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Computational modelling of cormorant swarm

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ABSTRACT

The great cormorant (*Phalacrocorax carbo*) is a species with a strong impact on the environment in the areas inhabited by breeding colonies or migrating colonies. Depending on the size of colonies, destruction of tree cover, soil sterilization due to the supply of enormous amounts of aggressive faeces and overpreying on fish from nearby water bodies can be observed. In this study, an iterative algorithm for modelling the annual life cycle of a swarm of cormorants was described. The procedure was based on a mathematical model of a herd of birds, taking into account both fixed biological factors, such as food demand, availability of habitats and the reproductive cycle, and random factors occurring in the environment, e.g., flooding, storms or human activity. Additionally, the algorithm included the variable time of inhabitance depending on the duration of the ice cover over water bodies, and the possibility of conducting a killing programme. The proposed procedure was tested and verified positively using data obtained from the literature.

1. Introduction

The great cormorant (*Phalacrocorax carbo* L., 1758) belongs to the order of Pelecaniformes and the family of Phalacrocoracidae (cormorants). It is commonly referred to as the "black cormorant", but the currently allowed name is the great cormorant (Mielczarek and Cichocki, 1999). It is a widespread species that occurs is in the entire Europe, Asia, Africa, Australia and on the east coast of North America. Currently in Poland, no ground colonies are observed, and nests are built primarily on trees. The great cormorant colonies in Poland are found either on the coast of the Baltic Sea or in the vicinity of inland water bodies. The subspecies nesting in Poland is *Phalacrocorax carbo sinensis* shaw et Nodder 1801, and the North Atlantic great cormorant (*Phalacrocorax carbo carbo*) can also be observed in the coastal zone in the winter.

No sexual dimorphism is exhibited between individuals, but differences in size can be observed-males are approx. 30% larger than females (Ropert-Coudert et al., 2006). In the morphometric measurements, body length is 80–100 cm, wing span is 130–160 cm, while body weight is approx. 1.6–3.6 kg. The plumage is black with a metallic shine in adult individuals, and brown and matt with brighter abdominal and pectoral region in juvenile individuals. Adult birds in their nuptial plumage have narrow white feathers on the thighs, neck and the back of the head. The skin around the long, hook-tipped bill is yellow and bare. An individual's age can be preliminarily estimated based on the eye pupil, since it is emerald green in adult birds and brown in young birds (Cramp and Simmons, 1977). Selected morphological characteristics allow estimation of the age of cormorants in a colony, and thereby characterization of the age structure and condition of the entire colony (Table 1).

Cormorants are considered very voracious. Their daily average consumption of fish is 273 g (according to Keller, 1997), 400 g (according to Marion, 1997), 146–700 g (according to Noordhuis et al., 1997), 425–700 g (according to Rae et al., 1969), 350–420 g (according to Mellin and Mirowska-Ibron, 1994), or 318 g (according to Feltham and Davies, 1997). The nutritional requirement of nestlings is 250 g in April and May, 300 g in June and 350 g in July and August (Dam et al., 1995). Cormorants are very efficient predators. Their water-absorbing plumage is an advantage improving their efficiency. Cormorant feathers are not lubricated with grease, no air remains between them and thus no insulating layer is formed, which reduces heat loss. This improves the energy balance of cormorants compared to other birds. As a result, cormorants gain on the ease and speed of diving. Since no air remains between the feathers, buoyancy does not affect them. This reduces the time spent on preying. In the winter, adult individuals prey once a day, and young individuals sometimes prey twice a day (Trauttmansdorff, 2003).

Preying occurs in every type of waters. Cormorants also consume dead or diseased fish since these are easy prey. The preferred food are

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Table 1
The size of the prey of cormorants in lakes, according to various authors (Krzywosz, 2008).

Species	Mean length in cm l.c	Max. length in cm l.c and weight
Common roach (*Rutilus rutilus*)	(9.8–10.3)	25.8 (352 g)
Common bream (*Abramis brama*)	(14.9–15.2)	24.9 (285 g)
European perch (*Perca fluviatilis*)	(7.4–9.1)	18.8 (121 g)
Northern pike (*Esox lucius*)	(19.7–20.4)	43.9 (933 g)
Tench (*Tinca tinca*)	(15.3–15.6)	29.2 (642 g)
European eel (*Anguilla anguilla*)	(39.4–51.8)	80.0 (938 g)

small fish up to 10 cm in length. Cormorants also feed small fish to their nestlings, as the latter have no ability to fragment the prey into smaller pieces. Among the species most frequently consumed by cormorants are the round goby (*Neogobius melanostomus*, Gdansk Bay) and the ruffe (*Gymnocephalus cernuus*, Vistula Lagoon and Szczecin Lagoon), while species exploited commercially are rarely preyed on (Bzoma, 2011a). According to the general conclusion by Keller and Visser (1999), the length of the fish consumed by cormorants is 5–50 cm.

The composition of the diet of cormorants reflects the availability of fish in the water body. Cormorants usually avoid very small fish species, as well as those characterized by long body, e.g., the common bream, the white bream and flatfish. The composition of their diet in one area should not be compared with or extrapolated to other areas, as cormorants prey on fish most easily available in the given water body (Winkler et al., 2012).

Cormorants are migratory birds. They migrate at distances often exceeding 1000 km Bzoma (2011b). The cormorants that spend the winter in Poland originate from the coasts of the Baltic Sea, as well as northern parts of Scandinavia and Western Europe.

Cormorants are monogamous. Their reproductive season starts at the beginning of April by laying 3–6 eggs at the intervals of 2–3 days. Both males and females brood eggs, and the incubation period lasts 23–24 days. A single clutch gives rise to 0–3 nestlings (Cramp and Simmons, 1977).

Water eutrophication and overfishing of large species on the one hand, and species protection on the other hand, resulted in a significant increase in the population of those birds. It has been observed not only in Poland, but also worldwide. In 1980, the population of *Phalacrocorax carbo sinensis* inhabiting the catchments area of the North Sea and the Baltic Sea was as small as 10–20 thousand pairs, while in 2000 it was 217,000 pairs (Bregnballe et al., 2003). As the population increased, an increase in the size and number of colonies was observed. After a period of rapid growth, stabilization or even decrease of 20% occurs. The growth on the east and north coast of the Baltic Sea began in 1990 and has continued ever since Bregnballe et al. (2003).

The documented history of the great cormorant in Poland starts before World War I, when approx. 150 nests at 3–4 breeding sites were found. The subsequent observations included: in 1959–7 colonies and 1800 nests; in 1973–8 colonies and 1200 nests (legal protection in Poland was given to the species that year); in 1981–9 colonies and approx. 1500 nests; in 1988–23 colonies and over 5000 nests; in 1992–32 colonies and 8260 nests (Krzywosz, 2008). The domestic breeding population is considered the number of breeding pairs nesting in Poland in the given year. Therefore, the size of the population is slightly lowered, as the results are based on the count of occupied nests. Thus, the best solution would be to count the nests several times during the season. The results of nest counting in known colonies should therefore be considered as the minimum size of the breeding population. The estimates of the domestic population conducted in 2006 under the project Wetlands International Cormorant Research Group established that 25,795 pairs in 53 colonies nested in Poland. Another round of counting was conducted in 2010 in order to develop a management strategy for the cormorant population in Poland. The estimates were carried out at all known nesting sites of *Phalacrocorax carbo sinensis* throughout the country. The results demonstrated that the population consisted of 27 thousand breeding pairs. 27,108 nests were counted at 60 locations, 50 of which were colonies of more than 10 nests, while the remainder were smaller colonies. The largest colony is that observed in Kąty Rybackie (Pomeranian Voivodeship), where 8142 cormorant pairs (30% of the domestic population) nested in 2010. Nest counting was also conducted in 2012. Based on the data covering 96% of the population, gathered two years ago, a decrease of 2.5% in the number of nests was observed, which allows a conclusion that the population has stabilized (www.cormocount.eu).

Cormorants cause damage of various extent to different branches of economy. The main problem for the fishing economy is the damage to fisheries and angling, reduction of the size of the catches and of the effectiveness of fish introduction (loss of the introduced material-cormorants prey on the introduced fish), reduction of the natural reproduction by preying on the spawning fish, decrease in the efficiency of catches using certain tool types by eating fish directly from nets and chasing fish away. Damage is also often done to nets, resulting in decreased fishing efficiency. Cormorant attacks are not always effective, leaving fish wounded and thereby more prone to diseases and death. When assessing the damage to fisheries, the most significant argument is the piscivorous nature of the birds. The composition of the species that are preyed on is different depending on the type of waters and composition of the ichtyocenoses in water bodies (Bzoma, 2011a). In 2006, a total of approx. 7000 t of fish were eaten in the coastal waters of the Baltic Sea (Bzoma, 2008).

The damage should be considered separately for the Baltic coast, inland waters, lake districts, inland waters of the rest of the country and aquaculture.

Fish consumption in the waters of the Baltic Sea amounts to thousands of tonnes. In the record year of 2006, cormorants ate 4800 t of fish in Gdansk Bay, from which 3300 t in Kąty Rybackie. The cormorants of Mielino Island ate 1100 t of fish. Those from Gardzka Kępa and Dębina Island (Szczecin Lagoon) ate a total of 1130 t (Bzoma, 2008). The most valuable Baltic fish species preyed on by cormorants is the eel, very important for coastal fisheries due to its high price. This causes a conflict between the large population of cormorants and the need for the recovery of the eel population (Robak, 2009).

Inland waters of the lake districts include areas in which natural lakes occur, spanning the Warmian-Masurian, Pomeranian, West Pomeranian and Kuyavian-Pomeranian Voivodeships, as well as the northern parts of the Podlaskie, Lubuskie and Greater Poland Voivodeships. Due to the intensified fish production through reintroduction, the presence of cormorants is considered unfavourable. Cormorants prefer the most abundant fish species (the common roach in lakes), therefore cause adverse changes in the species composition. Depending on the type of lake, the species preyed on most often (from a few to twenty percent) are the zander (*Sander lucioperca*) or the pike and the tench, which is the greatest damage caused by cormorants (Krzywosz and Traczuk, 2009).

Apart from the lake districts and breeding ponds, *Phalacrocorax carbo sinensis* inhabits large rivers and their retention reservoirs. In studies from neighbouring countries, high sensitivity of the salmonid population to the pressure exerted by cormorants can be noticed. In the Czech Republic, Spurny and Guziur (2002) considered cormorants responsible for a 60% decline in the population of the grayling (*Thymallus thymallus*) and the brown trout (*Salmo trutta m. fario*). In Switzerland, Suter (1995) described the adverse impact of those predators on the populations of the grayling and trout. In Poland, the scale of the problem is reflected in the growing number of requests for permission to shoot these birds in the areas of such rivers as San, Wisłoka, Ropa, Dunajec, as well as areas with fisheries, mainly breeding ponds. The latter are very attractive sites for preying