Aqua reports 2016:18

Applying the European hydroacoustic standard on fish abundance estimation (EN 15910)

Survey experiences from three European countries

Thomas Axenrot, Jean Guillard, Milan Riha, Michal Tušer

Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Aquatic Resources

Applying the European hydroacoustic standard on fish abundance estimation (EN 15910)

Survey experiences from three European countries

Thomas Axenrot[1], Jean Guillard[2], Milan Riha[3], Michal Tušer[3]

1 Swedish University of Agricultural Sciences, Department of Aquatic Resources,
Institute of Freshwater Research, SE-178 93 Drottningholm

2 UMR CARRTEL (INRA-USMB), 75, Avenue de Corzent,
F-74203 Thonon-les-Bains cedex, France

3 Biology Centre CAS, Institute of Hydrobiology, Na Sádkach 7,
České Budějovice 370 05, Czech Republic

December 2016

Aqua reports 2016:18
ISBN: 978-91-576-9451-5 (electronic version)

Corresponding author:
thomas.axenrot@slu.se

This report has been reviewed by:
Leonard Sandin, Department of Aquatic Resources, Swedish University of Agricultural Sciences
Olavi Kaljuste, Department of Aquatic Resources, Swedish University of Agricultural Sciences

This report may be cited as:
Axenrot, T., Guillard, J., Riha, M & Tušer, M. (2016). Applying the European hydroacoustic standard on fish abundance estimation (EN 15910). Survey experiences from three European countries. Aqua reports 2016:18. Department of Aquatic Resources, Swedish University of Agricultural Sciences, Drottningholm Lysekil Öregrund. 22 p.

Key words:
Aquatic ecosystems, fish abundance, hydroacoustics, standardization, water quality

Download the report from:
http://pub.epsilon.slu.se/

Funding:
The Swedish Agency for Marine and Water Management (dnr SLU aqua.2011.5.2-134)
The Societies for Water Conservation of Lakes Vänern and Vättern (Vänerns vattenvårdsförbund, Vätternvårdsförbundet)
Project no.7F14316 (MacFish, France)
Project no. P504/12/1186 of the Czech Science Foundation

Series editor:
Magnus Appelberg, Head of Department, Department of Aquatic Resources, Öregrund

Front cover: Sunset over smooth water – what can we see below the surface (Lake Vättern, Sweden). Photo: Thomas Axenrot.

Summary

Hydroacoustics is an internationally approved method to study fish for abundance estimates and behaviour to increase our understanding of aquatic ecosystems. In Europe and North-America, the need to compare results between years, lakes and countries has been recognized and as a consequence of this, acoustic methods are being standardized. To study how the European standard Water quality – Guidance on the estimation of fish abundance with mobile hydroacoustic methods (CEN 2014) was perceived by different users, a joint evaluation of the implementation of the standard was performed in 2014 by hydroacoustic experts from three European countries. In some parts of the standard the participants´ actions were different from what was described by the standard, and in some cases methods differed among the participants. A general explanation for most of these cases was that stable equipment performance and experience from discrete surveys reduce the need of controlling actions. We suggest that the results of this study should be considered at the revision of the standard (EN 15910) scheduled for 2017.

Sammanfattning

Hydroakustiska metoder är internationellt accepterade för skattning av beståndsstorlek och för studier av fiskars beteenden i syfte att öka våra kunskaper om akvatiska ekosystem. I Europa och Nordamerika insåg man behovet av att kunna jämföra resultat mellan olika år, sjöar och länder vilket resulterade i att standarder arbetades fram för hydroakustiska metoder. För att undersöka hur den europeiska standarden Vattenundersökningar – Vägledning för beståndsskattning av fisk med mobila hydroakustiska metoder (CEN 2014) uppfattades av olika användare, genomfördes år 2014 en gemensam utvärdering av hur standarden tillämpades av hydroakustisk expertis från tre europeiska länder. I vissa delar av standarden avvek deltagarnas arbetssätt från vägledningen, och i några fall skiljde sig arbetssättet även bland deltagarna. En generell förklaring till de flesta avvikelserna var att stabil funktion hos utrustningen och erfarenhet från tidigare undersökningar minskade behovet av kontrollerande åtgärder. Vi föreslår att resultaten i denna studie beaktas vid den planerade revisionen av standarden (EN 15910) 2017.

Table of contents

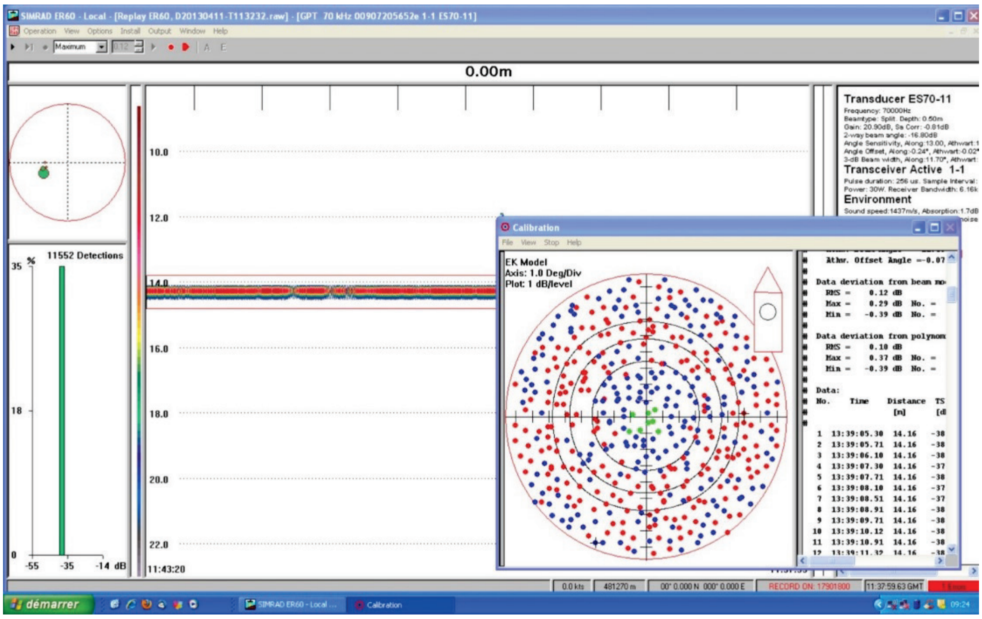
Introduction

Hydroacoustic technology and methods are being extensively and increasingly used, and today have become accepted tools to describe aquatic ecosystems (Trenkel et al. 2011) and to estimate fish abundance (Rudstam et al. 2012). The equipment and software have advanced rapidly over the last 30 years, and accordingly so have hydroacoustic methods. After advances in calibration methodology for hydroacoustic equipment in the late 1980´s, it has been suggested that the main challenge in addressing uncertainties in hydroacoustic data lies in taking fish behaviour in consideration when planning and performing hydroacoustic surveys (Fréon and Misund 1999, Simmonds and MacLennan, 2005) and the use of appropriate statistics (Rivoirard et al. 2000). For governmental agencies, administration offices, the scientific community and other users of the results from surveys that include hydroacoustic methods, it is of great importance that results can be trusted and that uncertainties can be measured to compare results between surveys. Furthermore, factors like fish habitats, pollution, climate change and so forth, are not restricted by borders between countries, and consequently it is important and necessary that estimates of fish abundance can be compared.

In the marine environment, large areas are often surveyed by several countries and it is necessary that results can be compared, and even compiled, to provide a picture of fish stocks for the whole area as, e.g., the North and Baltic Seas. For this purpose the International Council for Exploration of the Sea (ICES) has produced recommendations for participating member countries (ICES 2014). In North America, the need to compare results from hydroacoustic surveys in the Great Lakes resulted in the document Standard Operating Procedures (Parker Stetter et al. 2009, Rudstam et al. 2009, http://www.acousticsunpacked.org/acoustics/. In Europe, this need was identified and addressed in 2006, based on a need to develop a common method in the framework of the European policy of water quality (WFD). At a joint workshop on March 22-23, 2006, arranged by the European Inland Fisheries Advisory Commission (EIFAC) and the European Committee for Standardization (CEN), an international group of experts composed an initial draft for a European hydroacoustics standard.

In November 17, 2013, the document (CEN 2014) was approved as a European Standard by CEN, and subsequently became a national standard without any alteration (CEN/CENELEC Internal Regulations). European Standards are regularly revised and a revision of EN 15910 (CEN 2014) is scheduled for 2017. Therefore, it is important to evaluate the feasibility of the standard for possible improvements in the future use of the document.

The objective of this study was to evaluate how well the standard could be followed when applied to planning and performing surveys according to regular national routines and procedures, and if there were differences between users in interpreting the guidelines in the new standard. For these purposes, experienced hydroacousticians (called "participants" in the following text) from France, the Czech Republic and Sweden participated in an evaluation of implementing and applying the standard. Based on their experiences, areas of improvement are highlighted to be considered at the scheduled revision of the standard in 2017.



Echogram showing ongoing calibration of a scientific Simrad echosounder with a standard sphere target. The number of accepted target hits and the position in the sound beam can be followed throughout the calibration.

Materials and Methods

To conduct surveys in order to determine species composition, abundance and age structure of fish in rivers, lakes and transitional waters there are four European Standards that provide guidance. The standards are:

- EN 14011 Water quality – Sampling of fish with electricity (CEN 2003).
- EN 14757 Water quality – Sampling of fish with multi-mesh gillnets (CEN 2015).
- EN 14962 Water quality – Guidance on the scope and selection of fish sampling methods (CEN 2006).
- EN 15910 Water quality – Guidance on the estimation of fish abundance with mobile hydroacoustic methods (CEN 2014).

Consequently, a decision to investigate fish for any of these purposes must be followed by a planning phase in which the appropriate fish sampling method(s) is selected.

In this study, the decision on survey method is given and the evaluation is limited to the European Standard EN 15910 (CEN 2014).

In spring 2014, hydroacousticians from CEN member countries were invited by Thomas Axenrot to a joint evaluation of the new standard on hydroacoustic methods (EN 15910). Apart from Sweden (Thomas Axenrot), representatives from France (Jean Guillard) and the Czech Republic (Milan Riha and Michal Tušer) had the opportunity to participate in the evaluation. The agreed activities were:

- Individually walk through chapters 5 and 6 of the standard (Equipment and Survey design, respectively) and fill in a questionnaire about fulfilment and comments (if needed). This was meant to be finished before the Swedish annual large lakes survey - performed according to the CEN standard - started in mid-August. The general aim of the Swedish large lakes survey was abundance estimation of pelagic fish. Results were shared and discussed.
- Participation by French and Czech hydroacousticians on the Swedish surveys on lakes Vättern and Mälaren, respectively, to further discuss the joint results from chapters 5 and 6, and apply and discuss chapter 7 Survey data acquisition.
- Continue to fill in the questionnaire for chapters 7 Survey data acquisition, 8 Post-processing of acoustic data, and 9 Calculation of results. Results were shared and discussed.

The ensuing and finishing chapters 10 Quality control and quality assurance and 11 Survey report were not treated in this joint study.

In June 4-5 2014, Jean Guillard, France, arranged a workshop focused on the European Standard EN 15910 - Intercalibration of Hydroacoustic Method for WFD Fish Monitoring. The results and conclusions from the workshop were summarized and shared (http://www6.dijon.inra.fr/thonon/Centre-Alpin-de-Recherche-sur-les-Reseaux-Trophiques-des-Ecosystemes-Limniques/Actualites-de-L-INRA-UMR-CARRTEL/Hydro-fish-Workshop-June-2014-Thonon).

At the international conference Ecology of Fish in Lakes and Reservoirs (EcoFIL, September 8-11, 2014, Ceske Budejovice, Czech Republic), reworked results of the inter-comparison exercise (Hateley et al. 2013, Drastik et al. submitted) were presented.

Results

The collective response by the participants from the questionnaire on fulfilment of the standard and their comments are presented for each chapter and numbered following the standard (CEN 2014). Paragraphs that were fulfilled by all participants, and not specifically commented on, are not presented in the following.

Chapter 5 Equipment

5.2 Minimum and optimum requirements

All participants fulfilled the stipulated requirements. Different frequencies are being used - 38, 70 and 120 kHz. These frequencies are all appropriate for the surveyed aquatic environments (Parker-Stetter et al. 2009, CEN 2014, Guillard et al. 2014).

5.3 Calibration

Most criteria were fulfilled by all participants. In a few cases - generally in common for the participants – the criteria of the standard were not fulfilled or not fully met. The items which were not always fulfilled were:

- Beam pattern calibration prior to each survey.
- Standard target test at the start at each new survey site/day.
- The number of passages of a standard target on axis and within each quadrant (split-beam).
- Standard target test conducted in the same environmental conditions as experienced during survey.

Chapter 6 Survey design

6.2 Design for appropriate resolution and detection

Opposite to participants from France and Sweden, the participants from the Czech Republic reported covering the blind zone (uppermost ~0-4 m) using mobile horizontal or upward-looking hydroacoustics.

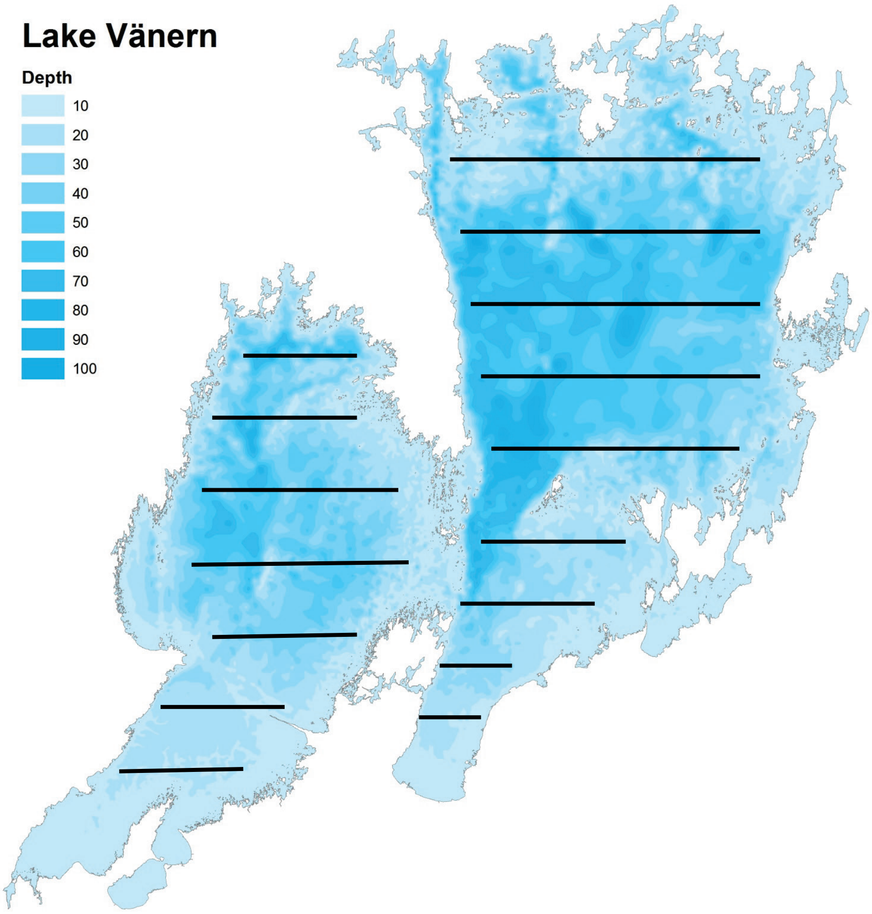
6.3 Pre-planning

The participants from France and Sweden calculated preliminary coverage from the area to be surveyed, transect lengths and an acceptable CV (coefficient of variation) in the pre-planning process based on previous experience and published works (Aglen 1983 and 1989, Simmonds & MacLennan 2005). The participants from the

Czech Republic commented that an experienced acoustician considered the coverage in the planning process and that actual coverage was calculated after data collection during data processing.

Bad weather conditions were mentioned by all participants as a potential obstacle in fulfilling time plans.

Cruise speed varied. The participants from the Czech Republic reported going at the slowest speed (4-7 km/h) and from Sweden going at the fastest speed (11 km/h). The French participant reported a speed between those two.



Survey design - 300 km of parallel hydroacoustic transects covering 4 500 km^2 of pelagic area in Lake Vänern (Sweden) result in an acceptable pre-planned coverage (Aglen 1983). Analyses of survey results may result in adaptions of the initial survey design.

6.4 Timing of surveys

All participants reported that night surveys do not start until one hour after sunset and stop at the latest one hour before sunrise. The participants from the Czech Republic also reported performing surveys daytime. To further investigate the recommended timing when to start and stop night time surveys, light data were collected on L. Mälaren during the survey period September 29th to October 2nd. Preliminary results supported that the vertical distribution of fish was different in daylight and in darkness at night. The changes were mainly in the epi- and metalimnion and stabilized one hour after sunset (mean secchi-depth in this part of L. Mälaren approximately 3 m). Similar results are reported from Czech reservoirs where fish activity and horizontal migrations between open water and the littoral were performed during the same time period and fish distribution stabilized one hour after sunset (Prchalová et al. 2012).

Concerning homogenous environmental conditions throughout a survey, the participants from France and the Czech Republic fulfilled these criteria as surveys lasted for 1-2 nights. The participant from Sweden reported variation in both weather and environmental conditions as surveys take 1-3 weeks per lake depending on size.

6.5 Transducer orientation and position – vertical surveys

Only the participant from Sweden had permanently fixed, hull mounted transducers, and consequently adjusting the transducer orientation is more complicated, laborious and expensive.

Chapter 7 Survey data acquisition

7.2 Echosounder settings

For sound speed and attenuation, temperature profiles (Sweden) and surface temperatures (Czech Republic) were recorded regularly, at least one per subarea. The participant from France reported using data from limnological monitoring surveys done twice by month, and tried to perform the acoustic survey concurrently.

7.3 Data acquisition from additional equipment

Only the participants from the Czech Republic used additional equipment to measure actual tilt of a transducer. France and Sweden used visual inspection of fish targets and, when doubtful, calculating swimming angles from tracks (Sweden).

Chapter 9 Calculation of Results

9.5 Outputs of acoustic data

9.5.1 Fish abundance as numerical density

As should be the case because of the variation of surveyed areas and variable fish densities different EDSU´s (Elementary Distance Sampling Unit) were used by the participants. The participant from France tested different EDSUs (Guillard et al. 1990) for a surveyed lake and kept the chosen EDSU constant, assuming that fish distribution in a similar environment was comparable. Sweden tested the density results (number of fish per hectare) along transects in the different subareas to decide on which EDSU to use. The Czech participants reported using 300-600 m EDSU´s based on previous experience and tests.

Discussion

Chapter 5 Equipment

5.2 Equipment

The frequencies regularly used by the participants – 38, 70 and 120 kHz – were appropriate for the aim of performed surveys. However, the results from the international hydroacoustic inter-comparison exercise (Hateley et al. 2013), the reworked analysis of these data presented at the EcoFIL Conference in 2014 (Drastik et al. submitted), and a comparative study simultaneously using 70, 120 and 200 kHz transducers (Guillard et al. 2014) strongly suggest that more studies should be encouraged about results for high fish densities at different hydroacoustic frequencies. The European guidance (EN 15910) allows for a very wide range of frequencies (between 38 kHz and 1.8 MHz) while, e.g., the North-American equivalent (Standard Operating Procedures; Parker-Stetter et al. 2009, Rudstam et al. 2009, http://www.acousticsunpacked.org/acoustics/AcousticsUnpacked.asp) is more conservative and even, in general, advice against higher frequencies (>200 kHz) as being "less appropriate for fisheries acoustics in the Great Lakes because of higher absorption rates and higher reverberation from invertebrates". These results and advice suggest that the European guidance (EN 15910) should discuss the choice of frequency in more detail based on recent findings for an updated recommendation.

5.3 Calibration

All participants shared the criteria that were not fulfilled or fully met, and the explanations were also similar. The general view was that they calibrate their own acoustic equipment set-up, i.e. transducer(s), cables and echosounder(s), regularly and if nothing was changed or damaged, and had shown stable performance for a reasonably long period of time, there was no need for (i) beam pattern calibration prior to each survey and (ii) standard target test at the start at each new survey site/day. This should be considered in a future revision of the standard.

In the guidance, the recommendation on the number of passages of the standard target through the beam opens for different interpretations, from 250 to 1 250 echoes. The participants reported from 250 to 400 echoes. Demer et al. (2015) suggested recording at least 100 sphere-TS measurements throughout the beam and at least 10 sphere-TS measurements near the beam axis. The recommendation in CEN (2014) on the number of passages needs to be clarified to eliminate different interpretations.

The criterion that standard target tests should be conducted in the same environmental conditions that are experienced during the survey was not fulfilled or fully met, and was not considered practically possible at times. Calibration, per se, is a test of the performance of the set-up, i.e. transducer, cables, echo-sounder etc., and could be done in any kind of environment, given accurate knowledge of water temperature and salinity. The need is to get calm weather, space enough to avoid multiple echoes from bottom and borders, and avoid other targets like fish, bubbles, etc. Furthermore, if weather conditions deteriorate during a survey, it is usually not possible to perform a calibration. In some situations it might be problematic to define when and where to perform a new calibration, e.g., when the depth of the thermocline changes gradually from one part of a lake to the other. The inter-comparison exercise in L. Windermere, using four different frequencies (70-400 kHz), showed some bias with changing weather conditions and high fish densities, especially for higher frequencies, although the general performance and results were encouraging (Hateley et al. 2013, Drastik et al. submitted).

The most workable solution might be a recommendation in the guidance to avoid performing surveys and record hydroacoustic data in bad weather conditions. However, how much weather conditions may affect data quality must be decided from time to time based on purpose and technical prerequisites, previous knowledge about or experience from the survey area and the used boat. In this context it becomes obvious that taking notes about these conditions before, during and after a survey is important for later interpretation of data and results as well as for future surveys. Notably, calibrations - without exceptions - are performed in good weather conditions to assure high data quality. As most calibrations show system stability, the guidance could recommend a suitable interval for calibrations instead of repeated field calibrations in – at times – chancy conditions. A full calibration must always be performed if any part of the set-up has experienced physical damage.

Chapter 6 Survey design

6.2 Design for appropriate resolution and detection

The need to cover the water volume immediately below the surface may vary with several different parameters like the type of lake, the fish community, diel timing, season, the purpose of the survey, etc. In some cases where this water volume should be included, there should also be reliable, and preferably standardized, methods to apply. Generally, horizontal hydroacoustics (EN 15910) is commonly used in small to moderately sized lakes, reservoirs and rivers, i.e. aquatic systems with small depths or where the fish community dwells in the subsurface layer. However, this technique does not perform equally well in wind-exposed lakes where wind and wave action reduce functionality most of the time, thereby obstructing the possibilities to obtain data of acceptable quality. However, the upper water volume may often be of significant importance also in such lakes. We suggest a joint effort to investigate the best method(s) to be introduced in wind-exposed lakes in order to produce reliable results also for the water volume immediately below the surface, when applicable. Notably, upward-looking beaming is still a vertical application (e.g. Jurvelius et al. 1996). The guidance also mentions this method briefly in paragraph 6.5 Transducer orientation and position.

6.3 Pre-planning

The objectives of a hydroacoustic survey determine how it should be conducted. Ideally, this should set the time frame for the survey including collecting hydroacoustic, biological and hydrographic data. For lakes, reservoirs and rivers, the study area is often obvious because of natural boundaries such as land (Simmonds and McLennan, 2005). Still, only a part of the total area/volume can usually be surveyed. Consequently, a sampling intensity has to be decided. With pre-existing information, e.g., from previous surveys of the same area, a sampling intensity that will provide results with acceptable precision can be estimated. If this estimation shows that the precision is too low, the coverage must be increased accordingly. Opposite, an unnecessarily high coverage may be decreased to reduce survey time and costs. Without pre-existing information, it is necessary to decide on a level of precision of the results. This depends on the spacing of transects (Aglen 1983). After an initial (or preliminary) survey is accomplished, the data collected should be used to evaluate the coverage that was used. Such use of earlier, initial or preliminary survey data could be better explained and clarified in the standard at hand (EN 15910) and should be developed further in a future revision.

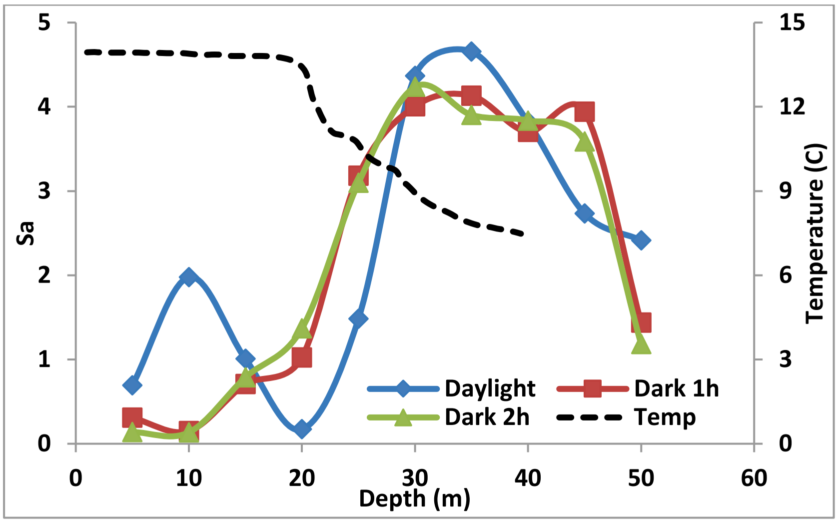
Bad weather (wind and wave action) is a highly variable risk factor that varies with lake size, exposure to wind, season, etc. The international hydroacoustic intercomparison exercise in L. Windermere and the later reworked analysis (Hateley et al. 2013, Drastik et al. submitted) found sensitivity to rough weather in the performance of the hydroacoustic equipment, especially for higher frequencies (>200 kHz). In consequence, the risk of encountering bad weather should be considered when available working time is calculated.

The recommended maximum cruise speed in the guidance is 10 km/h. The different cruise speeds reported by the participants probably reflect differences in the size of lakes that are surveyed and size of boats more than data quality aspects. The guidance comments on this also in paragraph 6.5.2 Requirements specific to vertical surveys. For hydroacoustic surveys conducted in deep lakes it is important to realize the compromise between ping rate, cruise speed and target detection. Due to reverberation (producing noise in the surveyed water volume), the ping rate must be decreased over deep areas. To withhold the recommendation in the guidance of a minimum of 3 hits on a fish, speed can be adjusted accordingly. The cone-shape of the emitted sound pulses results in a lower probability of hitting fish in the upper part of the insonified water volume. We suggest that the revised guidance considers this with regard to the recommended number of hits.

6.4 Timing of surveys

Regarding diel timing of surveys, the guidance recommends generally to avoid the transitional periods dawn and dusk and to start/stop the surveys one hour after/before sundown/sunrise. The preliminary results from L. Mälaren, where light data were collected during the acoustic survey in 2014, and from investigations in Czech reservoirs, suggested that one hour after sundown was sufficient time for the fish community to stabilize. However, this might vary with, e.g., secchi-depth, different fish species, moon phase and artificial lights.

Apart from weather conditions, there are other environmental conditions that might affect fish distribution and behaviour which need to be considered when designing a survey. One example – more predictable than weather conditions - is thermal stratification. For most comparisons of results it is important that surveys are performed during periods with similar thermal stratification. This might be better clarified in the guidance, i.e. not only commented for calibration and pre-planning.



Hydroacoustic registrations of vertical fish distribution in the same water volume with decreasing light conditions. s_a *is symbol for the area backscattering coefficient (*$m^2 \cdot m^{-2}$*). The water column was thermally stratified. Example from Lake Mälaren, Sweden.*

6.5 Transducer orientation and position – vertical surveys

A permanently mounted transducer reassures little variation caused by temporary, repeated mounting/dismounting of the hydroacoustic equipment. On the other hand, adjusting transducer orientation is not feasible without sophisticated technology. Especially on relatively small vessels, the transducer orientation may change with ship-loading, bunker-fill etc. for permanently mounted transducers (see also paragraph 7.3 below).

Chapter 7 Survey data acquisition

7.2 Echosounder settings

The guidance postulate a priori knowledge to set sound speed and attenuation. Routines for this may vary depending on time of the year, size and hydrography of the lake, survey time and previous experience. During certain parts of the year temperature profile data are mostly stable and one or a few measurements can be sufficient, especially for surveys that last for a short period of time, i.e. a few days. However, large lakes may show substantial differences between areas within a lake, also during expected stable periods, caused by wind, currents and hydrographic differences. In these cases it is good practice to collect data on sound speed and attenuation once per survey day/night for depths that will be sampled to enable correction in the analyses software. Some analysis software allow for adding temperature profiles before analysing data. The importance of temperature on the hydroacoustic data quality should be tested further, e.g., temperature settings based on surface water only vs. mean temperature based on data from the whole water column.

7.3 Data acquisition from additional equipment

Measuring tilt is a good step to avoid a systematic error in data, especially when new platforms are being used. Such a step also provides the opportunity to correct a possible tilt before data are collected.

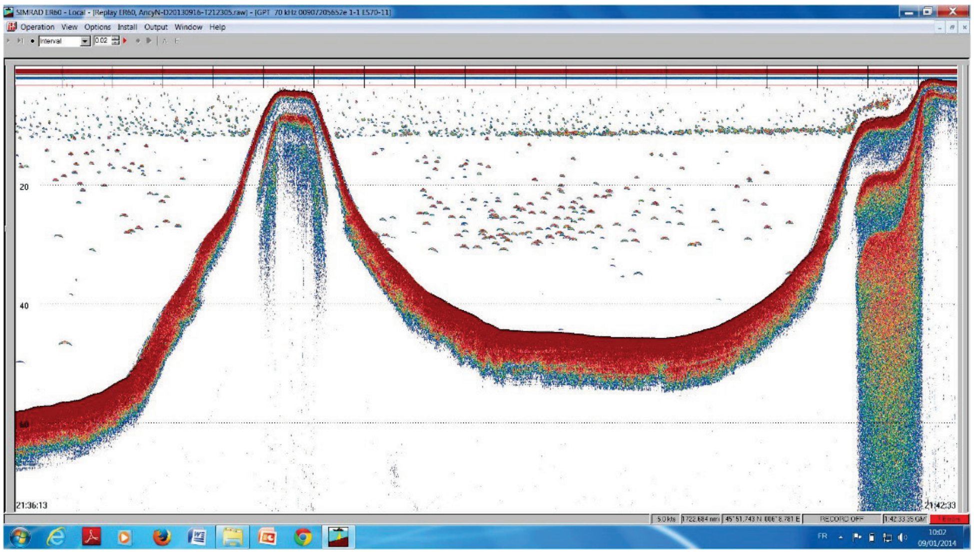
The participant from Sweden experienced from hull-mounted transducers that even a relatively large vessel (12 m) can be sensitive to tilt from ship-loading and bunker fill which would call for possibilities of adjustment.

Chapter 9 Calculation of Results

9.5 Outputs of acoustic data

9.5.1 Fish abundance as numerical density

If fixed intervals are used (EDSUs), these should capture the main spatial structure but avoid autocorrelation between successive samples (Simmonds and MacLennan 2005, CEN 2014). Consequently, the length of EDSUs should be tested for new surveys. For previously surveyed areas, the length of EDSUs should be tested if fish distribution has changed significantly, e.g., when a survey area is visited at different seasons of the year.



Hydroacoustic echogram from a stratified lake with cold water species below the thermocline, i.e. below 10 m depth. The red area below the fish echoes represents the bottom. For data analyses hydroacoustic data sets need to be compartmentalised into segments (EDSU´s) to avoid statistic autocorrelation, and depth layers to improve resolution. Example from Lake Annecy, France.

Summary and suggestions

As a result of this study we could conclude that the standard generally could be followed through a hydroacoustic survey, but that there were parts that needed improvements and clarifications. Our suggestions are:

- The wide range of frequencies allowed for in the guidance should be reappraised. (5.2)
- The guidance should clarify the recommendation on minimum number of echoes for Calibration - standard target tests. (5.3)
- The guidance should consider previous experience from equipment, set-ups and documentation of previous calibrations/performance when recommending calibration activities and intervals. Based on system stability, calibration intervals could be recommended instead of repeated field calibrations. (5.3)
- Conduct a joint effort to find the best solution (standard) to cover the water volume immediately below the surface (blind zone) in wind-exposed lakes. (6.2)
- The guidance should expand Pre-planning on the use of previous, initial or preliminary survey data. (6.3)
- Further studies should be initiated on possible differences in data quality for different frequencies/systems at bad weather conditions. (6.3)
- The guidance should expand on recommended minimum number of hits per fish and consequences at large depths - the relationship between ping rate, vessel speed and survey depth. (6.3)
- The guidance should include more considerations regarding timing of surveys. (6.4)
- Studies should be conducted on the impact of moon phase, Secchi depth and artificial lights to provide general guidance in relation to fish behaviour. (6.4)
- Data on sound speed and attenuation (from temperature profiles) should be collected once per survey day/night, at least for larger lakes, long lasting surveys and during the period of thermal stratification. (7.2)
- Collection and use of temperature data should be more comprehensively described and structured in the guidance in perspective of echo sounder settings, data collection and processing. (7.3)

Acknowledgements

We are grateful for support from our institutes, departments and universities, and for the supportive work by the crew of R/V Asterix. The study was financed through funding by the Swedish Agency for Marine and Water Management (dnr SLU aqua.2011.5.2-134), the Societies for Water Conservation of Lakes Vänern and Vättern, and by projects no.7F14316 (MacFish, France) and no. P504/12/1186 of the Czech Science Foundation.

References

Aglen A. 1983. Random errors of acoustic fish abundance estimates in relation to the survey grid density applied. FAO Fisheries Report 300:293-298.

Aglen A. 1989. Empirical results on precision-effort relationships for acoustic surveys. ICES CM 1989B:30, 28 pp.

[CEN] Comité Européen de Normalisation (European Committee for Standardization). 2003. Water quality – Sampling of fish with electricity. EN 14011.

[CEN] Comité Européen de Normalisation (European Committee for Standardization). 2015. Water quality – Sampling of fish with multi-mesh gillnets. EN 14757.

[CEN] Comité Européen de Normalisation (European Committee for Standardization). 2006. Water quality – Guidance on the scope and selection of fish sampling methods. EN 14962.

[CEN] Comité Européen de Normalisation (European Committee for Standardization). 2014. Water quality – Guidance on the estimation of fish abundance with mobile hydroacoustic methods. EN 15910.

Demer DA, Berger L, Bernasconi M, Bethke E, Boswell K, Chu D, Domokos R, et al. 2015. Calibration of acoustic instruments. ICES Cooperative Research Report No. 326. 133 pp.

Drastik V, Godlewska M, Balk H, Clabburn P, Kubečka J, Morrissey E, Hateley J, Winfield IJ, Guillard J. Fish hydroacoustic survey standardization: a step forward based on comparisons of methods and systems from vertical surveys in a large deep lake. Submitted.

Fréon P, Misund OA. 1999. Dynamics of pelagic fish distribution and behaviour: Effects on fisheries and stock assessment. Oxford: Fishing News Books.

Guillard J, Gerdeaux D, Chautru JM. 1990. The use of geostatistics for abundance estimation by echo integration in lakes: the example of Lake Annecy. Rap P-V CIEM. 189:410-414.

Guillard J, Lebourges-Daussy A, Balk H, Colon M, Jóźwik A, Godlewska M. 2014. Comparing hydroacoustic fish stock estimates in the pelagic zone of temperate deep lakes using three sound frequencies (70, 120, 200 kHz). Inland Waters. 4:435-444

Hateley J, Clabburn P, Drastik V, Godlewska M, Guillard J, Kubecka J, Morrissey E, Thackeray SJ, Winfield IJ. 2013. Standardisation of hydroacoustic techniques for fish in fresh waters. In: Papadakis JS, Bjørnø L, editors. Proceedings of the 1st Underwater Acoustics Conference and Exhibition. Corfu (Greece). IAPCM. p. 1595-1600.

ICES. 2014. Manual of International Baltic Acoustic sSrveys (IBAS). Series of ICES Survey Protocols SISP 8 – IBAS. 24 pp.

Jurvelius J, Leinikki J, Mamylov V, Pushkin S. 1996. Stock assessment of three-spined stickleback (Gasterosteus aculeatus): A simultaneous up- and down-looking echo-sounding study. Fisheries Research 27:227-241.

Parker-Stetter SL, Rudstam LG, Sullivan PJ, Warner DM. 2009. Standard operating procedures for fisheries acoustic surveys in the Great Lakes. Great Lakes Fisheries Commission Special Publication. 09-1.

Prchalová M, Mrkvička T, Kubečka J, Peterka J, Čech M, Muška M, Kratochvíl M Vašek M. 2010. Fish activity as determined by gillnet catch: A comparison of two reservoirs of different turbidity. Fisheries Research 102:291-296.

Rivoirard J, Simmonds J, Foote KG, Fernandes P, Bez N. 2000. Geostatistics for estimating fish abundance. Oxford: Wiley-Blackwell.

Rudstam LG, Jech JM, Parker-Stetter SL, Horne JK, Sullivan PJ, Mason DM. 2012. Fisheries Acoustics. In: Zale AV, Parrish DL, Sutton TM, editors. Fisheries Techniques, 3rd ED. Bethesda (MD). American Fisheries Society. 40p.

Rudstam LG, Parker-Stetter SL, Sullivan PJ, Warner DM. 2009. Towards a standard operating procedure for fishery acoustic surveys in the Laurentian Great Lakes, North America. ICES Journal of Marine Science 66:1391-1397.

Simmonds EJ, MacLennan DN. 2005. Fisheries Acoustics: theory and practice. Oxford (UK): Blackwell Science. 437 p.

Trenkel VM, Ressler PH, Jech M, Giannoulaki M, Taylor C. 2011. Underwater acoustics for ecosystem-based management: state of the science and proposals for ecosystem indicators. Marine Ecology Progress Series 442:285-301.