# Changes of emergent aquatic macrophyte cover in seven large boreal lakes in Finland with special reference to water level regulation

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The latest studies on the development of aquatic vegetation in Finland have mainly focused on relatively small lakes. Research on emergent macrophytes in large lakes poses challenges as the habitats as well as the conditions of the lakes vary. Black and white aerial photographs from 1947–1963 and colour, mainly infrared aerial photographs from 1996–2000 were used to study quantitative vegetation changes in seven large (80–1116 km$^2$) lakes in Finland: Kemijärvi, Unnukka, Kallavesi, Päijänne, Näsijärvi, Pyhäjärvi and Vanajavesi. Vegetation changes were evaluated by comparing the situation before large-scale water level regulation and eutrophication to the current situation. Quantitative changes in emergent vegetation were frequently noticeable. Vegetation had decreased by 31–93% in three study lakes due to the mean water level rise and increased by 49–73% in three study lakes due to the spring flood reduction and suitable surrounding soils. The cover changes were in general relatively uniform between different study sites in each of the study lakes. The regulated and unregulated situations differed statistically from each other. The results point out the crucial impact of changing water levels and the significance of the surrounding soils to the cover of emergent aquatic vegetation.

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## Introduction

Many large lakes in Finland have now been reported to be in improved condition after the era of industrial, agricultural and human effluents during the 1960s–1970s and the start of water level regulation in the 1950s (Sarvala 1996; Granberg 1998; Riihimäki et al. 2003). Despite favourable development, a significant increase in emergent macrophytes has been observed and sheltered bays in large lakes have started to overgrow (e.g. Rintanen 1996; Hellsten 2000). Aquatic vegetation reflects the local conditions of the littoral zone while those of open lake areas can differ greatly from the state of a sheltered shore (Toivonen 1984). Eutrophication has been commonly seen as an important factor for the vegetation increase (Suominen 1968; Kurimo 1970; Uotila 1971; Mäkirinta 1978a) as well as the lowering of the water level (Anttonen-Heikkilä 1983; Rørslett 1991). On the other hand, totally opposite observations have also been reported, especially related to increased erosion due to regulation (Hellsten & Riihimäki 1996; Hellsten 2001).

Earlier studies on aquatic macrophyte changes in lacustrine littoral environments in Finland have been mostly conducted in smaller eutrophicated lakes (Hinneri 1965; Meriläinen & Toivonen 1979; Toivonen 1983; Toivonen & Bäck 1989; Toivonen & Nybom 1989; Rintanen 1996; Leka et al. 2003). With inadequate historic field data the actual long-term changes of emergent macrophyte communities in large lakes has not been researched with the exception of the floristic studies of Rintanen (1996). Most studies are based on a comparison between reference lakes (Hellsten & Riihimäki 1996; Hellsten 2001) and seldom on data before regulation (Hellsten 2002). Aerial photographs have been utilized in emergent macrophyte studies for decades in Finland (Jussilainen & Eloranta 1976; Mäkirinta 1991; Valta-Hulkkonen et al. 2003b). As the usual method for large lakes studies is the transect or square method, the lack of both spatial and temporal data for larger boreal lakes in Finland is evident. The value of historical data and aerial photographs on emergent macrophyte changes over time is well acknowledged. The subject, as well as the method, has been studied lately vividly (Dömötörfy et al. 2003; Valta-Hulkkonen et al. 2003a; Fredriksen et al. 2004) also due to the need of geographic data for the EU Water Framework Directive (Jäger et al. 2004). The actual cover changes of emergent aquatic vegetation in large boreal lakes have been previously researched by Andersson (1972, 2001).

In this study we included the main factors affecting on the coverage of emergent aquatic macrophyte vegetation in large boreal lakes. Historical aerial photographs and visual aerial photograph interpretation were used to enable a comparison of the emergent macrophyte cover changes over the time period of approximately 50 years. The following questions and aims were addressed: 1) Is there a measurable change in the cover of emergent macrophytes in large lake environments? and 2) Which are the major environmental lake specific factors causing the change?

## Theoretical background

### Aquatic macrophytes

Phytogeographical research focuses on the past and present distribution and occurrence of vegetation. It studies vegetation changes in different habitats and the components affecting that. Vegetation species form the prerequisites of botanic geography, certain species form the local flora, and species growing with each other form communities and finally the vegetation of the area. Vegetation communities can be further classified according to their physiognomic-ecological structural features of environmental adaptation (Kalliola 1973). Aquatic vegetation can be divided according to structure and environmental adaptation into life forms (Mäkirinta 1978b). The classification is based on three morphological basic criteria consisting of the occurrence of emergent, floating and submergent leaves. The main life forms are thus helophytes, nymphaeids, isoetids, lemnids, elodeids, ceratophyllids, charids and bryids.

Aquatic vegetation plays an important role in many littoral functions of the aquatic ecosystem in boreal lakes. A well-developed vegetation zone protects the shoreline from erosion, impedes nutrients flowing from the shore and affects the quality and quantity of bottom sediment (Pearsall 1920; Spence 1982). It provides a habitat for epiphytic algae and benthic fauna as well as prey and reproduction areas for fish (Tikkanen et al. 1988). Macrophytes work as indicators of the general ecological status of waters. The recent EU Water Framework Directive emphasizes the littoral zone of lakes as an indicator of the ecological status of the entire lake (e.g. Janauer 2003). Certain environmental and biological factors determine the quality and quantity of the vegetation at a given location. The main geographical factors affecting the growth of aquatic vegetation locally are water level fluctuation (Rørslett 1989), exposure (Segal 1971; Keddy 1983; Weisner 1991), bottom quality (Barko & Smart 1983), the amount of light (Spence 1982) and water quality (Ilmavirta & Toivonen 1986).

### Water level regulation

Most of the largest lakes in Finland are regulated and one third of the total area of lakes is regulated. Lake regulation originates in Finland mainly from the 1950s and the main purposes for it are flood protection and hydropower energy production as well as acquiring suitable conditions for ship traffic, industry, agriculture and recreation (Marttunen et al. 2001). In a natural lake the water level variation follows a certain natural yearly rhythm. The water stored in snow and ice during the winter results in diminished flow and water level lowering towards the spring. Melting snow increases the water volume and this causes the spring flood. The spring flood goes down through increased evaporation and when the snow has melted. At the end of the summer, the water level is slightly raised by the autumn rains and decreased evaporation. In the natural situation, the mean and lowest water levels are relatively stable from year to year, but the highest water level can alternate largely depending on the weather conditions during the spring (Keränen 1980).

With regulation the natural variation is altered and water levels are either lowered or raised according to human benefits (Quennerstedt 1958; Hejny 1971). In the northern part of the Europe the water levels are raised at the beginning of the regulation to increase the storage capacity of the lake (Nilsson 1981; Rørslett 1988; Hellsten 1997). The water level is lowered during the winter to maximize the production of electricity when it is most needed. During the early spring the water level is lower compared to its natural state and the spring flood is delayed towards the summer or is cut down totally. The summer water level is held fairly high.

Water level fluctuation is an important factor in the ecology of macrophytes and it usually determines the plant zonation in the littoral zone (Quennerstedt 1958; Hejny 1971; Hellsten 2001). The vegetation is distributed in accordance to the depth, amount of light and life forms into zones along with the summer water level (Mäkirinta 1978a). Over a long period of time the water level fluctuation affects the selection of different species and ecotypes (Hejny 1971). The ability of different species to tolerate flooding and drought becomes a significant selective factor (Anttonen-Heikkilä 1983). The intense continuous fluctuation of water levels during the different growing seasons results in the fracture of the developed vegetation zones and the nature of the lake can totally change with an unnatural water level fluctuation (Quennerstedt 1958). Many research works related to water level regulation and aquatic macrophytes have been done only concerning submergent vegetation (Rørslett 1989). The responses to water level regulation, and their ecology and physiology are very much different for emergent helophytes and nymphaeids (Rørslett 1989). The helophytes are primarily affected by the water level changes whereas the large isoetids and some nymphaeids are more exposed to the ice (Hellsten 2001).

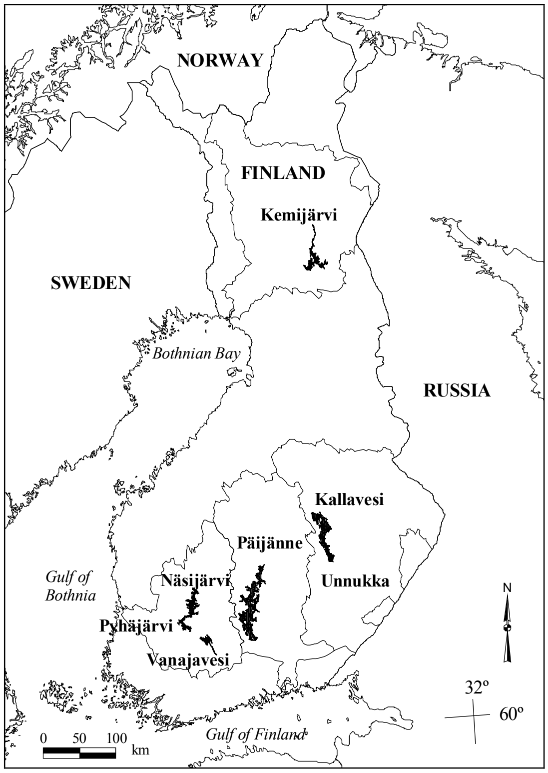



Fig. 1. Geographical location of the Lakes Kemijärvi, Unnukka, Näsijärvi, Kallavesi, Päijänne, Vanajavesi and Pyhäjärvi and their location in the major drainage basins in Finland.

## Study areas

The study lakes Kemijärvi, Unnukka, Näsijärvi, Kallavesi, Päijänne, Vanajavesi and Pyhäjärvi are situated in north-eastern Europe in Finland (Fig. 1). Seven boreal and regulated lakes were chosen, as the study material was collected during the years 1998–2003 in connection with the following projects: The development of regulation of Lake Päijänne 1995–1999 (Hellsten 2000), the development of regulation of Kallavesi and Unnukka 1999–2001 (Hellsten et al. 2002a), the development of regulation of Näsijärvi, Pyhäjärvi and Vanajavesi (Riihimäki et al. 2003) and the Lake Kemijärvi case study of designation of a lake as heavily modified (Marttunen & Hellsten 2003). The study lakes form the head basins of almost all major drainage basins in Finland (Fig. 1). Lake Kemijärvi is the central basin of the Kemijoki drainage basin, which is the second biggest drainage basin in Finland. It empties its waters to the Bothnian Bay. Lake Unnukka and Lake Kallavesi belong to the drainage basin of Vuoksi, which is the biggest drainage basin in Finland with its waters running through Russia to the Gulf of Finland. Lake Näsijärvi, Lake Pyhäjärvi and Lake Vanajavesi belong to the Kokemäenjoki drainage basin area, which is the fourth biggest drainage basin in Finland and its waters run through the River Kokemäenjoki to the Gulf of Bothnia. Lake Päijänne belongs to the Kymijoki drainage basin, the third largest in Finland, which discharges into the Gulf of Finland through the River Kymijoki. The seven study lakes can be regarded to be large on a Finnish scale (Maristo 1941) as they all exceed 80–90 km$^2$ in size. The

Table 1. The main hydrogeographical properties of the research lakes from the Finnish Environment Institute database. The length of the lake is measured from the map. Total nitrogen (N-tot), total phosphorous (P-tot), water colour and chlorophyll-a median values of the surface water (0–2 m) from long term measurement stations during June–August 1990–1997 (Pietiläinen & Räike 1999).

| Lake variables | Kemijärvi | Unnukka | Näsijärvi | Kallavesi | Päijänne | Vanajavesi | Pyhäjärvi |
|---|---|---|---|---|---|---|---|
| Surface area ($km^2$) | 231 | 80 | 256 | 473 | 1116 | 160 | 122 |
| Length of the shoreline (km) | 572 | 478 | 595 | 1700 | 2706 | 395 | 450 |
| Mean depth (m) | 5.2 | 7.5 | 13.0 | 12.1 | 18.1 | 5.5 | 6.2 |
| Volume of the water ($km^3$) | 1.45 | 0.61 | 2.76 | 4.86 | 15.32 | 1.03 | 0.83 |
| River basin area above the lake in outlet ($km^2$) | 27,424 | 17,338 | 7672 | 17,338 | 26,459 | 2739 | 17,073 |
| Duration of the ice free period (d) | 173 | 195 | 220 | 202 | 208 | 222 | 217 |
| Mean water level (m) | 147.28 | 81.16 | 95.02 | 81.58 | 78.24 | 79.15 | 76.84 |
| Length of the lake (km) | 36 | 24 | 44 | 60 | 120 | 38 | 27 |
| N-tot (µg/l) | 318 | 510 | 510 | 600 | 490 | 980 | 630 |
| P-tot (µg/l) | 16.0 | 15.0 | 14.0 | 17.0 | 13.0 | 36.0 | 25.0 |
| Colour (mg pt/l) | 80 | 40 | 40 | 50 | 35 | 48 | 35 |
| Chlorophyll-a (µg/l) | 6.7 | 7.8 | 4.4 | 6.4 | 4.4 | 9.2 | 10.0 |

Table 2. Study sites and their characteristics with the dominant shore use and the soil type based on base maps of the National Land Survey of Finland and soil maps of the Geological Survey of Finland. *Exact information not available due to incomplete mapping.

| Study lake | Study site | Study site characteristics | Dominant shore use | Dominant soil type |
|---|---|---|---|---|
| Näsijärvi | Pengonpohja | large deep and open bay | forest recreational | sandy moraine |
| | Pöllöselkä | large and open bay | forest agriculture | rock and clay |
| | Siivikkala | small sheltered shallow bay | settlement | sandy moraine |
| | Aitolahti | large and open bay | forest agriculture | sandy moraine |
| Vanajavesi | Uskilanlahti | shallow sheltered bay | agriculture settlement | clay |
| | Heinunlahti | open and large bay | forest agriculture settlement | peat and sandy moraine |
| | Kapeikko | narrow shallow sheltered | settlement agriculture | clay |
| Pyhäjärvi | Saviselkä | open shores and minor bays | agriculture settlement | clay and sandy moraine |
| | Vakkalanselkä | open shores sheltered bays | forest agriculture | sandy moraine and clay |
| | Vesilahti | open shores sheltered bays | agriculture | sandy moraine and clay |
| Päijänne | Vähä-Äiniö | open shores | forest | sand |
| | Vähäniemi | shallow bay and small peninsulas | forest settlement agriculture | sandy moraine and sand |
| | Mustalahti | open and deep bay | forest | sandy moraine |
| | Virmaila | deep and open shore | forest | sandy moraine |
| | Kankarniemi | deep and sheltered | forest agriculture | sandy moraine |
| | Kuhmalahti | shallow and sheltered | agriculture settlement | sandy moraine and clay |
| | Säynätlahti | open deep and shallow | forest agriculture settlement | sandy moraine |
| | Pihlajalahti | sheltered deep and shallow | forest settlement | sandy moraine and rock |
| | Viisti | variable | settlement agriculture | * |
| | Ruolahti | sheltered | forest | sandy moraine and clay |
| | Rutalahti | shallow | agriculture settlement | sandy moraine and clay |
| Unnukka | Leveäsaari | shallow island group surrounded by sub-basin | forest settlement | rock and sandy moraine |
| | Varkaus | shallow and sheltered | settlement agriculture | sandy moraine and clay |
| Kallavesi | Lamperila | open | forest agriculture settlement | sandy moraine |
| | Autioranta | open | forest agriculture settlement | * |
| | Vaajasalo | variable | settlement forest agriculture | * |
| | Puutossalmi | open | settlement agriculture | sandy moraine |
| | Sotkanniemi | mainly shallow | agriculture forest | sandy moraine and clay |
| | Koirusvesi | open and deep | forest | sandy moraine and rock |
| Kemijärvi | Kokkoselkä | open islands and mainland | forest | * |
| | Termusniemi | open and deep | forest agriculture settlement | * |
| | Kaippiosaari | former flood islands varying | none | * |
| | Ollinsaari | 0.5–2.2 km in size, now under | none | * |
| | Koivusaari | water due inundation | none | * |
| | Lammassaari | | none | * |

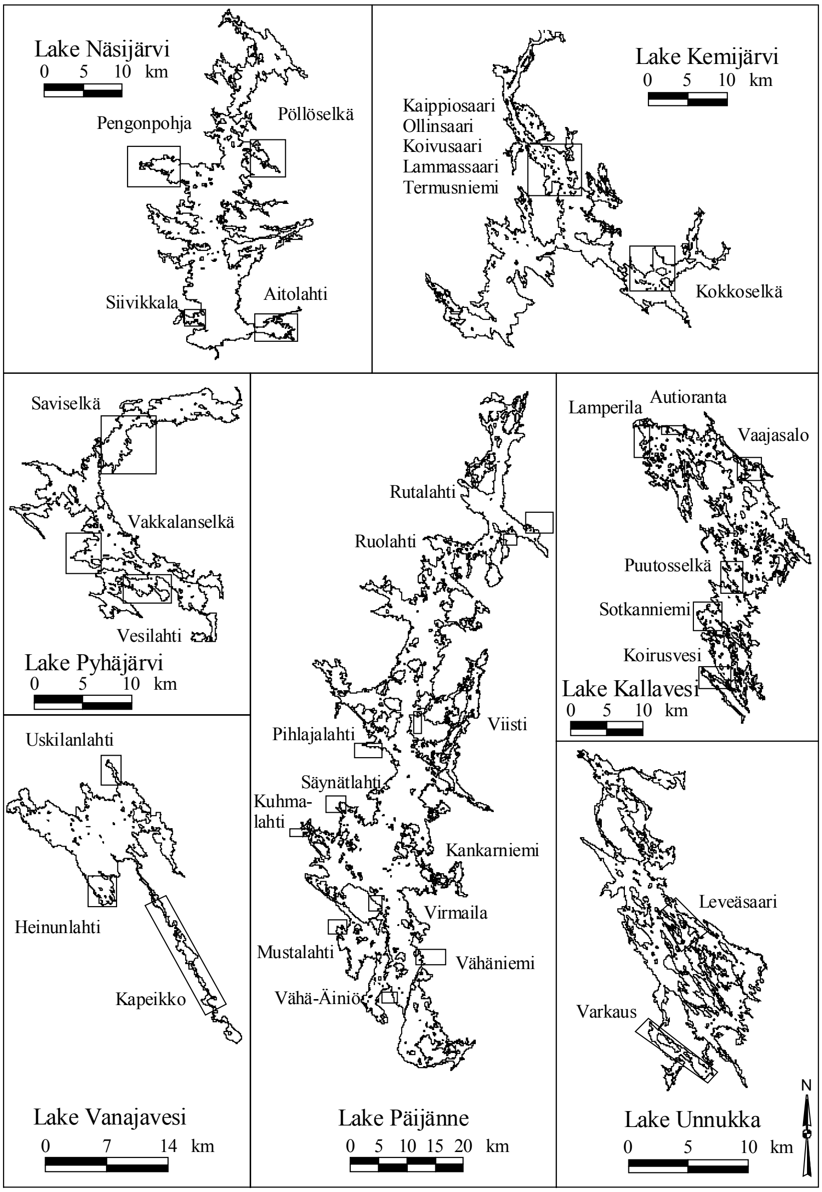



Fig. 2. Study lakes and the location of the study sites. Refer to Table 4 for details in aerial photography.

shoreline of the lakes is alternating, and the lake basins are characteristically relatively shallow, but vary in size and depth (Table 1). Larger bays and numerous islands are typical and the open waters usually remain relatively limited in size which is characteristic for large Finnish lakes (Vaarama 1961). Study lakes are divided into study sites (see Fig. 2) and detailed description of study lakes and study sites is found in Tables 1 and 2.

## Climate

All the other study lakes belong to the South Boreal region and are situated in the Lake District except Lake Kemijärvi, which belongs to the North Boreal climate region. The duration of the growing season (>5 ºC) is 160–175 days in the South Boreal and 100–140 days in the North Boreal (Hämet-Ahti 1988). The effective temperature sum during

Table 3. The mean monthly temperatures in Hattula Leteensuo (61°04′, 24°15′) representing Lake Vanajavesi and Lake Päijänne, in Tampere (61°30′, 23°46′, during the year 1998 location 61°28′, 23°45′ and year 2000 location 61°25′, 23°35′) representing Lake Näsijärvi and Lake Pyhäjärvi and in Kuopio Rissala (63°01′/00′, 27°48′) representing Lake Kallavesi and Lake Unnukka during the study years.

| Station | Year | May | June | July | August |
|---|---|---|---|---|---|
| Hattula | 1950 | 9.5 | 14.8 | 14.9 | 15.1 |
| | 1952 | 7.7 | 13.5 | 15.5 | 13.1 |
| | 1953 | 9.4 | 16.9 | 16.2 | 14.6 |
| | 1999 | 7.7 | 17.6 | 18.0 | 14.4 |
| | 1961–1991 | 9.8 | 14.7 | 16.2 | 14.5 |
| Tampere | 1947 | 9.9 | 16.1 | 17.5 | 15.7 |
| | 1949 | 11.1 | 13.0 | 16.1 | 13.9 |
| | 1950 | 9.0 | 14.5 | 15.0 | 15.3 |
| | 1998 | 9.2 | 14.0 | 15.8 | 13.5 |
| | 2000 | 10.3 | 13.9 | 16.0 | 14.2 |
| | 1961–1990 | 9.5 | 14.6 | 16.3 | 14.5 |
| Kuopio | 1951 | 5.0 | 13.0 | 14.7 | 17.3 |
| | 1952 | 5.9 | 13.5 | 15.8 | 13.2 |
| | 1963 | 12.4 | 13.0 | 16.1 | 15.6 |
| | 1996 | – | – | – | – |
| | 1999 | 6.4 | 18.4 | 17.8 | 13.9 |
| | 1961–1990 | 8.8 | 14.6 | 16.8 | 14.5 |

the growing season varies approximately between 1100–1250 °C in the South Boreal region and stays under 900 °C in the North Boreal. The duration of the ice free period in every lake is in Table 1. The annual precipitation varies between 600–750 mm a year in the study area. The duration of snow cover on open ground varies between 130–160 days in the South Boreal region and 180–200 days in the North Boreal (Solantie 1987). The mean monthly temperatures in each study year during May, June, July and August in Hattula, Tampere and Kuopio are in Table 3.

## Soil geology

The majority of the lake shores of the study lakes are covered with moraine formations. The drainage basin of Lake Kemijärvi consists of moraine (Nenonen 1987). The soils in the Unnukka research area are mainly sandy moraines, more moraines and outcrops are found from northern Unnukka, compared to the clay rich areas in the south (Kejonen 1989; Huttunen 1990). A uniform moraine layer largely covers the Kallavesi study area. Sandy areas are most common in central Kallavesi, whereas clay areas form a notable part of the shoreline in the north and south (Vaarama 1938). The surroundings around Näsijärvi are largely formed of uncovered bedrock or thin soils with an influence of moraine deposits along the whole shoreline. Rocky shores are more common in the open lake areas. Sheltered bays occasionally have considerable silt and clay occurrence (Virkkala 1959; Kejonen 1985). Lake Päijänne is bordered in the south by the glacial end-formation Salpausselkä, which contains assorted material and moraine. Päijänne is well known for eskers, which are most dominant in south. The widest and most continuous clay areas are situated on bay shores in central Päijänne (Teräsvirta 1978). Lake Vanajavesi and Pyhäjärvi are dominated with more clayey soils. The bedrock along the Vanajavesi is covered with thick moraine deposits or eskers, specially along the Vanajanselkä. Silty clay is most common of mineral soils of finer texture, which are restricted to the edges of the bays. Organic soils are most prevalent on the shores of large bays (Virkkala 1961; Uotila 1971; Kae 1980). The soils in the Pyhäjärvi region are principally dominated by silt and clay but uncovered bedrock and moraine formations are generally prevailing as well (Virkkala 1959; Perttunen 1976).

## Limnological properties

In the limnological classification of lakes, Järnefelt (1952) divided Finnish lakes into three main categories: oligotrophic, eutrophic and dystrophic. The lakes Kemijärvi, Päijänne, Kallavesi, Unnukka and Näsijärvi belong to the dystrophic type characterized by the water of yellowish or brownish colour resulting from dissolved or colloidal humic material. The southern end of Päijänne is in the limits of dystrophic and oligotrophic. Pyhäjärvi and Vanajavesi belong to the eutrophic limnological lake classification, and are classified as rich in nutrients (Järnefelt 1952). The current general water quality classification in Finland divides waters into five classes: excellent, good, satisfactory, passable and poor according to different physical and chemical variables (see Vuoristo 1998 for details). The latest water quality classification covers the period of 2000–2003. Lakes Päijänne and Näsijärvi belong to the classes excellent and good and Lake Unnukka to the class good. Lakes Kallavesi and Kemijärvi belong to the classes good and satisfactory. Lakes Pyhäjärvi and Vanajavesi are only reaching the status of satisfactory, with some parts of the lake representing the status of passable. The present general water quality of all study lakes is shown in Table 1.

### Vegetation

Phytogeographically Finland is divided into four different major regions (Hämet-Ahti 1988). All study lakes besides Kemijärvi are in the second southernmost category, the South Boreal region. Kemijärvi belongs to the northernmost category, the North Boreal region (Hämet-Ahti 1988). On a floristic-ecological basis Finland can be divided into botanical lake type areas (Maristo 1941). Based on this classification, Lake Pyhäjärvi and Lake Vanajavesi are categorized as eutrophic *Typha–Alisma* and *Schoenoplectus lacustris* type. Lakes Näsijärvi, Päijänne, Kallavesi and Unnukka are furthermore classified into the oligotrophic *Phragmites* type and Lake Kemijärvi into the oligotrophic *Carex* type. The present flora of the lakes has been researched previously by Hellsten (2000), Hellsten (2002), Hellsten et al. (2002a) and Riihimäki et al. (2003). Most frequent and abundant from present helophytes on lakes are water horsetail (*Equisetum fluviatile*), common reed (*Phragmites australis*), slender tufted-sedge (*Carex acuta*), reed sweet-grass (*Glyceria maxima*) and common club-rush (*Schoenoplectus lacustris*), and from nymphaeids yellow water-lily (*Nuphar lutea*) and amphibious bistort (*Persicaria amphibia*).

### Lake Kemijärvi

The River Kemijoki and two artificial reservoirs bring their waters to Lake Kemijärvi (66º45′–66º29′) and it empties its waters to the River Kemijoki via a power plant. The lake is characterized by vast open sub-basins and extreme water level regulation. The water levels in Lake Kemijärvi are regulated mostly for hydroelectric power production but also for flood protection purposes. The regulation interval is almost 7 m being the most intensive in Finland (Marttunen & Hellsten 2003). From point source pollution the biggest wastewater producer is a cellulose factory established in 1965. Compared to the industrial wastes, human effluents are not significant in Kemijärvi (Nenonen 1987). The artificial basins Lokka and Porttipahta built in 1967–1970 affect the nutrient load.

### Lake Unnukka

Lake Unnukka (62º30′–62º18′) receives its waters north from Lake Kallavesi and empties its waters to the south. Lake Unnukka is characterized by numerous large and small islands filling the lake and having a few smaller sub-basins in-between the islands. The current regulation started benefiting water traffic, hydropower energy production, recreation and farming. The yearly water level interval has been only 0.2 m, which is the smallest regulation interval in Finland (Marttunen et al. 2002). In Lake Unnukka the human impact to the waters can be distinguished from the 1960s onwards. Kurimo (1970) classified the waters in southern Unnukka affected by domestic sewage and farming while northern Unnukka remained uncontaminated. The water quality surveyed from 1965 onwards shows slight improvements, these days being mesotrophic (Hellsten et al. 2002a).

### Lake Näsijärvi

The waters in Lake Näsijärvi (61º30′–61º53′) run south towards Lake Pyhäjärvi. Typical for Lake Näsijärvi are the large sub-basins and many large bays situated in an east-west direction. Water level regulation has been mainly planned to benefit hydropower production. The water quality in Lake Näsijärvi varies between good and excellent with only a few minor bay areas being satisfactory. The wastewater loading to Lake Näsijärvi peaked at the turn of the 1970s when purification was just starting. The essential turning point was also the ceasing of the pulp and paper industry in southwestern Näsijärvi in 1985. The current non-point source loading to Lake Näsijärvi is insignificant (Oravainen 2002).

### Lake Kallavesi

Two large watercourses empty their waters into Lake Kallavesi (62º30′–63º06′). The lake is divided into various sub-basins and islands of diverse nature. The water level regulation started in Lake Kallavesi together with Lake Unnukka and its benefits are equally directed. In Kallavesi the water level regulation has been very mild and possibilities for the regulation are also limited (Marttunen et al. 2002). The water quality coming to Lake Kallavesi has been surveyed from the beginning of the 1960s. However no clear trends for change has been found and there are large differences in the water quality and nutrient content between areas. Northern Kallavesi is strongly mesotrophic, but the water quality changes towards having fewer nutrients in the south (Hellsten et al. 2002a). According to the classification, the water quality in Lake Kallavesi is mainly good, but in northern Kallavesi and in many bay areas it is satisfactory.

### Lake Päijänne

Lake Päijänne (61º10′–62º15′) is the third largest lake in Finland and the deepest point of 95 m in Finnish inland waters is located in Päijänne. Lake Päijänne receives its waters from 6 different drainage basins in the north, east and west, and they flow towards the south. Characteristic to Päijänne are the several east to west directed large bay areas and numerous sub-basins. To prevent rare but harmful floods Lake Päijänne has been regulated and regulation is also beneficial to industry, log floating and water traffic. Lake Päijänne is widely known for its almost pristine water quality and the waters in southern Päijänne belong to the excellent classification. Waters in northern Päijänne are classified as good and in a few bay areas good and satisfactory. Generally the water quality improves towards the south. As a consequence of the location of bigger cities and industrial areas in the north and west, northern Päijänne has been an object for greater effluent loads during history, especially in 1960–1985. Even if the water quality remains excellent in open lake areas, sheltered bays and bottom areas suffer from eutrophication and its side-effects (Granberg 1998).

### Lake Vanajavesi

The waters from Lake Vanajavesi (61º14′–60º57′) run towards Lake Pyhäjärvi. Major parts of the lake are the narrow and shallow straits and the larger, deeper and more open sub-basin with few smaller bays. The water levels are regulated with the purpose to help farming, log floating and hydropower energy (Marttunen et al. 2000). Lake Vanajavesi is a nutrient rich and turbid lake. The nutrient levels in loaded areas have had a descending trend lately (Hakaste 1999) and the water quality has been improving. The agricultural load is substantial and the lake receives wastewaters from the cities. The water quality in the 1970s was classified partly as heavily polluted. At the turn of 1960–1970 many factories, villages and the city of Hämeenlinna discharged their almost untreated wastes to Lake Vanajavesi. The pulp factory and city of Tervakoski also affected the water quality flowing from the south-east to Lake Vanajavesi (Uotila 1971).

### Lake Pyhäjärvi

Lake Pyhäjärvi (61º30′–61º14′) receives its waters from the direction of Lake Vanajavesi through a canal. Lake Pyhäjärvi is a long, partly narrow and sheltered lake with a chain of the larger sub-basins. The water levels have been regulated mainly to help farming, log floating and hydropower energy (Marttunen et al. 2000). The water quality in Lake Pyhäjärvi resembles Lake Vanajavesi being nutrient rich and turbid (Hakaste 1999). The development of the water quality has been most affected by the era of extensive human activities including industrial and wastewaters from the 1950s to 1960s. After the 1970s the water quality has been improved dramatically with the start of water purification practices for both industrial and human effluents.

## Materials and methods

### Vegetation cover

Aerial photographs are the most applied method for aquatic macrophyte mapping (Lillesand & Kiefer 1994). The main materials used in this study have been black and white aerial photographs from 1947 to 1963 and colour, mainly infrared, aerial photographs from 1996 to 2000 (Table 4). Only photographs from the later summer months, July to September, have been primarily used due to the nature of the growing season of aquatic vegetation. The scale of the photos varied between 1:7000 and 1:30,000. Digital base maps and the digital coastline of 1:20,000 from the digital Finnish base map has been used. The methods used in this study restrict the interpretation mainly to visible aquatic macrophytes, helophytes and nymphaeids, as they outnumber the two biggest macrophyte cover classes in larger boreal lakes (Andersson 2001; Valta-Hulkkonen et al. 2003a).

The visual aerial photo interpretation was carried out using the GIS softwares ArcView and MapInfo. The aerial photographs were scanned with an accuracy of 400 dpi. The obtained digital image was geo-referenced with the digital Finnish base map with common reference points. The vegetation was digitized using the digital coastline 1:20,000 as a reference layer. Stereo glasses were used to obtain a three-dimensional view from the

Table 4. The date, map scale, quality and the place of acquisition of the aerial photographs, and the length of the studied shoreline. *Unable to calculate the present shoreline due to inundation of the studied islands.

| Lake | Study area | Date of photography | Map scale and the type of the aerial photographs | Photographer | Length of the studied shoreline (km) |
|---|---|---|---|---|---|
| Kemijärvi | Kokkoselkä | 16.7.1959 | 1:30,000 BW paper | National Land Survey of Finland | 14.0 |
| | | 11.7.1997 | 1:30,000 CIR paper | FM-Kartta Oy | |
| | Termusniemi | 16.7.1957 | 1:20,000 BW paper | The Finnish Defence Forces | 9.0 |
| | | 25.7.2000 | 1:20,000 CIR paper | FM-Kartta Oy | |
| | Kaippiosaari | 16.7.1957 | 1:20,000 BW paper | The Finnish Defence Forces | * |
| | | 25.7.2000 | 1:20,000 CIR paper | FM-Kartta Oy | |
| | Ollinsaari | 16.7.1957 | 1:20,000 BW paper | The Finnish Defence Forces | * |
| | | 25.7.2000 | 1:20,000 CIR paper | FM-Kartta Oy | |
| | Koivusaari | 16.7.1957 | 1:20,000 BW paper | The Finnish Defence Forces | * |
| | | 25.7.2000 | 1:20,000 CIR paper | FM-Kartta Oy | |
| | Lammassaari | 16.7.1957 | 1:20,000 BW paper | The Finnish Defence Forces | * |
| | | 25.7.2000 | 1:20,000 CIR paper | FM-Kartta Oy | |
| Unnukka | Leveäsaari | 23.7.1963 | 1:25,000 BW paper | National Land Survey of Finland | 37.1 |
| | | 14.8.1999 | 1:22,432 color slide | Jari Venetvaara Oy | |
| | Varkaus | 23.7.1963 | 1:25,000 BW paper | National Land Survey of Finland | 21.7 |
| | | 14.8.1999 | 1:22,432 color slide | Jari Venetvaara Oy | |
| Näsijärvi | Pengonpohja | 29.8.1949 | 1:20,000 BW paper | National Land Survey of Finland | 15.5 |
| | | 15.9.2000 | 1:20,000 CIR paper | FM-Kartta Oy | |
| | Pöllöselkä | 4.8.1950 | 1:20,000 BW paper | National Land Survey of Finland | 18.6 |
| | | 26.6.1998 | 1:30,000 CIR paper | FM-Kartta Oy | |
| | Siivikkala | 21.6.1947 | 1:20,000 BW paper | National Land Survey of Finland | 6.7 |
| | | 26.6.1998 | 1:30,000 CIR paper | FM-Kartta Oy | |
| | Aitolahti | 21–22.6.1947 | 1:20,000 BW paper | National Land Survey of Finland | 32.7 |
| | | 26.6.1998 | 1:30,000 CIR paper | FM-Kartta Oy | |
| Kallavesi | Lamperila | 14.7.1951 | 1:20,000 BW paper | The Finnish Defence Forces | 10.2 |
| | | 3.8.1999 | 1:30,000 CIR paper | FM-Kartta Oy | |
| | Autioranta | 14.7.1951 | 1:20,000 BW paper | The Finnish Defence Forces | 8.1 |
| | | 4.8.1999 | 1:30,000 CIR paper | FM-Kartta Oy | |
| | Vaajasalo | 14.7.1951 | 1:20,000 BW paper | The Finnish Defence Forces | 6.1 |
| | | 19.7.1999 | 1:30,000 CIR paper | FM-Kartta Oy | |
| | Puutossalmi | 24.8.1951 | 1:20,000 BW paper | The Finnish Defence Forces | 20.0 |
| | | 2.8.1999 | 1:30,000 CIR paper | FM-Kartta Oy | |
| | Sotkanniemi | 24.8.1951 | 1:20,000 BW paper | The Finnish Defence Forces | 19.8 |
| | | 20.8.1996 | 1:30,000 CIR paper | FM-Kartta Oy | |
| | Koirusvesi | 19.6.1952 | 1:20,000 BW paper | The Finnish Defence Forces | 13.2 |
| | | 18.8.1996 | 1:30,000 CIR paper | FM-Kartta Oy | |
| Päijänne | Vähä-Äiniö | 5.8.1951 | 1:20,000 BW paper | National Land Survey of Finland | 2.8 |
| | | 21–25.7.1996 | 1: 7000 color slide | Jari Venetvaara Oy | |
| | Vähäniemi | 5.8.1951 | 1:20,000 BW paper | National Land Survey of Finland | 8.2 |
| | | 21–25.7.1996 | 1: 7000 color slide | Jari Venetvaara Oy | |
| | Mustalahti | 5.8.1951 | 1:20,000 BW paper | National Land Survey of Finland | 5.3 |
| | | 21–25.7.1996 | 1: 7000 color slide | Jari Venetvaara Oy | |
| | Virmaila | 5.8.1951 | 1:20,000 BW paper | National Land Survey of Finland | 5.5 |
| | | 21–25.7.1996 | 1: 7000 color slide | Jari Venetvaara Oy | |
| | Kankarniemi | 9.7.1952 | 1:20,000 BW paper | National Land Survey of Finland | 3.2 |
| | | 21–25.7.1996 | 1: 7000 color slide | Jari Venetvaara Oy | |
| | Kuhmalahti | 5.8.1951 | 1:20,000 BW paper | National Land Survey of Finland | 5.0 |
| | | 21–25.7.1996 | 1: 7000 color slide | Jari Venetvaara Oy | |
| | Säynätlahti | 5.8.1951 | 1:20,000 BW paper | National Land Survey of Finland | 5.6 |
| | | 21–25.7.1996 | 1: 7000 color slide | Jari Venetvaara Oy | |
| | Pihlajalahti | 5.8.1951 | 1:20,000 BW paper | National Land Survey of Finland | 5.3 |
| | | 21–25.7.1996 | 1: 7000 color slide | Jari Venetvaara Oy | |
| | Viisti | 5.8.1951 | 1:20,000 BW paper | National Land Survey of Finland | 3.8 |
| | | 21–25.7.1996 | 1: 7000 color slide | Jari Venetvaara Oy | |
| | Ruolahti | 13.8.1953 | 1:20,000 BW paper | National Land Survey of Finland | 1.3 |
| | | 21–25.7.1996 | 1: 7000 color slide | Jari Venetvaara Oy | |
| | Rutalahti | 13.8.1953 | 1:20,000 BW paper | National Land Survey of Finland | 6.3 |
| | | 21–25.7.1996 | 1: 7000 color slide | Jari Venetvaara Oy | |
| Vanajavesi | Uskilanlahti | 21–23.6.1953 | 1:20,000 BW paper | National Land Survey of Finland | 9.1 |
| | | 14.8.1999 | 1:22,432 color slide | Jari Venetvaara Oy | |
| | Heinunlahti | 11.8.1950 | 1:20,000 BW paper | National Land Survey of Finland | 16.8 |
| | | 14.8.1999 | 1:22,432 color slide | Jari Venetvaara Oy | |
| | Kapeikko | 9.7.1952 | 1:20,000 BW paper | National Land Survey of Finland | 42.3 |
| | | 21–23.6.1953 | 1:20,000 BW paper | National Land Survey of Finland | |
| | | 14.8.1999 | 1:22,432 color slide | Jari Venetvaara Oy | |
| Pyhäjärvi | Saviselkä | 22.6.1947 | 1:20,000 BW paper | National Land Survey of Finland | 21.5 |
| | | 26.6.1998 | 1:30,000 CIR paper | FM-Kartta Oy | |
| | Vakkalanselkä | 23.6.1947 | 1:20,000 BW paper | National Land Survey of Finland | 11.6 |
| | | 16.9.2000 | 1:20,000 CIR paper | FM-Kartta Oy | |
| | Vesilahti | 23.6.1947 | 1:20,000 BW paper | National Land Survey of Finland | 16.1 |
| | | 16.9.2000 | 1:20,000 CIR paper | FM-Kartta Oy | |

former material when necessary. Similar methodology has been used in the macrophyte study by Valta-Hulkkonen et al. (2003a).

Study sites were outlined to be the same sections of the shoreline of the former and the current aerial data. The length of the researched shoreline was measured. No aerial interpretation has been carried out without personally surveying the study site in the field except Päijänne, which was reinterpreted, from a previous study. The length of the investigated shoreline varied from lake to lake according to the availability of the aerial photography material and the current project funding and needs. Unfortunately the later aerial photographs from Lake Vanajavesi, Lake Päijänne and Lake Unnukka were only available in slide format with a large map scale and were transferred into GIS manually.

### Hydrological analysis

The analysis of actual measured daily water level fluctuation (Fig. 3) is based on regulated and natural water levels over a certain period of time (Marttunen et al. 2000; Hellsten et al. 2002b). The time series varied from lake to lake, but in principle a 20 years period before the aerial photography was used. A general water level analysis is shown in Table 5. This water level analysis is based on the REGCEL-application (Hellsten et al. 2002b). The REGCEL water level analysis tool was developed in the Finnish Environment Institute (SYKE) between the years 1999–2000. It calculates more than thirty parameters of daily water level values. The water levels are based on regulated and natural water levels. The natural water levels are re-calculated from the regulated water levels. The identification of water level characteristics as indicators was made in several research projects published in a review by Marttunen et al. (2001). Water level duration of the open-water period was determined according to Hellsten (1997). The fluctuation range is bound to the Finnish metric altitude levels (NN+ or N43+).

### Statistical analysis

The number of lakes was low and the length of the shoreline of different study sites varied such that the statistical analysis for the previous and current situation was not performed on actual coverage per study site, but on vegetation coverage in hectares per studied shore kilometre in each study site. All study lakes except Lake Kemijärvi were included as the shoreline is under water due to the regulation. Total vegetation coverage per studied shore kilometre was calculated in previous (1947–1963) and in current (1996–2000) situations and this data was used in the statistical analyses. The normality of the data was tested with the Shapiro-Wilk test. The data was not normally distributed, consequently the Wilcoxon test was used to analyse the difference between the natural and regulated situation comparing the vegetation per shore kilometre in all study sites in natural and regulated states (29 sites). The previous and the current amount of vegetation between the 6 lakes were tested with the Kruskall-Wallis test to see whether there is more vegetation in some of the lakes. The differences within the study sites in the individual lakes was tested with the Wilcoxon test. As the amount of different study sites was very low per each lake, the regional differences in each lake were not relevant for testing.

## Results

### Changes in the water level fluctuation regime

The water levels in Lake Kemijärvi in its natural and regulated state differ considerably from the rest of the studied lakes (see Table 5 and Fig. 3 for all lakes). The water level regulation has more than doubled the annual water level fluctuation and the water level remains almost 2 m higher after the spring flood during the open water period. The regulation practice also includes an extensive winter draw down of more than 6 m. In Lake Unnukka the regulation amplitude is very limited. More than 0.3 m higher water levels prevail throughout the year compared to the natural state and the water level remains stable the whole year. In Lake Näsijärvi, the water level fluctuation amplitude has remained almost constant. During the open water period, water levels have increased by 0.4 m. Water level regulation also includes a cut of the spring flood by 0.55 m. Water level changes in Lake Kallavesi are very moderate, and neither the amplitude nor the frequency has been altered much. The regulation practice includes only a slight decrease in the spring flood and higher water levels during dry summers. Water level regulation during the open water period in Lake Vanajavesi, Pyhäjärvi and Päijänne includes a cut-down of spring floods and stabilized summer time water levels. The reg-

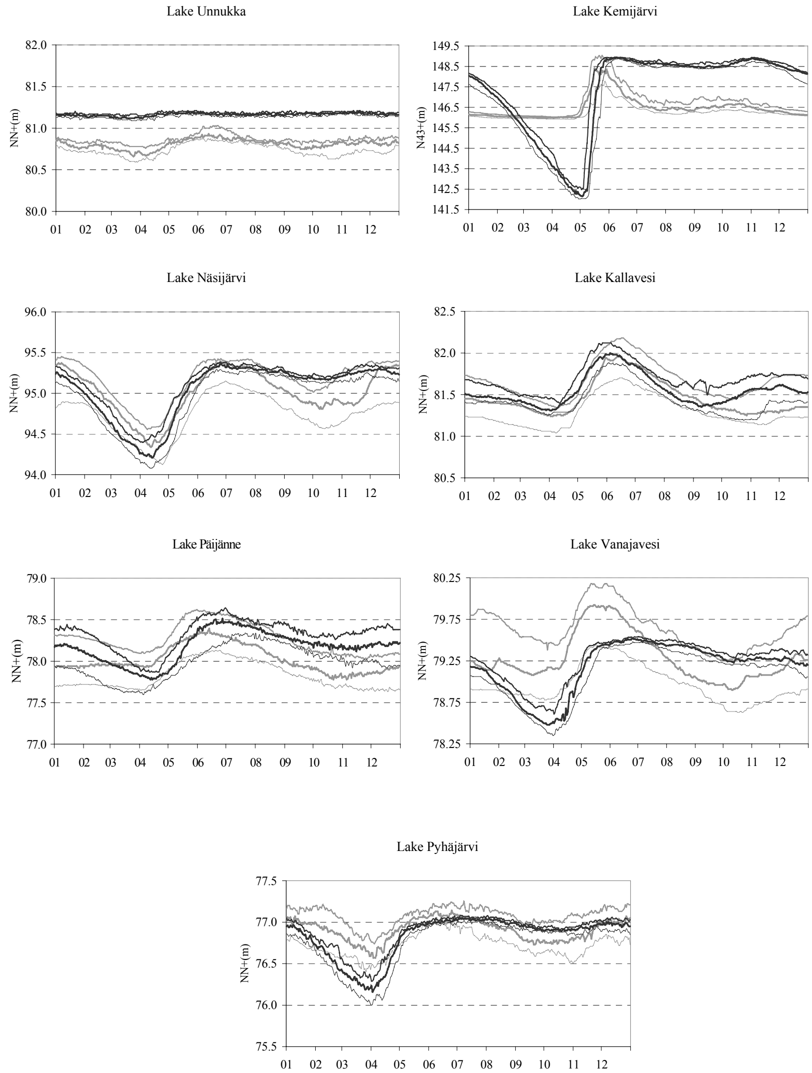



Fig. 3. Water level fluctuation in the research lakes in natural (grey) and regulated (black) stages. All water levels are actual measured water levels presented in median, upper quartile (75%) and lower quartile (25%) for years 1939–1958 and 1980–2000 in Lake Kemijärvi, 1943–1963 and 1979–1999 in Unnukka, 1927–1947 and 1975–1995 in Näsijärvi, 1931–1951 and 1979–1999 in Kallavesi, 1933–1951 and 1976–1996 in Päijänne, 1930–1950 and 1975–1995 in Vanajavesi and 1927–1947 and 1975–1995 in Pyhäjärvi (SYKE database).

Table 5. Water level regulation indicators calculated by REGCEL during the years 1980–1999. Annual water level fluctuation (MHW – MNW), decrease in spring flood (W (breakup of the ice) – MW 50% (open water period)), mean water level rise (MWregul 50% (open water period) – MWnatur 50% (open water period)). Natural water levels are re-calculated from the regulated water levels.

| | Current regulation started | Annual water level fluctuation (m) | | Decrease in spring flood (m) | Mean water level rise (m) | Water level fluctuation during the summer (m) | |
|---|---|---|---|---|---|---|---|
| | | Natural | Regulated | | | Natural | Regulated |
| Kemijärvi | 1965 | 3.19 | 6.96 | –1.66 | 2.05 | 2.75 | 2.07 |
| Unnukka | 1972 | – | 0.20 | 0.01 | 0.32 | – | 0.14 |
| Näsijärvi | 1923/80 | 1.02 | 1.18 | –0.55 | 0.40 | 0.84 | 0.74 |
| Kallavesi | 1972 | 1.02 | 0.87 | 0.13 | 0.03 | 0.91 | 0.77 |
| Päijänne | 1964 | 0.82 | 0.89 | –0.26 | 0.02 | 0.69 | 0.65 |
| Vanajavesi | 1962 | 1.07 | 1.00 | –0.33 | –0.02 | 0.90 | 0.53 |
| Pyhäjärvi | 1962 | 1.33 | 0.93 | –0.16 | 0.26 | 1.17 | 0.35 |

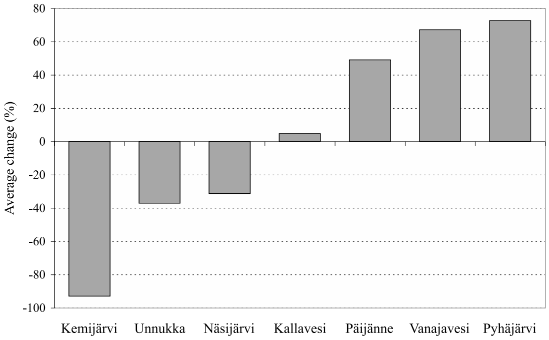



Fig. 4. The average percentage cover change of emergent aquatic vegetation in all seven study lakes during the study years of 1947–1963 and 1996–2000.

ulation of Lake Pyhäjärvi also included a slight increase of the water level by 0.26 m during the open water period.

## Vegetation cover changes between the study lakes

The macrophyte vegetation cover changes in seven study lakes during the study period varied considerably. The percentage change of the vegetation cover is shown in Fig. 4. A clear vegetation decrease took place in three lakes. In Lake Kemijärvi the vegetation decreased by 93%, in Lake Unnukka by 37% and in Lake Näsijärvi by 31%. In Lake Kallavesi the vegetation almost stayed the same with a slight vegetation cover increase of 5%. In contrast, a clear vegetation increase took place in three lakes. The vegetation increase was 49% in Lake Päijänne, 67% in Lake Vanajavesi and 73% in Lake Pyhäjärvi.

## Vegetation cover changes between the study sites

The changes between different study sites (Fig. 5) in the study lakes also varied a great amount, however a certain convergent trend was definite. In the lakes where the vegetation coverage had generally decreased, the decrease also took place in all study sites and the same situation occurred in lakes with increasing vegetation. The changes between the study sites are relatively uniform among lakes, except Lake Kallavesi. Lake Kallavesi was the only lake having both increasing and decreasing vegetation changes.

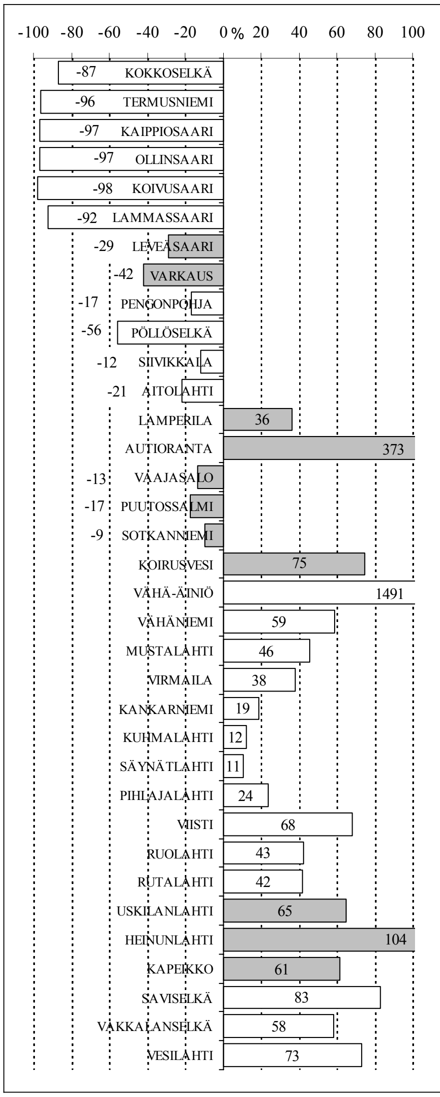
A vegetation decrease took place in Lake Kemijärvi, Lake Unnukka and Lake Näsijärvi. The vegetation decrease was the most uniform in Kemijärvi. In six study sites the change varied from 87% to 98%. The amount of sedge vegetation out of the whole flooded research area in Kemijärvi was 49% during the years 1957–1959. During the study period of 1997–2000 the amount of sedge vegetation was only 2–12% of the former situation. In Unnukka and in Näsijärvi the vegetation decrease was less uniform. The vegetation had decreased by 29% in the Leveäsaari area in the north and by 42% in the south at the Varkaus area. In Näsijärvi the vegetation decrease varied from 12% to 56%. Vegetation area changes were of a dual nature in Lake Kallavesi. The amount of vegetation had increased in study sites in northern Kallavesi and at the Koirusvesi. On the other hand, vegetation cover has decreased in southern central Kallavesi.

A general vegetation increase took place in Lake Pyhäjärvi, Lake Vanajavesi and in Lake Päijänne. It was most uniform in Lake Pyhäjärvi and in Lake Vanajavesi. In Lake Pyhäjärvi the vegetation increased in three study sites from 58% to 83%. In Vanajavesi the vegetation increase in three study sites varied from 61% to 104%. In Päijänne the increase varied from 11% to 1491% in 11 study sites. The vegetation had increased mostly in the north and south and somewhat in central Päijänne. Some examples of the increasing and decreasing vegetation changes are presented in Fig. 6.

## Vegetation coverage per shore kilometre

There were no statistical differences between the lakes in the natural (1947–1963) situation regarding vegetation coverage per studied shore kilometre, but with the regulation (1996–2000) a change had occurred. The former natural situation and the present regulated situation differ from each others ($Z = -2.303$, $p = 0.21$). The lakes did not differ statistically from each other in the amount of vegetation neither in the former ($p = 0.688$) nor in the present ($p = 0.193$) situation. Among the 6 study lakes there were not any statistical differences in the amount of vegetation between different study sites ($p = 0.068$–$0.600$) except in Lake Päijänne ($p = 0.003$).

The vegetation coverage per studied shore kilometre was calculated for each study site in Fig. 7 for the former and the present situation. The four most vegetation rich study sites for the former and




| Lake | Study site | 1947–1963 (ha) | 1996–2000 (ha) |
|---|---|---|---|
| Kemijärvi | Kokkoselkä | 69.0 | 9.0 |
| | Termusniemi | 37.0 | 1.5 |
| | Kaippiosaari | 55.0 | 1.9 |
| | Ollinsaari | 5.3 | 0.2 |
| | Koivusaari | 14.4 | 0.3 |
| | Lammassaari | 1.9 | 0.2 |
| Unnukka | Leveäsaari | 25.6 | 18.2 |
| | Varkaus | 40.3 | 23.4 |
| Näsijärvi | Pengonpohja | 40.6 | 33.7 |
| | Pöllöselkä | 41.7 | 18.5 |
| | Siivikkala | 12.9 | 11.3 |
| | Aitolahti | 19.5 | 15.3 |
| Kallavesi | Lamperila | 17.4 | 23.8 |
| | Autioranta | 5.8 | 27.4 |
| | Vaajasalo | 32.1 | 27.8 |
| | Puutossalmi | 53.5 | 44.1 |
| | Sotkanniemi | 116.2 | 105.3 |
| | Koirusvesi | 10.8 | 18.9 |
| Päijänne | Vähä-Äiniö | 0.9 | 13.7 |
| | Vähäniemi | 13.8 | 21.8 |
| | Mustalahti | 3.0 | 4.3 |
| | Virmaila | 2.6 | 3.6 |
| | Kankarniemi | 10.6 | 12.5 |
| | Kuhmalahti | 14.2 | 15.9 |
| | Säynätlahti | 5.2 | 5.8 |
| | Pihlajalahti | 4.8 | 5.9 |
| | Viisti | 3.5 | 5.8 |
| | Ruolahti | 3.1 | 4.4 |
| | Rutalahti | 29.2 | 41.5 |
| Vanajavesi | Uskilanlahti | 19.7 | 32.5 |
| | Heinunlahti | 8.9 | 18.2 |
| | Kapeikko | 49.1 | 79.3 |
| Pyhäjärvi | Saviselkä | 10.9 | 20.0 |
| | Vakkalanselkä | 8.9 | 14.1 |
| | Vesilahti | 32.3 | 56.0 |

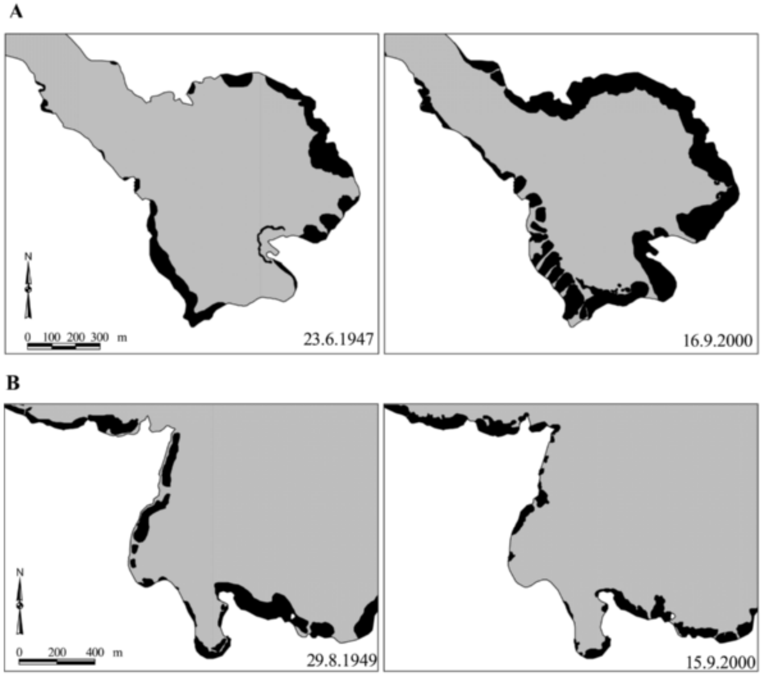
Fig. 5. Vegetation cover changes in different study sites in study lakes during the years 1947–1963 and 1996–2000. The percentage change is shown on the left and different lakes are separated with shading. The actual cover in hectares is in the table on the right.

the present situation were found from Lake Päijänne and Lake Kallavesi. The most vegetation poor study sites were in the former situation in Lake Päijänne and Lake Pyhäjärvi and in the present situation in Lake Näsijärvi and Lake Unnukka.

## Discussion

### Water level regulation

As the occurrence of vegetation on the shore is a mixture of many variables (Spence 1982), the separation of different factors can be hard due to the confounding effect. The results of this study give however new information about the effects of water level changes on emergent aquatic vegetation over a period of half a century. It was statistically shown, that the amount of vegetation cover in study lakes changed along with the water level regulation. The vegetation clearly increased, decreased or nearly stayed the same during the study period in seven large lakes. Changes in the vegetation are not merely due to the yearly water level changes but the regulation dynamics. Even if the regulation limits do not differ much from the natu-



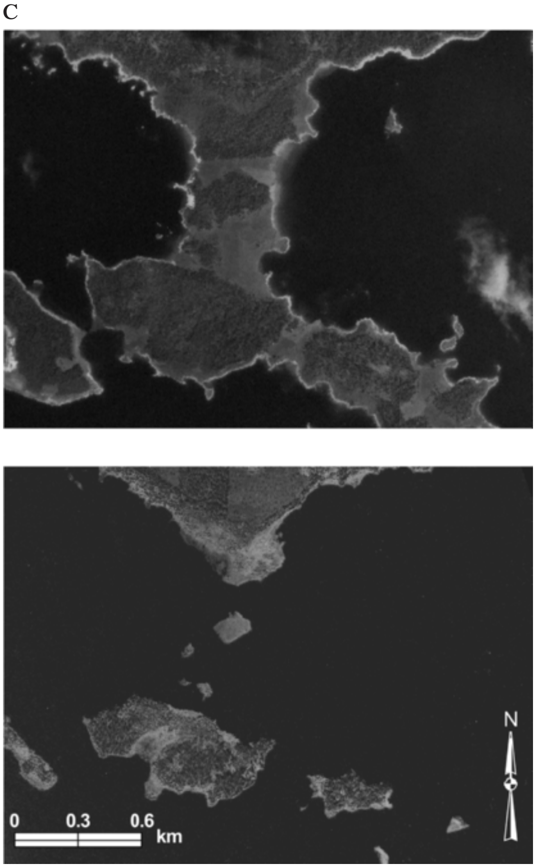




Fig. 6. Changes in the vegetation coverage of three study sites. A) Part of the study site Vesilahti in Lake Pyhäjärvi, with increased vegetation of the lake. B) Part of the study site Pengonpohja in Lake Näsijärvi with decreased total vegetation. C) Part of a study site Kokkoselkä in Lake Kemijärvi with decreased vegetation. The picture above is taken on 16.7.1959 (© National Land Survey of Finland 49/MYY/04) and the picture below is taken on 11.7.1997 (© FM-Kartta Oy).

ral limits, the dynamics of the fluctuation has been greatly altered.

The open water period water levels have been raised at the beginning of the regulation in Kemijärvi, Näsijärvi and Unnukka, in which lakes a vegetation decrease took place in each study site. The vegetation decrease was greatest in Kemijärvi, which suffered from the greatest level rise. The mean water level rise in Lake Unnukka and Näsijärvi resulted in a fall in vegetation coverage as well. Similar observations exist also in other lakes of Fennoscandia. Sjörs and Nilsson (1976), Wallsten and Forsgren (1989) and Hellsten (2001, 2002) have reported a decrease in vegetation with raised water levels. In lakes where water levels exceed the natural levels, the littoral zone is reported to be less uniform and species rich (Quennerstedt 1958; Jonasson 1976; Hellsten 2001). According to Sjörs and Nilsson (1976) the harmful effects of water level regulation are directly proportional to the regulation amplitude, which usually correlates in Finnish lakes with a water level rise during the open water period. The production of the littoral zone is furthermore lower in lakes with higher amplitudes (Quennerstedt 1958). The aquatic vegetation of Lake Kemijärvi has been previously studied by Raitala et al. (1984) and Hellsten (2002), with a report of aquatic vegetation suffering from the

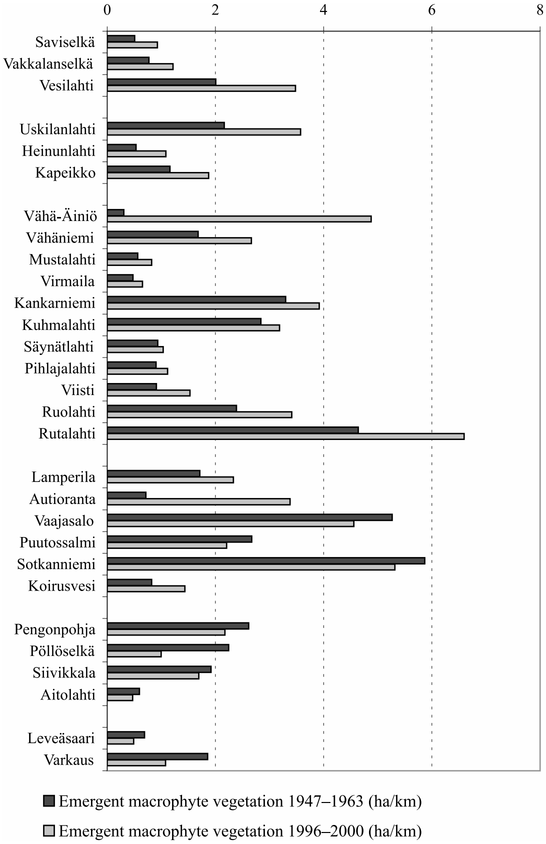



Fig. 7. The amount of vegetation in hectares per studied kilometre of shoreline.

regulation (Hellsten 2002). As the regulation was most intensive in Lake Kemijärvi and the decrease between different study sites of all study lakes was most uniform in Lake Kemijärvi, the proportion of the regulation out of the total vegetation change was biggest in Lake Kemijärvi. The adjustment of the water levels will narrow the belt of the littoral vegetation as well (Riihimäki & Hellsten 1997; Andersson 2001).

Several other studies show that a mean water level decrease from the natural state will result in a vegetation increase (Quennerstedt 1958; Meriläinen & Toivonen 1979; Anttonen-Heikkilä 1983; Toivonen & Bäck 1989; Keränen et al. 1992). The most significant influence on the vegetation compared to the natural state is the change in the spring water levels (Hejny 1971; Juola 1975; Anttonen-Heikkilä 1983; Hellsten et al. 2002b). The spring flood peak is cut down and delayed by 2–4 weeks in Päijänne, Vanajavesi and Pyhäjärvi where the vegetation had increased in each study site in each lake. The effect of the spring flood is based on the different preferences of the emergent vegetation (e.g. Quennerstedt 1958). Some species tolerate the flooding, some species are severely damaged and some benefit from the flooding. The spring flood also removes the decayed material upwards from the shores and when the spring flood is lowered this material will remain in the shore (Hellsten 2000).

The changes in the water level dynamics of the study lakes will explain the major vegetation changes. In the majority of the lakes the changes were uniform between the study sites even if the study sites did differ in the trophy level and other characteristics. The inconsistent vegetation changes in Lake Kallavesi can be explained by the water level dynamics in the lake. Both increased and decreased vegetation changes among the study sites only took place in Lake Kallavesi, which had the mildest water level regulation. Thus the water level regulation is not the major factor affecting the emergent macrophyte changes in Lake Kallavesi. The corresponding regulation studies done abroad are not often comparable with the Finnish studies, because in Finland the regulation interval in usually less than 5 m whereas in Norway and in Sweden it can be up to 20 m. The relatively limited regulation amplitude can be explained by the abundance of lakes in Finland, low terrain altitudes and densely inhabited lakeshores (see Sjörs & Nilsson 1976).

## Eutrophication

The pollution effects on aquatic macrophytes have been investigated in Finland from the 1930s onwards (Maristo 1935; Perttula 1952; Kurimo 1970; Uotila 1971). According to Uotila (1971) pollution became the most important factor affecting the vegetation of Finnish lakes during the 1950s and 1960s. As the primary cause of the nutrient enrichment is the local occurrence of clay and clay-like fine deposits, the occurrence of eutrophy as a primary and purely limnological character is exceptional in the Finnish Lake District (Järnefelt 1958; Vaarama 1961). The secondary eutrophy is likely to develop anywhere as a results of intensive farming or dense population (Järnefelt 1952). Due to the improvement of wastewater treatment the proportion of non-point source pollution, mainly agriculture, has increased (Vuorenmaa et al. 2001).

General eutrophication is mostly reflected on the species composition and abundance of submergent species such as elodeids and ceratophyllids, which are directly taking nutrients via leaves (e.g. Toivonen 1984). Emergent species such as helophytes and nymphaeids are mainly using roots the for same purpose and are therefore not so sensitive for rapid changes in the nutrient level. They are instead reflecting the slow changes in the nutrient content of sediments, which is partly a consequence of eutrophication and partly related to a higher sedimentation rate (Weisner 1991; Coops et al. 1996). According to Kurimo (1970) most taller helophytes and nymphaeids concerned in this study are indifferent to pollution effects or suffering from wastes. It is also well known that increasing eutrophication will lead to a decrease of some common helophytes such as common reed (e.g. Weisner 1991). On the other hand Valta-Hulkkonen et al. (2005) found a clear positive relationship between the colonization degree of helophytes and nymphaeids and the water quality in small Finnish lakes. When the eutrophication or pollution goes further a decline in vegetation can also occur at least in a smaller lake (Pieczynska et al. 1988).

The general water quality trend in large lakes appears to be evident; slightly improved water quality over the past half a century. Unfortunately water quality data does not cover the investigated period and the evaluation of the trends is mainly based on literature. The most significant vegetation increase was observed in lakes Pyhäjärvi and Vanajavesi, where the water quality was most eutrophic. In Lake Vanajavesi the water quality has been improving moderately since the 1960s but there are clear regional differences between different parts of the lake (Riihimäki et al. 2003). Lake Vanajavesi is also situated in nutrient rich areas, which means that background values have also been relatively high (Uotila 1971). Uotila (1971) described the number of aquatic species in Vanajavesi as rather high with a note about most oligotrophic species being missing due to the strong human influence with pollution before. The same previous low status in the water quality and an improvement since the 1970s can be seen in Lake Pyhäjärvi as well (Riihimäki et al. 2003). It is evident that vegetation change might have been enhanced by the eutrophication trend. Today both Lake Vanajavesi and Lake Pyhäjärvi are in general intensively populated and farmed. The effect of the increased nutrient content to the vegetation increase was researched by Wallsten (1981). Her reinvestigations show an enlargement of the vegetation areas in the main part of the lakes, surrounded by arable land. The increased nutrient content had encouraged and increased vegetation in nearly all lakes in 40 years.

In contrast, a vegetation increase took place also in Lake Päijänne, which seems together with Lake Näsijärvi to be by all variables, the most oligotrophic of the study lakes. The investigations of the previous state of Lake Päijänne based on zoobenthos (Särkkä 1979; Sarvala 1996) show a slight decline in the condition already after the 1940s. The state was lower in 1960s–1970s and has been fundamentally improving during the past two decades (Sarvala 1996; Granberg 1998). The water quality also differs at different ends of the lake. It has been most eutrophic in the northern part and oligotrophic in the southern part of Päijänne (Hellsten 2000). Inconsistently the largest change was observed in the southern part of the lake. Also in Lake Näsijärvi the water quality has been improving clearly since the 1960s (Riihimäki et al. 2003). Contradictory vegetation changes of these two lakes with similar water quality status show the importance of water level fluctuation; relatively small changes in the summer time water level have significantly affected emergent vegetation. The vegetation decrease in Lake Näsijärvi and a vegetation increase in Lake Päijänne found in our study were largely supported by the observations of Rintanen (1996). The effect of a rise in water levels has been reported also in raised eutrophicated lakes, where the water level has just been raised once due to restoration purposes; in many cases the helophytes have disappeared almost totally (Rintanen 1996). No special long term trend was observed in Kallavesi, but the water quality in northern Kallavesi differs greatly from the oligotrophic waters in the south, being close to the upper limits of mesotrophy (Hellsten et al. 2002a). It could partly explain the increase of vegetation in the north and decrease in the southern part of the lake.

The water quality in this study has referred to the existing water quality classification in Finland. The classification has been done according to the usability of the waters for human benefits, and environmental conditions such as naturally nutrient rich soils are not included in the classification. Water quality samples have been taken from the pelagial areas of the lakes and this does not represent the water quality of sheltered bays. The water quality data available in this form is insufficient to assist spatiotemporal changes from the 1950s onwards covering all study lakes, since large-scale water monitoring has been effected with accepted criteria only from the early 1970s (Vuoristo 1998).

As a conclusion the water quality of the studied lakes has improved during the years but the studied vegetation has still increased in many lakes. Many decades of nutrient loading has increased the nutrient availability in the littoral zone and relatively quick changes in the water quality do not affect the nutrient status of plants taking the nutrients with their roots from the bottom sediments. In spite of these obvious patterns the cover changes of emergent vegetation in studied lakes are not explained by eutrophication history. Especially the opposite trend of vegetation development in lakes with a similar history of nutrient loading emphasizes the importance of the water level fluctuation regime and other factors.

## Effect of geology

The physico-chemical conditions of the bottom sediments are very significant factors affecting macrophytes (Keddy 1983). The occurrence of clay and clay associated deposits were found to explain vegetation changes. According to Järnefelt (1952, 1958), eutrophic lakes are situated mainly in south-western Finland in the south of Salpausselkä due to submergence during the glacial period particularly in the region of Hämeenlinna–Tampere. Soils along the shores in Lake Pyhäjärvi and Lake Vanajavesi are especially dominated by silt and clay and the vegetation increase was biggest among those study lakes.

Lake Pyhäjärvi is in many ways an exception among research lakes; there is a notable increase in vegetation, although a significant water level rise should reduce the vegetated area. It seems that relatively nutrient rich waters and suitable soil quality keep the production of emergent macrophytes high and the vegetation is more resistant against water level fluctuation. The soil type differences applied also between the study sites. The vegetation increase was quite equal between the two sheltered and soft bottom study sites in Lake Vanajavesi but slightly larger in the open lake hard bottom study site. Despite the dual changes, the study sites in Kallavesi have always been abundant with vegetation as the vegetated area per kilometre shows. At Lake Unnukka even if the vegetation had diminished in both sites the Varkaus study site rich in clay, compared to the Leveäsaari study site, had more vegetation in both the former and present situation.

The occurrence of clay does not explain all the vegetation changes. The vegetation increase in Päijänne is not in connection with clay deposits, as the dominant soil is moraine and major clay areas are outside the study sites. The biggest vegetation increase took place in southern Päijänne, where the dominant soil is sand. Open, sandy shores with oxygen rich waters are favoured by vegetation compared to muddy sheltered shores lacking oxygen (Weisner 1991). The invasion of the common reed (*Phragmites australis*) could be the main reason for the expansion of vegetation cover as noted by Keto et al. (2002).

The fastest change in the topographical factors group is the land uplift. The isostatic uplift after the glacial period has affected the normal development of the lakes (Vaarama 1961). The isostatic uplift affects the slope of the lake basin especially in long lakes situated transversely against isoclines (Renqvist 1952). The difference in the vertical height of lake ends of the longest study lake Päijänne has resulted in several metres of new shore in northern Päijänne during the study period (Hellsten 2000). The land uplift works correspondingly in Lake Kallavesi as well due to the north-south direction. If the land uplift would be the determining factor for macrophyte changes, north sides of both lakes should be more vegetation rich. The results do not support the theory, because an increase was observed also in the southern parts of the lakes.

When considering large lakes, the lake size plays an important role. The exposure is one of the most important factors affecting aquatic macrophytes (Segal 1971; Keddy 1983; Weisner 1991). Very open study sites such as Mustalahti, Virmaila and Säynätlahti carried less vegetation both in hectares and compared to the rest of the study sites. From the 25 lakes studied by Wallsten (1981), the vegetation cover increase did not occur in the largest lakes having the longest shoreline and a low percentage of the lake area covered by the vegetation. Naturally the depth limits the maximum extent of the vegetation (Spence 1982), and according to Wallsten (1981) longer shorelines give a larger range of different habitats and this reduces the competition and increases the species diversity. In this study, Lake Päijänne showed the biggest differences in the coverage between different study sites and this was shown statistically. Even if the study sites were relatively short in Päijänne, the size of the lake compared to the other lakes was considerable. Different habitat characteristics differ very much between each site as would not be in a smaller lake.

### Other human induced factors

The littoral zone has been commonly used as animal pasture in Finland and taller helophytes were cut for winter-feeding purposed from the shore (Vaheri 1932). Shore pasture practices were still common in Finland in the 1950s, but ceased largely during the turn of the 1960–1970 with intensified farming. Evidence of this practice has been reported at least from Näsijärvi (Maristo 1935) and Vanajavesi (Uotila 1971). In Päijänne evidences of large scale animal pastures on shores are until the mid 1970s, but in some places pasturing is still in use (Hellsten 2000). It was estimated that in Vanajavesi of all the shores, which were not too steep or rocky, the majority of the shores have been pastured in this century. At the end of the 1960s the proportion of pastured shores was only a fraction of the previous proportion (Uotila 1971). The effect of pasturing varies and mostly taller helophytes suffer from it (Vaheri 1932; Meriläinen & Toivonen 1979; Uotila 1997), which are soon replaced by vascular grasses (Maristo 1935). The effect of pasture almost ceases after 1 m of depth (Maristo 1935). The end of this practice naturally had an impact on vegetation increase. It may partly explain the increase of vegetation in the shallow parts of Lake Vanajavesi.

Even if invasive species are not usually a problem in Finland, Uotila (1971) mentioned the most important factor responsible for the changes during the first half on this century being the invasion of reed sweet-grass (*Glyceria maxima*). This relatively rapidly spreading grass is extremely tolerant against water level fluctuation and forms floating islands. Studies by Riihimäki et al. (2003) show that it was one of the most common species in Lake Pyhäjärvi and Vanajavesi. The relatively clear increase of vegetation in spite of the raised water level in Lake Pyhäjärvi might be explained by the invasion of it (Andersson 2001). Geomorphologic characteristics such as not having exposed shores will diminish the degradation of vegetation by wave erosion. Vegetation removal by cutting can also be counted as a human induced factor affecting vegetation (Uotila 1971). Restoration activities are mainly concentrated on shores under recreational use, which are not so common on shallow vegetation rich shores in large lakes. According to Hellsten (2000) only 7% of the shoreline of Lake Päijänne was affected by dredging or other restoration activities although the overgrowth of vegetation was one of the main problems of the lake.

### Methodological aspects and error sources

A visual aerial interpretation of emergent aquatic macrophytes, mainly helophyte and floating leaved vegetation in large boreal lakes, was found to be successful in this study. Methodology based on manual mapping means is still used in the latest macrophyte studies (Fredriksen et al. 2004) and it allows the acquisition of species specific data and the combination of older and newer aerial photography sets which are often problematic. The use of aerial photographs provided a method for studying the water level regulation impacts before and after the regulation on the same lakes as the impact assessment is often based on regulated and non-regulated reference lakes (Alasaarela et al. 1989). The methodology includes however several error sources due to the diverse set of primary data. There are study lakes where all the photographs are not taken during the same year either from the newer material or from the older. A year difference in the vegetation coverage can be considerable (Anttonen-Heikkilä 1983) as the temperature, water level fluctuation etc. vary between years. A general interpretation key is hard to develop (Wallsten 1974; Valta-Hulkkonen et al. 2003a), as photographs taken at different times of the year and in different years result in varying conditions (Andersson 1972). Acquiring the same photograph sets from different decades was a compromise. The economical resources of the projects defined the limits for the amount of study sites and the quality and amount of aerial photographs. The aerial photographs were not all taken during the best season from July to August, due to the limited availability of the photographs. The photographs have been taken during different periods of the growing season and in a few cases early summer photographs were compared with later summer months and vice versa. For example the study site Pöllöselkä was the only study site in Lake Näsijärvi were the later summer situation from 1950 and early summer situation from 1998 were compared and the vegetation decrease was noticeably largest in Pöllöselkä. The study site Saviselkä was the only site in Lake Pyhäjärvi where photographs from the same time of the growing season were compared, but the vegetation increase was generally even in all study sites.

Clearly defined and dense macrophyte populations were easily separated from the older black and white material, but sparse populations turned out to be more problematic (Andersson 1972). In clear water bottom sand can easily be mixed with vegetation, shallows or sun reflectance, and algae blooms or such turbidity can complicate the interpretation. The quality of the older photographs varied. Stereo glasses were used to obtain a three-dimensional view enabling the differentiation between vegetation and non-vegetation. Errors in data collection resulting from the interpretation of older and newer photographs are possible. The shore line has changed either due to human influence by dredging and construction or by natural overgrowth or isostatic uplift, and this makes it hard to distinguish the boundary of the shore. The shadows of the shore trees produced problems in a few newer photographs. Unnatural vegetation boundaries in some current photographs gave evidence of restorations and this has an effect on the interpretation result. The number of study sites per lake should have been equal and the length of the study sites should have been comparable between the lakes. The study sites should have been geographically distributed more evenly.

Having the emphasis only on quantitative changes can obscure the fact that some species have been increasing and some decreasing, or expanding landward (Andersson 2001) resulting in a zero effect. Furthermore, in this study the vegetation change was only measured at the beginning and at the end of the study period and there might have been situations where the vegetation had been peaking and coming down to the same point. By using historical data the fact that it represents one certain moment and not a long period of time (Dömötörfy et al. 2003) has to be acknowledged. Vegetation change was also measured to the extent of emergent macrophytes as the life forms other than helophytes and nymphaeids are often poorly or not at all detected from the aerial photographs (Andersson 2001; Jäger et al. 2004; Valta-Hulkkonen et al. 2003a). The majority of the study areas have been in sheltered bays. They do not naturally represent the situation of the entire lake but often open sections lack vegetation to be researched (Andersson 1972). As this study was conducted in large lakes, there are vast regional differences firstly between the study lakes and secondly between the different study sites in the lakes. Environmental factors such as water quality or soil type vary in the different parts of the lake. Large lakes consist of a vast number of different habitats among the parts of the lake and different environmental factors such as slope angle, exposure or land use vary strongly. These important factors have not been considered here and will be left for future purposes.

## Conclusions

The visual aerial photo interpretation proved to be a useful tool in distinguishing the changes in the coverage of emergent aquatic vegetation. It allowed the comparison of the situation before and after regulation without using reference lakes. It showed, that the total vegetation coverage had clearly decreased in three lakes, stayed almost the same in one lake and increased clearly in three lakes. Using several study sites per lake resulted in finding that the coverage in different study sites in study lakes varied from a majority of quite uniform change over the whole lake to increased and decreased coverages in adjacent sites.

From the geographical features affecting the coverage of emergent macrophytes in large lakes in Finland, the geological aspects in general were found to be the most important. Geology defines the occurrence and magnitude of many other factors which affect macrophyte growth: the size and the depth of the lake, the slope and the exposure of the shore, soil type and bottom quality. Geology contributes to the nutrient content of the lake and primary eutrophication. Indirectly the geology affects the type and magnitude of human settlement in the area and further has an impact on the secondary eutrophication.

From the anthropogenic features water level regulation has most significantly affected the coverage in study lakes and this was shown statistically. Regardless of the different physical properties of the lakes, such as geology, size, depth or location, the study lakes were easily separated according to the vegetation coverage change and the water level variation. A water level rise during the open water period at the beginning of the regulation decreased the cover of the vegetation in several lakes. On the contrary the lowering of the water level during the open water period increased the vegetation. The change in the spring water levels compared to the natural state increased the cover of emergent macrophytes.

Despite the fact that certain trends were distinguished in this study there is a need to acquire more site specific data of different factors. The differences within the study lakes in vegetation coverage were partly extensive so there is a need to separate in more detail the affecting factors including local water quality and for example variation in exposure. The use of the shore areas in Finland has dramatically changed from the 1950s with the change of society and communities in many places. Animal pasture was widely in use still in the 1950s along with unregulated water levels both decreasing the amount of vegetation. Urbanization along with industrial development has brought many changes to the littoral zone not least the water level regulation. Even if the water quality seems to have improved, the environmental changes have been strong and they work with a delay.

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