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Using reverse-time egg transport analysis for predicting Asian carp spawning grounds in the Illinois River

Zhenduo Zhu[a], David T. Soong[b,*], Tatiana Garcia[c,1], Mina Shahed Behrouz[a], Steven E. Butler[d], Elizabeth A. Murphy[e,1], Matthew J. Diana[f,2], James J. Duncker[b], David H. Wahl[d]

[a] Department of Civil, Structural and Environmental Engineering, University at Buffalo, Buffalo, NY 14228, United States
[b] U.S. Geological Survey, Central Midwest Water Science Center, Urbana, IL 61801, United States
[c] Optimatics, United States
[d] Illinois Natural History Survey, Kaskaskia Biological Station, Sullivan, IL 61951, United States
[e] University of Illinois at Urbana-Champaign, IL 61801, United States
[f] Michigan Department of Natural Resources, Plainwell, MI 49080, United States

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ABSTRACT

Identifying spawning grounds of Asian carp is important for determining the reproductive front of invasive populations. Ichthyoplankton monitoring along the Illinois Waterway (IWW) has provided information on abundances of Asian carp eggs in the IWW's navigation pools. Post-fertilization times derived from egg development stages and water temperatures can be used to estimate spawning times of Asian carp eggs, but estimating how far these eggs have drifted requires information on river hydraulics. A Fluvial Egg Drift Simulator (FluEgg) program was designed to predict the drift of Asian carp eggs in the riverine environment with egg growth considered. This paper presents a reverse-time particle tracking (RTPT) algorithm for back-casting the spawning location of eggs from their collection site. The RTPT algorithm was implemented as a module in FluEgg. The new version of FluEgg was coupled with an unsteady hydrodynamic model of the IWW to predict the spawning locations for 530 eggs that were collected in June 2015. The results indicate that tailwater sections below the Locks and Dams (L&Ds) in each navigation pool appear to be preferred spawning locations for Silver Carp (a species of Asian carp). From the data analyzed, the most upstream spawning location for the June 2015 spawning period was in the upper Marseilles navigation pool, downstream of the Dresden Island L&D. The RTPT algorithm can efficiently estimate spawning locations for multiple egg samples.

1. Introduction

Asian carp are a group of Cyprinid fishes (carp family) that are native to East Asia, but have been introduced into waters of North America. The term Asian carp is specifically used to refer to four species, the Bighead Carp (*Hypophthalmichthys nobilis*), Silver Carp (*Hypophthalmichthys molitrix*), Black Carp (*Mylopharyngodon piceus*), and Grass Carp (*Ctenopharyngodon idella*). Ecosystem responses to individual species vary, but Asian carp have the potential to deplete plankton densities (Wittmann et al., 2014; Dibble et al., 2009; Schrank et al., 2003), out-compete native fish species (Sampson et al., 2009; Grippo et al., 2017; Deboer et al., 2018), and alter fish communities and aquatic food web structure (Solomon et al., 2016; Collins and Wahl, 2017; Pendleton et al., 2017).

Bighead Carp and Silver Carp are known to have established reproducing populations in the Mississippi, Ohio, Missouri, and Illinois Rivers (Tucker et al., 1996; Nico and Fuller, 1999). The Illinois Waterway (IWW), including the Illinois River and the Chicago Area Waterway System (CAWS, not shown in Fig. 1), is the only continuous aquatic connection between the Mississippi River system and Lake Michigan, and ultimately the other Great Lakes (Fig. 1). Adult Asian carp are known to exist in all pools of the IWW downstream of Brandon Road Lock and Dam (L&D) (Asian Carp Regional Coordinating Committee, 2016), with extremely dense populations downstream of Starved Rock L&D (Roth et al., 2012). Despite various control efforts including the presence of electric barriers (Asian Carp Regional Coordinating Committee, 2016; Davis et al., 2017; Asian Carp Monitoring and Response Plan, 2017), if the population front continues

* Corresponding author.
E-mail address: dsoong@usgs.gov (D.T. Soong).
[1] Formerly with the U.S. Geological Survey, Central Midwest Water Science Center.
[2] Formerly with Illinois Natural History Survey, Kaskaskia Biological Station, Sullivan, IL 61951, United States.

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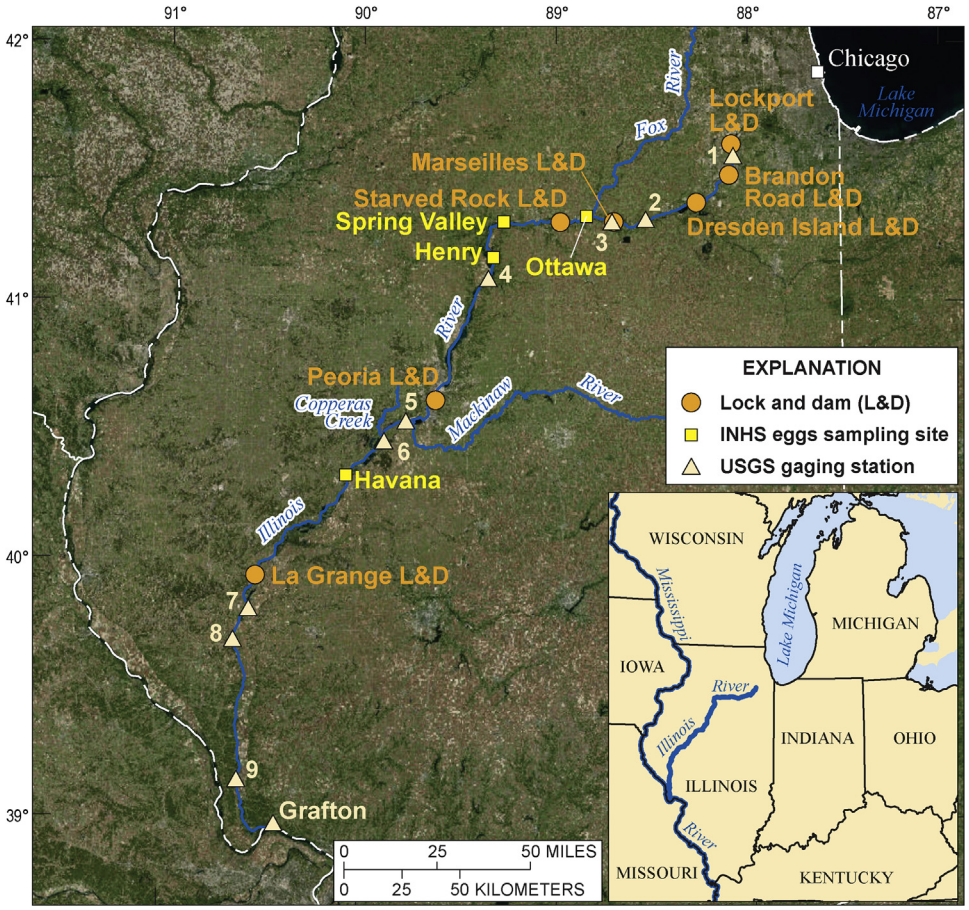

Fig. 1. A map showing the Illinois River, locations of Locks & Dams, USGS gaging stations, and ichthyoplankton monitoring sites, and the Fox and Mackinaw tributaries. Note the ichthyoplankton sampling sites shown are only those locations where Asian carp eggs analyzed in this study were collected, and not all tributaries of the Illinois Waterway are shown in the figure.

to expand, Asian carp could potentially enter Lake Michigan through the CAWS. Preventing the expansion of Asian carp into the Great Lakes is a high priority among several state, federal, provincial, and tribal agencies (Asian Carp Monitoring and Response Plan, 2017).

Intensive ichthyoplankton monitoring has been conducted by the Illinois Natural History Survey (INHS) to provide better understanding of reproduction and recruitment success of Asian carp in different sections of the IWW (Asian Carp Regional Coordinating Committee, 2016). Knowing the locations where Asian carp recruitment can occur may be useful in developing control efforts (George and Chapman, 2015), and identifying Asian carp spawning locations is important for determining the reproductive front of these populations (Schrank et al., 2001; DeGrandchamp et al., 2007; Lohmeyer and Garvey, 2009; Deters et al., 2013; Coulter et al., 2013, 2016; Hintz et al., 2017). Spawn timing can be estimated by collecting drifting eggs and determining their developmental stages and associated post-fertilization times (Papoulias et al., 2006; Deters et al., 2013; Coulter et al., 2013; Embke et al., 2016). Identifying spawning locations, however, requires estimation of the distance that eggs have drifted prior to collection (Deters et al., 2013).

This paper describes a reverse-time particle tracking (RTPT) algorithm that reverses the streamflow dynamics that move eggs downstream to predict the spawning location from where drifting eggs are collected in the river. For practical applications the RTPT is implemented as a module of the existing Fluvial Egg Drift Simulator (FluEgg) computer program (Garcia et al., 2013). FluEgg was developed to predict the transport and drift of Asian carp eggs in rivers following spawning, i.e., in forward-time particle tracking (FTPT) mode. FluEgg is a viable platform for implementing the RTPT algorithm because FluEgg consists of a hydrodynamic module (influence of flow velocity, shear dispersion, and turbulence diffusion) for transporting the eggs, a biological growth module describing the development of eggs over time, and the interactions between hydrodynamic and biological functions (Garcia et al., 2013; Murphy et al., 2016). In its FTPT mode FluEgg has been applied to simulate the transport and risk of hatching of Silver Carp eggs in the Lower Saint Joseph River, Michigan, under various water temperatures and hydrodynamic conditions (Garcia et al., 2015), to assess the vulnerability of the CAWS and the Lower Des Plaines River to Asian carp spawning and recruitment using hypothetical spawning grounds and assigned flow conditions (Murphy et al., 2016), and to estimate spawning locations of Grass Carp in the Lower Sandusky River, Ohio (Embke, 2017). This paper demonstrates the applicability and efficiency of the RTPT module using a portion of the Asian carp eggs collected by INHS in 2015.

2. Methodology

2.1. Study area and the 2015 Asian carp egg samples

The study area for this project extends from the Lockport L&D to the confluence of the Illinois River with the Mississippi River, at Grafton, Illinois, encompassing six other L&Ds (Fig. 1). This study uses river kilometers (RKm, hereafter) as a reference system, beginning at the most upstream cross section (RKm 0) and continuing downstream. This system differs and should be distinguished from the river miles (RM) typically used for navigation purposes.

The overall hydraulics varies along the river due to the longitudinal gradient pattern, river geomorphology, and man-made structures. Higher bed gradients (~20 cm/km) and narrower floodplain feature the reach upstream of Hennepin (a town downstream of Spring Valley and upstream of Henry, not shown in Fig. 1). In the reaches downstream of Hennepin the IWW has much milder bed gradients (~2 cm/