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The impact of Great Cormorants on biogenic pollution of land ecosystems: Stable isotope signatures in small mammals

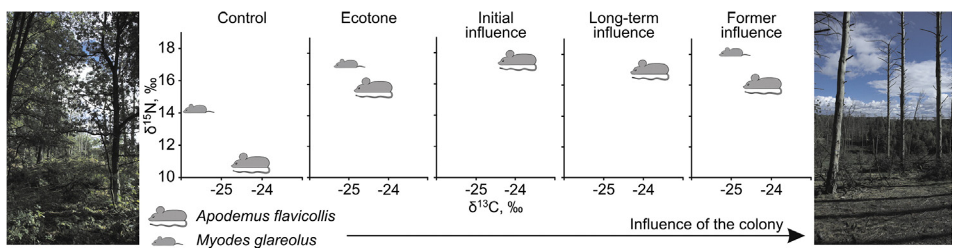
Linas Balčiauskas [a,*], Raminta Skipitytė [a,b], Marius Jasiulionis [a], Giedrius Trakimas [c,d], Laima Balčiauskienė [a], Vidmantas Remeikis [b]

[a] Nature Research Centre, Akademijos 2, LT-08412 Vilnius, Lithuania
[b] Center for Physical Sciences and Technology, Savanorių 231, LT-02300 Vilnius, Lithuania
[c] Center for Ecology and Environmental Research, Vilnius University, Vilnius, Lithuania
[d] Institute of Life Sciences and Technology, Daugavpils University, Parades Str. 1a, Daugavpils, LV-5401, Latvia

HIGHLIGHTS

- Cormorants transport nutrients from water to land ecosystems and pollute biogenically.
- We studied stable isotope composition of small mammal hair in 3 cormorant colonies.
- $\delta^{13}C$ and $\delta^{15}N$ were measured using elemental analyzer–isotope ratio mass spectrometer.
- $\delta^{13}C$ and $\delta^{15}N$ values were higher in rodents inhabiting cormorant colonies.
- Disruption of the ecosystem caused by Great Cormorant colonies affects small mammals.

GRAPHICAL ABSTRACT



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ABSTRACT

Studying the isotopic composition of the hair of two rodent species trapped in the territories of Great Cormorant colonies, we aimed to show that Great Cormorants transfer biogens from aquatic ecosystems to terrestrial ecosystems, and that these substances reach small mammals through the trophic cascade, thus influencing the nutrient balance in the terrestrial ecosystem. Analysis of $\delta^{13}C$ and $\delta^{15}N$ was performed on two dominant species of small mammals, *Apodemus flavicollis* and *Myodes glareolus*, inhabiting the territories of the colonies. For both species, the values of $\delta^{13}C$ and $\delta^{15}N$ were higher in the animals trapped in the territories of the colonies than those in control territories. In the hair of *A. flavicollis* and *M. glareolus*, the highest values of $\delta^{15}N$ (16.31 ± 3.01‰ and 17.86 ± 2.76‰, respectively) were determined in those animals trapped in the biggest Great Cormorant colony. $\delta^{15}N$ values were age dependent, highest in adult *A. flavicollis* and *M. glareolus* and lowest in juvenile animals. For $\delta^{13}C$ values, age-dependent differences were not registered. $\delta^{15}N$ values in both small mammal species from the biggest Great Cormorant colony show direct dependence on the intensity of influence. Biogenic pollution is at its strongest in the territories of the colonies with nests, significantly diminishing in the ecotones of the colonies and further in the control zones, where the influence of birds is negligible. Thus, Great Cormorant colonies alter ecosystem functioning by enrichment with biogens, with stable isotope values in small mammals significantly higher in the affected territories.

* Corresponding author at: Nature Research Centre, Akademijos 2, Vilnius, Lithuania.
E-mail addresses: linasbal@ekoi.lt (L. Balčiauskas), raminta.skipityte@ftmc.lt (R. Skipitytė), mjasiulionis@ekoi.lt (M. Jasiulionis), giedrius.trakimas@gf.vu.lt (G. Trakimas), laiba@ekoi.lt (L. Balčiauskienė), vidrem@fi.lt (V. Remeikis).

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1. Introduction

Small mammals (for example rodents) represent an important ecological group in terrestrial ecosystems (Bogdziewicz and Zwolak, 2014). They provide a base for trophic webs as they occur in great numbers and are usual prey for carnivores (Prevedello et al., 2013). The species composition of small mammals is not accidental: it depends on vegetation type and area, the food specialization of the small mammal species and various other influences. Small rodents channel nutrients and energy up to the higher trophic levels as they mostly utilize green plant material (*Microtus* spp), seeds and fruits and/or foods of animal origin (*Apodemus* spp., *Micromys* spp.) or feed on both low and high energetic plant resources and animal food (e.g. *Myodes glareolus*) (Renaud et al., 2005; Butet and Delettre, 2011; Čepelka et al., 2014). Information on changes in rodent communities and their food sources in natural and altered environments is key in the understanding of ecosystem functioning.

Colonies of Great Cormorants (*Phalacrocorax carbo*) are one of the factors that can most affect a terrestrial ecosystem. Cormorants deposit a lot of excreta at their nesting sites and play an important role in transporting nutrients from water to land ecosystems. They have a direct impact on forest ecosystem and damage vegetation through their breeding activities and excreta deposition (Ishida, 1996; Kameda et al., 2006; Klimaszyk et al., 2015). The impact is long-lasting as nutrient enrichment in the forest soil is significant not only in active colonies, but also in previously occupied areas abandoned by the birds (Hobara et al., 2001). Similarly, high nitrogen isotope ratios have been reported in the forest floor and living plants in areas both occupied by the cormorants and already abandoned (Kameda et al., 2006).

Despite recognizing cormorants as a vector of change in terrestrial ecosystems, their effects on autotrophs and consumers (e.g. rodent communities) are still poorly understood. Recent studies have shown that colonies of the cormorants significantly alter their environment by changing soil pH, nitrogen and phosphorus levels (Klimaszyk et al., 2015) and affecting lichens (Motiejūnaitė et al., 2014), fungi (Kutorga et al., 2013) and plants and arthropods (Kolb et al., 2010). Enrichment of the ecosystem by biogens and destruction of the typical woody vegetation imposes consequences on the small mammals in the territory, in particular a reduction in species diversity and decreased relative abundance of small mammals in the most heavily bird-influenced parts of the colony (Balčiauskienė et al., 2014). Within a cormorant colony, it was shown that the population structure of yellow-necked mice (*Apodemus flavicollis*) was biased toward a higher representation of males and young individuals in the most intensively used nesting area for the cormorants. Additionally, mice were characterized by smaller body weight and a lower average body index (Balčiauskas et al., 2015). Such a biased population structure is indicative of a poor or disturbed habitat or a variation of the habitat quality over time (Panzacchi et al., 2010; Sollmann et al., 2015). In the zones with both the highest number of cormorant nests and the longest-standing influence of the colony, *A. flavicollis* and bank voles (*Myodes glareolus*) also developed skull morphometric features that enhanced their ability to survive in specific conditions (Balčiauskienė et al., 2015).

Natural variability in the stable isotopic ratios of carbon, nitrogen and sulfur (δ^{13}C, δ^{15}N, δ^{34}S) is widely used in animal ecology, including studies of animal migration, food webs, trophic position estimation and food source reliance (Vander Zanden et al., 2015). Stable isotope analysis (SIA) has proven to be a useful tool in reconstructing diets, characterizing trophic relationships, elucidating patterns of resource allocation and constructing food webs, including diet (Boecklen et al., 2011).

Distributions of stable isotopes in investigated populations of animals can be a valuable technique for estimating trophic niche width (Bearhop et al., 2004) and finding differences in resource availability between sexes and age groups (Smiley et al., 2015). Stable isotope ratios can help to distinguish between resident animals and migrants (Hobson, 1999) as different environments have different stable isotope signals and this is reflected in the stable isotope ratios of the animal tissues. Using shaved hairs of the animals has the potential to be an effective non-lethal method for stable isotope measurements (Caut et al., 2008) and provides a direct technique to study feeding behavior in or between the populations. In small mammals, SIA has been used to investigate trophic segregation between two rodent species (Selva et al., 2012), dietary habits (Miller et al., 2008), trophic levels (Nakagawa et al., 2007) and trophic diversity and niche packing (Dammhahn et al., 2013).

A. flavicollis and *M. glareolus* are among the most common small mammals in European forest habitats. These species are good model organisms for examining nutrient and energy flow in forest ecosystems as they occur in high densities and have wide geographic ranges (Niedzialkowska et al., 2010). Using the SIA method, we studied the carbon and nitrogen isotope composition of *A. flavicollis* and *M. glareolus* hair in three Great Cormorant colonies and one cormorant-free forest in Lithuania. Stable carbon (δ^{13}C) and stable nitrogen (δ^{15}N) isotope ratios were measured. We aimed to show that Great Cormorants transfer biogens from aquatic ecosystems to land ecosystems, and that these substances reach small mammals through the trophic cascade, thus influencing the nutrient balance in the terrestrial ecosystem.

2. Material and methods

2.1. Study sites

Small mammals were trapped in 2014 in three Lithuanian colonies of *P. carbo*, situated in Juodkrantė (WGS 55° 31′ 14.22″, 21° 6′ 37.74″), Elektrėnai (54° 45′ 37.22″, 24° 40′ 41.45″) and Lukštas (55° 51′ 0.94″, 26° 12′ 6.11″). All three colonies had control zones. In addition, small mammals were also trapped at Zarasai (55° 44′ 46.36″, 25° 45′ 14.59″), a control site only with no breeding cormorants (Fig. 1).

The colony in Juodkrantė was formed in 1989 and is one of the largest in the Baltic Sea region: following a rise to 3303 pairs breeding in 2013, control measures reduced this to 1883 successful pairs in 2014 (with about the same number of unsuccessful nests). The area of the colony covers around 12 ha and several zones of differing levels of colony influence have been defined:

Zone I (the control zone with no direct influence by cormorants on the habitat).

Zone II (the zone of initial influence by the colony – the expanding part of the colony, thus only a recent and developing influence).

Zone III (the zone of long-term influence by the colony and with the highest concentration of nests).

Zone IV (the zone of former active influence by the colony with dead trees, many of them rotten, fallen and decaying).

Zone V (the zone of the ecotone between zones II and III and the surrounding forest).

These zones were described in detail by Balčiauskas et al. (2015). Additional information is given in Appendix (Fig. S1).

The two other studied colonies are much smaller and have never exceeded 200–300 breeding pairs. In 2014, 163 pairs successfully bred in Elektrėnai, while only 95 pairs in the Lukštas colony. The Elektrėnai cormorant colony is the oldest in Lithuania, forming in 1985 on a 6.5 ha island, 700 m from the nearest shore of the reservoir. The control zone for this colony was a cormorant-free part of the island, a distance >50 m from the nests. The Lukštas cormorant colony is the smallest and youngest colony in Lithuania. It is situated on a 1.3 ha peninsula in the northern part of Lukštas lake. The control zone of this colony was on the lakeshore, 200 m from the nests.

Control zones of the territories were selected on the basis of long-term knowledge of the Great Cormorant distribution and use of the surroundings of the colonies. To our knowledge, use of the control territories by these birds in Juodkrantė, Elektrėnai and Lukštas in 2014 was accidental and negligible. It is possible however that small amounts of biogens could have been transferred with seepage of rainwater.