

Temporal changes in the diet of great cormorant (*Phalacrocorax carbo sinensis*) on the southern coast of Finland — comparison with available fish data

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The population increase of the piscivorous cormorant in the archipelago areas of the Baltic Sea, Finland, has raised discussion about the potential harm to the commercial fisheries. We investigated the diet of the cormorant in the western Gulf of Finland and compared the results with commercial and test fishing catches from nearby waters. The most numerous species in the diet were eelpout, roach, perch and three-spined stickleback, respectively. The annual proportion of perch and roach decreased, while the proportion of sticklebacks in the diet increased significantly during 2002–2010. At the same time, the size of prey eelpout decreased significantly. No decreasing trends were found in gillnet monitoring catches of perch or roach, or in the commercial perch catches in nearby waters during 2005–2010. Thus, based on the available fish data, no impacts of cormorant predation on the local perch and roach populations were detected.

Introduction

One of the fundamental questions in community ecology is whether prey populations are regulated by predators (top-down) or predator numbers are regulated by the amount of prey (bottom up) (e.g. Hunter and Price 1992, Verity and Smetacek 1996, Salo *et al.* 2010). One such example is the interaction between seabirds and their prey. Reported impacts of piscivorous birds on commercial fish populations have been controversial (e.g. Bax 1998, Harris *et al.* 2008, Zydalis and Kontautas 2008).

The continental population of the great cormorant, *Phalacrocorax carbo sinensis* (hereafter

cormorant), has rapidly increased during recent decades in many European countries (e.g. Van Eerden and Gregersen 1995, Bregnballe *et al.* 2003). This population increase has been caused by the improved protection status and decreasing concentrations of environmental contaminants (Bondewijn and Dirksen 1995, Van Eerden and Gregersen 1995). Due to the population increase, the breeding distribution of this piscivorous species has expanded northwards (Engström 2001c, Lehikoinen 2006).

The rapid population increase has raised discussion on whether the species could compete for the same resources with commercial fishermen and thus cause economic losses (Veldkamp

1997, Van Dam and Asbirk 1997, Carss 2004). Nevertheless, the effects of cormorants on the fish assemblages in different water systems have seldom been examined.

Engström (2001b) observed no long-term effects of cormorants in Swedish lakes, and Dalton *et al.* (2009) found no population consequences in anadromous alewife *Alosa pseudoharengus* due to predation by double-crested cormorants, *Phalacrocorax auritus* (a sister species of great cormorants). However, some recent publications have suggested that consequences may exist. Vetemaa *et al.* (2010) argued that cormorants had reduced the number of spawning perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*) in a shallow semiclosed bay of the Baltic Sea. Furthermore, the double-crested cormorant (*P. auritus*) could have caused a decline in the populations of walleye (*Sander vitreum*) and yellow perch (*Perca flavescens*) in the Great Lakes (Rudstam *et al.* 2004, Fielder 2008, 2010). In contrast, Diana *et al.* (2006) found no such effects in Lake Huron.

The cormorant colonized the Finnish coast of the Baltic Sea in 1996, and started to breed in an area where the species had not bred for more than 200 years (Lehikoinen 2006). Since then, the Finnish population has rapidly increased and the population growth rate has been the highest in Europe due to the large number of immigrants from the southern breeding areas (Lehikoinen 2006). In 2009, the population included more than 16 000 pairs, and colonies were distributed over the whole coastal area of Finland (Finnish Environment Institute, www.ymparisto.fi).

Despite the species receiving considerable attention in the media as a potential threat to fisheries in Finland, very few studies concerning the diet of the species in this area have been published. In a 2002 study in the Gulf of Finland, along the southern coast of Finland, the three clearly most abundant in numbers fish species recorded in the diet of breeding cormorants were eelpout (*Zoarces viviparus*; 38%), roach (28%) and perch (23%) (Lehikoinen 2005). In 2009 and 2010 in the Archipelago Sea (south-west Finland), the diet in numbers of breeding cormorants mainly consisted of eelpout (42% in 2009, 33% in 2010), perch (19%, 17%) and Baltic herring (*Clupea harengus membras*; 13%,

17%), but there were large differences between the colonies (Korhonen 2010).

This study investigated the diet of cormorants within colonies in the western Gulf of Finland and aimed to compare it with data from test fishing (perch and roach) and commercial perch catches in nearby waters. Perch was in this case the only prey species of cormorants that has notable economic importance (Lehikoinen 2005). Here, we discuss possible reasons for the observed changes in the diet of cormorants during their population increase.

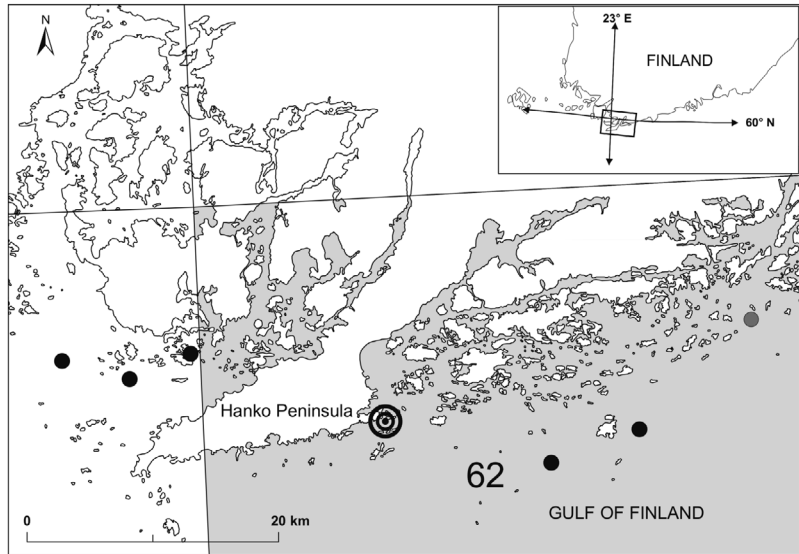
Material and methods

The western Gulf of Finland is a brackish water area, the salinity of surface waters varying from 3 to > 6 ppm. The northern coast is highly indented and off the coastline there is an archipelago zone consisting of numerous small islands. Here, the coastal fish communities include both marine and freshwater species. Marine species such as the Baltic herring, sprat (*Sprattus sprattus*), flounder (*Platichthys flesus*) and eelpout are typically common in the outer archipelago. Several freshwater species such as perch, pike (*Esox lucius*), ruffe (*Gymnocephalus cernuus*), sticklebacks, roach and bream (*Abramis brama*) are abundant from the inner bays to the outer archipelago, whereas pikeperch (*Sander lucioperca*) and certain warm-water cyprinids are commonly only found in the inner archipelago and shallow bays (Lappalainen *et al.* 2000).

Population sizes of the five nearby cormorant colonies situated in the archipelago area close to the Hanko Peninsula, southern coast of Finland (between 59°48'–59°52'N and 22°47'–23°37'E), have been monitored since they were established in 1996 (one colony), 2002 (three additional colonies) and 2003 (one further colony) (Fig. 1). The study site is situated in the area where cormorants first started to breed in Finland. Thus, the potential long-term effects should be easier to detect than at sites recently colonized by the species.

The diet of cormorants can be investigated by sampling pellets or regurgitations, or examining the stomach contents of culled birds. Pellets of indigestible material appear to cause bias by

Fig. 1. Map of the study area. Cormorant colonies are marked with dots. Black dots are colonies where prey-fish sampling was conducted and which were thus included in this study. The grey dot represents one additional colony in the area where fish samples were not collected. The site of the gillnet monitoring programme at Tvärminne is shown as a double circle. ICES rectangle 62 is indicated in grey.



overestimating the proportion of species with larger bones and otoliths, whereas stomach contents may overestimate invertebrates and their analysis requires killing study individuals. Some water birds, including cormorants, regurgitate recently eaten prey items as a panic reaction when humans enter the colony. In this study, we used fresh regurgitations of breeding birds, which should cause less bias in the analysis than, for instance, pellets (Barret *et al.* 2007). In double-crested cormorants, stomach content data from shot birds have been shown to agree with regurgitated fish data in terms of both the relative frequency and biomass of prey species (Seefelt and Gillingham 2006).

The diet was monitored in five cormorant colonies during annual visits carried out during the breeding seasons from 2002 to 2010. All regurgitated fresh fish found in the colonies were counted, the species were identified and the lengths of the individual fish were measured (to the nearest 1 cm). The sizes of slightly digested fish were estimated based on the length of the remaining body, but extensively digested fishes were omitted from the analysis. Small and soft-bodied prey items are likely to be digested more rapidly than larger ones. However, since our data included only fresh regurgitated fish, this was not expected to cause any significant bias to the analysis. Due to problems with identification, some of the fish species were grouped as

follows: red-finned cyprinids (including roach, ide (*Leuciscus idus*) and scardinius (*Scardinius erythrophthalmus*); this group is hereafter referred to as roach, since the proportion of ide and scardinius was marginal; see results), bream or white bream (*Blicca bjoerkna*) (hereafter breams), Baltic herring or sprat (hereafter clupeids) and sculpins (Cottidae).

The diet of cormorants changes during the breeding season, because they prefer smaller, thinner and more soft-bodied fishes at the time when chicks are small (Lehikoinen 2005). However, prey size is larger during egg-laying, incubation and at the time when the young have grown older. Prey species composition also differs between these three periods (Lehikoinen 2005). However, since the period when the chicks are small and the diet is temporally changed is rather short (about three weeks) as compared with the whole breeding season (over three months), we used the fish samples collected during egg-laying, incubation and the brood caring period. The sampling was done between 27 April and 30 June, during two visits to each colony, once during incubation (mid-May) and once at the time of ringing nearly full-grown nestlings (mid-June). Because the regurgitations of individual birds could not be distinguished, the samples from each visit and colony were aggregated. Altogether, the samples included 3046 prey items (Table 1).

We calculated the mass for each fish species by using species-specific length–mass regressions (see Lehikoinen 2005 and references therein). Furthermore, the possible change in the individual mean size of the prey species was examined for the most regularly observed prey species: eelpout, perch and roach.

The species composition and length distribution of the prey fish were compared with the catches from a permanent gillnet monitoring programme, started in 2005 by the Finnish Game and Fisheries Research Institute at Tvärminne, an adjacent archipelago and nature conservation area (59°50'N, 23°15'E; Fig. 1). The same 30 fishing sites, covering different habitats and depth zones (2–10 m) in the inner and outer archipelago, were fished annually in late August using coastal multimesh test fishing gillnets (length 45 m, height 1.8 m) composed of panels with 9 mesh sizes from 10 mm to 60 mm (bar length), specifically planned to representatively sample the size distribution of the fish assemblage. The catches from each fishing site and mesh size were weighed by species and the total lengths of the individuals were measured to the nearest 1 cm. The gillnet monitoring area was situated in the middle of the studied cormorant colonies (13–33 km from the colonies;

Fig. 1), and cormorants were regularly seen feeding in these waters (A.L.'s own observations). Breeding birds typically feed in waters within 20–30 km from the colonies (Van Eerden and Gregersen 1995, Kierckbuch and Koop 1996). In the study area, the feeding waters included both the inner and outer archipelago, although most of the colonies were situated in the outer archipelago (Fig. 1).

In the official commercial fish catch statistics of Finland (Finnish Game and Fisheries Research Institute), rectangles of 50 × 50 km are used as areal units, in accordance with the International Council for the Exploration of the Sea (ICES). ICES rectangle 62 (Fig. 1) covers our study area, and the perch catch and effort data from this rectangle were used to calculate the catches per unit effort (CPUE) with gillnets (catch with one gillnet in one day) during the study period (2000–2009). The catches per unit of effort (CPUE) of the target species in the commercial fishery generally indicate the abundance of the fish population (Hilborn and Walters 1992). This commercial data set was used as the baseline data for the study area over a slightly longer period than available from the gillnet monitoring station, and qualitative comparisons were made with the diet data.

Table 1. Prey fish species and their proportion (in number and mass) in the diet of the great cormorant in southwestern Finland in 2002–2010.

Species	<i>n</i>	Percentage	Mass (kg)	Percentage
Eelpout, <i>Zoarces viviparus</i>	1319	46.3	36.5	24.0
Roach, <i>Rutilus rutilus</i> *	425	14.9	65.1	42.9
Perch, <i>Perca fluviatilis</i>	359	12.6	25.2	16.6
Three-spined stickleback, <i>Gasterosteus aculeatus</i>	290	10.2	0.4	0.3
Clupeids, <i>Clupea harengus/sprat</i> , <i>Sprattus sprattus</i>	183	6.4	3.3	2.2
Ruffe, <i>Gymnocephalus cernuus</i>	124	4.4	3.6	2.4
Bream, <i>Abramis brama</i> /white bream, <i>Blicca bjoerkna</i>	57	2.0	6.2	4.1
Pikeperch, <i>Sander lucioperca</i>	30	1.1	5.6	3.7
Lumpfish, <i>Cyclopterus lumpus</i>	25	0.9	3.4	2.2
Fourhorn sculpin, <i>Triglopsis quadricornis</i> **	13	0.5	0.9	0.6
Sea stickleback, <i>Spinachia spinachia</i>	10	0.4	<0.1	0.0
Burbot, <i>Lota lota</i>	5	0.2	1.3	0.8
European flounder, <i>Platichthys flesus</i>	4	0.1	0.2	0.2
Sand goby, <i>Pomatoschistus minutus</i>	3	0.1	<0.1	0.0
Black goby, <i>Gobius niger</i>	1	0.0	<0.1	0.0
Butterfish, <i>Pholis gunnellus</i>	1	0.0	<0.1	0.0
Sandlance species, <i>Ammodytidae</i>	1	0.0	<0.1	0.0
Total	2850	100.0	151.8	100.0

* includes *Leuciscus* sp.,** includes sculpins, Cottidae.

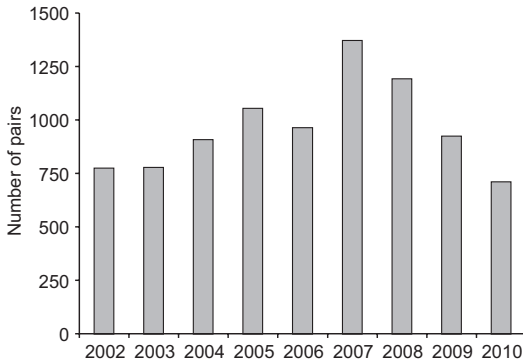


Fig. 2. Breeding population of cormorants in the five study colonies in 2002–2010.

We used Spearman rank correlation of year against CPUE to analyse temporal trends in fish abundance in the gillnet monitoring data. To test for potential temporal trends in the relative proportions of different fish species in the diet of cormorants we used logistic regression (GLM with logit link and binomial error distribution), where each prey item is a trial. This explicitly models the probability that an individual that is preyed upon belongs to the focal species. Furthermore, we tested the potential trends in the mean size of fishes by using linear regression. Lastly, we tested whether the size of the prey fishes consumed by the cormorants differed from the size of fishes caught in the gillnet monitoring programme at Tvärminne using the Mann-Whitney *U*-test.

Results

The monitored cormorant population in the study area had increased until 2007, but declined thereafter due to illegal persecution in the westernmost colonies (Fig. 2).

The identified prey items, comprising 13 species and five groups of species, together with their proportions in the samples are listed in Table 1. The four most abundant prey fish were eelpout ($n = 1319$), roach ($n = 425$), perch ($n = 359$) and three-spined stickleback (*Gasterosteus aculeatus*) ($n = 289$) (Table 1). In terms of mass, the three clearly dominant species were roach (42.9%), eelpout (24.0%) and perch (16.6%) (Table 1).

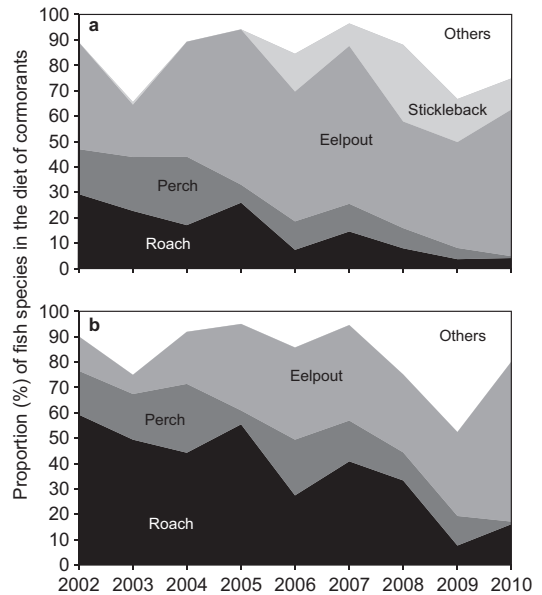


Fig. 3. Proportion of three-spined stickleback (*Gasterosteus aculeatus*, $n = 289$), eelpout (*Zoarces viviparus*, $n = 1319$), perch (*Perca fluviatilis*, $n = 359$) and roach (*Rutilus rutilus*, $n = 425$) in the diet of cormorants (total $n = 2857$) measured (a) as individuals and (b) in mass in five Finnish breeding colonies during the breeding seasons from 2002–2010. Note that the mass proportion of sticklebacks is negligible.

When analysed according to the number of individuals, the annual probability of finding sticklebacks in the diet increased significantly (GLM, logistic regression: $b = 0.44$, $t_{1,7} = 2.90$, $p = 0.023$; Fig. 3a), whereas the proportions of perch and roach decreased significantly during the study period (GLM, logistic regression: $b = -0.24$, $t_{1,7} = -4.57$, $p = 0.003$ and $b = -0.26$, $t_{1,7} = -4.79$, $p = 0.002$, respectively; Fig. 3a). There was no significant annual trend in the numbers of consumed eelpout (GLM, logistic regression: $b = 0.10$, $t_{1,7} = 1.34$, $p = 0.22$; Fig. 3a). When examining the annual summed body mass of species in the diet, the proportion of sticklebacks was found to be negligible (Fig. 3b and Table 1). Furthermore, in terms of mass, eelpouts showed increasing, and roach and perch decreasing trends during the study period (Fig. 3b).

The mean sizes (\pm SD) of perch, roach and eelpout consumed by cormorants in 2002–2010 were 16.4 ± 4.0 ($n = 423$), 19.1 ± 4.8 ($n = 486$) and 15.2 ± 3.7 ($n = 1375$), respectively. The

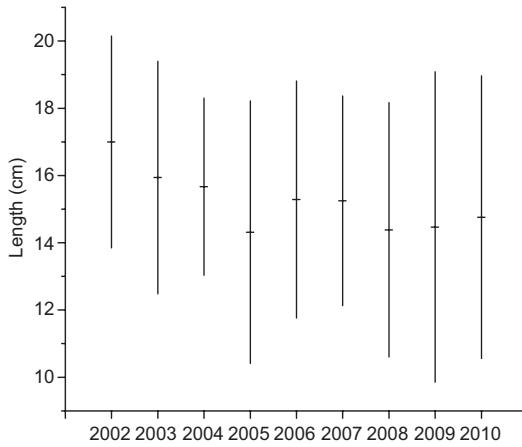


Fig. 4. Annual mean length (\pm SD) of eelpouts in the diet of cormorants during 2002–2010.

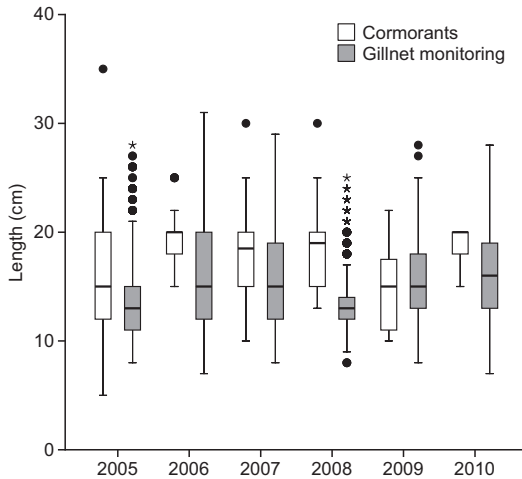


Fig. 6. The length of roach (including other red-finned cyprinids) in the catches from gillnet monitoring at Tvärminne ($n = 5177$) and consumed by cormorants ($n = 205$) in the study area in 2005–2010. The boxes represent 50% of the annual observations and bars the rest of the observations. Dots and asterisks are outliers.

annual mean size of eelpout decreased significantly (linear regression: $r = 0.78$, $b = -0.22 \pm 0.07$, $F_{1,7} = 10.7$, $p = 0.013$; Fig. 4) in the diet of cormorants during the study period, but the mean size of perch and roach did not change significantly (linear regression: $r = 0.35$, $b = -0.26 \pm 0.26$, $F_{1,6} = 1.00$, $p = 0.35$ and $r = 0.55$, $b = -0.44 \pm 0.25$, $F_{1,6} = 3.05$, $p = 0.12$, respectively).

The red-finned cyprinids caught during the gillnet monitoring programme included roach (99.4%) and ide (0.6%). The number of perch

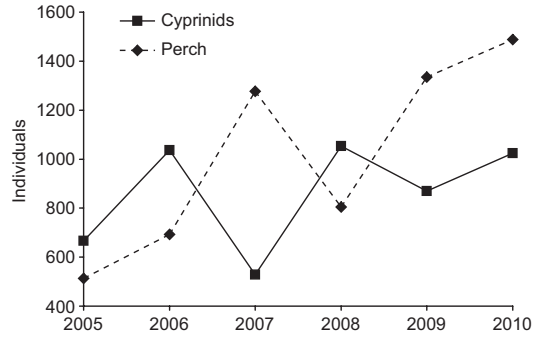


Fig. 5. Annual numbers of perch and cyprinids in the catches from gillnet monitoring at Tvärminne in 2005–2010.

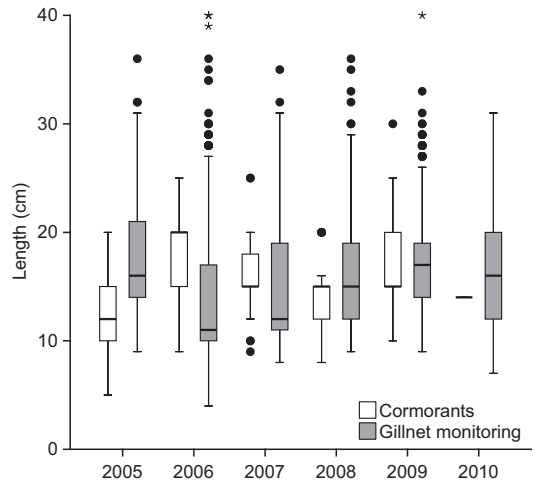


Fig. 7. The length of perch in the catches from gillnet monitoring at Tvärminne ($n = 6110$) and consumed by cormorants ($n = 169$) in the study area in 2005–2010. The boxes represent 50% of the annual observations and bars the rest of the observations. Dots and asterisks are outliers.

individuals increased significantly in the gillnet monitoring catches from 2005 to 2010 ($r_s = 0.94$, $df = 4$, $p = 0.005$), but there was no trend in the numbers of red-finned cyprinids (roach) during the same period ($r_s = 0.26$, $df = 4$, $p = 0.62$; Fig. 5).

There was no apparent trend in the mean size of perch or roach caught in gillnet monitoring in 2005–2010 (Figs 6–7). The annual length distributions of roach indicated some year class fluctuations, the number of individuals > 15 cm being low in 2005, 2007 and 2008 but high in 2006, 2009 and 2010 (Fig. 6). Among perch,

the number of consumed individuals > 15 cm increased during the study period, being highest in 2009 and 2010 (Fig. 7).

The median size of roach consumed by cormorants during 2005–2010 was significantly larger than that from the gillnet monitoring catches (median \pm SD; cormorants: 17 ± 4.6 cm, $n = 205$, gillnet monitoring catches: 14 ± 4.9 cm, $n = 5177$; Fig. 6; Mann-Whitney U -test: $Z = -6.07$, $p < 0.001$). However, there was no similar difference in the median sizes of perch (cormorants: 15 ± 4.1 cm, $n = 159$; gillnet monitoring catches: 15 ± 5.2 cm, $n = 6110$; Fig. 6; Mann-Whitney U -test: $Z = -0.79$, $p = 0.43$).

The total commercial perch catch from ICES rectangle 62 had been 30 tonnes in 2000. The catch decreased during the next five years. In the latter half of the decade, the CPUE remained at a steady level, or even slightly increased with the 36–45 mm gillnets (Fig. 8). Most of the annual perch catch (89%–99%) was taken with gillnet mesh sizes 36–45 mm and 46–50 mm (bar length).

Discussion

Our results demonstrated a clear change in the diet of cormorants during 2002–2010. The proportion of perch and roach decreased in numbers and mass, whereas that of sticklebacks increased. The individual size of prey fish decreased for eelpout, but not for perch and roach.

There are several hypotheses for the potential causes of the changes in the diet. First, even though cormorants prefer certain species and sizes of fish (Engström 2001a, Lehikoinen 2005), they are generalist predators, the diet of which probably reflects the relative availability of suitable sized prey fish (Halsey *et al.* 2007, Cosolo *et al.* 2010, Johnson *et al.* 2010). Accordingly, the changes in the diet could be caused by (1) natural fluctuations in the fish stocks (Houde 2009) or alternatively by (2) large-scale environmental changes such as eutrophication, which may have affected the composition of the fish assemblage (e.g. Ådjers *et al.* 2006, Engström-Öst *et al.* 2007). Secondly, cormorant predation may itself affect the fish assemblage (3) indirectly (e.g. long-living fish species learn to avoid

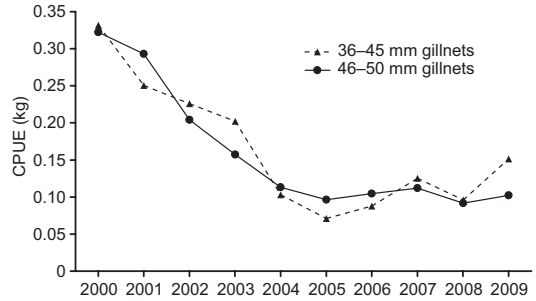


Fig. 8. Perch catches per unit of effort (CPUE) in commercial gillnet fishing, mesh sizes 36–45 mm and 46–50 mm (bar length) in ICES rectangle 62 from 2000–2009.

cormorant predation; e.g. Vilhunen and Hirvonen 2003, Vilhunen *et al.* 2005) or (4) directly by causing selective mortality in certain species and size classes (Fielder 2008, 2010).

In the study area, the cormorant population showed a moderate increase until 2007 (*see also* Lehikoinen 2006), when the highest predation pressure of cormorants on the local fish population so far occurred. There was a decrease in the commercial perch CPUE during 2000–2004 at the time when the cormorant population was still increasing. However, a similar decline was also observed in the Archipelago Sea, apparently due to year class fluctuations in the perch stock (coastal fish stock assessment data, Finnish Game and Fisheries Research Institute). Cormorants occupied the Archipelago Sea a few years later than the Gulf of Finland (Lehikoinen 2006), and the decline in the perch population started clearly before the cormorant became an abundant breeding bird in the area. Furthermore, the commercial perch CPUE with gillnets in 2005–2010 was stable, even though the highest cormorant densities in the area were reported at the same time.

Perch and roach catches during the gillnet monitoring did not decrease during 2005–2010, and perch densities (> 15 cm) even increased. The pattern was hence similar to that in the commercial perch CPUE. Thus, comparison with gillnet monitoring data and commercial CPUE data does not support the contention that the increasing predation pressure of cormorants could have harmed the perch and roach populations. This is in contrast to findings from Esto-

nian coastal areas, where a shallow semiclosed Käina bay was studied (Vetemaa *et al.* 2010).

It should be noted that the test fishing data from Käina Bay on the Estonian coast, used as evidence for the effect of cormorants (Vetemaa *et al.* 2010), were only collected during two years (1995 and 2005). In the adjacent area (12–15 km from the colonies), there were marked fluctuations in the abundance of the target species within the intervening 10-year period. Roach apparently declined in abundance in the 2000s, but the potential effects of environmental factors such as salinity (Härmä *et al.* 2008), or the effect of the strongly increased population of ruffe in Käina Bay (Vetemaa *et al.* 2010) cannot be excluded.

Interestingly, there are indications of an increased density of highly abundant sticklebacks in open sea areas of the Baltic Sea (Ljunggren *et al.* 2010, reports of the Working Group on Baltic International Fish Survey, ICES, 2006–2009) at the same time during which the species was found in increasing numbers in the diet of cormorants. The decreasing proportions of perch in the diet of cormorants during 2002–2010 could be also explained by the decline in the perch population in 2000–2004, as shown in commercial catches. The reason for the decline in the individual size of eelpouts in the diet of cormorants might also be due to year-class fluctuations of this species, i.e. changes in the availability of different size classes, but no data are available on the population dynamics of eelpouts in the study area.

Monitoring of the diet of cormorants could in some cases provide information on changes in the fish community (Furness and Greenwood 1993, Johnson *et al.* 2010), especially for species that cannot be assessed in traditional gillnet monitoring or commercial fishing (e.g. eelpout and sticklebacks). Thus, changes in the diet of cormorants might reflect changes in the state of the water system (e.g. Harris and Wanless 1997).

The size comparison between consumed individuals and catches from gillnet monitoring revealed that cormorants seem to prefer slightly larger roach, but there was no difference between consumed perch individuals and the average in the population. Even though regurgitated fresh fish are the most reliable way to collect diet

data, there might be some small biases (Barrett *et al.* 2007). One such bias could be that larger fish individuals are more difficult to regurgitate. However, this would not alter our results in the case of roach, because larger individuals were eaten as compared with the average in the fish population.

Although our analyses were based on a relatively short time series, they nevertheless indicate that rapid changes in the diet of cormorants have occurred. These changes and the underlying mechanisms should be investigated in more detail, since interpretations of the role of cormorants in the coastal ecosystem of the Baltic Sea are still contradictory. However, monitoring data on commercial fish species in the fishing area of cormorants do not indicate any relevant signs of negative effects on the fish populations. Moreover, observed changes in the diet of cormorants might be useful as indicators reflecting the state of the ecosystem.

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