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Piscivorous birds as top predators and fishery competitors in the lagoon ecosystem

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Abstract Piscivorous birds have received much attention with respect to competition with fisheries for resources. The majority of studies have been focused on cormorants *Phalacrocoracidae*, while predation by other piscivorous bird species has often been overlooked. This study was designed to supplement sociological research (Bell, 2004), which revealed that the fishermen community at the Lithuanian section of the Curonian Lagoon considers great cormorants *Phalacrocorax carbo,* but not other fish-eating birds, to be significant competitors of fish resources. In this paper, we estimate fish consumption by cormorants and other abundant piscivorous birds, and attempt to interpret this level of predation in relation to fish resources and commercial fishery landings. We estimate that four piscivorous bird species consumed nearly 700 tonnes of fish during the breeding season of 2001 and winter 2001/2002, which corresponds to ~9% of the total fish resources in our study area. Bird consumption equalled two-thirds of the amount of fish landed by commercial fishermen. However, we argue that direct competition between birds and humans for fish resources is low, because there is a size segregation of exploited fish stock segments and abundant fish species that dominate the diet of birds. Fish monitoring and commercial fish landings indicated no apparent changes in fish stock size and composition, which could be attributed to a recent increase in piscivorous birds. Great cormorants consumed the largest biomass of fish compared to other piscivorous bird species. However, total fish intake by grey herons *Ardea cinerea*, great-crested grebes *Podiceps cristatus*, and goosanders *Mergus merganser* combined, equalled that of cormorants. Our results do not support the common public perception that cormorant predation greatly exceeds that of other piscivorous birds, and is detrimental to commercial fisheries.

Keywords Piscivorous birds · Fish consumption · Lagoon systems · Curonian Lagoon · Fish resources

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European Lagoons and their Watersheds: Function and Biodiversity

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Introduction

The role of piscivorous birds in aquatic ecosystems has been studied by many researchers in both marine and freshwater environments. Birds are important top predators in certain marine ecosystems and consume an appreciable amount of fish (Greenstreet & Tasker, 1996; de Brooke, 2004). The role of predatory birds in fresh water habitats has been more controversial. Expansion of cormorant *Phalacrocoracidae* populations across Europe and North America has motivated numerous assessments of fish consumption by these birds in freshwater environments since the early 1980s (Nettleship & Duffy, 1995; Van Eerden et al., 1995; Carss, 2003). Cormorants are usually considered pest-predators of artificially stocked fish populations in hatcheries, fishponds, and small lakes (Carss, 2003). However, varying opinions exist regarding the importance of cormorant predation in natural ecosystems (e.g., Draulans, 1988; De Nie, 1995; Dirksen et al., 1995; Carss, 2003; Carss & Marzano, 2005).

Aside from cormorants, the role of other piscivorous bird species in freshwater environments has received little attention, despite the wide distributions and often sizable populations of these species. Steinmetz et al. (2003) suggested that birds are overlooked as top predators in aquatic food webs and demonstrated that birds act as important predators in a stream ecosystem. Several other studies have also reported that piscivorous birds, other than cormorants, are significant top predators in natural freshwater environments (e.g., Winfield, 1990; Mous, 2000; Wilson et al., 2003).

Quantification of fish consumption by piscivorous birds might also provide insight for fisheries management considerations. The ecosystem-based fisheries management concept suggests moving the focus from managing target species only toward understanding and sustaining healthy aquatic ecosystems (Pikitch et al., 2004). Therefore, understanding the role of natural predators, especially piscivorous birds, should be considered in parallel with human use of aquatic resources.

We conducted our study in the Curonian Lagoon, one of the most productive natural aquatic systems in the Baltic region, and traditionally important for fisheries (Ådjers et al., 2006). A lagoon is an estuarine system enclosed from the sea by a barrier, and is distinguished by a unique highly fertile ecosystem created by the environment of mixing fresh and salt water, and influx of nutrients carried by rivers (Gonenc & Wolflin, 2005). Curonian Lagoon, including the Nemunas delta, was designated as Ramsar Site, Important Bird Area, and Natura 2000 site as an internationally important area for breeding, wintering, and staging birds (Švažas et al., 1999; Skov et al., 2000). Rapid increase of great cormorant *Phalacrocorax carbo* numbers since the early 1990 s was negatively perceived by local fishermen, who consider these birds as competitors for fish resources (Bell, 2004; Hampshire et al., 2004). Žydelis et al. (2002) suggested that cormorants consumed 250–300 tonnes of fish in 2001. Sociological studies revealed that the local fishermen community has not perceived other piscivorous bird species as significant predators, despite their large numbers in the area (Bell, 2004; Hampshire et al., 2004).

Our study was designed to provide a biological component to this sociological research, and we address the following questions: (1) how much fish is consumed by the most abundant piscivorous bird species; (2) how bird predation relates to the lagoon fish resources and commercial fishery landings; and (3) how cormorant predation compares with that of other piscivorous birds.

Materials and methods

Study area

The study was conducted in the Lithuanian section of the Curonian Lagoon and Nemunas river delta (55°25′ N 21°10′ E). The lagoon is cut off from the Baltic Sea by the Curonian Spit and connects with the Baltic through the Klaipėda Strait. The northern part of the lagoon (413 km^2) belongs to Lithuania, while the southern portion is under the jurisdiction of Russia. Nemunas is the biggest river flowing into the lagoon, which forms an extensive delta.

The most comprehensive assessment of the fish resources in the Lithuanian section of the Curonian Lagoon was undertaken by Repečka (1997). These estimates (Table 1) apply to the summer season when some migratory fish species (e.g., Smelt *Osmerus eperlanus*) were absent from the lagoon. Although fish resources are dynamic and vary between years,

Table 1 Estimated fish biomass in Lithuanian part of the Curonian Lagoon (adopted from Repečka, 1997) and commercial catch composition in Lithuanian part of the Curonian Lagoon and Nemunas Delta in 2001

Fish species	Biomass		Commercial fish catch, tonnes
	kg/ha	tonnes	
Bream *Abramis brama*	42.5	1755	386
Roach *Rutilus rutilus*	65.2	2690	375
Perch *Perca fluviatilis*	29.7	1225	45
Pikeperch *Sander lucioperca*	5.2	216	80
Ruffe *Gymnocephalus cernuus*	25.2	1039	61
Silver bream *Blicca bjoerkna*	20.0	824	9
Vimba *Vimba vimba*	5.7	230	40
Smelt *Osmerus eperlanus*	?	?	177
Other fish	3.7	154	76
Total	197.2	8133	1249

general stock size, and structure, commercial fish landings did not indicate major changes in stock composition during 1993 and 2002 (Repečka et al., 1998; Žydelis et al., 2002; Repečka, 2003a, b).

Official catch statistics from the commercial fishery (collected and managed by the Department of Fisheries, Ministry of Agriculture of the Republic of Lithuania) were used to compare fish landings and consumption by birds. According to the catch statistics for the Lithuanian part of the Curonian Lagoon, commercial fishery landings averaged 1200 tonnes or ~30 kg/ha annually during the period between 1998–2002. In 2001, commercial fish catches were dominated by bream and roach, constituting about 60% of the total catch together in the Curonian Lagoon and Nemunas Delta (Table 1). Gillnets and fyke nets and are main gears used by commercial fishermen in the Curonian Lagoon.

Fish consumption by birds

In order to estimate fish consumption by birds, the following parameters were evaluated: (1) period of presence and abundance of piscivorous bird species in the study area, (2) bird diet composition, and (3) daily food intake by individual birds of each species.

Abundance, distribution, and periods of presence of the four most abundant waterbird species; great cormorant, grey heron *Ardea cinerea*, great-crested grebe *Podiceps cristatus*, and goosander *Mergus merganser*, were monitored. The first three are breeding species, and the goosander is a winter visitor. Tree-nesting great cormorants and Grey Herons share the same colony, which is the only breeding site of these species in the study area. Numbers of breeding birds in the colony are monitored annually, but for our assessment, we only used data collected in 2001. Nesting success was assessed by counting fledglings in 100 randomly selected great cormorant nests and 50 grey heron nests at the end of the breeding season (late June). Numbers of breeding great-crested grebes were assessed by counting nests in selected reed bed sections in the Nemunas delta in 2001 and extrapolating the results for the entire study region. As a result of restricted access to reed beds and habitat variability, the assessment was based more on "expert evaluation," involving observations of bird distribution and knowledge of ornithologists working in the region for many years, rather than on computational extrapolation of survey data. In addition, productivity of 1.5 juveniles per great-crested grebe pair was assumed from the literature (range = 1.2–2.5 per pair: Cramp & Simmons, 1977). Evaluation of fish consumption by breeding species of piscivorous birds was restricted to the periods of highest abundance and definite presence in the area. These were from one month prior to one month after the breeding season, which lasts approximately 80 days for great cormorants and grey herons and 60 days for great-crested grebes. Pre-breeding period of great cormorants and grey herons typically starts in early March, when birds arrive to the area from their wintering grounds; great-crested grebes usually arrive in mid April. Abundance of piscivorous birds, especially that of cormorants, starts to decrease in August; therefore, we limited our assessment to one month after juveniles fledge. It was assumed that the abundance of birds present in the area during pre-breeding season equalled the numbers of breeding individuals. Numbers of breeders plus estimated numbers of fledged juveniles were used to evaluate fish consumption by grey herons and great-crested grebes during the month after the breeding period, as direct counts of these species were not possible due to their solitary and cryptic habits. Cormorant numbers during the post-breeding period were obtained through direct bird surveys at roosting sites. Wintering goosanders were monitored through monthly shoreline-based surveys and midwinter (January) aerial survey in winter 2001/2002.

Great cormorant diets were assessed by collecting freshly regurgitated fish in the colony during nesting seasons 2001 and 2002 (months April, May, and June). The colony was visited during times when adults return to their nests with food and disturbed birds often regurgitate their meals. Full body length and biomass of collected intact fish specimens were recorded. When the fish was partly digested, its body length and biomass were reconstructed using allometric equations (Leopold, 2001; own reference collection). Diet composition of great-crested grebes, grey herons, and goosanders were determined from oesophagi and stomach contents of dead birds, which were obtained from fishermen (drowned in gillnets) or hunters (accidentally shot). Digested fish specimens were identified and their size was reconstructed using identifiable fish remains such as otoliths and chewing pads of cyprinid fish (Härkönen, 1986; Leopold, 2001; own reference collection).

Average daily food intake (and 95% CL) by breeding and non-breeding birds was estimated by applying the approach used by Grémillet & Argentin (1998) to calculate fish consumption by great cormorants on Chausey Islands, and correcting for the mean body weight of subspecies *Phalacrocorax carbo sinensis* (Carss & Ekins, 2003). Cormorants have comparable food requirements to those of other aquatic birds of similar size (Grémillet et al., 2003). Therefore, the same model to calculate food intake by grey herons and great-crested grebes was used, scaling for the mean body weight of each species (Hickling, 1983; Grémillet & Argentin, 1998). Daily food intake for wintering goosanders was calculated by scaling values suggested by Grémillet et al. (2003) for wintering cormorants. Total fish consumption was estimated by multiplying daily food intake by number of birds and number of days when birds were present. Our calculated daily food intake values for adult birds (Table 2) were in agreement or lower compared to figures reported by other authors: 350–450 g for cormorants (van Dam et al., 1995), 270 g for grey herons (Kushlan & Hafner, 2000), 248 g for great-crested grebes (Ulenaers & van Vessem, 1994), and 250–450 g for goosanders (Wilson et al., 2003).

We assumed that arbitrarily chosen period (2001 breeding season and 2001/2002 wintering season) for

Table 2 Estimated annual fish consumption by great cormorants, grey herons, great-crested grebes, and goosanders in the Lithuanian part of the Curonian Lagoon (based on breeding bird numbers in 2001 and wintering goosander abundance in winter 2001/2002)

	Number of bird-days	Daily food intake, kg	Estimated consumption, tonnes	Confidence limits, tonnes	
				Lower	Upper
Great cormorants					
Breeders	284,000	0.723	205	164	251
Non-breeders	357,000	0.396	141	89	206
Grey herons					
Breeders	86,080	0.415	36	29	44
Non-breeders	103,000	0.227	23	15	34
Great-crested grebes					
Breeders	216,000	0.316	68	55	83
Non-breeders	297,000	0.173	51	32	75
Goosanders					
Non-breeders	540,000	0.315	170	112	277
Total			694	496	970

the assessment of bird predation represents a typical year, although we recognize that trend of the local great cormorant population was increasing: it grew prior to, during, and after our study (Žydelis et al., 2002; J. Zarankaitė pers. comm.). We recalculated fish consumption by great cormorants reported earlier by Žydelis et al. (2002) to be consistent with depredation assessment methods used in this study.

Size distribution of fish species most commonly taken by birds was compared with those caught in fish monitoring samples conducted from April through October 2001 and 2002 by following the methodology suggested by Thoresson (1993). However, multi-mesh gillnets used in this sampling design underrepresented juvenile fish, as the smallest mesh size used was 12 mm. Fish caught in gillnets with mesh size of 45–50 mm were assumed to represent fishery landings; nets of this size are those most frequently used by commercial fishermen in the study area.

Results

Piscivorous bird abundance and fish consumption

The only permanent breeding colony of great cormorants in the study areas was located on the Curonian Spit and was shared with grey herons. At the end of the breeding season, a total of 1775 active cormorant nests were counted in the colony. Great cormorants raised by 2.72 ($\pm$0.67, $N = 100$) chicks per nest in 2001. The highest total number of great cormorants was recorded during early post-breeding period in July, when ~8500 individuals were counted in the study area. A total of 538 active grey herons nests were counted in the colony, where nesting success was 2.36 ($\pm$0.63, $N = 50$) chicks per nest. Total breeding population of great-crested grebes was estimated at 1800 pairs. Wintering goosanders were present from November 2001 through March 2002. Goosander numbers fluctuated greatly from 560 to 11600 across the winter (Fig. 1).

It was estimated that great cormorants, grey herons, and great-crested grebes consumed 346, 59, and 119 tonnes of fish during pre-breeding, breeding, and early post-breeding period in 2001, respectively (Table 2). Wintering goosanders consumed approximately 170 tonnes of fish from November 2001 till March 2002 (Table 2).

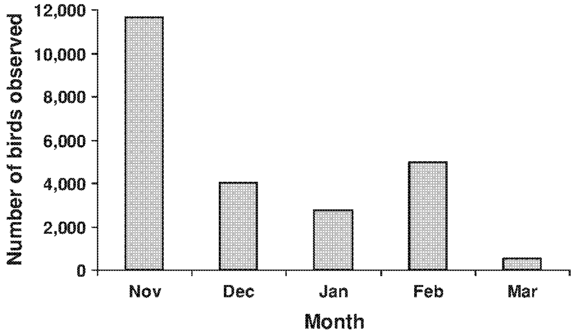

Fig. 1 Maximal number of goosanders counted in the Lithuanian part of the Curonian Lagoon in the winter of 2001/2002

Bird diet composition

A total of 176 and 122 regurgitated fish specimens were collected for cormorant diet assessment in 2001 and 2002, respectively. Proportions of dominant prey species did not differ significantly between the 2 years ($\chi^2 = 8.44$, df = 4, $P > 0.05$), and therefore, datasets were pooled together. Numerically, roach *Rutilus rutilus* was the most frequent prey item (51%), followed by perch *Perca fluviatilis* and ruffe *Gymnocephalus cernuus* (12% and 10% respectively). In terms of biomass, roach was still the most abundant prey species (53%), followed by pikeperch *Sander lucioperca* and bream *Abramis brama* (17% and 13%, respectively).

Grey heron diet samples were rather small: contents of six bird stomachs. Numerically, fish specimens dominated the diet comprising 99%, other identified prey items being insects and a shrew *Soricidae*. Of the 346 fish identified, most numerous were perch (35% by number), followed by carps *Cyprinus*/*Carassius* (32%) and roach (13%). Mean estimated length of perch and carps was 64 mm (SE = 1.5, $N = 121$) and 64 mm (SE = 3.7, $N = 111$), respectively, and mass of these juvenile fish ranged between 2 and 5 g (precise mass assessment was not possible due to prey digestion and range limits of fish length/mass allometric equations).

Great-crested grebe diet samples were also limited ($N = 9$ stomachs). Of the 179 food items identified, most were juvenile ruffe (53% by number) and perch (39%). Mean estimated length of ruffe and perch was 42 mm (SE = 1.7, $N = 95$) and 50 mm (SE = 3.4, $N = 70$), respectively (mass approximately 1–3 g).

Out of 28 goosanders collected, 24 individuals contained fish or fish remains. In total, 168 fish specimens were identified, and prey composition was dominated by smelt *Osmerus eperlanus* (84% according to biomass and numbers). Average estimated smelt length was 169 mm (SE = 2.3, $N = 141$), and average mass was 31 g (SE = 1.2, $N = 141$).

Fish consumption by birds in relation to fishery catches and stock composition

We estimated that biomass of fish consumed by four bird species corresponded to 56% of commercial fish landings in 2001 or 8.5% of the total fish stock, as estimated by Repečka (1997). All fish species, which dominated the diet of birds, except ruffe, are commercially important and harvested in the study area. However, the majority of fish specimens ingested by cormorants were smaller than those found in fish monitoring catches or targeted by the fishery (Fig. 2). Of fish species most commonly taken by cormorants, only the size distribution of roach did not differ significantly between fish collected by monitoring sampling vs. fish taken by cormorants (Mann-Whitney U-test: $U_{roach} = 40896$, $P_{roach} = 0.07$; $U_{ruffe} = 261$, $P_{perch} < 0.01$; $U_{perch} = 515$, $P_{perch} < 0.01$; $U_{pikeperch} = 114$, $P_{pikeperch} < 0.01$; $U_{bream} = 226$, $P_{bream} < 0.01$). Fish taken by cormorants were significantly smaller than those in commercial fishery catches ($U_{roach} = 756$, $P_{roach} < 0.01$; $U_{perch} = 23$, $P_{perch} < 0.01$; $U_{pikeperch} = 60$, $P_{pikeperch} < 0.01$; $U_{bream} = 190$, $P_{bream} < 0.01$). All smelt consumed by goosanders could be considered as a part of the stock targeted by fisheries, as fishery regulations do not limit the size of smelt. Grey herons and great-crested grebes fed on juvenile fish, and we did not find commercial size specimens in the diet of these birds.

Discussion

Our assessment of bird predation in the Lithuanian part of the Curonian Lagoon suggests that four piscivorous bird species consumed nearly 700 tonnes of fish in 2001, which corresponds to ~ 17 kg of fish per hectare. Our estimates fall within the range of fish predation values for piscivorous birds on other large natural waterbodies at similar latitudes. Fish consumption by seven piscivorous bird species was estimated at 48.3 kg/ha in the highly productive Lake Ijsselmeer, The Netherlands (Mous, 2000). Cormorants alone were estimated to have consumed 12.8 kg/ha of fish in Lake Ymsen, south-central Sweden (Engström, 2001). Three main piscivorous bird species consumed 13.7 kg/ha of fish in Dobczyce Reservoir, southern Poland (Gwiazda, 2003). In two lakes in the Netherlands, cormorants consumed 12.5 kg/ha and 2.1 kg/ha of fish annually, and these differences were related to different structure of fish communities (Dirksen et al. 1995).

Although our diet composition samples were limited, they generally agree with those reported in other regions across Europe. Reviewing data from different sources about great cormorant diet in Europe, Carss (2003) summarized that these birds are opportunistic foragers with more than 50% of their diet consisting of cyprinid fish *Cyprinidae*, of which roach was the most common prey species. In the Gulf of Gdańsk (Poland), cormorant diet composition consisted mostly of round goby (*Neogobius melanostomus*), a recent mass invader (Bzoma & Meissner, 2005), which contrasts with the general pattern across Europe of cyprinids dominating. However, this example illustrates well the opportunistic foraging nature of cormorants and their ability to switch to a novel, but very abundant prey.

We found relatively high number of carp in the diet of grey herons compared to the stock composition in the lagoon, which could suggest that birds have been foraging on fish farms located in the vicinity of the study area. However, bird foraging outside the Curonian Lagoon was not typical, as we did not observe regular commute flights of breeding birds to either of the two fish farms adjacent to the Curonian Lagoon. Smelt, which is only seasonally present in the lagoon, dominated the diet of wintering goosanders. Schools of smelt enter the lagoon in winter months and spawn in the Nemunas delta in April, but these fish might not be present in the Curonian Lagoon during early bird wintering season; therefore, goosanders should be feeding on other fish species then. Švažas et al. (1994) reported that a few goosanders obtained from the Curonian Lagoon ate perch and pikeperch. Nonetheless, we speculate that schooling smelt could be attracting goosanders to the Curonian Lagoon, because the dense flocks, often consisting of thousands individuals, of these birds need a reliable and abundant food source. Generally,

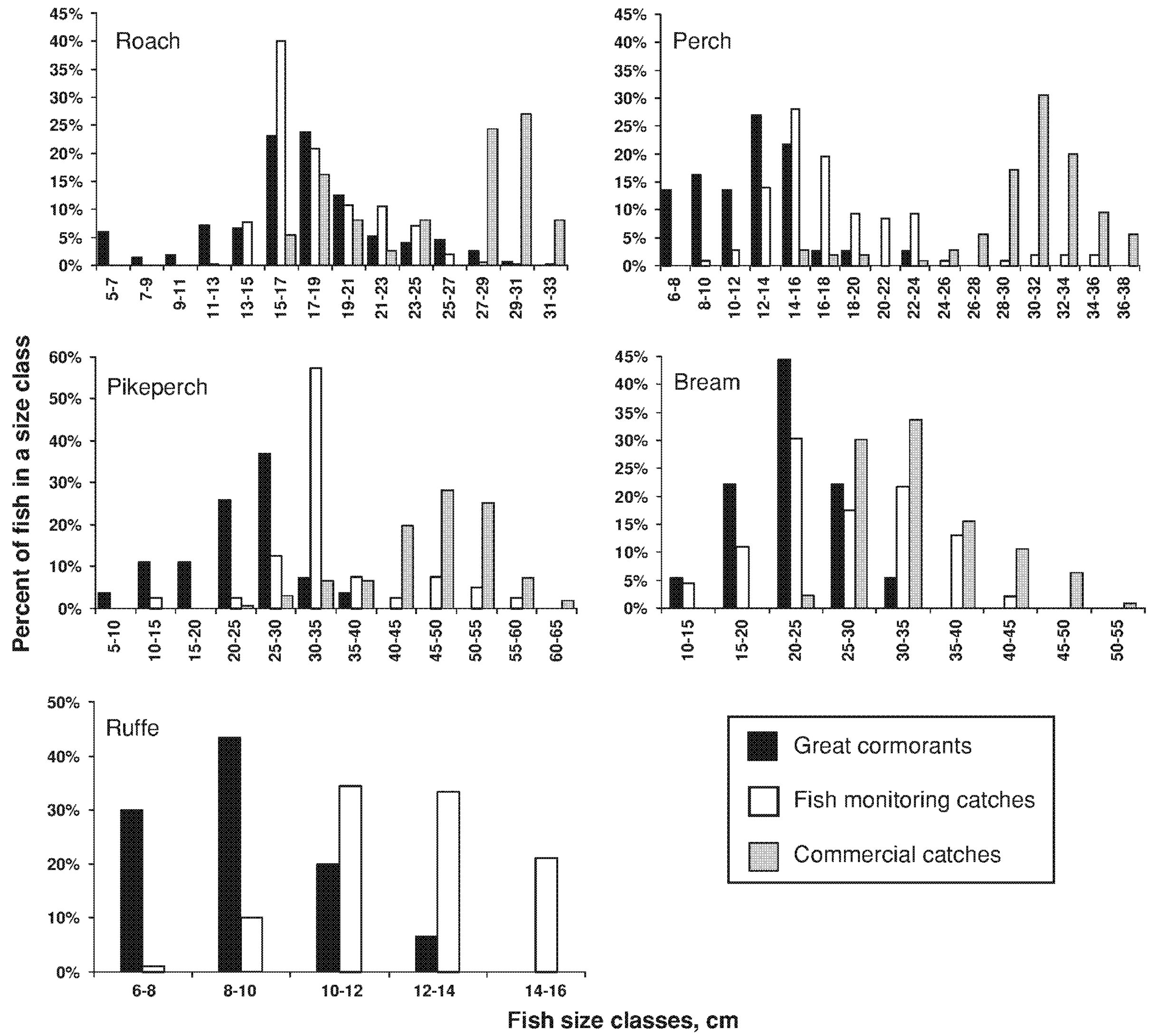

Fig. 2 Size distribution of fish in the diet of great cormorants, fish stock monitoring samples, and commercial gillnets (mesh size 45–50 mm)

our results indicate that piscivorous birds fed on fish species that were most common in the study area or within specific foraging habitats.

Estimated fish consumption by four piscivorous bird species in the Curonian Lagoon corresponded to approximately 56% of the mass of fish taken by commercial fishery. No official statistics exist about angler catches, and obviously the amount of fish landed by poachers and unreported catches by commercial fishermen are unknown. Considering our best guesses about unreported landings and fish caught by anglers, bird consumption probably does not exceed one-third of fish caught by humans. Although birds and fisheries target the same fish species, piscivorous birds and humans use mostly different segments of the fish stock in terms of prey size. Only roach taken by cormorants was of similar size to those found through monitoring sampling of the fish stock, whereas other fish species in cormorant diet were significantly smaller. Commercially caught fish was remarkably bigger than cormorant prey. Grey herons and great-crested grebes foraged exclusively on juvenile fish, and only goosanders foraged on smelt falling within the size range targeted by fishermen. Although fish sampling with standard multi-mesh monitoring gillnets did not allow us to evaluate the full spectrum of size classes, comparison with fish sizes ingested by birds clearly indicated that there is little direct competition between birds and fishermen for resources. Roach, the most frequent prey of cormorants, has low market value, and considering the state of its resources in the Curonian Lagoon, fishery managers suggest that this species is underutilized. Smelt is a very popular target by both commercial and recreational fishers. The resources of smelt are presumably within a range of hundreds tonnes in the Curonian Lagoon. Just before smelt enters the lagoon, commercial fishermen catch up to 200 tonnes in the nearshore zone of the Baltic Sea and up to 200 tonnes in the Curonian Lagoon and the Nemunas delta. If ice conditions permit, anglers might also catch up to 100 tonnes. Therefore, goosanders are taking only a fraction of this seasonally abundant fish, and thus, direct competition with fishery is low. Considering the above, we conclude that piscivorous birds, although being responsible for the consumption of about 9% of fish resources in the Curonian Lagoon, do not suppress stocks of any particular fish species nor affect fish community structure. Neither fish monitoring nor commercial fish catches indicated any major changes in fish abundance and stock composition during 1993 and 2002 (Repečka et al., 1998; Repečka, 2003a, b), when numbers of cormorants increased tenfold from 200 to about 2000 breeding pairs in 2002 (Žydelis et al., 2002). This agrees with earlier findings for other regions that piscivorous birds do not detrimentally affect fish resources in large eutrophic waterbodies with natural fish densities and are integral parts of aquatic ecosystems (Feunteun & Marion, 1994; Carss, 2003).

Although great cormorant predation accounted for half of the estimated fish consumption by piscivorous birds, collective fish biomass intake by other species was comparable to that of cormorants. Given these results, the strongly negative public perception toward cormorants in Lithuania and elsewhere, but not other piscivorous bird species, appears unfounded (Carss, 2003; Hampshire et al., 2004; Bell, 2004).

This study was the first insight about the level of predation of the piscivorous bird guild in the Curonian Lagoon. However, it is a snapshot of a single year, and bird diet composition data were based on limited samples. Our estimates of fish consumption by breeding piscivorous birds are likely underestimates, as breeding birds are typically present in the area a little longer than the core period of presence considered in this study. Nevertheless, our results concur with similar findings reported in the literature, and characterize piscivorous bird predation and competition with fisheries in highly productive lagoon ecosystem.

Conclusions

Four dominant piscivorous bird species consumed about 9% of the total fish resources in the Curonian Lagoon in 2001. No apparent changes in fish stocks size and composition were reported as a result of fish monitoring and commercial fish landings, despite recent increase in great cormorant numbers. However, to understand community dynamics, food web structure, and ecosystem energy flows, the role of piscivorous birds in this ecosystem and the mechanisms of bird predation warrant further study.

Although bird consumption totalled ~56% of the amount of fish landed by commercial fishermen, direct competition between birds and humans for fish resources is low due to apparent size segregation of exploited fish stock segments and abundant fish species dominating bird diet.

Great cormorants consumed the highest amount of fish compared to other piscivorous bird species. However, fish intake by grey herons, great-crested grebes, and goosanders collectively compared that of great cormorants. Therefore, our results do not support the common public perception that cormorant impact on fish resources is much greater than that of other birds.

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References

Ådjers, K., J. Andersson, M. Appelberg, R. Eschbaum, R. Fricke, A Lappalainen, A. Minde, H. Ojaveer, W.

Pelczarski & R. Repečka, 2006. Assessment of coastal fish in the Baltic Sea. Baltic Sea Environment Proceedings 103A, 26 pp.

Bell, S., 2004. Integrated management of European wetlands. Report to the European Commission (IMEW final report), 227 pp.

de Brooke, M. L., 2004. The food consumption of the world's seabirds. Proceedings of the Royal Society B: Biological Sciences 271: S246–S248.

Bzoma, S. & W. Meissner, 2005. Some results of long-term counts of waterbirds wintering in the western part of the gulf of Gdańsk (Poland), with special emphasis on the increase in the number of Cormorants (*Phalacrocorax carbo*). Acta Zoologica Lituanica 15: 105–108.

Carss, D. N., 2003. Reducing the conflict between Cormorants and fisheries on a pan-European scale. Report to the European Commission (REDCAFE final report), 169 pp.

Carss, D. N. & G. R. Ekins, 2003. Further European integration: mixed sub-species colonies of great cormorant *Phalacrocorax carbo* in Britain – colony establishment, diet, and implications for fisheries management. Ardea 90: 23–41.

Carss, D. N. & M. Marzano (eds), 2005. Reducing the conflict between Cormorants and fisheries on a pan-European scale. Summary & National Overviews. Report to the European Commission, 374 pp.

Cramp, S. & K. Simmons (eds), 1977. Birds of Europe, the Middle East and North Africa. I. Ostrich to Ducks. Oxford University Press, Oxford.

De Nie, H., 1995. Changes in the inland fish populations in Europe in relation to the increase of the Cormorant *Phalacrocorax carbo sinensis*. Ardea 83: 115–122.

Dirksen, S., T. J. Boudewijn, R. Noordhuis & E. C. L. Marteijn, 1995. Cormorants *Phalacrocorax carbo sinensis* in shallow eutrophic freshwater lakes: prey choice and fish consumption in the non-breeding period and effects of large-scale fish removal. Ardea 83: 167–184.

Draulans, D., 1988. Effects of fish-eating birds on freshwater fish stocks: an evaluation. Biological Conservation 44: 251–263.

Engström, H., 2001. Long term effects of cormorant predation on fish communities and fishery in a freshwater lake. Ecography 24: 127–138.

Feunteun, E. & L. Marion, 1994. Assessment of grey heron predation on fish communities: the case of the largest European colony. Hydrobiologia 279–280: 327–344.

Gonenc, I. E. & J. P. Wolflin (eds), 2005. Coastal Lagoons: ecosystem processes and modelling for sustainable use and development. CRC Press, Boca Raton, Florida.

Greenstreet, S. P. R. & M. L. Tasker (eds), 1996. Aquatic Predators and their Prey. Fishing News Books, Oxford.

Grémillet, D. & G. Argentin, 1998. Cormorants, shags and fisheries in the Chausey Islands area. Le Cormoran 10(47): 196–202.

Grémillet, D., G. Wright, A. Lauder, D. N. Carss & S. Wanless, 2003. Modelling the daily food requirements of wintering great cormorants: a bioenergetics tool for wildlife management. Journal of Applied Ecology 40: 266–277.

Gwiazda, R., 2003. Changes in the piscivorous bird community at a Polish submontane reservoir between 1990 and 2000 in relation to water level. In Cowx, I. G. (ed.), Interactions between Fish and Birds: Implications for Management. Blackwell Science, Oxford, Malden: 211–220.

Hampshire, K., S. Bell, G. Wallace & F. Stepukonis, 2004. "Real" poachers and predators: shades of meaning in local understandings and threats to fisheries. Society and Natural Resources 17: 305–318.

Härkönen, T., 1986. Guide to the otoliths of the bony fishes of the Northeast Atlantic. Danbiu ApS, Hellenep.

Hickling, R. (ed.), 1983. Enjoying Ornithology. T & AD Poyser Ltd, Calton, England

Kushlan, J. A. & H. Hafner (eds), 2000. Heron Conservation. Academic Press, San Diego.

Leopold, M., 2001. Otoliths of North Sea Fish – Fish Identification Key by Means of Otoliths and other Hard Parts. CD-ROM.

Mous, P. J., 2000. Interactions between fisheries and birds in Ijsselmeer, The Netherlands. PhD Thesis, Wageningen University, Wageningen, The Netherlands.

Nettleship, D. N. & D. C. Duffy (eds), 1995. The Double-Crested Cormorant: Biology, Conservation and Management. Colonial Waterbirds 18, Special Publication 1.

Pikitch, E. K., C. Santora, E. A. Babcock, A. Bakun, R. Bonfil, D. O. Conover, P. Dayton, P. Doukakis, D. Fluharty, B. Heneman, E. D. Houde, J. Link, P. A. Livingston, M. Mangel, M. K. McAllister, J. Pope & K. J. Sainsbury, 2004. Ecosystem-based fishery management. Science 305: 346–347.

Repečka, R., 1997. Investigation of abundance and topographical structure of commercial fish in the Curonian Lagoon. Report for Lithuanian Hydrobiological Society (in Lithuanian with English summary).

Repečka, R., 2003a. The species composition of the ichthyofauna in the Lithuanian economic zone of the Baltic Sea and the Curonian Lagoon and its changes in recent years. Acta Zoologica Lituanica 13: 149–157.

Repečka, R., 2003b. Changes in biological indices and abundance of salmon, sea trout, smelt, vimba and twaite shad in the coastal zone of the Baltic Sea and the Curonian Lagoon at the beginning of spawning season. Acta Zoologica Lituanica 13: 195–216.

Repečka, R., G. Rudzianskiene, K. Gaigalas, L. Ložys, S. Stankus & T. Overkaitė, 1998. The monitoring of commercial fish population structure and abundance in the Curonian Lagoon and Nemunas River Delta. Žuvininkystė Lietuvoje 3: 153–173 (in Lithuanian with English summary).

Skov, H., G. Vaitkus, K. N. Flensted, G. Grishanov, A. Kalamees, A. Kondratyev, M. Leivo, L. Luigujõe, C. Mayr, J. F. Rasmussen, L. Raudonikis, W. Scheller, P. O. Sidlo, A. Stipniece, B. Struwe-Juhl & B. Welander, 2000. Inventory of Coastal and Marine Important Bird Areas in the Baltic Sea. BirdLife International, Cambridge.

Steinmetz, J., S. L. Kohler & D. A. Soluk, 2003. Birds are overlooked top predators in aquatic food webs. Ecology 84: 1324–1328.

Švažas, S., W. Meissner & V. Nehls, 1994. Wintering populations of Goosander and Smew at the Southeastern Baltic coast. Acta Ornithologica Lituanica 9–10: 56–70.

Švažas, S., E. Drobelis, L. Balčiauskas & L. Raudonikis, 1999. Important Wetlands in Lithuania. Akstis, OMPO Vilnius, Vilnius.

Thoresson, G., 1993. Guidelines for coastal monitoring. Fishery biology. Kustrapport 1993: 1.

Ulenaers, P. & J. van Vessem, 1994. Impact of great crested grebes (*Podiceps cristatus* L.) on fish ponds. Hydrobiologia 279/280: 353–366.

Van Dam, C., A. D. Buijse, W. Dekker, M. R. van Eerden, J. G. P. Klein Breteler & R. Veldkamp, 1995. Cormorants and commercial fisheries in the IJsselmeer, the Markermeer and Northwest Overijssel. Rapport IKC Natuurbeheer 19, Wageningen, 104 pp (In Dutch with English summary).

Van Eerden, M. R., K. Koffijberg & M. Platteeuw, 1995. Riding on the crest of the wave: possibilities and limitations for a thriving population of migratory Cormorants *Phalacrocorax carbo* in man-dominated wetlands. Ardea 83: 1–9.

Wilson, B. R., M. J. Feltham, J. M. Davies, T. Holden, I. G. Cowx, J. P. Harvey & J. R. Britton, 2003. A quantitative assessment of the impact of goosander, *Mergus merganser*, on salmonid populations in two upland rivers in England and Wales. In Cowx, I. G. (ed.), Interactions between Fish and Birds: Implications for Management. Blackwell Science, Malden, Oxford: 119–135.

Winfield, I. J., 1990. Predation pressure from above: observations on the activities of piscivorous birds at a shallow eutrophic lake. Hydrobiologia 191: 223–231.

Žydelis, R., G. Gražulevičius, J. Zarankaitė & R. Mečionis, 2002. Expansion of cormorant (*Phalacrocorax carbo sinensis*) population in western Lithuania. Acta Zoologica Lituanica 12: 283–287.