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# Feasibility of controlling coarse fish populations through pikeperch (*Stizostedion lucioperca*) stocking in Lake Köyliönjärvi, SW Finland

Seppo Salonen, Harri Helminen & Jouko Sarvala

*Salonen, S., University of Turku, Satakunta Environmental Research Centre, Konttorikatu 1, FIN-28900 Pori, Finland*
*Helminen, H., Southwest Finland Regional Environment Centre, Inkilänkatu 4, FIN-20300 Turku, Finland*
*Sarvala, J., University of Turku, Department of Biology, FIN-20014 Turku, Finland*

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In order to create a new equilibrium fish community, in which fish consumption by piscivorous fish equals the production of prey fish, mass removal of unwanted fish and intensified stocking of young-of-the-year pikeperch has been performed in Lake Köyliönjärvi. A revised bioenergetics model of walleye (*Stizostedion vitreum vitreum*) was used for pikeperch to calculate consumption rates from the growth rate, fish population size and ambient temperature. According to model calculations, food consumption of pikeperch alone is insufficient to control production of prey fish in Lake Köyliönjärvi. Combinations of fishing restrictions, removal of unwanted fish and intensified stocking are needed to enhance the pikeperch population and its predatory effect.

## 1. Introduction

Lake Köyliönjärvi in South-West Finland is a nutrient-rich lake suffering from annual long-lasting mass blooms of blue-green algae. Although the lake has probably always been naturally eutrophic, anthropogenic eutrophication has been rapid for the last few decades. The main reason for this unwanted development is intensive cultivation of edible roots and vegetables in the drainage area, which has resulted in an excessive level of external nutrient loading into the lake. Meanwhile, the fish stock in Lake Köyliönjärvi, especially roach (*Rutilus rutilus*) and bream (*Abramis brama*), is responsible for a considerable internal nutrient loading through their feeding activities.

In order to improve water quality and to balance the fish community, biomanipulation of Lake Köyliönjärvi has been performed since 1992. Manipulation has included mass removal of unwanted fish, mainly cyprinids and smelt (*Osmerus eperlanus*), and, lately, intensified stocking of piscivorous fishes such as pikeperch and pike (*Esox lucius*). These measures aim to permanently change the fish community structure. The ultimate target is a new equilibrium fish community in which fish consumption by piscivorous fish equals the production of unwanted prey fish.

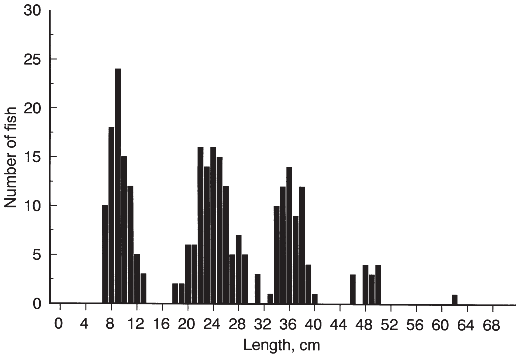


Fig. 1. Length distribution of pikeperch in Lake Köyliönjärvi in 1992–95.

Mass removal of coarse fish by means of winter seine net has been performed for four winters in 1992–95 and the total catch corresponds to 230 kg/ha. Pikeperch stocking has increased to a stocking density of 46 young-of-the-year (YOY)/ha in 1994, 2.5 times higher than the usual rate in the 1990s. In this study we have analyzed whether it is possible to maintain a balanced fish community structure, possibly achieved by restoration of Lake Köyliönjärvi, by enhancing the pikeperch stock, and what the required amount is of pikeperch.

## 2. Study area, material and methods

Lake Köyliönjärvi is a shallow, non-stratified and very eutrophic lake. It has a total area of 12.3 km$^2$, mean depth 3.1 m, Secchi depth$_{min}$ 0.3 m, total-P$_{max}$ 160 µg/l and chlorophyll-$a_{max}$ 200 µg/l.

The fish community structure of Lake Köyliönjärvi was studied through 199 fish catch samples from 251 winter seine net hauls in 1992–95. We took a random sample from the cod end of winter seine net as 5 subsamples (using a 30-l plastic container) when fishermen were removing the seine net catch from the cod end to the sleigh. Length and weight were measured and sex determined of 100 randomly chosen fish per sample. The proportion of biomass of every fish species in a sample was calculated. The catch size of every single haul was weighed in a local fish farm.

All pikeperch observed while treating the mass removal catch were sorted out, giving a total sample size of 833 fish. Length and weight were measured and age determined (from opercular bone or scale) of 273 individuals (Fig. 1). Because the age-groups formed clearly separate modes in the length

Table 1. Age distribution of pikeperch in mass removal catches in 1994–95 in Lake Köyliönjärvi and the results of chi-square test of agreement for the Chapman-Robson survival model, when respective age-group has been coded to zero (Bagenal 1978). The numbers of age 0+ pikeperch were calculated from their proportion in the catch samples.

| Age-group | Number | Statistic ($c^2$) | $P$ |
|---|---|---|---|
| 0+ | 8 790 | 459.4 | < 0.001 |
| 1+ | 481 | 3.414 | > 0.05 |
| 2+ | 147 | | |
| 3+ | 52 | | |
| 4+ | 6 | | |

Table 2. Energetics equations (Hewett & Johnson 1992) used in this study.

$C = (R + S) + (F + U) + (\Delta B)$,
where: $C$ = Consumption, $R + S$ = Metabolic losses, $F + U$ = Waste losses, $\Delta B$ = Growth.

Consumption:
$C = C_{max} \times P\text{-value} \times f(T)$
$C_{max} = CA \times W^{CB}$
$f(T) = V^X \times e^{(X(1-V))}$
where:
$V = (CTM - T)/(CTM - CTO)$
$X = (Z^2 \times (1 + (1 + 40/Y)^{0.5})^2)/400$
$Z = \mathrm{Ln}CQ \times (CTM - CTO)$
$Y = \mathrm{Ln}CQ \times (CTM - CTO + 2)$

Respiration:
$f(T) = V^X \times e^{(X(1-V))}$
$ACTIVITY = ACT$
where: $V$, $X$, $Z$, $Y$ as above.

Egestion and excretion:
$F = FA \times t^{(FB)} \times e^{(FG \times P\text{-value})} \times C$
$U = UA \times T^{(UB)} \times e^{(UG \times P\text{-value})}$

Table 3. Parameter values used in this study. Original walleye model (Hewett & Johnson 1992) parameter value in parentheses if changed value has been used in our analysis.

| Consumption | | Respiration | | Egestion and excretion | |
|---|---|---|---|---|---|
| *CA* | 0.25 | *RA* | 0.0108 | *FA* | 0.158 |
| *CB* | – 0.27 | *RB* | – 0.20 | *FB* | –0.222 |
| *CQ* | 2.3 | *RQ* | 2.1 | *FG* | 0.631 |
| *CTO* | 27.0 | *RTO* | 33.0 | *UA* | 0.0253 |
| | (22.0) | | (27.0) | *UB* | 0.58 |
| *CTM* | 33.0 | *RTM* | 36.0 | *UG* | – 0.299 |
| | (28.0) | | (33.0) | | |
| | | *ACT* | 1.0 | | |
| | | *SDA* | 0.172 | | |

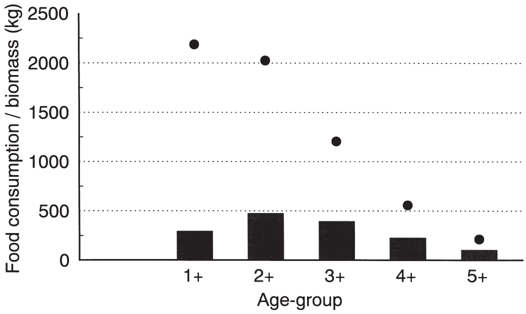


Fig. 2. Annual food consumption (dots) and mean annual biomass (bars) of pikeperch population by age-group in Lake Köyliönjärvi.

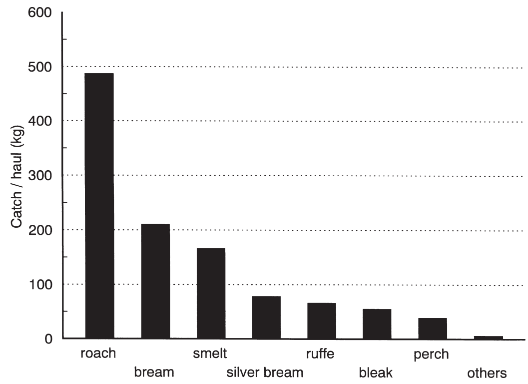


Fig. 3. The mean catch of different fish species in the mass removal fishery in Lake Köyliönjärvi in 1992–95 (251 hauls).

frequency distribution (Fig. 1), the ages of 560 individuals were derived from their length (Bagenal 1978). Age structure determination of pikeperch was based on these observations, except for 0+ pikeperch, which were difficult to detect from among other fish and were thus underrepresented in the pikeperch subsample. Therefore the number of 0+ pikeperch was separately assessed using their proportion in the catch samples (Table 1).

We applied a bioenergetics model (Tables 2 and 3) in order to estimate the annual food consumption of pikeperch in Lake Köyliönjärvi from the growth rate realized in the lake. The model used was based on the walleye model (Hewett & Johnson 1992), but it was slightly revised. The maximum and optimum temperatures of consumption and respiration were increased (Table 3), because pikeperch is a species adapted to warmer waters than walleye (Colby & Lehtonen 1994). Parameter value modifications were based on laboratory studies (Horoszewicz 1973, Hokanson 1977, Marshall 1977, Willemsen 1977) and modelling instructions by Hewett and Johnson (1992). In our modelling analysis, pikeperch was assumed to eat only fish (energy content 4.18 kJ/g). Other required data such as the water temperature (mean temperature of the whole water column at 6 stations; there is no temperature stratification during the open water season) and growth of pikeperch were collected during the mass removal of cyprinids in 1992–95. The total annual mortality was estimated from the age distribution of pikeperch in the mass removal catch (Chapman-Robson method; Bagenal 1978). 0+ pikeperch were excluded from food consumption calculations for two reasons. Firstly, according to the age distribution, natural recruitment of 0+ pikeperch in Lake Köyliönjärvi is negligible. On the other hand, the stocking of the 0+ pikeperch takes place in autumn. Therefore the overall contribution of 0+ pikeperch to the total annual food consumption of the whole pikeperch stock in Lake Köyliönjärvi is small. Secondly, according to the chi-square test of agreement used in the mortality estimation method (Bagenal 1978), 0+ pikeperch had to be excluded from the analysis due to a sampling bias (Table 1).

Table 4. Growth and annual food consumption of individual pikeperch by age-group in Lake Köyliönjärvi according to the bioenergetics model. The lengths of age 5+ and 6+ pikeperch were extrapolated from the Von Bertalanffy equation (Bagenal 1978; $L_\infty = 93.1$, $K = 0.192$, $t_0 = -10.3$) and converted to respective weights by length-weight relationship equation (Bagenal 1978; $\log w = -5.5807 + 3.3508(\log l)$, $df = 272$, $R^2 = 0.997$).

| Age-group | Start length (cm) | Start weight (g ww.) | Growth (g ww.) | Consumption (g ww.) | Growth conversion efficiency (%) |
|---|---|---|---|---|---|
| 1+ | 9.5 | 5 | 111 | 315 | 35 |
| 2+ | 24.5 | 116 | 288 | 949 | 30 |
| 3+ | 35.5 | 404 | 560 | 1 964 | 29 |
| 4+ | 46 | 964 | 716 | 3 150 | 23 |
| 5+ | 54 | 1 680 | 841 | 4 248 | 20 |
| 6+ | 61 | 2 521 | | | |
| sum | | | | | 10 626 |

The coarse fish stock size was assessed by mass removal data by the depletion method (DeLury-method; Ricker 1975, Helminen *et al.* 1993). When calculating the catch per unit effort (*CPUE*), fishing effort was measured as fishing days (2 winter seine net hauls per day).

## 3. Results

The growth of pikeperch in Lake Köyliönjärvi is relatively fast (Table 4). In spite of the good growth, the total food consumption of the pikeperch population remains low, because the stock seems to be small: pikeperch in the mass removal catch belonged predominantly to youngest age-groups. Pikeperch older than 4 years have rarely been caught in Lake Köyliönjärvi (Fig. 1).

According to model calculations, an individual pikeperch with a final weight of 2.5 kg eats 10.6 kg fish during its first five years (1+–5+) in Lake Köyliönjärvi (Table 4), implying a growth conversion efficiency of 24%. The total annual mortality calculated from the age distribution was 71.8% ($Z$ = 1.27) (95% *c.l.* 67.8–74.9%; $Z$ = 1.13–1.38). Using estimated mortality rate, water temperature data (Table 5) and the mean annual stocking rate of YOY pikeperch (23 000 ind. in 1990–93) in the bioenergetics model, the calculated stock size of pikeperch (1+–5+) in Lake Köyliönjärvi was 1 500 kg (1.2 kg/ha) and the annual food consumption 6 200 kg (5.0 kg/ha) (95% *c.l.* 5 200–7 300 kg; 4.2–5.9 kg/ha) (Fig. 2).

Roach, bream and smelt were the most abundant fish species in Lake Köyliönjärvi. The proportion of cyprinids and smelt (% wet mass) in the mass removal catch was 90%. (Fig. 3). According to the catch, the fish stock consisted of relatively small fish: the median length was 8 cm (Fig. 4). The coarse fish stock size estimate in 1993 was 163 kg/ha (95% *c.l.* 155–191 kg/ha, 38 fishing days, $R^2$ = 0.42). In other years fishing pressure was not sufficient to produce a decline in *CPUE*. The estimated coarse fish stock size in Lake Köyliönjärvi in 1993 corresponds to 191 000–235 000 kg. In 1995, after two intensive winter seining periods, *CPUE* (catch/haul) was 30% smaller than in 1993. Based on this reduction of *CPUE*, the coarse fish stock size in Lake Köyliönjärvi in 1995 was calculated as 135 000–166 000 kg. The annual production/biomass-ratio of roach, which is the most abundant fish species in Lake Köyliönjärvi, was 0.24 in the beginning of mass removal (Salonen, unpubl.). If it is generalized to the whole coarse fish stock, the present annual coarse fish production equals 32 000–40 000 kg (26–33 kg/ha), which is 4–8 times greater than the estimated annual pikeperch fish consumption rate. To achieve a situation in which pikeperch would consume the whole coarse fish production, the stocking rate should be increased to 80–150 YOY pikeperch/ha. These figures are probably underestimates, because it is probable that the P: B-ratio of the coarse fish stock has increased during the mass removal period as the stock size has decreased. The depletion method also tends to underestimate stock sizes (Helminen *et al.* 1993). Using the production/biomass-ratio of 0.3–0.5 reported for roach in biomanipulated Finnish lakes (Sarvala *et al.* 1992, Horppila & Peltonen 1994), the annual production of the coarse fish population in Lake Köyliönjärvi in 1995 would have been 41 000–83 000 kg (33–67 kg/ha). Therefore, with the given growth and mortality rate, the pikeperch biomass in Lake Köyliönjärvi should be 6–16 times greater than at present, if the pikeperch stock is expected to regulate the coarse fish stock. This corresponds to a stocking rate of 110–300 YOY pikeperch/ha.

## 4. Discussion

There are several possible reasons for the small pikeperch catch in Lake Köyliönjärvi. The fishery may be too effective (especially gillnet-fishing in summer), intraspecific predation may be remarkably high, and the anoxic conditions during winter and high pH during mass blooms of blue-green algae in late summer may lead to increased mortality. At the moment it is not possible to single out the most important factor regulating pikeperch stock in Lake

Table 5. Mean water temperatures in the whole water column (depth 0–8 m, six stations, no stratification) in Lake Köyliönjärvi 1984–93.

| Day no. | °C | Day no. | °C | Day no. | °C |
|---|---|---|---|---|---|
| 1–90 | 2.0 | 161–170 | 15.7 | 241–250 | 14.8 |
| 91–100 | 2.2 | 171–180 | 16.9 | 251–260 | 12.6 |
| 101–110 | 2.4 | 181–190 | 18.3 | 261–270 | 10.4 |
| 111–120 | 3.6 | 191–200 | 18.6 | 271–280 | 9.1 |
| 121–130 | 6.3 | 201–210 | 19.4 | 281–290 | 7.3 |
| 131–140 | 10.1 | 211–220 | 19.3 | 291–300 | 4.7 |
| 141–150 | 13.6 | 221–230 | 17.8 | 301–310 | 3.2 |
| 151–160 | 14.5 | 231–240 | 16.6 | 311– | 2.0 |

Köyliönjärvi, but we think that the fishing mortality may be of great importance, because the deepest area of the lake, where pikeperch usually tend to congregate (Colby & Lehtonen 1994) is relatively small and can be easily filled with gillnets. Intraspecific predation seems to be the least important factor, because according to the mass removal data, pikeperch must encounter other prey fish species much more frequently than small pikeperch. The seemingly small population size of pikeperch in Lake Köyliönjärvi may also be partly due to a sampling bias of the winter seine net, but in any case, the estimated total annual mortality of pikeperch in Lake Köyliönjärvi (72%) is very high.

The pikeperch population may be enhanced through increased stocking, but another approach is to increase pikeperch stock size through lower mortality by restricting the pikeperch fishery. According to our calculations, if total annual mortality percentage for example would decrease 10 units from 72% to 62% ($Z = 1.27$ and $Z = 0.96$, respectively), the total food consumption of the pikeperch population would roughly double. Therefore, if the fishing mortality turns out to be the main reason for the present low stock levels, fishing restrictions could be a relatively cheap and effective way to enhance pikeperch stock (Johnson *et al.* 1996). In contrast, if the fishing mortality is negligible, there is no reason to regulate the pikeperch fishery. In that case, the overall feasibility of pikeperch as the regulator of unwanted fish in Lake Köyliönjärvi is also questionable.

According to our study pikeperch grows rapidly in Lake Köyliönjärvi compared with other relatively fast-growing pikeperch stocks in Finland and Sweden (Svärdson & Molin 1973, Lehtonen & Miina 1988). So far the mass removal of cyprinids has not affected the growth of pikeperch in Lake Köyliönjärvi. Therefore an increase in the stocking rate seems possible without lowering the expected predation effect. However, with higher stocking rates, the food consumption and growth of individual pikeperch will sooner or later decrease due to intraspecific food competition. The population dynamics of the prey fish are also likely to be altered. These changes must be taken into consideration when calculating the required food consumption of pikeperch in Lake Köyliönjärvi in future.

A lake restorer especially wants to reduce the biomass of the cyprinid fish species, for example roach and bream. Studies made in other lakes indicate that pikeperch, or at least its youngest age-groups, prefer smelt as a prey species if it is available (Van Densen & Grimm 1988, Peltonen *et al.* 1996). That is likely to be true also in Lake Köyliönjärvi where smelt is the most numerous fish species in the pelagic area where pikeperch mostly feed. Our limited stomach analyses support this assumption.

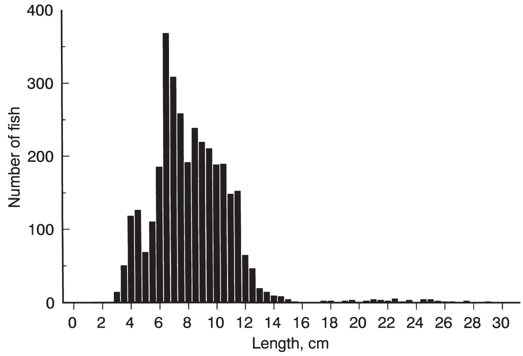


Fig. 4. Length distribution of fish in the mass removal catch in 1994 in Lake Köyliönjärvi.

Pikeperch is also known to be a gape-limited predator. Therefore a size-structured predator-prey model is needed. Nevertheless, in Lake Köyliönjärvi, due to the slow growth rate of prey fishes and the fast growth of pikeperch, prey fish size does not limit pikeperch feeding; virtually all types of prey fish available in Lake Köyliönjärvi can be swallowed by 2+ pikeperch (Knight *et al.* 1984) (Fig. 4), and the 1+ pikeperch are able to use all sizes of smelt (Van Densen 1985). The deep-bodied bream is an exception. In the mass removal catch in 1994, the median length of bream was 17 cm. Bream of that size is vulnerable to pikeperch predation if the length of pikeperch is > 54 cm (corresponds to 4+ pikeperch in Lake Köyliönjärvi) (Van Densen & Grimm 1988), which means that due to the scarcity of older pikeperch, a considerable proportion of the bream stock can avoid pikeperch predation in Lake Köyliönjärvi. However, winter seine net fishing has reduced the proportion (% wet mass) of bream from 30% to 5% in the mass removal catch in 1992–95 (Hirvonen & Salonen 1995), and the removal fishery thus seems to be controlling bream production in Lake Köyliönjärvi.

Although pikeperch is an effective predator, it is not necessarily an effective management tool in Lake Köyliönjärvi, because pikeperch itself is hard to manage (Barthelmes 1988, Raat 1990), especially in the northern latitudes. There are also many uncertainties in the biology of pikeperch in our study lake as well as in general (Barthelmes 1988). We have calculated only the food consumption of pikeperch population, but favouring one predatory fish species of several may not be the most sensible policy in predatory fish management (Benndorf 1990). There are also other predatory fish species in Lake Köyliönjärvi, such as pike and large perch (*Perca fluviatilis*), but from the lake manager's point of view these species are even more difficult to manage than pikeperch. Pike and perch are most successful in lakes with abundant aquatic vegetation (Winfield 1986, Grimm 1989), which is scarce in Lake Köyliönjärvi due to its turbid water. Therefore the future success of pike and perch seems to be more related to the overall success of lake restoration, especially to the reduction of algal biomass and the increase of Secchi depth, which will enhance the development of aquatic vegetation.

Our present treatment contains several simplifications and uncertainties. However, the estimated food consumption by pikeperch was far below the levels required for controlling the coarse fish populations in the Lake Köyliönjärvi. Moreover, possible refinements of the food consumption model concerning food selection of pikeperch in Lake Köyliönjärvi would tend to decrease the importance of pikeperch predation in controlling the cyprinids even further. Thus, even our rough assessment quite convincingly shows that at this present moment in time, pikeperch cannot be a regulator of the coarse fish population in Lake Köyliönjärvi without other fish manipulation activities.

On the whole, probably the best solution in controlling the coarse fish population is the creation of a self-sustaining multi-species predatory fish stock in Lake Köyliönjärvi. If this is not possible, it is doubtful if there is any possibility of maintaining a balanced fish community structure only through pikeperch stock enhancement. At the moment removing coarse fish by winter seining is still also more economic (FIM 1.90/kg; Hirvonen & Salonen 1995) than enhancing the fish consumption by predatory fishes through pikeperch stocking (FIM 3.20/kg; based to our consumption calculations and present YOY pikeperch stocking costs in Lake Köyliönjärvi). On the other hand, the pikeperch catch itself has its own monetary and recreational value that must be taken into consideration. Having a moderate pikeperch stock in the restored lake may also evoke more public interest and positive attitude towards the lake restoration. Thus, a suitable combination of catch restrictions, mass removal of coarse fish and pikeperch stocking is needed to increase the relative importance of pikeperch food consumption in Lake Köyliönjärvi.

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