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Measuring fish school swimming speeds with two acoustic beams and determining the angle of the school detection

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ABSTRACT

The measurement of school swimming speeds across an acoustic beam from a fixed-platform split-beam transducer is difficult because it is impossible to accurately discern individual fish within a school, or track the displacement of the leading edge of the school over time. However, with two acoustic transducers the swimming speed of schools can be estimated as long as the school swims through both beams, and the detection angle when the school first interacts with the beam is known. Here we present a methodology for (1) measuring school swimming speeds with two 120 kHz elliptical ($4^\circ \times 10^\circ$) split-beam acoustic transducers, and (2) estimating the detection angle of the school using Angular Position data within the school region. We verify the use of Angular Position data by comparing our derived detection angle with Diner's Attack Angle algorithm for a set of mobile vertical surveys on the same lake. Our derived detection angle methodology may also provide a method for fisheries biologists to correct school dimensions under conditions for which Diner's Attack Angle is not appropriate (i.e. when schools are smaller than the beam width), which should be common in lake surveys or generally when using elliptical acoustic beams.

1. Introduction

Movement is a fundamental characteristic of life for many organisms and is frequently one of the basic parameters needed for understanding the ecological dynamics of populations, communities and ecosystems (Gurarie and Ovaskainen, 2013; Hutchinson and Waser, 2007). Only a few decades ago the principle challenge in incorporating movement patterns into ecological models was the high sampling effort required to collect animal movement data. More recently a wide range of technological solutions for collecting data have become available, and so the challenge has evolved into developing analytical tools to translate technological outputs into meaningful ecological parameters (Frouzova et al., 2005; Gerlotto et al., 2006). The substantial improvements and affordability of computing power, imaging analysis and sound transmission technology over the last few decades has allowed acoustic fisheries survey methodologies to be applied towards ecological and behavioural research including in situ studies of fish movement using split-beam and multi-beam acoustic surveys (Arrhenius et al., 2000; Balk and Lindem, 2000; Dunlop et al., 2010; Jarolím et al., 2010; Steig and Johnston, 1996; Tušer et al., 2009).

While split-beam acoustic technology and methodologies have facilitated in situ studies of fish swimming behaviour, the study of fish school (sensu Pitcher, 1983) swimming behaviour has remained much more elusive (but see recent applications of multi-beam sonar technology to the study of schooling behaviour and movement in Brehmer et al., 2011). Once schools enter acoustic beams, the echoes generated from multiple individual fish in close proximity to one another can either mask individuals through acoustic shadowing or combine with one another to be detected as fewer single targets each containing object detections with inflated target strength values (Soule et al., 1995, 1997; Foote, 1996). Therefore it becomes difficult to accurately track the movement of individuals within the school across the acoustic beam. Consequently, the strength of school echoes are typically discussed in terms of volume backscattering strength S_v for which the echoes are averaged across the volume of the sample (a particular depth range), and so alone they do not provide any spatially explicit information. However, at the moment that a school is first detected at the edge of the beam, if no other school is present within the same sample, the echo received at the transducer could provide a spatial reference for the leading edge of the school. At this moment the school would likely be less sensitive to the biases from

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averaging the echoes over the sample but instead be susceptible to bias related to the angle of detection. Simulations by Diner (2007, 2001) found that large and dense schools may be detected at wider angles than assumed by the geometry of the ideal acoustic beam depending on the minimum S_v threshold used for the analysis. To correct this bias, Diner (2001) derived the Attack Angle algorithm, however it can only be applied to schools that are larger than the beam width, and has only been simulated for mobile surveys using circular transducers.

This study presents and evaluates a method for measuring school swimming speeds using two split-beam, elliptical (i.e. 4° minor × 10° major 3 dB axes) 120 kHz acoustic transducers deployed from a fixed platform side by side on a lake inhabited by Cisco (*Coregonus artedi* Lesueur), a schooling pelagic planktivore. As the school moves between the two acoustic beams, the swimming speed and heading can be calculated from the time and spatial location of the school detections at the edges of the beams. To achieve this measurement, this paper also addresses the challenge of determining school detection angles for fixed platforms and elliptical beams on study systems that contain schools that are often smaller than the beam width. We address this challenge in three approaches.

Starting at the simplest approach, as long as the two transducers used in the survey are of a similar make, model and ideal beam axes (as well as properly calibrated), the general detection biases should be equivalent across both transducers and compensate for each other when calculating swimming speeds. In this case, a range of minimum S_v thresholds, applied to both transducers might be appropriate for reliably identifying 'analysis regions'. This range of acceptable S_v thresholds would be bounded below by values that include unacceptable noise levels, and bounded above by values that generate unacceptable levels of 'lost targets'. We explore this hypothesis by developing a range of minimum S_v thresholds and comparing the average swimming speeds and coefficients of variation among them.

For our second approach, we identify the Angular Position (*AP*) data within school regions that are delineated by the S_v data. The *AP* data from split beam transducers is used for identifying the spatial coordinates of a single target (or fish), and not traditionally used in school detection. Consequently, this approach hinges on the assumption that *AP* data is not significantly biased by the close proximity of fish within the school to give positional values that fall well outside the school detection region. If this assumption is correct then as the school moves across the beam under fixed platform conditions, or the beam moves across the school under mobile surveys, the *AP* data should change accordingly. If swimming or survey speeds are relatively constant, the change in position over time as determined by the *AP* data should be smooth and symmetrical across the beam. We employed an additional mobile survey with a circular (i.e. 7° × 7° 3 dB axes) 120 kHz acoustic split beam transducer, along with fixed platform data with an elliptical transducer to test for these patterns in *AP* data and thus test our assumption regarding the nature of the biases in *AP* data.

Finally, Diner's (2001) correction for the school detection angle is not based on *AP* data and so provides an independent estimate of beam geometry which can be used to verify our use of *AP* data in our second approach. Although the Attack Angle was developed for mobile surveys, there is no a priori reason why it could not be applied to fixed platform surveys as long as the schools move across the major axis (i.e. it should make no difference from an acoustics perspective whether it is the boat carrying the transducer or the school that is moving). The Attack Angle correction is effectively a two-step process where (1) the S_v of large schools is corrected based on their depth and length, and (2) the detection angle derived from S_v estimates at the centre of the beam (*B*) is corrected to the edge of the beam (*A*). We first use our mobile surveys with circular transducers to compare *A* with *AP* derived detection angles under similar conditions to Diner's (2001) simulations except with shallower depths. We then apply our findings to fixed-platform surveys with elliptical transducers.

2. Methods and procedures

2.1. Field surveys

All acoustic surveys were conducted on the South Arm of Lake Opeongo in Algonquin Provincial Park in Ontario, Canada (45°42′ N, 78°22′ W). The lake is 58 km^2 with a maximum depth of 49.4 m and contains only two pelagic schooling fish, Cisco and Yellow Perch (*Perca flavescens* Mitchill), although young of the year Lake Whitefish (*Coregonus clupeaformis* Mitchill) are occasionally found within Cisco schools. Fixed-platform acoustic surveys were conducted over 24 h periods between October 22 and 24, 2010, and the mobile survey was conducted over 3 h on August 16, 2009.

Fixed-platform acoustic data were collected using two Simrad EK60 elliptical 4° x 10° 120 kHz split-beam systems (Kongsberg Maritime, Kongsberg, Norway) mounted side by side on an aluminium platform (Fig. 1). Both transducers were submerged 1 m below the water surface and tilted down towards the lake bottom at an angle of 10°. The transducer on the western side of the platform (T1) was oriented due north, and the transducer on the eastern side of the platform (T2) was oriented 16° east. The slope of the lake bottom at the platform was steep and allowed depths of 20 m to be reached within 50 m of the shore such that interference from the lake bottom was detected at an approximate range of 150 m from the transducers. The transducers were operated with one General Purpose Transmitter outfitted with a Simrad multiplexer ("Mux Box") which alternated pulses between transducers. This setup reduces the potential for one transducer to pick up the echoes from the other. Transducers were set to 0.128 ms pulse duration, maximum ping interval, and a power of 300 W in the Simrad EK60 Echosounder software (Kongsberg Maritime, Kongsberg, Norway). The mobile survey on August 16, 2009 utilized a Simrad EK60 circular 7° × 7° split-beam 120 kHz transducer mounted facing downwards from aluminium poles affixed to the mid-ship of survey vessels and set to 0.128 ms pulse duration, maximum ping interval, and a power of 300 W in the Simrad EK60 Echosounder software (Kongsberg Maritime, Kongsberg, Norway). All surveys on Lake Opeongo following 2008 adhere to the Great Lakes Standard Operating Protocols (Rudstam et al., 2009) with the exception of a smaller pulse length because our surveys are not primarily designed for echo-integration. All transducers were calibrated within the field at the time of the surveys.

All raw acoustic data was processed using Echoview® (Myriax Software Pty. Ltd. version 5.2.70). All echograms were first examined to identify and remove bad data regions due to electronic noise, cavitation and bottom intrusion within the analysis area. All data within 5 m from the surface were excluded from the analysis to minimize noise from wave action. For fixed-platform surveys all data beyond a depth of 15 m was excluded to minimize noise from benthic fish and invertebrate species, and to target mid-water pelagic schools. For mobile surveys, all data 0.5 m from the bottom was excluded. All nighttime data was also excluded because the pelagic planktivores only school during the day (Milne et al., 2005). Estimates of the magnitude of background noise at 1 m were obtained from passive listening of each transducer. Using a Time Varied Gain data generator in Echoview the predicted noise was first modelled and then removed from the S_v data for each transducer by linear subtraction.