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Observer bias and subsampling efficiencies for estimating the number of migrating fish in rivers using Dual-frequency IDentification SONar (DIDSON)

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ABSTRACT

Fixed-location, side-looking, multibeam, sonar techniques offer a practical approach to estimate the numbers of migrating fish in rivers that are too large or occluded for traditional sampling methods, such as weir trapping, visual observation techniques, and netting. While this technology has been used to enumerate salmonid escapement in coastal river systems of western North America, little use and evaluation has occurred in inland waters such as the Great Lakes, where rivers and runs of fish are considerably smaller than those along the Pacific coast. We use a "Dual-frequency IDentification SONar" ("DIDSON") imaging sonar system to investigate the error and variability among nine people performing fish counts. There was no significant difference found among observers' estimates of fish abundance per DIDSON file; however, the total count of all fish differed from the benchmark value by as much as 26%. Post-processing simple fish counts from DIDSON raw data is labour-intensive and costly. Three subsampling methods of fish passage estimations were developed and evaluated for their accuracy and precision for daily and seasonal time frames. The random and systematic subsampling methods had similar seasonal and daily accuracy and precision with few exceptions. Automation-assisted counting was much more accurate and efficient for seasonal estimates. A ratio of approximately 2:1 was found for the automated to manual fish counts and this varied little among years. The DIDSON multibeam sonar unit is useful in estimating potamodromous fish migrations for large tributaries of the Great Lakes. DIDSON image processing costs can be minimized through suitable subsampling approaches. The automation-assisted method is the most cost-effective means of estimating moderate levels of fish passage over longer study periods. Multiple individuals can be used interchangeably for the manual post-processing of DIDSON data.

1. Introduction

Fixed-location, side-looking, high-definition sonar techniques represent a practical approach to estimate the number of migrating fish in rivers that are too large and occluded for use of traditional methods such as weir trapping, visual observation techniques, and netting (Bonar et al., 2009). Although multibeam sonar technology has been used to enumerate salmonid escapement in coastal river systems of western North America (e.g., Holmes et al., 2006; Burwen et al., 2010; Pipal et al., 2012), little use and evaluation has occurred in inland waters such as the Great Lakes; where rivers and runs of fish are considerably smaller than many rivers along the Pacific coast (Landsman et al., 2011). In the present study, we assessed a Dual-frequency IDentification SONar (DIDSON) system, for its effectiveness in monitoring daily and seasonal fish migration numbers in a Lake Superior tributary.

While the initial effort of setting up a fixed-location riverine high-definition sonar system is high, ongoing maintenance is comparably very low (see Enzenhofer and Cronkite, 2000 or Coyle and Reed, 2012). Once the setup has been completed, the limiting factor of achieving a constant fish migration census then becomes the post-processing time. The work involved in manual fish counting (or "tallywhacking", Hateley and Gregory, 2006) requires approximately 30 s of astute examination of image playback per minute of real-time data collection (variable depending on fish density). Some researchers have investigated optimal manual subsampling methods (e.g., Lilja et al., 2007); while others have looked towards newly developing computer-automated methods

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to lighten their post-processing workloads (e.g., Boswell et al., 2008).

Tallywhacking fish requires that a person plays back the acoustic high-definition imagery files while attempting to accurately count each fish moving through the acoustic beams. Performing these manual fish counts is tedious, time consuming, and requires exhaustive mental concentration. This constant vigilance is particularly stressful when the observer is required to work for extended durations (Scerbo, 2001). For consistency, and to reduce errors, a study may solely employ one expert observer to enumerate fish throughout an entire study period. Employing more individuals to conduct the counting is more expedient, but may create unwanted variability and error in fish counts between observers. Holmes et al. (2006) found excellent agreement between a DIDSON's tallywhacked salmon counts and visual counts from a fish-enumeration fence. They concluded that the DIDSON system is as accurate as an enumeration fence when employed to count fish within their observed range of densities.

The alternative to tallywhacking, is to employ a computer-automated method for processing multibeam sonar data. This quickly evolving technology has the potential to significantly reduce the costs and time associated with generating fish count data (Boswell et al., 2008). Programming a computer to detect fish "motion" through a mathematical analysis of large, temporally-related matrices is a complex problem. Downstream-moving objects, such as detritus and leaf litter, can easily be confused as small fish. Mobile sediment on the river bed can create regions of acoustic shadowing, or signal saturation, where acoustic backscatter from fish is less easily detected. These bottom features are dynamic, particularly during high flows (e.g., Video 1). When a fish passes through a region of low-detectability, the software is no longer able to track the movement vector of the fish as it crosses through the ensonified area. This can lead to the same fish being counted a second time once it reveals itself on the opposite side of the obstruction. Some detection algorithms may count a single fish which mills in the ensonified field multiple times per minute. Despite these sources of error for automation processes, the potential cost savings may be an efficient solution for many management and research needs. Executing a data auto-processing solution can also help detect rare or abnormal events (e.g., discovery of exceptionally large targets (Crossman et al., 2011) or pulses of high fish activity) and can more easily yield fish data of greater detail than manual counts (e.g., fish location, average bearing, time in ensonified area).

Instead of relying solely on automated or manual counts, researchers can use automated counts as a guide for manual counting efforts. The automated counts can then be used to develop relationships with manual counts in a semi-automated process. If a reasonable relationship can be determined between manual and automated counts, tallywhacking a small portion of the raw data may be necessary and will still yield a reduction of total costs. The lengthy post-processing requirements of raw high-definition sonar data call for a robust subsampling procedure to ensure cost-efficiency.

We used a stationary, horizontally-orientated, DIDSON unit (Sound Metrics Corporation, Bellevue, WA) to record multibeam sonar images from a cross-section of the Michipicoten River, a Lake Superior tributary. From this, fish migration numbers were observed and enumerated through time. This work addresses the following research questions: (i) What is the error among multiple, minimally-trained observers performing manual fish counts when viewing DIDSON data and are their counts different from each other or that of an expert observer? We anticipated that the amateur and experts counts would be significantly different. (ii) How can subsampling the DIDSON data be conducted to lessen the costs of post-processing while maximizing accuracy and precision? (iii) What is the relationship between software-automated fish counts and manually observed counts, and can this relationship be used to increase efficiencies in post-processing of DIDSON-derived fish migration estimates? In answering these research questions, we hope to improve the efficiency and accuracy of estimating the number of migrating fish in rivers while reducing the costs. Such improvements will support future adoption of high-definition sonar as a powerful fisheries research tool.

2. Material and methods

The Michipicoten River is a large tributary to north-eastern Lake Superior, near the town of Wawa, Ontario, Canada (N47 58, W84 47). This river supports a significant sport fishery that includes potamodromous native and non-native species (e.g., Chinook Salmon *Oncorhynchus tshawytscha*, Pink Salmon *Oncorhynchus gorbuscha*, Coho Salmon *Oncorhynchus kisutch*, Rainbow Trout *Oncorhynchus mykiss* and Lake Sturgeon *Acipenser fulvescens*). Previous methods of estimating these fish populations have included mark-recapture surveys, aerial-visual counts, and split-beam echosounder assessment (Cronkite et al., 2005); yet the DIDSON system may be a more effective and efficient means to estimate fish migrations in the river.

The site chosen for the DIDSON was approximately 3.5 km upstream from the river mouth where the channel is approximately 55 m wide but can vary in width and depth based on the regulated discharge and spillage through the Brookfield Renewable Power generating station located at Scott Falls 13 km upstream (N47 54 30.5 W84 42 48.7, Fig. 1). Water clarity is typically moderate at 1.5–2.5 m depending on time of year. Turbidity values in the Michipicoten River typically range 1–2 NTUs. The riverbed at the site consisted primarily of gravels and secondarily of sand. The site was chosen using the criteria outlined by Enzenhofer and Cronkite (2000) which includes: a straight channel with laminar flow; a planar bottom profile; a river bottom free of large boulders; minimal human activity on the river; and a place where fish should be actively migrating and not holding or milling (Cronkite et al., 2007).

We used a DIDSON 300 Long Range model that was mounted 0.5 m above the river bottom and positioned nearest the river bank

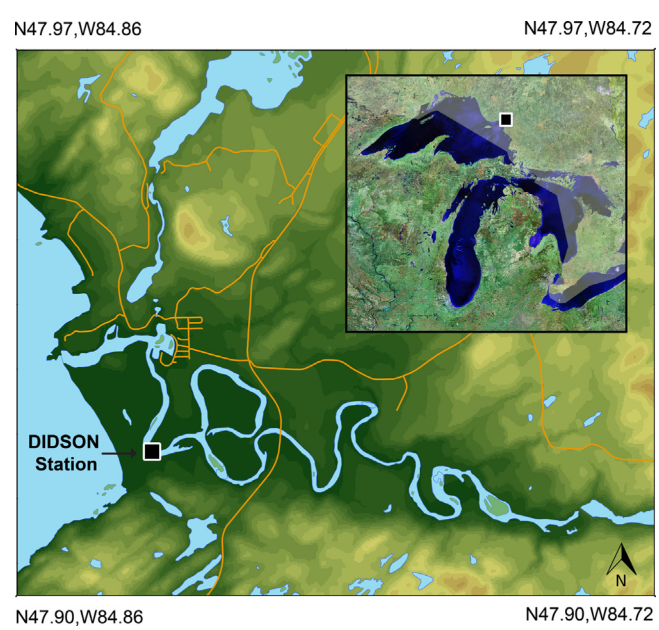

Fig. 1. Map of the DIDSON site near Wawa, Ontario, Canada during the years 2007 and 2009. The DIDSON was deployed on the Michipicoten River 3.5 km upstream of Lake Superior.