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Distribution and foraging patterns of common loons on Lake Michigan with implications for exposure to type E avian botulism

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ABSTRACT

Common loons (*Gavia immer*) staging on the Great Lakes during fall migration are at risk to episodic outbreaks of type E botulism. Information on distribution, foraging patterns, and exposure routes of loons are needed for understanding the physical and ecological factors that contribute to avian botulism outbreaks. Aerial surveys were conducted to document the spatiotemporal distribution of common loons on Lake Michigan during falls 2011–2013. In addition, satellite telemetry and archival geolocator tags were used to determine the distribution and foraging patterns of individual common loons while using Lake Michigan during fall migration. Common loon distribution observed during aerial surveys and movements of individual radiomarked and/or geotagged loons suggest a seasonal pattern of use, with early fall use of Green Bay and northern Lake Michigan followed by a shift in distribution to southern Lake Michigan before moving on to wintering areas. Common loons tended to occupy offshore areas of Lake Michigan and, on average, spent the majority of daylight hours foraging. Dive depths were as deep as 60 m and dive characteristics suggested that loons were primarily foraging on benthic prey. A recent study concluded that round gobies (*Neogobius melanostomus*) are an important prey item of common loons and may be involved in transmission of botulinum neurotoxin type E. Loon distribution coincides with the distribution of dreissenid mussel biomass, an important food resource for round gobies. Our observations support speculation that energy transfer to higher trophic levels via gobies may occur in deep-water habitats, along with transfer of botulinum neurotoxin.

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Introduction

The Great Lakes afford an important resource to migrating and wintering waterbirds by providing abundant resting and foraging opportunities. However, little information exists on the pelagic distribution and abundance of waterbirds on Lake Michigan during migration and wintering periods. Resource managers seek information on Great Lakes waterbird concentrations during migration and winter as they deal with several priority conservation issues, including impact assessment of near-shore and off-shore wind turbine placement, characterization of sea duck wintering distribution and population status, and elucidating factors that influence the outbreak of type E avian botulism caused by exposure to *Clostridium botulinum* neurotoxin type E (BoNT/E). All of these issues and more require a better understanding of the distribution, abundance, and temporal use patterns of waterbirds.

Episodic outbreaks of type E botulism have resulted in die-offs of waterbirds in the Great Lakes since at least the 1960s, but outbreaks have become more common and widespread since 1999, particularly in Lakes Michigan and Erie (Riley et al., 2008). Type E botulism has likely been responsible for nearly 100,000 waterbird mortalities on the Great Lakes (Chipault et al., 2015), and extensive bird mortality in northern Lake Michigan near the Sleeping Bear Dunes National Lakeshore has caused great concern among resource managers and the public. Common loons (*Gavia immer*) made up a substantial proportion of these waterbird mortalities associated with avian botulism outbreaks (Brand et al., 1988; Chipault et al., 2015). The actual sites of BoNT/E exposure for birds remain unknown. The physical and ecological factors that lead to type E botulism outbreaks are poorly understood; but invasive species, such as dreissenid mussels (*Dreissena bugensis* and *D. polymorpha*) and round gobies (*Neogobius melanostomus*), may serve to mobilize the toxin from lake-bed sediments to fish-eating waterbirds and other aquatic species (Getchell and Bowser, 2006; Lafrancois et al., 2011). An understanding of feeding patterns and exposure routes of sentinel waterbird species historically at risk to type E botulism die-offs, such as

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the common loon, is central to developing ecological studies to assess pathways of BoNT/E exposure through aquatic food chains in the Great Lakes and identification of physical and biological linkages that drive botulism outbreaks.

To address the information needs of resource managers, we 1) documented the fall distribution and relative abundance of common loons using selected areas of Lake Michigan via aerial surveys during the falls of 2011 through 2013 and 2) monitored movements and foraging patterns of a sample of common loons breeding in Wisconsin, Minnesota, and Michigan, fitted with satellite transmitters and/or archival geolocator tags, to determine spatial and temporal patterns in their distribution and abundance during fall migration with an emphasis on staging on the Great Lakes.

Methods

Aerial surveys

We surveyed fixed-width transects to determine waterbird distribution and estimate relative density. Survey areas were established to document the fall distribution and foraging patterns of waterbirds at-risk to type E botulism on areas of Lake Michigan that have been associated with past type E botulism waterbird mortality events and are also based on partner (U.S. Fish and Wildlife Service and Great Lakes Commission) information needs relevant to potential wind energy development and wintering sea duck distribution. Fixed-width transects were spaced at 4.8 km intervals and extended up to 32 km offshore so as to include waters with depth up to 80 m. Transects generally paralleled shorelines to maximize efficiency and safety. Transects were established using snapPLAN software (TRACK'AIR Aerial Survey Systems, The Netherlands).

Surveys were flown at an average ground speed of about 220 km/h at an altitude of about 61–76 m above the water using a U.S. Fish and Wildlife Service fix-winged aircraft (Partenavia P68 Observer 2). Two trained observers, one on each side of the plane, identified and tallied waterbirds within 200 m-wide strip transects on either side of the plane. Each observation was linked to a GPS waypoint and recorded using an integrated GPS voice recording system (Hodges and Thorpe, 2002).

Waterbird survey data were transcribed from audio files to Excel spreadsheets. Excel files containing location coordinates and waterbird counts were imported into ArcGIS and converted into an ESRI Shapefile of observation points. The Batch Kernel Density Tool (automates density estimates by species and by search radii; Fox, 2018a) was used to create surfaces of density of observed loons based on a kernel distribution function estimation (ArcGIS, ESRI, Redlands, CA, USA). The analysis parameters used were search radius of 10 km, output cell size of 100 m, density units of observed birds per square kilometer, and mask layer of open water within the study area. It is important to note that the distribution maps do not reflect absolute density of loons, but rather provide a relative density based on observed birds along the transect observation area (i.e., loons that occur between the transect strips are not included in the density estimate). Surveys were typically conducted roughly once per month during fall migration (September through December).

Tracking movements of individuals using satellite telemetry and archival geolocator tags

Breeding common loons tracked for the movement and foraging pattern study were obtained from lakes in central and northern Minnesota and Wisconsin and the Upper Peninsula of Michigan during summers 2009–2012 (Fig. 1). Lakes with loon territories considered for inclusion in the study were selected in consultation with Minnesota Department of Natural Resources (DNR) and Wisconsin DNR personnel. Loon territories were monitored for nesting activity and breeding success. Adult loons that successfully produced chicks and the resulting juveniles were captured using night-lighting techniques (Evers, 1993). Each loon was marked with an aluminum numbered U.S. Fish and Wildlife Service band and a unique combination of colored leg-bands to aid with future field identification of individuals. The sex of individual loons of each territorial pair was determined by noting which loon yodeled, a call made only by male loons (McIntyre, 1988). Both adults of a territorial pair were fitted with archival geolocator tags (Model LAT 2500; 34.6 × 8.3 mm, 4.4 g; Lotek Wireless Inc.). A combination of adhesive and plastic cable ties were used to affix the geolocator tag to a modified lock-on aluminum leg band (Fig. 2). Geolocator tags were attached to 176 common loons (Table 1). Tags were programmed to collect 1) daily location estimates for up to two years, 2) temperature (0.02 °C accuracy, ≤0.05 °C resolution) at 30-minute intervals, and 3) pressure data (±1% accuracy, 0.05% resolution) at 20-second intervals during daylight hours to document foraging patterns (dive profiles) during fall migration and during the first few weeks after arriving on the wintering grounds. Data stored on geolocator tags were not transmitted, requiring that the marked loon be recaptured to recover the tag and download the data. The geolocator tags were capable of storing data for several years before the devices needed to be downloaded.

Radiomarked loons were incorporated into the study to provide fine-resolution location data for a sample of the adult male common loons fitted with geolocator tags. Satellite transmitters (Model PTT-100, Microwave Telemetry, Inc) were implanted in 31 adult male common loons that were captured on breeding lakes in Minnesota, Wisconsin, and the Upper Peninsula of Michigan during July 2010 and July 2011 (Table 1). Transmitters were surgically implanted in the abdominal cavity following procedures developed by Korschgen et al. (1996). Surgical techniques and the handling and care of loons were done under approval of the Animal Care and Use Committee of the Upper Midwest Environmental Sciences Center and complied with the Animal Welfare Act (Public Law 99–198 and 9 CFR Parts 1, 2, and 3). The surgical procedures were conducted in a portable laboratory by Dr. Darryl Heard, College of Veterinary Medicine, University of Florida, Gainesville, Florida. After surgery, loons were held until demonstrating control of head and neck and an ability to assume an alert posture.

The satellite transmitters were programmed to transmit on a variable schedule based on the anticipated stage of migration during the loon's annual cycle - 8 h on: 72 h off during the breeding season, 8 h on: 24 h off while migrating, 6 to 8 h on: 96 h off on the wintering grounds, 8 h on: 24 h off during spring migration, and 8 h on: 96 h off for the remaining life of the transmitter. Loon locations were estimated from the Doppler shift in the transmitter carrier frequency and provided by the Argos system (CLS America, Lanham, Maryland). Location estimates were acquired using Argos Standard Service Processing (Argos Location Classes [LC] 3, 2, 1, and 0) and Auxiliary Location Processing (LC A, B, and Z). One standard deviation of nominal accuracy for location estimates with LC 3, 2, 1, and 0 are <250, 250 to 500, 500 to 1500, and >1500 m, respectively (Argos, 2016). We utilized the most accurate locations per 8-hour transmission period for each individual to describe the daily location of that adult loon.

Geotagged adult loons were recaptured during subsequent breeding seasons using diurnal lift-net trap and night-light nest-capture techniques (Kenow et al., 2009) and night-lighting during chick rearing (Evers, 1993). Geolocator tag data collected over the previous year (s) were downloaded from tags using LAT Viewer Studio software (Lotek Wireless Inc.). Geolocator tag location estimates were determined by light-based geolocations using the template-fitting approach (Ekstrom, 2004), in combination with tag temperature (water surface temperature) and pressure (dive depth) data. Template-fit error estimates were used to filter aberrant geolocation estimates. Sea surface temperature (derived from NASA Moderate Resolution Imaging Spectroradiometer [MODIS] imagery) across North America inland lakes, Atlantic coastal waters, and the Gulf of Mexico, coupled with diving depth information were used to improve or obtain location

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