Journal of Great Lakes Research xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Journal of Great Lakes Research

journal homepage: www.elsevier.com/locate/jglr

A fate and transport model for Asian carp environmental DNA in the Chicago area waterways system

Carl F. Cerco [a,*], Martin T. Schultz [a], Mark R. Noel [a], Brian Skahill [b], Sung-Chan Kim [b]

[a] Environmental Laboratory, US Army Engineer Research and Development Center, 3909 Halls Ferry Road, Vicksburg, MS 39180, USA
[b] Coastal and Hydraulics Laboratory, US Army Engineer Research and Development Center, 3909 Halls Ferry Road, Vicksburg, MS 39180, USA

ARTICLE INFO

Article history:
Received 5 September 2017
Accepted 19 April 2018
Available online xxxx

Editor: Craig Stow

Keywords:
Asian carp
eDNA
Chicago area waterways system
Fate and transport models
Lake Michigan
Polymerase chain reaction

ABSTRACT

Detection of environmental DNA (eDNA) is widely employed to infer the presence of endangered or invasive species in the aquatic environment. Detection of eDNA, however, does not guarantee the presence of the species in question. The location, time, and nature of the eDNA source are unknown. An eDNA fate and transport model can help to address these unknowns. Construction of such a model requires resolution of multiple issues including: 1) Quantification of eDNA concentration in the environment; 2) Quantification of the eDNA source; 3) Quantification of decay rate; and, 4) Model application and validation. We address these issues and present the results of a fate and transport model for eDNA originating from an invasive species, silver carp (*Hypophthalmicthys molitrix*), in the Chicago Area Waterways System, USA. Results indicate the presence of roughly 4600 kg of silver carp, distributed along the major axes of the system, is required to produce the eDNA detected in routine monitoring. Positive detection of eDNA in a sample suggests a source within days and km of the sample time and location.

Introduction

The detection of species-specific environmental DNA (eDNA) is a widely-employed tool used to infer the presence of endangered or invasive species in aquatic environments (Diaz-Ferguson and Moyer, 2014; Rees et al., 2014). The detection of eDNA does not, however, guarantee the presence of living organisms, associated with the eDNA, at the sample collection site. The eDNA may originate from dead organisms or, more significantly, from secondary sources such as contaminated bilgewater (Darling and Mahon, 2011; Diaz-Ferguson and Moyer, 2014). The eDNA may also have travelled an unknown distance from origin to collection site over an unknown period of time.

Asian carp

Asian carp were imported into the United States in the 1970s to control phytoplankton and macrophytes in fish ponds and wastewater treatment lagoons (Kolar et al., 2007). Since then, these fish have become established in natural waterways and are gradually expanding their range within the Mississippi River basin. Two species of Asian carp are of particular concern. Bighead carp (*Hypophthalmicthys noblis*) and silver carp (*H. molitrix*) have caused significant ecological damage by impacting food webs and out-competing native fish populations (Chick and Pegg, 2001; Kolar et al., 2007).

Asian carp are presently established roughly 32 km downstream of the Chicago Area Waterways System (CAWS) which connects the Mississippi River basin with the Great Lakes. Justified fear exists that these species may invade the Great Lakes and out-compete native fish species there. In order to reach Lake Michigan via the CAWS, the invasive carp must traverse several lock and dam structures as well as an electric fish barrier intended to incapacitate fish swimming upstream. Despite these impediments, Asian carp have been captured in CAWS, upstream of the electric barrier, on two occasions, in 2010 and 2017 (http://www.ens-newswire.com/ens/jun2010/2010-06-23-093.html; http://www.asiancarp.us/news/silvercarpcapture.htm). Asian carp eDNA has been detected in the CAWS much more frequently. Sampling conducted from 2009 to 2012 by the US Army Corps of Engineers (USACE) and partner agencies detected bighead carp eDNA in 43 of 5522 samples tested and silver carp eDNA in 236 of 5503 sample tested (Schultz et al., 2014). Although presence of eDNA would seem to indicate the presence of fish, alternate, secondary sources of Asian carp eDNA have been identified including feces from fish-eating birds, contamination from vessels that have passed through carp-infested waters downstream, contamination from fishing gear that has been used in carp-

* Corresponding author.
E-mail address: carlcerco@outlook.com (C.F. Cerco).

https://doi.org/10.1016/j.jglr.2018.04.010
0380-1330/

infested waters, and storm sewers (ECALS, 2014; Guilfoyle and Schultz, 2017; Merkes et al., 2014).

The Chicago Area Waterways System

The CAWS (Fig. 1) consists of 126 km of canals in the vicinity of Chicago, Illinois, USA. Roughly 75% of the system consists of man-made channels while the remainder consists of highly-modified natural waterways. The system was constructed to drain municipal waste away from Lake Michigan, the source of Chicago's drinking water. The CAWS still serves this purpose, but the system also supports significant commercial navigation. The outstanding characteristic of the CAWS is that it connects two previously distinct continental-scale watersheds, that of the Great Lakes to the east and that of the Mississippi River to the west. The connection facilitates commercial traffic between the Great Lakes and the Mississippi River valley. The connection also potentially allows the migration of indigenous and invasive species between the two watersheds.

The CAWS is a highly regulated waterway which flows through an urbanized area. Flow in the CAWS is generally from Lake Michigan (upstream) towards the west (downstream). The Wilmette Pumping Station, Chicago River Controlling Works, and O'Brien Lock and Dam (L&D) regulate exchange with Lake Michigan while the Lockport Powerhouse and Lock controls discharge to the Mississippi River valley. Exchange with Lake Michigan, from mid-October to May, is restricted and consists largely of leakage and of exchange incidental with navigation through the structures. In this study, this period is referred to as the "gates-closed" season. Flow is continuous from Lake Michigan through the structures from June to mid-October. We refer to this period as the "gates-open" season.

The CAWS receives inflows from a variety of sources including water reclamation plants (WRP's), combined sewer overflows (CSO's), the local watershed, and Lake Michigan. Inflows from WRP's predominate among the flows for which data are available. During the gates-open season, >40% of the total inflow comes from a single WRP at Stickney. Remaining inflows include Lake Michigan (≈30%), additional WRP's (≈17%) and gauged local inflows. The WRP flows show little seasonal

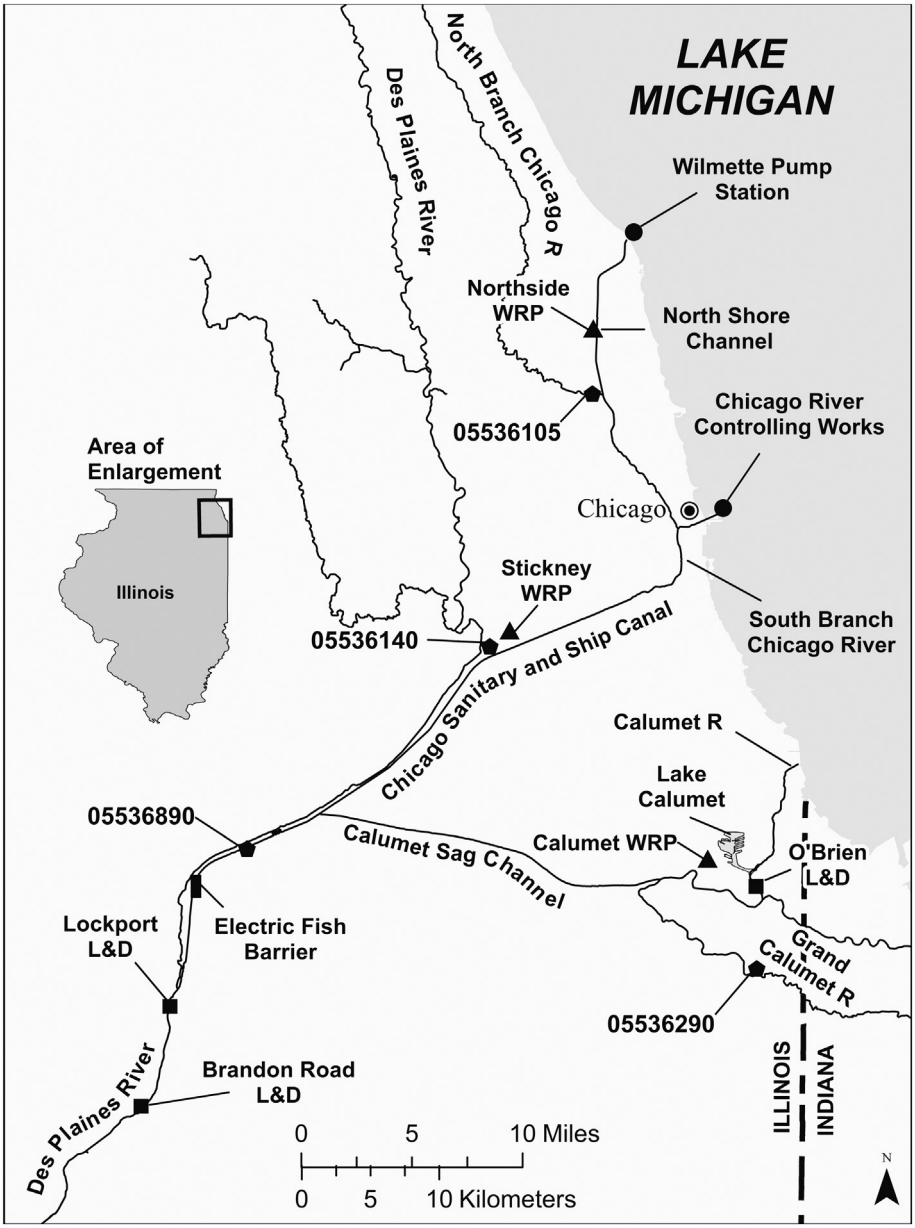

Fig. 1. The Chicago Area Waterways System (CAWS).

Please cite this article as: Cerco, C.F., et al., A fate and transport model for Asian carp environmental DNA in the Chicago area waterways system, J. Great Lakes Res. (2018), https://doi.org/10.1016/j.jglr.2018.04.010