REPORT

Pikeperch (*Sander lucioperca* (L.)) in Decline: High Mortality of Three Populations in the Northern Baltic Sea

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Received: 1 November 2012 / Revised: 18 April 2013 / Accepted: 1 July 2013 / Published online: 6 August 2013

Abstract The development of three pikeperch (*Sander lucioperca* (L.)) populations in the northern Baltic Sea was monitored using standardized multimesh gillnets in 1995–2009. Declining trends in the abundances of pikeperch over 40 cm total length, low numbers of individuals older than 6 years, and high mortality rates were observed in all three populations. In the site with the largest commercial catches per unit area and a rapidly increased colony of great cormorants (*Phalacrocorax carbo sinensis* Blumenbach 1798), also the abundance of pikeperch below 40 cm total length and year-class strength showed declining trends. The adverse population level changes did not correlate with changes in water quality or eutrophication status. Together, the results suggest that in all study sites fisheries are harvesting a large proportion of the pikeperch soon after or even before reaching the maturity, and that predation from great cormorants may increase mortality of juveniles. Pikeperch is important not only for fisheries but also for ecosystem functioning, and our results point at the need for further management measures to ensure viable populations in the areas studied.

Keywords Year-class strength · Commercial fishing · Multimesh gillnet monitoring · Mortality · Great cormorant

INTRODUCTION

In the densely populated Baltic Sea region the shallow coastal areas are under considerable anthropogenic influence by eutrophication, hazardous substances, habitat

exploitation, and fisheries (HELCOM 2006, 2009, 2012). It is imperative to follow the development of coastal fish stocks as these are likely to be impacted by the multiple pressures. Moreover, large predatory fish, which are prime target for both commercial and recreational fisheries, are keystone species of the coastal ecosystem and decreasing populations may have profound indirect effects on ecosystem functioning (Brabrand and Faafeng 1993; Eriksson et al. 2011).

Pikeperch (*Sander lucioperca* (L.)) is a large freshwater piscivorous fish, common in the eastern and northern Europe. In the brackish Baltic Sea, it inhabits the coastal zone (Lehtonen et al. 1996). Pikeperch reaches sexual maturity in the Baltic Sea at the age of 4–6 years and length of 35–44 cm (Kosior and Wandzel 2001; Lappalainen et al. 2003). Males reach the maturity younger and at smaller size than females (Lappalainen et al. 2003; Ozyurt et al. 2011). Spawning takes place in May–June in warm, shallow areas with low salinity and high turbidity (Lehtonen et al. 1996; Veneranta et al. 2011). There is a lot of evidence on that larger and thus older females in many fish species have better spawning success than the younger ones (Berkeley et al. 2004; Olin et al. 2012). Because the year classes of pikeperch are stronger in warm summers (Kjellman et al. 2003; Pekcan-Hekim et al. 2011) and pikeperch prefer turbid water (Veneranta et al. 2011), they are generally expected to benefit from eutrophication and rising sea temperatures (Lehtonen et al. 1996; Pekcan-Hekim et al. 2011; Veneranta et al. 2011).

Pikeperch is highly valued as a commercial species, and the stocks in the Baltic Sea are harvested intensively (Eero 2004; Heikinheimo et al. 2006). Minimum landing size of pikeperch at the Swedish Baltic Sea coast is 40 cm (Swedish Board of Fisheries 2011). The smallest allowed mesh size for pikeperch fishing is 45 mm bar length in

Electronic supplementary material The online version of this article (doi:10.1007/s13280-013-0429-z) contains supplementary material, which is available to authorized users.

parts of the coast, while in other parts there are no restrictions. In Finland, including the Åland Islands, the minimum landing size of pikeperch is 37 cm [Fishing Decree (Kalastusasetus 191/2008)]. In addition, in the Åland Islands the smallest allowed mesh size for pikeperch fishing is 45 mm bar length and pikeperch fishing is prohibited during the spawning time (25 May–5 July). The three sites where this study was conducted are among the main pikeperch reproduction and fishing areas in the northern Baltic Sea (Sundblad et al. 2011; Veneranta et al. 2011).

At the Swedish Baltic Sea coast pikeperch catches were stable during the 1980s, but then decreased sharply and have now stabilized at one-fourth of the level of the 1980s (Lehtonen et al. 1996; Swedish Board of Fisheries 2011). In the Finnish Archipelago Sea the catches of pikeperch increased during the 1990s, but declined again during the 2000s (Lappalainen et al. 2002; Finnish Game and Fisheries Research Institute 2006; Pekcan-Hekim et al. 2011). The increase in catches in the 1990s was in part due to strong year classes of 1988 and 1991 (Pekcan-Hekim et al. 2011), but also due to increased fishing pressure since the late 1990s, which was caused by the decrease of cod (*Gadus morhua* (L.)) in the 1980s. These factors in combination with restrictions on salmon (*Salmo salar* (L.)) fishing and an increase in pikeperch price caused an increase in catches, which was probably larger than the actual increase in the stock size (Lappalainen et al. 2002). High fishing pressure, weak year-classes and gear damage by gray seal (*Halichoerus crypus* (L.)) have been blamed for the declining catches in the 2000s (Finnish Game and Fisheries Research Institute 2006; Söderkultalahti and Ahvonen 2011; HELCOM 2012).

During the last decades, the numbers of both great cormorant (*Phalacrocorax carbo sinensis* Blumenbach 1798) and gray seal have increased in the Baltic Sea area (Wikman 2010; Herrmann et al. 2011), and the increased predation pressure from them may affect fish stocks and fisheries (Lundström et al. 2010; Söderkultalahti and Ahvonen 2011; Östman et al. 2012). Gray seals feed mainly on herring (*Clupea harengus*) and sprat (*Sprattus sprattus* (L.)), and available diet studies have rarely found pikeperch in their diet (Lundström et al. 2010), which indicates that predation pressure on pikeperch from gray seals, although probably rising, is of minor importance. However, the gray seal may be an issue for the commercial pikeperch fishing as it eats fish directly from the gear destroying the catch and the gear alike (Söderkultalahti and Ahvonen 2011). Great cormorants feed on pikeperch, but seem to be generalist predators favoring the most abundant and easily available species (Korhonen 2010; Lehtikoinen et al. 2011). Some previous studies have argued that predation by cormorants can have an effect on fish populations

of importance for fisheries (Vetemaa et al. 2010; Östman et al. 2012), but in other studies no effect was detected (Lehtikoinen et al. 2011). A great cormorant nesting colony accompanied by a large number of subadults is located in one of the sites of this study. There are no nesting great cormorants in close proximity to the other two study sites and no bird counts are available, even though cormorants occur there.

An improved understanding of pikeperch population dynamics and regulation in the Baltic Sea is essential for the management of this valuable resource, providing ecosystem services such as regulation of mesopredators (Brabrand and Faafeng 1993; Eriksson et al. 2011), beside the more obvious food and recreation. The aim of this study was to analyze abundance, year-class strength (YCS), growth, and mortality in three pikeperch populations in the northern Baltic Proper, and to relate observed changes to potential pressures such as commercial fishing, water quality, and predation.

MATERIALS AND METHODS

Study Sites

The study sites, Galtfjärden (60°10'N 18°34'E) on the Swedish east coast, and Lumparn (60°07'N 20°07'E) and Ivarskärsfjärden (60°16'N 19°48'E) in the Åland Islands, are semi-isolated brackish water embayments located in the inner archipelago zone in the northern Baltic Sea (Fig. 1). The total area of Galtfjärden and the adjacent bays and straits where pikeperch is mainly found is c. 74 km² and the average depth is 6 m. The total area of Lumparn and the adjacent bays is c. 160 km² and the average depth is 12 m. The total area of Ivarskärsfjärden with the adjacent bays and straits is c. 62 km² and the average depth is 4 m.

Hydrography

Water sampling in Galtfjärden was conducted at two points (depth 8–12 m, 60°12'N 18°29'E) by Svealand's Coastal Water Management Association in 1996–2009. Water sampling in Lumparn was conducted at five points (depth 20–30 m, 60°08'–60°11'N, 20°03'–20°13'E) by the Environment Agency of the Provincial Government of the Åland Islands in 2000–2009. Water sampling in Ivarskärsfjärden was conducted at one point (depth 10 m, 60°16'N 19°48'E) by Husö biological station in 1995–2009.

In each study site, water sampling was conducted annually in August (1–4 times each year). Parameters studied were salinity (psu), total phosphorus (µg l⁻¹), total nitrogen (µg l⁻¹), temperature (°C), and chlorophyll *a* (µg l⁻¹), measured at 1 m depth, and Secchi depth (m).

Fig. 1 Study sites Galtfjärden (60°10'N 18°34'E) in Sweden and Lumparn (60°07'N 20°07'E) and Ivarskärsfjärden (60°16'N 19°48'E) in Åland Islands, Finland. Fishing stations are marked (circles) on the map

Annual mean values of measurements in August were calculated for each study site.

Water Temperature

Data on mean daily water temperatures for Galtfjärden in 1992–2006 were obtained from the Forsmark nuclear power plant, 30 km north of the study site (60°24'N 18°11'E, surface water).

For Lumparn and Ivarskärsfjärden the water temperature was estimated based on air temperature. Data on mean daily air temperature on the Åland Islands in 1996–2006 were obtained from the Finnish Meteorological Institute at Jomala meteorological station (60°09'N 19°52'E). Water temperature data consisted of measurements made by the Environment Agency of the Provincial Government of the Åland Islands in Lumparn (200 measurements) and by Husö biological station in Ivarskärsfjärden (280 measurements) in 1996–2006 during the open-water period (approx. March–October). Estimated mean daily water temperatures were calculated based on a linear regression (LR) model with air temperature as the independent variable and the available water temperatures as the dependent variable: Lumparn: $\text{temperature}_{\text{water}} = 0.776 \times \text{temperature}_{\text{air}} + 4.698$ ($R^2 = 0.68$), and Ivarskärsfjärden: $\text{temperature}_{\text{water}} = 0.765 \times \text{temperature}_{\text{air}} + 5.739$ ($R^2 = 0.75$). The monthly average water temperatures (°C, Pekcan-Hekim et al. 2011) and the monthly degree-day sums over a threshold temperature of 10 °C (DD10, Kjellman et al. 2003) in the study sites were calculated.

Commercial Pikeperch Fishing

Data on commercial pikeperch fishing catches (kg) in Galtfjärden in 1994–2008 were obtained from the Swedish Board of Fisheries. Data on commercial pikeperch fishing catches (kg) and the numbers of nets and fishing nights in Lumparn and Ivarskärsfjärden in 1996–2009 were obtained from the Finnish Ministry of Agriculture and Forestry. The data are the official catch statistics of Sweden and Finland, respectively, and are based on reports by commercial fishermen.

Annual commercial catch (kg ha^{-1}) was calculated for each study site:

$$\text{Catch}_{\text{commercial}} = \text{kg}_{\text{pikeperch}} / \text{ha}_{\text{site}}$$

Annual commercial fishing effort (nets ha^{-1}) and commercial catch-per-unit-effort (CPUE, $\text{kg net}^{-1} \text{night}^{-1}$) were calculated for Lumparn and Ivarskärsfjärden:

$$\text{Effort}_{\text{commercial}} = n_{\text{nets}} / \text{ha}_{\text{site}}$$

$$\text{CPUE}_{\text{commercial}} = \text{kg}_{\text{pikeperch}} / (n_{\text{nets}} * n_{\text{night}})$$

Pikeperch Consumption by Great Cormorants in Galtfjärden

Galtfjärden was the only study site with nesting great cormorants. The great cormorants were counted twice or thrice yearly during the nesting season in May–July. Both the birds in close proximity the colony and the nests were counted. The maximum number of individuals recorded in

the counts was used in the consumption calculations. By combining data on numbers of nesting and subadult great cormorants with estimates of total consumption and the proportion of pikeperch in the diet, we estimated their potential pikeperch consumption. No cormorant diet data were available from the study area. Instead we used data from two studies in the Finnish Archipelago Sea (Korhonen 2010; Lehtikoinen et al. 2011), where the environment and composition of the fish community is similar to the three sites in this study (HELCOM 2006). In these studies, the proportion of pikeperch in the diet of great cormorants in weight was estimated to 10.5 % (Korhonen 2010; average of 2 years) and 3.7 % (Lehtikoinen et al. 2011). We used the mean of these two studies, 7.1 %, in our calculations to get a rough estimate of the potential consumption.

The total expected fish consumption was estimated from published bioenergetic models and tests (reviewed in Ridgeway 2010) according to Östman et al. (manuscript). The average daily consumption per adult breeder, including the consumption of chicks, was estimated to 608 g over a 150-day-long period from egg incubation to post-breeding. The total length of the period was estimated to be 30 days shorter than in Östman et al., as a consequence of a shorter summer in this more northerly area. For subadults, the daily consumption was set to 540 g.

Gillnet Monitoring

In all study sites gillnet monitoring was conducted with standardized annual multimesh gillnet monitoring on the same six stations on each area in the autumn (weeks 39–42). The stations were chosen to represent all depths and habitats within the study sites. The gillnet monitoring in Galtfjärden was conducted in 1995–2008 by the Swedish Board of Fisheries. The gillnet monitoring in Lumparn and Ivarskärsfjärden was conducted in 2000–2009 by the Fisheries Division of the Provincial Government of Åland Islands.

The gear consisted of four or five bottom-set, 60.0 m long and 3.0 m high gillnets with different mesh sizes organized as one gillnet series. The soak time was 16 h, set at 3–5 pm and lifted at 7–9 am. Fishing was conducted on three consecutive nights (one gillnet series per station per night). The gear used in Galtfjärden in 1995–1998 consisted of four gillnets of mesh sizes 25, 30, 38, and 50 mm bar length. In 1999, a gillnet with mesh size of 45 mm was added to the series. The gear used in Galtfjärden in 1999–2008 and in Lumparn and Ivarskärsfjärden in 2000–2009 thus consisted of five gillnets (mesh sizes 25, 30, 38, 45, and 50 mm bar length).

The total number of pikeperch caught during this study was 8124, of which 3307 were from Galtfjärden, 2437 from Lumparn, and 2380 from Ivarskärsfjärden. Each pikeperch

was measured for the total length in mm, and the age of each pikeperch (years) was determined either from scales or otoliths. The age reading results were regularly cross-evaluated.

We used number-per-unit-effort (NPUE) as a measure of pikeperch abundance, number of pikeperch as a measure of catch, and number of nets as a measure of effort. Therefore, $NPUE = \text{the average number of pikeperch per gillnet}$. We have attempted to stabilize annual catchability by conducting the monitoring on the same stations, effort and gear at the same time each year.

Following annual NPUE values were calculated for the gillnet monitoring catches on each station:

Average number of pikeperch per net:

$$NPUE = \frac{n_{\text{pikeperch}}}{n_{\text{nets}}},$$

Average number of small ($L_T < 40$ cm) pikeperch per net:

$$NPUE_{\text{small}} = \frac{n_{\text{pikeperch} < 40\text{cm}}}{n_{\text{nets}}},$$

Average number of large ($L_T \geq 40$ cm) pikeperch per net:

$$NPUE_{\text{large}} = \frac{n_{\text{pikeperch} \geq 40\text{cm}}}{n_{\text{nets}}}.$$

$NPUE_{\text{large}}$ describes the abundance of adult pikeperch, i.e., spawning stock size, and the abundance of pikeperch targeted by commercial fishing.

The NPUE values from Galtfjärden in 1995–1998 were multiplied with a correction factor for the absence of the mesh size of 45 mm:

$$\text{correction factor} = \frac{NPUE_{45\text{mm}}}{NPUE_{\text{no}45\text{mm}}},$$

where $NPUE_{45\text{mm}} = NPUE$ since 1999 and $NPUE_{\text{no}45\text{mm}} = NPUE$ since 1999 with 45 mm mesh size excluded. Correction factors were then for $NPUE = 0.855$, $NPUE_{\text{small}} = 0.844$, and $NPUE_{\text{large}} = 1.14$.

The YCS in a specific year was approximated based on the NPUE of 3-year-old pikeperch caught in the gillnet monitoring 3 years later:

$$YCS_a = NPUE_{\text{age}3_{a+3}},$$

where $a = \text{year}$ and

$$NPUE_{\text{age}3} = \frac{n_{\text{age}3\text{pikeperch}}}{n_{\text{nets}}}$$

The NPUE of 3-year-old pikeperch was chosen as the estimate for the YCS since it was the youngest age group fully recruited to the gear in this study.

Commercial pikeperch fishing is typically conducted with the mesh size of 45 mm. We calculated the proportion of pikeperch shorter than the minimum landing size caught in the mesh size of 45 mm in the gillnet monitoring in order to estimate if the mesh size regulation is appropriate.

Statistical Analyses

All statistical analyses were performed with the statistical program package PASW Statistics 18.0. Parametrical tests were used if the data met the requirements of normality and homogeneity.

The differences among the study sites in parameters for hydrography and gillnet monitoring were analyzed either with one-way analysis of variance (ANOVA) and Bonferroni post hoc test or the non-parametric Kruskal–Wallis test (K–W) followed by pairwise comparisons with Mann–Whitney *U* test and Bonferroni-correction for significance levels (5 % significance level = $0.05/n_{\text{comparisons}}$). Trends in the above-mentioned parameters within study sites over time were analyzed with the non-parametric Spearman rank-correlation analysis (*r*; time–parameter correlation). This approach was chosen as the data, even after transformations, did not meet the requirements for two-way parametrical tests.

Mortality values were calculated for ages fully recruited to the gear. Ages above the first age where only one individual was encountered were excluded (Dunn et al. 2002). The instantaneous mortality (*Z*) and annual mortality (*A*) in each study site for the whole study period were estimated with LR model:

Instantaneous mortality = $Z = -\text{slope of the LR of } \ln(\text{age-wise mean of NPUE}_{a,y}) \text{ against } a$, where

$$\text{NPUE}_{a,y} = \frac{n_{\text{pikeperch},a,y}}{n_{\text{nets},y}}, \quad a = \text{age}, \quad y = \text{year}$$

$$\text{Annual mortality} = A = 1 - e^{-Z}$$

The *Z*-at-age (Z_a) in the study sites was calculated:

$$Z_a = \ln(\text{age-wise mean of NPUE}_{a,y}) - \ln(\text{age-wise mean of NPUE}_{a+1,y})$$

The *Z* for each year of catch (Z_y) in the study sites was calculated:

$$Z_y = \text{yearly mean of } (\ln(\text{NPUE}_{a,y}) - \ln(\text{NPUE}_{a+1,y+1}))$$

Relationship between log-transformed YCS and water temperature (mean water temperature and DD10 for each month separately and for all combinations of months from April to October) was studied with LR analysis.

For Galtfjärden, where cormorant count data and pikeperch predation estimates were available for the whole time-series, the combined effect of DD10 and cormorant predation on YCS (estimated from NPUE of age 3) was described using a two-factor LR. Cormorant predation was estimated as predation on age 2 fish, as previous studies have shown that cormorants mainly consume pikeperch of lengths corresponding to ages 1 and 2 (Korhonen 2010).

Regarding total length and age, the sexes were pooled as no difference in length-at-age was detected between males and females (ANCOVA factor sex: $F_{1,6034} = 1.63$, $p = 0.20$, covariate age: $F_{1,604} = 14\,121.32$, $p < 0.001$). In order to illustrate length-at-age, a von Bertalanffy growth model was fitted to the data:

The von Bertalanffy equation: $E[L|t] = L_{\infty} (1 - e^{-K(t-t_0)})$, where $E[L|t]$ is the expected average length at age *t*, L_{∞} is the asymptotic average length, *K* is the rate of approach to the L_{∞} , and t_0 is the theoretical age at length 0 (Beverton and Holt 1957).

RESULTS

Hydrography

During the years 2000–2009, Galtfjärden had the highest chlorophyll *a* concentration and the lowest salinity, while Lumparn had the lowest chlorophyll *a* concentration, lowest total nitrogen, and total phosphorus concentrations but highest Secchi depth (Table 1). The only water parameters that displayed a statistically significant change over time were the decreasing chlorophyll *a* concentration in Lumparn ($r_s = 0.71$, $p < 0.05$) in 2000–2009, and increasing chlorophyll *a* concentration ($r_s = 0.84$, $p < 0.05$) and decreasing

Table 1 Water quality parameters in August (mean ± SE) in 2000–2009

	Galtfjärden	Lumparn	Ivarsjöfjärden	Analysis
Secchi depth (m)	1.5 ± 0.09 ^a	2.5 ± 0.13 ^b	1.6 ± 0.09 ^a	ANOVA; $F_{2,26} = 24.2^{***}$
Temperature (°C)	17.3 ± 0.44 ^a	19.5 ± 0.49 ^b	19.8 ± 0.43 ^b	ANOVA; $F_{2,26} = 8.9^{***}$
Chlorophyll <i>a</i> (µg l ⁻¹)	11.2 ± 1.5 ^a	3.3 ± 0.3 ^b	5.3 ± 0.2 ^c	K–W; $\chi^2_2 = 22.9^{***}$
Total phosphorus (µg l ⁻¹)	45 ± 13.6 ^a	17 ± 0.6 ^b	28 ± 1.0 ^a	K–W; $\chi^2_2 = 16.8^{***}$
Total nitrogen (µg l ⁻¹)	450 ± 33 ^a	340 ± 10 ^b	430 ± 11 ^a	K–W; $\chi^2_2 = 13.0^{***}$
Salinity (psu)	5.0 ± 0.1 ^a	5.7 ± 0.04 ^b	5.5 ± 0.03 ^b	ANOVA; $F_{2,26} = 29.9^{***}$

Within a row, means followed by the same letter are not significantly different at $p < 0.05$ with Bonferroni-correction

ANOVA One-way analysis of variance for difference among study sites, K–W Kruskal–Wallis test for difference among study sites

Significance levels: NS $p > 0.05$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

salinity ($r_s = -0.65$, $p < 0.05$) in Ivarskärsfjärden in 1995–2009 (Supplementary material).

Commercial Pikeperch Fishing

The average catch_{commercial} in 1996–2009 was the highest in Galtfjärden (17 060 kg year⁻¹ resp. 2.3 kg ha⁻¹ year⁻¹), second highest in Lumparn (26 960 kg year⁻¹ resp. 1.7 kg ha⁻¹ year⁻¹) and the lowest in Ivarskärsfjärden (6500 kg year⁻¹ resp. 1.0 kg ha⁻¹ year⁻¹). The catch_{commercial} in Lumparn and Ivarskärsfjärden peaked in the early 2000s, while the catch_{commercial} in Galtfjärden peaked in 2007 (Fig. 2a). The annual effort_{commercial} was on average higher in Lumparn (5.5 nets ha⁻¹) than Ivarskärsfjärden (2.8 nets ha⁻¹, Fig. 2b), while the CPUE_{commercial} was on average slightly lower in Lumparn (0.48 kg net⁻¹ night⁻¹) than Ivarskärsfjärden (0.41 kg net⁻¹ night⁻¹, Fig. 2c). No statistically significant relationships between the commercial catches and hydrography, pikeperch NPUE or pikeperch YCS were found in any study site.

Predation by Great Cormorants

In Galtfjärden, the number of breeding great cormorant birds averaged 655, in 1995–2008, peaking in 2004 with 1800 nesting cormorants. The number of subadults was on average 615, with a maximum of 1500 individuals in 2000 (Fig. 3). Combining the count data and the 7.1 % proportion of pikeperch in the great cormorant diet with the estimates of total fish consumption resulted in a mean pikeperch consumption estimate of 8600 kg year⁻¹, with a maximum of 20 000 kg in 2005. This corresponds to about 50 % of the commercial catches on average, while in several years the cormorant consumption estimate is above 80 % of the commercial catches.

Gillnet Monitoring

Pikeperch Abundance

During the years 1995–2008 in Galtfjärden, the NPUE, NPUE_{small}, and NPUE_{large} all declined. In Lumparn and Ivarskärsfjärden in 2000–2009, NPUE and NPUE_{small} did not show a trend over time, while NPUE_{large} declined (Fig. 4; Table 2). In 2000–2008, the time period with data from all study sites, NPUE, NPUE_{small}, and NPUE_{large} was lower in Galtfjärden than in Lumparn and Ivarskärsfjärden. The NPUE_{large} was highest in Ivarskärsfjärden (Fig. 3; Table 2). No statistically significant relationships between the NPUE values and hydrography, pikeperch YCS or cormorant predation were found in any study site.

Fig. 3 Development of the numbers of breeding and subadult great cormorants in Galtfjärden in 1995–2008

Fig. 2 Commercial pikeperch fishing in the study sites Galtfjärden in 1994–2009, Lumparn in 1996–2009, and Ivarskärsfjärden in 1996–2009. **a** Commercial catch, kg ha⁻¹, **b** commercial effort nets ha⁻¹, and **c** commercial CPUE kg net⁻¹ night⁻¹

Fig. 4 Abundance of pikeperch (average number per net $\pm$ SE) in the gillnet monitoring catches in Galtfjärden in 1995–2008, Lumparn in 2000–2009, and Ivarskärsfjärden in 2000–2009. **a** Abundance of all pikeperch (NPUE), **b** abundance of small pikeperch (pikeperch < 40 cm total length; NPUE_{small}), and **c** abundance large pikeperch (pikeperch $\geq$ 40 cm total length; NPUE_{large}). Note the different scales on y-axes

Pikeperch Catch in the Mesh Size of 45 mm in the Gillnet Monitoring Gear

Mean length of pikeperch caught in the mesh size of 45 mm was in Lumparn 39.6 cm (min 18 cm, max 47 cm), in Ivarskärsfjärden 41.2 cm (min 14 cm, max 56 cm), and in Galtfjärden 31.2 cm (min 9 cm, max 56 cm). Of the pikeperch caught in the mesh size of 45 mm, 18 % in Lumparn, 15 % in Ivarskärsfjärden, and 55 % in Galtfjärden were shorter than the minimum landing size (Lumparn and Ivarskärsfjärden 37 cm, Galtfjärden 40 cm, respectively).

Age and Length of Pikeperch

In all sites, pikeperch of ages 2–4 were the most abundant in the catches (Fig. 5a). In all study sites and years, the

proportion of pikeperch older than 6 years was less than 1 % of the annual catch. The total length of majority of the pikeperch was within the range of 25–35 cm (Fig. 5b). The age distributions indicate that the pikeperch were fully recruited to the gear at the age of 3 years and length of 25–27.4 cm (Figs. 5, 6). More small-sized (<25 cm) pikeperch were caught in Galtfjärden than in the two other areas (Fig. 5b). The Bertalanffy analysis showed that pikeperch grew rather similarly in all study sites (Fig. 6).

Pikeperch Mortality

The mortality (Z) was calculated for individuals from the age of three upwards (Table 3). There were no statistically significant differences among the study areas on Z values,

Table 2 Abundance (average number per net $\pm$ SE) of all pikeperch (NPUE), small pikeperch (pikeperch < 40 cm total length; NPUE_{small}), and large pikeperch (pikeperch $\geq$ 40 cm total length; NPUE_{large}) in the gillnet monitoring catches during the whole study period and in 2000–2008, the time period with data available from all study sites. See also Fig. 4

		Galtfjärden 1995–2008	Lumparn 2000–2009	Ivarskärsfjärden 2000–2009	Analysis
NPUE	Whole period	1.76 $\pm$ 0.15	2.79 $\pm$ 0.20	2.56 $\pm$ 0.17	None
	Whole period	$r = -0.42^{***}$	$r = 0.11$ NS	$r = -0.28$ NS	r_s
	2000–2008	1.32 $\pm$ 0.12 ^a	2.68 $\pm$ 0.20 ^b	2.63 $\pm$ 0.19 ^b	ANOVA; $F_{2,159} = 17.4^{***}$
NPUE _{small}	Whole period	1.66 $\pm$ 0.14	2.63 $\pm$ 0.19	2.24 $\pm$ 0.16	None
	Whole period	$r = -0.39^{***}$	$r = 0.15$ NS	$r = -0.21$ NS	r_s
	2000–2008	1.27 $\pm$ 0.15 ^a	2.51 $\pm$ 0.20 ^b	2.29 $\pm$ 0.17 ^b	ANOVA; $F_{2,159} = 14.0^{***}$
NPUE _{large}	Whole period	0.10 $\pm$ 0.02	0.16 $\pm$ 0.02	0.31 $\pm$ 0.03	None
	Whole period	$r = -0.72^{***}$	$r = -0.52^{***}$	$r = -0.47^{***}$	r_s
	2000–2008	0.05 $\pm$ 0.02 ^a	0.17 $\pm$ 0.02 ^b	0.34 $\pm$ 0.03 ^c	K–W; $\chi^2_2 = 64.3^{***}$

Within a row, means followed by the same letter are not significantly different at $p < 0.05$ with Bonferroni-correction

r_s Spearman rank-correlation analysis for time-parameter correlation; ANOVA one-way analysis of variance for difference among study sites; K–W Kruskal–Wallis test for difference among study sites

Significance levels: NS $p > 0.05$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Fig. 5 Age distributions and length distributions of pikeperch in the study sites in the gillnet monitoring. **a** The number of pikeperch of each age (years) in Galtfjärden, Lumparn, and Ivarskärsfjärden, and **b** the number of pikeperch within each 2.5-cm-length interval (total length) in Galtfjärden, Lumparn, and Ivarskärsfjärden

Fig. 6 Length-at-age of pikeperch (circles) and von Bertalanffy curves (lines) in the gillnet monitoring catches in Galtfjärden in 1995–2008, and Lumparn and Ivarskärsfjärden in 2000–2009

i.e., the regression slopes ($F_{2,15} = 0.42$, $p = 0.66$ NS). The Z calculated for each year of catch did not show any statistically significant trends and did not correlate with commercial fishing, cormorant predation, pikeperch NPUE, or pikeperch YCS.

YCS, Temperature and Cormorant Predation

In all study sites, year classes 1996, 2000, and 2004 were relatively weak and year classes 1997 and 2001 were strong (Fig. 7). Best fit between temperature and YCS was obtained for water DD10 in May–June in Galtfjärden, and for estimated water DD10 in June–September in Lumparn and Ivarskärsfjärden (Table 4). The YCS declined over

Table 3 Instantaneous mortality (Z) and annual mortality (A) for the whole study period and the mortalities at age a (Z_a) in the gillnet monitoring catches

	Galtfjärden 1995–2008 Ages 3–10	Lumparn 2000–2009 Ages 3–8	Ivarskärsfjärden 2000–2009 Ages 3–9
Z/A	1.06/65 %	1.15/68 %	1.16/69 %
Z_4	1.09	1.47	1.23
Z_5	0.94	0.62	0.42
Z_6	0.81	1.89	1.60
Z_7	1.68	1.53	1.66
Z_8	1.52		1.39
Z_9	0.15		

time in Galtfjärden, but neither in Lumparn nor in Ivarskärsfjärden. The YCS was lower in Galtfjärden than in Lumparn and Ivarskärsfjärden (Fig. 7; Table 4).

For Galtfjärden, cormorant predation affected YCS negatively. The LR of YCS against DD10 and cormorant predation was highly significant ($F_{2,11} = 10.93$, $p = 0.002$) and explained 66.5 % of the variability between-year classes. The positive influence of DD10 on YCS was stronger ($p = 0.009$) than the negative influence of cormorant predation ($p = 0.046$). No other statistically significant relationships between pikeperch YCS and hydrography, commercial fishing or pikeperch NPUE were found in any study site.

DISCUSSION

Several adverse changes were observed in the three pikeperch populations studied. A high mortality and a decline in the abundance of large individuals (≥ 40 cm total length) were observed in all study sites, and the proportion of large

Fig. 7 Year-class strength (YCS) and DD10 temperature sums in the gillnet monitoring catches in **a** Galtfjärden 1992–2005, DD10 = water DD10 in May–June, **b** Lumparn 1996–2006, DD10 = estimated water DD10 in June–September, and **c** Ivarskärsfjärden 1996–2006, DD10 = estimated water DD10 in June–September

individuals was low. In addition, declining trends in abundance of small pikeperch (<40 cm total length) and in pikeperch YCS were observed in Galtfjärden, the area with the highest commercial catches and the only site with rapidly increased great cormorant population.

In line with previous studies (Kjellman et al. 2003; Lappalainen et al. 2003; Pekcan-Hekim et al. 2011), we found a positive relationship between pikeperch YCS and temperature. This result, as well as the strong and weak year classes corresponded to previous studies (Finnish Game and Fisheries Research Institute 2006; Pekcan-Hekim et al. 2011). Also the increases and decreases in the commercial pikeperch fishing catches were rather similar to those recorded from the Finnish Archipelago Sea (Lappalainen et al. 2002; Heikinheimo et al. 2006; Pekcan-Hekim et al. 2011).

The few changes observed in water quality and eutrophication status parameters differed between areas and could not explain the consistent decrease in large pikeperch observed in the three areas. No statistically significant

relationships were found between hydrography and pikeperch abundance, mortality or YCS. Galtfjärden, with the most turbid water conditions of the three study areas, should provide the most suitable pikeperch habitat (Lehtonen et al. 1996; Veneranta et al. 2011), but instead the gillnet monitoring revealed the lowest pikeperch abundances and the most profound declines in this area. Thus, neither spatial differences nor temporal changes indicate that water quality is responsible for the observed changes in pikeperch population parameters.

The pikeperch population development according to the results of the gillnet monitoring matched the predation pressure from great cormorants, with the most notable pikeperch population level changes in Galtfjärden, the only site with rapidly increased great cormorant population. The estimated amount of pikeperch removed by cormorants in Galtfjärden was on average 50 % of, and in some years almost equal to, the commercial catch. Simultaneously, the analysis of YCS regulation in Galtfjärden indicates that cormorant predation may have contributed to the decrease

Table 4 Year-class strength (YCS; mean $\pm$ SE). See also Fig. 7

	Galtfjärden 1992–2005	Lumparn 1996–2006	Ivarskärsfjärden 1996–2006	Analysis
YCS	0.51 ± 0.10^a	0.91 ± 0.23^b	1.00 ± 0.19^b	ANCOVA; $F_{2,26} = 4.4^{**}$
	$F_{1,12} = 11.2^{**}$	$F_{1,10} = 5.2^*$	$F_{1,10} = 7.5^*$	LR
	$R^2 = 0.48$	$R^2 = 0.60$	$R^2 = 0.45$	
	Slope = 0.012	Slope = 0.006	Slope = 0.006	
	$r = -0.64^*$	$r = -0.09$ NS	$r = 0.06$ NS	r_s

Within a row, means followed by the same letter are not significantly different at $p < 0.05$ with Bonferroni-correction

LR Linear regression analysis, dependent variable year-class strength, independent variable DD10 (Galtfjärden water DD10 in May–June, Lumparn and Ivarskärsfjärden estimated water DD10 in June–September); r_s Spearman rank-correlation analysis for year–YCS correlation; ANCOVA analysis of covariance for difference among study sites with DD10 as covariate ($F_{1,26} = 13.4^*$)

Significance levels: NS $p > 0.05$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

observed in small pikeperch during the last years. For a more thorough analysis of the potential impact of great cormorants and seals on pikeperch populations, diet and abundance data from all study areas would, however, be needed.

The mortalities in the study sites are of the same magnitude as in a previous study from the Finnish Archipelago Sea in 1978–1997, where mortality was 1.1 (Heikinheimo et al. 2006). A study from the Estonian coast shows that pikeperch fishing was sustainable at fishing mortalities around 0.8 for 6-year-old pikeperch but the stock collapsed when fishing mortality was doubled (Eero 2004). The mortality level of 6-year-old fish at collapse (c. 1.9) was approximately the same as observed in this study, which suggests that the pikeperch stocks are endangered in the study areas. Mortality estimates are based on gillnet fisheries, which may cause uneven mortality estimates among years due to different temperature regimes followed by between-year differences in recruitment success and growth of pikeperch. However, also the previous studies (Eero 2004; Heikinheimo et al. 2006), being mainly based on gillnet catches, are associated with similar difficulties, making the comparisons justified. Furthermore, the previous studies are based on variable commercial catches while our results come from standardized test fishing, which ought to give more reliable results than the variable, both regarding fishing effort and time of catch, commercial catches.

A notable proportion of the pikeperch (Lumparn 18 %, Ivarskärsfjärden 15 %, Galtfjärden 55 %) caught in the mesh size of 45 mm bar length, the smallest mesh size allowed in commercial fishing, was shorter than the minimum landing sizes (37 cm in Lumparn and Ivarskärsfjärden, and 40 cm in Galtfjärden, respectively). This observation leads us to conclude that gillnet fishing in the study sites shapes pikeperch populations by catching considerable amounts of juvenile fish and first-time spawners. Especially juvenile females may be susceptible for fishing effects, since the females mature older and at larger size than males (Lappalainen et al. 2003). This may have negative effects on pikeperch populations through decreased recruitment success (Berkeley et al. 2004; Olin et al. 2012). Also genetic consequences may be possible through faster growth and maturation at younger age (Law 2000). The larger proportion of undersized fish caught in the mesh size of 45 mm in Galtfjärden may to some extent be a consequence of the larger proportion of small-sized pikeperch in the population, but reveals that the mesh size of 45 mm bar length is clearly insufficient for and in contradiction with the minimum landing size of 40 cm.

Opposite to earlier studies by Heikinheimo et al. (2006) and Pekcan-Hekim et al. (2011), we observed nearly as high mortalities at the age of 3–4 years as in older ages,

which together with the length distribution in the mesh size of 45 mm suggests that pikeperch may already be caught as by-catch at the age of 4 years. In Galtfjärden, also predation by great cormorant may affect mortalities at ages 3 and 4 years. The high mortality rates resulted in low proportions of individuals older than 5 years and the oldest individuals in the gillnet monitoring catches were around 8 years. Pikeperch undoubtedly has potential to live longer than 8 years, in this study demonstrated by one 21-year-old individual caught in Galtfjärden. In the southern Baltic Sea, several individuals of ages 8–14 years have been encountered (Kosior and Wandzel 2001).

According to previous studies, pikeperch at these latitudes become sexually mature at the age of 4–6 years and length of 35–44 cm (Kosior and Wandzel 2001; Lappalainen et al. 2003). Our results show that the mortality in the study sites is so high that the majority of the pikeperch probably spawn only once or not at all. Also, the abundance of pikeperch larger than 40 cm ($NPUE_{large}$), which represents the spawning stock, declined in all study sites. It seems that both the minimum landing sizes and the minimum mesh size regulation currently used in the study sites are inadequate to protect the spawning stocks (Kosior and Wandzel 2001; Lappalainen et al. 2003; Eero 2004; Birkeland and Dayton 2005).

Based on our results we come to the following conclusions; hydrography did not explain the patterns observed in the studied pikeperch populations, although YCS was affected by temperature. In all study sites overfishing seemed to cause adverse population trends, and in Galtfjärden cormorant predation could partly contribute to the decline by predation on small pikeperch.

As a management measure, protection by minimum landing size may have disadvantages, such as decreased weight-at-length (Law 2000). However, set high enough, the minimum landing size will protect the spawning stock, and as a management method it is simple and traditional enough for implementation in reasonably near future (Heikinheimo et al. 2006; Vainikka and Hyvärinen 2012). Previous studies have suggested a minimum size limit of 45 cm (Vainikka and Hyvärinen 2012) and a mesh size of 50 mm (Heikinheimo et al. 2006) for sustainable pikeperch fishing. In Swedish Lake Hjälmaren, the minimum size limit of pikeperch was increased from 40 to 45 cm in 2001, and the minimum mesh size set to 60 mm. After these changes the pikeperch stock has increased markedly and commercial catches increased threefold (Swedish Board of Fisheries 2011).

In our opinion, in all study sites both the minimum landing size of pikeperch and the smallest allowed mesh size for commercial fishing should be increased. Additional measures such as closed areas, restrictions of catches, or protection of reproduction habitats should be seriously

considered (Birkeland and Dayton 2005; Sundblad et al. 2011). Although the measures may lead to a situation where commercial pikeperch fishing is unprofitable for some years due to the low abundance of large pikeperch, in time the catches should increase when the stocks recover (Heikinheimo et al. 2006; Swedish Board of Fisheries 2011).

Although the magnitude of impact from fishing is difficult to establish, our results clearly show that the state of three important pikeperch stocks in the northern Baltic Sea is worrying, and the adverse changes observed call for immediate management measures in order to sustain fisheries and functioning of the Baltic Sea coastal ecosystems (Brabrand and Faafeng 1993; Eero 2004; Heikinheimo et al. 2006; Eriksson et al. 2011; Vainikka and Hyvärinen 2012). The most straight-forward way to decrease pikeperch mortality in the three study areas is to reduce fishing pressure. In Galtfjärden, the pikeperch stock might benefit from regulation of the cormorant colony. Taken together, this study points to the need for considering not only commercial fishing when trying to understand changes in fished populations but instead to take a holistic approach where factors affecting both production and mortality are taken into account. The severity of the changes observed in the three study populations suggests that caution should be taken in exploitation of pikeperch populations also in other parts of the Baltic Sea area, since fishing pressure combined with effects of large predators on this highly valued species may easily become unsustainable.

Acknowledgments We thank the Environment Agency of the Provincial Government of Åland Islands, Husö biological station, Finnish Meteorological Institute and Svealand's Coastal Water Management Association for providing data. Special thanks to Outi Heikinheimo, Tom Karlsson, Åsa Hägg, Kerstin Söderberg, Maria Boström and everyone involved in performing the gillnet monitoring. This study was financed by the Baltic Sea 2020 Foundation, Åbo Akademi University Endowment and Swedish Cultural Foundation in Finland.

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