Fisheries Research 96 (2009) 17–22

Contents lists available at ScienceDirect

Fisheries Research

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

The relationship between sampling intensity and sampling error—empirical results from acoustic surveys in Polish vendace lakes

Małgorzata Godlewska[a,*], Bronisław Długoszewski[b], Lech Doroszczyk[b], Adam Jóźwik[c]

[a] International Institute of Polish Academy of Sciences, European Regional Centre for Ecohydrology under the auspices of UNESCO, ul. Tylna 3, 90 364 Łódź, Poland
[b] The Stanisław Sakowicz Inland Fisheries Institute, ul. Oczapowskiego 10, 10-719 Olsztyn , Poland
[c] Institute of Biocybernetics and Biomedical Engineering, Polish Academy of Sciences, ul. Ks. Trojdena 4, 02-109 Warszawa, Poland

ARTICLE INFO

Keywords:
Hydroacoustics
WFD
Fish abundance
Coverage
Variance

ABSTRACT

The relationship between sampling effort and the variance of hydroacoustic estimates of fish abundance was studied on the basis of 17 surveys in four lakes. These differed in their morphometric and trophic characteristics, but all contained fish communities dominated by vendace (*Coregonus albula* L.). Regression between the degree of coverage and the coefficient of variation was produced. The sampling error of abundance estimates was less than 10% at coverage higher than 2 for all the observations. Seasonal changes in fish spatial distribution did not affect the variability significantly. The zigzag survey design gave less variable results than regular parallel transects but the difference was not statistically significant.

1. Introduction

Reliable estimates of fish abundance in marine and fresh waters are important prerequisites for many purposes. Knowledge of the fish stock is required for sustainable fisheries management as well as for quantitative ecological investigations of food webs and ecosystem quality. Recently, the new European Water Framework Directive requested that all countries monitor aquatic ecosystems (including fish abundance) and ensure that they attain good ecological status by 2015. This means that there is an urgent need to develop monitoring techniques that provide reliable estimates over large areas with a minimum expenditure of time and effort. In this respect hydroacoustics offers a very promising tool, especially for monitoring fish abundance in large, deep lakes (Simmonds and MacLennan, 2005). However, only a small proportion of the lake volume is observed during acoustic surveys even in large volumes of water. It is assumed that acoustic measurements provide samples that are representative of the total water body, but the precision attained has not been well-studied. Accuracy of the results depends, among other factors, on transect spacing, or the degree of coverage (D)—defined as the ratio between the total transect length (T) and the square root of the area surveyed (A), that is $D = T/\sqrt{A}$ (Aglen, 1983). The extended studies by Aglen, which were done for marine populations in fjords and large areas of the open sea, have shown that the relationship between the coefficient of variation (CV = standard deviation of the abundance estimate divided by the mean) and the degree of coverage D can be described by a power law in the form:

$CV = aD^b$, where "b" by Aglen (1983) was close to −0.5, and "a" varied between 0.4 and 0.8.

Similar investigations have not yet been reported for inland waters so we decided to perform work similar to that of Aglen based on freshwater populations. It is obvious that more data give more reliable results, but the objective of any monitoring technique is to determine the minimum effort necessary to reach a given precision. Such information is of crucial importance if acoustic methods are to be used in EU monitoring procedures.

The aim of this paper is to investigate the variance of fish abundance estimates from hydroacoustic surveys performed in different lakes in relation to the degree of coverage, season, and lake morphology, and to compare two different survey designs: parallel and zigzag transects.

2. The study site, materials and methods

Seventeen surveys were conducted in the years 2001–2007 in four coregonid lakes located in northeastern Poland. The lakes differed by size, depth, and the state of eutrophication (Cydzik et al., 2000; Zdanowski et al., 2006). Morphometric and trophic characteristics of the lakes are summarized in Table 1. The fish community of all these lakes was dominated by vendace (*Coregonus albula* L.) which inhabited the hypolimnion, while cyprinids and percids were present in the epilimnion. Vendace is often considered as an indicator of the healthy state of a lake, but, being

* Corresponding author. Tel.: +48 22 8729304.
E-mail address: margogod@wp.pl (M. Godlewska).

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doi:10.1016/j.fishres.2008.09.014

Table 1
Morphometric and trophic parameters of the investigated lakes

	Lake Hancza	Lake Lansk	Lake Pluszne	Lake Mielno
Area (ha)	311	1024	903	363
Maximum depth (m)	108	53	52	40
Mean depth (m)	39	16	15	12
Volume ($\times 10^6$ m^3)	120	186	135	44
Quality class	I	II	II	II
Secchi disc (m)	4.7–5.2	3.8–3.9	3.4–4.9	1.3–1.5
Chl *a* (mg m^3)	3.6	8.9	12.8	18

a planktivore, it eliminates zooplankton from the lake thus lowering its quality (Schmidt et al., 2005). Therefore, the vendace stock must be monitored to keep it at the right level, having regard to both, fisheries management and ecosystem quality objectives.

Hydroacoustical measurements were conducted from the 5 m long boat "Echo" sailing at the constant speed of 8 km h^{-1}, with the geographical positions recorded by the GPS connected to the sounder. The transducer was fixed on a special frame in front of the boat at a depth of 0.5 m. The SIMRAD EY500, split beam echo-sounder was used with operating frequency 120 kHz and a circular transducer with opening angle of 7° at −3 dB points. The pulse duration was set to medium (0.3 ms), repetition rate to "as fast as possible", and the TS threshold to −56 dB. Simrad EP 500 post-processing software was used for data analysis, and the echo-integration method was applied. Measurements were performed at night, when all fish were scattered (over 90% single fish). At the beginning of each study the whole system was calibrated *in situ* according to the procedure described by Foote et al. (1987). Control catches of pelagic fish were made at different depths to identify the species and the size structure of the fish population. Water temperature and dissolved oxygen content were determined in the deepest part of the lake at 1 m intervals from the surface to the bottom using the OXI 196 (WTW).

Three different factors affecting the estimate of fish abundance were investigated:

(1) The degree of coverage, i.e. the proportion of the area covered with measurements to the total area of interest,
(2) season: summer as opposite to autumn, and
(3) survey design: zigzag versus parallel transects (Fig. 1).

3. The degree of coverage

To investigate the influence of the degree of coverage on the estimated distribution and abundance of fish, measurements were performed along dense zigzag or parallel transects (the latter running perpendicularly to the main axes of the lakes and separated by ca. 200 m). The contours and bathymetry of the lakes together with the survey design are shown in Fig. 1. Echo-integration provides independent samples along the track at each Elementary Sampling Distance Unit (ESDU). The ESDU for all the lakes was chosen to be approximately 100 m, which was small enough to reveal the fish distribution pattern, and easy for calculations of area density. Calculation of the mean abundance in a lake was performed initially for all the ESDU, giving the maximal degree of coverage. Subsequent calculations were performed skipping every second ESDU (which gave two independent estimates of abundance), every third (three estimates), and so on, until we reduced the degree of coverage by 10 times from the maximum (giving ten independent abundance estimates). We worked on ESDU and not the transects to increase the possible number of independent estimates and to keep a nearly constant degree of coverage between the estimates in a given group (the ESDU were the same length approximately, while transects were not). Because of the repeated fish abundance estimates for each degree of coverage we calculated two different coefficients of variation: SV1 defined as standard deviation divided by the mean, and SV2 defined as the difference between the maximum and minimum divided by the mean. The relationship between the degree of coverage and both coefficients of variation was approximated by

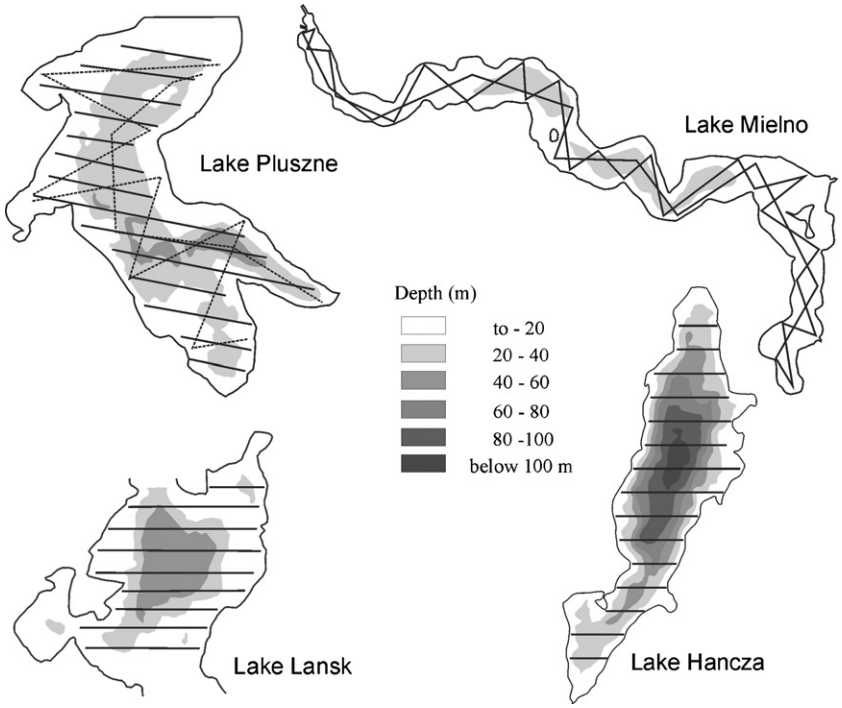

Fig. 1. Bathymetric maps with hydroacoustic transects in four lakes: Hancza, Pluszne, Lansk, and Mielno.