Ann. Zool. Fennici 32: 411–419
Helsinki 8 December 1995
ISSN 0003-455X

Year-class strength of pikeperch (*Stizostedion lucioperca* L.) in relation to environmental factors in a shallow Baltic Bay

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Received 15 February 1995, accepted 8 May 1995

The effects of several environmental factors on the relative year-class strength variations of pikeperch (*Stizostedion lucioperca* (L.)) were studied in a shallow brackish Baltic bay in Helsinki, Finland, during 1971–1990. The year-class strength correlated positively with the mean summer water temperature from June to September during the first year of life. Negative correlations between the year-class strength and wind indices were found with the southerly and southwesterly winds in July. These winds explained 35% ($F = 4.53$, $P = 0.027$, $n = 20$) and the mean temperature alone 40% ($F = 9.89$, $P = 0.007$, $n = 17$) of the total variation in year-class strength. When the exceptionally weak year-class in 1971 was excluded from the analysis, the corresponding values were 62% for the winds ($F = 6.50$, $P = 0.007$, $n = 19$) and 55% for the mean summer temperature alone ($F = 16.92$, $P < 0.001$, $n = 16$). No correlation existed between the year-class strength and water level, water salinity or water transparency.

1. Introduction

Fish populations living in extreme environments, e.g. pikeperch (*Stizostedion lucioperca* (L.)) in the northern Baltic Sea, are especially sensitive to even minor changes in their habitat (Colby & Lehtonen 1994). The pikeperch is a warm-water fish species with a relatively high temperature preference during the spawning and larval periods (Hokanson 1977), emphasizing the importance of interannual climatic variations in the success of reproduction. In addition, the Baltic pikeperch is a typical freshwater fish species which is also stressed by salinity in brackish water.

The changes in fish abundance are often combined effects of multiple abiotic and biotic factors e.g. climatological changes, environmental trends and annual variations, habitat alteration and interactions with other species (Buijse et al. 1992, Lappalainen et al. 1995, Lehtonen & Lappalainen 1995). Abiotic factors which have been found to affect the year-class strength of pikeperch include temperature (Svärdson &

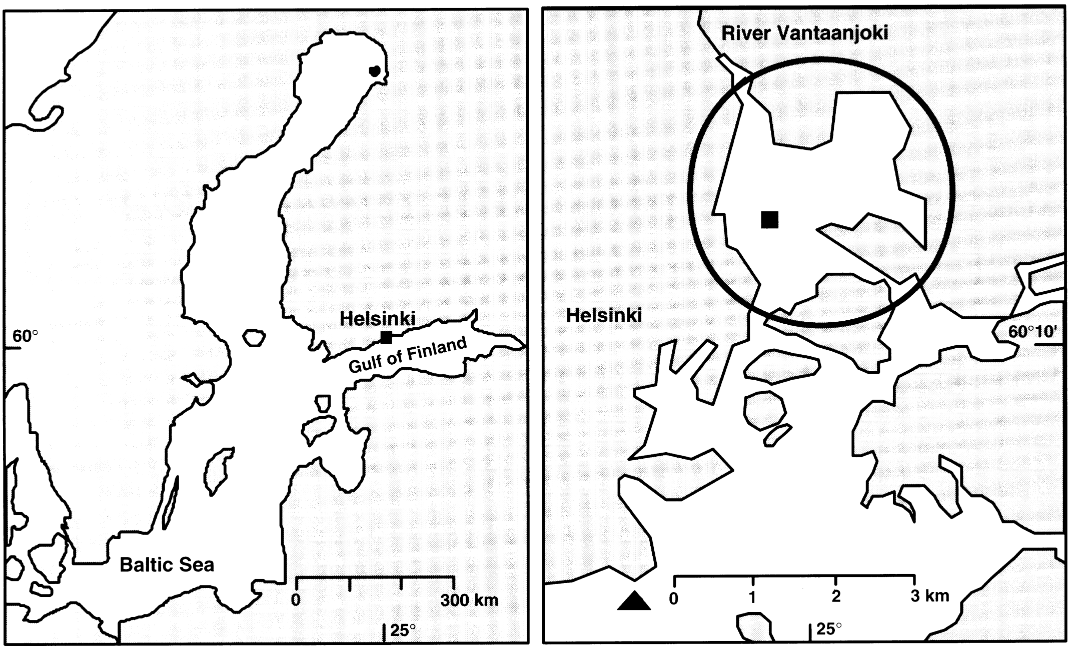

Fig. 1. Study area. Vanhankaupunginlahti Bay is rounded with a circle. Square indicates water sampling station (maximum depth is 3 m) and triangle the site of water level measurements. Wind station was located about 11 km south of Vanhankaupunginlahti Bay.

Molin 1968, Koonce et al. 1977, Willemsen 1977), wind velocity and wave action (Woynarovich 1963) and high water levels which may affect turbidity and food production (Svärdson & Molin 1973).

Very few pikeperch populations have been monitored for a sufficient length of time with the intention of estimating environmental influences. Our materials consisted of an almost 20-year-long monitoring with gill nets and fyke nets. The main objective of the present study was to examine the effects of environmental factors (temperature, salinity, wind velocity and direction, water level and transparency) on the year-class strength formation of pikeperch. The year-class strengths from both the gill net and fyke net samples were calculated to test the possible differences between gear.

2. Study area

The study area, Vanhankaupunginlahti Bay, is a shallow, eutrophic and turbid inlet in Helsinki on the southern coast of Finland (Fig. 1). The surface area is about 4 km^2 and the maximum water depth is about 5 m with a mean value of 1.5–2.5 m; the depth increases evenly from north to south. The bottom is primarily mud and in the northern area occur large stands of giant reed (*Phragmites australis* L.). The bay is an important spawning, nursery and feeding area for pikeperch and many other fish species.

The Vantaanjoki River empties into the northwestern area of the bay with a mean discharge of 15–20 m^3 s^{-1}. The peak discharges occur in April and May, and again in November, during June-August the mean discharge is < 10 m^3 s^{-1} (Viljamaa 1988). The salinity varies from almost fresh to 5‰ in the deepest area. The mean Secchi disk depth varied during the study period from 47.7 cm ($S.D.$ = 22.2, n = 35) in June to 28.6 cm ($S.D.$ = 13.6, n = 36) in August. Water temperatures of 20–25°C are attained annually, in winter the bay is ice-covered for 4–5 months.

Water level variations are caused mainly by winds or atmospheric pressure, the mean tidal water level fluctuation is 54 mm in Helsinki sea area (Hari & Sipilä 1972, Vermeer et al. 1988). Along the northern coast of the Gulf of Finland the water level is lower with northerly winds and rises with southwesterly winds. The mean wind velocities from different directions are 4.4–6.0 m s^{-1} during June–August.

3. Material and methods

3.1. Environmental data and statistical methods

The water level measurements were obtained from the Finnish Institute of Marine Research, wind observations from the monthly publications of the Finnish Meteorological Institute, and the water temperature, water salinity and Secchi disk transparency data from the City of Helsinki, Centre for the Environment. The wind indices were calculated by multiplying the mean monthly velocities (m s^{-1}) from different directions with their percentage monthly distribution, as it was hypothesized that both these quantities are effective simultaneously and meaningless if used separately. The wind index for example for southwesterly winds in June 1980 was thus 0.96 (4.8 × (20/100)). The relative year-class strengths and wind indices were log-transformed because these distributions were approximately log-normal (Sokal & Rohlf 1981). The Pearson correlation analysis (SAS 1985) was used to study the correlation between variables. In those cases when two environmental factors were intercorrelated, the significance with the year-class strength was tested with a partial correlation analysis (Sokal & Rohlf 1981). The effects of several environmental factors on year-class strengths were analysed with regression analysis; only uncorrelated variables ($P > 0.05$) were used as independent variables.

3.2. Calculation of year-class strength

The relative year-class strengths were calculated according to the method of Svärdson (1961) and adjusted by Neuman (1974). The year-class strengths were estimated stepwise beginning with calculation of the age distribution percentage in the yearly samples, and the mean age distribution percentage for each age-group during the entire period was then established. In the next step, the various year-classes in different years were expressed as percentages of this mean age distribution. The relative year-class strengths were the mean of these percentages, thus the 1983 year-class strength in gill nets was calculated as in Table 1. The relative year-class strength in 1983 was therefore the mean of the values in column V (index = 123). Only year-class indices based on at least three years were used. With this method, the mean year-class strength in a population was 100. To estimate the validity of the method, the year-class strengths were calculated from gill net and fyke net samples. Pikeperch were collected with gill nets ($n = 4080$) during 1977–1994 and with a fyke net ($n = 3638$) during 1980–1991. The gill nets were monofilament nets 30 m in length and 1.8 m in depth with a mesh size of 45 mm. The fyke net samples of pikeperch were obtained from commercial catches in Vanhankaupunginlahti Bay. The year-class strengths were calculated from age-groups 2–8 in gill nets and 3–9 in fyke nets. In gill nets the total number of two-year-old pikeperch was lowest ($n = 54$) and that of the six-year-olds highest ($n = 1316$). The number of nine-year-old fish in fyke net was likewise lowest ($n = 51$) and that of the five year-olds highest ($n = 1407$).

The most important prerequisite for this method is that all fish samples are collected using the same equipment in different years. In Vanhankaupunginlahti Bay all pikeperch were collected with similar gill nets and fyke nets. The second prerequisite is that the variation in natural mortality after the first year of life is low, as has been noted in many studies concerning pikeperch (Deelder & Willemsen 1964, Willemsen 1977, Densen & Grimm 1988, Sonesten 1991). The use of this method also presumes that the fish collected have been hatched in the same area and that the larvae and juveniles remain in the nursery area or near it during the first summer. Pikeperch fulfill these requirements because the homing behaviour towards the same spawning areas is well developed and the juveniles leave the nursery area in late summer or in autumn (Lehtonen & Toivonen 1987, Urho et al. 1990, Lappalainen et al. 1995).

Table 1. Example of calculation of relative year-class sttrength (year-class 1983).

I Age	II Year of samplig	III Age distribution in yearly samples (%)	IV Mean age distribution for age-group for entire study period (%)	V Index (= III/IV* 100)
2	1985	2.1	1.3	161.5
3	1986	3.2	3.0	106.7
4	1987	10.0	8.9	112.4
5	1988	44.6	30.8	144.8
6	1989	64.3	32.3	199.1
7	1990	16.3	18.6	87.6
8	1991	2.5	5.2	48.1
				Mean = 122.9

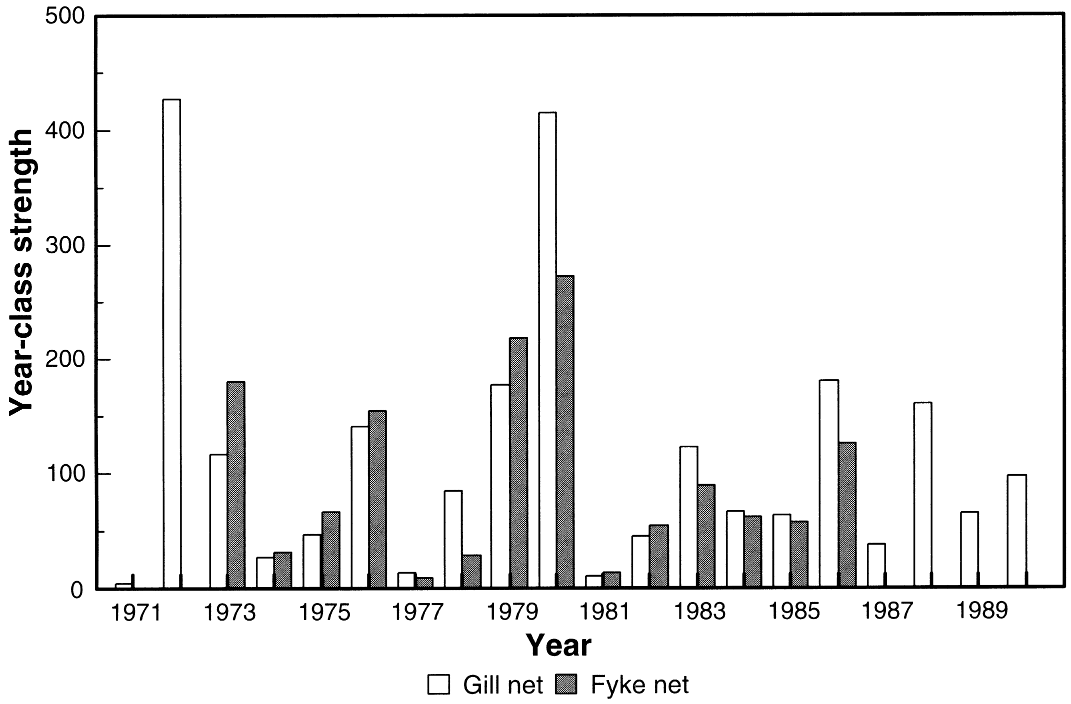

Fig. 2. Relative year-class strength of pikeperch estimated from gill net (1971–1990) and fyke net (1973–1986) samples in Vanhankaupunginlahti Bay.

The advantage of this method is that no estimations of the mortality are needed if all the other above-mentioned prerequisities are fulfilled. The disadvantage is that if the annual growth of the fish varies greatly, this method could overestimate the relative year-class strength in rapidly growing year-classes. This error was minimized by using only year-class indices based on catches from at least three-year-long periods. This method or modifications of it has been used recently by Wyatt (1988), Böhling et al. (1991), Lehtonen et al. (1993) and Lehtonen and Lappalainen (1995).

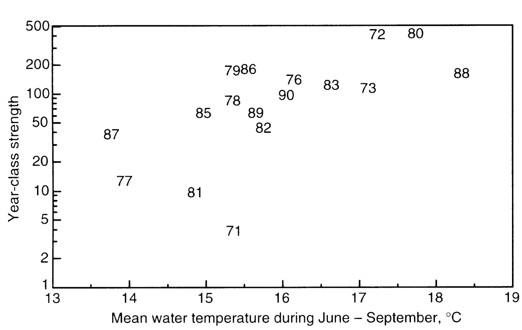

Fig. 3. Relationship between year-class strength and mean water temperature during June–September.

4. Results

Very weak year-classes with relative strengths < 30 were evident in 1977 and 1981 in calculations analysed from both gill net and fyke net samples (Fig. 2), while gill net samples also showed weak year-classes in 1971 and 1974. On the other hand, a very strong year-class, with relative strength > 200, was observed in 1980 in samples from both gears, while very strong year-classes were also observed in 1972 in gill net and in 1979 in fyke net samples. The year-class strengths calculated from gill nets and fyke nets correlated strongly ($r = 0.90$, $P < 0.0001$, $n = 14$; both log-transformed). As a result of the strong correlation and the longer time period available, the year-class strengths calculated from gill nets were selected to study the effects of environmental factors on year-class strength.

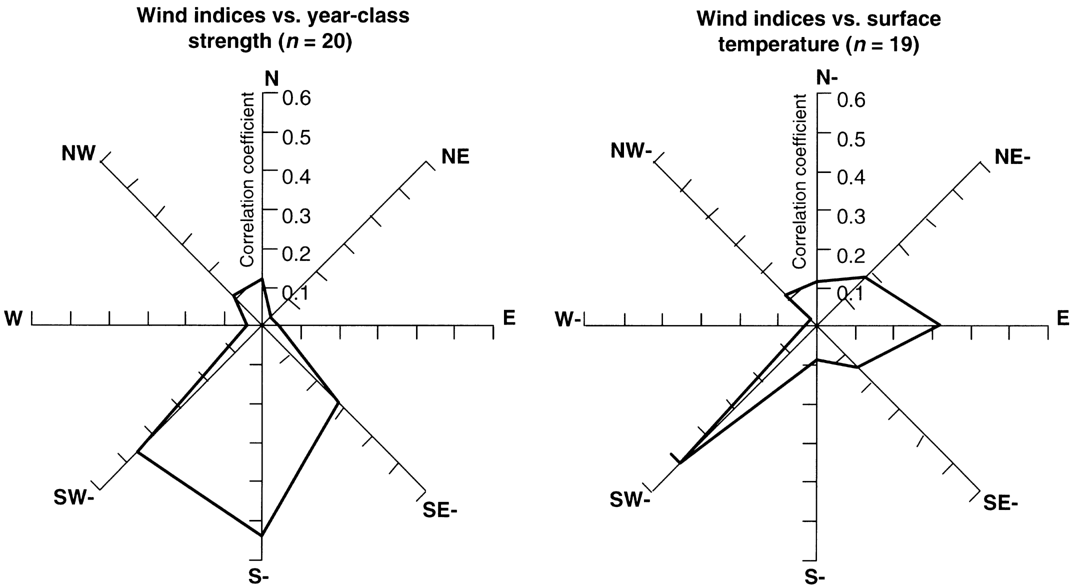

Fig. 4. Correlation coefficients between wind indices and year-class strength on left side and wind indices and mean water temperature on right side in July. The correlation coefficients are combined with a line, e.g. correlation coefficients between southerly and southwesterly wind indices and year-class strengths were – 0.50 and – 0.48, respectively. The corresponding correlation coefficient between southwesterly wind indices and mean water temperature was – 0.50. Number of observations (years) is in parentheses. Negative correlations are marked with (-) after wind direction.

No significant correlations between the year-class strength and the monthly water level, water salinity or water transparency were found. On the other hand, the correlation between the year-class strength and mean monthly water temperature during June–September (mean = 15.8, *S.D.* = 1.2, $n = 17$) was significant ($r = 0.63$, $P = 0.007$, $n = 17$; Fig. 3). The years 1974, 1975 and 1984 were not included in correlation calculations due to missing mean monthly temperatures. The correlations between the year-class strengths and the mean monthly water temperatures (2–7 measurements mo^{-1}) during June–September were all positive with statistically significant correlation in July ($r = 0.46$, $P = 0.049$, $n = 19$). The correlation analysis, however, also showed that the mean monthly water temperatures in June ($r = 0.79$, $P = 0.0002$, $n = 17$) and in July ($r = 0.80$, $P < 0.0001$, $n = 17$) were strongly correlated with the mean water temperature during June–September. These two mean monthly temperatures explained 88% of the total variation in the mean water temperature ($r^2 = 0.88$, $P < 0.0001$, $n = 17$). It is thus possible that the correlation between the year-class strength and the water temperature in July is only due to that between the year-class strength and the mean water temperature during June–September.

The strongest correlations between the wind indices and year-class strengths were found in July (Fig. 4). The southerly ($r = -0.50$, $P = 0.025$, $n = 20$) and southwesterly ($r = -0.48$, $P = 0.034$, $n = 20$) wind indices were negatively correlated with the year-class strength, as were the southwesterly wind indices with the water temperature ($r = -0.50$, $P = 0.030$, $n = 19$). Since the southerly wind indices in July were correlated with the water temperature and year-class strength, partial correlation coefficients were calculated. The partial correlation analysis showed that when the effects of temperature or winds were removed no independent effects on year-class strength were evident, suggesting that an other common factor is probably behind these correlations.

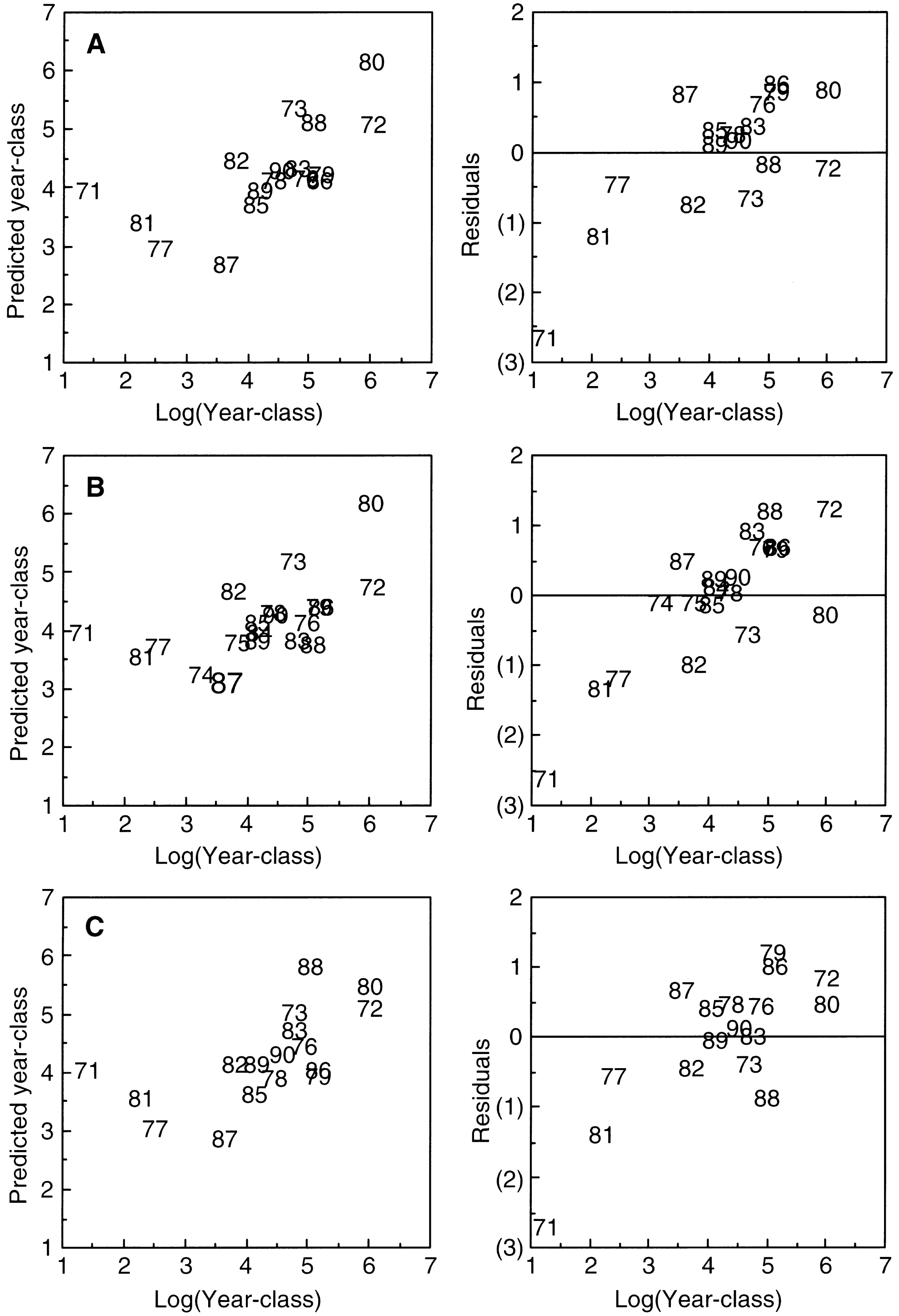

Fig. 5. Relationships between predicted and actual year-class strength estimated from following independent variables: A) mean water temperature during June–September, southerly and southwesterly wind indices in July, B) southerly and southwesterly wind indices in July and C) mean temperature during June–September. The residuals are plotted on right side.

The regression analyses were used to estimate the effects of several environmental factors on year-class strength. When the mean water temperature, southerly and southwesterly winds were used as independent variables the model explained 46% of the total variation in year-class strength (Table 2). The mean water temperature in July was excluded from the analyses, because it was significantly correlated with the other independent variables. The coefficient of determination was lower ($r^2 = 0.35$) when only the southerly and southwesterly wind indices were used as independent variables. The mean water temperature alone explained 40% of the variation in year-class strength (Table 2).

Examination of the residuals in the abovementioned models indicated that the very weak year-class strength in 1971 was clearly an outlier (Fig. 5), which could have been due to the exceptionally high salinity during the spawning and larval periods in June (1971: mean = 4.92, *S.D.* = 0.36, n = 6; 1972-1990: mean = 3.01, *S.D.* = 1.42, n = 68). It is known that the survival of eyed pikeperch eggs decreases almost linearly from 0.7‰ where survival is highest to 6.7‰ where no eggs are alive (Klinkhardt & Winkler 1989). The weak year-class in 1971 could also have been due to the calculation method used, because the year-class estimate of 1971 is based only on the relative abundance of 6–8 -year-old pikeperch. It is impossible to conclude which of these factors may have caused the weak year-class in 1971, but when it was excluded from the regression analysis, the coefficients of determination were clearly higher in models 5 and 6 compared with models 2 and 3 (Table 2).

5. Discussion

A general feature in studies on pikeperch year-class formation is that high summer temperatures exert positive effects on the year-class strength (Willemsen 1977, Svärdson & Molin 1981, Buijse et al. 1992, Lehtonen & Lappalainen 1995). The positive effects of water temperature during the first growing season from June to September were also evident in Vanhankaupunginlahti Bay. It was observed in the Netherlands that both the mean length and year-class strength of 0+ pikeperch in November were highly correlated with the mean summer temperature (Buijse & Houthuijzen 1992). In warm summers the growth rate of 0+ pikeperch is more rapid and the onset of piscivory earlier than in cold summers (Buijse & Houthuijzen 1992), while the ability of 0+ fry to survive over the first winter is usually size-dependent near the northern distribution range (Shuter & Post 1990, Conover 1992). Both the growth rate during the first summer and the size in the first autumn thus seem to be important factors affecting the year-class strength of pikeperch.

According to Erm (1981) no pikeperch populations exist on the northern coast of Estonia, located in the southern Gulf of Finland, because the prevailing southwesterly winds tend to replace the warmer surface water with the colder, more saline seawater during the spawning and larval periods. Böhling et al. (1991) observed that the year-class strength of several perch populations correlated most strongly within the different sides of the Baltic Sea. They suggested that this could have been caused by southwesterly winds tending to replace surface wa-

Table 2. Regression analysis with year-class strengths during 1971–1990 as dependent variables. The independent variables are: Mean = mean water temperature during June–September, S = southerly wind indices in July and SW = southwesterly wind indices in July.

Model	Years not included	Independent variables	n	r^2	Adj. r^2	F	P
1	1974, 1975, 1984	Mean, S, SW	17	0.46	0.34	3.70	0.040
2		S, SW	20	0.35	0.27	4.53	0.027
3	1974, 1975, 1984	Mean	17	0.40	0.36	9.89	0.007
4	1971, 1974, 1975, 1984	Mean, S, SW	16	0.44	0.37	6.19	0.010
5	1971	S, SW	19	0.62	0.52	6.50	0.007
6	1971, 1974, 1975, 1984	Mean	16	0.55	0.51	16.92	0.001

ter with colder water on the western but not on the eastern side. The negative effects of southwesterly winds on water temperature were demonstrated in the present study. Viitasalo et al. (1994) found that the southwesterly winds were negatively correlated with the water temperature and the total zooplankton biomass in a relative open outer archipelago off the Hanko peninsula on the southwest coast of Finland. Although these results cannot be generalized to cover semienclosed areas such as Vanhankaupunginlahti Bay, the food shortage could directly or indirectly be a possible explanation for the negative correlations between the year-class strength and the wind indices in July. In our earlier study (Lehtonen & Lappalainen 1995) no correlations between the mean wind velocity and the year-class strength of perch or pikeperch were found, as was also observed by Buijse et al. (1992). It thus seems that the direction and duration of the winds must also be considered when the effects of winds on the year-class formation of pikeperch are studied.

No correlation existed between the year-class size and water level, even though the latter was shown to correlate positively with the year-class strength of pikeperch (Svärdson & Molin 1973, Koonce et al. 1977). The spawning areas of pikeperch always occur in semienclosed bays or inlets in the Baltic Sea (Ojaveer et al. 1981), in which melting snow and possible river water discharges increase turbidity and decrease salinity. Increased turbidities in turn have been suggested to provide better life conditions for pikeperch (Woynarovich 1963, Erm et al. 1992). The high turbidity in Vanhankaupunginlahti Bay was probably at suitable levels during the summer months and hence had no effect on the year-class strength.

Pikeperch spawn on shallow bottoms at 1–3 m depths (Sonesten 1991). The water levels do not normally drop low enough in the Baltic Sea such that the pikeperch eggs could dry. When the water levels are low, the potential effects of waves increase, although in semienclosed inlets and bays the influence of waves on eggs is smaller than in more exposed areas.

Acknowledgements. We thank Lauri Pesonen and Ilkka Rinne from the City of Helsinki, Centre for the Environment for the water data off Vanhankaupunginlahti Bay. The English language was corrected by Dr James Thompson.

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