ARTICLE IN PRESS

JGLR-01336; No. of pages: 10; 4C:

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

Benthic video image analysis facilitates monitoring of *Dreissena* populations across spatial scales

Alexander Y. Karatayev [a,*], Knut Mehler [a], Lyubov E. Burlakova [a], Elizabeth K. Hinchey [b], Glenn J. Warren [b]

[a] Great Lakes Center, SUNY Buffalo State, Buffalo, NY, USA

[b] United States Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL, USA.

ARTICLE INFO

Article history:
Received 17 October 2017
23 April 2018
Accepted 26 April 2018
Available online xxxx

Editor: Lars Rudstam

Keywords:
Remote sensing
Dreissena rostriformis bugensis
Lake Michigan
Underwater video
Distribution
Benthos

ABSTRACT

In contrast to marine systems where remote sensing methods in studies of benthic organisms have been widely used for decades, these methods have experienced limited use in studies of freshwater benthos due to the general lack of large epifauna. The situation has changed with the introduction of dreissenid bivalves capable of creating visible aggregations on lake bottoms into North American freshwaters in the 1980s and 1990s. The need for assessment of *Dreissena* densities prompted exploration of videography as a potentially cost-effective tool. We developed a novel sampling method that analyzes video recorded using a GoPro camera mounted to a benthic sled to estimate *Dreissena* coverage, density, and biomass over relatively large areas of the lake bed in the Laurentian Great Lakes compared to traditional sampling methods. Using this method, we compared quagga mussel coverage, density, and biomass estimates based on three replicate Ponar grabs vs. 500 m-long video transects across 43 stations sampled in Lake Michigan in 2015. Our results showed that analysis of images from video transects dramatically increased the bottom area surveyed compared to Ponar grabs and increased the precision of *Dreissena* density and biomass estimations at monitoring stations. By substantially increasing the ability to detect relatively small (<20%) changes between years within a particular station, this method could be a useful and cost-effective addition for monitoring *Dreissena* populations in the Great Lakes and other freshwater systems where they occur.

Introduction

Dreissena species (*Dreissena polymorpha*, the zebra mussel and *D. rostriformis bugensis*, the quagga mussel) have similar life history characteristics including high reproductive potential, planktonic free-swimming larvae and an attached benthic adult stage, and they are highly efficient suspension feeders. These features are typical of marine mussels, but represent a novel ecological type in freshwaters of North America and most of Europe (Karatayev et al., 2002, 2007a, 2007b, 2015). Both zebra and quagga mussels have strong ecological and economic impacts on invaded waterbodies and are considered the most aggressive freshwater invaders in the Northern hemisphere (reviewed in Karatayev et al., 2002, 2007a, 2015; Nalepa and Schloesser, 1993, 2014). The ecological impacts of *Dreissena* are associated with their role as ecosystem engineers because they provide a direct link between benthic and planktonic environments through their feeding and filtering activities (benthic-pelagic coupling). They also alter the lakebed surface from a two- to three-dimensional structure by creating large multilayer mussel aggregations (reviewed in Burlakova et al., 2012; Gutierrez et al., 2003; Karatayev et al., 2002, 2007a, 2015; Sousa et al., 2009; Vanderploeg et al., 2002). The overall ecological impact of *Dreissena* in a given waterbody is dependent upon many factors including *Dreissena* species, their population density, dynamics, and distribution across the lake bottom, as well as upon characteristics of the invaded ecosystem (reviewed in Karatayev et al., 1997, 2010, 2015).

Dreissena distribution, however, is extremely heterogeneous at all spatial scales from local (meters) to regional (kilometers), which is a challenge for generating precise estimates of mussel densities. It is not uncommon to observe a three order of magnitude difference in density at local spatial scales along environmental gradients of substrate, hydrodynamics, dissolved oxygen, etc. (reviewed in Karatayev et al., 1998, this issue). Similarly, a three order of magnitude difference was recorded at the waterbody scale along littoral to profundal zone depth gradients (Burlakova et al., 2006; Karatayev et al., 2014; Nalepa et al., 2010; Patterson et al., 2005). In addition to environmentally-induced heterogeneity, sessile organisms such as *Dreissena* develop patchiness due to spatial self-organization (Rietkerk and van de Koppel, 2008). As a result, even on homogeneous substrates the distribution of sessile mussels is patchy due to facilitation and competition (Babarro and Carrington, 2013; Gascoigne et al., 2005; Liu et al., 2014; van de Koppel et al., 2005, 2008). While competition was shown to occur at large scales due to depletion of food sources, facilitation takes place at the smallest scales within mussels clumps or druses (Gascoigne et al.,

* Corresponding author.
E-mail address: karataay@buffalostate.edu (A.Y. Karatayev).

https://doi.org/10.1016/j.jglr.2018.05.003

2005; Liu et al., 2014; Rietkerk and van de Koppel, 2008; van de Koppel et al., 2005). Therefore, similar to the environmental factors, different aspects of spatial self-organization could govern *Dreissena* patchiness at different spatial scales.

It is necessary to obtain precise, reliable estimates of *Dreissena* population size in a given waterbody across both space and time if we are to quantify their ecological role. Increases in the precision of *Dreissena* spp. density estimates is especially important for benthic monitoring programs such as the U.S. EPA Great Lakes National Program Office (GLNPO) Biology Monitoring Program and the NOAA Great Lakes Environmental Research Laboratory Long-Term Research (LTR) Program in Lake Michigan, which need accurate estimates with sufficient statistical power to detect population changes and to realistically model lake-wide distribution and growth and filtration rates.

Although hundreds of studies of *Dreissena* distribution have been conducted since early in the 20th century (reviewed in Karatayev et al., 1998, 2015), almost all of these studies employed bottom grabs or diver assessments with low overall sampling area and a limited number of sampled stations and replicates. This sample size limitation, coupled with the patchy distribution of *Dreissena*, make estimation of *Dreissena* population sizes extremely challenging both in space and time, especially in large waterbodies like the Laurentian Great Lakes. As a result, statistical power to detect even large differences in *Dreissena* abundances between lake zones or sampling events is typically low (Barton et al., 2005; Karatayev et al., 2014; Patterson et al., 2005). Large scale ecological studies, like lake-wide *Dreissena* surveys in the Great Lakes, require time and resources. Therefore, monitoring programs should strive to develop cost-efficient sampling methods.

The substantial progress made during the last several decades in studies of distribution pattern and patch structure of large bodied benthic sessile organisms in marine habitats (e.g. submerged aquatic vegetation beds, mussel beds, inner continental shelf, deep sea, etc.) was largely due to the deployment of various underwater remote sensing methods, including acoustic and video surveys (reviewed in Van Rein et al., 2009; Zajac, 2008). In contrast to marine systems, these methods have experienced limited use in studies of freshwater benthos due to the general lack of large epifauna. The introduction of dreissenid bivalves into North American freshwaters in the 1980s and 1990s created visible aggregations of mussels on lake bottoms and provided a need for assessment, for which videography was explored as a potentially cost-effective tool. *Dreissena* in the Great Lakes have been studied using side scan sonar (Coakley et al., 1997) and underwater video in the nearshore zone (Custer and Custer, 1997; Lietz et al., 2015; Mehler et al., 2018; Ozersky et al., 2009, 2011). Incorporation of remote sensing methods into designs of benthic surveys allows much larger bottom areas to be sampled than surveys with traditional bottom grabs or SCUBA diving, provides valuable information on the distribution patterns of *Dreissena* at various spatial scales, and may significantly increase the precision of mussel population size estimates.

To further investigate the utility of remote sensing tools for estimation of *Dreissena* distribution and population density in the Great Lakes, we conducted the first lake-wide benthic survey of a Laurentian Great Lake (Lake Michigan) that coupled underwater image analysis with traditional bottom grab sampling. In addition, we collected and analyzed underwater video images from benthic stations across all Great Lakes that are regularly sampled by the U.S. EPA GLNPO Biology Monitoring Program summer survey to increase the range of environmental conditions sampled. In contrast to the previous investigations that used underwater video to survey *Dreissena* in relatively few video images at individual study stations (Lietz et al., 2015; Mehler et al., 2018; Ozersky et al., 2009, 2011), our Lake Michigan study collected continuous video footage from 500 m-long transects along the lakebed at 47 sampling locations and then estimated mussel coverage from 100 randomly selected still images (screen shots) from the video transect. As *Dreissena* distribution and density varies greatly across depth gradients (Watkins et al., 2007; Nalepa et al., 2010; Karatayev et al., 2014) and they form aggregations of different size at different depths (Karatayev et al., 2015), we collected videos both from shallow well-mixed heterogeneous nearshore areas and from deep, relatively stable and homogeneous profundal environments. We hypothesize that, due to a much greater sampling area, this remote sensing approach will allow us to greatly increase the area sampled, reduce errors associated with estimates of patchy populations in *Dreissena* distribution at each station, and substantially improve precision in detection and population estimation of *Dreissena* in the Great Lakes across large depth gradients.

Methods

Dreissena sampling protocol

In July 2015, *Dreissena* spp. presence, density (number of individuals, m^{-2}), total wet biomass (total wet weight, tissue with shell, g m^{-2}), and length-frequency distribution were measured at 143 stations sampled aboard the U.S. Environmental Protection Agency (EPA) R/V *Lake Guardian* during the Lake Michigan Cooperative Science and Monitoring Initiative (CSMI) benthic survey (Fig. 1). An EPA monitoring station is defined as a bottom area of approximately 300 m in diameter. If, due to weather and currents, the *Lake Guardian* drifts far off the station, the boat will be re-positioned and sampling will resume (EPA Standard Operating Procedure (SOP) for General Shipboard Scientific Operation, LG100, Revision 05, March 2014). Three types of samples were collected to study *Dreissena* including: 1) Ponar (spring loaded benthic grab, sampling area 0.0483 m^2, Great Lakes Engineering) samples were processed for mussel density, size-frequency distribution, and sediment analysis; 2) video images from a GoPro Hero 4 Black camera (resolution: 1080 p, frame rate: 29 frames/s, screen resolution: 1920 × 1080, certified to a depth of 1500 m due to custom made camera housing, GroupBinc.com; hereafter, GoPro) mounted to the Ponar; 3) video images from a GoPro camera mounted on the benthic sled 60 cm above the bottom (Figs. 1–3). Ponar samples and the attached GoPro camera covered a small bottom area at the location of each Ponar impact, while images obtained from video transect covered a much larger area (see below).

Three replicate Ponar samples were collected at each of the 143 stations, and a total of 429 samples were analyzed for *Dreissena* population

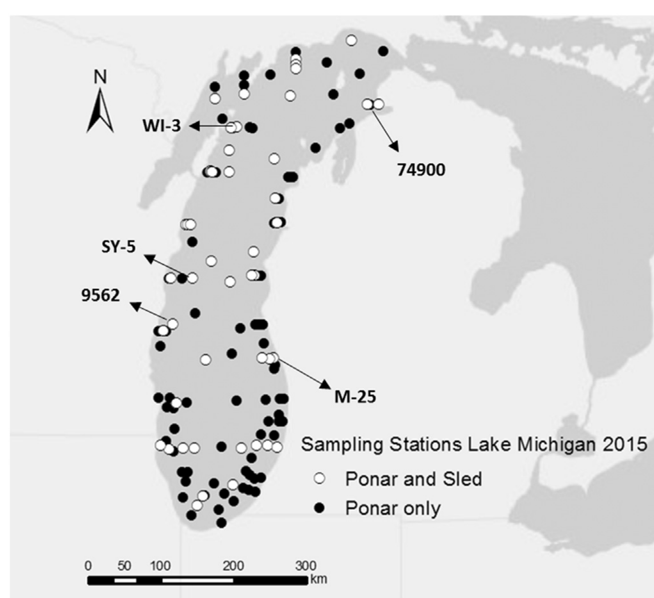

Fig. 1. Location of stations in Lake Michigan in 2015 sampled with Ponar (black circles) and with both Ponar and benthic sled (white circles). Labeled arrows identify select transects where every still shot image collected along the transect was analyzed (as shown in Fig. 4).