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BSI Standards Publication

# Water quality — Guidance on the estimation of fish abundance with mobile hydroacoustic methods

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## National foreword

This British Standard is the UK implementation of EN 15910:2014.

The UK participation in its preparation was entrusted by Technical Committee EH/3, Water quality, to Subcommittee EH/3/5, Biological Methods.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

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| 30 April 2014 | Implementation of CEN correction notice 22 January 2014: editorial corrections throughout; brackets deleted in the bibliographical references contained in square brackets; and amendments to both Table A.1 and Table C.4. |

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# EN 15910

January 2014

ICS 13.060.70

English Version

# Water quality - Guidance on the estimation of fish abundance with mobile hydroacoustic methods

Qualité de l'eau - Guide sur l'estimation de l'abondance des poissons par des méthodes hydroacoustiques mobiles

Wasserbeschaffenheit - Anleitung zur Abschätzung der Fischabundanz mit mobilen hydroakustischen Verfahren

This European Standard was approved by CEN on 17 November 2013.

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**CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels**

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# Foreword

This document (EN 15910:2014) has been prepared by Technical Committee CEN/TC 230 “Water analysis”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by July 2014, and conflicting national standards shall be withdrawn at the latest by July 2014.

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# Introduction

This document is one of several European Standards developed for the evaluation of species composition, abundance and age structure of fish in rivers, lakes and transitional waters. The following standards have already been published:

- EN 14011, *Water quality — Sampling of fish with electricity*;
- EN 14757, *Water quality — Sampling of fish with multi-mesh gillnets*;
- EN 14962, *Water quality — Guidance on the scope and selection of fish sampling methods*.

The initial draft of this document was constructed by an international group of experts during an ad hoc joint EIFAC/CEN workshop.

**WARNING — Persons using this European Standard should be familiar with normal laboratory and fieldwork practice. This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and to ensure compliance with any national regulatory conditions.**

**IMPORTANT — It is absolutely essential that tests conducted according to this European Standard be carried out by suitably trained staff.**

# 1 Scope

This European Standard specifies a standardized method for data sampling and procedures for data evaluation of fish populations in large rivers, lakes and reservoirs, using hydroacoustic equipment deployed on mobile platforms (boats and vessels).

This standard covers fish population abundance estimates of pelagic and profundal waters > 15 m mean depth with the acoustic beam oriented vertically, and the inshore and surface waters of water bodies > 2 m depth with the beam oriented horizontally. The size structure of fish populations can only be determined to a relatively low degree of precision and accuracy, particularly from horizontally-deployed echosounders. As acoustic techniques are presently unable to identify species directly, other direct fish catching methods should always be used in combination.

This standard provides recommendations and requirements on equipment, survey design, data acquisition, post-processing of data and results and reporting. A selected literature with references in support of this standard is given in the Bibliography.

# 2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 14962:2006, *Water quality - Guidance on the scope and selection of fish sampling methods*

# 3 Terms, definitions, symbols and abbreviated terms

## 3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 14962:2006 apply.

## 3.2 Symbols and abbreviated terms

Common abbreviations used in this document:

| | | |
|---|---|---|
| — | EDSU | Elementary Distance Sampling Unit; Unit: Metre (m); |
| — | GPS | Global Positioning System; |
| — | MUR | Maximum Usable Range; Unit: Metre (m); |
| — | PST | Peak of Small Targets; |
| — | $S_a$ | Area Backscattering Strength; Unit: decibel, dB re 1 ($m^2$ $m^{-2}$); |
| — | $S_v$ | Volume Backscattering Strength; Unit: decibel, dB re 1 $m^{-1}$; |
| — | SED | Single Echo Detection; |
| — | SNR | Signal to Noise Ratio; |
| — | ST | Single Target; |
| — | TS | Target Strength; Units = dB re 1$m^2$; |
| — | TVG | Time Varied Gain; |
| — | YOY | Young of the year. |

## 4 Principle and field of application

Hydroacoustic (or echosounding) technologies are effective and efficient methods for sampling fish in the water column [35]. Fisheries acoustics methods are analogous to remote sensing techniques and advantageous to other sampling methods as nearly the entire water column can be sampled quickly and non-destructively, areal coverage is continuous, data resolution is on the order of tenths of metres, and data can be post-processed in a variety of ways. However, other methods and procedures are required for determination of species identity and age structure.

Acoustics is used to gather information remotely by transmitting a pulsed beam of sound energy into a water body and subsequently detecting and analysing the returning echoes. Systems are available with single-, dual-, split- and multi-beams, although the latter two types have now superseded the other two systems. Acoustic systems are usually deployed from a moving boat in large water bodies. A computer is required for control of the echo sounder in the field and for the data processing.

This standard covers acoustic sampling of deep lakes, reservoirs, shallow lakes and wide lowland rivers. The pelagic and profundal waters of lakes > 15 m depth are surveyed with the acoustic beam oriented in the vertical axis, whilst inshore and surface waters of lakes and lowland rivers > 2 m depth are surveyed with the beam oriented horizontally ([21], [25]). Water bodies of all trophic levels can be sampled acoustically and a wide range of fish communities and targets, ranging from young of the year to large mature fish can be detected and quantified (Table 1).

Mobile acoustic surveys provide several layers of information; from relatively simple presence / absence studies of target species, to spatial (or temporal) distributions of individuals or groups, to fully quantitative density and (when combined with other sampling techniques) system-wide biomass estimates.

Correctly obtained acoustic sampling data are directly related to population density. The strategy shall be to sample a defined area or volume of lake or river using appropriate equipment (Clause 5), data collection (Clause 7) and data processing procedures (Clause 8), presenting the results in a standard reporting format (Clause 9) to provide estimates of fish abundance. Abundance in this context can be either a relative or an absolute measure of assessment based on a single survey of a known area or volume of water.

**Table 1 — Suitability of hydroacoustic sampling techniques for inland water bodies and fish communities**

| Application | Objectives | Water Types | Target Species and Life Stages | Limitations |
|---|---|---|---|---|
| Vertical Beaming | Fish population abundance estimates<br>Fish population size structure | Lake Category 1[a]<br>Lake Category 3[b] | Fish in pelagic and profundal waters<br>YOY to adult | Poor coverage of surface and littoral waters<br>Shall be used in conjunction with direct capture methods for species composition and age structure |
| Horizontal Beaming | Fish population abundance estimates<br>Fish population size structure | Lake Category 1[a]<br>Lake Category 3[b]<br>River Category 3[c]<br>River Category 4[d]<br>River Category 5[e] | Fish in littoral and surface waters<br>YOY to adult | Poor coverage of pelagic and profundal waters<br>Vulnerable to interference from macrophytes and entrained air<br>Low confidence in size-structure from lakes and slow-flowing rivers<br>Shall be used in conjunction with direct capture methods for species composition<br>Temperature gradients can introduce biases in fish estimates due to bending of the sound beam. |
| Combined Vertical and Horizontal Beaming | Fish population abundance estimates<br>Fish population size structure | Lake Category 1[a]<br>Lake Category 3[b] | Fish in pelagic, profundal, littoral and surface waters<br>YOY to adult | Horizontal beaming vulnerable to interference from macrophytes and entrained air<br>Low confidence in size-structure from horizontal beaming<br>Shall be used in conjunction with direct capture methods for species composition |

Categories of lakes and rivers: see EN 14962

[a] With a pelagic or profundal zone, area < 0,5 km$^2$;

[b] With a pelagic and profundal zone, area > 0,5 km$^2$;

[c] Width < 30 m, maximum depth > 2 m;

[d] Width 30 m to 100 m, maximum depth > 2 m;

[e] Width > 100 m, maximum depth > 2 m.

# 5 Equipment

## 5.1 General

Although current acoustic equipment is accurate and reliable, it shall be used correctly with a fundamental understanding of factors that can affect its performance. Sources of systematic error or bias in acoustic survey results include calibration errors, hydrographic conditions, diel fish behaviour and migration ([35]). Other practical limitations are sources of unwanted echoes (reverberation), such as plankton, debris, submerged macrophytes and entrained air bubbles.

## 5.2 System performance

### 5.2.1 Minimum requirements

Whilst it is accepted that useful information may be obtained from a wide variety of echosounder types, the minimum requirement for a scientific survey is that a “Scientific” sounder with the following characteristics shall be used:

— quantitative fisheries echosounder (calibrated) and operating at an appropriate frequency for the waterbody and target fish species, probably between 38 kHz and 1,8 MHz [36];

- enables data storage of calibrated data for reprocessing;
- enables data processing in order to generate abundance and size distribution outputs.

#### 5.2.2 Optimum requirements

Because of their inherent and obvious advantages, it is recommended to use scientific split or multi-beam sounders if possible.

## 5.3 Calibration

### 5.3.1 General

Calibrations are conducted to ensure that the echosounder and transducer are measuring fish abundance and fish size correctly. Secondly, they verify that the complete acoustic system is operating properly and remaining stable over time, permitting comparisons amongst survey periods and allowing inter-echosounder comparisons. All calibrations should be based on and follow the manufacturer's manual and recommendations.

### 5.3.2 Types of calibration

#### 5.3.2.1 Full instrument and equipment calibration

This calibration is usually conducted by the manufacturer, once in a lifetime for most transducers, but it should also be done whenever there is reason to believe that the transducer has been subjected to physical damage.

Full calibrations shall be conducted by the manufacturer, or at a facility approved by the manufacturer.

Full calibrations shall be done separately for each transmitted pulse duration, transmit source level and receiver gain settings being used.

Full calibrations should also be done if the transducer, transducer cable or echosounder have experienced any physical damage.

Records shall be kept of each full calibration (if possible, raw data should be stored) and archived with the survey data in order to assess substantial changes in power parameters during the lifetime of the transducer.

#### 5.3.2.2 Beam pattern calibration

This should be conducted prior to each survey (as per manufacturer's instructions) or whenever the transducer or cable is suspected of being subjected to physical damage.

For both vertical and horizontal applications (i.e. vertical deep or shallow lake surveys and horizontal lake and river surveys), beam pattern calibrations shall involve:

- vertical calibration in a free field (i.e. one with no lateral boundaries) under high signal to noise ratio (SNR) conditions;
- confirmation of temperature and salinity in order to accurately determine the speed of sound and absorption coefficient;
- mean water temperature should be measured as a depth profile in 1 m intervals over the whole water column;
- a minimum target distance of 2 × the theoretical near field:

  the transducer may need to be lowered well below the surface of a deep water body to avoid, for example, wave action and bubbles at the surface, whilst still having the necessary range available;

- avoidance of scattering layers such as thermal stratification, fish, air bubbles or zooplankton;
- a minimum distance of 2 × the transmitted pulse length between the calibration sphere and the bottom;
- measurement of beam-width and angle-offset.

After physical trauma to the cable and transducer housing, damage shall be repaired and a new beam pattern calibration shall be conducted.

If the calibration parameters do not deviate too much from previous calibrations, the transducer and cable can be considered fully functional. The manufacturer should be able to provide information about acceptable deviation.

Records shall be kept of each calibration (if possible, raw data should be stored) and archived with the survey data in order to assess substantial changes in power parameters during the lifetime of the transducer.

#### 5.3.2.3 Standard Target tests

These should be conducted at each survey site in order to verify that the system is operating properly and to correct for environmental factors (as per manufacturer's instructions).

For both vertical and horizontal applications (i.e. vertical deep or shallow lake surveys and horizontal lake and river surveys) the standard target test should ideally be carried out at the start of every new survey or day (irrespective of the survey location or strategy) and shall include the following.

a) The passage of a standard target through the beam to check that results are, within tolerances, as expected (e.g. Table 2). Tolerances will vary depending on beam orientation (vertical or horizontal) and the signal to noise ratio (SNR). A minimum of 250 echoes is recommended on the acoustic axis and within each quadrant.

b) The transducer shall be acclimated to water temperature and air bubbles removed from the transducer face and standard target.

c) The standard target test shall be conducted in the same environmental conditions (water temperature and salinity) as are experienced during the survey.

d) Standard target tests shall be conducted with the same pulse durations, transmit powers, and bandwidths used during the survey.

e) For mobile horizontal surveys, a horizontal standard target test, ideally with the standard target positioned at different ranges from the transducer, shall be performed. Low confidence in shallow water or near-boundary TS measurements can be expected due to the potential for non-spherical spreading between boundaries.

f) For mobile horizontal surveys, periodic fixed location temperature profile measurements shall be taken in order to verify normal spherical spreading of the acoustic beam.

No adjustments shall be made to the equipment settings as a result of this test, but a beam pattern or full calibration is required if the result is unsatisfactory. For shallow lakes or horizontal surveys this may require relocating to a suitable test site.

**Table 2 — Example values for target strengths (TS) of tungsten carbide spheres with different diameters for speed of sound (1 450 m/s) in fresh water [35]**

| Frequency<br>kHz | Diameter<br>mm | Fresh Water TS<br>dB |
|---|---|---|
| 38 | 38,1 | −42,0 |
| 70 | 33,2 | −41,3 |
| 70 | 38,1 | −40,6 |
| 120 | 33,2 | −41,0 |
| 120 | 38,1 | −40,1 |
| 200 | 36,4 | −39,8 |
| 200 | 38,1 | −40,0 |
| 420 | 21,2 | −44,3 |

# 6 Survey design

## 6.1 General

Acoustic surveys are conducted to investigate large volumes of water. In practice, owing to the limited time available to perform the survey, only a small proportion of this volume can be observed acoustically. Transect based surveys are, therefore, based on the assumption that the measurements, which are made along the survey tracks, are representative samples of the wider distribution of the target species in the water volume under study [35]. Since only a portion of the overall area of concern is actually sampled, any survey design consists of choices that need to address specific objectives, which can vary from an overall estimate of abundance for an entire population to simply the identification of locations of fish concentrations.

## 6.2 Design for appropriate resolution and detection

When planning a vertical acoustic survey, sampling should be planned in order to produce a three-dimensional picture of fish density using depth strata at least to the resolution of EN 14757 gillnet layers (0 m to 3 m, 3 m to 6 m, etc.). For both vertical and horizontal surveys, the signal to noise ratio should be maximized.

## 6.3 Pre-planning

Prior to conducting an acoustic survey, the following information should be assembled for the water body under study:

a) **Sufficient bathymetric data**. If necessary, pre-surveys specifically for the collection of depth data should be conducted. For surveys of reservoirs, it is important to make a record of water depth at the time of the survey.

b) Resident **fish species data** and **limnological information**.

c) Potential **temperature and oxygen stratification**.

d) **Access permissions**.

e) **Weather forecast** (particularly wind speeds and direction).

f) Identification of the **cruise track**. Define the area to be covered by the survey. Ideally, this would be the entire lake or river, although some areas may not be feasible for hydroacoustics (e.g. too shallow or obstructed by stands of macrophytes). Within the area under consideration, the choice of spacing and track layout (e.g. systematic parallel, random parallel, systematic zig-zag, etc.) should reflect an understanding of the serially correlated nature of the acoustic sampling technique and a consideration of the expected patchiness of the population of interest.

**For lakes** the preferred recommended hierarchy of cruise tracks are:

1) a systematic parallel design, with allowance for inshore bathymetry and weather conditions;

2) a zig-zag design.

Other options should only be considered if conditions preclude the above.

**For rivers** the preferred cruise track is to move up one bank beaming horizontally to the far bank, returning along the other bank. Ideally, the surveyed stretch should be between impounding structures such as locks and weirs.

When designing the cruise track, it is important to understand how the precision of the results depends upon the transect spacing. The coefficient of variation ($CV$) of the abundance estimate depends upon the degree of coverage, $\Lambda$ ([3]) defined as:

$$\Lambda = D / \sqrt{A} \tag{1}$$

where

$D$ is cruise track length;

$A$ is the area being surveyed.

Then:

$$CV = a(\Lambda)^{-0,5} \tag{2}$$

where

$a$ is a variable between 0,4 and 0,8, depending on fish distribution; higher values of $a$ are appropriate when fish are concentrated in a few large schools, low values when the fish are more uniformly distributed [35].

g) **Working time**. The working time available for the collection of acoustic data should be calculated. For both water bodies (lakes and rivers), time may have to be factored in for stationary measurements for specific purposes, e.g. aspect identification for sizing Target Strength (TS) in horizontal surveys, hydrographic sampling, etc.

h) **Preparation of the survey track data for GPS**. The survey plan (i.e. waypoints and transects) should be in a format suitable for transfer to GPS.

i) **Appropriate vessel**. The selection of an appropriate vessel is important. This should be stable and low noise (with a preference for 4 stroke over 2 stroke motors, or electric if feasible). Cruise speed should be a maximum of 10 km/h Actual speed selection should be appropriate for the ping rate and water depth, aiming for a minimum of 3 hits on a fish of interest when target-tracking / trace-counting.

## 6.4 Timing of surveys

The timing of acoustic surveys should consider the following factors.

Surveys should be conducted during the period when the target fish are in open water and most dispersed.

The following seasonal factors should be considered when planning an acoustic survey [38]:

- recruitment patterns; depending on the objective of the survey, under-yearlings may be deliberately included or excluded;
- beware of spawning time generally;
- beware of winter aggregations;
- beware of migrations (e.g. diadromous species);
- beware of sources of acoustic interference (e.g. Chaoborus larvae, other invertebrates, fish larvae, macrophytes, bubbles as a result of decreased hydrostatic pressure associated with draw-down, leaves, increased noise during high flows, boat traffic, etc.).

Optimal sampling periods may differ between countries and regions.

Diel timing of acoustic surveys is also important. If no pre-existing information on fish distribution patterns is available, then carry out both day and night surveys. For night surveys, avoid the full moon. Avoid transitional times (usually dawn and dusk). Restrict survey time from 1 h after sunset to 1 h before sunrise. Night is usually best for surveys of both lakes and rivers.

Surveys shall be conducted under homogeneous environmental conditions. If conditions change significantly during the course of a survey, it should be abandoned.

## 6.5 Transducer orientation and position

### 6.5.1 General

In 6.3 and 6.4 factors, that are common to both vertical and horizontal surveys, are considered. There are also factors that are specific to the survey mode, requiring different approaches to equipment deployment and operation.

In general, the uncertainties and potential errors are much greater for horizontal data. The preferred method for acoustic sampling is vertical beaming, due to a number of factors (Table 3).

Combined vertical and horizontal surveys, or combined up-beaming and down-beaming surveys, may be required on deeper lakes when a large proportion of the fish population are distributed close to the water surface ([17], [21]).

**Table 3 — Comparison of factors influencing data quality for horizontal and vertical surveys**

| | **Horizontal surveys** | **Vertical surveys** |
|---|---|---|
| Signal-to-noise ratio | Low | High |
| Aspect of fish relative to the transducer | Often unknown | Dorsal |
| Weather conditions | Highly susceptible to adverse weather (wind, waves, heavy rain) | Less susceptible to adverse weather |
| Vessel stability | High influence on measurements | Low influence on measurements |
| Boat traffic | Susceptible to acoustic interference from other vessels | Less susceptible to acoustic interference from other vessels |

### 6.5.2 Requirements specific to vertical surveys

The maximum pulse repetition rate shall be calculated according to the maximum depth sampled.

The transducer depth should be as shallow as possible, but greater than depths that generate micro-bubbles.

The transducer should be oriented as near as possible to the vertical.

### 6.5.3 Requirements specific to horizontal surveys

Transducers with a short nearfield and small side-lobes should be used in small, shallow rivers (width = 15 m, depth = 2 m).

The transducer should be on an adjustable mount allowing small changes in both vertical (tilt) and horizontal (pan) planes.

The transducer shall be at least one transducer face dimension below the surface of the water.

The transducer shall be tilted in order to approach the Maximum Useable Range (MUR). This is a function of the space between the surface and bottom boundaries and the beam shape ([22]).

The transducer tilt and pan angles shall be optimized, recorded and maintained during the course of an acoustic survey.

The acoustic beam should be approximately perpendicular (or slightly forwards) relative to the cruise track.

Care should be exercized selecting a ping-rate when beaming across substantial water widths towards a distant, non-smooth shore. One approach is to measure reverberation levels with increasing ping rate, the optimal rate being just before reverberation levels sharply increase.

## 6.6 Requirements for acoustic inter-comparisons

When inter-calibrating or comparing the outputs from different acoustic systems or survey teams, care shall be taken to ensure there is no acoustic interference between the test echosounders.

Trials shall be conducted prior to the investigation to test for significant cross-talk between the systems on the survey vessel. In the absence of cross-talk, the echosounders can be operated simultaneously on the same boat.

Where significant interference is detected, the second system shall be mounted on a separate boat. The second vessel shall follow the first vessel along the same route, approximately 300 m apart ([37]). The two vessels should interchange the lead on alternate transects.

It is important to ensure there is no acoustic interference from other devices on the vessel (e.g. depth sounders, invertors).

# 7 Survey data acquisition

## 7.1 Acoustic data

For both vertical and horizontal surveys, the following acoustic data are required in order to measure abundance:

- intensity samples with as high range resolution and ping rate as the equipment, data storage capacity and environment will allow;
- the time of each ping;
- the start and end ranges of sample collection;
- where possible, unthresholded raw data should be collected; otherwise, the lowest possible threshold should be used for data collection appropriate for normal survey conditions.

NOTE Echo Integration and Single Echo Detection (SED) / Single Target (ST) are regarded as post-processing techniques and are described in Clause 8.

## 7.2 Echosounder settings

The following echosounder settings shall be adjusted and recorded in order to optimize the acoustic data collected:

- ping-rate, based on maximum depth or range to be surveyed;
- the transmit power, pulse length and bandwidth should be set to give the best signal to noise ratio for the appropriate range resolution, these parameters are directly linked;
- speed of sound ($c$) and sound attenuation ($\alpha$); setting $c$ and $\alpha$ requires a priori knowledge of environmental conditions (water temperature and salinity).

## 7.3 Data acquisition from additional equipment

Fish sampling is affected by physical and geographical factors. Therefore supplementary data should be collected (see Annex A, Table A.1). As a minimum, acoustic data should be supported by the following geographic and environmental information as part of a survey log.

a) **Geographical position**.

b) **Temperature** (required for sound attenuation and speed of sound values in echosounder settings). For vertical surveys, determining average water temperature from a temperature profile is recommended. For mobile horizontal surveys, periodic fixed location temperature profile measurements should be taken in order to verify normal spherical spreading of the acoustic beam.

c) **Salinity/conductivity** (required for sound attenuation and speed of sound values in echosounder settings).

d) **Tilt angle of transducer**. The use of an attitude or orientation sensor is recommended.

e) **Weather data**, including prevailing wind strength and direction and wave action (height).

f) **Moon phase**.

g) Prevailing **water currents**.

h) **Lake surface area, mean** and **maximum depths**.

A comprehensive survey log is required, recording all anomalies during the survey and any changes to system settings.

All data shall be recorded in a consistent format. The recommended format is the HAC format of the ICES FAST technical committee, however .RAW (HTI and Simrad), .SMP (HTI), .DG (Simrad) and .DT4 formats (BioSonics) are also acceptable.

# 8 Post-processing of acoustic data

## 8.1 General

Post-processing of acoustic data consists of a pre-analysis phase and an analysis phase, and requires the use of specialist acoustic post-processing software (e.g. Echoview, EchoScape, Visual Analyzer and Sonar5-Pro[1]).

## 8.2 Pre-analysis

### 8.2.1 Bottom detection

Bottom detection is an essential component of accurate acoustic abundance estimates:

In vertical surveys, the collection of samples from the bottom should be avoided as they usually represent a very large acoustic biomass. Bottom tracking algorithms should be used for setting the bottom position, beyond which no usable data are accepted. A bottom window or margin can also be used to decrease the probability of echo integrating the bottom signal, however this will increase the ‘blind zone’ and fish close to the bottom will not be recorded [35]. The margin should not exceed 0,5 m for most applications. When automatically applying the bottom line within the software, the line should be visually inspected and corrected for any errors.

In horizontal surveys, the “bottom” (i.e. the opposite bank) is often of variable strength and range. The maximum range should be defined as where the background noise exceeds a level 6 dB below the minimum target size. Manually setting the bottom is often the most practical option.

### 8.2.2 Discrimination

#### 8.2.2.1 General

Discrimination is the separation of unwanted echoes such as air bubbles, debris, surface and bottom reverberation and plankton from target echoes. In order to set target threshold levels, the noise level at range shall be defined. As modern digital echosounders enable all sample data to be collected, there is no need to filter the data during data collection, and all filtering procedures can be conducted during data processing.

#### 8.2.2.2 Separating noise reverberation and setting TS thresholds

Weak unwanted signals (noise echoes) are usually extremely numerous and can seriously bias abundance estimates. Setting a noise threshold (i.e. a low threshold) is the most common way of drawing a clear line between wanted and unwanted signals. In less frequent cases, a high threshold can be used where targets bigger than a certain size are excluded. This can be useful, for example, when larvae are targets of interest and larger fish are considered interference [8], [18].

The theory behind setting both low and high thresholds is similar. The investigator should know what size targets require analysis, and what is possible.

The investigator should decide on the size range of investigated fish in terms of length and Target Strength. Minimum and maximum lengths of fish should be converted into Target Strength using an appropriate regression based on fish species present and aspect to the transducer (examples of which are given in Annex C). The resulting $TS_{min1}$ and $TS_{max1}$ provide the first guidance for setting an appropriate threshold.

The population of targets should be processed using a TS threshold 20 dB lower than $TS_{min1}$ in order to obtain the TS frequency distribution of targets (Figure 1) around the suggested $TS_{min1}$. At this stage, SED /

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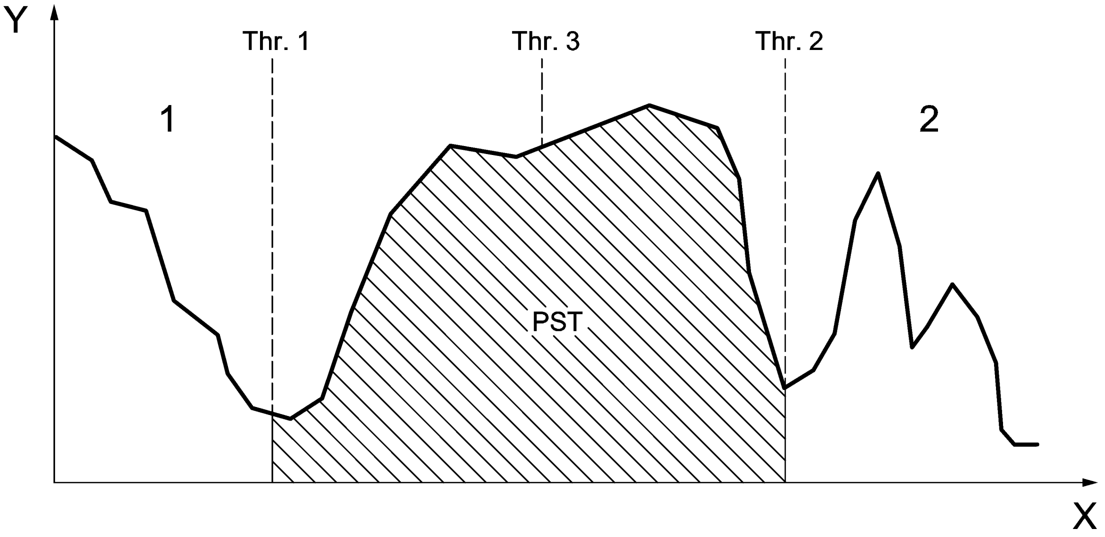
[1] Sonar5-Pro® (Lindem Data Acquisition, Oslo, Norway), Echoview® (Myriax, Tasmania, Australia), EchoScape® (HTI, Seattle, USA) and Visual Analyzer® (BioSonics, Seattle, USA) are examples of suitable products available commercially. This information is given for the convenience of users of this European Standard and does not constitute an endorsement by CEN of these products.

ST criteria can be kept on default values (see Single Echo / Target Detection Scenarios below). The analysis threshold (Thr.) should then be set at a trough in the TS frequency distribution, thereby accepting or rejecting a whole peak of small targets (PST; see Figure 1, Thr. 1 or Thr. 2).

Setting a threshold that cuts through a peak in the TS frequency distribution is poor practice (Figure 1, Thr. 3), as this would result in an undefined population of targets being analysed. For example, a small change in the threshold or a small increase in fish length would result in a false increase in abundance.

The decision about accepting or rejecting a peak of small targets should comply with the aims of the survey and/or the nature of PST assessed by direct biological sampling.

The threshold established by this protocol (TSmin2) should be displayed on a 40 log R TVG amplitude echogram in order to check whether the targets are thresholded beyond background noise levels (noise signals often do not satisfy SED / ST criteria but can be recorded on amplitude echograms). If the targets are not safe from the noise, the threshold setting procedure above and hence TSmin2 should be reconsidered.



**Key**

| | |
|---|---|
| X | TS (dB) |
| Y | frequency |
| 1 | noise |
| 2 | larger fish |
| Thr 1 | Threshold value 1 |
| Thr 2 | Threshold value 2 |
| Thr 3 | Threshold value 3 |
| PST | Peak of Small Targets |

NOTE PST represents the peak of small targets, often young-of-the-year fish, which can seasonally be very numerous in natural populations.

**Figure 1 — Hypothetical example of unsuitable (Thr.3) and more suitable (Thr. 1 and 2) ways of setting the noise threshold for fisheries surveys**

NOTE 1 In poor signal-to-noise conditions, finding the natural minima of a TS distribution can be difficult. In such conditions, the abundance estimates of small targets will not be reliable.

NOTE 2 Noise levels usually increase with the range, so it is possible to estimate small and larger fish at close ranges but only larger fish at further ranges. If estimates of small fish are required, it can be necessary to lower the range. Larger fish can be estimated in all ranges using the same (higher) threshold.

If echo-integration is being used, $TS_{min2}$ shall be transferred to volume backscattering strength ($S_v$) values. If processing 20 log R echogram is a priority, the $S_v$ threshold should be adjusted until approximately the same population of targets can then be seen on both 20 log R and 40 log R echograms. At longer ranges, the 20 log R threshold can be range dependent.

#### 8.2.2.3 Separating noise echoes by manual classification

Some sources of noise cannot be removed with a threshold and other methods shall be used to remove them from the analysis. For example, reverberation from bubbles (e.g. boat wake or surface entrainment), transducer ring-down and interference from other echosounders all fall into this category. These sources of noise shall be manually or automatically excluded from the analysis by setting exclusion or ‘bad data’ areas on the echogram.

### 8.2.3 Single Echo/Target Detection (SED/ST) scenarios

#### 8.2.3.1 General

SED/ST criteria shall be selected according to the chosen abundance estimation method (see 8.3.1) and the signal to noise ratio (SNR) defined below.

#### 8.2.3.2 Accurate size distribution when SNR is high (>10 dB)

Under high SNR conditions, high precision TS measurements are obtained from the central part of the beam, when the phase is stable, there is good suppression of multiple echoes and a low degree of unwanted detections from noise and background. This is normally obtained with SED / ST criteria set below:

| | |
|---|---|
| — Echo Length detector: | 0,7 times to 1,4 times the transmitted pulse length; |
| — Pulse length determination level: | 6 dB; |
| — Maximum Phase Standard Deviation (if available): | 0,15. |

Maximum Phase Standard Deviation is the standard deviation in mechanical samples measured in degrees. Different echosounders operate with different definitions. In general, the manufacturer’s recommendations for a strict setting should be applied.

| | |
|---|---|
| — Max Gain Compensation: | 3 dB (one-way); |
| — Multi-peak suppression: | applied. |

#### 8.2.3.3 Track counting when SNR is medium (<10 dB)

When track-counting (trace-tracking) in a medium SNR environment, wider echo selection criteria can be applied:

| | |
|---|---|
| — Echo Length detector: | 0,6 times to 1,6 times the transmitted pulse length; |
| — Pulse length determination level: | 6 dB; |
| — Maximum Phase Standard Deviation (if available): | 0,5; |
| — Max Gain Compensation: | 6 dB (one-way); |
| — Multi-peak suppression: | not applied. |

#### 8.2.3.4 Track counting when SNR is low

If the SED / ST criteria for medium SNR fail (i.e. it generates insufficient detections in each size-class in question to be statistically valid) and sample data are available, methods designed for low SNR conditions such as a cross filter detector [5] or the track before-detection method [14] can be used.

## 8.3 Analysis

### 8.3.1 Abundance estimate methods

Three different methods can be used to provide acoustic abundance and biomass estimates; $S_V$/TS scaling, track-counting (trace tracking) and echo counting. Selection of the appropriate method for any given survey depends on target density, quality of SEDs/STs, the signal to noise ratio and the quality of GPS data. A description of each method and conditions under which each may be used is summarized in Annex B (Table B.1).

These methods can take four different sources for the involved size distribution; single echo detections, tracked fish *in situ*, tracked fish ex situ and catch data. The following subclauses give advice on which source to select.

*In situ* means that the size distribution will be built from echoes within the analysed region of the echogram. *Ex-situ* means that the size distribution will be built from targets outside the analysed region.

### 8.3.2 Vertical surveys

#### 8.3.2.1 Method 1 - Echo integration

In high SNR environments with high densities of targets, echo integration (Sv/TS scaling) is recommended. The backscattered energy should be scaled using the size distribution of tracked fish, as they provide more accurate TS estimates. If densities are too high for target tracking, use SEDs/STs, ensuring the TS data originates from the layers of interest. If these densities are too high, SEDs/STs from other layers or other locations and periods should be used assuming they apply to a given case (see 8.2.3 and Annex B, Table B.1).

#### 8.3.2.2 Method 2 - Track-counting

Track-counting should be used in all SNR conditions with low target densities.

#### 8.3.2.3 Method 3 - Echo-counting

In high SNR environments with a low density of targets and in the absence of GPS information, echo counting can be employed.

### 8.3.3 Horizontal Surveys

Horizontal surveys of rivers and lakes are generally conducted in low SNR environments. Track counting is therefore recommended under these conditions.

### 8.3.4 Biomass estimates

#### 8.3.4.1 General

Conversion from numerical density estimates to biomass estimates requires information on the size distribution of the targets of interest.

These can be established for acoustic data from:

1) Target Strength of tracked fish;

2) Target Strength of SEDs/STs;

3) Catch (converted via appropriate TS - length and length - weight regressions).

#### 8.3.4.2 Vertical surveys

For vertical surveys the recommended hierarchy of size distribution data sources are:

1) tracks;

2) SED/ST;

3) catch.

#### 8.3.4.3 Horizontal surveys

For horizontal surveys in lakes and slow-flowing rivers under low SNR conditions, the recommended hierarchy of size distribution data sources are:

1) catch data;

2) tracks.

For faster flowing rivers, where fish are oriented into the current or in side-aspect to the transducer (identified, for example, from fixed location data) or under high SNR conditions, tracks are preferred to catch data.

## 9 Calculation of Results

### 9.1 Aim

Following survey data acquisition and post-processing, the following data outputs are used in order to quantify and assess the lake or river fish stock.

a) Echograms obtained from the survey; these should always be visually inspected.

b) Volume backscattering strength ($S_v$), area backscattering strength ($S_a$), TS distribution and fish abundance (per unit volume or area).

c) Vertical and horizontal distributions of $S_v$, $S_a$, TS and fish abundance.

d) Associated environmental data (temperature, oxygen, nutrients, flow), if available.

e) Biological fish samples, if available.

### 9.2 Identification of targets

Apportioning targets between species or groups of species is termed “Identification”.

Acoustic techniques are presently unable to reliably identify species directly. Therefore, biological data should be acquired to supplement the acoustic data and for comparisons.

Where possible, direct or indirect biological records should be assembled. These shall come from the same area, depths, time (season and diel) and size range as the acoustic data. If applicable, the appropriate sampling method should be used (see EN 14962).

Imaging techniques like video footage may also be used.

It may not always be possible to acquire biological samples from all water bodies or all areas of a water body. In the absence of comprehensive sampled data, information may be inferred from biological or local knowledge.

In vertical surveys, species such as coregonids inhabit deep waters whereas underyearlings are found near the surface.

In horizontal surveys, there may be inter basin and intra basin (e.g. inshore vs. offshore) differences in species distribution.

The biological identification information may be supplemented to a limited extent by using acoustic data. Some approaches that may aid identification of species are:

a) Fish behaviour. This is a limited application where fish may be identified by:
    1) differences in swimming speeds from fixed location studies;
    2) the direction of movement in both vertical and horizontal planes;
    3) differences in diel and seasonal timings of movements;
    4) the release of bubbles by fish [20].
b) Individual fish and groups of fish may be identified through their echo signature:
    1) the existence of shoals and their size and shape [33];
    2) Target Strength can be an indicator of individual size and shifts in TS over time as a function of growth can be identified (see 9.3).

### 9.3 Interpretation of Target Strength data

The relationship between Target Strength and fish length depend on a number of factors.

a) **Directivity** (i.e. aspect to the transducer) has the highest explanatory power, explaining > 80 % of the data variability [11], [28].
b) Individual **size** explains > 12 % of the variability in TS.
c) **Fish species**, although in practice this is not so important between most European fresh water species.
d) The transmitted **sound frequency**. Again, in practice this is not so important between 50 kHz and 500 kHz.

The following recommendations apply to conversions from Target Strength to fish length.

For vertical surveys, see Annex C, Table C.1, for examples of dorsal TS - length regressions.

For horizontal surveys, see Annex C, Tables C.2 and C.3, for examples of all aspects, or limited side and head/tail aspect TS - length regressions. Fish lengths may be estimated from all aspect TS distributions (e.g. shallow water lakes surveys) using the deconvolution procedure described in Annex D [23].

For both vertical and horizontal surveys (combined surveys), Bibliographical Entry [28] is a source of reference if little is known of the investigated species.

If the biologically observed length distribution disagrees significantly with that reconstructed from acoustics, then this shall be flagged as a quality assurance issue (see Clause 10).

### 9.4 Determination of weight and biomass

If biomass is to be derived from acoustic data, the average weight of the target fish should first be determined. This can be done in three ways:

- — assume the average weight of fish based on biological sampling;
- — apply appropriate length - weight relationships to length data derived from the TS distribution;
- — directly use weight - TS regressions.

Examples of appropriate relationships for both horizontal and vertical data are presented in Annex C, Table C.4.

Biomass is subsequently determined as abundance multiplied by the average weight. If working with length-weight relationships and different length groups, Formula 9.17 in [35] applies. An unbiased estimate of the total weight is:

$$W_t = a_f \sum_j n_j \left\{ (L_j + \Delta L / 2)^{b_f + 1} - (L_j - \Delta L / 2)^{b_f + 1} \right\} / \left\{ (b_f + 1) \Delta L \right\} \tag{3}$$

where

| | |
|---|---|
| $a_f$ and $b_f$ | are constants for one species from the relationship $Weight = a_f \cdot Length^{b_f}$ ; there are $n_j$ individuals in the j<sup>th</sup> class; |
| $L_j$ | is the mean length; |
| $\Delta L$ | is the interval between successive classes. |

## 9.5 Outputs of acoustic data

### 9.5.1 Fish abundance as numerical density

Abundance can be defined with respect to area or volume. It is recommended that results from vertical surveys are reported as an area-based metric (e.g. fish per ha), and results from horizontal surveys as a volume-based metric (e.g. fish per 1 000 $m^3$).

Each transect can provide a single local estimate of the mean density of the insonified fish. However, a fixed time interval or length of the cruise track along which the acoustic measurements are averaged can also be used to give one sample (termed the elementary distance sampling unit - EDSU). The EDSU should be small enough to capture the main spatial structure of the stock, but not so small that the correlation between pairs of successive samples is rather large [35]. A worked example is given in Annex E. Typically, the EDSU may be in the range of 0,1 km to 5 km.

Area abundance is an integral of depth-specific volume abundance.

Calculating the sampling error (variance) of the abundance estimate will depend on the sampling design. For randomly positioned or systematic parallel transects samples are independent, so simple statistical theory can be applied. Geostatistics is an appropriate approach to apply to data collected from parallel, zig-zag and longitudinal designs, where the samples are spatially correlated. Further information on estimating variances is given in 9.6 and Annex F.

### 9.5.2 Size structure

The acoustic size-structure of the surveyed fish population can be presented as TS frequencies.

If length frequencies derived from TS data are presented, the TS – length regression applied and assumed aspect (e.g. dorsal, side, all aspect, all aspect deconvolution, etc.) shall be stated.

### 9.5.3 Biomass

Biomass is a function of abundance and individual weight (see 9.4) and should be expressed as kg per unit volume or area.

Biomass can also be expressed as acoustic biomass; $S_v$ is volume backscattering strength whilst $S_a$ is $S_v$ recalculated into area backscattering strength [30].

## 9.6 Estimates of sampling variance and precision

### 9.6.1 Precision of estimates

The precision of acoustic abundance and biomass estimates is mostly affected by the survey design, the patchiness of the fish distribution and the inherent variability of the densities encountered [3]; [35]. Further information is given in Annex F.

### 9.6.2 Simple Random Analysis

These formulae are appropriate for data collected by simple random and systematic parallel transect surveys. Each transect provides a single local estimate of fish density. Calculations of means and variance assume the randomly selected observations are independent and identically distributed:

Average density ( $\bar{\rho}$ ) and variance ( $s_\rho^2$ ) are calculated from the density for each transect $i$ ( $\rho_i$ ) over all $n$ transects:

$$\bar{\rho} = \frac{1}{n}\sum_{i=1}^{n}\rho_i \tag{4}$$

$$s_\rho^2 = \frac{1}{n-1}\sum_{i=1}^{n}(\rho_i - \bar{\rho})^2 \tag{5}$$

The standard error for the estimate of the average abundance per transect ( $SE(\bar{\rho})$ ) is:

$$SE(\bar{\rho}) = \sqrt{\frac{s_\rho^2}{n}} \tag{6}$$

Assuming the transects are representative of the whole area ($A$) and that the area is known, expansion of average density to an estimate of total population ($N$) is straightforward:

$$N = A \cdot \bar{p} \tag{7}$$

The corresponding standard error of the total abundance estimate $SE(N)$ would be:

$$SE(N) = A \cdot SE(\bar{p}) \tag{8}$$

### 9.6.3 Stratified Analysis

The following formulae are appropriate for surveys with systematic parallel samples nested within strata (e.g. different basins within a lake). Individual density estimates are calculated for each stratum and then merged based on the relative size of each stratum.

Average density ( $\bar{\rho}_h$ ) and between transect variance ( $s^2_{\rho_h}$ ) within each stratum $h$:

$$\bar{\rho}_h = \frac{1}{n_h} \sum_{i=1}^{n_h} \rho_{h,i} \tag{9}$$

$$s^2_{\rho_h} = \frac{1}{n_h - 1} \sum_{i=1}^{n_h} (\rho_{h,i} - \bar{\rho}_h)^2 \tag{10}$$

where

$n_h$ is the number of transects in strata $h$, and;

$\rho_{h,i}$ is average density on transect $i$ in strata $h$.

The global mean for the stratified estimate ( $\bar{\rho}_{str}$ ) is:

$$\bar{\rho}_{str} = \frac{1}{A} \sum_{h=1}^{L} A_h \cdot \bar{\rho}_h \tag{11}$$

where

$L$ is the total number of strata;

$A$ is the total area of all strata ( $\equiv A_1 + A_2 + ... + A_L$ );

$A_h$ is the total area of each stratum $h$, and;

$\bar{\rho}_h$ is the average density within each stratum $h$.

The corresponding standard error for the stratified estimate (*SE*( $\bar{\rho}_{str}$ )) is:

$$SE(\bar{\rho}_{str}) = \sqrt{\left[ \sum \left( \frac{A_h}{A} \right)^2 \left( \frac{s^2_{\rho_h}}{n_h} \right) \right]} \tag{12}$$

where

$n_h$ is the number of transects in each stratum $h$, and;

$s^2_{\rho_h}$ is the between transect variance in average abundance for strata $h$.

Assuming the transects are representative of each strata and that the area of each strata is known, the expansion to total population is identical to the simple random survey calculations above (Formulae (9) and (10)).

## 10 Quality control and quality assurance

### 10.1 General

All protocols and procedures should be directed towards the collection of good quality data in the first instance. This will minimize the need for adjustments and compensation during post-processing and help to reduce uncertainty.

### 10.2 Quality control

Quality control is an active process which derives from good practice and requires, *inter alia*, the following:

- consistent application of this standard, including proper understanding and use of terms and definitions;
- clear objectives of the survey purpose and required outputs;
- appropriate training of personnel in acoustic theory and practice (for survey and post processing of the data) in accordance with international, national and/or organizational requirements (the use of dedicated personnel will assist in this context);
- ongoing review of performance and updating of procedures in line with International best practice;
- continuous control of integrity of all the acquired data;
- consideration of replication of survey(s) to assess the reproducibility of the results; this means, for example, that population estimates for an enclosed water body should be within the acceptable confidence limits.

### 10.3 Quality assurance

Quality of data is influenced by the quality of the equipment used (see minimum equipment specification), design of the sampling programme, accuracy and precision of the measurements and the reliability of the system, including proper calibration as described above.

Data storage may be an issue if data are stored on magnetic tape – appropriate handling and storage procedures should be followed. Appropriate data backup is strongly recommended in all cases.

When upgrading hardware, inter-comparison surveys between old and new equipment should be carried out.

Given the diversity of systems and approaches in use, it is recommended that, where possible, inter-comparison shall be carried out, comparing the results of different teams and types of equipment (see 6.6 and ([37])). This will be especially important at sites of mutual interest e.g. water bodies crossing National boundaries but any inter-calibration or comparison is highly desirable. The same will apply to equipment upgrades and changes.

Cross-checks should also be applied to data analysis, whereby data are subjected to re-analysis and review by other experts.

## 11 Survey report

### 11.1 General

The survey report shall contain a reference to this European Standard (EN 15910) and the information listed in the following.

### 11.2 Objectives, sampling location and staff

The following details are minimum requirements and shall be reported:

a) objectives (distribution, abundance, behaviour, etc.);

b) sampling site (name);

c) type of water (river, lake, reservoir, etc.);

d) water body (name);

e) geographic locality coordinates (e.g. by GPS or a large-scale map);

f) survey team (leader and crew members);

g) acoustic survey method (vertical, horizontal, combined, mobile, fixed location, etc.);

h) date (year-month-day);

i) time of the day (beginning and end of survey);

j) other details (including previous knowledge such as fish species present, mean depth, maximum depth, etc.).

## 11.3 Equipment and prerequisites

The following details are minimum requirements and shall be reported:

a) acoustic equipment employed (manufacturer, model and version of data collection software);

b) operating frequency in kilohertz (kHz);

c) pulse duration in Milliseconds (ms);

d) pulse repetition rate per second ($s^{-1}$);

e) range sampled in metres (m);

f) transmit power in Watt (W) and receiver sensitivity in decibel (dB);

g) temperature of water in degree Celsius (°C);

h) vessel used and details (e.g. engine type);

i) transducer depth and orientation.

The following additional information is optional:

j) resistance or conductivity value of water in Megaohms per centimetre (MΩ/cm) or Millisiemens per metre (mS/m).

## 11.4 Track details, site details and conditions

The following details are minimum requirements and shall be reported:

a) transect waypoint locations (GPS);

b) transect lengths in metres (m);

c) direction and repetition of transect surveys;

d) geographic position of any fixed-location sites (GPS);

e) degree of coverage [3]; also specify whether the survey covers the whole waterbody or a defined area of the waterbody;

f) survey speed in metres per second (m/s);

g) altitude of waterbody in metres (m);

h) water level (e.g. low, intermediate, etc.); in metres (m) if surveying a reservoir;

i) weather conditions (air temperature, precipitation, cloud cover, wind speed and direction);

j) visibility (colour and/or turbidity of the water);

k) biological sampling method, locations and effort (e.g. seine net, gillnet, etc.).

The following additional information is optional:

l) photographic documentation;

m) presence of submerged macrophytes.

### 11.5 Survey results

The following details are minimum requirements and shall be reported:

a) EDSU lengths in metres (m);

b) TS and $S_V$/$S_a$ $_a$ thresholds in decibel (dB);

c) SED/ST criteria used (echo length, Maximum Gain Compensation, Maximum Phase Deviation, Multi-peak suppression, etc.) and applied SED/ST detector (e.g. integral Simrad, integral HTI, cross-filter, etc.);

d) density estimate method applied (e.g. $S_v$/TS scaling, track-counting, echo-counting);

e) post-processing software used and version;

f) arithmetic mean density of all individual transects or EDSU samples with Standard Deviation or confidence limits. Vertical surveys should be reported as area density (e.g. fish per ha), horizontal surveys should be reported as volume density (e.g. fish per 1 000 $m^3$). In some situations, geometric mean may be more appropriate ([6]);

g) acoustic size structure (dB classes);

h) recorded species (common name and reference to scientific name);

i) recorded number of specimens by species or group of species;

j) length of specimens in millimetres (mm).

The following additional information is optional:

k) method used in conversion from acoustic size to biomass estimate (e.g. regressions used);

l) geometric mean biomass of all individual EDSU samples and Standard Deviations or confidence limits (use area biomass for vertical surveys and volume biomass for horizontal surveys).

Numerical density may be converted into and reported as biomass (in kg per unit volume or area, e.g. kg/ha) but this may introduce additional uncertainty because of the inherent assumptions.

# Annex A
(informative)

## Supplementary data

### Geographical information

#### Lake identification

Name and number of the lake (coordinates in national grid system or longitude-latitude).

#### Watershed identification

Name and number of water system.

#### Altitude

Altitude is given in m above sea level. Preferably data from national geographical or hydrological institutes are used.

#### Lake area

The area of the lake should be given according to accepted references. If the area substantially deviates from the area measured from maps or by other sources, both areas and references should be given.

#### Lake depth

If available both maximum and average depth should be given in m. If no published data are available, data obtained during fish sampling using an echosounder may be given as preliminary data.

### Physical data (usually measured once during fish sampling)

#### Vegetation

Coverage and plant infested volume shall be given when appropriate.

#### Water transparency (at deepest part)

Water transparency, usually is measured as Secchi disc depth, given in fractions of a metre.

#### Temperature (at deepest part)

A temperature profile is registered at 0,5 and then at each full metre to maximum depth.

#### Water chemistry (at deepest part)

When available, water chemistry data should be added to the fish sampling. Water quality data reflecting nutrient load (phosphorus and nitrogen), oxygen depletion (oxygen at hypolimnion) and acidification status (pH, alkalinity and/or Acid Neutralization Capacity) are preferable.

### Sampling information

#### Date of sampling effort

When gill-netting or fyke-netting, the first and last date for setting and lifting the nets should be given.

**Number of efforts**

The total number of fishing efforts used at different depth strata in the sampling should be recorded.

**Type of sampling equipment used**

Including mesh sizes, trawl aperture and speed, etc.

**Type of sampling design**

The type of sampling design should be given (e.g. time series, inventory sampling, etc.).

**Timing of sampling effort**

Hourly precision.

**Responsibility**

The sampler and institute responsible for the sampling should always be given.

# Annex B
(informative)

## Methods for estimates of fish abundance

**Table B.1 — Summary of methods for estimates of fish abundance**

| METHOD | USE | ABUNDANCE | COMMENT |
|---|---|---|---|
| Method 1a:<br>$S_v$/TS scaling with SED / ST or *in situ* targets as source | Use this method in situations with:<br>- High target density<br>- Reliable *in situ* single echo / target detections (SED / ST) | Abundance is found by dividing the average integrated $S_v$ with average TS obtained from the SED / ST-echogram or from tracked fish. If tracked fish are selected as the source for size distribution data, only tracks found within the analysed region will be applied. | Applying tracked targets or fish may reduce variability in the TS distribution and exclude noise- based detections. If no reliable TS-distribution can be obtained, consider applying ex-situ targets or catch as the source for size distribution data.<br>Note that this method assumes a constant density within each layer to be analysed. |
| Method 1b:<br>$S_v$/TS scaling with ex-situ targets or catch as source | Use this method when you have:<br>- High fish density<br>- No reliable single echo detections | Abundance is estimated by $S_v$/TS scaling, but the size distribution is taken from the selected tracked targets or artificial tracks obtained from catch data. Targets outside the analysed region will be applied to build the size distribution, in addition to tracks located within the analysed part of the echogram. | This method is the established method for abundance estimation for large schools at sea. As an example, a herring school is normally too dense to give reliable SED / ST and single targets seen around the school are often predators. Applying catch data from the school will therefore provide a more reliable size distribution than the detected single echoes. |
| Method 2:<br>Trace or track counting with *in situ* tracks as source | Use this method when you have:<br>- Low fish density<br>- Noise<br>- Reliable GPS data | Abundance is found by dividing the number of tracked fish by the monitored water volume. Water volume is estimated as a wedge along the sailed transect. This method works only with tracked fish. Since this method counts tracks and not SEDs, it is more robust to missing detections than the echo counting method. Note that the method needs GPS information to calculate the sampling volume. | For fish size information, it is recommended to use the arithmetic mean TS from the off-axis compensated echoes making up the track (i.e. TS is transferred to the linear domain before the mean is calculated). |
| Method 3:<br>Echo counting with SED / ST or *in situ* tracks as source | Use this method when you have:<br>- Low fish density<br>- High single echo detection probability<br>- No GPS data | Abundance is found by dividing the number of single echo detections by the number of pings * beam volume. The method is:<br>- sensitive to missing detections from fish due to noise and schooling<br>- sensitive to false detections from unwanted targets. This can be avoided with tracking.<br>- does not assume constant density in the analysed layer. | Use this method in situations with low fish density, few false SEDs / STs within the size classes in question and no GPS data available for track-counting. All SEDs / STs in the echogram or just SEDs / STs making up fish tracks can be applied. With tracked fish SEDs / STs, the use of false detections is minimized. |

# Annex C
(informative)

## Interpretation of TS into fish length and weight

The relationship between fish length ($L$) and target strength (TS) (see also [35]) generally has the form:

$$\mathrm{TS}=\mathrm{A}\cdot\log(L)+\mathrm{B} \tag{C.1}$$

$$\mathrm{TS}=\mathrm{A}\cdot\log(L)-0{,}9\cdot\log(f)+\mathrm{B} \tag{C.2}$$

where

| | |
|---|---|
| $A$ and $B$ | are constants given in Table C.1; |
| $f$ | is the frequency in kHz |

The same applies for the fish weight (W). However, the situation is complicated by different lengths being measured, e.g. total length – ($TL$), fork length ($FL$), standard length ($SL$), different units (mm and cm), fish species, frequencies and especially by different aspect directivity. As most references give $TL$, all tables in this annex standardize to $TL$. The relationships for other lengths can be found in original references or can be transformed using simple formulae:

$TL = 1{,}2 \cdot SL$ or $TL = 1{,}1 \cdot FL$

Units, species and frequencies are given in the tables. The TS - length conversion is generally simpler for discrete body aspects such as dorsal aspect (see Table C.1) and side and head/tail aspects (see Table C.3). For horizontal surveys the conversion at any angle of the fish's horizontal plane is useful and the conversion formulae are more complicated (Table C.2). For TS weight conversions (Table C.4), only the regressions for mixed species assemblage are given.

Table C.1 — Regression relationships between target strength (TS) in dB and total length ($TL$) in millimetres or centimetres for dorsal aspect of fish, according to Formulae (C.1) or (C.2)

| Frequency kHz | Formula | Common name | Latin name | Range of length and units | $A$ | $B$ | Reference |
|---|---|---|---|---|---|---|---|
| all | (C.2) | mixture of species | | 1,5 cm to 100 cm | 19,1 | −61,94 | Love, 1971 |
| 70 | (C.1) | mixture of species | | 10 cm to 39 cm | 19,39 | −62,63 | Borisenko et al., 1989 |
| 70 | (C.1) | whitefish | *Coregonus lavaretus* | 20 cm to 39 cm | 20,63 | −65,11 | Borisenko et al., 1989 |
| 70 | (C.1) | perch | *Perca fluviatilis* | 18 cm to 36 cm | 31,88 | −76,3 | Borisenko et al., 1989 |
| 70 | (C.1) | bream | *Abramis brama* | 10 cm to 33 cm | 26,47 | −72,06 | Borisenko et al., 1989 |
| 70 | (C.1) | roach | *Rutilus rutilus* | 13,5 cm to 25,4 cm | 21,2 | −62,87 | Borisenko et al., 1989 |
| 120 | (C.1) | mixture of species | | 72 mm to 690 mm | 21,15 | −84,95 | Frouzova et al., 2005 |
| 120 | (C.1) | roach | *Rutilus rutilus* | 117 mm to 305 mm | 18,11 | −77,96 | Frouzova et al., 2005 |
| 120 | (C.1) | trout | *Salmo trutta* | 72 mm to 259 mm | 24,4 | −89,44 | Frouzova et al., 2005 |
| 120 | (C.1) | perch | *Perca fluviatilis* | 101 mm to 290 mm | 33,11 | −110,68 | Frouzova et al., 2005 |
| 120 | (C.1) | carp | *Cyprinus carpio* | 140 mm to 690 mm | 28,17 | −104,68 | Frouzova et al., 2005 |
| 120 | (C.1) | juvenile perch | *Perca fluviatilis* | 10 mm to 41 mm | 20,79 | −86,41 | Frouzova and Kubecka, 2004 |
| 120 | (C.1) | smelt | *Osmerus eperlanus* | 29 mm to 82 mm | 20 | −65,9 | Peltonen et al., 2006 |
| 120 | (C.1) | vendace | *Coregonus albula* | 3 cm to 20 cm | 25,5 | −70,9 | Mehner, 2006 |
| 420 | (C.1) | juvenile perch | *Perca fluviatilis* | 12 mm to 41 mm | 14,37 | −77,15 | Frouzova and Kubecka, 2004 |

### Table C.2 — Regression relationships between target strength (TS) in dB and total length ($TL$) in millimetres or centimetres for any body aspect in horizontal plane; $\alpha$ is angle of fish body in a beam in degrees

| Frequency kHz | Formula | Common name | Latin name | Range of $L$ | $M$ | $N$ | $P$ | $Q$ | References |
|---|---|---|---|---|---|---|---|---|---|
| 200 | $\text{TS} = \left(M \cdot \log(TL) + N - (P \cdot \log(TL) + Q \cdot \cos^3 2\alpha\right)$ $+ P \cdot \log(TL) + Q$<br>side aspect α = 90° | mixture of species | | 47 mm to 480 mm | 23,90 | −87,30 | 18,66 | −85,16 | Kubecka and Duncan, 1998 |
| 200 | | rainbow trout | *Oncorhynchus mykiss* | 114 mm to 403 mm | 29,55 | −102,18 | 18,99 | −88,94 | Kubecka and Duncan, 1998 |
| 200 | | roach | *Rutilus rutilus* | 47 mm to 230 mm | 27,72 | −95,29 | 16,40 | −80,57 | Kubecka and Duncan, 1998 |
| 200 | | dace and chub | *Leuciscus leuciscus and L. cephalus* | 50 mm to 475 mm | 24,90 | −89,97 | 18,34 | −84,50 | Kubecka and Duncan, 1998 |
| 200 | | perch | *Perca fluviatilis* | 50 mm to 249 mm | 23,49 | −85,60 | 18,60 | −85,16 | Kubecka and Duncan, 1998 |
| 200 | | common and crucian carp | *Cyprinus carpio and Carassius carassius* | 126 mm to 423 mm | 19,89 | −75,82 | 23,58 | −93,98 | Kubecka and Duncan, 1998 |
| 200 | | bream | *Abramis brama* | 65 mm to 480 mm | 23,42 | −86,76 | 18,02 | −82,91 | Kubecka and Duncan, 1998 |
| 200 | $\text{TS}\alpha = M \cdot \log(TL) + N \cdot \cos^3 2\alpha + P$<br>side aspect α = 0° | salmon +trout | *Salmo salar and Salmo trutta* | 29 cm to 119 cm | 22,2 | 8,7 | −75,20 | | Lilja et al., 2000 |
| 200 | | pike | *Esox lucius* | 42,5 cm to 73 cm | 26,1 | 9,5 | −81,20 | | Lilja et al., 2000 |
| 200 | | whitefish | *Coregonus lavaretus* | 34,5 cm to 54 cm | 35 | 9,8 | −95,80 | | Lilja et al., 2000 |
| 420 | $\text{TS} = \left(M \cdot \log(TL) + N - (P \cdot \log(TL) + Q \cdot \cos^3 2\alpha\right)$ $+ P \cdot \log(TL) + Q$<br>side aspect α = 90° | mixture | | 47 mm to 480 mm | 27,49 | −96,16 | 22,40 | −94,26 | Kubecka and Duncan, 1998 |
| 420 | | rainbow trout | *Oncorhynchus mykiss* | 114 mm to 403 mm | 27,48 | −98,60 | 24,83 | −102,52 | Kubecka and Duncan, 1998 |
| 420 | | roach | *Rutilus rutilus* | 47 mm to 230 mm | 30,29 | −101,25 | 21,85 | −93,11 | Kubecka and Duncan, 1998 |
| 420 | | dace and chub | *Leuciscus leuciscus and L. cephalus* | 50 mm to 475 mm | 27,89 | −96,91 | 21,89 | −93,29 | Kubecka and Duncan, 1998 |
| 420 | | perch | *Perca fluviatilis* | 50 mm to 249 mm | 31,01 | −102,49 | 21,98 | −92,60 | Kubecka and Duncan, 1998 |
| 420 | | common and crucian carp | *Cyprinus carpio and Carassius carassius* | 126 mm to 423 mm | 20,58 | −80,14 | 23,47 | −94,76 | Kubecka and Duncan, 1998 |
| 420 | | bream | *Abramis brama* | 65 mm to 480 mm | 31,08 | −104,40 | 24,51 | −98,97 | Kubecka and Duncan, 1998 |

### Table C.3 — Regression relationships between target strength (TS) in dB and total length ($TL$) in millimetres or centimetres for two discrete aspects of the horizontal plane: side aspect, according to Formula $\text{TS} = A \cdot \log(TL) + B$ , or tail aspect, according to Formula $\text{TS} = C \cdot \log(TL) + D$

| Frequency<br>kHz | Common name | Latin name | Range of length and units | Side aspect<br>$A$ | Side aspect<br>$B$ | Tail aspect<br>$C$ | Tail aspect<br>$D$ | References |
|---|---|---|---|---|---|---|---|---|
| $B$ | $C$ | $D$ | 12 mm to 14 mm | 18,34 | −80,82 | | | Frouzova and Kubecka, 2004 |
| 120 | mixture of species | | 72 mm to 710 mm | 24,71 | −89,63 | 19,14 | −101,08 | Frouzova et al., 2005 |
| 120 | roach | *Rutilus rutilus* | 117 mm to 305 mm | 33,55 | −107,51 | 2,49 | −62,66 | Frouzova et al., 2005 |
| 120 | trout | *Salmo trutta* | 72 mm to 259 mm | 17,25 | −75,48 | 6,77 | −73,87 | Frouzova et al., 2005 |
| 120 | perch | *Perca fluviatilis* | 101 mm to 290 mm | 24,98 | −88,98 | 15,36 | −93,20 | Frouzova et al., 2005 |
| 120 | carp | *Cyprinus carpio* | 140 mm to 710 mm | 25,27 | −92,06 | 27,47 | −119,43 | Frouzova et al., 2005 |
| 120 | bream | *Abramis brama* | 168 mm to 380 mm | 33,03 | −108,36 | 20,97 | −106,51 | Frouzova et al., 2005 |
| 200 | mixture of species | | 52 mm to 528 mm | 23,90 | −87,30 | 13,41 | −83,02 | Kubecka and Duncan, 1998 |
| 200 | rainbow trout | *Oncorhynchus mykiss* | 125 mm to 443 mm | 29,55 | −102,18 | 8,43 | −75,70 | Kubecka and Duncan, 1998 |
| 200 | roach | *Rutilus rutilus* | 52 mm to 253 mm | 27,72 | −95,29 | 5,08 | −65,85 | Kubecka and Duncan, 1998 |
| 200 | dace and chub | *Leuciscus leuciscus and L. cephalus* | 55 mm to 523 mm | 24,90 | −89,97 | 11,79 | −79,02 | Kubecka and Duncan, 1998 |
| 200 | perch | *Perca fluviatilis* | 55 mm to 274 mm | 23,49 | −85,60 | 13,71 | −84,72 | Kubecka and Duncan, 1998 |
| 200 | common and crucian carp | *Cyprinus carpio and Carassius carassius* | 139 mm to 465 mm | 19,89 | −75,82 | 27,27 | −112,13 | Kubecka and Duncan, 1998 |
| 200 | bream | *Abramis brama* | 72 mm to 528 mm | 23,42 | −86,76 | 12,62 | −79,07 | Kubecka and Duncan, 1998 |
| 200 | mixture of species | | 29 mm to 119 cm | 24,2 | −68,3 | | | Lilja et al., 2000 |
| 200 | salmon | *Salmo salar* | 30 mm to 119 cm | 25,6 | −72,6 | | | Lilja et al., 2000 |
| 200 | trout | *Salmo trutta* | 29 cm to 63 cm | 28,9 | −77,8 | | | Lilja et al., 2000 |
| 200 | whitefish | *Coregonus lavaretus* | 34,5 cm to 54 cm | 39,7 | −90,3 | | | Lilja et al., 2000 |
| 200 | pike | *Esox lucius* | 42,5 cm to 73 cm | 24,2 | −68,3 | | | Lilja et al., 2000 |
| 420 | juvenile perch | *Perca fluviatilis* | 7mm to 14 mm | 19,88 | −85,88 | | | Frouzova and Kubecka, 2004 |
| 420 | mixture of species | | 52 mm to 528 mm | 27,49 | −96,16 | 17,31 | −92,35 | Kubecka and Duncan, 1998 |
| 420 | rainbow trout | *Oncorhynchus mykiss* | 125 mm to 443 mm | 27,48 | −98,60 | 22,18 | −106,44 | Kubecka and Duncan, 1998 |
| 420 | roach | *Rutilus rutilus* | 52 mm to 253 mm | 30,29 | −101,25 | 13,41 | −84,97 | Kubecka and Duncan, 1998 |
| 420 | dace and chub | *Leuciscus leuciscus and L. cephalus* | 55 mm to 523 mm | 27,89 | −96,91 | 15,90 | −89,67 | Kubecka and Duncan, 1998 |
| 420 | perch | *Perca fluviatilis* | 55 mm to 274 mm | 31,01 | −102,49 | 12,95 | −82,72 | Kubecka and Duncan, 1998 |
| 420 | common and crucian carp | *Cyprinus carpio and Carassius carassius* | 139 mm to 465 mm | 20,58 | −80,14 | 26,36 | −109,39 | Kubecka and Duncan, 1998 |
| 420 | bream | *Abramis brama* | 72 mm to 528 mm | 31,08 | −104,40 | 17,94 | −93,54 | Kubecka and Duncan, 1998 |

**Table C.4 — Regression relationships between target strength (TS) in dB and weight (W) in g or kg for two discrete aspects of the horizontal or vertical plane: side or dorsal aspect, according to Formula TS = A*log (W)+B, or tail aspect, according to Formula TS = C*log (W)+D**

| Frequency (kHz) | Common name | Range of weight (or length), units | A | B | C | D | References |
|---|---|---|---|---|---|---|---|
| | | | | Horizontal plane | | | |
| 120 | mixture of species | 4 g to 6913 g | 7,28 | −47,00 | 6,10 | −68,97 | Frouzova et al., 2005 |
| | | | | | | | |
| 200 | mixture of species | 52 mm to 528 mm | 5,66 | −46,48 | 4,05 | −60,05 | Kubecka and Duncan, 1998 |
| | | | | | | | |
| 200 | mixture of species | 0,180 kg to 16,06 kg | 7,3 | −49,8 | | | Lilja et al., 2000 |
| | | | | | | | |
| 420 | mixture of species | 52 mm to 528 mm | 8,69 | −50,36 | 5,39 | −63,05 | Kubecka &Duncan, 1998 |
| | | | | Vertical plane | | | |
| 120 | mixture of species | 4 g to 6 010 g | 5,4 | −47,11 | 5,48 | −68,87 | Frouzova et al., 2005 |

# Annex D
(informative)

## Deconvolution procedure

Deconvolution allows the determination of fish size from the Target Strength (TS) of fish randomly oriented with respect to the transducer. Random fish aspect is assumed to be prevalent in horizontal surveys of lakes and lowland rivers with low flows.

The deconvolution procedure is described in Bibliography Entry [23] A frequency distribution of all-aspect TS is first summarized in a matrix (e.g. Table D.1). In this example, the largest TS class was −24 dB, which formed 0,064 % of all targets; this group is considered to be from the biggest fish recorded from their most reflective side-aspect. For such fish, their weakest tail or head-aspect was −47 dB, according to the relationship between fish TS and its orientation in the sonar beam. From this relationship, the equivalent size in standard length was 442 mm.

This model also shows that when an insonified fish is turned through 360° in the horizontal plane, the TS frequency is spread more or less homogeneously between the minimal TS (−47 dB) and the maximal TS (24 dB). Therefore it can be expected that this length group of fish also contributed a 0,064 % presence to each of the TS classes from −24 dB to −47 dB. This is indicated in Column 1 of Table D.1 together with the final sum of percentage occurrences (0,768 %).

The next TS class was −26 dB, which also contributed 0,064 % of all targets. This group is assumed to contain the second most reflective aspect of the biggest fish as well as the most reflective side-aspect of the second biggest group of fish (386 mm). Since all the targets of this TS class have already been quantified as belonging to the 442 mm fish, the deconvolution model assumes there were no fish of 386 mm.

The TS class of −28 dB formed 0,096 % of all targets. Of these, 0,064 % were represented by 442 mm fish and 0 % by 386 mm fish, leaving 0,032 % of fish with a side aspect TS of −28 dB and length 337 mm.

The same procedure is applied to each size class of TS until every group had been considered.

The deconvolution procedure can be applied to single species or mixed species assemblages, if the relative proportions of each component species is known (e.g. from direct capture).

**Table D.1 — An example of the deconvolution procedure applied to the all-aspects TS frequency distribution for the trout population in Loch of Boardhouse ([23])**

| Length Group | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Side aspect TS (dB) | | | −24 | −26 | −28 | −30 | −32 | −34 | −36 | −38 | −40 | −42 | −44 | −46 | −48 | −50 |
| Head / tail aspect TS (dB) | | | −47 | −47 | −48 | −49 | −50 | −51 | −52 | −53 | −54 | −55 | −56 | −57 | −58 | −59 |
| | | | | | | | | | | | | | | | | |
| TS (dB) | Original Frequency (%) | Frequency of occurrence (%) | | | | | | | | | | | | | | |
| −24 | 0,064 | | 0,064 | | | | | | | | | | | | | |
| −26 | 0,064 | | 0,064 | 0 | | | | | | | | | | | | |
| −28 | 0,096 | | 0,064 | 0 | 0,032 | | | | | | | | | | | |
| −30 | 1,02 | | 0,064 | 0 | 0,032 | 0,924 | | | | | | | | | | |
| −32 | 0,67 | | 0,064 | 0 | 0,032 | 0,57 | 0 | | | | | | | | | |
| −34 | 1,53 | | 0,064 | 0 | 0,032 | 0,924 | 0 | 0,51 | | | | | | | | |
| −36 | 2,01 | | 0,064 | 0 | 0,032 | 0,924 | 0 | 0,51 | 0,48 | | | | | | | |
| −38 | 2,87 | | 0,064 | 0 | 0,032 | 0,924 | 0 | 0,51 | 0,48 | 0,86 | | | | | | |
| −40 | 6,29 | | 0,064 | 0 | 0,032 | 0,924 | 0 | 0,51 | 0,48 | 0,86 | 3,42 | | | | | |
| −42 | 6,6 | | 0,064 | 0 | 0,032 | 0,924 | 0 | 0,51 | 0,48 | 0,86 | 3,42 | 0,31 | | | | |
| −44 | 10,7 | | 0,064 | 0 | 0,032 | 0,924 | 0 | 0,51 | 0,48 | 0,86 | 3,42 | 0,31 | 4,16 | | | |
| −46 | 13,9 | | 0,064 | 0 | 0,032 | 0,924 | 0 | 0,51 | 0,48 | 0,86 | 3,42 | 0,31 | 4,16 | 3,2 | | |
| −48 | 16,8 | | | | 0,016 | 0,924 | 0 | 0,51 | 0,48 | 0,86 | 3,42 | 0,31 | 4,16 | 3,2 | 2,92 | |
| −50 | 13 | | | | | | 0 | 0,51 | 0,48 | 0,86 | 3,42 | 0,31 | 4,16 | 3,2 | 0,028 | 0 |
| −52 | 10,6 | | | | | | | | 0,24 | 0,86 | 3,42 | 0,31 | 4,16 | 1,61 | 0 | 0 |
| −54 | 7,28 | | | | | | | | | | 1,71 | 0,31 | 4,16 | 1,1 | 0 | 0 |
| −56 | 3,96 | | | | | | | | | | | | 2,08 | 1,81 | 0 | 0 |
| −58 | 1,5 | | | | | | | | | | | | | | 1,5 | 0 |
| −60 | 1,02 | | | | | | | | | | | | | | | 1,02 |
| Total % in length group | | | 0,77 | 0,00 | 0,34 | 8,89 | 0.00 | 4,59 | 4,08 | 6,88 | 25,65 | 2,17 | 27,04 | 14,12 | 4,45 | 1,02 |
| Midpoint standard length (mm) | | | 442 | 386 | 337 | 295 | 258 | 225 | 197 | 172 | 150 | 131 | 115 | 100 | 87,6 | 76,5 |

# Annex E
(informative)

## Determination of the Elementary Distance Sampling Unit (EDSU)

The elementary distance sampling unit (EDSU) is the length of the cruise track along which the acoustic measurements are averaged to give one sample. When using such a fixed time interval or distance to provide density estimates, there is a risk the samples will be serially autocorrelated, in which case the sample variance is a poor indicator of the precision. The extent of the autocorrelation depends on the horizontal distribution of the fish; when fish are homogeneously distributed the sample size may be small, but a more patchy distribution will require a larger sample size.

The length at which the samples are independent (elementary distance sampling unit – EDSU) can be determined by calculating the autocorrelation coefficient of samples at different ranges from each other. The autocorrelation coefficient is calculated using Formula (E.1):

$$\rho_L = \frac{(n-1)}{(n_L - 1)} \cdot \frac{\sum_{i=1}^{n_L} (F_i - F_{\text{mean}})(F_i + L - F_{\text{mean}})}{\sum_{\text{i}=1}^{n} (F_i - F_{\text{mean}})^2} \qquad \text{(E.1)}$$

where

$\rho_L$ is the autocorrelation coefficient;

$F_i$ is the value of the $i^{\text{th}}$ sample;

$F_{\text{mean}}$ is the mean of all samples;

$n_L$ is the number of samples separated by $L$ observations;

$n$ is the number of samples in total.

Plotting the autocorrelation coefficient against the distance between samples displays the lag distance when serial correlation is negligible ( $\rho_L$ will be approximately zero) and successive samples can be considered independent of each other [19].

# Annex F
(informative)

# Estimates of sampling variance and precision

Acoustic abundance estimates have been demonstrated to be repeatable [16], [12], [13] and robust with respect to different equipment and operators [34], [37], sampling design and analysis method [13]. Different levels of precision are attainable, dependant primarily on the degree of survey coverage and variability in the spatial distribution of fish [35].

Repeated surveys have demonstrated that the precision of a properly designed acoustic survey can be extremely good. For example, Hansson [15] determined that repeated transects within one night were highly correlated, with coefficients of variation ($CV$ = standard deviation / mean) from different nights ranging from 9 % to 29 %. Axenrot and Hansson (2004) [4] achieved geostatistical coefficients of variation ($CV_{\text{geo}}$) of between 3 % and 11 % for repeated surveys of a Baltic Sea coastal area.

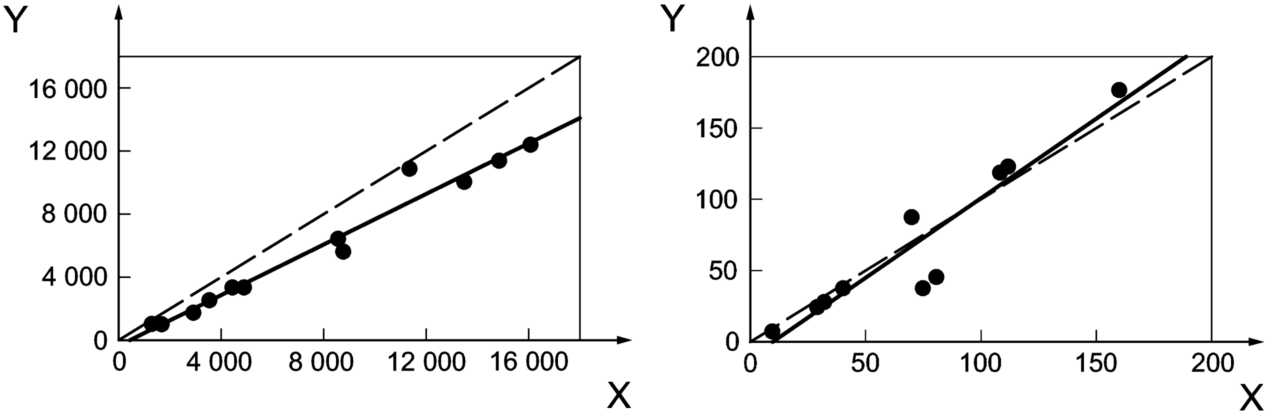
An alternative illustration of precision is the repeatability of acoustic surveys. Vertical surveys of reservoirs [12] and the hypolimnion of lakes [13] demonstrated no significant differences in acoustic abundance estimates amongst surveys conducted on successive days or nights. Acoustic outputs have also been found to be repeatable when conducted using different operators and equipment [34], [37], sampling design and analyses methods [13].

Surface waters generally produce more variable acoustic density outputs. For example, horizontal surveys of two reservoirs were repeatable except during periods of increased wind [12], and acoustic biomass estimates from the epilimnion of Lake Chalain were affected by fish behaviour [13]. Longitudinal fish distributions in lowland rivers are typically patchy [9], [29], resulting in relatively high variances in acoustic density estimates. $CV$ ranged from 50 % to 132 % for six impounded sections of the River Trent in the UK (Hateley, unpublished data).

# Annex G
(informative)

## Published inter-comparison studies

Inter-agency comparisons compliant with this standard have been conducted on two deep lakes; Stechlinsee in Germany and Irrsee in Austria ([37]). In the Stechlinsee study, two teams using identical 120 kHz Simrad EY500 echosounders produced highly correlated fish density estimates derived from $S_v$/TS scaling analyses, but the slope of the regression differed from the expected value of 1. The biomass estimates were also highly correlated, but in this case the regression did not differ significantly from 1. This pattern could be explained by the two survey vessels differentially encountering small targets that only marginally contributed to overall biomass (Figure G.1).



**a) Number of fish per hectare**

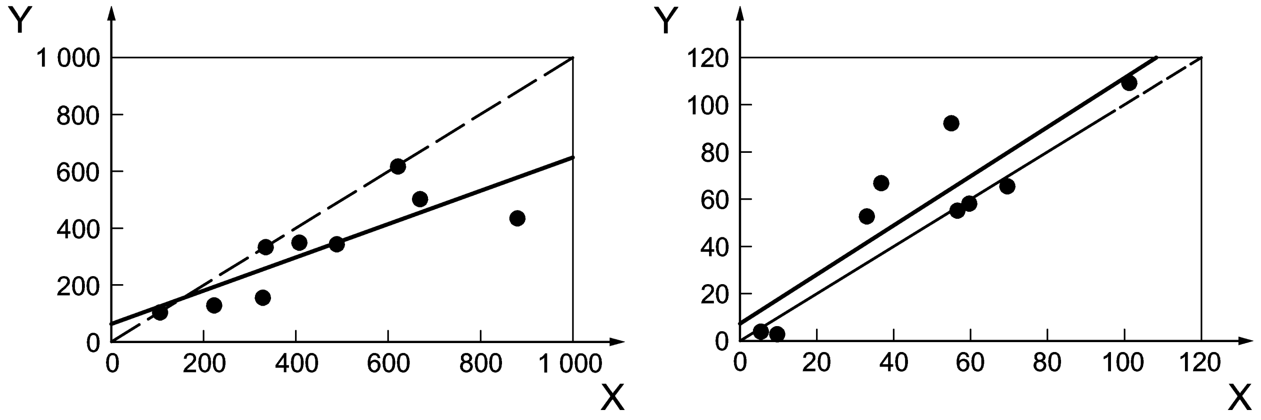
**b) biomass in kilogram per hectare (kg/ha)**

**Key**

X results team 1 (Germany) with Simrad EY500

Y results team 2 (Austria) with Simrad EY500

**Figure G.1 — Regressions relating the results of the two teams for fish density values (a) and for biomass values (b) for each of the 12 transects at Stechlinsee**



**a) Number of fish per hectare** **b) biomass in kilogram per hectare (kg/ha)**

**Key**

Y results with Biosonics DT 6000

X results with Simrad EY500

**Figure G.2 — Regressions relating the results of the two teams for fish density values (a) and for biomass values (b) for each of the 9 transects at Irrsee**

In the Irrsee study, two teams operated different echosounders; a 120 kHz Simrad EY500 and a 200 kHz Biosonics DT 6000. The abundance estimates were correlated significantly, but more weakly than for the identical gear test on Stechlinsee. The biomass estimates were again robustly correlated with the regression slope not significantly different from unity (Figure G.2). The authors concluded that hydroacoustic surveys of deep lakes can be reliably reproduced by independent teams using identical equipment, and expert teams using different equipment, settings and analytical software can produce directly comparable biomass estimates. [Figures have been reproduced with the permission of the publisher].

To date, no appropriate inter-comparative studies have been published on shallow lakes, reservoirs and rivers.

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