Fisheries Research 188 (2017) 173–182

Contents lists available at ScienceDirect

Fisheries Research

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

Sparse targets in hydroacoustic surveys: Balancing quantity and quality of *in situ* target strength data

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ARTICLE INFO

Article history:
Received 22 February 2016
Received in revised form
27 December 2016
Accepted 28 December 2016
Handled by Prof. George A. Rose

Keywords:
Great Lakes
Walleye
Shallow-water
Low-density
Beam compensation
Fisheries

ABSTRACT

Hydroacoustic sampling of low-density fish in shallow water can lead to low sample sizes of naturally variable target strength (TS) estimates, resulting in both sparse and variable data. Increasing maximum beam compensation (BC) beyond conventional values (i.e., 3 dB beam width) can recover more targets during data analysis; however, data quality decreases near the acoustic beam edges. We identified the optimal balance between data quantity and quality with increasing BC using a standard sphere calibration, and we quantified the effect of BC on fish track variability, size structure, and density estimates of Lake Erie walleye (*Sander vitreus*). Standard sphere mean TS estimates were consistent with theoretical values (−39.6 dB) up to 18-dB BC, while estimates decreased at greater BC values. Natural sources (i.e., residual and mean TS) dominated total fish track variation, while contributions from measurement related error (i.e., number of single echo detections (SEDs) and BC) were proportionally low. Increasing BC led to more fish encounters and SEDs per fish, while stability in size structure and density were observed at intermediate values (e.g., 18 dB). Detection of medium to large fish (i.e., age-2+ walleye) benefited most from increasing BC, as proportional changes in size structure and density were greatest in these size categories. Therefore, when TS data are sparse and variable, increasing BC to an optimal value (here 18 dB) will maximize the TS data quantity while limiting lower-quality data near the beam edges.

1. Introduction

Fisheries researchers often rely on hydroacoustic estimates of fish size and abundance (MacLennan, 1990; MacLennan and Holiday, 1996; Rose, 2003; Simmonds and MacLennan, 2005); however, this technique's effectiveness can be limited when sampling low-density fish in shallow-water, resulting in a small sample size (Kubecka and Wittingerova, 1998; Knudsen and Saegrov, 2002). In addition, TS estimates are highly variable (McClatchie et al., 1996), therefore, at times estimates may be based on both sparse and variable data. Conventional data analysis methods (Rudstam et al., 2009; Parker-Stetter et al., 2009; Kocovsky et al., 2013) restrict data to a subset of high quality (i.e., accurate and precise) TS estimates collected near the acoustic beam axis, within the 3 dB beam width (i.e., 6 dB two-way beam width; Simmonds, 1984; Simmonds and MacLennan, 2005). While the practice of limiting data quantity is intended to ensure quality, the net effect may reduce accuracy and precision of population level estimates due to small sample size, especially when fish are sparsely distributed. Therefore, when TS data are already limited, it may be beneficial to use more permissive data analysis procedures to balance quantity and quality of TS data.

Increasing maximum beam compensation (e.g., greater than 3 dB beam width) can increase quantity of TS data (Rudstam et al., 2009); however, this may result in reduced data quality (Ehrenberg and Torkelson, 1996). Maximum beam compensation (BC) controls the maximum allowable adjustment applied to single echo detections (SEDs) measured off the acoustic beam axis. SEDs measured off-axis have lower TS measurements than similar SEDs measured on-axis due to phase differences in the received sound pulse (i.e., directivity loss). Off-axis SED TS-measurements are adjusted (i.e., compensated) to theoretical on-axis values using a beam compen-

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http://dx.doi.org/10.1016/j.fishres.2016.12.020
0165-7836/

sation function which describes the acoustic beam pattern and theoretical directivity loss (Reynisson, 1999). Increasing BC uses a larger portion of the acoustic beam, resulting in a larger sampled volume and the inclusion of additional SEDs. However, inconsistencies between theoretical and realized acoustic beam patterns (Simmonds, 1984), as well as small-angle approximation errors caused by transducer motion (Furusawa and Sawada, 1991) and low signal-to-noise ratios (Kieser et al., 2000) can cause measurement errors in compensated TS estimates. These measurement errors can result in incorrect compensation of off-axis targets, the degree of which may increase with distance from the acoustic beam axis.

TS data are critical to estimating size and abundance of low-density fish using echo-counting; however, TS data are naturally variable, affecting accuracy and precision of these estimates. Natural TS variability is caused by changes in orientation and physiological characteristics affecting the swim bladder (Ona, 1990; McClatchie et al., 1996; Hazen and Horne, 2004; Frouzova et al., 2005), which reflects 90% of the sound energy contributing to TS estimates (Foote, 1980). Echo-counting relies on SEDs, where the acoustic characteristics of individual fish are described by multiple grouped SEDs (i.e., a fish track; Kieser and Mulligan, 1984; Ehrenberg and Torkelson, 1996). Increasing TS data quantity using more permissive BC can increase the number of SEDs per fish track and the number of fish tracks, thereby providing more information to estimate individual fish size, population size structure, and density. Although increasing TS data quantity may introduce additional compensation related variability (i.e., measurement error), it is not clear if this extra variation contributes substantially to total variability in fish size estimates. Therefore, identifying the effect of BC on variability of fish size estimates, and estimates of population size structure and density will help determine the optimal balance between TS data quantity and quality.

Lake Erie walleye (*Sander vitreus*) is an economically and ecologically important species (Locke et al., 2005) that presents a challenging scenario for hydroacoustic quantification. Walleye migrate throughout Lake Erie and into Lakes St. Clair and Huron during the spring and summer and return to Ohio waters of western Lake Erie during autumn (Wang et al., 2007). To date, the population has been monitored primarily through an inter-agency gill net survey; however, researchers are exploring the integration of hydroacoustic sampling. During the primary fall sampling period, the population occupies a large expanse of relatively shallow water habitats (<15 m; Pandit et al., 2013), resulting in sparse TS data for estimating size structure and density.

Our goal was to identify the optimal BC to estimate walleye size structure and density using echo-counting, balancing the benefits of data quantity against the costs to quality. First, to identify the contribution of measurement error, we quantified the BC effect on quantity and quality of TS estimates using a standard sphere. Next, we determined the effect of BC on in-lake survey data by (1) quantifying the relative contribution of BC to TS variability in fish tracks, and (2) identifying the BC effect on population size structure and density estimates. These steps optimized the use of collected hydroacoustic data to determine walleye size structure and density.

2. Methods

2.1. Beam compensation effect on TS measurement error

We performed a transducer calibration to measure the change in quantity and quality of TS estimates with increasing BC (Foote et al., 1987). We collected data with a BioSonics DTX split-beam hydroacoustic system and a 210 kHz transducer (3 dB beam width = 6.5°) using a 0.2 ms pulse duration and 15 pings per second (pps) from a 36.4 mm diameter tungsten carbide sphere, with theoretical TS = −39.6 dB at 1460 m/s speed of sound through ~15 °C water throughout the acoustic beam. The sphere was positioned approximately 5 m below the face of the transducer. We held the calibration sphere near to acoustic beam axis to assess on axis sensitivity, and moved it throughout the beam to asses beam pattern consistency and beam compensation accuracy. Raw data were imported and analyzed in Echoview version 5 software (Echoview Software Pty. Ltd., Hobart, Australia). SED filter criteria were set to match those recommended in the Great Lakes Standard Operating Procedures (Parker-Stetter et al., 2009), except BC, which was increased to the maximum (35 dB) allowed for BioSonics data. The distribution of SEDs among transducer beam quadrants was not even; therefore, we took a random subset (N = 500) from each quadrant (1–4; Fig. 1A). This reduced the total number of SEDs included in the calibration from 5942 to 2000, with 500 randomly sampled from each quadrant. From the subset of SED, we obtained SED TS estimates within 7 BC intervals (0.00–6.49 dB, 6.50–9.49 dB, 9.50–12.49 dB, 12.50–15.49 dB, 15.50–18.49 dB, 18.50–25.49 dB, and 25.50–35.00 dB). We transformed SED TS estimates into backscattering cross-section (σ_{bs}) values to calculate mean and standard deviation within BC intervals. Standard deviation of σ_{bs} was converted to standard deviation in dB using the delta method described in Crockett et al. (2006). We counted the number of SEDs within each BC interval, and summed these to show cumulative increase with BC.

We estimated sample beam angle (i.e., wedge angle) associated with the maximum BC in each BC interval. For each BC interval, we subset the calibration SEDs by the maximum amount of correction applied (i.e., 6, 9, 12, 15, 18, 25, and 35 dB), corresponding with the maximum BC from each interval. Next, we took the absolute value of estimated major and minor axis angles and summed the maximum values. This produced a maximum estimated sample wedge angle for each BC interval, used to estimate water volume sampled. Estimated sample wedge angles matched those displayed on beam pattern polar plots provided by BioSonics factory calibrations. For the following survey data, we calculated wedge volume sampled in Echoview using wedge angles estimated from calibration data.

2.2. Hydroacoustic and gill net survey description

We compared sample data from paired gill net and hydroacoustic surveys to understand the effect of BC on TS variability and density estimates. We performed 21 paired sampling events at 19 locations in Lake Erie's western basin and Sandusky sub-basin during the fall of 2012 (Fig. 2A and B). At each site we sampled fish with overnight multi-filament gill net sets of approximately 396.5 m by 1.8 m with stretch meshes ranging from 51 to 127 mm. Overnight gill nets were set during late afternoon prior to sunset and lifted in the early morning after sunrise to encompass crepuscular foraging periods. Gill nets were suspended 2 m below the surface to target walleye and reduce bycatch following previously established survey protocols for walleye assessment (Pandit et al., 2013). Catches were identified to species, and total length (TL) was measured to the nearest mm. Hydroacoustic data were collected during the daytime; on days adjacent to overnight gill net sets. Three sites were collected while the gill nets were soaking, and sixteen sites were collected either prior to setting or after gill nets were lifted, with average length of time between gill net soak and hydroacoustic sampling ~3.5 h (min 0 and max 7 h). Hydroacoustic sampling at two sites was delayed to the day after, ~29 h after the gill nets were lifted. We sampled 3–8 1000-m transects at each sample site (Fig. 2C). We used a down-facing transducer deployed from a BioSonics towed body at a depth of 1 m alongside the vessel, and sampled transects at ~8 km/h. We used the same data collection settings described above including 15 pps. Sampling speed and pulse rate produced ~7 pings per meter of transect, while sampling