LAKE RESTORATION

Oxygenation of pond water and sediment with granulated calcium peroxide

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KLUTAS, OSKARI:

Järvien kunnostus
Lammen veden ja sedimentin hapetus rakeistetulla kalsiumperoksidilla

Ympäristötekniikan opinnäytetyö, 48 sivua, 1 liitesivua

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TIIVISTELMÄ

Tämän opinnäytetyön tarkoituksena on tarjota yleistä tietoa Suomen järvistä, niiden tilasta ja ongelmista, sekä menetelmistä joita järvien kunnostuksessa voidaan käyttää.

Ensimmäisessä osiossa käsitellään Suomen järviä, jotka peittävät lähes 10% koko maan pinta-alasta ja joiden vaikutus suomalaiseen kulttuuriin on ollut huomattava. Samalla perehdytään ongelmiin joista järvet kärsivät. Ongelmien taustalla on suurelta osin yhteiskuntakehitys ja laajentunut ihmisasutus.

Toinen osio keskittyy järvien kunnostukseen, erilaisiin kunnostusmenetelmiin sekä niihin liittyviin taloudellisiin ja oikeudellisiin seikkoihin. Järvien kunnostuksen tavoitteena on pidentää järven elämänkaarta ja samalla parantaa sen tilaa esimerkiksi vapaa-ajan käyttöä varten.Kunnostusmenetelmät voidaan jaotella kahteen eri luokkaan, eli järven ulkoisiin ja sisäisiin menetelmiin. Sisäiset menetelmät ovat tarkkoja ja niitä yleensä käytetään, kun halutaan ratkaista joku erityinen järveä vaivaava ongelma.

Käytännön osion tarkoituksena on tarjota tietoa koskien uutta kunnostusmenetelmää, joka perustuu kalsiumperoksidin kykyyn luovuttaa happea reagoidessaan veden kanssa. Tavoitteena on tuottaa happea hapettomuudesta kärsivälle sedimentille ja pohjan vesikerrokselle ilman, että kemikaalin levitykseen tarvitaan erityislaitteistoa tai että vesikerroksia ja sedimenttiä tarvitsee sekoittaa. Kenttäkokeessa käytettiin kahta Lohjan lähellä sijaitsevaa lampea. Ensimmäiseen lampeen levitettiin kalsiumperoksidia (CaO_2) 50 g/ m^2, ja toisen lammen tarkoituksena oli tuottaa vertailudataa saaduille tuloksille.Kerätyt näytteet analysoitiin Helsingin Yliopiston Ympäristöekologianlaitoksella. Tuloksista ei ilmene negatiivisia vaikutuksia ja vapautunut happi on todettavissa kohonneesta bakteeriaktiivisuudesta ja siitä seuranneesta biomassan määrän vähenemisestä.

Käytännön osuus on osa Anne Nykäsen (FM) väitöskirjaa.Projektin johtajana toimi Martin Romantschuk (FT).

Valvojat: Anne Nykänen (FM) ja Silja Kostia (FT)

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ABSTRACT

This thesis provides general information about Finnish lakes and their problems. It also presents restoration methods, which can be used to improve the condition of the lakes and to ensure their presence for the next generations.

The first part discusses Finnish lakes that cover almost 10% of the country, and which have had an enormous effect on the Finnish culture and the way of life. This is done without forgetting the problems that lakes are suffering from, the problems that are for the most part caused by the development in the society and habitation.

The second part concentrates on lake restoration, on the different restoration methods, and, on the financial and legal issues. Lake restoration is a way to increase or to return years in the lifecycle of the lake and mostly it is done to improve the recreational value. Restoration methods can be separated in two categories, out and in-lake methods. This study mainly focuses on the latter ones. In-lake methods are specific, and usually aimed at some particular problem in a lake that has to be dealt with.

The practical part offers information about a new restoration method based on calcium peroxide's oxygen release when exposed to water. The purpose of the method is to oxygenate anoxic sediment and the bottom layer of water without special equipment in the distribution of the chemical, and without radical treatments or mixing the water and sediment. The field experiment was done by using two ponds near the town of Lohja. 50 g/ m^2 of CaO_2 was added into the test pond. The second pond was used to provide a comparison point. The collected samples were processed and analyzed at the Department of Ecological and Environmental Sciences of the University of Helsinki. The results show no negative effects, and oxygen release can be detected in the increasing of bacterial activity, and the decreasing of biomass.

The practical part is a part of Anne Nykänen’s (M.Phil.) academic dissertation. The project leader was Martin Romantschuk PhD prof.

Monitors: Anne Nykänen (M.Phil.) and Silja Kostia PhD

Key words: lake restoration, calcium peroxide, Finnish lakes

CONTENTS

GLOSSARY

Algae = small aquatic plants that occur as single cells, colonies, or filaments

Anoxia = a condition of no oxygen in the water.

Crustacean = group of arthropods, e.g. animals like crabs, lobsters, shrimp

Eutrophic = a lake with a high nutrient content

Eutrophication = an increase in chemical nutrients (N, P)

Food web = feeding interactions among all the lake's organisms

Hypolimnium = dense, bottom layer of water in a thermally-stratified lake

Hypoxic = low in oxygen

Invertebrate = an animal lacking a vertebral column (spine)

Oligotrophic = a lake with a low nutrient content

Piscivore = a carnivorous fish (animal) which lives on eating fish

Plantivores = fish and invertebrate that collectively prey on zooplankton

Thermocline = a layer which separates the upper mixed layer from the water below

Trophogenic = the upper layer of the lake where photosynthesis occurs

Tropholytic = deep zone in a lake where dissimilation of organic matter predominates

Turnover time = (in this study) the transition of the phosphorus from inorganic to organic

1 INTRODUCTION

Finland is a country whose landscape is enriched with thousands of varying size lakes and ponds. Fresh water covers altogether about 33 600 km^2, which is almost a tenth of the country‘s total land area. Although the surface area of water bodies is large, the total water volume is very modest due to the shallowness of the lakes, whose estimated average depth is just 6.9m (Särkkä, 1996, 14-15, 19). Mainly Finnish lakes are considered to be in good or even in excellent condition. These lakes are usually either considerably large and/or they are located far from habitation. Less than one third of the categorized lakes are valued to be in a condition below good (Pintavesien ekologinen ja kemiallinen tila, SYKE, 2009).

The two most common problems in Finnish lakes are eutrophication and acidification. Eutrophication is usually related with agriculture and inhabited areas that cause nutrient flows to nearby water bodies. Eutrophication causes increase in the amount of algae and water plants, which diminish the free surface area of a lake, and increase the need of dissolved oxygen needed by aquatic organisms. The growing oxygen demand can lead into an anoxic condition which can cause a decline of the species, and, in the worst case, a long-term oxygen depletions may result even a complitely fishless lake. The lack of oxygen also amplifies the effects of eutrophication as phosphorus is released from the sediment in anaerobic condition (Restoring and Protecting the World’s Lakes and reservoirs, 1995, 14). Acidification is a problem from which lakes are slowly recovering due to reductions in the atmospheric deposition of sulphur compounds. Water bodies that are oligotrophic and have an acidic geology, such as granite or a peat-based soil, are the most vulnerable to acidification (Happamoituminen, SYKE, 2009). The negative effects of acidification appear when pH falls below 6.5, at this point the most sensitive aquatic species are affected. As the acidity increases the shifts in biomass, the reduction in the diversity of species can be observed. Finally lakes can become fishless (Restoring and Protecting the World’s Lakes and reservoirs, 1995, 17).

First Finnish lake restoration projects where made in the late 1960s, and by 2002 restoration work had been carried out or planned for a total of some 800 lakes or lake waters (Järvienkunnostuksen historiaa, 2008.) The waters requiring restoration have typically been shallow and rather small in size, and the goal has usually been in improving the quality of water, or in increasing the depth of the lakes. The initiative for a restoration project usually comes from people who have permanent or holiday homes by a lakeshore as they realize that the recreational value of the lake suffers due to its poor condition (Järvien kunnostus ja hoito, 2009). In lake restoration projects, the most commonly used methods are so called in-lake methods. These methods can roughly be separated in three different groups, which are mechanical, chemical and biological methods. Nowadays these methods are used to complement each other to improve the effectiveness of the overall restoration process (Restoration methods and their use in Finland, SYKE, 2006).

The aim of the practical part is to examine the oxygenizing capabilities of calcium peroxide, and the effects that CaO_2 addition causes to water ecosystem and sediment. Possible risks are changes in pH and alkalinity. On the other hand, results, such as increasing oxygen level and its byproduct bacterial activity, are expected. Tentatively the greatest benefit of calcium peroxide as an oxidizing agent is the absence of need to treat and/or mix water and sediment. This should decrease nutrient releases from the sediment and the lower water layers. The field experiment was done near the town of Lohja, by using two ponds. Calcium peroxide was added into the first pond used in the experiment and the other pond was used to provide a comparison point for the results. During the experiment time, the condition of both ponds were monitored with in-situ measurements as well as collected samples, which were analyzed at the Department of Ecological and Environmental Sciences in Lahti.

2 FINNISH LAKES

Finland truly is a country of thousands of lakes. The total amount of lakes and ponds vary between 56 000 to 188 000 depending on what surface area size is used for determination, if 500 m^2 is used as lower bound then the latter number is correct. Separation between lake and pond can be made by evaluating the effects of wind in the mixing of water. If water body's water is mainly mixed by wind it is called a lake, if not, a pond. Fresh water covers 33 600 km^2 which is almost a tenth of the country's total land area. Although the surface area is large the total water volume of Finnish lakes is only 235 km^3 which is as a comparison less than a third of the volume of Russia's Lake Ladoga or two weeks water flow of the Amazon. This is because, the estimated average depth of Finnish lakes is just 6.9 m (Särkkä, 1996, 14-15, 19).

Lakes are so shallow because the rocks in this geologically stable region have been gradually evened out by erosion over millions of years and during successive recent ice ages. Finnish lakes are called glacial because the fresh water they contain is originated on great glaciers that covered the land during the ice age. Because of this, lakes are considered young, only between 0 – 10 000 years. Another thing that is special in Finnish lakes is the fact that they also lose depth because of the rising ground. Due to this and sedimentation, it is estimated that for example the northern part of Lake Päijänne will be dry in 5 000 years (Särkkä, 1996, 17-18).

2.1 Condition of Finnish lakes

The main part of Finnish lakes are considered to be in a good or even in an excellent condition. Usually these lakes are either considerably large, or they are located far from habitation. In a condition below good are less than one third of categorized lakes, half over rivers and over 80% of coastal area. The overall chemical condition is good with a couple of exceptions. This categorization is made in 2008 with new categorization method which is based on EU's directive in water policy. The main purpose of the method is to estimate how much human activity has affected aquatic life (Pintavesien ekologinen ja kemiallinen tila, SYKE, 2009). Figure 1 below illustrates the ecological condition of the different water areas. First bar from left is rivers, second lakes and the third coastal waters. Different colors indicate the levels of condition in the regarded water area, blue is excellent, green good, yellow fair, orange adequate and red poor.

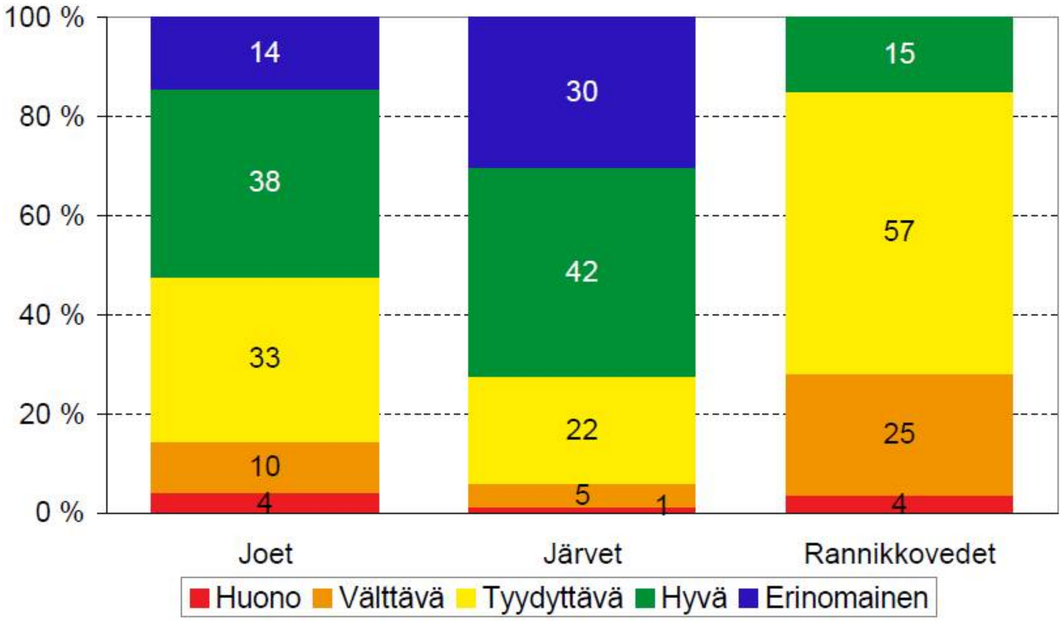

FIGURE 1. Ecological condition of different water areas (SYKE, 2009)

As shown above, the condition in lakes is relatively good, and the main differences in the levels of condition can be explained with the size of water area, and the nutrient flow from agriculture, which causes problems, such as algae and aquatic plant overgrowth. Still a risk remains because shallow lakes with relatively small water volume are easily contaminated by pollution. Even rather low concentrations of excess nutrients, acidic deposition or other harmful contaminants can easily disrupt aquatic ecosystems. If disruptions occur they can lead in to long-term problems which are hard to solve and usually demand a considerably large sum of money. In 2000, Finland's environmental administration estimated that 1500 lakes are in need of restoration to some extent.

2.2 Typical problems

The two most common problems in Finnish lake waters are eutrophication and acidification. Eutrophication is usually related with agriculture and inhabited areas that cause nutrient flows to nearby water bodies. Acidification is a problem from which lakes are slowly recovering due to reductions in the atmospheric deposition of sulphur compounds.

2.2.1 Eutrophication

Eutrophication can be said to be one of the most common and visible problems in lake ecosystems. Eutrophication is a natural process in water bodies because over its lifetime, a lake progresses from an oligotrophic to a more eutrophic state. When nutrients such as phosphorus and nitrogen wash into a lake with storm water or by soil erosion, they fertilize the lake and encourage algae and larger plants to grow. As plants and the animals that feed on them die and decompose, they accumulate on the lake bottom as organic sediments. After hundreds or thousands of years of plant growth and decomposition, the character of a lake may more closely resemble a marsh or a bog. This natural aging process of the lake is called eutrophication (Restoring and Protecting the World’s Lakes and reservoirs, 1995, 13-14).

Lakes also obtain nutrients from various human activities, which can shorten the natural lifespan of lakes. This accelerated transition is called cultural eutrophication. Nutrients from agricultural area, urban development, fertilized yards and gardens, land clearing, municipal and industrial wastewater and recreational activities contribute to accelerated rate of eutrophication (Rehevöityminen, SYKE, 2008).

Eutrophication causes water bodies’ problems which often lead in to changes in animal and plant populations. Results are usually unnaturally high rates of plant production and accumulation of organic matter that can degrade water and habitat quality. As the biomass of aquatic plants and algae increases, it forms depositions that sink and fuel bacterial growth in bottom waters and sediments. This bacterial growth and their metabolism consume oxygen in ever increasing amounts, which can lead into a situation where bottom sediment and waters become hypoxic or anoxic. Under these anaerobic conditions undesirable harmful gases are also produced, such as methane and hydrogen sulfide, which are toxic to most aquatic organisms (Restoring and Protecting the World's Lakes and reservoirs, 1995, 14). In Finnish lakes the oxygen levels are at lowest in the end of winter and sometimes in summer. In these occasions conditions are stressful or even lethal for invertebrates and fish.

When the eutrophication process has begun, it is hard stop. Even decreasing the amounts of external nutrient loads entering aquatic ecosystems may not help if the level of internal load is already so high that a self-maintaining problem of nutrient circulation has begun. In this process, the nutrients stored in sediment are repeatedly reabsorbed into the water, where they feed the growth of algae and plants (Rehevöityminen, SYKE, 2008).

Lakes suffering of eutrophication can be repaired through extensive restoration projects, at least to some extent. Usually, the removal of nutrients from the aquatic system, is done with selective fishing and/or the removal of excess plant growth. Also the nutrient-rich organic sediment on lake bottoms can be removed or covered. Aeration is also used, especially during winter time, to increase the level of oxygen in bottom waters which reduces the release of nutrients from bottom sediments (Rehevöityminen, SYKE, 2008).

2.2.2 Acidification

Atmospheric depositions of sulphur compounds are the main cause to acidification of aquatic systems, through acid rain and leaches from affected watershed. Other sources are industrial waste waters and drying of sulphate rich soils. The most vulnerable to acidification are water bodies, that are oligotrophic and have an acidic geology such as granite or a peat-based soil. Acidic, sulphate rich soils are problem especially in Pohjanmaa, where rivers are constantly suffering of the effects of acidification. Acidic soil is a long-term problem, which can only be cured with time, as the acidic compounds are slowly washed a way (Happamoituminen, SYKE, 2009).

Usually surface waters are slightly acidic, having pH less than 7. Negative effects on the most sensitive aquatic species e.g. the larvae of the salmonid fishes and freshwater crustaceans, begin to appear when pH falls below 6.5. As the acidity increases, more species become affected. This leads into shifts in biomass, and also a reduction in the diversity of species can be observed. Finally lakes whole fish population can be lost (Restoring and Protecting the World's Lakes and reservoirs, 1995, 17).

Neutralization is the restoration method, that is used to improve condition in acidic lakes. Usually this is done by using lime as a neutralization chemical. With liming, the pH and alkalinity can be returned, and maintained at levels where fish populations can be sustained by natural reproduction. Liming, as a process, is commonly used, although it is rather expensive and usually must be repeated so that permanent results are achieved (Restoring and Protecting the World's Lakes and reservoirs, 1995, 18).

Finnish lakes are slowly recovering from the effects of acidification. Main reason to this, is the restrictions concerning sulphur emissions, which have significantly reduced the amount of the atmospheric deposition. Due to this, the concentrations of sulphur compounds have declined, and buffering capacity has increased in all Finnish lakes during the 1990s. It is estimated, that in Finland, 5 000 smaller lakes are recovering well from the serious acidification problems (Happamoituminen, SYKE, 2009).

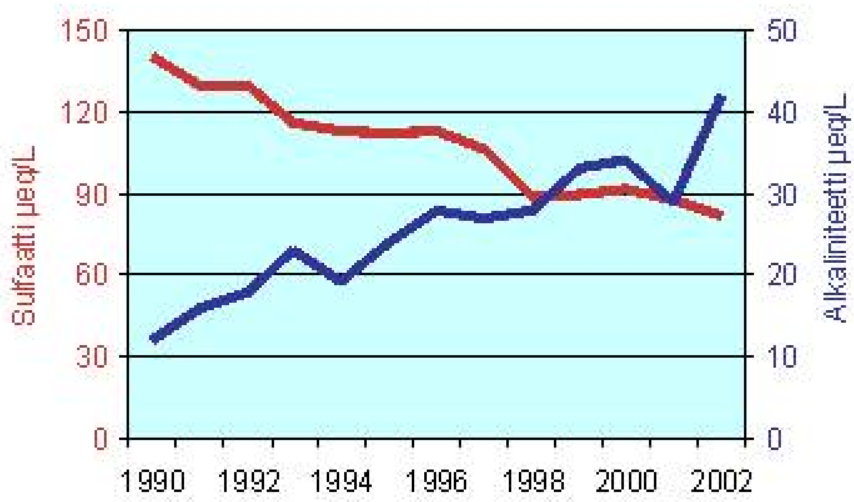

FIGURE 2. Average development of sulphur compound amounts and water alkalinity in southern Finland lakes. (Vesistöjen happamoituminen, Syke, 2008)

In Figure 2. shows the average development of sulphur compounds and water alkalinity (= buffer capacity) in 62 lakes, located in southern Finland. The red line indicates the amount of sulphur compounds, and the blue water alkalinity. From the diagram it can be seen, that in 12 years, the alkalinity has almost quadrupled and simultaneously the amount of sulphate compounds are nearly halved. This favorable development has made the recovering process possible in the lakes, that used to suffer from the effects of acidification.

3 LAKE RESTORATION

The first lake restoration projects that were made in Finland date in the late 1960s. In the following decades, conditions have been improved or restored in numerous lakes, using an ever growing number of different methods (e.g. aeration, dredging, raising water levels and macrophyte control). By 2002, the restoration work had been carried out or planned for a nearly 800 lakes or fresh water areas (Järvienkunnostuksen historiaa, 2008).

Waters that have required restoration, have typically been shallow and small in size. Usually the goals of restoration projects have been in improving the quality of water, or in increasing the depth of the lake, so that the value for recreational use is improved. Typically, the initiative for restoration projects comes from people, who have permanent or holiday homes by a lakeshore. This happens when people realize that their opportunities to enjoy recreational activities begin to suffer, because of the problems in lakes condition (Järvien kunnostus ja hoito, 2009).

Lake restoration projects are usually rather small that do not include large scale water protection measures taken in watershed areas of lakes, such as reducing nutrient or pollutant discharges. Of course, for a lake restoration project to have any chance of success, external loads must be decreased in to a tolerable level. And so in practice the measures carried out in a watershed area and in a lake are closely linked, so that the best results with water restoration work could be achieved (Järvien kunnostuksen historiaa, 2008).

Between 1970 and 1995, methods such as aeration, macrophyte control and raising the water level were the most commonly used. In 223 projects registered from 1998 to 2002, new methods have risen to rival the old. Methods, such as dredging and biomanipulation are nowadays used alone in lake restoration projects or are combined with macrophyte control, raising the water level and aeration (Restoration methods and there use in Finland, SYKE, 2006).

Some lakes require continuous maintenance with regular treatments even after restoration work. The Purpose is to maintain the achieved condition, and to monitor for changes, that might predict turn to the worse (Järvien kunnostus ja hoito, 2009).

3.1 Problem identification and restoration demand

Problems of the lake can be divided in two main groups. The first are problems caused by external load that are mainly a result from poorly managed watershed. And the second are problems, which are caused because of internal load. Usually, the problems with internal load are an effect of former or on-going problems with external load. This has destroyed the natural balance of the lake, and created a self maintaining, gradually collapsing and problem creating system.

Restoration demand is evaluated, and the evaluation is based on the collected information of the lake, and on needs of the people who are using the lake. Through this evaluation process is created the timetable, which specifies the order of actions, from the first restoration method to be used, to the monitoring of success of the entire restoration project (Ulvi, Lakso 2005, 61 and 75).

Table 1. presents some of the most common problems and solutions in lake management and restoration.

TABLE 1. Most common lake problems and restoration actions (NALMS 2001, 102-106.)

Problem	Effect	Cause	Solution
Shallow water depth	Restricts boating and swimming	Soil erosion and flow from watershed, sedimentation	Control erosion with plants Dredging or raising water level
Turbid water	Reduces aesthetic value	Soil flow Undesired fish species	Erosion control Fishing/food chain manipulation
Taste and odor	Affect aesthetics and use as drinking water	Pollutants Bacteria Releases from watershed	Watershed management Water oxygenation or aeration
Oxygen depletion	Fishkills Odor	Eutrophication Long hydraulic residence time	Aeration or oxygenation Watershed management
Excess algae and aquatic plants	Restrict lake use Reduces aesthetic value	Nutrient releases from watershed	Watershed management Biomanipulation or removal of plant life Dredging/raising water level

3.1.1 Watershed management

A watershed is the area of land from which water drains into a given lake, pond or river. A lake reflects its watershed because the watershed contributes both the water required to maintain a lake, and the majority of the nutrients, soil and possible pollutants that enter the lake (Lake problems, 2008).

The releases coming from a watershed can be controlled by building artificial wetlands or by protective tree zones. These areas can absorb most of the nutrient overflow, pollutants and soil washed out from watershed by erosion, before they end up in a lake causing eutrophication and sedimentation. Still the key to a successful watershed management, look Figure 3 below, is to control the releases from the beginning, in other words e.g. limiting the use of fertilizer in agriculture, using plants to stop erosion and preventing polluting emissions (Ulvi, Lakso 2005, 138-148).

FIGURE 3. Generalized watershed planning process (NALMS, 2001, 168.)

3.1.2 In-lake methods

In-lake methods are used when improvements are sought for in matters such as, removing internal load, aesthetic value, water quality and volume, and value for leisure use, such as fishing and swimming. These methods can roughly be separated in three different groups, which are mechanical, chemical and biological methods.

The long term effectiveness of the in-lake techniques are highly related to the success, in which the flow of nutrients, silt, and organic matter from watershed to the lake, is controlled. Due to that, most in-lake procedures will be quickly overwhelmed by continued accumulation of these substances and all the progress gained, will be lost. Then again if efforts are just made on watershed control, it is likely, that the natural state of the lake can not be achieved unless an in-lake procedure is also used (Lake restoration / Management, 2006).

3.2 Mechanical restoration methods

Mechanical restoration is the oldest method used to improve the condition of the lake. Methods like dredging and aeration, have been used for decades, and changes in the surface level have been done even longer ago. Mechanical methods are usually quite radical and their impact in the surrounding area can be significant. Although if done properly, they have a high chance of success, and their effect is long lasting.

3.2.1 Hypolimnetic aeration

Hypolimnetic aeration/oxygenation is a method where air or oxygen is either injected directly into hypolimnium, or mixed into surface water which is then pumped into the hypolimnium. When using air, care must be taken to not supersaturate the water with nitrogen gas. Hypolimnetic aeration can result in inadequate oxygen values throughout the lake, without significant increases in hypolimnetic temperatures. It is an effective means of improving water quality and creating suitable habitat for yearlong survival of animal life (Ulvi, Lakso 2005, 157-158).

The hypolimnetic aeration may cause some negative effects by promoting some algae growth due to phosphorus activation reaction under, high oxygen and high iron, conditions. Hypolimnetic aerators need a large hypolimnium so that they work properly and also their maintenance needs extra effort, when aerators are used in harsh conditions e.g. during winter time (Ulvi, Lakso 2005, 157-158).

3.2.2 Circulation of hypolimnetic water

Different kinds of equipment, siphons, pumps etc., are used to circulate nutrient rich water from the hypolimnium. This process increases the thickness of the biologically active, trophogenic layer, and reduces inactive, tropholytic layer. Circulation reduces the nutrient and toxic amounts in the hypolimnium, and improves the level of oxygen in water layers, which are low in oxygen, or lacking it completely. The main side effect can be the increase in algae and aquatic plants due to the flow of nutrient rich water from hypolimnium. This method is usually used in relatively small, deep lakes with a suitable topography (Lake restoration / Management, 2006).

3.2.3 Dredging

Dredging, Figure 4, is a method that is used in shallow seas or fresh water areas. Its purpose is to gather up bottom sediments and other soft bottom masses, and then dispose of them at a different location (Wikipedia, 2009).

FIGURE 4. Excavator dredging (Lakeside Marine Construction, 2008)

Dredging usually is used to keep water ways navigable, or in increasing the depth of some particular area etc. a harbour. In a lake restoration project, it is most often used to increase overall depth and water volume of the lake. Dredging also diminishes the amount of aquatic plants, because their roots are also extracted. Sometimes, the aim is to decrease internal nutrient load by removing phosphorous rich part of the sediment. Occasionally, dredging has also been used to remove the toxic substances that have accumulated in the sediment (Ulvi, Lakso 2005, 213).

The main problem of dredging as a restoration method, is the use, or disposing of, the removed sediment, which can be very expensive. It can also increase the nutrient amounts in water, and as a short time effect, it causes turbidity that reduces the aesthetic value of a lake (NALMS 2001, 102-103).

3.2.4 Water management methods

There are many methods that are related with the volume control of the water in the lake. These methods are usually based on a two different kind of procedures, they either control the level of water, or they control the content of water that flows out of the lake.

The most usual water level controlling method is the raising of the surface level so, that the overall depth and water volume increases. This can diminish the amount of aquatic plants and the risk of overgrowth. This method is usually used as an alternative for dredging (Ulvi, Lakso 2005, 227). Sometimes the water level of a lake can be lowered, or the lake can even be dried, so that aquatic plants and/or sediment can be removed more easily. These water level changes are temporary and the surface is raised back to its normal level after the planed actions have been carried out (Lake restoration / Management, 2006).

Usually the out flowing water is from the surface layer of the lake that is rich in oxygen and low in nutrients. This order can be artificially changed, and the content of out flowing water can be regulated by pumping water from hypolimnium. Then the outflow is either partially or totally of hypolimnetic water. Thus, it is possible to remove nutrients, and simultaneously improve the oxygen level in the deepest part of the lake (Ulvi, Lakso 2005, 203).

3.3 Chemical restoration methods

There are an increasingly wide range of chemicals at the market, which can be used in an in-lake restoration. Chemicals may vary, but usually they are used to bind nutrients or other undesired substances, and form with them such compounds that are either less harmful, or make nutrients unavailable for e.g. aquatic plants. Some of the latest chemicals are also used to replace mechanical oxygenation, because their reaction with water releases oxygen.

3.3.1 Phosphorus chemical precipitation

Iron, aluminum and calcium have salts that can combine with, or absorb, phosphorus and remove phosphorus-containing particulate matter from the water column as part of a floc (Lake restoration / Management, 2006.) Because of this property, they are all used in tha lake rastoration.

Aluminum salts are the most often used, because they can bind phosphorus tightly over a wide range of ecological conditions, including in low or zero dissolved oxygen. Aluminum can also produce a layer, if enough alum is added that will cover the sediments, and significantly diminish the release of phosphorus into the water as an internal load. With the use of aluminum salts, reduction in phosphorus amounts has been between 50-77%. The down side in the aluminum use is its acidifying effect, and its toxicity to fish in lower pH-values (Metsätalous ja vesistöjen kunnostaminen, 2001, 40-41).

Iron and ferrosulphate have also been used in precipitation of phosphorus, but the main problem in their use is their oxygen demand. That is because all reactions between iron and phosphorus require oxygen. Hence, the use of iron salts is impossible in lakes that are badly contaminated and/or suffering of oxygen depletion. Reduction level achieved with the use of iron salts has been between 50-85% (Metsätalous ja vesistöjen kunnostaminen, 2001, 40-41).

Either chemical above, can not create a permanent state of condition, and so the treatment has to be repeated. For example, when using iron salts, the treatment has to be renewed after 3-5 years (Metsätalous ja vesistöjen kunnostaminen, 2001, 40-41).

3.3.2 Liming

Chalking or liming is used to elevate the pH-level of the water, and prevent harmful effects of the acidification. Chalk or chalkstone ($CaCO_3$, calcium carbonate) is the most commonly used chemical for neutralization. The process, also shown in Figure 5., is easy to handle, and chalk is safe to use in workers point of view, as well as for lake-ecosystem, because even large amounts do not raise pH in to a harmful levels. Lime is also relatively cheap, and usually easy to obtain and transport (Ulvi, Lakso 2005, 277).

Liming of the lake alters many of the biotic properties in the lake. Alkalinity, pH and conductivity will rise, and then again, water will loose transparency and metal concentration amounts will decrease. The overall concentration of the phosporus becomes more stable, and after initial adjustment, diversity of species, biomass and primary production, will increase (Restoring and Protecting the World's Lakes and reservoirs, 1995, 75).

FIGURE 5. Liming ponds for aquaculture (SRAC, 2002)

3.3.3 Gypsum treatment

Gypsum treatment is, still more or less, an experimental restoration method that is usually used to complement other procedures. It seems to work only in relatively deep, but still small lakes, that suffer water quality problems. Generally, these are a result of internal load, that causes anoxic conditions in hypolimnium (Ulvi, Lakso 2005, 309).

Treating sediment with gypsum, limits simultaneously many factors that are related with internal load. Gypsum stabilizes sediment by creating a layer on top of it. This layer limits gas releases, and mixing of organic matter and nutrients. Because of that, sediments oxygen demand decreases, and oxygen level raises in the surface layer of the sediment and also in hypolimnium. Gypsum treatment also precipitates phosphorus (Ulvi, Lakso 2005, 309).

3.3.4 Sediment covers

Clay can be used to create a layer that prevents the releases from the sediment. Clay cover is estimated to be effective, when it is 5-10cm thick, and when the sediment is chemically treated before it. Benefits of this procedure are similar to the gypsum treatment mentioned before (Ulvi, Lakso 2005, 317).

Sediment covers can also be used to stop plant growth. Usually these covers are made of plastic based textiles or membranes, that create a barrier from which the plants can not grow through. Due to the high cost of these covers, they are only used in small areas such as dock spaces and swimming beaches (Lake restoration / Management, 2006).

3.3.5 Chemical oxygenation

Inorganic peroxides can be used as a slow oxygen release agent. Usually, they are in powder form, but some manufacturers also make them compressed in granules, briquettes, flakes etc. These more coarsely formed peroxides sink more easily to the bottom, and due to that, they release the oxygen where it is needed. Peroxides react slowly in contact with water and generate oxygen and heat. The amount and speed of gaseous oxygen generation is related with the physical and chemical properties of the surrounding water such as temperature and pH (Patentdocs, 2009).

$$2\ CaO_2 + 2\ H_2O \rightarrow 2\ Ca(OH)_2 + O_2\ (g)$$

$$2\ MgO_2 + 2\ H_2O \rightarrow 2\ Mg(OH)_2 + O_2\ (g)$$

The greatest benefit of the chemical oxygenation is the fact that it does not require mixing of the water, which would bring nutrients to the surface, and encourage the formation and growth of algae and aquatic plants. They are also quite safe to use, because decomposed peroxides form oxides, hydroxides or carbonates, are all substances which exist in the nature and which have no negative/significant influence on the environment (Solvay Inorganic Peroxides, 2008).

3.4 Biological restoration methods

These methods can be said to have two main objectives. Their purpose is either to remove excess nutrients from aquatic system by removing biomass or they can be aimed in improving the structure of food chain in the lake. Usually biological methods are used together with other in-lake methods so that the changes e.g. in nutrient circulation and fish community can be repaired.

3.4.1 Biomanipulation

Biomanipulation, or in other words food web (/chain) remediation, is a process in which the balance between plantivores and piscivores is altered. A typical food chain is presented in Figure 6. Usually this is done by fishing plantivorous fishes, in Finland usually roach, and/or planting more piscivorous fishes (Metsätalous ja vesistöjen kunnostaminen, 2001, 42-43).

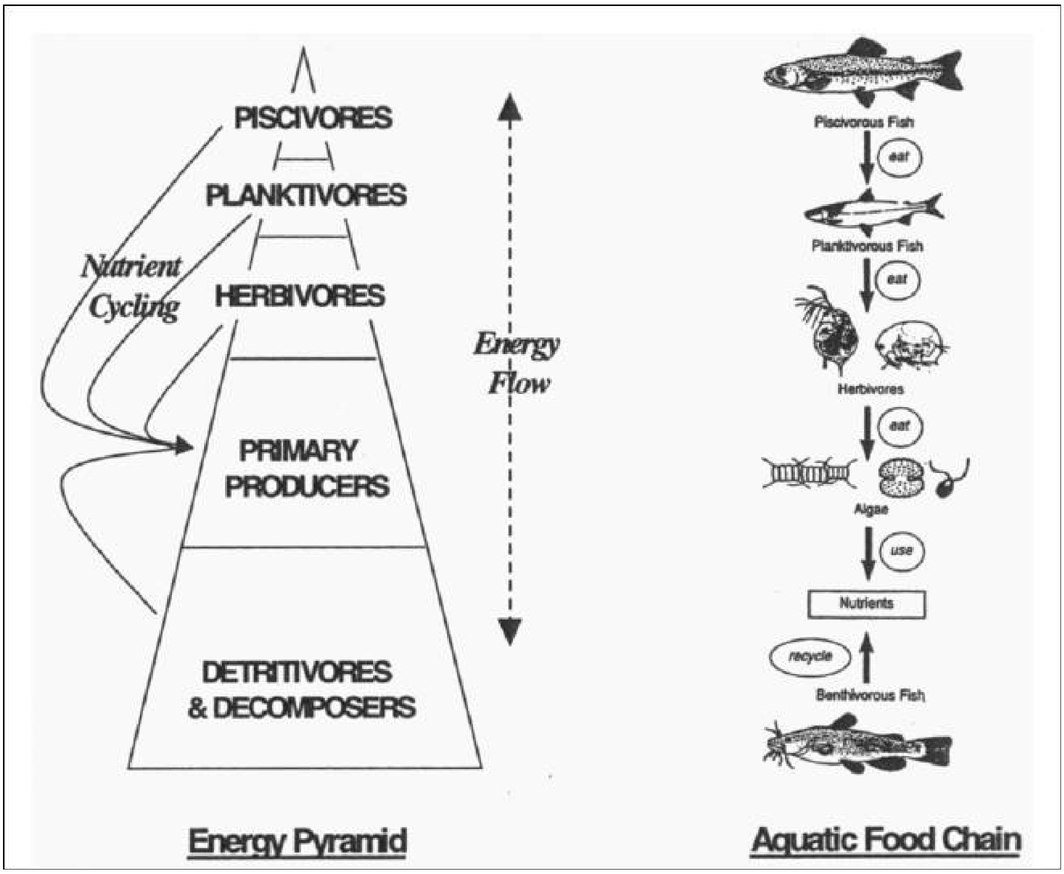

FIGURE 6. Lakes food chain (NALMS, 2001, 39)

Biomanipulation is a suitable method for those lakes that have an eutrophication problem even after the amount of external load has been decreased. Eutrophication is maintained in this kind of a lake by high level of internal load. One reason for this is changes in food chain structure and interactions. When biomanipulation is successfully done, the fish communitys structure and water quality slowly normalizes. Then the recreational value of the lake rises, because conditions make activities like fishing and swimming possible (Ulvi, Lakso, 2005, 169).

3.4.2 Removal of aquatic plants/weeds

Aquatic plants (macrophytes) are a vital part of the lake, because they provide cover, habitat and sometimes food for fish, and the organisms that fish eat. However, too many rooted and floating plants can limit, not only leisure activities and aesthetic appreciation, but excessive plant growth, like shown in Figure7., can also physically prevent the mixing of oxygen into the water, which can cause oxygen depletion. Also when plants die, they can introduce significant quantities of nutrients and organic matter back into the water, stimulating algal blooms and raising oxygen consumption (Ulvi, Lakso, 2005, 249).

Figure 7. Excessive aquatic plant growth due to eutrophication (Robert Thompson, 2005.)

Advantages gained from the removing of extra plants are quite simple. Less plants means, better aeration, less biomass and less biomass based nutrients, especially phosphorus. Also aesthetic and recreational value of the lake improves, because free surface area is increased (Metsätalous ja vesistöjen kunnostaminen, 2001, 70).

3.5 Benefits of lake restoration

The benefits from improving or restoring the lake in its original state, has usually been evaluated through the needs that the lake users have and how the better condition meets them. Usually these needs have been related to peoples will to perform recreational activities, such as swimming and fishing.

Research made and published in 2008 by Heini Ahtiainen concentrated in financial value of lake restoration. Lake Hiidenvesi was used as an example when this research was made. The financial benefit was not estimated by calculating how much the value of land property and lake side estates would rise due to restoration, but instead, how much owners of those properties and users of the lake would be willing to pay to get the lake restored (Ahtiainen, 2008, 9-10).

A query was made to find out the households will to pay for a lake restoration. Questionnaire was send to a total 1900 households, of which 903 answered the query. Results are quite hard to interpret without any biased assumption, but they show, that amount of money for restoration for five year period varies between 660000 - 7700000 €. So the payment per month for one household would be between 0.34 – 4.54 €. These figures are only estimates and so the sum in reality is probably in the middle, because after all, the query could not reach all reference groups and people involved. Besides it is probale, that after some positive results due to restoration, the people that are at this moment hesitant or skeptic, would be willing to participate financially (Ahtiainen, 2008, 55-56).

3.6 Funding of lake restoration projects

Lake restoration projects require a lot of planning and investigating, before the restoration work itself can be started. The whole process requires different professionals, a huge number of working ours and especially money. The funding and the funding sources must also be defined in the very beginning, so that the restoration project could succeed. This makes it possible to carry out planning in realistic way, in which all the decisions made can be transferred in to action. The money is usually the limiting factor which in the end decides what methods and restoration companies can be afford to use.

The most common funding sources are government, towns and the EU. Other funding sources are different kinds of development projects e.g. ALMA, TE-keskus and Regional Environment Centers. Usually public funding has four requirements:

1. Restoration project has a significant public impact and demand.
2. Costs are moderate and the benefits of the project are considerably greater than drawbacks.
3. Project has strong local support and people are active about it.
4. Project fulfills all the criteria that different funding sources require.

A notable fact is that all public funding sources demand some amount of local funding e.g. from land owners, cottage owners etc. Usually the amount of local funding is 30%, but it is good to remember that voluntary work is accepted as a part of it (Lounais-Suomen järvikunnostusopas, 2003).

TABLE 2. Costs of most common restoration methods (Airaksinen, 2004, 61)

Restoration method	Costs	Repetition need in 10 year period
Aeration	54-184 €/ha/a	3-10
Removal of aquatic plants	92-540 €/ha/a	1-3
Biomanipulation	36-810 €/ha/a	2-4
Dredging	5400-22000 €/ha	1
Raising of water level	9200-54000 €/ha	1
Phosphorus precipitation	54-184 €/ha/a	3

Table 2. presents the prices of the most commonly used restoration methods in Finland. The 2002 costs have been modified with inflation index, 8%, to match the costs in 2009 (Statistics Finland, 2009.)

The usual costs for one lake restoration project have been ca 200000 €/a, but only projects magnitude decides the final costs. A good example is Kosteikko Life-project, 2001-2006, which included 11 different areas that were restored. The cost of the whole project was 1,6 M€ and half of the funding was done by EU’s Life Nature fund and another half by national sources. Project was a part of Natura 2000 ,nature conservation program (Kosteikko Life 2001-2006, 2008).

A comparison between the different methods is useless because every project is unique, with special demands and expectations. The first thing is to define the problem and the possible solutions, and then, how all of it is going to be funded. Third thing is the choosing of the methods, and last but not least, is the surveillance and maintenance. Some things like biomanipulation can be done with voluntary work and thus the costs are low, but if the restoration project needs more sophisticated methods, it is advisable to use consults. Money can also be saved by tendering restoration companies and then signing a contract in which, all costs, results and surveillance measurements are specified into the smallest detail. This guarantees that you get what you are buying, not just sales speeches and great promises of improvement.

3.7 Legislation concerning restoration methods

Practically projects that can be considered to be significant, require a permit from the Regional Environment Centre. Smaller projects can be done, when approval concerning the project has been received from landowner(s), neighbor(s) and/or other reference group(s). Still, when starting a restoration project, how ever small, it is required to notify the authorities before and after the actual work is done. If the project is to be carried out in an area, that is part of Natura 2000 network, or has been suggested as a part of it, it is wise to contact authorities at a very early stage, and usually try to get them involved in the project. This is because such areas are under special legislation and permits can be hard to get or at least take a long time (Ulvi, Lakso, 2005, 93).

A new law concerning water conservation was enacted in 30th of December 2004. Law is named “Laki Vesienhoidon järjestämisestä” which translates as an “Act on Water Resource Management”. This law is a part of an act, in which the national legislation is modified, so that it responds better in to the EU directive given in 2000. The law enacts, among other things, about matters that concern the categorizing of the water areas, and goals for the their overall condition. It also enacts about the defining of the factors which have an affect on the condition of

water, what responsibilities different authorities have, and how the planning on water conservation is to be carried out. The goal of this law, and the directive that it is based on, is to ensure that all waters can be categorized to be in a good condition by year 2015 (Ympäristöministeriö, 2004).
The original law text can be read on FINLEX web page:
http://www.finlex.fi/fi/laki/alkup/2004/20041299

TABLE 3. Requirement of approvals and permits concerning different restoration methods, x = required, (x) = required in some cases (Ulvi, Lakso, 2005, 97)

Restoration Method	Approval	Permit
Aeration	x	(x)
Biomanipulation	x	
Phosphorus precipitation	x	x
Removal of hypolimnetic water	(x)	x
Dredging	(x)	x
Raising of water level	x	x
Removal of aquatic plants	x	(x)
Neutralization	x	(x)
Gypsum treatment	x	(x)
Sediment cover (clay)	(x)	x
Water level management methods	x	x

Table 3. shows some of the most common restoration methods and their requirement for, reference groups approvals, and permits from authorities. Principally all restoration projects are good to be made in co-operation with authorities and the people, that it has an affect on. This ensures that mistakes can be avoided, and all unfortunate surprises can be anticipated and dealt with.

4 MATERIALS AND METHODS

4.1 Study sites

Ponds used in this study are located in southern Finland, near the town of Lohja. Both are artificial and they were originally made for crayfish growing.

The experiment pond, in which the calcium peroxide ($Ca0_2$) addition was made, has a surface area of ca. 2500m^2 and an average depth of 1,5 meters. And so, the estimated water volume is about 3700-3800m^3. The pond used as control site, has approximately same amount of surface area, but the average depth is 2.5 meters, which gives a water capacity of about 6200-6300m^3.

Both ponds have a tendency to suffer from an oxygen depletion during winter times, when ice covers the surface. Situation is worse in the experiment pond, because of its shallower composition. These anoxic conditions make it almost impossible, that either pond can support higher life, (fish, crayfish,) over a winter.

4.2 Experiment setup

Calcium peroxide, (CaO_2, *IXPER* 75C®) with an amount of 50 g/m^2 , was spread in to the pond used in this experiment, and so the total amount was ca. 125kg. Theoretical amount of the released oxygen from this amount of CaO_2, is 21kg of gaseous oxygen, which could raise the oxygen amount of the water by 5.5 mg/l.

The distribution of calcium peroxide was done manually, and as evenly as possible, from a rowing boat. The used calcium peroxide was in a granule form, so that it would easily settle to the bottom of the pond, and thus come into a direct contact with the sediment.

After this, parameters such as pH, oxygen level etc, were measured from the pond through the experiment time. Received values were compared with the values from the control pond, where the same measurements were made to determine the effect, what CaO_2 addition caused.

4.2.1 Calcium peroxide

Calcium peroxide (CaO_2) is a solid peroxide with a white or yellowish color. When in contact with water, calcium peroxide starts slowly release oxygen as it breaks down into calcium hydroxide, oxygen and water.

$$2CaO_2 + 2H_2O \Rightarrow 2\,Ca\,(OH)_2 + O_2$$

As an example, calcium peroxide (CaO_2) has been used as a slow oxygen release agent for bioremediation, when polluted sediments have been treated. Sediments were collected from intensive shrimp farms containing high organic carbon, nitrogen and phosphorus. Experiments with sediment treatment were carried out, with and without CaO_2 addition. In the sediment treated with calcium peroxide, amounts of organic-C, organic-N and organic-P decreased, in order, up to 95%, 17.6% and 75%. As in comparison decrease was 66%, 8.6% and 57% in the controlled treatment without CaO_2. Research indicates that the addition of CaO_2 could boost the degradation of organic-C, organic-N and organic-P in sediment treatment (Hanh, Rajbhandari, Annachhatre, 2005).

Risk in using CaO_2 is the fact that it changes the pH of the water, usually in the range of 10 to 12. Shifts to high pH conditions have usually a negative effect on fishes, bacteria etc., but depending on the alkalinity of the water as a buffering capacity, the pH shifts may be totally or partially neutralized (Shangyuchem, 2008).

4.2.2 IXPER 75C

The *IXPER* 75C® used in this study, has approximately 75% of calcium peroxide out of total mass, and it can release 16.6% of oxygen from its mass. It has pH of approx. 12 and it weighs ca 600 kg/m^3 (Solvay S.A, 2008).

Calcium peroxide is considered as an ecologically pure substance, and because of that, it is easy to use in the aquaculture industry to oxygenate and disinfect water. It can also be used in the ecological restoration, for example in the treatment of soils and sediments (Solvay S.A, 2009).

4.3 Sample collecting and treatment

Three spots were chosen from both ponds, that worked as sample taking places through the study. One was located in the deepest place (sample spot1) of the pond, and the other two so, that the three spots together formed a letter L. Water samples were also taken from a rivulet leading out of the experiment pond, until it was completely frozen.

Samples were taken over winter time, between 29.10.2008 and 6.3.2009. The first samples were taken before $Ca0_2$ addition, and the second ones approximately one hour after it. Three weeks from the beginning of the experiment, samples were collected weekly from the experiment pond and once in every two weeks from the control pond. After that, the sample taking interval was first increased in two weeks, then to three, and final interval was four weeks, depending on weather and ice conditions.

Water samples were taken from the surface water, because of the relatively small average depth in both ponds. In situ, during every sample taking, values of water oxygen level, temperature, pH and conductivity (REDOX) were measured with field measuring devices. Above values were measured, from the bottom, ca. 10cm up from the bottom and from the surface of the water. Measured parameters from water samples were: total nitrogen, total phosphorus, ammonium, nitrate, phosphate, calcium and alkalinity.

Sediment samples were collected at the same days as water samples, just after the collecting of the water samples. Samples were taken with Ekman bottom corer. The measured parameters from the sediment samples were pH, conductivity and microbial activity (CFU). The dry mass and the amount of organic matter were also determined.

4.4 Sample treatment

4.4.1 Nutrient determination

The nutrient (total N, total P, NH_4^+, NO_3^- and PO_4^{3-}) amounts were determined from water samples, that were first filtered through glass fiber filter paper (GF/A, 1820-047, Whatman), and then conserved by adding 1% of HCl (concentration 38 weight-%), in to the filtered water sample. Conserved samples were frozen for further treatment.

When adequate amount of samples were collected, storaged samples were melted and they were put through a lachat-analysis (Lachat Quickhem 8000), in which the amounts of different nutrients were determined.

4.4.2 Calcium determination

Collected water samples for calcium determination were frozen, until they were measured by atomic emission spectroscopy (AES). Measuring was done with Thermo Electron Corporation Solaar Series AAS spectrometer, that was used in AES mode.

Collected water samples were diluted in half with ultra pure water, and lanthanum was used as matrix modifier. Calibration was done with Ca-solutions that had 0 (or blank), 1, 2, 4, 6 and 8 mg Ca/l. As a control, solutions of 3 and 5 mg Ca/l were used. Also a sample taken from Likolampi, and whose Ca concentration was determined by Ramboll Analytics Oy, using ICP-OES machinery and RA3001 method, was used as a control sample. Uncertainty of measurement was calculated by measuring a series of blank samples, and from those, it was possible to determine an average value and also the +/- % variation between samples. Solutions and standards were made as explained in instructions from Norsk institutt for luftforskning (NILU 2008)**.**

4.4.3 Water alkalinity

Water alkalinity was measured by using SFS 3005 standard. Titration was done with a 20 mmol Hcl/l-solution. Other volumes and solutions were made according to standard.

4.4.4 Microbial activity

Microbial activity was measured by making a dilution series from the sediment. Petri dishes were inoculated with dilutions and the final dilutions on plates were 10^{-2}, 10^{-4} and 10^{-6}. 1/5 TGY (0.5g tryptone, 0.1g glucose, 0.25g yeast extract, 7.5g agar and 500ml purified water) with sykloheksimid addition (0.025g/500ml) was used as a growth medium. Cultivated dishes were incubated in room temperature for 3 or 4 days, depending on the growth speed and the amount of colony forming units (CFU). After the incubation time the CFU's were calculated and results presented as CFU/ g of dry mass.
PH and conductivity were also measured at same time with a field measuring device.

4.4.5 Dry weight and organic matter

Dry weight and organic matter were measured by using SFS 3008 standard. First the sediment samples were dried in an oven in 105 degrees Celsius over a night, and then they were weighted so that the amount of vaporized water could be measured. After that the dried samples were burned in an oven, in 550 degrees Celsius, for two hours. Then they were weighted again to determine the amount of organic matter that had burned away.

5 RESULTS

The following results are from the samples collected between 29th of October 2008 and 6th of March 2009, which means that the total duration of this study was ca 16 weeks. The nutrient results make an exception, because they were only included for 12 weeks of the study. When viewing the results, it is important to know that both ponds were frozen during study week 6 and stayed so till the end of the study.

5.1 Quantity of aerobic bacteria in the sediment

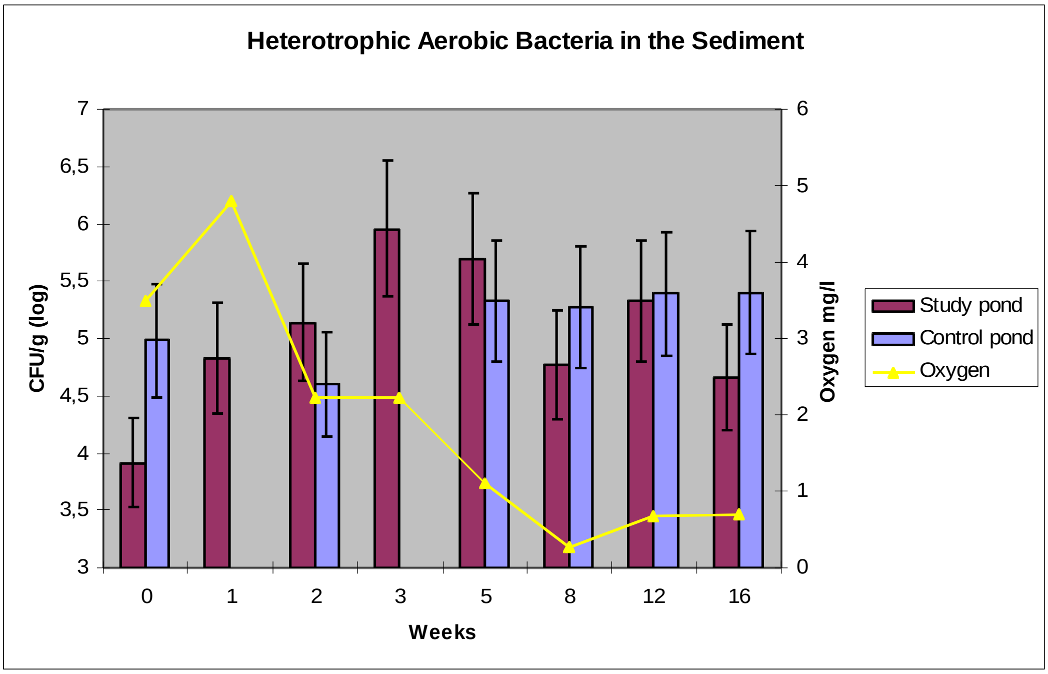

FIGURE 8. Heterotrophic aerobic bacteria in the sediment

Figure 8. shows the development of the bacteria quantity in a sediment in the samples from the deepest part of both ponds used in this study, also the +/-10% error margin is shown. These samples were chosen because the quality of the sediment samples collected from those spots was most homogenous. The oxygen displayed in the graph is the average oxygen value in the bottom of the study pond and so it does not have any effect on the bacteria quantity in the control pond. The

value was measured at a same time when the sediment samples were taken. Noticeable is the fact that bacteria quantity is considerably higher now than it was in the beginning of the experiment, even though it has decreased from peek values. On the other hand, the oxygenating effect of the calcium peroxide does not show in the oxygen level. The most probable reason for this is the fact that extra oxygen, that calcium peroxide provided, is used in bacteria growth and metabolism.

5.2 Amount of organic matter in sediment

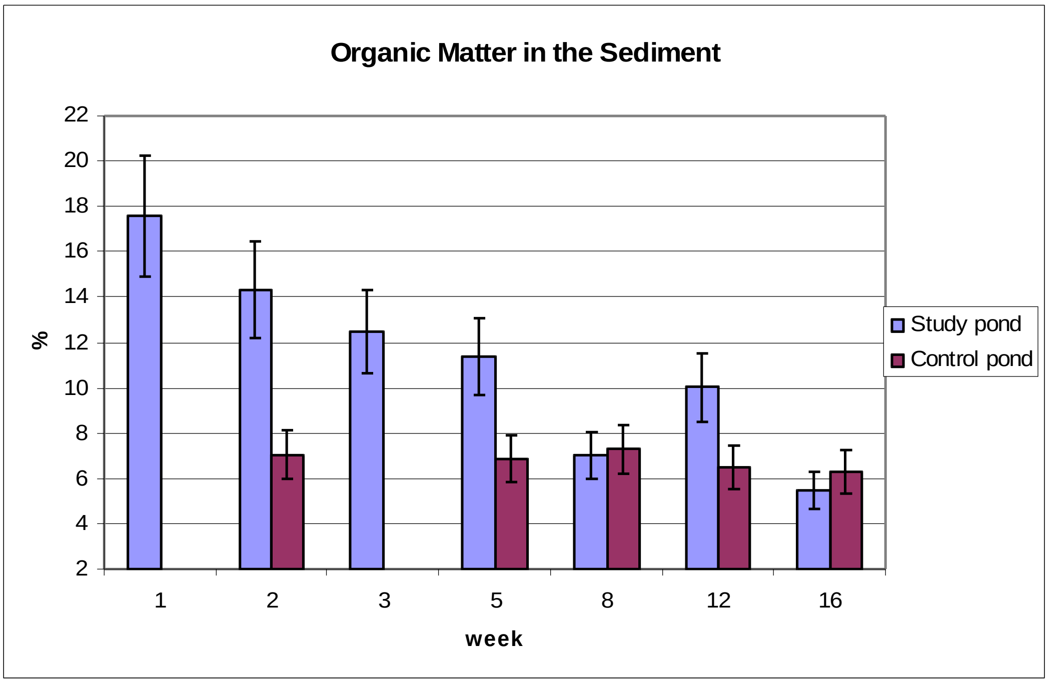

FIGURE 9. Organic matter in the sediment

Figure 9 presents how the amount of organic matter in the sediment developed during the study period. The organic matter amount presented in the graph is the average value of all three sample spots and has a +/- 15% error margin, as shown in graph. As can be seen, the amount of organic matter has decreased in study pond, and it is in week 16 just about one third of the amount that it was in the beginning of the study. At same time, the amount in the control pond has stayed at an approximately same level. The decrease in the study pond can be explained by the increase of bacteria presented in Figure 8.

5.3 Oxygen levels

The following three graphs, Figures 10, 11 and 12, present the average oxygen level with +/- 15% error margin, in all three sample spots. As mentioned earlier, the oxygen level was measured from the bottom, 10 cm up from the bottom and from the surface. The graphs are in the same order, so that the comparison would be easier.

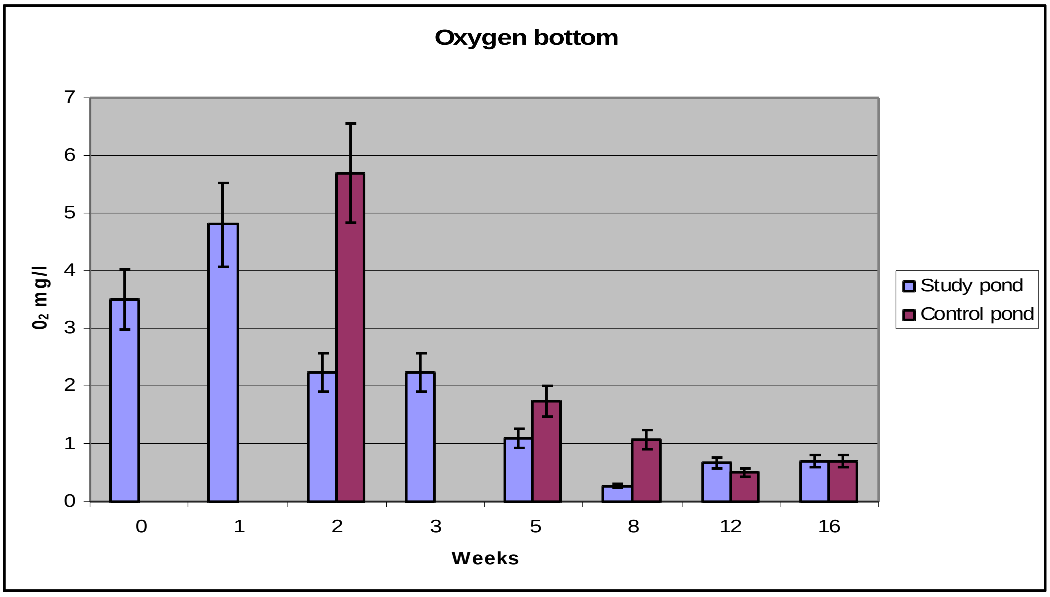

FIGURE 10. Oxygen level at the bottom of ponds

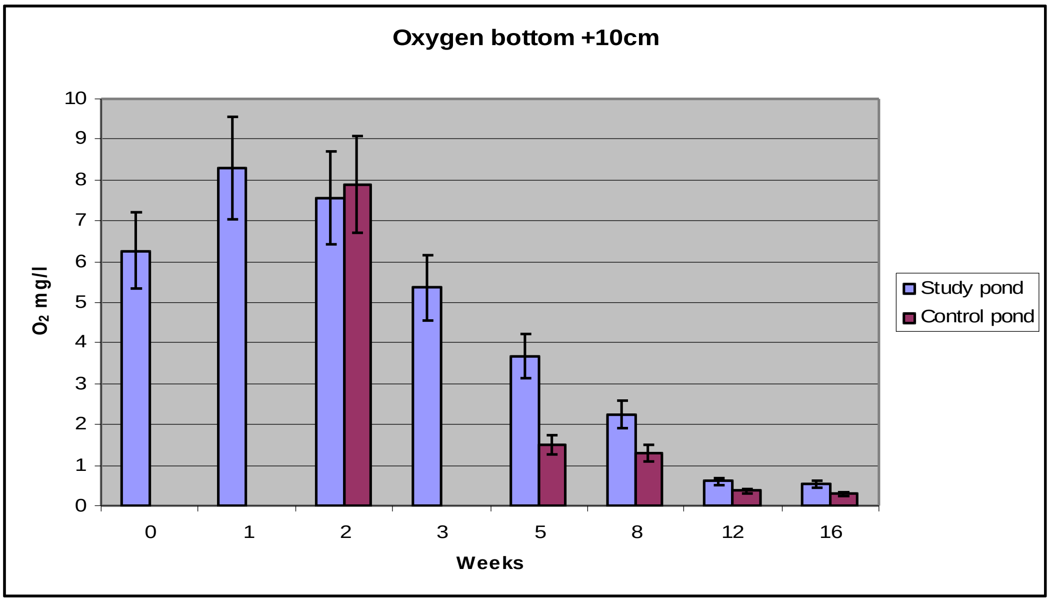

FIGURE 11. Oxygen level 10cm up from bottom

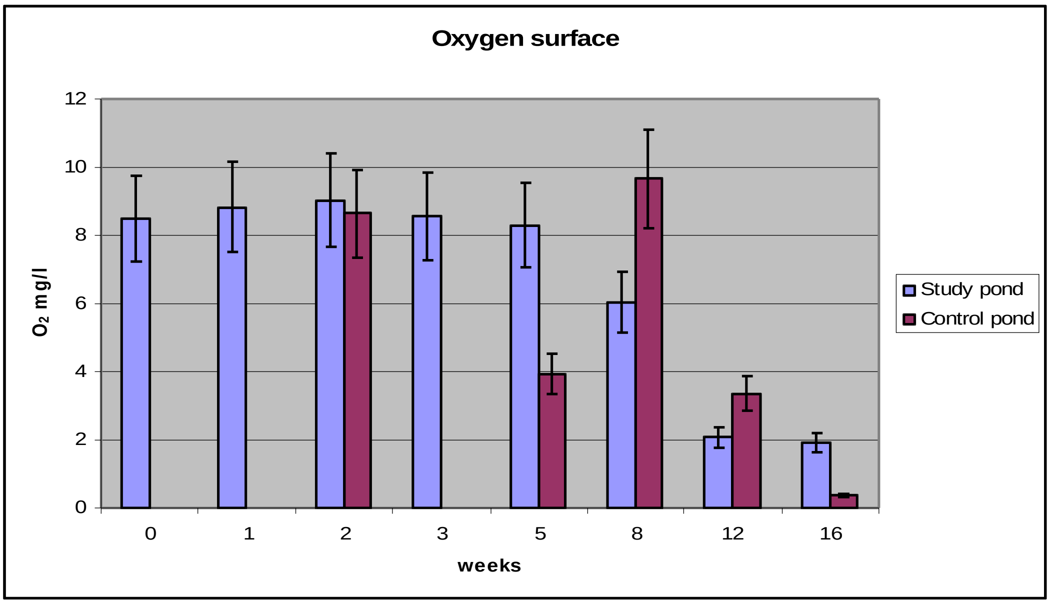

FIGURE 12. Oxygen level at surface

As shown in Figures 10, 11 and 12, the calcium peroxide addition can not be said to have any significant effect on the oxygen level in the study pond. With an exception in week 1 when a small increase in the oxygen levels at the bottom and 10cm up from the bottom can be noticed. Without that exception, the oxygen levels at the bottom of the study pond are slightly lower than in the control pond. On the other hand, the situation is the other way around in the oxygen levels 10 cm up from the bottom. It is surprising that the oxygen level starts to decrease near the bottom, between weeks 2 and 5, in both ponds. In the study pond this can be explained with increasing microbial activity, but that is not the case in the control pond. One explanation can be thermocline which isolates bottom water, and without mixing the water, the oxygen level in hypolimnium falls, due to bacterial activity (Särkkä, 1996, 52.) If the situationis similar in the study pond, one might ask, how much of the oxygen loss can be explained with increasing bacterial activity, and how much with thermocline. The oxygen level in the surface water is rather stable, and the decreasing that begins between weeks 5 and 8 can be explained by the freezing of the pond in study week 6.

5.4 Nutrient levels

Figure 13 below presents the amounts of total phosphorus in water samples with error marginal +/- 9%. Phosphorus is a nutrient which is usually the factor that limits growth in an aquatic system. Because of that and its short turnover time, phosphorus is used very efficiently in water ecosystem. The results show that the amount of phosphorus, has decreased in the study pond as well as in the control pond, during the study period. Even the fact that the bottom has been almost without oxygen, has not raised the phosphorus amount. That is unusual, because usually the anoxic conditions free phosphorus from sediment, in its water soluble form. Then again the same process also enhances bacterial activity, which could explain, why the amount of the phosphorus in the water has not increased, and also why the oxygen level has stayed low (Särkkä, 1996, 64-66).

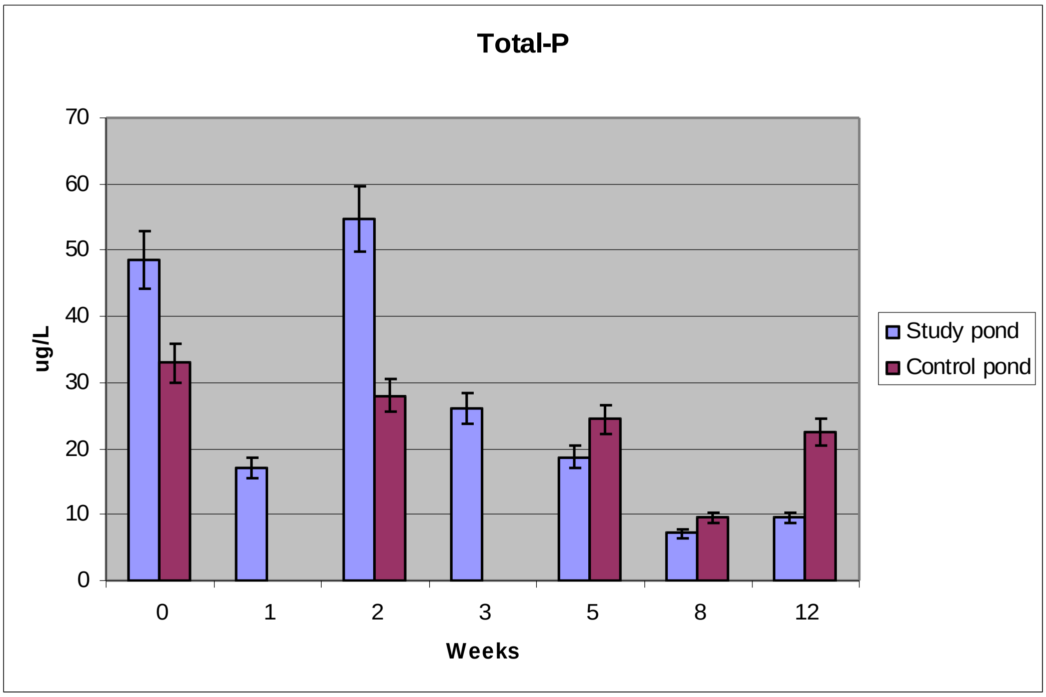

FIGURE 13. Total phosphorus in water samples

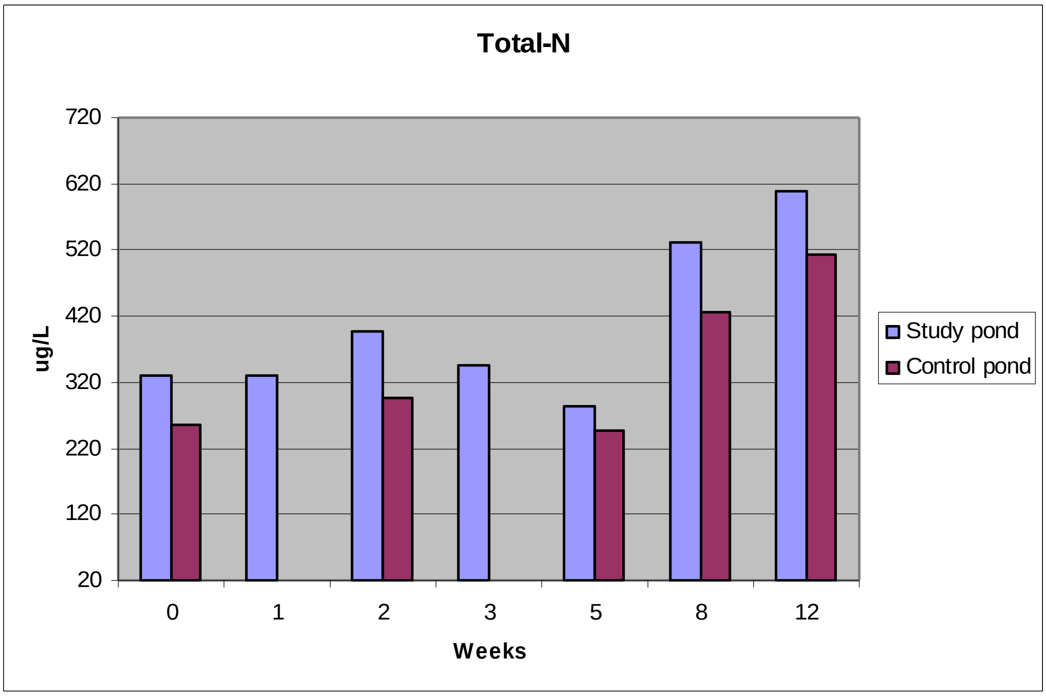

FIGURE 14. Total nitrogen in water samples

The results in Figure 14 show that the nitrogen concentration in both ponds remains stable, until it begins to rise after week 5. This indicates that the freezing of the ponds in the week 6, has an effect on it. There are two probable reasons for the increasing nitrogen amount. First is the fact that freezing of the pond reduces biological activity, which decreases nitrogen demand. The second reason is the ice, which prevents the gaseous nitrogen's evaporation to atmosphere. Gaseous nitrogen is created at the bottom in an anoxic conditions through reduction reaction, in which the nitrate is reduced to nitrogen gas. Increasing amount of gaseous nitrogen in the water would also explain, why the total nitrogen amount rises, and still the amounts of nitrate and ammonium stay low (Särkkä, 1996, 66-68).

Phosphate, ammonium and nitrate were also measured from water samples. The amounts of ammonium and phosphate were, with a few exceptions, under the detection limit. Then again, both are the most preferable sources for the nitrogen, and the phosphorus for microbes, which would explain their absence in water. In the beginning of study, the amount of the nitrate was also under the detection limit, but after week 5 the amount started to increase, and, in the end of the study, it was approximately 40µg/l, which is still under the average amount of 92µg of nitrate per liter in Finnish lakes.

The results concerning the nutrient levels were also viewed by Anne Ojala, PhD, who is specialized in limnology of boreal lakes. Ojala works for the University of Helsinki at the Department of Ecological and Environmental Sciences. Her opinion was that the nutrient results in this study represented normal, average values and the few spike values are probably caused by measurement errors or samples that are collected from a so called hot spot.

5.5 Calcium in water samples

Figure 15 shows the results of calcium determination and +/- 10% error margin is shown. The results indicate that the amounts of the calcium begin to increase, after stable beginning, between weeks 5 and 8. The most probable reason for this, is the carbon dioxide, which is generated by the bacterial activity. CO_2 can not vaporize in to the atmosphere, because of the ice, and so it begins to dissolve the calcium in the soil and in the sediment (Särkkä, 1996, 57-58).

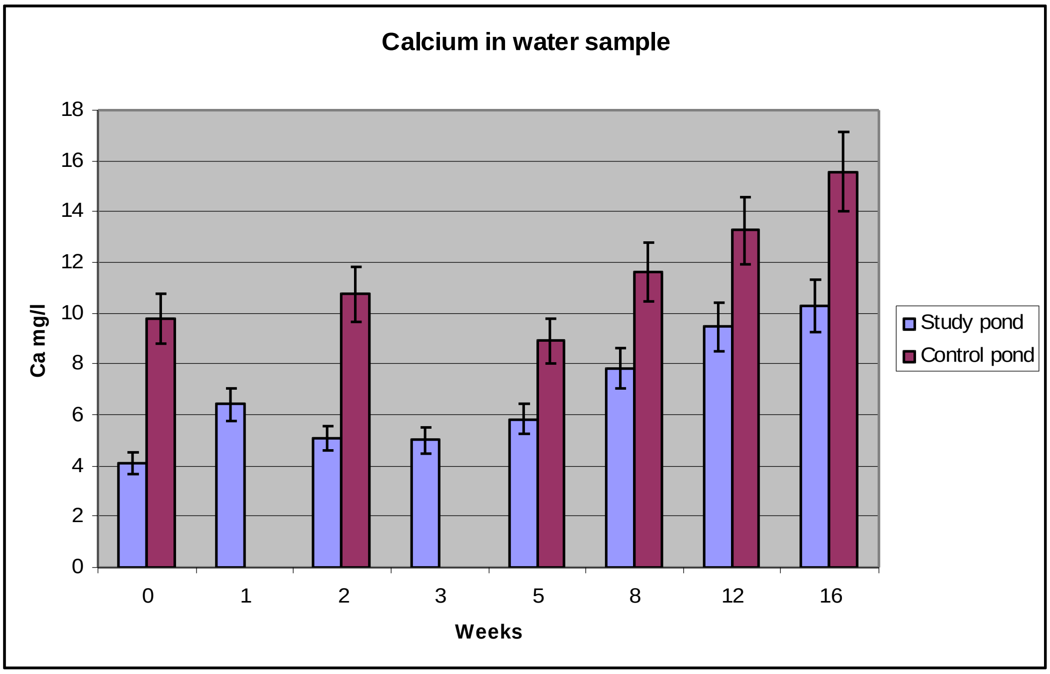

FIGURE 15. Calcium amount in water samples

5.6 Other measured parameters

Temperature, conductivity, alkalinity and pH were also among the measured factors. The main purpose of the alkalinity and the Ph measurements were to provide information about the calcium peroxides effect on the buffer capacity of the pond. As mentioned earlier, the use of the calcium peroxide can cause a rise in pH, and, at the same time eliminate the alkalinity as buffer capacity. Such change did not happen in the study pond and values stayed stable, pH between ca 6-7 and the alkalinity between 1.0-0.6 mmol/l. Conductivity and temperature were parameters that gave information about the overall condition of the bond and its water. They could have also offered clarification, if some radical changes would have happened.

6 CONCLUSIONS

The results clearly indicate that due to the released oxygen, the amount of bacteria increased significantly. The decrease of the organic matter was almost 66% from the value that was measured in the beginning of the experiment. This is a result that can be considered to be the best indicator, which shows the effectiveness of the calcium peroxide as a chemical restoration method. The problem is that even though oxygen was apparentaly released, it was rapidly used by the bacteria and their metabolism as they multiplied and degraded the organic matter. Thus, the amount of dissolved oxygen did not increase in the hypolimnium, which would have been a preferable result when concentrating on the pond's financial value for grayfish growing.

The problem with the organic matter is difficult to solve, because as long as even some of it exists, the oxygen released from CaO_2 is consumed totally or partly in its degrading. Although it is probable that if the treatments were repeated, the overall oxygen level in the hypolimnium will eventually start to rice. The removal of the sediment, or at least its top layer, were the most of the organic matter is, would speed up the process considerably. The problem is that the use of dredging, would remove the benefits that can be considered to be this methods greatest advantages; no mixing or treating of water and sediment needed. And so, the solution, if the addition of the calcium peroxide would be kept as the only restoration method, would be in increasing the addition to 100-150 g per square meter or in repetition of the treatment. Both alternatives have their limits. The amount of the added calcium peroxide must be kept below the levels where radical changes start to happen. Finding that level would require further studies, so that things like, the effects of a large addition of the CaO_2 could cause, and how negative the effects are, could be answered. With repetition, the problem would be very much similar. Although with the data from this study, it could be possible to give an estimate on, how many times the treatment should be renewed, so that the amount of the organic matter would be low enough that the oxygen released from calcium peroxide would start to show as a rising oxygen level in the hypolimnium.

Calcium peroxide might also be used with the mechanical oxygenation to insure, that the degrading of the organic matter by bacteria would not affect the fish life near the bottom. Calcium peroxide could also be a formidable alternative for the treating of the organic matter rich sediment in a cases where methods, like the dredging, are not possible.

One question to consider is, what are the effects that aquatic plants, currents etc. might have when distributing CaO_2 in a lake or a pond. This is because they might prevent the calcium peroxide granules sinking to bottom or could move them from the area to be treated. In that case the oxygen would not be released there, where it is needed.

Removing the aquatic plants would be the easiest answer, at least in such a pond as used in this experiment. But when using calcium peroxide in a lake that has a large area to be treated and depth of 10 meters or more, bigger and heavier granules could be easier to distribute. They would sink more certainly and also be more immune to the effects of the currents, if such exist, which might float the lighter granules away like snow flakes. The downside is the fact that the same mass would be spread in a fewer spots and so the coverage would not be as good. But then again, the dissolving would take more time and so the oxygenating effect would be longer. Calcium peroxide could also be packed into bags, that could be lowered to the bottom and lifted up when all the CaO_2 is dissolved. Or the bags could be biodegradable. The problem is again how to compensate the lost coverage. A compromise solution between weight and size versus coverage would be worth solving.

Last but not least, is the question, if the pond used in this study is a lost cause, did it affect a good experiment with the fact, that without radical actions the ponds capability to sustain life is impossible. The problem with the pond is its average depth, 1.5m, which is too little if a really cold and long winter occurs. The ponds current problems are a result of such a winter, when it was almost frozen solid, and all the crayfish and fish died. When that happened, it led into an increase of biomass and nutrients. Those nutrients enhanced the growth of the aquatic plants that are now filling the pond. And now every year when the plants die, the biomass increases, and the cycle of the growing internal load continues and accelerates.

Like limnologist Juha Keto said, lake restoration should not be compared with a human medicine, but I am doing it anyway (Keto 2008.) There are illnesses that can be cured with medicine and in my opinion calcium peroxide is one of the medicines. Still, it must be remembered that all the restoration cases are unique, and there is no universal solution for all the problems. The water area considered for restoration, must be evaluated with care, and, after that, the restoration method(s) must be chosen accordingly.

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APPENDICES

APPENDIX 1 Lachat-analysis

APPENDIX 1 Lachat-analysis

ANALYYSITODISTUS | Nr | Date 18.12.2008

Oskari Klutas /Anne Nykänen

Ref:
Sample type Water
Date of arrival
Date of analysis 16.12.2008
Methods Lachat-analysis

		NO3-N	NH4-N	PO4-P	Total-N	Total-P
		µg/l	µg/l	µg/l	µg/l	µg/l
	LOQ*	6	20	10	10	10
Sample	ETU*	+/- 14%	+/- 18%	+/- 11%	ND	+/- 9%
29.10. 1.		<6	<20	<10	330	<10
29.10. 1.					380	75
29.10. 2.		<6	<20	<10	270	32
29.10. 2.					360	39
29.10. 3.		<6	<20	<10	210	<10
29.10. 3.					430	<10
29.10. lo		<6	<20	<10	220	<10
29.10. k 1		<6	<20	<10	200	33
29.10. k 1					320	<10
29.10. k 2.		<6	<20	<10	200	<10
29.10. k 2.					310	<10
29.10. k 3.		<6	26	<10	160	<10
29.10. k 3.					340	58
29.10. j		<6	<20	<10	270	<10
5.11. 1.		<6	<20	<10	270	<10
5.11. 1.					380	<10
5.11. 2.		<6	49	<10	290	<10
5.11. 2.					360	17
5.11. 3.		<6	<20	<10	290	<10
5.11. 3.					390	<10
5.11. lo		<6	<20	<10	290	<10
5.11. lo					330	35
13.11. 1.		65	46	<10	440	35
13.11. 1.					350	89
13.11. 2.		<6	<20	<10	540	<10
13.11. 2.					390	40
13.11. 3.		<6	<20	<10	320	<10
13.11. 3.					350	<10
13.11. lo		10	<20	<10	460	27
13.11. lo					580	29
13.11. k1		6,7	24	12	260	<10
13.11. k1					300	<10
13.11. k2.		8,4	<20	<10	290	33
13.11. k2.					330	23
13.11. k3.		89	118	<10	300	<10
19.11. 1.		<6	<20	<10	370	<10
19.11. 1.					410	<10
19.11.2.		32	30	<10	300	<10
19.11.2.					370	<10
19.11. 3.		<6	<20	<10	290	<10
19.11. 3.					340	26
4.12. 1.		13	<20	<10	270	24
4.12. 1.					330	<10
4.12. 2.		17	<20	<10	280	<10
4.12. 2.					250	<10
4.12. 3.		15	<20	<10	270	21
4.12. 3.					300	11
4.12. k1.		24	<20	10	160	<10
4.12. k1.					290	25
4.12.k2.		21	<20	<10	240	<10
4.12.k2.					290	24
4.12. k3.		19	<20	<10	250	<10
4.12. k3.					260	<10
4.12. lo		50	<20	<10	260	<10
Reference sample %					34	97
Control sample %		110	130	100	91	140

LOQ=limit of quantitation, ETU=expanded total uncertainty

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