Lake Norsjø. The curves are based on linear regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*

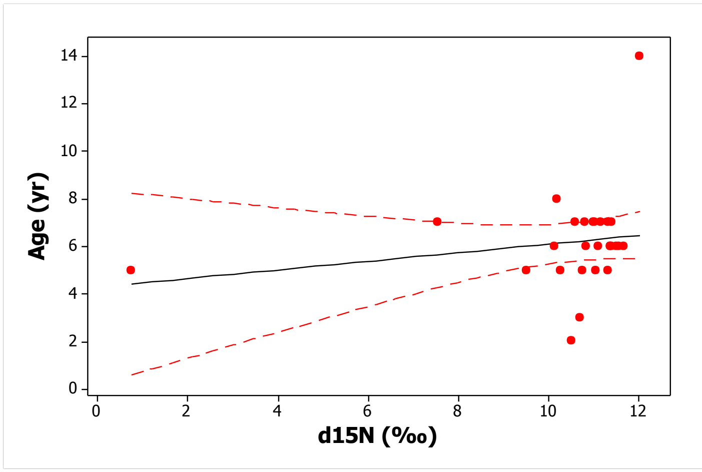
a) Weight versus $\delta^{15}N$ in European smelt



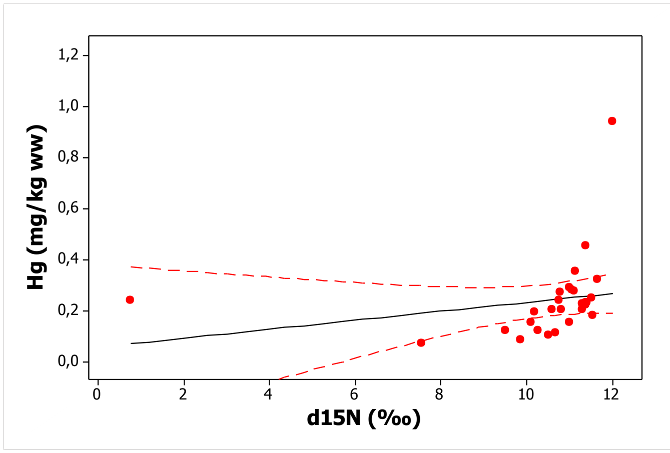
b) Length versus $\delta^{15}N$ in European smelt



c) Age versus $\delta^{15}N$ in European smelt



d) Hg in fish versus $\delta^{15}N$ in European smelt



a) Weight = 1,26 + 0,6402 $\delta^{15}N$
r^2 = 0,00 p = 0,517

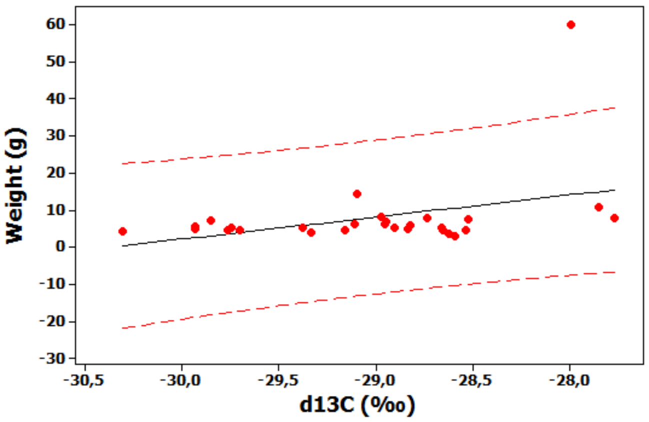
b) Length = 8,809 + 0,1721 $\delta^{15}N$
r^2 = 0,00 p = 0,441

c) Age = 4,292 + 0,1807 $\delta^{15}N$
r^2 = 0,00 p = 0,342

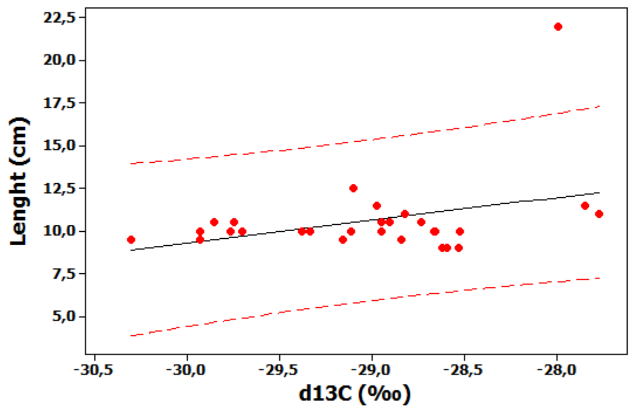
d) Hg = 0,0540 + 0,01765 $\delta^{15}N$
r^2 = 0,02 p = 0,243

Figure 3-2-3. *Relationship between stable nitrogen isotope ($\delta^{15}N$) and weight (a), length (b), age (c) and mercury (d) in European smelt from Lake Norsjø. The curves are based on linear regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*

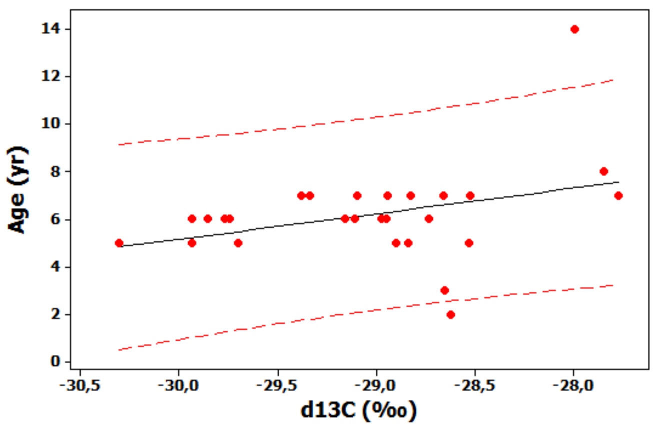
a) Weight versus $\delta^{13}C$ in European smelt



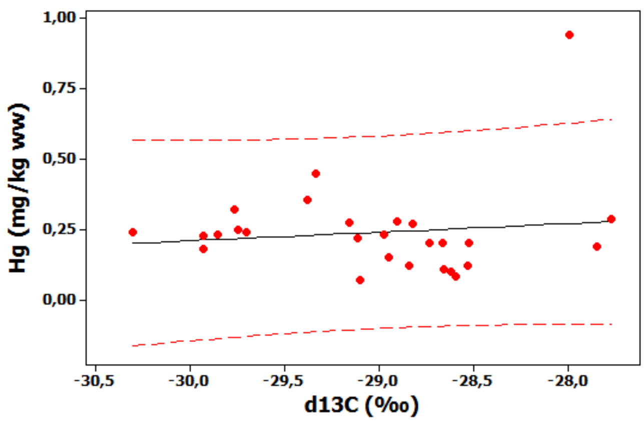
b) Length versus $\delta^{13}C$ in European smelt



c) Age versus $\delta^{13}C$ in European smelt



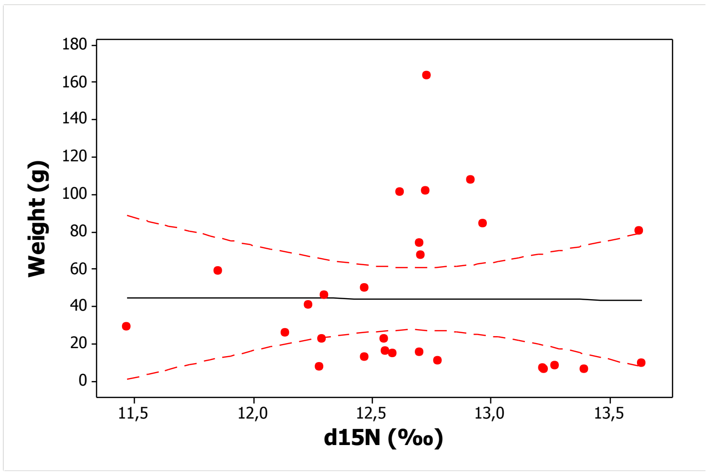
d) Hg in fish versus $\delta^{13}C$ in European smelt



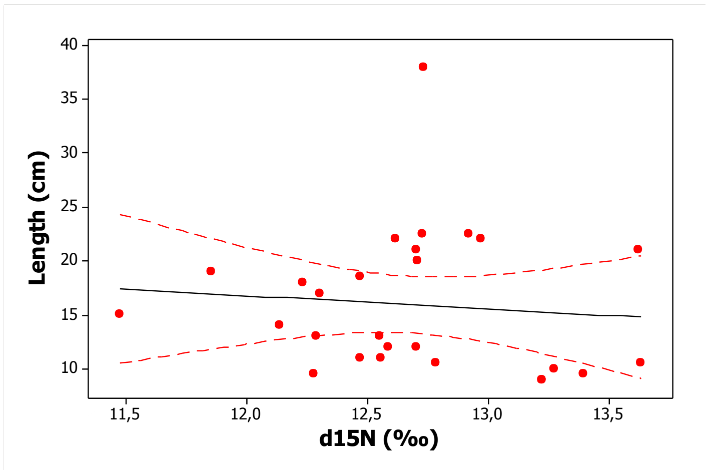
a) Weight = 181,3 + 5,973 d13C r^2 = 0,10 p = 0,056	b) Length = 49,14 + 1,328 d13C r^2 = 0,09 p = 0,061
c) Age = 37,40 + 1,075 d13C r^2 = 0,08 p = 0,079	d) Hg = 1,118 + 0,03030 d13C r^2 = 0,00 p = 0,543

Figure 3-2-4. *Relationship between stable carbon isotope ($\delta^{13}C$) and weight (a), length (b), age (c) and mercury (d) in European smelt from Lake Norsjø. The curves are based on linear regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*

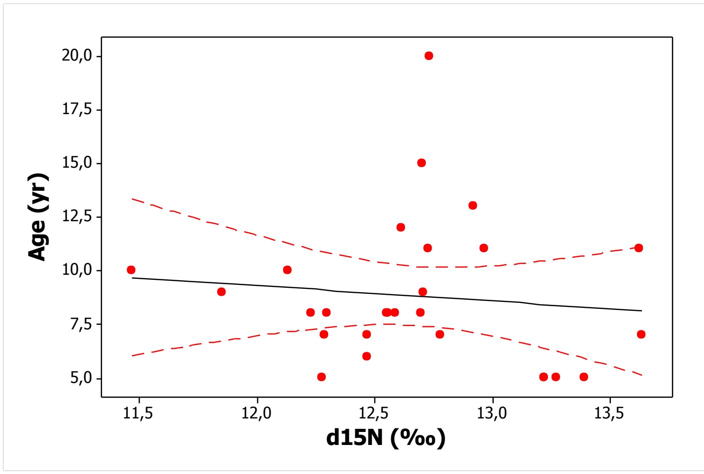
a) Weight versus $\delta^{15}N$ in Arctic char



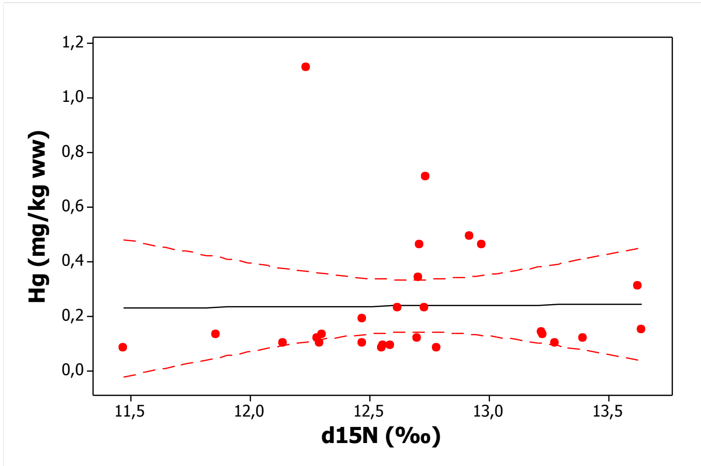
b) Length versus $\delta^{15}N$ in Arctic char



c) Age versus $\delta^{15}N$ in Arctic char



d) Hg in fish versus $\delta^{15}N$ in Arctic char



a) Weight = 51,7 - 0,61 $\delta^{15}N$
r^2 = 0,00 p = 0,970

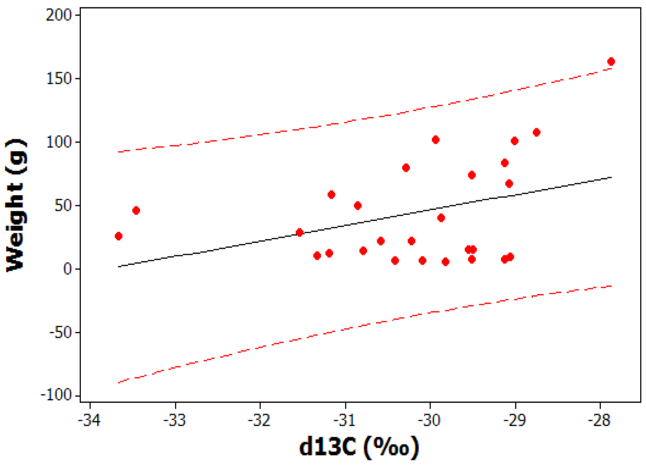
b) Length = 31,47 - 1,224 $\delta^{15}N$
r^2 = 0,00 p = 0,639

c) Age = 17,95 - 0,720 $\delta^{15}N$
r^2 = 0,00 p = 0,598

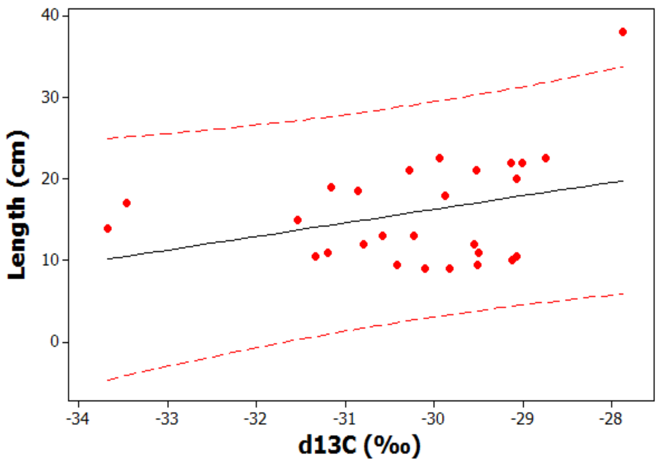
d) Hg = 0,152 + 0,00668 $\delta^{15}N$
r^2 = 0,00 p = 0,944

Figure 3-3-3. *Relationship between stable nitrogen isotope ($\delta^{15}N$) and weight (a), length (b), age (c) and mercury (d) in Arctic char from Lake Norsjø. The curves are based on linear regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*

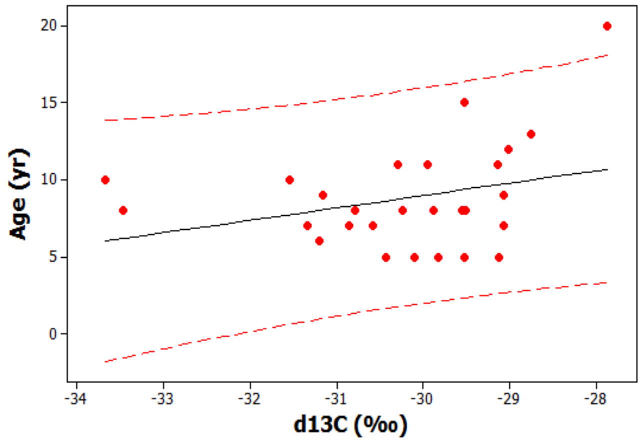
a) Weight versus $\delta^{13}C$ in Arctic char



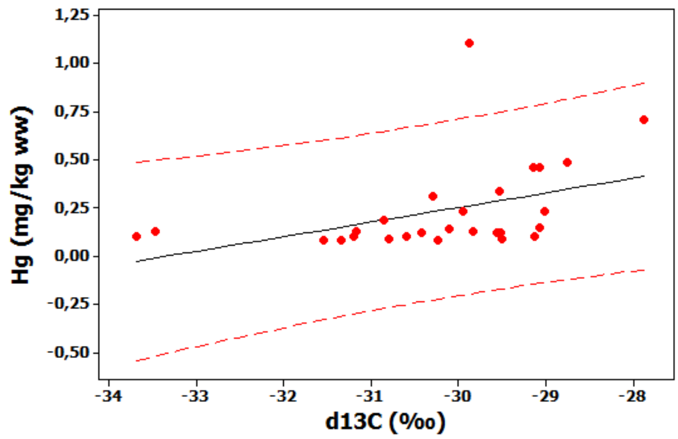
b) Length versus $\delta^{13}C$ in Arctic char



c) Age versus $\delta^{13}C$ in Arctic char



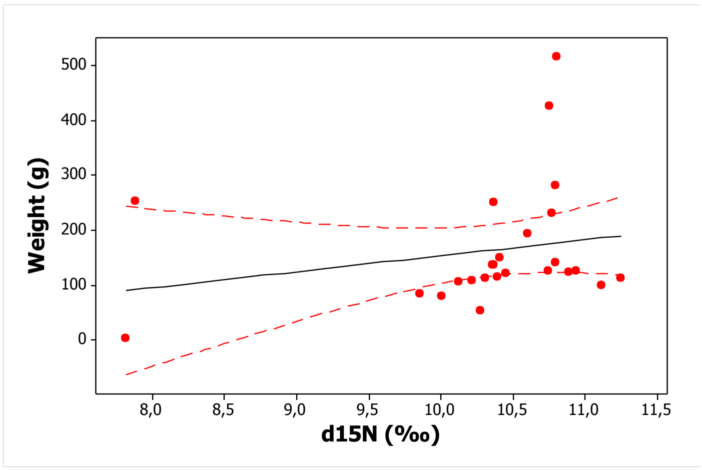
d) Hg in fish versus $\delta^{13}C$ in Arctic char



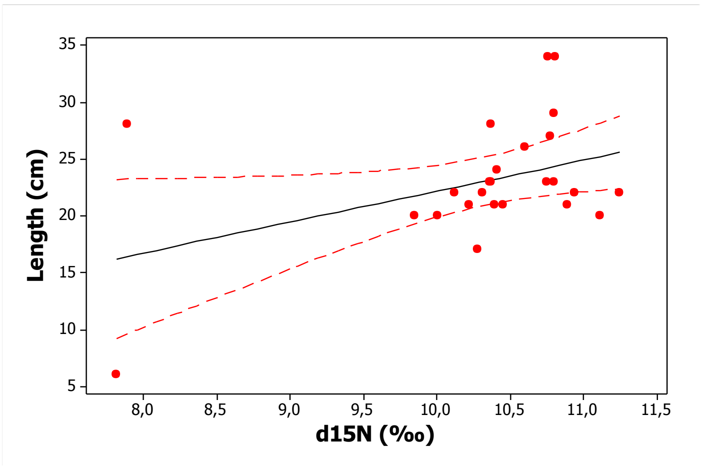
a) Weight = 412,0 + 12,19 d13C r^2 = 0,12 p = 0,045	b) Length = 66,10 + 1,661 d13C r^2 = 0,07 p = 0,900
c) Age = 33,10 + 0,8039 d13C r^2 = 0,06 p = 0,119	d) Hg = 2,534 + 0,07605 d13C r^2 = 0,14 p = 0,028

Figure 3-3-4. *Relationship between stable carbon isotope ($\delta^{13}C$) and weight (a), length (b), age (c) and mercury (d) in Arctic char from Lake Norsjø. The curves are based on linear regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*

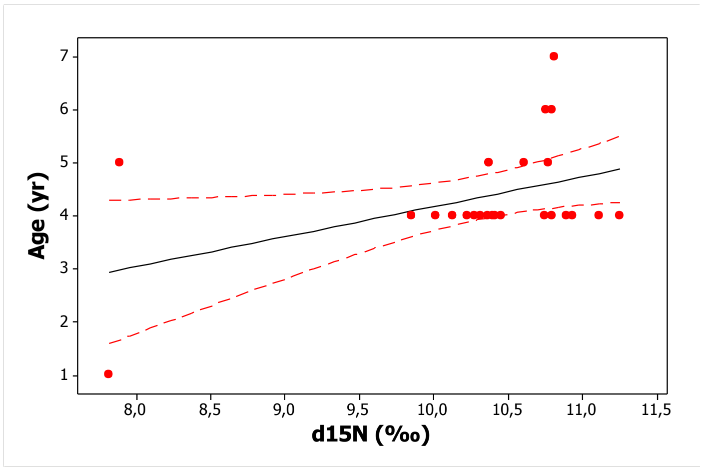
a) Weight versus $\delta^{15}N$ in perch



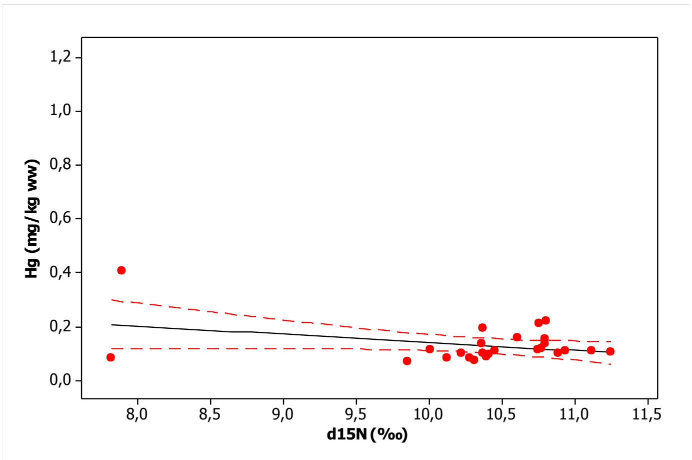
b) Length versus $\delta^{15}N$ in perch



c) Age versus $\delta^{15}N$ in perch



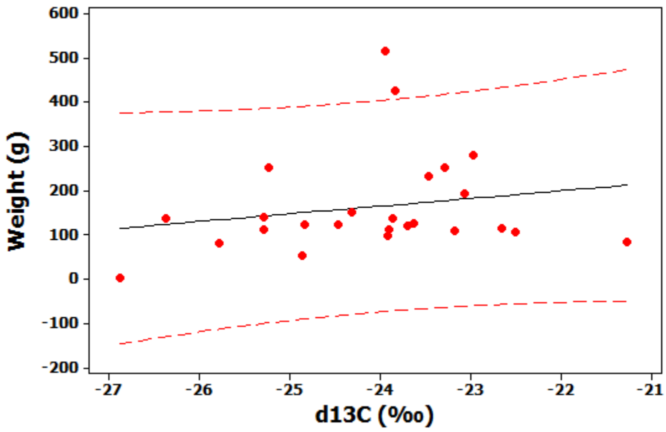
d) Hg in fish versus $\delta^{15}N$ in perch



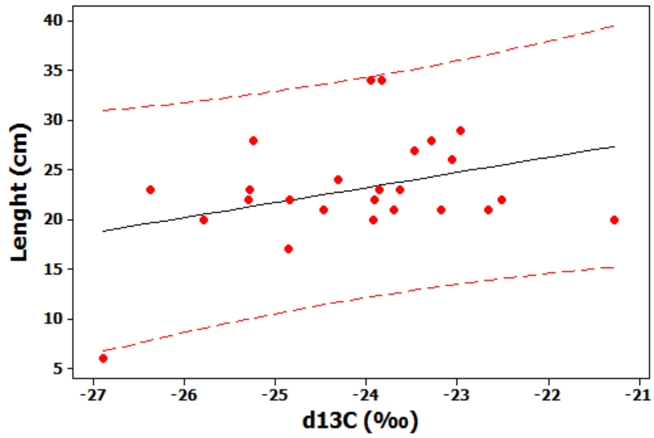
a) Weight = - 138,2 + 29,14 $\delta^{15}N$ r^2 = 0,03 p = 0,310	b) Length = - 5,03 + 2,721 $\delta^{15}N$ r^2 = 0,13 p = 0,044
c) Age = - 1,456 + 0,5629 $\delta^{15}N$ r^2 = 0,15 p = 0,032	d) Hg = 0,4425 - 0,03030 $\delta^{15}N$ r^2 = 0,09 p = 0,082

Figure 3-4-3. *Relationship between nitrogen stable isotope ($\delta^{15}N$) and weight (a), length (b), age (c) and mercury (d) in perch from Lake Norsjø. The curves are based on linear regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*

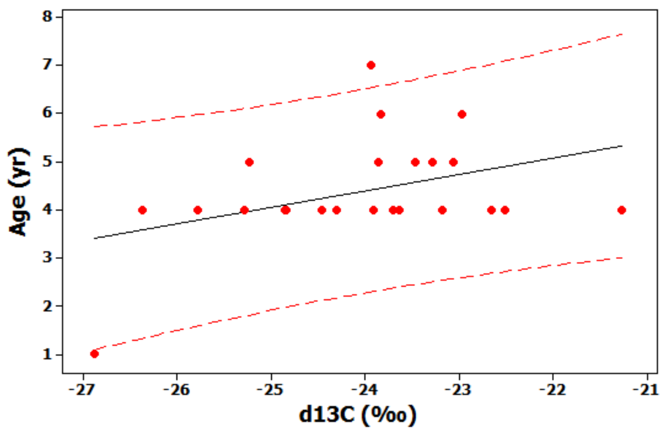
a) Weight versus δ^{13}C in perch



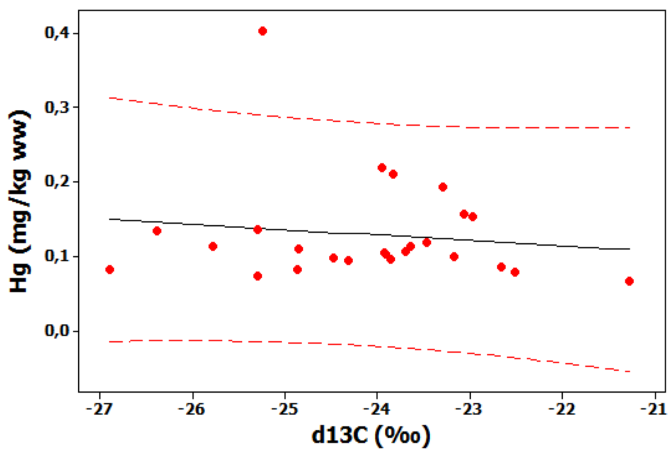
b) Length versus δ^{13}C in perch



c) Age versus δ^{13}C in perch



d) Hg in fish versus δ^{13}C in perch



a) Weight = 579,3 + 17,28 d13C
r^2 = 0,00 p = 0,352

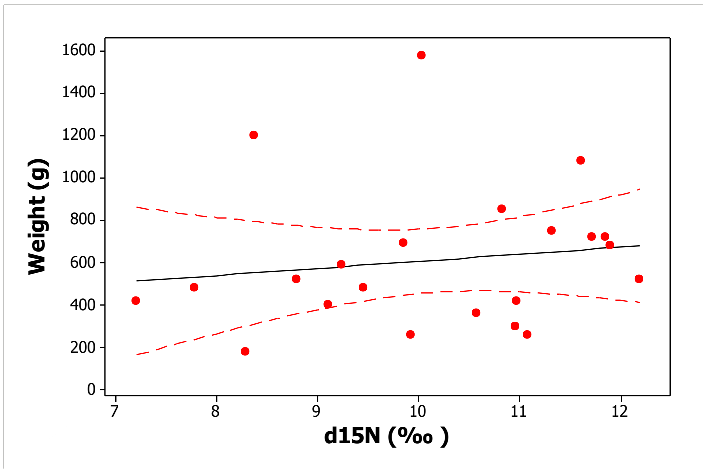
b) Length = 59,62 + 1,516 d13C
r^2 = 0,08 p = 0,086

c) Age = - 1,456 + 0,5629 δ^{15}N
r^2 = 0,15 p = 0,032

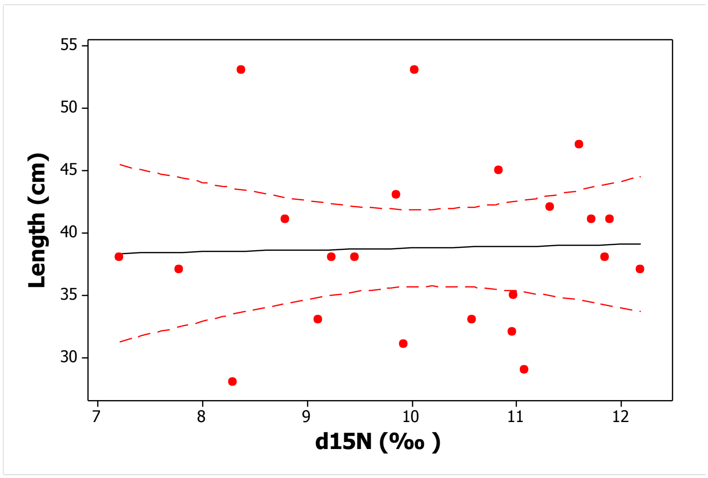
d) Hg = - 0,0428 - 0,00715 d13C
r^2 = 0,00 p = 0,538

Figure 3-4-4. *Relationship between carbon stable isotope (δ^{13}C) and weight (a), length (b), age (c) and mercury (d) in perch from Lake Norsjø. The curves are based on linear regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*

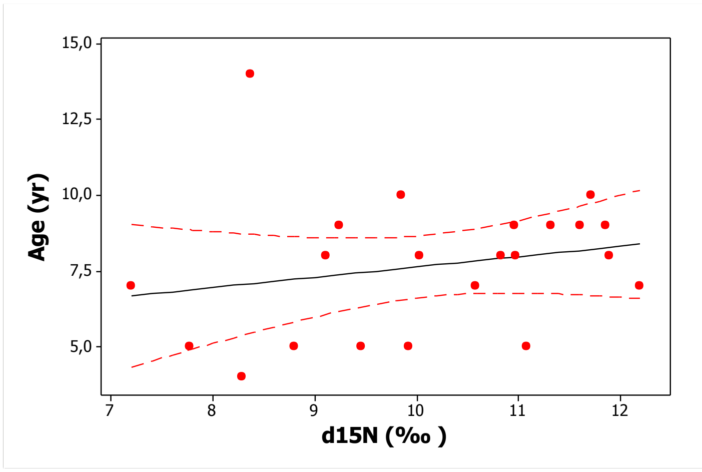
a) Weight versus δ^{15}N in brown trout



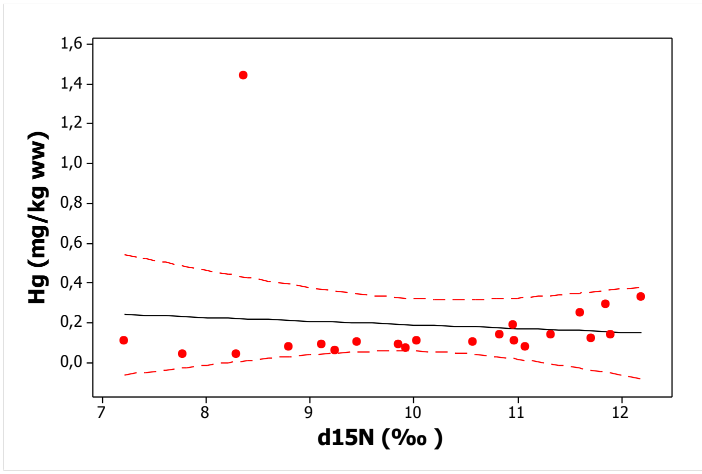
b) Length versus δ^{15}N in brown trout



c) Age versus δ^{15}N in brown trout

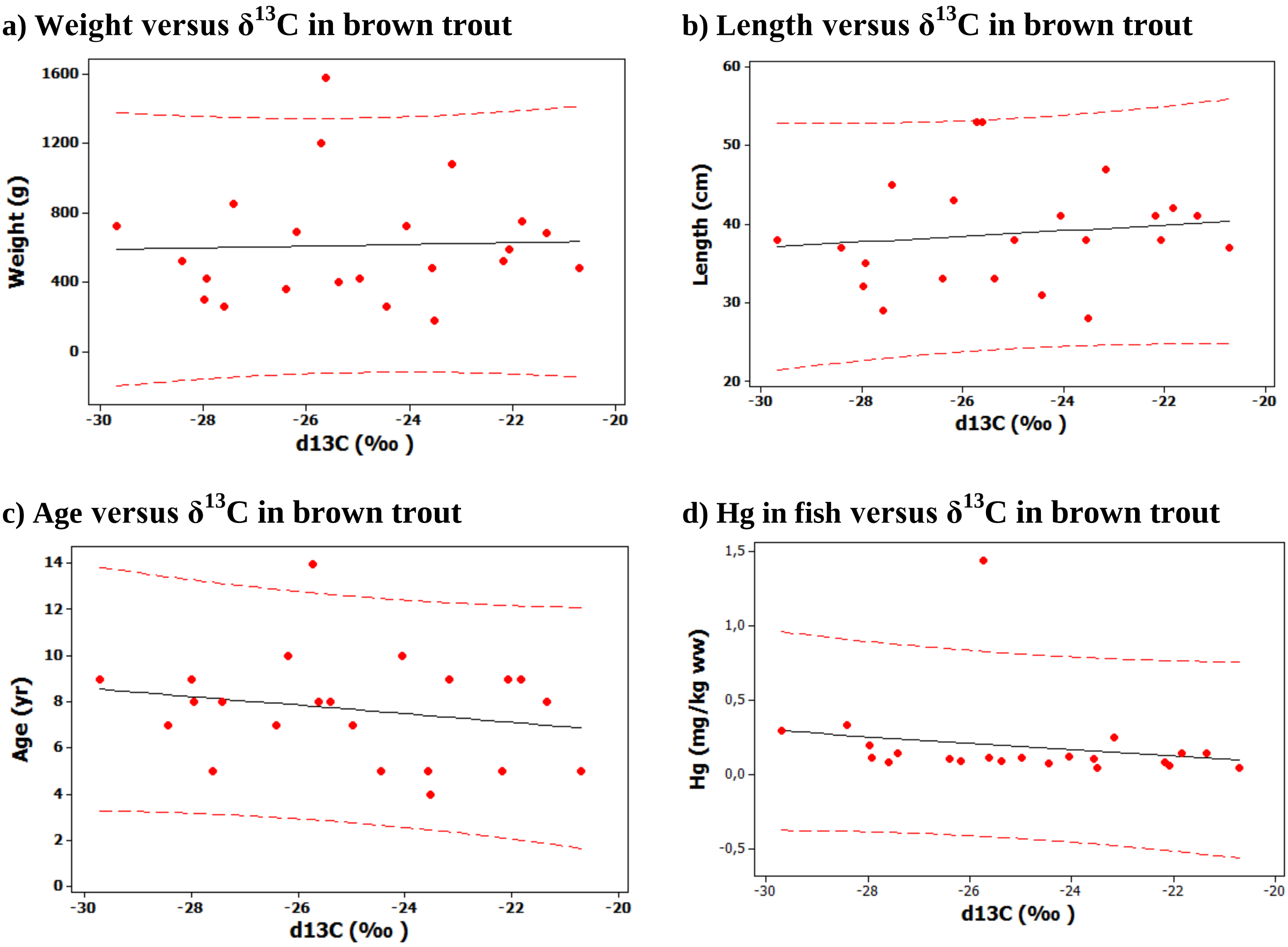


d) Hg in fish versus δ^{15}N in brown trout



a) Weight = 273,6 + 33,36 δ^{15}N r^2 = 0,00 p = 0,523	b) Length = 37,29 + 0,147 δ^{15}N r^2 = 0,00 p = 0,890
c) Age = 4,229 + 0,3406 δ^{15}N r^2 = 0,00 p = 0,336	d) Hg = 0,3735 - 0,01837 δ^{15}N r^2 = 0,00 p = 0,684

Figure 3-5-3. *Relationship between stable nitrogen isotope (δ^{15}N) and weight (a), length (b), age (c) and mercury (d) in brown trout from Lake Norsjø. The curves are based on linear regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*



a) Weight = 736,5 + 4,99 d13C
r^2 = 0,0% p = 0,868

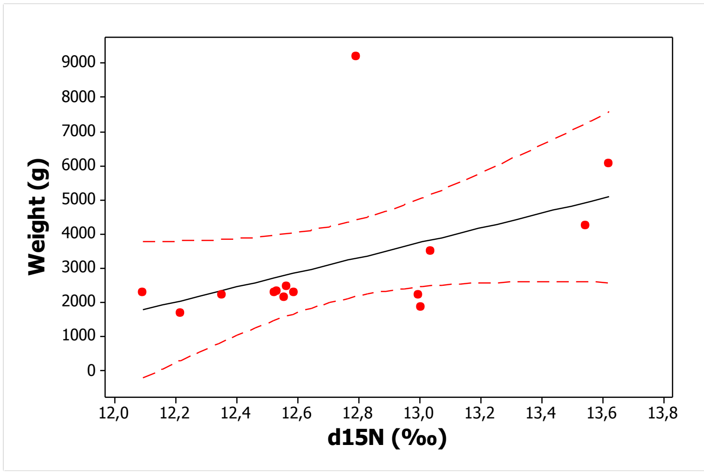
b) Length = 47,61 + 0,3534 d13C
r^2 = 0,00 p = 0,556

c) Age = 2,999 - 0,1873 d13C
r^2 = 0,00 p = 0,355

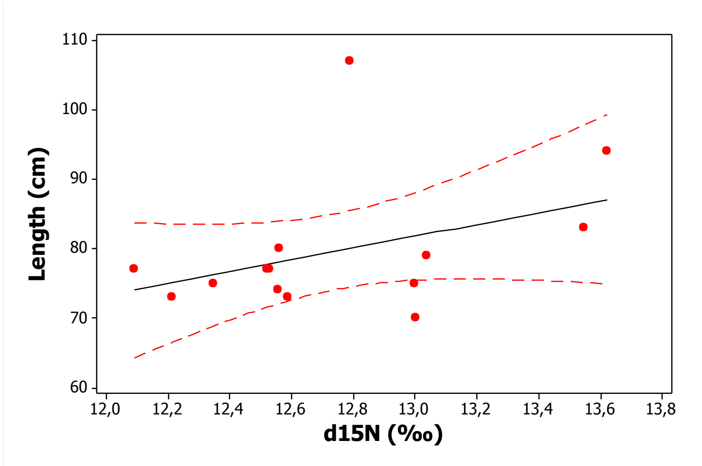
d) Hg = - 0,3548 - 0,02168 d13C
r^2 = 0,00 p = 0,397

Figure 3-5-4. *Relationship between stable carbon isotope ($\delta^{13}C$) and weight (a), length (b), age (c) and mercury (d) in brown trout from Lake Norsjø. The curves are based on linear regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*

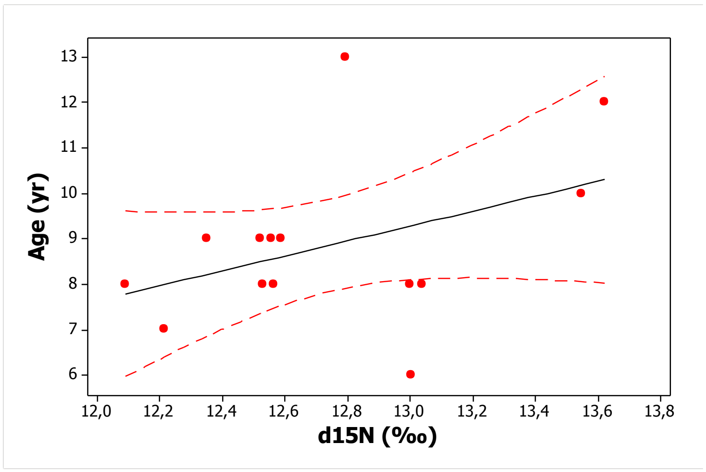
a) Weight versus $\delta^{15}N$ in Atlantic salmon



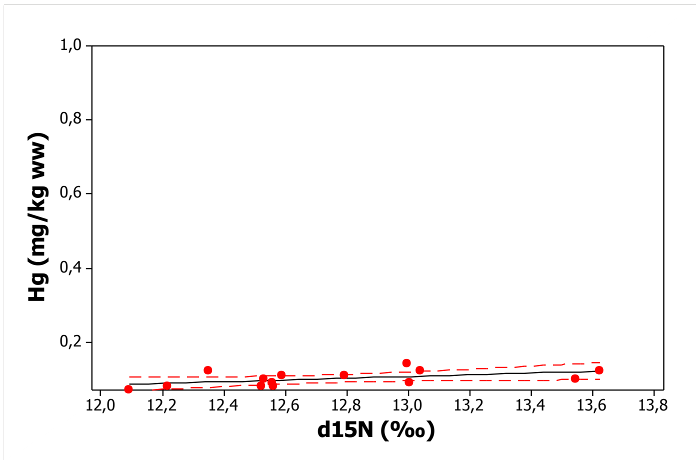
b) Length versus $\delta^{15}N$ in Atlantic salmon



c) Age versus $\delta^{15}N$ in Atlantic salmon

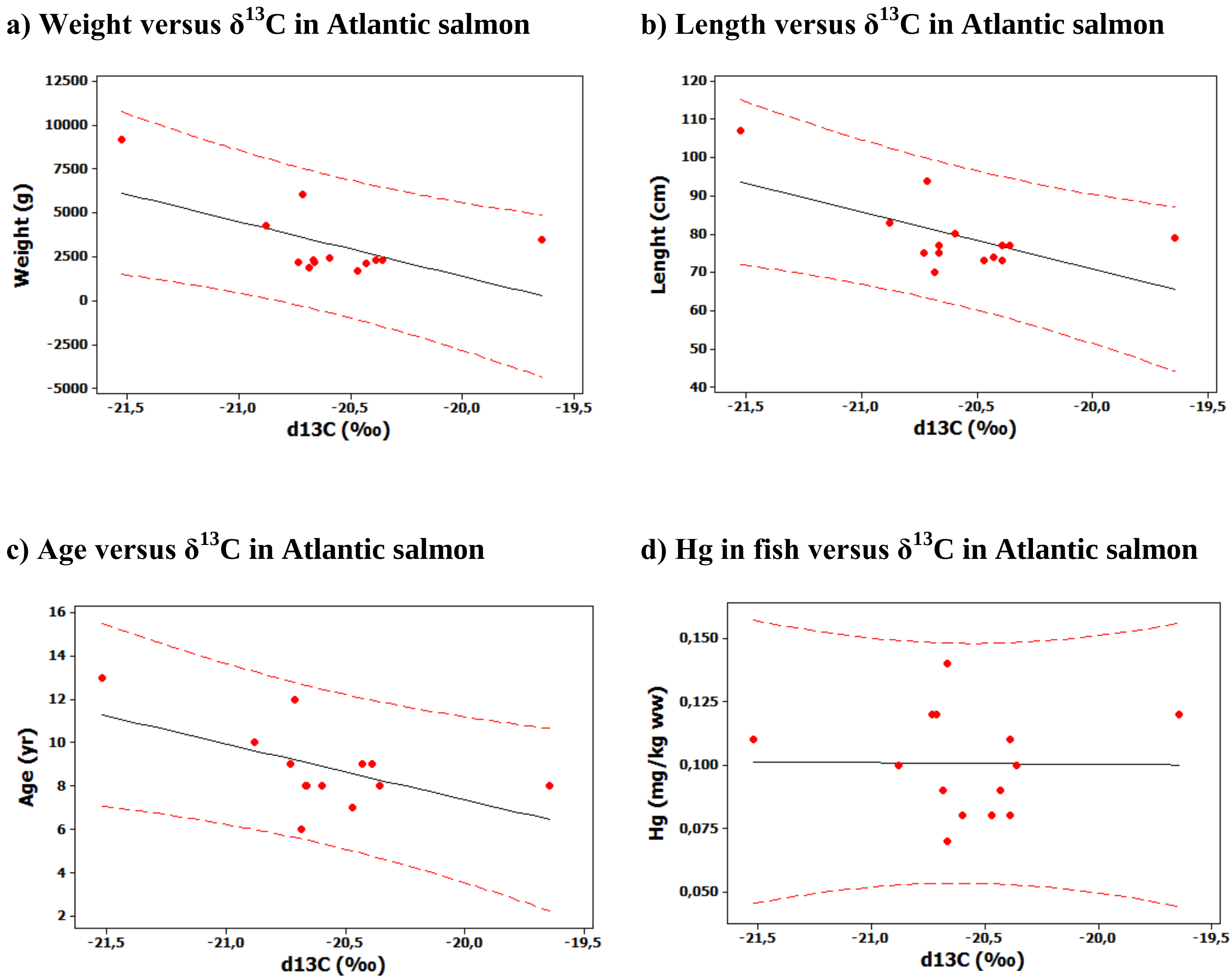


d) Hg in fish versus $\delta^{15}N$ in Atlantic salmon



a) Weight = - 24307 + 2158 $\delta^{15}N$ r^2 = 0,16 p = 0,090	b) Length = - 29,58 + 8,565 $\delta^{15}N$ r^2 = 0,09 p = 0,159
c) Age = - 12,05 + 1,640 $\delta^{15}N$ r^2 = 0,09 p = 0,149	d) Hg = - 0,1943 + 0,02315 $\delta^{15}N$ r^2 = 0,21 p = 0,056

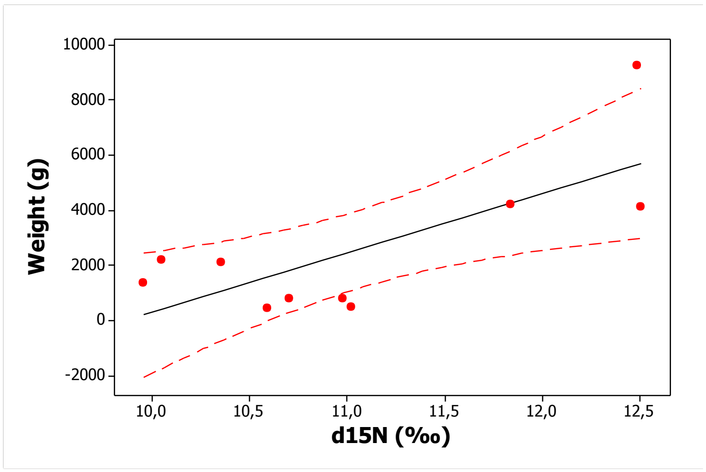
Figure 3-6-3. *Relationship between stable nitrogen isotope ($\delta^{15}N$) and weight (a), length (b), age (c) and mercury (d) in Atlantic salmon from Skienselva, the river outlet from Lake Norsjø. The curves are based on linear regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*



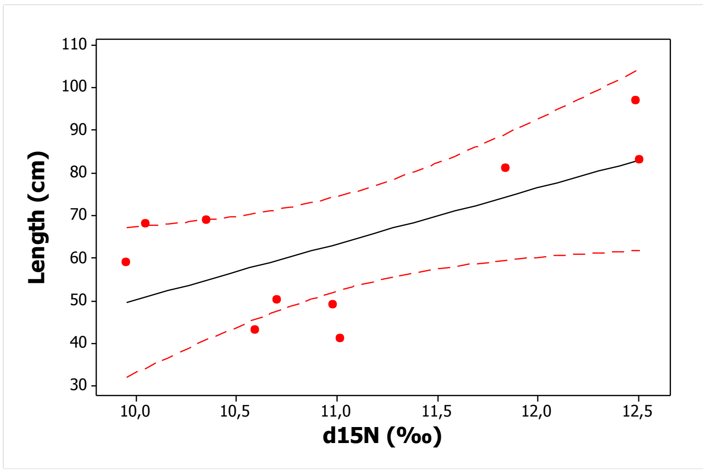
a) Weight = - 61084 - 3123 d13C r^2 = 0,30 p = 0,024	b) Length = - 227,1 - 14,90 d13C r^2 = 0,32 p = 0,021
c) Age = - 44,19 - 2,578 d13C r^2 = 0,26 p = 0,037	d) Hg = 0,0866 - 0,00069 d13C r^2 = 0,00 p = 0,963

Figure 3-6-4. *Relationship between stable carbon isotope ($\delta^{13}C$) and weight (a), length (b), age (c) and mercury (d) in Atlantic salmon from Skienselva, the river outlet from Lake Norsjø. The curves are based on linear regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*

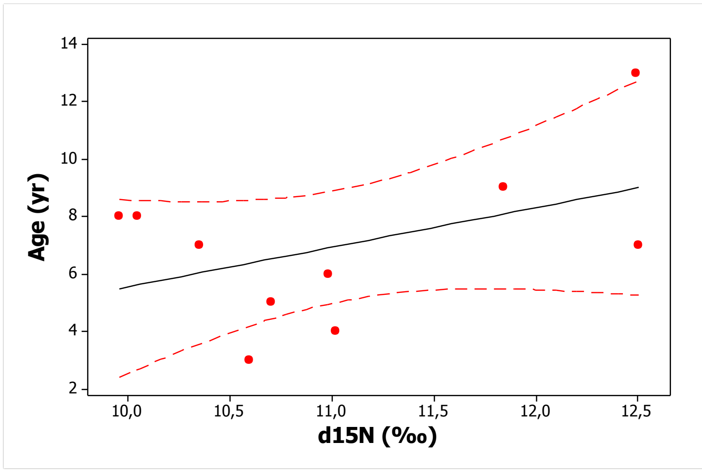
a) Weight versus δ^{15}N in northern pike



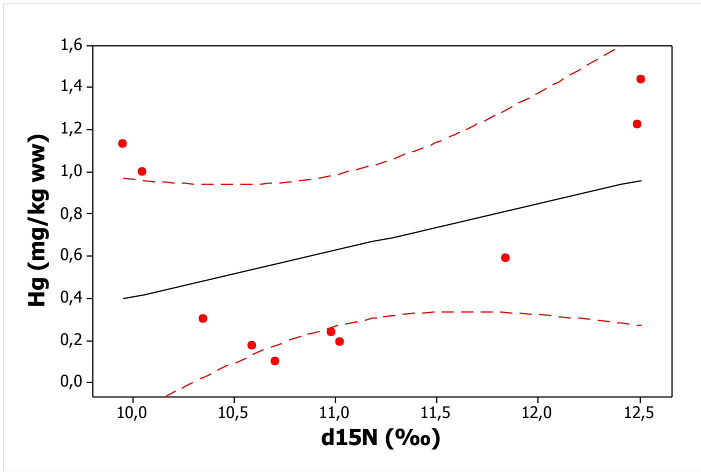
b) Length versus δ^{15}N in northern pike



c) Age versus δ^{15}N in northern pike



d) Hg in fish versus δ^{15}N in northern pike



a) Weight = - 21315 + 2161 δ^{15}N
r^2 = 0,49 p = 0,014

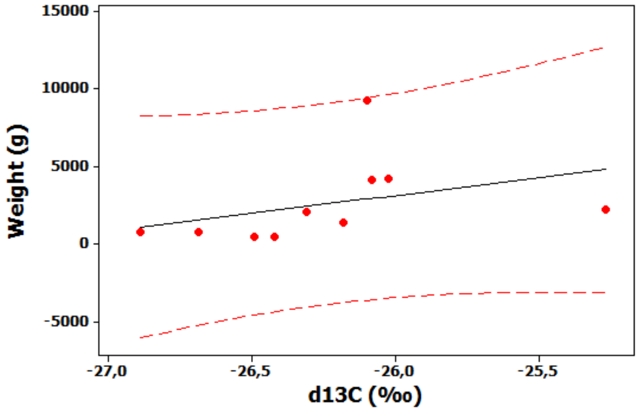
b) Length = - 80,78 + 13,10 δ^{15}N
r^2 = 0,35 p = 0,042

c) Age = - 8,22 + 1,377 δ^{15}N
r^2 = 0,11 p = 0,187

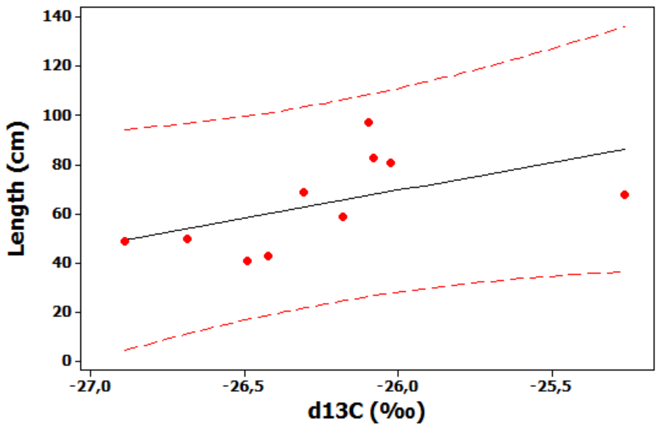
d) Hg = - 1,813 + 0,2218 δ^{15}N
r^2 = 0,06 p = 0,244

Figure 3-7-4. *Relationships between stable nitrogen isotope (δ^{15}N) and weight (a), length (b), age (c) and mercury (d) in pike from Lake Norsjø. The curves are based on linear regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*

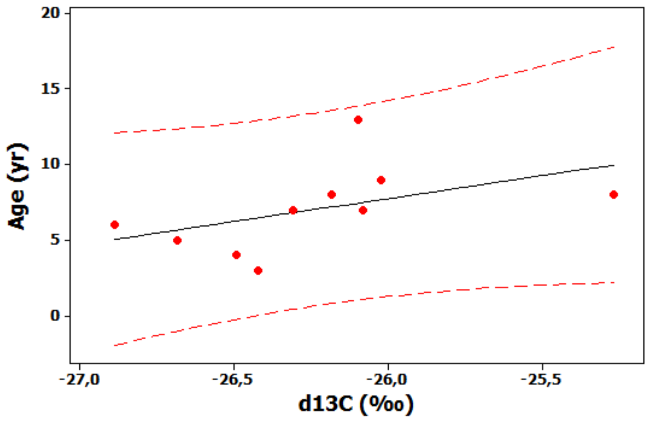
a) Weight versus $\delta^{13}C$ in northern pike



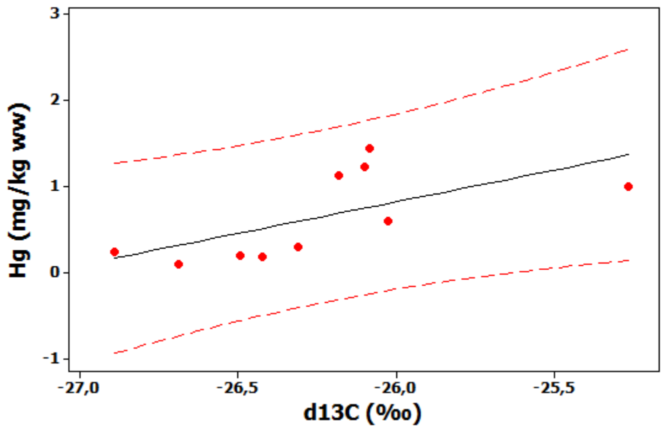
b) Length versus $\delta^{13}C$ in northern pike



c) Age versus $\delta^{13}C$ in northern pike



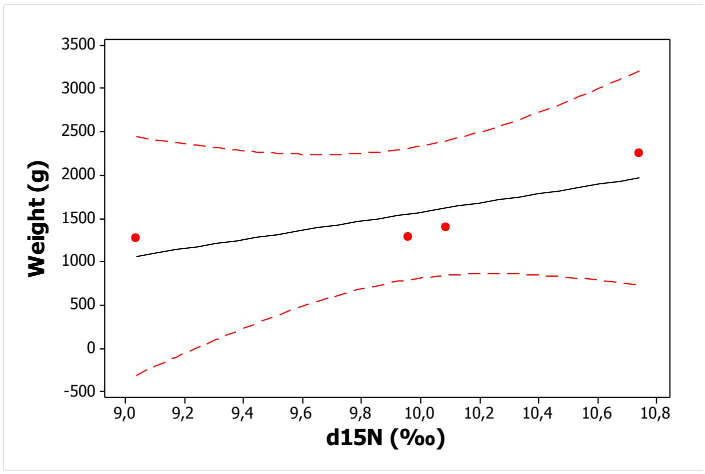
d) Hg in fish versus $\delta^{13}C$ in northern pike



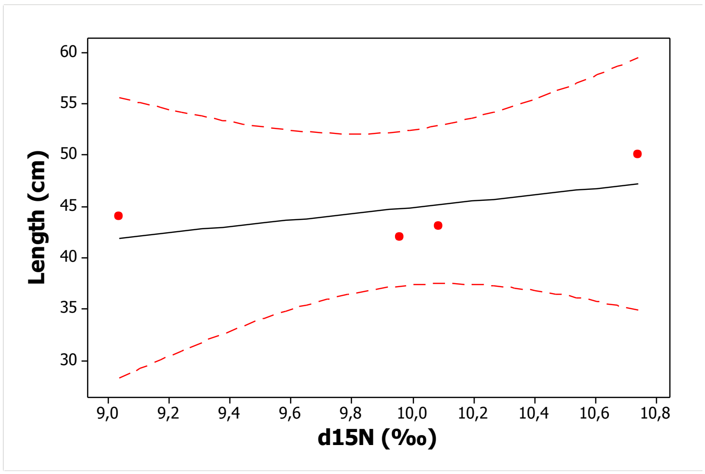
a) Weight = 62469 + 2283 d13C r^2 = 0,03 p = 0,292	b) Length = 662,5 + 22,81 d13C r^2 = 0,20 p = 0,111
c) Age = 86,56 + 3,032 d13C r^2 = 0,13 p = 0,166	d) Hg = 20,01 + 0,7381 d13C r^2 = 0,34 p = 0,046

Figure 3-7-5. *Relationships between stable carbon isotope ($\delta^{13}C$) and weight (a), length (b), age (c) and mercury (d) in pike from Lake Norsjø. The curves are based on linear regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*

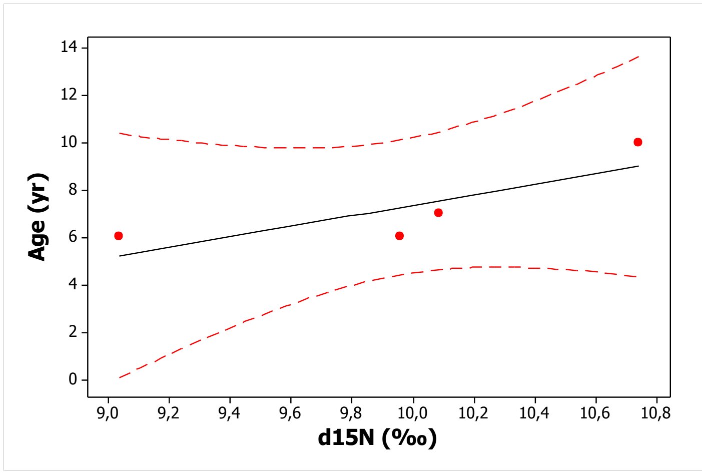
a) Weight versus δ^{15}N in tench



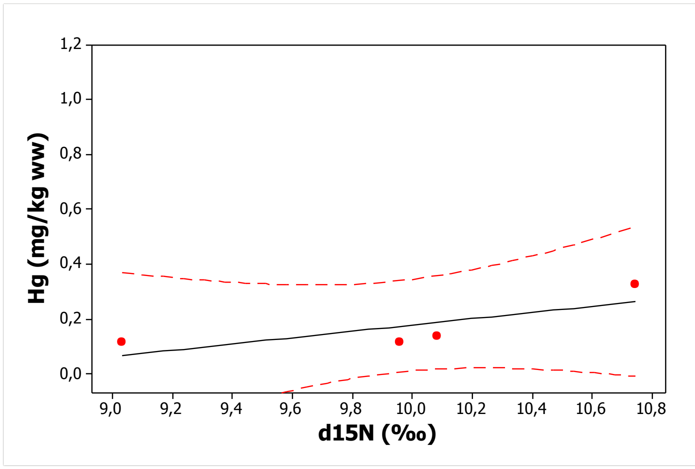
b) Length versus δ^{15}N in tench



c) Age versus δ^{15}N in tench



d) Hg in fish versus δ^{15}N in tench



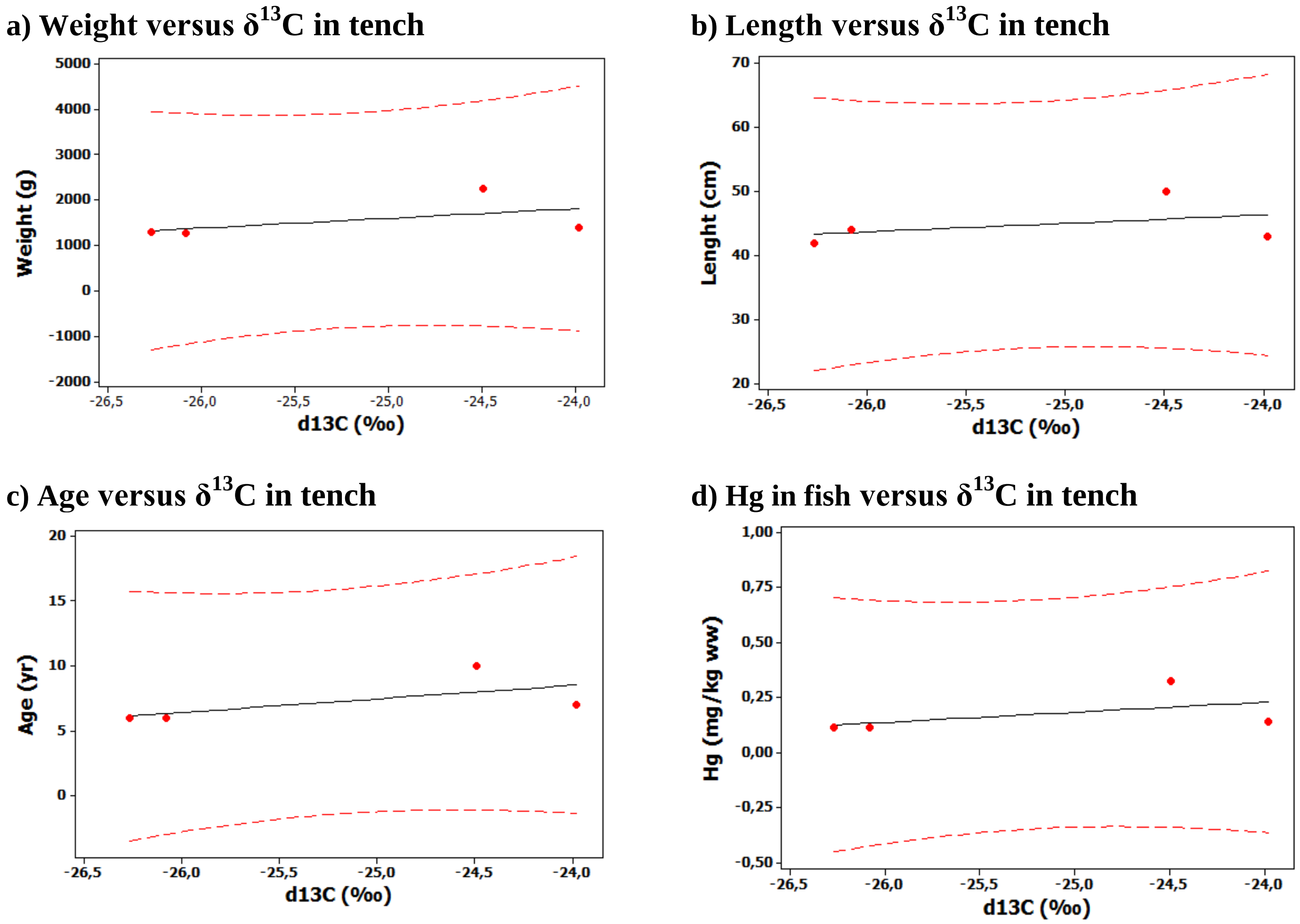
a) Weight = - 3699 + 527,3 δ^{15}N
r^2 = 0,43 p = 0,210

b) Length = 14,01 + 3,088 δ^{15}N
r^2 = 0,05 p = 0,395

c) Age = - 14,73 + 2,208 δ^{15}N
r^2 = 0,51 p = 0,179

d) Hg = - 0,9722 + 0,1150 δ^{15}N
r^2 = 0,43 p = 0,212

Figure 3-8-3. *Relationships between stable nitrogen isotope (δ^{15}N) and weight (a), length (b), age (c) and mercury (d) in tench from Lake Norsjø. The curves are based on linear regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*



a) Weight = 6960 + 214,7 d13C r^2 = 0,00 p = 0,479	b) Length = 78,25 + 1,329 d13C r^2 = 0,00 p = 0,578
c) Age = 33,60 + 1,045 d13C r^2 = 0,09 p = 0,370	d) Hg = 1,331 + 0,04595 d13C r^2 = 0,00 p = 0,490

Figure 3-8-4. *Relationships between stable carbon isotope ($\delta^{13}C$) and weight (a), length (b), age (c) and mercury (d) in tench from Lake Norsjø. The curves are based on linear regression. The dotted lines represent a 95% confidence interval. The regression equations, r^2 and p-values are shown on the panel above.*