

Net loading system for fish farming

Trash fish reduction and internal loading

Zeynep Pekcan-Hekim and Jukka Horppila



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Abstract

Trash fish removal as an environmental measure to establish a new type of environmental net load and permission system for Baltic Sea fish farming was evaluated in a preliminary study in 2007. This report is part of the project and presents the results from a literature survey. The aim of the survey was to determine whether any other positive consequences in addition to the effect of nutrient removal existed e.g., if internal loading or bioturbation by the fish would diminish.

Although numeric estimation is very difficult and caution is needed in interpreting the result, a very preliminary quantitative assessment of the effects is given.

It was estimated that a reduction of 300 metric tons of fish biomass in the Archipelago Sea (this is not the amount of fish caught) would reduce the internal nitrogen load by an amount that equals 10% of the fish farming load in the area and 9% of the phosphorus load.

Keywords: Fish farming, environment, nutrient load, trash fish removal

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Tiivistelmä

Tässä työssä arvioidaan julkaistujen tutkimusten perusteella, missä määrin tehokkaan kalastuksen avulla voisi olla mahdollista kompensoida kalankasvatuksen ravinnekuormitusta Saaristomerellä sen lisäksi, että kalastus poistaa ravinteita kalabiomassan mukana. Lähinnä tällä tarkoitetaan tehokkaan kalastuksen vaikutusta kalaston aiheuttamaan sisäiseen ravinnekuormitukseen.

Kalastuksen sisäisessä kuormituksessa aiheuttaman pienentymisen kvantitatiivinen arviointi voidaan tehdä vain hyvin karkealla tasolla, sillä asiaan vaikuttavat monet seikat. Pohjaravintoa käyttävät kalat aiheuttavat sisäistä ravinnekuormitusta, kun taas planktonia syövät kalat vain kierrättävät vedessä jo olevia ravinteita.

Kalankasvatuksen ulkoinen kuormitus Saaristomerellä on n. 25 000 kg fosforia ja n. 200 000 kg typpeä vuodessa. Kalojen fosforin ja typen eritysnopeuksien perusteella voidaan laskea, että jos keskimäärin 50 g:n painoisten kalojen biomassa alueella vähenee 300 000 kg:lla (esim. 3 kg jokaiselta hehtaarilta 1 000 km² alueella), vuotuinen kalojen aiheuttama sisäinen fosforikuormitus pienentyy n. 2 100 kg:lla. Tämä vastaisi n. 9:ää % kalankasvatuksen aiheuttamasta ulkoisesta fosforikuormituksesta. Typen osalta vastaava biomassan pienentäminen vähentäisi vuotuista kalojen aiheuttamaa sisäistä kuormitusta n. 21 000 kg, mikä vastaisi n. 10 % kalankasvatuksen ulkoisesta kuormituksesta.

Laskelmat sisältävät lukuisia olettamuksia ja epävarmuustekijöitä. Arviot perustuvat kalojen biomassan pienentymiseen tietyllä alueella, eivät kalansaaliin määrään. Edellä olevan esimerkin mukaiseen biomassan vähentymiseen pääsemiseksi voidaan tarvita moninkertainen saaliin määrä.

Itämeren ravintoverkot ja vaikutusketjut ovat erilaisia kuin sisävesillä, joissa suurin osa tässä työssä referoiduista tutkimuksista on tehty. Niiden perusteella ei voi suoraan tehdä Itämeren koskevia johtopäätöksiä.

Asiasanat: hoitokalastus, kalankasvatus, kuormitus, ravinteet, tehokalastus, ympäristö, ympäristöluvut

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Sammandrag

På basen av publicerade undersökningar bedöms, i vilken utsträckning det med ett effektivt fiske skulle var möjligt att kompensera fiskodlingens näringsbelastning i Skärgårdshavet, bortsett från att fisket avlägsnar näringsämnen med fiskbiomassan. Med det avses närmast den inverkan, som ett effektivt fiske har på fiskbeståndets inre belastning.

Endast en grov bedömning kan göras av det kvantitativa värdet för den belastningsminskning, som åstadkoms genom fisket, eftersom förhållandet påverkas av ett flertal faktorer. De fiskar, som utnyttjar föda från botten förorsakar en inre belastning, medan planktonätande fiskar enbart cirkulerar de näringsämnen som redan finns i vattnet.

Fiskodlingens yttre belastning i Skärgårdshavet är ca 25 000 kg fosfor och ca 200 000 kg kväve per år. På basen av den hastighet med vilken fiskarna utsöndrar fosfor och kväve kan man beräkna, att om biomassan för fiskar med medelvikten 50 g minskar i området med 300 000 kg (t.ex. 3 kg per hektar på ett 1 000 km² stort område), minskar den inre fosforbelastning, som fiskarna förorsakar, med ca 2 100 kg. Detta skulle motsvara ca 9 % av den yttre belastning, som förorsakas av fiskodlingen. För kvävet del skulle en motsvarande minskning av biomassan reducera den årliga inre belastningen från fisken med ca 21 000 kg, vilket skulle motsvara ca 10 % av fiskodlingarnas yttre belastning.

Kalkylerna innehåller ett stort antal antaganden och osäkra faktorer. Beräkningarna grundar sig på en minskning av biomassan inom ett visst område och inte på den totala fiskfången. För att uppnå en minskning av biomassan i föregående exempel, kan man behöva en mångdubbling av fångstmängden.

Näringsväv och orsakskedjor i Östersjön är andra än i insjöarna, där största delen av de refererade undersökningarna är gjorda. På basen av undersökningarna kan man inte dra slutsatser, som direkt gäller för Östersjön.

Nyckelord: fiskodling, miljö, belastnings, näringsämnen, miljötillstånd, intensivfiske, fiskevårdande fiske

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1. Introduction

Fish populations can have a substantial effect on water quality. Firstly, planktivorous fish can consume large amounts of zooplankton, thereby decreasing the consumption of phytoplankton and consequently increasing the biomass of phytoplankton (top-down control, Carpenter *et al.* 1985, Gulati *et al.* 1990). Thus, reduction of planktivorous fish stocks (biomanipulation) has been used as a restoration tool to improve the quality of water in lakes (Lammens *et al.* 1990, Meijer *et al.* 1990, Carpenter and Kitchell 1993, Horppila *et al.* 1998). Biomanipulation by removal of planktivorous fish aims to enhance water quality by increasing the grazing of phytoplankton by zooplankton, especially by cladocerans (Shapiro *et al.* 1975, Mehner *et al.* 2002).

Secondly, benthivorous and omnivorous fish can affect nutrient availability for phytoplankton growth (bottom-up control, McQueen *et al.* 1986), because these fish translocate nutrients from the sediment to the water column, thus causing internal nutrient loading. Internal loading is an important mechanism that affects water quality in freshwater lakes and in the Baltic Sea (Søndergaard *et al.* 1999, Pitkänen *et al.* 2001). Despite the significant reduction in external loading, internal loading of nutrients from sediment can support the production of phytoplankton. For instance, despite the 30% decrease in external loading in the 1990s, the state of the Gulf of Finland did not improve. The primary reason for this was internal phosphorus loading, which was triggered by poor oxygen conditions at the sediment-water interface of the eastern Gulf (Pitkänen *et al.* 2001). In addition to oxygen conditions, the exchange of nutrients between water and sediment is influenced by a large number of physical and chemical factors such as temperature, pH and wave disturbance (Mortimer 1941, Hamilton and Mitchell 1988, Zhu *et al.* 2005) and also by nutrient excretion and bioturbation by animals (Vanni 2002, with references). Several studies have shown that nutrient excretion and bioturbation by benthivorous fish can affect water quality without altering the zooplankton community (Drenner *et al.* 1984, Tatrai and Istvanovics 1986, Threlkeld and Drenner 1987, Horppila and Kairesalo 1990, Tatrai *et al.* 1990, van Donk *et al.* 1990, McQueen *et al.* 1992). Therefore, reduction of benthivorous fish may be used as a tool for water quality improvement.

Opinions on the importance of fish-mediated internal nutrient loading are variable. Internal nutrient loading caused by fish has been compared with zooplankton excretion, external nutrient loading, total internal loading and also nutrient demand by phytoplankton (Brabrand *et al.* 1990, Persson 1997, Horppila 1998, Mehner *et al.* 1998). In this report, based on the existing literature, the main aim was to estimate, to what extent external nutrient loading by fish farming in the Archipelago Sea, Southwest Finland, could be compensated by mass removal of fish through reduction of fish-mediated internal loading. The present annual phosphorus loading from fish farms to the Archipelago Sea area is c. 25 000 kg and the annual nitrogen loading c. 200 000 kg (2002) (<http://www.ymparisto.fi/default.asp?contentid=%2083544&lan=fi>, 31.10.2007).

2. Internal nutrient loading by fish

2.1. Nutrient release by fish

Fish need nutrients for their growth, reproduction and metabolism (Kitchell *et al.* 1977). The nutrients that are not assimilated are released in faeces (egestion) while the assimilated nutrients are excreted through the kidneys or similar organs. Egested nutrients are available to primary producers only after decomposition and mineralization by microbes. Nutrients such as phosphorus (P) and nitrogen (N) are excreted in inorganic form (phosphate and ammonia) and can be directly available for phytoplankton and primary producers (Brabrand *et al.* 1990).

2.2. Factors affecting nutrient release rate by fish

2.2.1. Individual body mass

The amount of nutrients excreted per unit body mass per unit time decreases with increasing body mass. Adult fish have lower mass-specific excretion rates than underyearling fish as a result of inverse allometric relationship between body size and respiration rate (Schindler *et al.* 1993). To obtain correct estimates of phosphorus release, it is thus important to consider the size structure of the fish population (Tarvainen *et al.* 2002). The relationship between nutrient release rate ($\mu\text{g g}^{-1} \text{h}^{-1}$; $\text{NH}_4\text{-N}$ and $\text{PO}_4\text{-P}$) and fish wet weight (g) from the literature with 95% confidence intervals can be found in Figure 1 (Tarvainen *et al.* 2005).

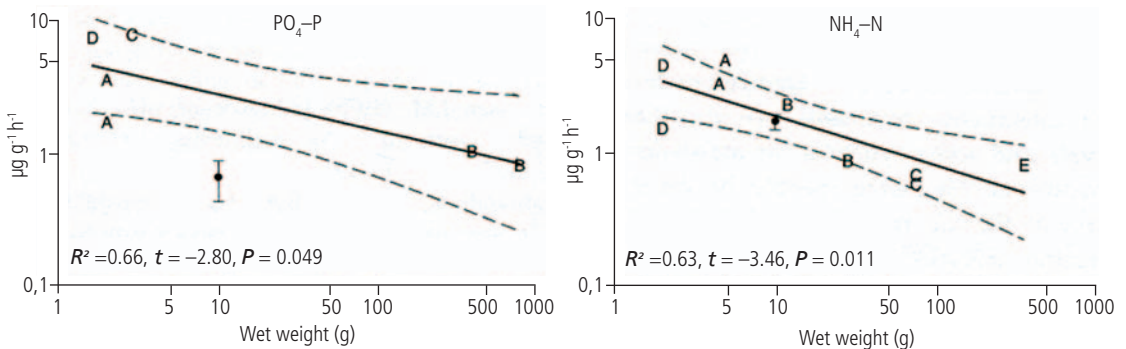


Figure 1. Relationship between nutrient release rate of dissolved $\text{PO}_4\text{-P}$ ($\mu\text{g g}^{-1} \text{h}^{-1}$) and $\text{NH}_4\text{-N}$ ($\mu\text{g g}^{-1} \text{h}^{-1}$) with fish wet weight (g) from the literature with 95% confidence intervals (Tarvainen *et al.* 2005). $\text{PO}_4\text{-P}$: A: Mather *et al.* (1995), B: Lamarra (1975), C: Brabrand *et al.* (1990), D: Heino *et al.* (unpublished). $\text{NH}_4\text{-N}$: A: Forsberg and Summerfelt (1992), B: Zakes *et al.* (2001), C: Zakes and Demaska-Zakes (2002), D: Mather *et al.* (1995), E: Yager and Summerfelt (1993).

2.2.2. Nutrient composition of fish and their food

Nutrient excretion rates are functions of the nutrient composition of animals and their food. Animal species maintain relatively constant body nutrient contents per unit body mass (Vanni 2002). Thus, during growth an animal will incorporate nutrients at rates needed to maintain this nutrient composition and will excrete nutrients that are assimilated but not needed for growth. The amount of nutrients excreted will thus be dependent on the nutrient content of the food the animal is consuming. Fish feeding on nutrient-rich food resources will excrete more nutrients than fish feeding on nutrient-poor diets (Vanni 2002). On the other hand, an animal with a relatively low nutrient content in its body will allocate fewer nutrients for growth and will excrete more nutrients than an animal with high body nutrient composition. For instance, among vertebrate taxa from tropical streams, the mass-specific P excretion rate varied 10-fold and was negatively related to animal body P content (Vanni *et al.* 2002).

2.2.3. Temperature

Nutrient excretion rates of fish increase with temperature (Lin *et al.* 2005), due to the increase in metabolic rates with increasing temperature (Vanni 2002). For instance, in Lake Balaton in Hungary excretion of total nitrogen by bream (*Abramis brama*) increased significantly with increasing water temperature, from 1.3 g N ind⁻¹ at 6.2 °C to 7.4 g N ind⁻¹ at 22.7 °C for age groups 0+ to 7+ (Tatrai 1987).

2.2.4. Feeding habit of fish

The contribution of fish to internal loading is also dependent on the feeding habits of the fish. Fish can physically move nutrients between habitats or ecosystems (Vanni 1996). This process is usually accompanied by transformation of nutrients from one chemical form to another. For example, when benthivorous fish feed on benthic prey and excrete nutrients into the water column, they translocate nutrients from benthic to pelagic habitats and convert nutrients from particulate to dissolved forms. In this case, new P is added to the water column and internal loading occurs (Lamarra 1975, Andersson *et al.* 1978, Brabrand *et al.* 1990).

Planktivorous fish recycle nutrients but do not add new nutrients to the water column. They feed on zooplankton in the water column and excrete nutrients back again into the water column, recycling nutrients within that habitat. Hence, planktivorous fish do not contribute to internal nutrient loading (e.g. Nakashima and Leggett 1980, Havens 1993). For instance in Lake Köyliönjärvi, P release of the dense roach (*Rutilus rutilus*) stock had only minor significance for internal phosphorus loading because roach fed mainly on zooplankton (Tarvainen *et al.* 2002). Similar results were obtained in experimental studies, in which access to the bottom was prevented in some experimental units and allowed in others. For instance, Havens (1993) showed that the total phosphorus concentration in the water did not increase in mesocosms where fish were not allowed to feed from the bottom, but remained at a levels similar to those in mesocosms with no fish (Figure 2). In mesocosms, where feeding from the bottom was possible, phosphorus concentration was substantially elevated.

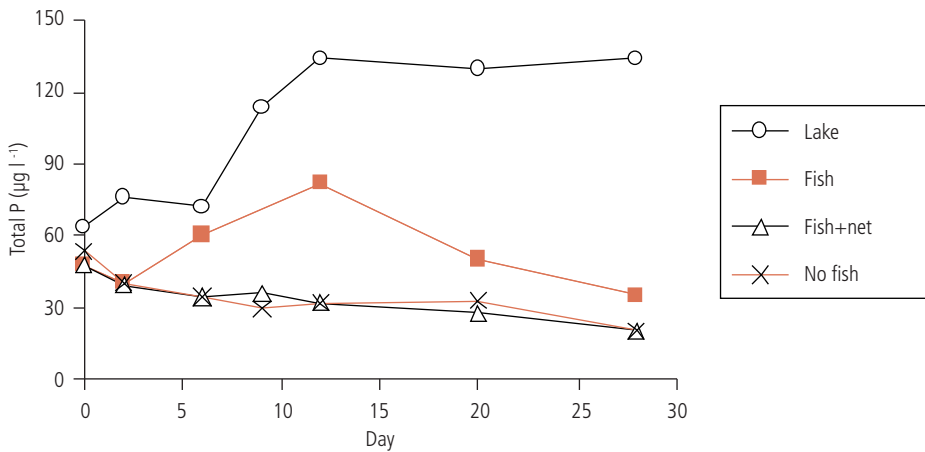


Figure 2. Total phosphorus concentrations in the mesocosms and in the surrounding lake during the experiments by Havens (1993). The fish species used in the experiments were brown bullhead (*Ictalurus nebulosus*) shiner (*Notropis sp.*) and smallmouth bass (*Micropterus dolomieu*). In mesocosms with net, fish were not able to feed from the bottom. Redrawn from Havens (1993).

2.3. Bioturbation by fish

Fish physically disturb the sediment by feeding and other activities. Bottom-feeding fish such as roach and bream can release nutrients by disturbing the surface sediments while searching for food (Persson and Hamrin 1994). Breukelaar et al. (1994) showed a positive relationship between bream and carp (*Cyprinus carpio*) biomass with both suspended solids and sediment found in traps in the experiments. These fish also contributed significantly to turbidity in the experimental set ups (Breukelaar et al. 1994). It is very difficult to distinguish internal nutrient loading caused by bioturbation from nutrient excretion by benthivorous fish (Lamarra 1975).

3. Methods for estimation of nutrient release rates by fish

Excretion rates can be estimated using bioenergetics models or by direct measurement (Vanni 2002). Using bioenergetics, the excretion rate is estimated as nutrients ingested minus nutrients allocated for egestion and growth (Kraft 1992, Horppila et al. 1998, Tarvainen et al. 2002). Direct measurements can be done by capturing animals in the field and placing them in containers in which the accumulation of nutrients is quantified (Persson 1997, Hood et al. 2005, Tarvainen et al. 2005). Both methods have advantages and disadvantages, but there are limited data suggesting that they yield similar excretion rates and ratios for fish (Vanni 2002).

4. Quantitative estimation of the effects of fish biomass reduction

4.1. Estimates on the effects of biomass reduction

As presented above, numerous factors affect nutrient release rate by fish. It is thus possible to make only very rough estimates of the effects of fish biomass reduction on internal nutrient loading. Therefore, the effects of biomass reduction were estimated with the different nutrient release rates presented in the literature.

The literature review by Tarvainen *et al.* (2005) showed that the $\text{PO}_4\text{-P}$ release rate by fish having individual weights from 1 to 1000 g varies approximately from 10 to $1 \mu\text{g g}^{-1} \text{h}^{-1}$ (Figure 1). For $\text{NH}_4\text{-N}$, the release rate varied from 5 to $50 \mu\text{g g}^{-1} \text{h}^{-1}$ for fish weights of 1-500 g (Figure 1). These ranges of nutrient release rates form the x-axis of Figures 3 and 4. The estimated reduction of fish-induced internal nutrient loading was calculated by multiplying the mass-specific nutrient release rates of fish by the biomass reduction of fish (y-axis). From the figures it is thus possible to read the estimated annual reduction in fish-induced internal nutrient loading with each combination of nutrient release rate by individual fish and biomass reduction caused by intensive fishing. The calculations were based on the assumption that nutrient release by fish occurs for 24 h per day during 150 days of the year (Tarvainen 2007).

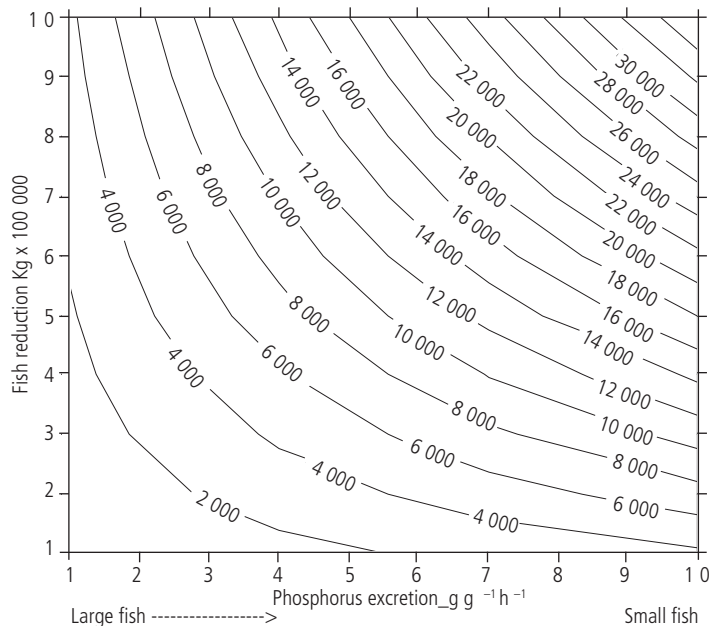


Figure 3. Estimated reduction of fish-induced internal P loading (kg) with different combinations of fish biomass reduction ($\text{kg} \times 10^4$) and mass-specific $\text{PO}_4\text{-P}$ release rates of fish obtained in previous studies, covering fish weights approximately from 1 g to 1000 g (Figure 1).

For instance, a 300 000 kg biomass reduction of fish releasing $8 \mu\text{g P g}^{-1} \text{ h}^{-1}$ would result approximately in an 8 000 kg annual reduction in fish-induced internal P loading (Figure 3). It is necessary to consider, however, that the calculation is based on the assumption that fish biomass reduction is comprised exclusively of benthivorous fish. Since most fish species, including cyprinids, are zooplanktivorous as juveniles and switch to benthic food when they grow in size (Persson 1983, Persson and Greenberg 1990), the highest values of individual nutrient release in the x-axis are probably not realistic. For an average size of 50 g for a benthivorous fish, a nutrient release rate of $2 \mu\text{g P g}^{-1} \text{ h}^{-1}$ should be used (Figures 1 and 3). Using this value, a 300 000 kg biomass reduction would cause c. 2 100 kg annual reduction in fish-induced internal P loading, corresponding to 9% of the external loading by fish farming. For nitrogen, similar calculations were made based on the published $\text{NH}_4\text{-N}$ release rates by fish (Figure 4).

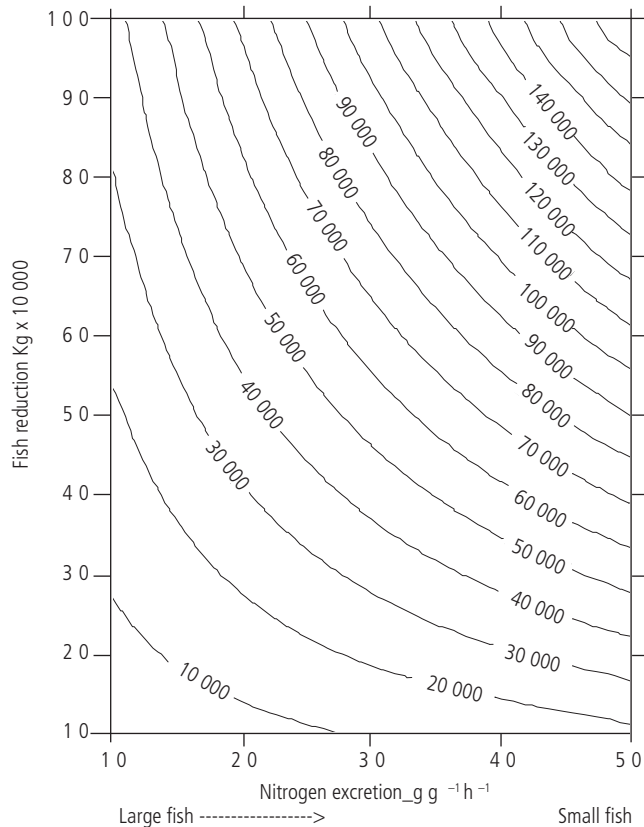


Figure 4. Estimated reduction in fish-induced internal N loading (kg) with different combinations of fish biomass reduction ($\text{kg} \times 10^4$) and mass-specific $\text{NH}_4\text{-N}$ release rates of fish obtained in previous studies, covering fish weights approximately from 1 g to 500 g (Figure 1).

Assuming an average fish size of 50 g for a benthivorous fish, a nutrient release rate of $20 \mu\text{g N g}^{-1} \text{h}^{-1}$ should be used (Figure 1). Using this value, for instance, a 300 000 kg biomass reduction of benthivorous fish would cause c. 21 000 kg annual reduction in fish-induced internal N loading, corresponding to 10% of the external loading by fish farming.

4.2. Caution needed in interpreting the results

In reading the figures, it is important to bear in mind that the calculations were based on the reduction in benthivorous fish biomass in a given area and not on the fish catch.

The possible catch amounts of different fish species in the Archipelago Sea area are evaluated to be about 250 tonnes (Mäkinen 2007). Additionally, use of some excretion period other than 24 h x 150 days would of course change the calculation results. However, outside the growing season the food intake and nutrient excretion rates are low, due to low water temperatures.

The behaviour of fish may be affected by mass removal. A change in the abundance of benthivorous fish may, for instance, affect the biomass of the zoobenthos (Svensson *et al.* 1999, Leppä *et al.* 2003), with consequences for the feeding habits of the remaining fish and thus for their effect on nutrient dynamics. Several studies have shown that the effect of fish on internal nutrient loading may depend on the availability of benthic food (Horppila and Kairesalo 1992, Zambrano *et al.* 2001, Tarvainen *et al.* 2005).

It is also very important to consider that the studies cited have been mostly conducted in freshwater environments. In most aquatic ecosystems, attention has focused on the cycling of nitrogen (N) and phosphorus (P) because they are the nutrients most likely to limit primary producers. For internal loading, phosphorus is often taken into account because P usually limits the growth rates or maximum yields of phytoplankton during summer in temperate freshwater lakes (Carpenter *et al.* 1985). However, this is not the case for the Baltic Sea since N is the limiting factor for phytoplankton growth in certain areas (Pitkänen and Tamminen 1995). In the Baltic Sea, the low N:P ratio of internal loading also partly explains the limiting role of N in primary production, despite the high N:P ratio of external inputs (Pitkänen and Tamminen 1995). The capacity of saline water sediments to permanently retain P is generally poorer than that of freshwater sediments because of the formation of insoluble Fe(II)S in anoxic saline water systems (Pitkänen and Tamminen 1995). This process reduces the number of potentially available adsorption sites for P (Caraco *et al.* 1990)

Most top-down control studies have been conducted in lakes and those that have been conducted in the Baltic Sea have focused on the lower trophic levels (zooplankton and algae) (Rudstam *et al.* 1992, Kivi *et al.* 1993). A strong coupling between fish and lower trophic levels was suggested to be due to the higher fish yield per unit of primary production in coastal areas, including the Baltic Sea (Rudstam *et al.* 1994). However, in comparing freshwater lakes with brackish lakes, Jeppesen *et al.* (1994) concluded that in brackish lakes the effects of planktivorous fish stock manipulations on water quality are weak compared with the effects in freshwater lakes.

5. Possible other effects of fish stock manipulations

Planktivorous fish can alter the species composition and size structure of zooplankton communities (Hrbáček *et al.* 1961, Drenner *et al.* 1984, Attayde and Hansson 2001). The change in size structure of zooplankton can lead to a change in consumption rate of phytoplankton, since large-sized zooplankton can consume higher biomasses of phytoplankton. Consequently the nutrient excretion rates of zooplankton may increase and lead to enhanced phytoplankton production (Vanni 1987). Possible changes in the N:P ratio can also affect phytoplankton communities (Carpenter *et al.* 1992). Benthivorous fish can affect the biomass and density of zoobenthos. Changes in the biomass of zoobenthos may have consequences for nutrient dynamics, because benthic invertebrates can play an important role in nutrient cycling by their burrowing activity that causes resuspension of the sediment and increases or decreases nutrient release from the bottom (Tátrai 1987, Philips *et al.* 1994).

The presence of benthivorous fish may prevent sediment consolidation (Scheffer *et al.* 2003). When benthivorous fish feed from the sediment, they leave small pits in the sediment surface (Lammens and Hoogenboezem 1991). These pits increase the effects of wind-induced waves and disturbance of the bottom sediment. After removal of benthivorous fish, the sediment may become more stable and firm, leading to reduction in sediment resuspension due to wind (Scheffer *et al.* 2003).

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