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# The contribution of double-crested cormorants (*Phalacrocorax auritus*) to silver carp (*Hypophthalmichthys molitrix*) DNA loads in the Chicago Area Waterway System

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ABSTRACT

Waterfowl and colonial waterbirds can have significant impacts on water quality in lakes and reservoirs by depositing feces that contribute to nitrogen and phosphorus loads. Piscivorous birds can also contribute the DNA of prey species to a water body. Here, we develop and apply a loading model to estimate the number of silver carp (*Hypophthalmichthys molitrix*) DNA target marker copies that are potentially deposited by nesting double-crested cormorants (*Phalacrocorax auritus*) in the Chicago Area Waterway System (CAWS). The model assumes a conservative breeding population estimate ranging between 6000 and 8000 cormorants distributed among three large colonies in the Chicago metropolitan area. The model also assumes that cormorants are distributing feces randomly throughout the CAWS in proportion to the amount of time spent at each location. Results show that cormorants may be contributing 2.6 to 113 target marker copies/m$^2$/day if birds are spending 22% of their time on open water and 6.4 to 291 target marker copies/m$^2$/day if birds are spending 56% of their time on open water. Over the entire CAWS, cormorants may contribute tens of millions to billions of silver carp DNA copies each day. These target marker loads may be contributing to positive detections of silver carp environmental DNA (eDNA) in the CAWS. This study does not address other potential sources of silver carp genetic material in the CAWS, including live fish, and provides no indication as to whether or not the loads attributed to cormorants are large or small in relation to these other potential sources.

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## Introduction

Fecal waste deposited by waterfowl and colonial waterbirds can have a significant impact on nutrient levels in lakes and reservoirs (Manny et al., 1994; Scherer et al., 1995; Hahn et al., 2007; Gwiazda et al., 2010; Klimaszyk et al., 2014). Birds may deposit feces directly into water bodies and accumulations of fecal material under communal roosts may leech into adjoining water bodies through runoff or erosion (Gwiazda et al., 2010; Klimaszyk and Rzymski, 2013). Researchers have developed nutrient loading models to analyze and understand the impact of waterfowl and waterbird populations on water quality (Manny et al., 1994; Scherer et al., 1995; Hahn et al., 2007). In most cases, the nutrient load contributed by birds through fecal deposition is considered minimal compared to other sources of nutrients entering the system (Murphy et al., 1984; Hoyer and Canfield, 1994; Scherer et al., 1995), or minimal at the landscape scale, with potential impacts at the local scale (Hahn et al., 2007). Nevertheless, in some situations, nutrient loading by birds may result in high nitrogen (N) and phosphorous (P) concentrations (Manny et al., 1994; Scherer et al., 1995; Hahn et al., 2007), contribute to associated algal blooms (Manny et al., 1994), exacerbate cadmium and lead pollution (Mathis and Kevern, 1975) and increase coliform bacteria loadings (Klimaszyk and Rzymski, 2013).

Waterbird populations can contribute the genetic material of prey species to waterbodies in the same way that they contribute nutrients (Merkes et al., 2014; Guilfoyle et al., 2017a). The genetic material is allochthonous if it is transported from one water body to another by means other than a live fish. Allochthonous DNA is a source of false positive error in environmental DNA monitoring studies, which attempt to document the presence of an aquatic species by detecting their genetic material in water samples (Darling and Mahon, 2011; Guilfoyle et al., 2017a). It is important to understand sources of error in eDNA studies because false positive errors can lead to faulty environmental management decisions that are costly and have negative environmental outcomes (Merkes et al., 2014; Guilfoyle et al., 2017a).

Natural resource managers are conducting eDNA studies to monitor for the presence of two invasive species of carp in the Chicago Area Waterway System (CAWS). These two species, bighead carp (*Hypophthalmichthys nobilis*) and silver carp (*H. molitrix*), have expanded their ranges north in the Mississippi and Illinois Rivers and are now approximately 115 km southwest of Lake Michigan (United States Fish and Wildlife Service, 2015). The probability that these fish

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will become established in the CAWS and Lake Michigan is reduced by the presence of an Electric Dispersal Barrier at Romeoville, Illinois, approximately 50 km downstream from Lake Michigan. If these fish were to become established upstream of the barrier, they would negatively impact the ecology of the Great Lakes and threaten commercial and recreational fishing opportunities (Zhang et al., 2016). Monitoring is being conducted upstream of the barrier to determine whether or not the fish may have penetrated the barrier and to inform decisions about the need to control or eradicate the fish.

Double-crested cormorants (*Phalacrocorax auritus*), hereafter cormorant(s), are known to feed on silver carp and are one potential source of allochthonous silver carp DNA. Presently, cormorants are not known to feed on bighead carp (Guilfoyle et al., 2017a). Our objectives in this paper are: 1) to develop a nutrient loading model that can estimate, to an order of magnitude, how much silver carp DNA cormorants might be contributing to the Chicago Area Waterway System (CAWS) each day; 2) to gather the information needed to parameterize that model for the 2009 to 2012 breeding seasons; and 3) to compare this result with one described by Schultz et al. (2014), who used a Bayesian Markov chain Monte Carlo (MCMC) simulation to estimate how many copies of the genetic marker sources other than live fish might be contributing to the CAWS. The output of the model is highly uncertain, but it suggests that, during the breeding season, the contribution of cormorants to the load of the silver carp genetic marker in the CAWS may be on the order of tens to hundreds of copies per meter$^2$ per day.

## Methods

The potential contribution of cormorants to the load of silver carp genetic marker in the CAWS is assessed using a nutrient loading model approach. In this section, we describe the model and its parameterization. The model is expressed using the following equation:

$$Z = \sum_j N_j \cdot b_j \cdot c \cdot d_j \cdot e \cdot f$$

The output, $Z$, is the sum of silver carp genetic marker copies deposited each day by all $j = \{1, 2, \ldots, J\}$ breeding colonies that may be defecating in the water body. $N_j$ is the number of cormorants in breeding colony $j$ that show evidence of silver carp in their diet. It is assumed that cormorants will distribute their feces randomly throughout their home range in proportion to the amount of time spent at each location. Therefore, the amount of feces deposited in the CAWS is proportional to the fraction of water surface area in the home range of colony $j$ that is the CAWS, $d_j$, and the fraction of time cormorants spend on open water, $c$. The amount of genetic material deposited in the CAWS is also proportional to the amount of feces produced each day, $f$, and the concentration of the genetic marker in the feces, $e$. Finally, we consider what fraction of each colony's diet consists of silver carp, $b_j$. Most of the inputs to this model are highly uncertain, so they are treated as random variables and uncertainty in the output of the nutrient loading model is obtained by Monte Carlo simulation. The following subsections describe how each input variable is defined and parameterized.

### *Number of cormorants with evidence of carp in their diet ($N_j$)*

$N_j$ is a binomially distributed random variable representing the number of breeding cormorants in colony $j$ that show evidence of silver carp in their diet. The distribution is defined by the parameters $n$ and $p$, where $n$ is equal to the population in a breeding colony and $p$ is equal to the fraction of cormorants that contain genetic material from silver carp in their gastrointestinal tract. The value of $p$, 0.47, is based on the results of a study that tested throat and cloacal swabs from cormorants at Bakers Lake (Fig. 1) for evidence of silver carp in their diet (Guilfoyle et al., 2017a). The population in each breeding colony is estimated from field surveys. Bird populations are inherently variable, and surveys can be very uncertain. Therefore, we used a uniform probability distribution with lower and upper bounds equal to the lower and upper bounds of population estimates to represent uncertainty in the $n$ parameter of the binomial distribution. However, no such bounds were available for the Baker's Lake colony, so we used a point estimate of that population.

The cormorant population in the Chicago metropolitan area is largely confined to three large breeding colonies, Baker's Lake near Barrington, Illinois, Lake Renwick near Plainfield, Illinois, and the ArcelorMittal Steel Mill, in East Chicago, Indiana (Fig. 1). The Baker's Lake colony typically supports about 1000 adult birds, and between 2009 and 2012, the number of breeding adults at Lake Renwick ranged from approximately 1200 to 1600 birds (Doug Stotz, The Field Museum Chicago, personnel communication, 2013). The Indiana Division of Fish and Wildlife makes regular cormorant nest counts at the ArcelorMittal Steel Mill colony site. Based on nest counts taken during the 2009 to 2012 breeding seasons, the number of adults in the ArcelorMittal Steel Mill colony was between 3582 and 5600 (John Castrale, Biologist, Indiana Division of Fish and Wildlife, 2013).

### *Fraction of the cormorant diet that is invasive carp (b)*

The random variable $b$ is the fraction of cormorant diet that is invasive carp. Since there are no data on the fraction of invasive carp in the diet of cormorants, we assume a uniform distribution for the variable with lower and upper bounds 0 and 1, respectively. Under this distribution, the diet of an individual cormorant may vary between 0% carp to 100% carp. The expected value of the random variable is 0.5, which may greatly overstate the fraction of silver carp in the diet of cormorants.

### *Fraction of time cormorants spend on open water during daylight hours in the breeding season (c)*

It is assumed that birds are defecating randomly during the day, during daylight and non-daylight hours. During non-daylight hours, cormorants are roosting in colonies away from the CAWS and are not defecating in the CAWS. Dorr et al. (2014) report that in the daily time budget of cormorants, at least 36% of daylight hours are spent on water and at most 93% of daylight hours are spent on water. There are, on average, about 14.5 h of daylight each day during the breeding season, which is 60.4% of a 24-hour day. Thus, we estimate that cormorants might be spending as little as 22% of their time on open water during daylight hours in the breeding season and at most 56% of their time. Uncertainty in this variable is addressed by estimating a lower and an upper bound on the number of copies of silver carp DNA contributed to the CAWS by cormorants.

### *Fraction of water surface area in home range j that is the CAWS ($d_j$)*

The variable $d_j$ is the fraction of total water surface area within the home range of colony $j$ that is the CAWS. The proportion of open water surface area that incorporates the CAWS in a cormorant's breeding territory was estimated using 95% convex polygons of breeding territories from nine cormorants captured at Baker's Lake (Fig. 1). Breeding territories from these cormorants were determined by use of Sirtrack® Argos Satellite Platform Transmitting Terminal (PTT) Harness Transmitters (model: K3H174A KiwiSat 303) (Guilfoyle et al., 2017b), and were combined to form one large polygon over the Baker's Lake colony site (Fig. 1). For the purposes of this model, the breeding territories of these nine birds are assumed to approximate the local breeding territories for all cormorants nesting in the region. The territories of cormorants from the other two colony sites was estimated by taking 25 random radial measurements from the Baker's Lake polygon (in km) and using the average radial distance to create a circular polygon around the Lake Renwick and ArcelorMittal Steel Mill colony sites (Fig. 1). Using ArcGIS (ver. 10.2), open water habitats within each polygon for small lakes, Lake Michigan, and the CAWS (Table 1) were calculated.