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Black spots for aquatic and terrestrial ecosystems: impact of a perennial cormorant colony on the environment

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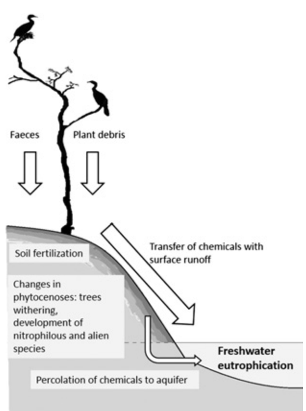
HIGHLIGHTS

- The complexity of ecological effects of cormorants colonies were investigated.
- Soil chemistry and plant vegetation were altered via extreme nutrients deposition.
- Promotion of nitrophilous and invasive alien species was observed.
- Large loads of nutrients were transferred to nearby lake through surface runoff.
- The colony increased coliform numbers in the nearby littoral zone.

GRAPHICAL ABSTRACT



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ABSTRACT

The global growth of populations of different cormorant species has raised concern on the consequences of their presence in the environment. This study examined the impact of a perennial colony (160 breeding pairs) of great cormorants on terrestrial and aquatic ecosystems. The deposition of bird-originating nutrients within the area of colony, their accumulation in soils and the fluxed of chemical substances to a nearby lake were investigated. The impact of cormorants on terrestrial vegetation and microbial pollution of the lake were also studied. The soils beneath the colony were found to contain extremely high concentrations of nitrogen and phosphorus. The overgrowing vegetation was largely limited with nitrophilous and invasive species being more abundant. Increased loads of organic matter, nitrogen and phosphorus were also found in groundwater and particularly, surface runoff. The colony area delivered significant amounts of nutrients to the lake also when the birds were absent. The lake water near colony was also characterized by increased nutrient content and additionally higher number of faecal bacteria. The present results demonstrate the complexity through which the effect of cormorant colonies can be manifested simultaneously in terrestrial and aquatic ecosystem.

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1. Introduction

Cormorants (*Phalacrocorax*), large piscivorous birds, demonstrate a nearly global distribution encompassing Asia, Africa, Australia and New Zealand, North America and Europe (Kennedy and Spencer, 2014). Considered by humankind as the competitors for fish resources, they were largely exterminated and their number remained low over the decades (Ostman et al., 2013). However, over the past 40 years, a great rise in the population of some species such as the North American double-crested cormorant (*Phalacrocorax auritus* Less.) and the great cormorant (*Phalacrocorax carbo* L.) has been observed (van Eerden and Gregersen, 1995; Bzoma et al., 2003; White et al., 2011; Rusell et al., 2012; van Eerden et al., 2012). Several reasons appear to be responsible for this phenomenon among which are: the decision to protect these birds in numerous countries, their high degree of ecological adaptation, ability to forage on marine and freshwater ecosystems, increase in fish biomass due to the eutrophication of surface waters and global climate changes (White et al., 2011; Skov, 2011). Changes in the population status of cormorants have raised serious concerns as to the consequences of their presence in the environment. In many cases these birds can colonize forested areas located directly adjacent to water bodies and therefore potentially affect the functioning of both the terrestrial and aquatic ecosystem (Klimaszyk et al., 2015).

Piscivorous birds such as cormorants represent a very important intermediate link in some food webs (Gwiazda et al., 2014; Skov et al., 2014) and a factor facilitating the dislocation of matter between aquatic and terrestrial ecosystems (Marion et al., 1994; Huang et al., 2014). Their diet is rich in nitrogen (N) and phosphorus (P), which results in a significantly higher excretion of these elements than in herbivorous birds (Marion et al., 1994; Sterner and Elser, 2002). During the breeding season, cormorants feeding on fish can deposit a large amount of biomass and chemical compounds beneath the colony area (Kameda et al., 2006). This usually results in a relevant increase in the status of N and P in soil (Mulder and Keall, 2001), a factor that has a great influence on primary production in terrestrial environments (Vitousek and Howarth, 1991).

On the other hand, some studies have indicated that piscivorous birds can successfully prevent the eutrophication of lakes due to the exclusion of N and P from the aquatic food chains and their consequent introduction to terrestrial biochemical cycles (Ligęza and Smal, 2003). Moreover, the foraging of cormorants can lead to the top-down control of the aquatic food web. This has been observed particularly in the case of small lakes, in which a significant decrease in the number of fish led to simultaneous increase in zooplankton density followed by the limited development of phytoplankton (Gmitrzuk, 2004). It is, however, worth noting that cormorants inhabiting one colony can feed on a relatively large area (up to 30 km from the colony) and on various water systems. At the same time, most of their excrements are deposited over a small area under the colony (Marion et al., 1994; Kameda et al., 2006) and near the lake shore (Klimaszyk et al., 2015). As the high deposition of nutrient-rich faeces of cormorants successfully limits terrestrial vegetation (Ellis et al., 2006), the large loads of chemical compounds can be transported with surface runoff or groundwater to the nearby lake (McCann et al., 1997; Klimaszyk et al., 2014). In such cases, cormorants can increase the bioavailable pool of N and P, promote primary production and trigger the eutrophication of surface waters (McCann et al., 2000; Klimaszyk et al., 2015).

Altogether, the effect of cormorants on the inhabited environment is most likely complex and its assessment requires multifaceted investigations. The present study evaluated the degree to which a perennial colony of the great cormorant affects terrestrial and lake ecosystems. The following hypotheses have been put forward:

(i) The deposition of nutrients originating from cormorant feaces significantly alters soil chemistry and induces long-term changes in plant communities. Plant species characteristic for forest are replaced by nitrophilous and alien species, and biodiversity decrease.
(ii) The cormorant-induced havoc in terrestrial vegetation promotes the surface runoff — overland flow is a main route of nutrients transfer from colony to aquatic environment.
(iii) The cormorant-derived N and P can constitute a significant share in nutrient budget of the surface freshwaters and promote their eutrophication.

To verify these hypotheses the chemistry of soil beneath the cormorant colony, out-flowing groundwater and surface runoff, and nearby lake as well as microbial pollution of the littoral and differences in the terrestrial vegetation were investigated. Our study clearly demonstrates the complexity through which the effect of cormorant colonies can be manifested simultaneously in terrestrial and aquatic ecosystem.

2. Material and methods

2.1. Study site — lake

The study area covered the cormorant (*P. carbo*) colony located on the island shore of Lake Ostrowiec (Northern Poland, Europe) at the latitude and longitude of 53°4′39″N and 15°57′66″E, respectively (Fig. 1). The lake consists of four basins. Exchange of water between them is hampered due to shallow isthmuses. The River Plociczna flows into and out of the northern basin of the lake, and this basin can be described as a through-flow basin, in contrast to the other lake basins, with no outflow (Klimaszyk et al., 2014). The total area of the lake is almost 400 ha and shoreline length is over 22 km. The maximum depth of the lake is 27.9 m. The immediate-direct catchment area of Lake Ostrowiec covers about 10 km^2, while the area drained by the River Płociczna is almost 202 km^2. More than 90% of the direct catchment area is covered by forest — over 70 year old plantations of Scots pine (*Pinus sylvestris*). Three islands with areas ranging from 2.2 to 0.6 ha are located on the lake (Fig. 1). The islands are overgrown by climax forest with the domination of: sessile oak (*Quercus petrea*), European beech (*Fagus sylvatica*) and Scots pine (*P. sylvestris*).

2.2. Study site — cormorant colony

Great cormorants have been observed on Lech Island (1.2 ha) at Lake Ostrowiec since the late 1960's. Until the early 1990's the number of breeding pairs did not exceed 50. From 1995 the number of birds started to increase. In 2004 almost 300 inhabited nests were reported and due to the withering of trees, the colony expanded from the central part of the island to an area closer to its edge. During the investigation period (March 2010–March 2012) the number of cormorants varied from 154–167 breeding pairs. At that time the birds did not occupy the central part of the island (site A; 0.39 ha; hereafter former colony) due to the lack of trees. The main colony (nearly 90% of nests) was located in the surrounding area (site B; 0.38 ha; hereafter central colony) where most of the trees were already withered. The peripheral zone of the island (site C; 0.43 ha; hereafter peripheral colony) was rich in vegetation and the number of nests did not exceed 20 (Fig. 1).

2.3. Sampling

Samples of cormorant droppings were collected monthly (at the beginning of the month) from April to October 2010 using 10 trays (60 × 60 cm) distributed for 24 h in transects (Fig. 1). Plant detritus (leaves, branches) found in trays was removed and not taken into consideration. The deposition of nutrients was recalculated as a monthly load of N and P per m^2. During sample collection, the number of adult cormorants inhabiting the colony was counted.