Report of the Study Group on Calibration of Acoustic Instruments in Fisheries Science (SGCal)

20 April 2013

Pasaia, Spain
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Executive summary

The ICES Study Group on Calibration of Acoustic Instruments in Fisheries Science (SGCal) convened its third meeting at AZTI Tecnalia in Pasaia, Spain on Saturday 20 April 2013. David Demer (USA) was Chair and Rapporteur. The Chair thanked the host, Guillermo Boyra (Spain), and Claire Welling (ICES) for supporting the SGCal.

Eleven scientists from eight nations participated (Annex 1). The agenda (Annex 2), according to the terms of reference (Annex 3), included presentations on calibration-related developments and was focused on reviewing draft chapters of a new Cooperative Research Report (CRR) on the calibrations of acoustic instruments.

The Chair recalled that the SGCal met first in San Diego in spring 2010; second in Reykjavik, Iceland in 2011; and was granted a one-year extension in 2012. This third meeting marked the end of the group’s third year. Therefore, the SGCal will endeavor to complete and submit a final report and draft of the CRR prior to the 2014 meeting of the ICES Working Group on Fisheries Acoustics Science and Technology, in New Bedford, Massachusetts, USA. The following is a summary of the CRR outline (Annex 4), including names of lead and contributing authors, and number of draft pages at the time of the meeting:

1) Summary (Demer) 2 pp.
2) List of Terms, Symbols, and Units (Demer, Jech, Macaulay, Chu) 5 pp.
3) Introduction (Jech, Bethke, Demer, Weber, Fässler, Le Bouffant)
   3.1) Acoustic theory (Demer, Le Bouffant) 9 pp.
   3.2) Signal processing theory (Bethke, Le Bouffant)
   3.3) Equipment 21 pp.
      • Echosounders (Weber, Lurton)
      • Transducer platforms (Fässler)
   3.4) Calibration methods (Jech, LeBouffant)
4) Standard Sphere Calibration (Macaulay, Demer, Ryan, Scalabrin, Bethke, MacLennan) 18 pp.
5) Calibration Uncertainty (Chu, Demer) 17 pp.
6) Calibration Protocols (Williamson, Parker-Stetter, Gauthier, Domokos, Le Bouffant, Demer, Korneliussen, Chu, Stienessen, Bernasconi, Melvin, Ryan)
   6.1) EK60, ES60/ES70 Calibrations (Williamson, Domokos, Gauthier, Parker-Stetter, Ryan) 27 pp.
   6.2) ME70 Calibrations (Le Bouffant, Demer, Korneliussen, Chu, Steinessen) 21 pp.
   7.1) Echosounders
   7.2) Omnidirectional sonars (Bernasconi, Melvin) 12 pp.
   7.3) Widebandwidth sonars (Jech, Chu)
   7.4) ADCPs (Lebourges-Dhaussy) 8 pp.
   7.5) Surface targets (Jech, Weber)
   7.6) Acoustic cameras (Boswell)
   7.7) Deeply deployed transducers (Ryan, Macaulay)
8) Future Research (All authors)

The following timeline was adopted:

- 30 June 2013 – Authors update draft chapters
- 15 August 2013 – Chair merges chapters, reduces redundancy, identifies issues, adds cross-references, and solicits reviews
- 30 September 2013 – Reviewers provide comments
- 31 October 2013 – Authors update draft chapters
- 31 December 2013 – Refinements made to draft CRR
- April 2014 – Chair submits final SGCal report and CRR to ICES

Chair will present a final report to the WGFAST in New Bedford, Massachusetts, USA during 5-9 May 2014.
1 Opening of the meeting

The ICES Study Group on Calibration of Acoustic Instruments in Fisheries Science (SGCal) convened its third meeting at AZTI Tecnalia in Pasaia, Spain on 20 April 2013. David Demer (USA) was Chair and Rapporteur. Chair thanked the host, Guillermo Boyra (Spain), and Claire Welling (ICES) for supporting the SGCal.

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Chair recalled that the SGCal met first in San Diego in spring 2010; second in Reykjavik, Iceland in 2011; and was granted a one year extension in 2012. This third meeting was held at the end of the group’s third year. Therefore, the SGCal will endeavor to complete and submit a final report and draft of the CRR (outline in Annex 4) prior to the 2014 meeting of the ICES Working Group on Fisheries Acoustics Science and Technology, in New Bedford, Massachusetts, USA.

Chair solicited revisions to the agenda. The proposed agenda was adopted.
2 Terms of Reference (ToR)

The Chair called for review of the ToR and principal resolutions from the 2011 meeting. Discussions highlighted the following issues:

- The CRR must include consistent use of terms, symbols, and units. Conformance to MacLennan et al., 2002 is preferred, with some exceptions.
- The CRR should present equations in linear terms as much as possible.
- The CRR should include a section on the decibel and ramifications of logarithmic transformation.
- The CRR should be an integrated reference, not a collection of independent papers.
- The CRR will have more longevity if fundamentals and equations are presented, and software for facilitating the computations are presented in annex.
- The CRR will include ‘Quick Start’ sections with easy-to-follow protocols for calibrations, as well as sections with details for advanced practitioners.

The longevity of a new CRR was discussed considering the 25-year lifespan of CRR 144. Recognized is the need for a living document to augment the new CRR. Chair is to investigate with ICES the possibilities for online annex to the new CRR.

The group reaffirmed that the new CRR should be developed around the concept of measurement uncertainty. Estimates of bias and precision, both required and realized, should guide the structure and content of the document.

3 Presentations to review recent calibration-related developments

Chair invited presentations to review recent calibration-related developments.

Adam Dunford (NZ) presented “ES60 Calibrations and implications”.

Stephane Gauthier (Canada) presented “An automated calibration rig and results from faulty transducers.”

Laurent Berger (France) presented “Significant differences between theoretical and measured values of wideband target strengths for a 38.1 mm diameter tungsten-carbide sphere.”
4 Draft CRR Chapter Reviews

The group discussed the draft chapters in general terms and provided guidance to the authors for additions and refinements. The salient points from the discussion follow:

- Before 30 June 2013, all authors should submit or resubmit their draft chapters to the Chair to assure that the correct versions will be merged and refined.
- The CRR will include ‘Quick Start’ sections with easy-to-follow protocols for calibrations, as well as sections with details for advanced practitioners.
- Fundamental equations and algorithms will be detailed in the main text of the new CRR; computer programs which facilitate calibrations and data processing will be identified in annex.
- Chair is to investigate with ICES the possibilities for online annex to the new CRR. The online CRR annex will include links to useful software. Contributors of these software packages should provide documentation to accompany the links, as appropriate, and authors should link their text to these annex.
- Chapter 3, include the theory of angle sensitivity, described in Bodholt (2002).
- Chapter 4, Laurent Berger reported that the ER60 calibration program reports RMS error that is low by a factor of 2. The ME70 calibration program does not have this apparent error.
- Chapter 4, Adam Dunford (NZ) explained that the robustness of calibration parameters depends greatly on the accuracy of the beam model.
- Lars Nonboe Anderson (Norway) indicated that Simrad was endeavouring to improve the beam model for the EK80. The beam model will have physical meaning, opposed to a simple polynomial fit to the data, and the parameters will relate to the transducer characteristics.
- Lars Nonboe Anderson (Norway) provided references to details regarding the ER60 calibration program (cal.exe; not to be referred to as “Lobe”) and single-target detection algorithm; and may provide the latest beam model for the ME70.
- Chapter 4, the ER60 calibration program should be recommended for calibrating both ES and EK systems in the ‘Quick Start’ section. That section will also note that the ES60/70 can use EK60 software in replay mode to post-process TWES-adjusted data.
- Chapter 4, ES60 section, the limitations of the ER60 calibration program should be described and other approaches to reduce error (e.g. NIWA program) discussed. The limitations of poor data quality should be highlighted.
- Chapter 4, include protocols for calibrating single-beam echosounders. These differ from those included in Chapter 6. The approach must be checked for consistency, redundancy eliminated, and cross-references added.
- Chapter 4, include a “Trouble Shooting” section. Other chapters may include more specific trouble-shooting guidance. For example, Stephane
Gauthier showed how ellipsoidal beam patterns in faulty transducers may be identified by fitting TS measurements with a polynomial beam model.

- Chapter 5, elaborate on standard sphere tolerances (e.g. transversal sound speed, densities, and tethering) and resulting target strength accuracy.
- Chapter 7, David Demer to include a section on impedance measurements for monitoring transducer performance and aging.
- Chapter 7, Michael Jech to include a section on wideband calibration protocol.
- Chapter 7, Michael Jech to include a section on surface target calibration (e.g. work done by Tom Weber, USA).
- Chapter 8, to include future research as identified in all chapters by all authors.

Over the next year, draft chapters, annex, and the combined CRR document will be available to co-authors via the SGCal SharePoint.
5 **Timeline**

The following timeline was adopted:

- **30 June 2013** – Authors update draft chapters  
- **15 August 2013** – Chair merges chapters, reduces redundancy, identifies issues, adds cross-references, and solicits reviews  
- **30 September 2013** – Reviewers provide comments  
- **31 October 2013** – Authors update draft chapters  
- **31 December 2013** – Refinements made to draft CRR  
- **April 2014** – Chair submits final SGCal report and CRR to ICES

Chair will present a final report to the WGFAST in New Bedford, Massachusetts, USA during 5–9 May 2014.

The third meeting of the SGCal was adjourned at 13:00 on 20 April 2013.
## Annex 1: List of participants

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<thead>
<tr>
<th>Name</th>
<th>Country</th>
<th>E-mail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andersen Lars</td>
<td>Norway</td>
<td><a href="mailto:lars.nonboe.andersen@simrad.com">lars.nonboe.andersen@simrad.com</a></td>
</tr>
<tr>
<td>Berger Laurent</td>
<td>France</td>
<td><a href="mailto:Laurent.Berger@ifremer.fr">Laurent.Berger@ifremer.fr</a></td>
</tr>
<tr>
<td>Demer David</td>
<td>United States</td>
<td><a href="mailto:David.Demer@noaa.gov">David.Demer@noaa.gov</a></td>
</tr>
<tr>
<td>Dunford Adam</td>
<td>New Zealand</td>
<td><a href="mailto:Adam.dunford@niwa.cri.nz">Adam.dunford@niwa.cri.nz</a></td>
</tr>
<tr>
<td>Fässler Sascha</td>
<td>The Netherlands</td>
<td><a href="mailto:sascha.fassler@wur.nl">sascha.fassler@wur.nl</a></td>
</tr>
<tr>
<td>Gauthier Stephane</td>
<td>Canada</td>
<td><a href="mailto:Stephane.gauthier@dfo.mpo.gc.ca">Stephane.gauthier@dfo.mpo.gc.ca</a></td>
</tr>
<tr>
<td>Jech Mike</td>
<td>United States</td>
<td><a href="mailto:Michael.Jech@noaa.gov">Michael.Jech@noaa.gov</a></td>
</tr>
<tr>
<td>Laczkowski Tomasz</td>
<td>Poland</td>
<td><a href="mailto:tlaczkowski@mir.gdynia.pl">tlaczkowski@mir.gdynia.pl</a></td>
</tr>
<tr>
<td>Le Bouffant Naig</td>
<td>France</td>
<td><a href="mailto:Naig.Le.Bouffant@ifremer.fr">Naig.Le.Bouffant@ifremer.fr</a></td>
</tr>
<tr>
<td>Macaulay Gavin</td>
<td>Norway</td>
<td><a href="mailto:gavin.macaulay@imr.no">gavin.macaulay@imr.no</a></td>
</tr>
<tr>
<td>Ryan Tim</td>
<td>Australia</td>
<td><a href="mailto:tim.ryan@csiro.au">tim.ryan@csiro.au</a></td>
</tr>
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Annex 2: Agenda – 2013 Meeting of SGCaI

Saturday, 20 April

09:00–09:15  Opening
- Greeting, introductions, and logistics
- Refinement and adoption of agenda

09:15–09:30  Review 2011 decisions

09:30–10:30  Discuss submitted chapters

10:30–11:00  Presentations
- Adam Dunford – ES60 calibrations and implications
- Stephane Gauthier – New automated calibration system
- Laurent Berger – Wideband sphere TS inaccuracies

11:00–12:00  Discuss emerging protocols
- Wideband protocol
- Omnidirectional sonar protocol
- Autonomous instruments protocols

12:00–12:30  Discuss other issues

12:30–13:00  Agree on schedule for final report and CRR

13:00  Adjourn
Annex 3: SGCal terms of reference for the 2013 meeting

The Study Group on Calibration of Acoustic Instruments in Fisheries Science (SGCal) chaired by David A. Demer, USA will meet in Pasaia, Spain, on 20 April 2013 to:

a) Review the draft Cooperative Research Report (CRR) and make refinements;

b) Recommend, via the CRR, protocols to be used for acoustic-system calibrations;

c) Document, via the CRR, current theory and recommended practice of acoustic-system calibrations.

Supporting Information

Priority

Acoustic data are currently being collected from a variety of acoustic systems in many countries to address a range of ecosystem monitoring and stock management objectives. The ICES CRR covering this topic (CRR 144, Foote et al., 1987) is now more than 20 years old. While much of the theoretical principles are still relevant, some need to be expanded to include currently used technologies (e.g. multibeam and broadbandwidth systems), and methods and standard protocols for calibrating these instruments need to be updated.

There exists an urgent need to evaluate this work and to develop recommendations for protocols appropriate to calibrations of acoustic systems used in fisheries research and surveys. This need has been identified by a number of ICES Member Countries and observer countries and has been conveyed to WGFAST and SSGESST.

Scientific justification

Term of reference a: The ICES reference for acoustic system calibrations needs review and revision to be useful to practitioners of fisheries acoustics for stock management. The first step in this process is to review, summarize and report on the literature regarding the acoustic systems that are currently used in fisheries research and surveys. The theoretical principles for calibrating these instruments must be capitolated, and the methods currently being practiced must be evaluated.

Term of reference b: Based the literature review, the Expert Group must make recommendations to the ICES community for standard protocols to be used for acoustic system calibrations. These protocols must cover the calibrations of all commonly used acoustic systems used in fisheries research and surveys, or be generic enough for calibrating other systems not specifically considered. The protocols must be practical and based on solid theoretical principles; and

Term of reference c): There is a recognized need to comprehensively document the current theory and recommended practice of acoustic instrument calibrations for use in Fisheries Science, and publish them in an easily accessible report.

WGFAST and SSGESST continue to recognize the difficulty of addressing these needs during full working group sessions and support the continuation of this study group comprised of experts to develop recommended methods and guidelines without delay. This Study Group will meet three times.

Resource requirements

No new resources will be required for consideration of these topics at the relevant group meetings. Having overlaps with WGFAST meetings, this SG will draw on a larger resource pool of experts which will increases efficiency in completing the objectives and reducing travel costs.
| Participants | It is expected that ca. twenty five scientists from six ICES and three observer countries will initially participate in the study group. History has shown this number will likely decline to about half that number as the meeting progress, and about one fourth may be active in authoring the report. Interested industry representatives, both hardware and software suppliers) should be actively invited to participate. |
| Secretariat facilities | None. |
| Financial | No financial implications. Having overlaps with other meetings of expert groups of SSGESST increases efficiency and reduces travel costs. |
| Linkages to advisory committees | There are no direct linkages to the advisory committees but the work is of relevance to ACFM. |
| Linkages to other committees or groups | No direct linkages, however, depending on the outcome organizations such as FAO will be interested in the results. |
| Linkages to other organizations | WGFAST. This work should have relevance to many working, groups carrying out stock assessment of many semi-demersal and pelagic species in many ICES countries. |
Annex 4: Draft Cooperative Research Report Outline

1. Summary (Demer)
2. List of Terms, Symbols, and Units (Demer, Jech, Macaulay, Chu)
   2.1. Echo range
   2.2. Electro-acoustic efficiency
   2.3. Beam directivity
   2.4. Equivalent two-way beam angle
   2.5. Ambient Noise
   2.6. Self Noise
   2.7. Absorption coefficient
   2.8. Absorption loss
   2.9. Spherical spreading loss
   2.10. Refraction loss
   2.11. Attenuation
   2.12. Backscattering cross-section
   2.13. Target strength
   2.14. Volume backscattering coefficient
   2.15. Volume backscattering strength
   2.16. Area backscattering coefficient
   2.17. Area backscattering strength
   2.18. Volume backscattering coefficient
   2.19. Volume backscattering strength
   2.20. Nautical area scattering coefficient
   2.21. Nautical area scattering strength
   3.1. Acoustic theory (Demer, Le Bouffant)
      3.1.1. Power budget (Sonar theory, Radar theory, Combining two worlds)
         3.1.1.1. Transmit power
         3.1.1.2. Transducer efficiency
         3.1.1.3. Transducer directivity
         3.1.1.4. Echo range
         3.1.1.5. On-axis gain
         3.1.1.6. Attenuation
            3.1.1.6.1. Geometric spreading loss
            3.1.1.6.2. Absorption loss
         3.1.1.7. Area backscattering strength
         3.1.1.8. Effective receiving area
         3.1.1.9. Target strength (TS; dB re 1 m²)
         3.1.1.10. Volume backscattering strength (Sv; dB re 1 m³)
         3.1.1.11. Integrated volume backscattering coefficient (sA)
         3.1.1.12. Biomass density (ρ; g·m²)
         3.1.1.13. Surface scattering strength (Ss; dB re 1 m²)
         3.1.1.14. Incidence angle (θ; º)
         3.1.1.15. Estimates of stochastic variables
   3.1.2. Signal processing theory (measurements)
      3.1.2.1. Echo range (r; m)
         3.1.2.1.1. Receiver delay
         3.1.2.1.2. Echo-pulse rise time
            3.1.2.1.2.1. Bandwidth
3.1.2.2. Target strength (TS; dB re 1 m^2)
3.1.2.3. Volume backscattering strength (S_v; dB re 1 m^3)
3.1.2.4. Integrated volume backscattering coefficient (s_A)
3.1.2.5. Biomass density (ρ; g-m^-2)
3.1.2.6. Spatial reference
   3.1.2.6.1. Relative
   3.1.2.6.2. Geographic
3.1.3. Measurement-error function
   3.1.3.1. Accuracy (systematic error)
   3.1.3.2. Precision (random error)
3.2. Seabed classification
3.2.1. Power Budget
3.2.2. Measurements
   3.2.2.1. Surface scattering strength (S_s; dB re 1 m^2)
   3.2.2.2. Incidence angle (θ; °)
   3.2.2.3. Seabed type
   3.2.2.4. Spatial reference
      3.2.2.4.1. Relative
      3.2.2.4.2. Geographic
3.2.3. Measurement error function
   3.2.3.1. Accuracy
   3.2.3.2. Precision
3.3. Echosounders (Weber)
3.3.1. Single-beam
   3.3.1.1. Single-frequency
   3.3.1.2. Multifrequency
   3.3.1.3. Broad bandwidth
3.3.2. Single-beam, split-aperture
   3.3.2.1. Single-frequency
   3.3.2.2. Multifrequency
   3.3.2.3. Broad bandwidth
3.3.3. Multiple-beams
   3.3.3.1. Single-frequency
   3.3.3.2. Multifrequency
   3.3.3.3. Broad bandwidth
3.3.4. Multiple-beams, split-aperture
   3.3.4.1. Single-frequency
   3.3.4.2. Multifrequency
   3.3.4.3. Broad bandwidth
3.4. Transducer platforms (Fässler)
3.4.1. Vessels
   3.4.1.1. Hull-mount
   3.4.1.2. Keel-mount
   3.4.1.3. Pole-mount
   3.4.1.4. Towed-body
3.4.2. Autonomous vehicles
   3.4.2.1. Drifters
   3.4.2.2. Propelled vehicles
   3.4.2.3. Gliders
3.4.3. Stationary
   3.4.3.1. Buoys
3.4.3.2. Landers

3.5. Calibration methods (Jech, Le Bouffant)

3.5.1. Standard sphere method
3.5.2. Element vs. beamformed-data calibration
3.5.3. Hydrophone reciprocity
3.5.4. Self-reciprocity (echo from air-water interface)
3.5.5. Impedance
3.5.6. Inter-ship comparison
3.5.7. Seabed echoes
3.5.8. Self-calibrating methods
   3.5.8.1. Echo-integration and in-situ target strength
   3.5.8.2. Echo-counting
   3.5.8.3. Multi-scattering in a cavity
3.5.9. Internal system tests and warnings (Le Bouffant)
   3.5.9.1. Continuous impedance measurements
3.5.10. System-performance simulation (Le Bouffant)
3.5.11. Factory calibration
   3.5.11.1. E.g., Biosonics

4. Standard Sphere Calibration (Macaulay, Demer)

4.1. Materials
   4.1.1. Sphere targets
   4.1.2. Apparatus
      4.1.2.1. Sphere range
      4.1.2.2. Centering the sphere

4.2. Method
   4.2.1. Measurements
      4.2.1.1. Hydrography
         4.2.1.1.1. Sound speed
         4.2.1.1.2. Absorption coefficient
      4.2.1.2. Equivalent Beam Angle
         4.2.1.2.1. Sound speed
         4.2.1.2.2. Mechanical angles
         4.2.1.2.3. Angle sensitivity
      4.2.1.3. Impedance
      4.2.1.4. Sphere TS vs. angular position
   4.2.2. Deeply deployed transducers (Ryan, Macaulay, Scalabrin, MacLennan)
      4.2.2.1. Towed bodies
      4.2.2.2. Cast echosounders (MacLennan)
         4.2.2.2.1. Real-time calibration
      4.2.2.3. AUVs
      4.2.2.4. Landers

4.3. Results
   4.3.1.1. On-axis gain (G; dB re 1W)
   4.3.1.2. Beam directivity
      4.3.1.2.1. Beam widths
      4.3.1.2.1.1. Off-axis angles
      4.3.1.2.2. Equivalent two-way beam angle
   4.3.1.3. On-axis gain correction factor (Sa_corr; dB re 1W)
      4.3.1.3.1. Bandwidth effect
      4.3.1.3.1.1. Filter delay (Bethke)
5. Calibration Uncertainty (Chu, Demer)

5.1. Accuracy (systematic error)

5.1.1. Sphere target strength
  5.1.1.1. Theoretical prediction
  5.1.1.2. Material
    5.1.1.2.1. Properties
    5.1.1.2.2. Homogeneity
  5.1.1.3. Sphericity
  5.1.1.4. Temperature
  5.1.1.5. Pressure

5.1.2. Bandwidth

5.1.3. Receiver delay (filter delay)

5.1.4. Linearity

5.1.5. Dynamic range

5.1.6. Equivalent beam angle

5.1.7. Time-varied gain
  5.1.7.1. Sound speed
  5.1.7.2. Absorption
  5.1.7.3. Geometrical spreading
  5.1.7.4. Refraction
  5.1.7.5. Bubble attenuation

5.1.8. Dynamic system performance
  5.1.8.1. Temperature
  5.1.8.2. Pressure
  5.1.8.3. Time
  5.1.8.4. Transducer biofouling

5.2. Precision (random error)

5.2.1. System stability

5.2.2. Noise

5.3. Error budget function

6. Calibration Protocols (Williamson, Ryan, Parker-Stetter, Gauthier, Domokos, Le Bouffant, Demer, Korneliussen, Chu, Stienessen, Bernasconi, Melvin)

6.1. Simrad EK60, vessel-mounted, hull-mounted or retractable keel
  6.1.1. Single-beam, split-aperture
    6.1.1.1. Single-frequency protocol
    6.1.1.2. Multiple-frequency protocol
  6.1.2. Calibration Worksheet
    6.1.2.1. Metadata

6.2. Simrad ES60, vessel-mounted (Ryan, Williamson, Gauthier)
  6.2.1. Single-beam
    6.2.1.1. Single-frequency protocol
    6.2.1.2. Multiple-frequency protocol
  6.2.2. Single-beam, split-aperture
    6.2.2.1. Single-frequency protocol
    6.2.2.2. Multiple-frequency protocol
  6.2.3. Calibration Worksheet
    6.2.3.1. Metadata

6.3. Simrad ME70 / MS70 (Le Bouffant, Demer, Korneliussen, Chu, Stienessen)
  6.3.1. Multiple-beams, split-aperture, multiple-frequency, vessel-mounted
  6.3.2. Calibration Worksheet
    6.3.2.1. Metadata
6.4. Omnidirectional sonars (e.g. Simrad SH80 / SX90; Bernasconi, Melvin)
   6.4.1. Multiple-beams, single-frequency, vessel-mounted
   6.4.2. Calibration Worksheet
   6.4.2.1. Metadata
6.5. ASL Water Column Profiler (Ryan)
   6.5.1. Single-beam, buoy-mounted
      6.5.1.1. Single-frequency protocol
      6.5.1.2. Multiple-frequency protocol
   6.5.2. Calibration Worksheet
      6.5.2.1. Metadata
   7.1. Echosounders
      7.1.1. Simrad SM20/2000 (Chu, Melvin, Perrot, Hufnagle)
      7.1.2. Hydrographic sonars (Weber, Lurton)
      7.1.3. Sidescan sonars
   7.2. Omnidirectional sonars (Bernasconi, Melvin)
   7.3. Widebandwidth sonars (Jech, Chu)
   7.4. ADCPs (Lebourges-Dhaussy)
   7.5. Surface targets (Jech, Weber)
   7.6. Acoustic cameras (Boswell)
   7.7. Deeply deployed transducers (Ryan, Macaulay)
      7.7.1. Towed bodies
      7.7.2. AUVs
      7.7.3. Landers
8. Future Research (All authors)
9. Conclusion
10. Acknowledgements
11. References
12. Appendices
   12.1. Equation for sound speed
   12.2. Equation for absorption coefficient
   12.3. Standard sphere target strengths