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# Influence of EU policy on agricultural nutrient losses and the state of receiving surface waters in Finland

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In Finland, the first large-scale efforts to control nutrient loading from agriculture got under way with the introduction of the EU Agri-Environmental Program in 1995. We examined whether these efforts have decreased agricultural nutrient losses and improved the quality of receiving waters. To do so we used monitoring data on fluxes of nutrients and total suspended solids in agricultural catchments in 1990–2004 and on the water quality of agriculturally loaded rivers, lakes and estuaries in 1990–2005. No clear reduction in loading or improvement in water quality was detected. Hydrological fluctuations do not seem to have eclipsed the effects of the measures taken, since there was no systematic pattern in runoff in the period studied. The apparent inefficiency of the measures taken may be due to the large nutrient reserves of the soil, which slowed down nutrient reductions within the period studied. Simultaneous changes in agricultural production (e.g. regional specialisation) and in climate may also have counteracted the effects of agri-environmental measures. The actions to reduce agricultural loading might have been more successful had they focused specifically on the areas and actions that contribute most to the current loading.

*Key words*: Agriculture, eutrophication, nutrients, water quality, runoff, rivers, lakes, estuaries, climate change

## Introduction

In Finland, the first large-scale efforts to reduce nutrient inputs from agriculture were started in 1995, when the country joined the European Union (EU) and introduced measures to implement its Agri-Environmental Program (EEC 1992). The main objective of the program is to reduce nutrient loads to surface waters, ground waters and the air. Additional objectives are to reduce the risks caused



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by plant protection, to maintain or increase biodiversity, to manage rural landscapes, to preserve humus in soil and to secure good conditions for agriculture. To be eligible for agri-environmental support, farmers had to implement all the basic measures plus one additional measure. They could also apply special voluntary actions. The conditions for support were modified between the first and second program periods (Table 1). In 1995–1999, about 88% of agricultural land was covered by the Agri-Environmental Program and in 2000–2006 over 90%. During the first period, the sum paid to farmers by the program totalled €259 million $yr^{-1}$ and during the latter period about €297 million $yr^{-1}$ (Ministry of Agriculture and Forestry 2004, Niemi and Ahlstedt 2005). According to an *a priori* estimate, adoption of the agri-environmental support scheme would decrease both erosion and nutrient losses into water bodies by some 20–40% (Valpasvuo-Jaatinen et al. 1997).

The Nitrates Directive (EEC 1991) was transposed to national legislation in 2000 (partially in 1998). The Decree contains provisions on good agricultural practices, storage of manure, spreading and allowable quantities of fertilisers and silage liquor, analysis and recording of N in fertilisers

Table 1. Main requirements of the Finnish Agri-Environmental Program in its first (1995–1999) and second (2000–2006) periods (Valpasvuo-Jaatinen et al. 1997, Ministry of Agriculture and Forestry 2004).

| Requirement | Period | Measures |
|---|---|---|
| Basic (Compulsory) | 1995–1999 and 2000–2006 | Farm-scale environmental planning and monitoring<br>Balanced fertilisation of arable crops<br>Good agricultural practices on livestock farms (storage and application of manure mainly regulated by Nitrates Directive)<br>1–3 m filter strips along waterways<br>Environmentally sound use of agro-chemicals |
| | 1995–1999 | At least 30% of arable land covered by crops or crop residues during winter in southern Finland |
| | 2000–2006 | Maintaining biodiversity and open landscape |
| Additional (One had to be chosen) | 2000–2006 | Arable cropping:<br>– Fertilisation based on crop, expected yield and soil test P<br>– Plant cover in winter or reduced tillage<br>– Biodiversity on farms<br>Livestock farming:<br>– Reducing ammonia emissions during manure storage and gaseous emissions in manure processing<br>– Improving welfare of animals<br>– Treatment of dairy wastewater |
| Special | 1995–1999 and 2000–2006 | Riparian zones<br>Wetlands and sedimentation ponds<br>Organic production<br>Balanced use of manure<br>Traditional biotopes<br>Other measures to enhance biodiversity<br>Improvement and management of open landscape<br>Raising local breeds and cultivation of local crops*<br>Measures to decrease acidity of soil and runoff<br>Controlled drainage and irrigation, recycling of drainage water |
| | 2000–2006 | Reducing N losses in arable farming in groundwater areas |

* The latter only in the second period.

and enforcement of the Decree (Mitikka et al. 2005). The Nitrates Directive applies to the whole of Finland without regional or local differentiation. The Water Framework Directive (EC 2000) is a more recent EU-driven pressure on agriculture. It requires the state of surface waters to be sustained and improved by controlling the input of nutrients, the aim being for all surface waters to have a good ecological status by 2015. This objective calls for assessment of the reference conditions of surface waters. Reference conditions are considered to prevail when disturbances due to human activities are very low or non-existent (EC 2000).

Before 1995, water protection measures within agriculture were implemented through advice and extension with the exception of the short-lived tax on P-fertilizers and obligatory set-aside intended to reduce over-production (Valpasvuo-Jaatinen et al. 1997). In 1995, the national set-aside obligations were replaced by those of the EU, which increased actively cultivated land area from 1.84 million hectares in 1990–1994 to about two million hectares after 1995 (see Fig. 1 for changes in area of set-aside, grasses and cereals). The increase in the cultivated land area may have counteracted the effects of agri-environmental measures to some extent. Moreover, average farm size has increased, agriculture has become more specialised, and the regional division between animal and crop farms has widened since Finland acceded to the EU (Lehtonen and Pyykkönen 2005, Niemi and Ahlstedt 2005). These tendencies have probably aggravated manure problems, among other things, by increasing the pressure to spread manure in autumn. Moreover, the area of grassland has declined (Fig. 1), increasing the vulnerability of soil to erosion and N losses.

Recent national policies may also have affected agricultural nutrient losses. For example, the Environmental Protection Act and Decree (issued in 2000) require permits and inspections on large animal farms. In addition, the raising of cattle outdoors in winter and the exercising of animals have become more common, both of which may increase nutrient losses (Uusi-Kämppä 2002, Uusi-Kämppä et al. 2007). Furthermore, the area of direct sowing has increased. Direct sowing effectively curtails erosion but increases losses of dissolved P (Puustinen et al. 2005). On the other hand, fertiliser applications, and consequently soil surface nutrient balances, have been decreasing in Finland since 1990 (Ministry of Agriculture and Forestry 2004).

Recent assessments of agricultural impacts on aquatic systems showed no clear reduction in either nutrient loading or eutrophication (Mitikka and Ekholm 2003, Räike et al. 2003, Granlund et al. 2005, Ekholm and Mitikka 2006). This may partly be explained by the lag period between the measures taken and the desired outcome due to the large nutrient reserves accumulated in the soil (Stålnacke et al. 2003, 2004). The effects of agri-environmental measures may be further obscured

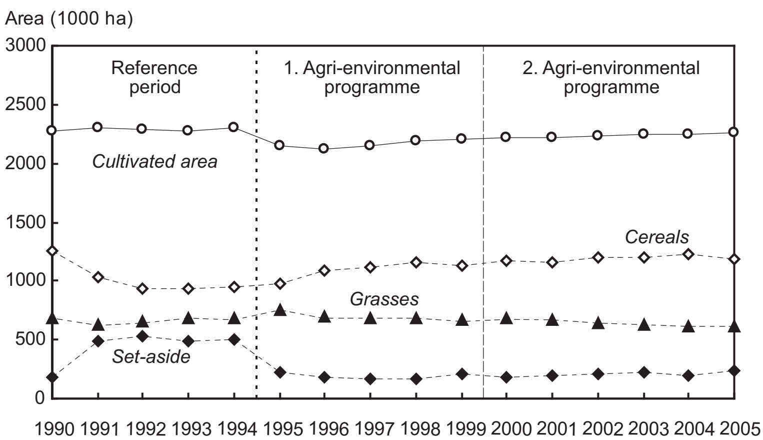


Fig. 1. Area of agricultural land in Finland in 1990–2005. Data from the Information Centre of the Ministry of Agriculture and Forestry.

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by variations in hydrology, especially outside the growing season, when fields lack vegetation to take up nutrients or prevent erosion. When a mild and rainy winter follows a rainy autumn, concentrations of total suspended solids (TSS) and particulate P (PP) in runoff may be double what they are when a cold winter follows a dry autumn (Puustinen et al. 2007). Observations from exceptionally mild winters indicate that N losses, too, can increase (Kallio et al. 1997). Wivstad et al. (2005) reported mineralisation of organic matter in agricultural soils outside the growing season, suggesting that the leaching of soluble nutrients depends on both runoff and soil processes. Winter runoff increased in southern and central Finland during the 20$^{th}$ century, as did annual discharges in the south and west to some extent. Precipitation increased in southern and central Finland, but there were no signs of long-term trends in annual evaporation (Hyvärinen 2003). There has been a clear rise in spring (March–May) air temperatures during the last 150 years (Tuomenvirta 2004), and the winters since 1988 have been milder than average (Drebs et al. 2002).

Because of the variations in nutrient losses, runoff, weather and farming practices, the differences produced by agricultural practices are hard to distinguish from those caused by other factors (Vagstad et al. 2004, Kronvang et al. 2005). In Norway, the concentration of TSS and total P (TP) declined due to erosion control and improved management of animal manure (Bechmann and Stålnacke 2005). In Sweden, downward trends in dissolved reactive P (DRP) and in $NO_3$-N from small agricultural catchments may have been due to a reduction in manure application (especially in autumn) and a change in crop distribution (Kyllmar et al. 2006). On the other hand, in Swedish agricultural rivers, the recent decreasing trends observed in reactive N may have been related to an increased area of catch crops and set-aside, a reduced area of autumn tillage and more efficient production (Ulén and Fölster 2007). In Denmark, a reduction in agricultural nutrient balances (41% for N and 42% for P), for example, resulted in a decrease in total N (TN) in agricultural streams, but no significant trends were found for TP (Kronvang et al. 2005).

None of the Finnish studies, except that of Granlund et al. (2005), which covered only the first programme period (1995–1999), concentrated explicitly on the effect of agri-environmental measures required by the EU. Since many of these measures have now been in operation for more than ten years, their effects should be visible in the environment. We sought to look for changes in agricultural nutrient loading and in the state of agriculturally impacted surface waters with the aid of monitoring data collected by the environmental authorities on small-, medium- and meso-scale agricultural catchments, rivers, lakes and coastal waters. Further, we investigated the reference state of agriculturally loaded lakes on the basis of sediment diatom assemblages. Our study is the first effort to compile all relevant monitoring data from agriculturally loaded waters in Finland. Since hydrological changes can mask the effects of water protection measures, special emphasis was paid to analysing trends in runoff.

# Material and methods

## Study sites

The trend in nutrient fluxes (kg km$^{-2}$ yr$^{-1}$) was analysed on the basis of water quality and flow measurements in two small-scale catchments (Savijoki, 15.4 km$^2$, of which 39% was cultivated; Löytäneenoja, 5.64 km$^2$, 68% cultivated), one medium-scale catchment (Yläneenjoki, 233 km$^2$, 27% cultivated) and 13 meso-scale rivers discharging into the Baltic Sea (listed in Fig. 5, 487–4923 km$^2$, proportions of fields and lakes in the catchment 21–44% and 0.3–13%, respectively). All these sites were located in southern and western Finland (Fig. 2).

Runoff from the two small catchments was sampled manually (ca. 15 yr$^{-1}$) and automatically [ca. 30–50 yr$^{-1}$ flow-weighted, see Vuorenmaa et al. (2002)]. In the Yläneenjoki catchment, the sampling frequency was 12–70 yr$^{-1}$. In these three catchments, the dominant production sector was cereal cultivation, the present proportion of animal farms being approximately 20% (Mattila et al. 2007). As there are no lakes in the catchments and artificial drainage is widely used on the fields, the residence time of water is short, and nutrient retention in the surface waters is therefore probably low. The 13 meso-scale rivers were typically sampled 12–20 $yr^{-1}$.

Annual loads of TP, DRP, TN, $NO_x$-N and $NH_4$-N for the two small-scale catchments were provided by Vuorenmaa et al. (2002) in 1990–1997. These data were complemented with calculations of annual loads for nutrients for 1998–2004, and for TSS in the entire study period. In the Yläneenjoki catchment and the 13 meso-scale rivers, annual losses were calculated for each variable. The load estimates presented below represent the sum of all non-point losses, point-source loading and natural background. Point-source loading was low or nonexistent, except in the River Porvoonjoki, where it accounted for approximately one quarter of the TN flux. The contribution of natural background was also low, as were impacts of forestry practices. Thus, at all sites, agriculture was the main source of nutrients.

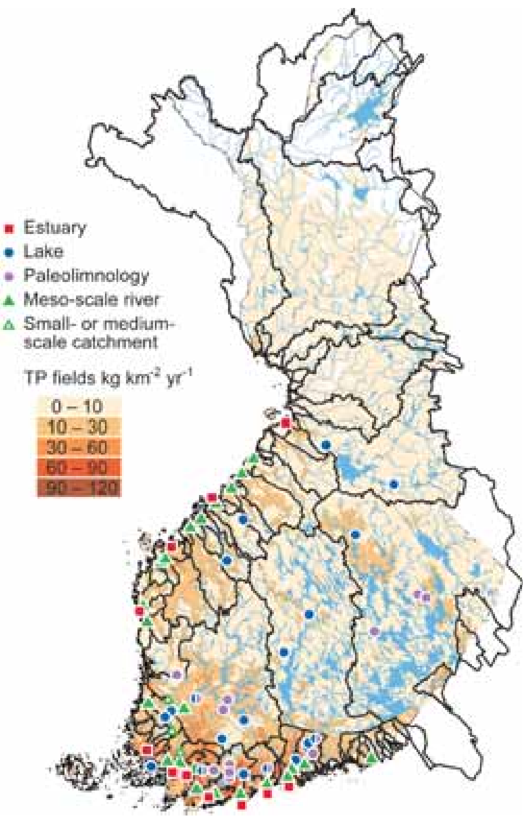


Fig. 2. Study sites and an estimate of agricultural loading in Finland based on the assessment system [VEPS, Tattari and Linjama (2004)] of the Finnish Environment Institute. The main river catchment areas are marked with lines.

As well as changes in fluxes, trends in water quality were examined in 20 rivers, 20 lakes and 12 estuaries, all impacted by agriculture (Fig. 2). The river data set consisted of ten of the above rivers (excluding the Siuntionjoki, Loimijoki and Närpiönjoki) plus 10 other rivers discharging into the Baltic Sea. Their catchments ranged from 357 to 4923 $km^2$ and the field and lake proportions of the catchments from 9.4% to 44% and from 0.2 % to 13%, respectively. All sites received nutrients from other sources besides agriculture. For details of the rivers, see Mitikka et al. (2005).

The 20 lakes studied are listed in Table 2 and have been described in detail by Ekholm and Mitikka (2006). Their size ranged from 0.4 to 155 $km^2$ and their maximum depth from 1.7 to 68 m. The majority did not undergo thermal stratification in summer. Of their catchment area, 6% to 41% was agricultural land, the remainder consisting of forest and peatland. At all sites, agriculture was the main anthropogenic source of nutrients. Some of the lakes were subject to in-lake restoration. The lakes were sampled approximately 1–9 times a year.

Because algal blooms are a serious problem, particularly in small Finnish lakes, temporal changes in the intensity and frequency of algal blooms during 1998–2005 were also evaluated. The data were based on the Finnish monitoring network of algal blooms, which comprises 145 lake sites situated throughout the country and varying in size, depth and trophy. Local environmental authorities have visually estimated algal abundances weekly in summer since 1998 (Lepistö et al. 1998).

The 12 estuaries (15 sites) studied (listed in Table 3, except for Mustijoki and Närpiönjoki) varied from well-mixed, stratified estuaries and relatively enclosed systems to winding, island-rich systems and relatively simple pocket estuaries. They were small (2–101 $km^2$) and shallow (mean

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Table 2. Water quality trends (Kendall's *tau*-b) of 20 agriculturally loaded lakes in 1990–2005. Late summer upper water layer. Empty space = no data.

| Lake | Total N | $NH_4$-N | $NO_x$-N | Total P | *a*-chlorophyll | Secchi depth | Turbidity |
|---|---|---|---|---|---|---|---|
| Ahmasjärvi | | | | | | | |
| Ahveninen | –0.05 | | 0.18 | 0.30 | 0.03 | –0.33 | –0.11 |
| Enäjärvi | –0.25 | –0.25 | –0.56* | –0.44* | –0.14 | 0.66** | –0.34 |
| Juoksjärvi | 0.21 | | 0.17 | 0.26 | 0.39* | –0.53** | 0.07 |
| Karhijärvi | –0.42 | –0.48* | 0.10 | 0.05 | –0.53* | 0.22 | –0.05 |
| Kirkkojärvi | –0.38 | –0.43* | –0.44 | –0.41* | –0.23 | 0.39 | |
| Kirmanjärvi | 0.02 | –0.26 | –0.27 | –0.21 | –0.10 | 0.01 | |
| Köyliönjärvi | 0.16 | –0.46* | –0.13 | 0.34 | –0.30 | –0.14 | 0.45* |
| Lappajärvi | 0.43* | –0.18 | 0.36 | 0.04 | –0.02 | –0.09 | 0.16 |
| Lehijärvi | 0.10 | –0.31 | –0.19 | 0.11 | 0.11 | –0.33 | 0.11 |
| Pusulanjärvi | 0.46* | –0.29 | 0.12 | 0.43* | 0.17 | –0.16 | 0.45* |
| Pyhäjärvi (Säkylä) | –0.01 | –0.14 | 0.07 | –0.09 | 0.33 | –0.10 | 0.30 |
| Pyhäjärvi (Tammela) | 0.04 | | –0.39 | 0.02 | 0.37 | –0.52* | 0.20 |
| Pyhäjärvi (Artjärvi) | –0.24 | –0.01 | –0.20 | 0.00 | 0.16 | –0.04 | 0.16 |
| Sotkamojärvi | 0.72** | –0.11 | 0.05 | 0.57* | 0.38 | –0.42 | 0.72** |
| Sääskjärvi | 0.16 | | | –0.07 | 0.28 | –0.22 | 0.11 |
| Tiiläänjärvi | –0.11 | | | 0.29 | | | |
| Ullavanjärvi | 0.50* | –0.20 | 0.31 | 0.36 | 0.29 | –0.53 | |
| Villikkalanjärvi | 0.25 | 0.23 | –0.05 | 0.18 | 0.04 | –0.37 | 0.40 |
| Ylisjärvi | 0.08 | 0.06 | –0.39 | 0.22 | 0.24 | 0.07 | 0.43* |

* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$

depth 3.8–18 m), with a salinity below 6 psu and a residence time from 0.04 to 5.62 yr. All the estuaries were non-tidal, the northern Baltic Sea having a weak tide of less than 3 cm on average (Myrberg et al. 2006). The proportions of fields in the catchments ranged from 10% to 43%. Three of the estuaries received direct point source loading (Porvoonjoki, Pohjanpitäjänlahti, Halikonlahti). The estuaries have been discussed in greater detail by Meeuwig et al. (2000) and Kauppila et al. (2003). The estuaries were sampled approximately 24 times a year.

Finally, for paleolimnological studies, sediment samples were taken from 15 agricultural lakes (fields in the catchment 11%–34%) in 2003 and diatoms were analysed from the top (0–2 cm) and bottom (30–90 cm) sediments [sampling and analysis described by Räsänen et al. (2006)]. Surface sediments represent present conditions and deeper sediments background conditions (Cumming et al. 1992, Miettinen et al. 2005). Bottom samples were taken from the homogenous sediment below any visible signs of human-disturbance, such as changes in sediment colour or composition. The lakes have been subjected to anthropogenic impacts for a long time and therefore the background conditions do not necessarily represent the pristine state, but rather the reference conditions described in the Water Framework Directive (EC 2000).

In summary, data were analysed from 72 agriculturally impacted sites (excluding the algal bloom lakes). Based on an estimate of the assessment system [VEPS, Tattari and Linjama (2004)] of the Finnish Environment Institute, the sites cover the areas with high agricultural loading of P (Fig. 2) rather well. The monitoring programmes from which the data were derived have been described by Niemi (2006).

Table 3. Water quality trends (Kendall's *tau*-b) in agriculturally loaded estuaries in summer (16 Jul–15 Sep) and winter (Jan– Apr) in 1990–2005. Upper water layer, except for oxygen saturation, which is from near-bottom water. Empty space = no data.

| Estuary/ Site | Total N | $NH_4$-N | $NO_x$-N | Total P | *a*-chlorophyll | Secchi Depth | Turbidity | $O_2$ saturation |
|---|---|---|---|---|---|---|---|---|
| Summer | | | | | | | | |
| Porvoonjoki | –0.05 | –0.23 | –0.33 | 0.08 | –0.33 | 0.06 | 0.30 | –0.26 |
| Vanhankaupunginlahti | –0.08 | 0.13 | –0.12 | –0.10 | –0.20 | –0.05 | 0.33 | 0.05 |
| Pikkalanlahti | 0.35 | –0.03 | –0.32 | 0.08 | 0.34 | –0.35 | | 0.13 |
| Pohjanpitäjänlahti | | | | | | | | |
| – Inner | –0.15 | –0.08 | | –0.25 | 0.07 | –0.09 | –0.35 | –0.17 |
| – Outer | 0.17 | –0.27 | 0.05 | –0.17 | 0.17 | –0.35 | –0.14 | –0.41* |
| Halikonlahti | | | | | | | | |
| – Inner | –0.06 | 0.18 | 0.04 | 0.15 | –0.11 | –0.18 | 0.15 | –0.29 |
| – Outer | 0.45 | –0.32 | | 0.15 | 0.55* | 0.00 | –0.06 | 0.21 |
| Paimionlahti | | | | | | | | |
| – Inner | 0.23 | | | 0.13 | 0.18 | –0.19 | 0.29 | –0.20 |
| – Outer | 0.54** | –0.36 | 0.14 | 0.39* | 0.24 | –0.41* | 0.47* | –0.11 |
| Mynälahti | 0.27 | –0.03 | –0.14 | 0.17 | 0.10 | 0.13 | 0.05 | 0.17 |
| Kyrönjoki | –0.22 | | | –0.2 | | | | |
| Perhonjoki | | | | | | | | |
| – Inner | –0.09 | –0.01 | –0.03 | –0.30 | –0.43* | 0.33 | –0.44* | 0.09 |
| – Outer | –0.19 | –0.18 | 0.09 | –0.24 | –0.53** | 0.64*** | –0.62** | 0.05 |
| Liminganlahti | 0.51* | 0.24 | 0.16 | –0.13 | 0.16 | | –0.36 | 0.27 |
| Winter | | | | | | | | |
| Vanhankaupunginlahti | 0.2 | 0.16 | 0.13 | 0.11 | | 0.22 | –0.16 | –0.38 |
| Pikkalanlahti | –0.04 | | | 0.29 | | –0.32 | | 0.27 |
| Pohjanpitäjänlahti | | | | | | | | |
| – Inner | –0.12 | 0.10 | | –0.26 | | 0.24 | –0.30 | –0.12 |
| – Outer | –0.46* | –0.35 | –0.54** | –0.23 | | 0.31 | –0.49* | –0.11 |
| Halikonlahti | | | | | | | | |
| – Inner | –0.14 | –0.17 | 0.10 | –0.36 | | 0.33 | –0.12 | –0.07 |
| – Outer | 0.20 | 0.13 | 0.11 | –0.09 | | 0.28 | –0.27 | 0.02 |
| Paimionlahti | | | | | | | | |
| – Inner | –0.28 | –0.29 | | –0.39* | | –0.32 | –0.22 | 0.31 |
| – Outer | 0.05 | –0.01 | 0.01 | 0.02 | | 0.07 | –0.19 | 0.00 |
| Mynälahti | 0.33 | –0.05 | 0.29 | 0.04 | | 0 | –0.02 | –0.01 |
| Kyrönjoki | –0.22 | | | –0.20 | | | –0.45 | |
| Perhonjoki | | | | | | | | |
| – Inner | –0.14 | –0.40* | | –0.55** | | –0.13 | –0.27 | 0.08 |
| – Outer | 0.32 | 0.30 | 0.60** | 0.10 | | | 0.44* | 0.23 |
| Liminganlahti | 0.2 | 0.24 | | 0.24 | | | | –0.04 |

* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$

## Analyses of water quality

The level of chlorophyll *a* (a-chl) was determined spectrophotometrically from an acetone (since 1994 from an ethanol) extract of the matter retained by fibreglass filters. Oxygen was analysed by Winkler's method. Total N determination was initiated by digestion with peroxodisulphate, followed by reduction of $NO_3$ with a Cd amalgam and determination of $NO_2$ by the azo colour method. $NO_3$-N and $NO_2$-N were analysed using the same basic procedure as described above, and $NH_4$-N was analysed by the indophenol blue method. The sum of $NO_3$-N and $NO_2$-N ($NO_x$-N; the concentration of $NO_3$-N was used if $NO_2$-N was lacking) is given below. Phosphorus analysis was performed by the molybdenum blue method with ascorbic acid as a reductant (Murphy and Riley 1962). For determination of TP, the sample was digested with potassium peroxodisulphate before the P analysis. Total dissolved P (TDP) and DRP were analysed on a filtered sample (Whatman/ Nuclepore polycarbonate, pore size 0.4 µm); in the analysis of TDP, the sample was digested before staining, whereas DRP was determined without digestion. Reactive P (RP) was analysed similarly to DRP, but on an unfiltered sample. Dissolved inorganic P (DIP) was assumed to be equal to DRP and dissolved inorganic N to the sum of $NO_x$-N and $NH_4$-N. TSS were analysed gravimetrically by filtering samples with Nuclepore filters. Secchi depth was determined with a white disc and turbidity nephelometrically. Faecal enterococci were enumerated by a membrane filter technique and m-Enterococcus agar at 35 or 37 °C for two days.

## Data analysis

Water quality and daily water flow data were extracted from the data bases of the Finnish Environment Institute. Annual losses of nutrients and TSS from the agricultural catchments were estimated using the period method (Rekolainen et al. 1991). To level off the effect of annual variation in the observed fluxes, 5-year mean fluxes were examined for the following three periods: 1990–1994 (the reference period when the agri-environmental programme was not yet applied), 1995–1999 (the first period of the programme) and 2000–2004 (the second period of the programme).

The trends in the analysed concentrations in the runoff from agricultural catchments were studied using the non-parametric partial Mann-Kendall test of Libiseller and Grimvall (2002), which accounts for seasonality and adjusts the concentrations with water flow (flow being a covariate). Owing to the scarcity of data, only two seasons were included (Jan–Jun and Jul–Dec) in the trend analysis for the two small catchments; in larger catchments, monthly mean values were used. DRP was analysed in small and medium-sized catchments and TDP in the meso-scale catchments.

The water quality of the 20 rivers was studied by calculating the annual and seasonal (summer, 15 Jul–30 Sep; winter, Jan–Apr) median concentrations for the three periods. All available observations from all depths were used. The seasonal medians within the periods did not differ much from each other, though the winter medians tended to be somewhat higher than the summer ones, particularly for $NH_4$-N. Only annual values are presented below.

Water quality trends in lakes and estuaries (1990–2005) were analysed using Kendall's *tau*-b. In lakes, the trend analysis was carried out for the 0–2-m layer and the near-bottom water layer for summer (16 Jul–15 Sep) and winter (Jan– Apr). In estuaries, the analysis was performed for the inner and outer sampling sites of each estuary on samples taken at 1 m (a-chl from 0 to 2–4 m) and near the bottom. In estuarine data, July to September represented summer, and February and March winter.

Algal bloom sites were divided by expert judgement into agriculturally impacted sites ($n$ = 57) and other sites ($n$ = 88). Algal blooms were classified as four abundance classes (0 = not visible, 1 = present, 2 = abundant, 3 = very abundant). A bloom index was calculated as the relative number of observations weighted by the abundance of the algal bloom. The index was first calculated for every year, and then averaged over the years for each site. The maximum value of the bloom index is 3, which was obtained when all (non-missing) weekly observations were classified as very abundant. To characterize the lake population, the water chemistry (0–2 m) at sampling sites nearest each algal bloom observation site in July–August 1998–2005 was examined. For each sampling site and water quality variable, first the annual means and then the period medians were calculated.

Finally, the long-term changes in 15 agricultural lakes were analysed by the transfer function of Kauppila et al. (2002), which describes the relationships between fossil sediment diatom assemblages and the concentration of TP in water (Stroemer and Smol 2000, Battarbee et al. 2001, Smol 2002, Miettinen 2003). The calibration data set for the model consisted of 61 southern Finnish lakes with an autumnal epilimnetic TP range of 3–89 µg $l^{-1}$. The transfer function was generated with the simple weighted averaging regression (Ter Braak and van Dam 1989).

Meriläinen et al. (1983) listed the typical diatom species found in productive and disturbed Finnish lakes surrounded by fields, and Miettinen (2003) presented the indicator species for agricultural areas. These species are *Aulacoseira ambigua*, *A. granulata*, *A. perglabra*, *A. tenella*, *A. subarctica*, *Cyclostephanos dubius*, *Stephanodiscus hantzschii*, *S. minutulus*, *Cyclotella stelligera*, *C. pseudostelligera*, *Asterionella formosa*, *Fragilaria brevistriata*, *F. construens, F. lapponica*, *F. pinnata* and *Navicula pupula*. Changes in amounts of these diatoms were also examined here.

## Hydrology

Annual and seasonal trends (May–Sep; Oct–Dec; Jan–Apr) during 1990–2004 in daily discharge ($m^3$ $s^{-1}$) and monthly cumulative runoff (mm) in all 23 rivers described above were analysed by linear regression analysis. Generalised Least Squares estimation with an ARMA-type model was applied to include autocorrelation of residuals (Brockwell and Davis 2002).

In addition, changes in extreme values (floods) between the agri-environmental programme period (1995–2004) and the preceding 10-year period (1985–1994) were examined. The magnitude of an extreme event is inversely related to its occurrence such that severe floods occur less frequently than moderate ones. Seasonality of floods was studied by means of frequency analysis (Chow et al. 1988). The annual maximum discharge in winter, summer and autumn was selected from recorded discharge time series. Extreme values were assumed to follow Gumbel's distribution. An increase (decrease) in the extreme value was assumed when the value in the latter period exceeded (went below) the 95% confidence interval of the extreme value of the first period.

North Atlantic Oscillation (NAO) is a recurrent pattern of atmospheric circulation variability and has been connected to hydrology in several studies (e.g. Yoo and D'Odorico 2002, Kalayci and Kahya 2006). It refers to a redistribution of atmospheric mass between the Arctic and the subtropical Atlantic. Positive values of the winter mean index indicate stronger-than-average westerly flows over the middle latitudes. An enhanced westerly flow across the North Atlantic in winter moves warm and moist maritime air over northern Europe, causing winters in Finland to be mild and rainy. The NAO index was compared with annual discharge in rivers and streams from which data were available from at least the 1960s. Data on annual discharges at each site were divided into two subsets according to the NAO index, i.e. the years with a negative NAO index and those with a positive NAO index. The relationship between the mean discharge and the NAO index was studied using Kendall's correlation.

# Results

## Trends in discharge

No annual or seasonal trend was observed in daily discharge or monthly cumulative runoff in any of the catchments (data not shown). Moreover, no trend was found in the winter NAO index, which was positive in 12 out of 16 years during 1990–2005 (see Fig. 3). The NAO index correlated with the annual mean discharge in three (Aurajoki, Loimijoki, Kalajoki) of the 13 rivers with long discharge data (data not shown).

There were no changes in the 10-year design flood (the maximum discharge taking place once every ten years) of the rivers in southern Finland (Virojoki, Porvoonjoki, Mustijoki, Vantaanjoki, Karjaanjoki, Kiskonjoki, Uskelanjoki) between

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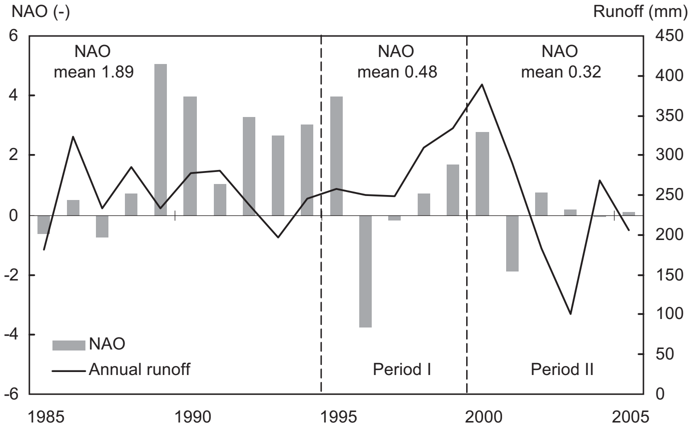


Fig. 3. NAO index and annual runoff in the River Aurajoki in 1985–2005.

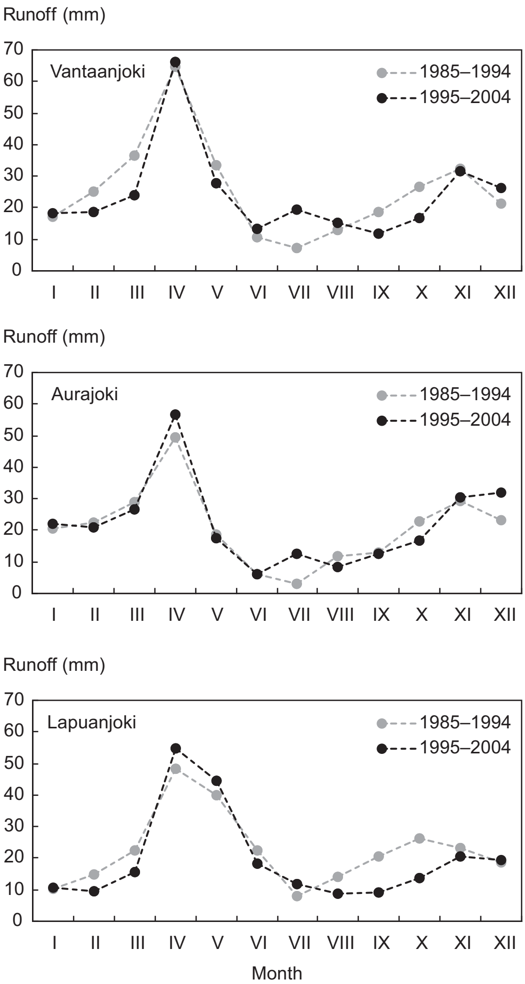


Fig. 4. Mean monthly discharge in the Rivers Vantaanjoki, Aurajoki and Lapuanjoki in 1985–1994 and 1995–2004.

1985–1994 and 1995–2004. However, in the rivers of south-western Finland (Paimionjoki, Aurajoki, Yläneenjoki, Loimijoki) the summertime design flood was lower during 1995–2004 than during 1985–1994 ($p < 0.05$). This pattern also applied to the Perhonjoki, a river in western Finland. By contrast, in several rivers (Kyrönjoki, Lapuanjoki, Ähtävänjoki, Kalajoki) in an area with intensive animal production in western Finland, the winter design flood tended to be higher in 1995–2004 than in the preceding period. A comparison of monthly mean discharges in western Finland (Fig. 4) showed that the spring flow peak was more pronounced and the autumn discharge lower during 1995–2004. In the other two regions, no clear pattern emerged.

## Trends in agricultural nutrient fluxes

Figure 5 shows the mean runoff and the mean fluxes of nutrients and TSS from the 16 agricultural catchments in the reference period (1990–1994) and in the two periods of the agri-environmental programme (1995–1999 and 2000–2004). Although there were no statistically significant trends in daily, seasonal or annual water runoff, the five-year mean runoff tended to decrease from the reference period to the second stage of the agri-environmental programme in many catchments. To account for this pattern, we here examine the trends in flow-adjusted concentrations.

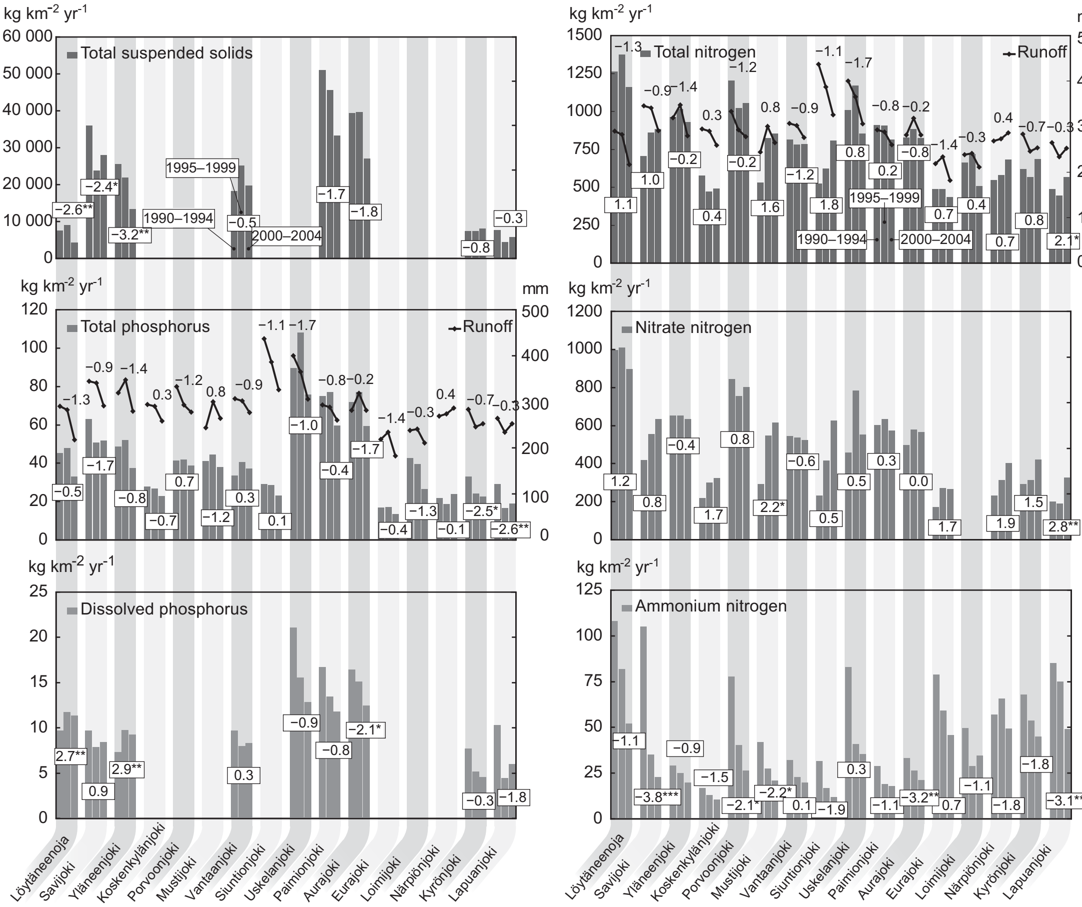


Fig. 5. Mean fluxes of nutrients and total suspended solids (bars) and mean runoff (lines) from agricultural small- to meso-scale catchments by three 5-year periods. Dissolved reactive phosphorus given for the Löytäneenoja, Savijoki and Yläneenjoki catchments and total dissolved phosphorus for other catchments. Partial Mann-Kendall test for trends in the concentrations given in boxes and those in runoff above the lines (years 1990–2004). * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

Concentrations of TSS decreased in each of the eight catchments with adequate data, although the trends were statistically significant only in the three small- and medium-scale ones (Fig. 5). As to TP, a decreasing trend was found in 13 of the 16 study sites, those for the Kyrönjoki and Lapuanjoki being significant. In the case of dissolved P, about half of the sites showed an increasing and about a half a decreasing trend, the Löytäneenoja and Yläneenjoki catchments having a significant increasing and the Aurajoki a significant decreasing trend. Most trends in TN and $NO_x$-N were increasing, although only those in the Lapuanjoki (TN, $NO_x$-N) and Mustijoki ($NO_x$-N) rivers were significant. $NH_4$-N was mostly decreasing, five trends being statistically significant.

## Trends and levels of nutrients in rivers, lakes and estuaries

Figure 6 shows the median concentrations of TP, TN, $NH_4$-N and a-chl in the agriculturally loaded

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rivers (no data on a-chl), lakes and estuaries. No clear pattern emerged here, except for $NH_4$-N which was mostly decreasing. In two intensively restored lakes (Enäjärvi and Kirkkojärvi), water quality improved. For example, in Kirkkojärvi, the TP median decreased from about 300 $\mu$g $l^{-1}$ in 1990–1999 to about 60 µg $l^{-1}$ in 2000–2005 (Fig. 6). No distinct changes could be found in the medians of the remaining water quality variables (e.g. nutrient fractions).

Table 2 shows the trend analysis for lake water quality. In summer, TP in the surface water layer increased statistically significantly in two out of 19 lakes with adequate data for trend analysis and decreased in the two restored lakes. TN increased significantly in four lakes. Of the nutrient fractions, $NH_4$-N showed a decrease in nearly all the lakes, three of the trends being significant. Turbidity mostly increased and Secchi depth decreased. Wintertime oxygen saturation increased in one lake and decreased in one. In addition TP, RP and turbidity decreased in one lake (data not shown). The trend analysis for estuarine data did not reveal any general pattern apart from the decreasing $NH_4$-N in many estuaries (Table 3). In the Paimionlahti estuary, the significant trends in TP, TN, Secchi depth and turbidity suggested intensifying eutrophication.

In 1998–2005, algal blooms were more common in agriculturally impacted than in non-agricultural lakes. The bloom index in the agricultural lakes was about twice that in the other lakes (Fig. 7). Abundant (class 2) and very abundant (class 3) blooms were also more common in agricultural lakes. The annual bloom index never exceeded 0.5 (Fig. 7), which indicates that severe blooms did

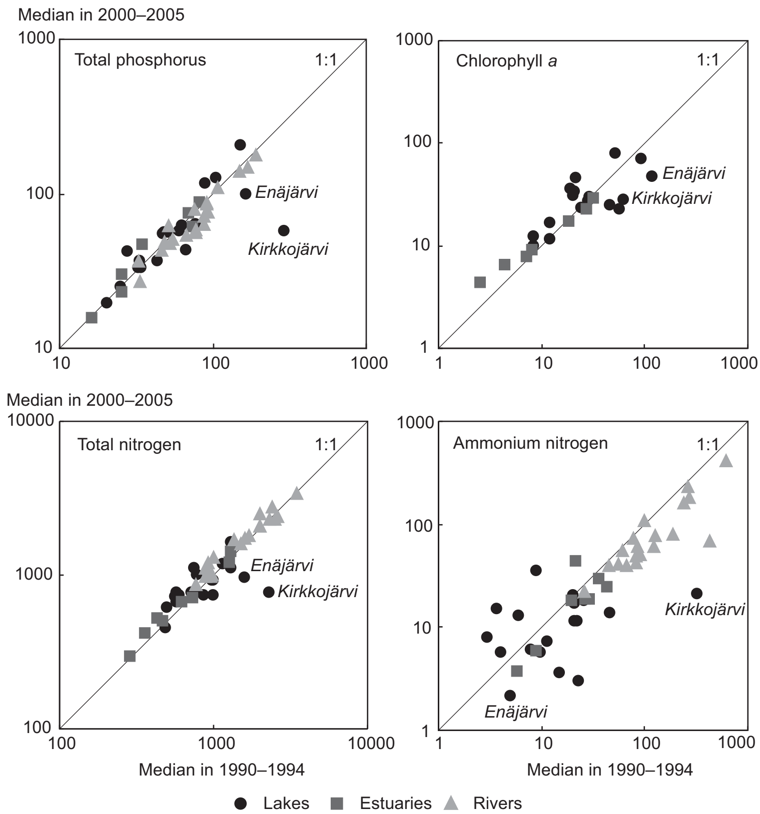


Fig. 6. Median concentrations of chlorophyll *a*, total phosphorus, total nitrogen and ammonium nitrogen by two periods in rivers, lakes and estuaries. For rivers annual data, for lakes and estuaries summer upper water data.

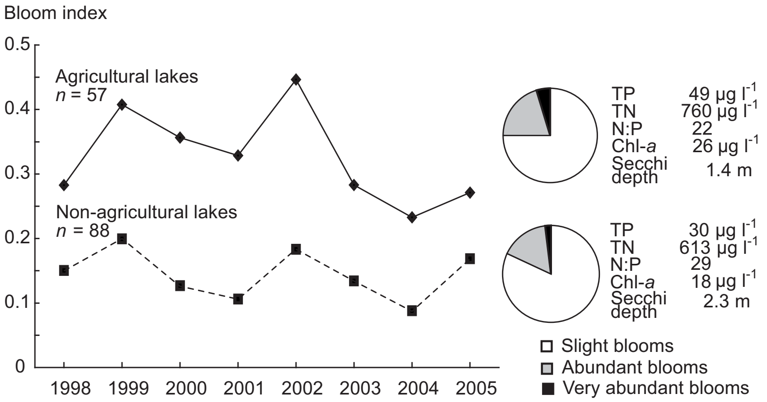


Fig. 7. Algal bloom index, relative amount of slight, abundant and very abundant blooms for all years studied and average water chemistry for agricultural and non-agricultural lakes in 1998–2005. The division between agricultural and non-agricultural lakes is based on expert judgement.

not last long. TP, TN and a-chl were higher in the agricultural than in the other lakes. Correspondingly, Secchi depth was lower in the agricultural lakes.

## Sediment diatoms

The diatoms in both bottom (representing background) and top sediments (representing present conditions) were typical of nutrient-rich environments, and the algal assemblages were dominated by only a few species. In 11 of the 15 lakes, the diatom-inferred concentration of TP increased towards the present (Fig. 8). In three lakes, Valkerpyy, Ylisjärvi and Aneriojärvi, the diatom-inferred concentration of TP approximately doubled. In two lakes, Särkijärvi and Mäyhäjärvi, where TP decreased, the present algal communities consisted mainly of small, benthic *Fragilaria* species and, in Mäyhäjärvi, of *Achnanthes minutissima*. These diatoms have wide tolerances of P and are thus poor indicators of the nutrient status of lakes. Their increase may indicate changes in diatom habitats, for example, an increase in macrophyte vegetation at the shores, rather than a change in nutrient concentration.

Generally, the relative abundance of the species typical of productive agricultural lakes was greater in top than in bottom sediments (Fig. 9). Planktonic taxa, *Stephanodiscus hantzschii* and *S. minutulus,* were found only in surface sediments and *Asterionella formosa* and *Cyclotella pseudostelligera* were also more common in samples representing present conditions. *Aulacoseira* species, *Cyclotella stelligera*, selected *Fragilaria* species and *Navicula pupula* did not show clear preferences, being abundant both in background and present conditions.

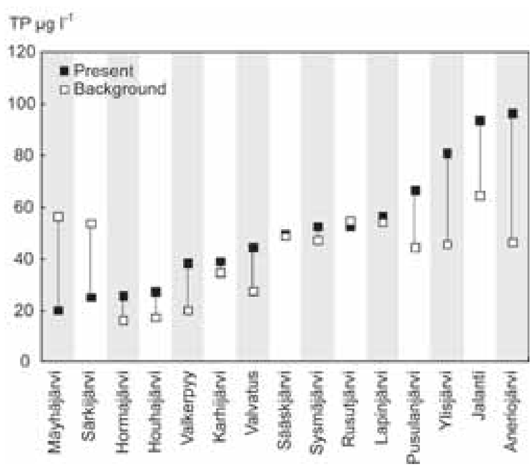


Fig. 8. Diatom-inferred total phosphorus concentrations in top (present) and bottom (background) sediments of the lakes studied. See text for definition of background.

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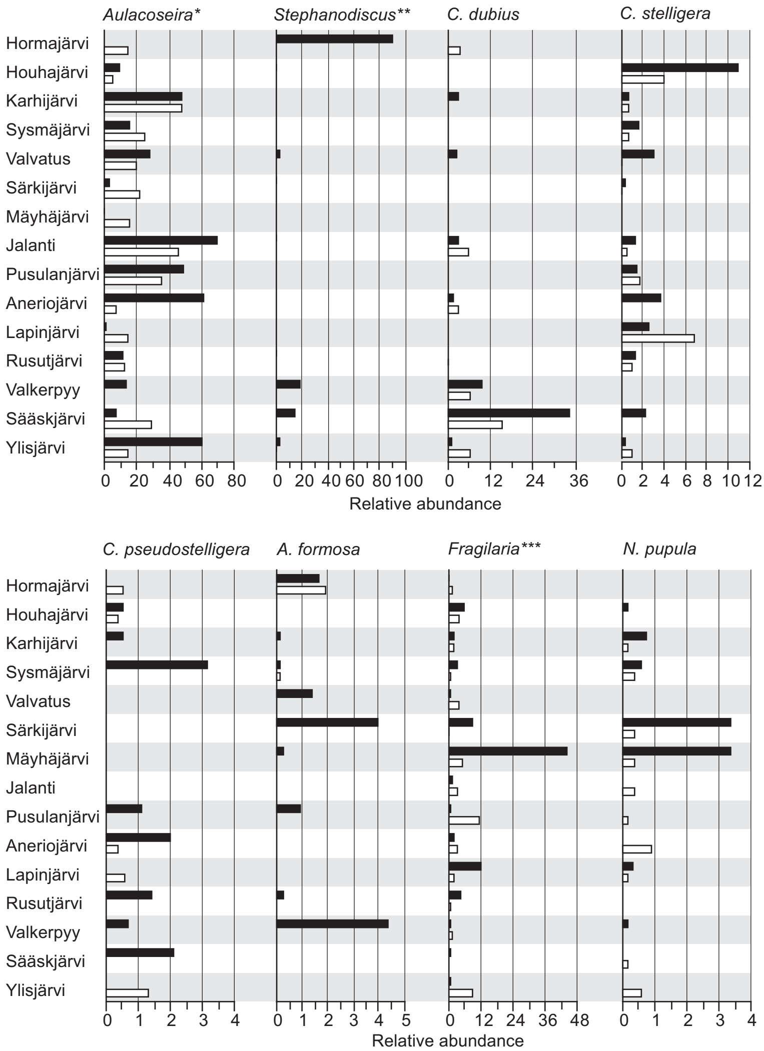


Fig. 9. Indicator species (see text) for productive, agricultural and disturbed lakes in top (black bars) and bottom samples (open bars), corresponding to present and background conditions. Lakes are classified according to their field percentage in the catchment area, Lake Ylisjärvi having the highest percentage of fields. *Aulacoseira** is a composite taxa of *Aulacoseira ambigua*, *A. granulata*, *A. perglabra*, *A. subarctica* and *A. tenella*. *Stephanodiscus*** is a sum of *Stephanodiscus hantzschii* and *S. minutulus/parvus*. *Fragilaria**** stands for *Fragilaria brevistriata*, *F. construes* f. *construens*, *F. lapponica* and *F. pinnata*.

# Discussion

Hydrology causes strong fluctuations in runoff and nutrient losses. However, we found no trends in daily discharge or monthly runoff in 1990–2005. Examination of two 10-year periods demonstrated an increase in the intensity of spring floods in western Finland and a decrease in that of summer floods in south-western Finland in 1995–2004 compared with 1985–1994. Rivers in western Finland are naturally fast flowing and floods develop rapidly. In addition, their catchments are effectively drained and river channels have been heavily modified for hydropower. In 1995–2004 there were some negative NAO indices, which may explain the increased spring floods, as years with a negative NAO index tend to have colder winters and higher spring snow-melt peaks than years with mild winters. The increase in spring floods may affect erosion and PP flux to some extent in western Finland, although the region is not very susceptible to erosion. However, the shifted frequency in summer floods probably does not have much effect on nutrient transport or erosion, because summer floods are typically low and vegetation protects the soil surface. Consequently, we could not detect any systematic large-scale changes in hydrology that might have significantly contributed to nutrient losses.

Small and medium-sized catchments showed evidence of decreasing TSS losses and increasing DRP losses. Such a pattern might result from an increased acreage of minimum cultivation, as observed, for instance, in the Yläneenjoki catchment (Pyykkönen et al. 2004). Depending on the soil properties, a change from traditional autumn ploughing to reduced tillage can lower the amount of erosion, but the loss of DRP may increase due to the accumulation of soluble P in the topsoil (Puustinen et al. 2005, Muukkonen et al. 2007, Turtola et al. 2007, Uusitalo et al. 2007b). In contrast to the observations in small- and medium-scale catchments, dissolved P decreased in some meso-scale catchments. Fertilizing with P has decreased in Finland (Ministry of Agriculture and Forestry 2004). However, the response of soil P status to changes in the soil surface balance of P is slow (Ekholm et al. 2005) and increase in soil P status levelled out not until in the late 1990s (Uusitalo et al. 2007a). The concentration of DRP in agricultural runoff has been found to be linearly dependent on soil P status (Uusitalo and Jansson 2002). The decrease in $NH_4$-N loss observed in many catchments may be due to implementation of the Nitrates Directive, which prohibits the spreading of manure in late autumn and winter. High losses of $NH_4$-N in agricultural runoff are often associated with wintertime or autumn surface application of manure (Niinioja 1993, Turtola and Kemppainen 1998), since the temperature is then too low for effective nitrification. However, otherwise the concentrations of $NH_4$-N are typically small and thus their contribution to TN losses is often negligible. Evidence of increasing N losses was observed at several sites. During 1990–2004, the net input of N to agricultural soil fell from 160 to 120 kg ha$^{-1}$, the highest N surpluses being found in the areas with intensive animal production (Salo et al. 2007). Field-scale modelling shows that losses of N will decrease if less N is applied in manure and fertilisers (Granlund et al. 2007, Rankinen et al. 2007). In Denmark, reduced use of N in agriculture resulted in lower concentrations of N in runoff (Kronvang et al. 2005), whereas no such change was found in riverine N concentrations within a few years of a drastic decline in application of N in the Baltic States (Löfgren et al. 1999). That we found an increase rather than a decrease in N may be attributed to greater specialisation and to regional intensification of animal husbandry. It would be tempting to link the increase in N to greater pressure to apply manure in autumn and to a smaller acreage of set-aside. Alternatively, the mineralisation of N may have been promoted by climate change (Kallio et al. 1997); mineralisation of soil organic matter outside the growing season increases the N concentrations of runoff (Rankinen et al. 2004).

The fluxes and medians presented here are somewhat uncertain, because the sampling was not flow-proportional (Rekolainen et al. 1991). This is especially true of TP and TSS (Haraldsen and Stålnacke 2006). In addition, incidental losses (Preedy et al. 2001) related to manure spreading have very likely been missed entirely. However, the failure of a clear systematic pattern to emerge from the analysis of 72 agriculturally loaded sites strongly suggests that, thus far, the agri-environmental measures applied in Finland have neither markedly decreased nutrient fluxes nor improved the state of receiving waters.

Sediment diatoms suggest that agricultural lakes that were rich in nutrients before the onset of modern agriculture have become more eutrophic. This is in accordance with the results of other paleolimnological studies on long-term water quality trends in Finnish agricultural lakes (Kauppi et al. 1990, Räsänen et al. 2006). However, in shallow agricultural lakes, sedimentation conditions may lead to sediment reworking that confuses paleolimnological interpretations. Some of these lakes have been partially drained to provide more arable land or to prevent floods. Such man-made changes further complicate estimation of the pristine state of Finnish agricultural lakes. In some estuaries impacted by agriculture, the first changes in species composition indicating eutrophy took place in the 1940s, coinciding with the intensification of Finnish agriculture. No simultaneous increase in diatom-inferred water TN concentrations was observed (Weckström 2006). The status of rural estuaries was lowest in the 1980s. Today, the mean of diatom-inferred total dissolved nitrogen (TDN) in rural estuaries departs by up to 20% from its reference conditions in the late 1880s, which is less than observed in urban estuaries (Weckström 2005).

Algal blooms were more common in agriculturally impacted than in other lakes. This finding confirms the earlier observation that agricultural lakes are the most eutrophic lake type in Finland (Mitikka and Ekholm 2003). It is difficult to conclude decisively whether the recurrent blooms are only due to anthropogenic nutrient loading or partially also due to the location of the lakes in fertile catchments, especially as algal blooms are a natural phenomenon occasionally observed in all waters (McGowan and Britton 1999).

# Conclusions

No consistent and systematic decreases in losses of nutrients (except of $NH_4$-N) from agricultural catchments were found when the Agri-Environmental Program period (1995–2004) was compared with the reference period (1990–1994). Consequently, no clear improvement in the state of agriculturally impacted rivers, lakes or estuaries was detected. Hydrological fluctuations do not appear to have eclipsed the effects of the measures taken, since there was no systematic pattern in hydrology in the period studied. The lack of explicit results may partly be due to the increased area of agricultural land and to the intensification of agricultural production in EU Finland. The conditions set for agri-environmental support for the third period (2007–2013) will be stricter in some respects, e.g. the application of P in fertilizers. Our study supports this new rigorous requirement. Reducing N fluxes in the changing climate calls for special attention. The agri-environmental measures carried out in Finland so far have not effectively taken into account the huge spatial diversity in agricultural loading. The programme could probably achieve better results if the measures focused specifically on the areas and actions that contribute most to the current loading.

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# SELOSTUS

## EU:n ympäristöohjelman vaikutus vesien ravinnekuormaan ja tilaan

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Maataloudestamme peräisin olevan ravinnekuorman vähentäminen aloitettiin laaja-alaisesti vuonna 1995, jolloin Suomessa käynnistettiin EU:n maatalouden ympäristöohjelma. Tässä tutkimuksessa selvitettiin valtakunnallisten seuranta-aineistojen perusteella, onko maatalouden ravinnekuorma ja maatalouden kuormittamien jokien, järvien ja rannikkovesien tila muuttunut verrattaessa kautta 1990–1994 kausiin 1995–1999 ja 2000–2004.

Yksiselitteistä kuormituksen vähentymistä ei havaittu. Eräillä alueilla ammoniumtypen ja kiintoaineen kulkeuma vähentyi, mutta vastaavasti liuenneen fosforin kuorma nousi. Myös vastaanottavien vesien tila pysyi pääosin ennallaan. Jos maatalouden vesiensuojelutoimet olisi kohdennettu kaikkein kuormittavimmille alueille, niiden teho olisi ehkä ollut parempi. Toisaalta maatalousmaan suuret ravinnevarat hidastavat kuormituksen vähenemistä. Vuodesta toiseen voimakkaasti vaihtelevat hydrologiset olot vaikeuttavat maatalouden toimien vaikutusten havaitsemista seuranta-aineistoissa. Muutokset hydrologiassa eivät kuitenkaan selittäneet vähäistä muutosta maataloudesta peräisin olevassa kuormassa. Maataloustuotannon keskittyminen ja erikoistuminen samoin kuin ilmaston muutos ovat voineet vähentää ympäristötoimien vaikutusta.