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Article *in* Lakes & Reservoirs Research & Management · June 2013
DOI: 10.1111/lre.12026

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Lakes and Reservoirs: Research and Management 2013 **18**: 167–177

Comparing echosounder efficiency using field observations

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Abstract

Time series, using different echosounders or large-scale multiship acoustic surveys, can be criticized because equipment changes might affect the final results. This criticism was addressed previously by comparing the results from different vessels using echo integration on the target species. The acoustically estimated standing stock of Nile perch (*Lates niloticus*) in Lake Victoria, East Africa, declined to 50% between successive surveys six months apart in 2007, prompting the criticism that a change in echosounder was responsible for this observation. This concern has been addressed, using data from the same four small localities around the lake, Emin Pasha Gulf, Nyanza Gulf, Speke Gulf and the vicinity of the Sesse Islands, from six surveys, spanning the time when the change in echosounder occurred. For three of the locations, echo integration and single target detections within the first bottom echo indicated no significant differences in echosounder performance. Results from the fourth location, Sesse Islands, showed very low backscatter, possibly due to a layer of detritus on the lake bed. It is concluded that all data are equally comparable, providing echosounders are correctly calibrated with the vessel being stationary, although there may still be differences under operational conditions. Characteristics of intercalibration sites are discussed in this study. The results also show changes in substrate, likely attributable to local environmental changes between surveys.

Key words

calibration, echosounder, intership, substrate, time series.

INTRODUCTION

Internationally accepted and standardized echosounder calibration protocols, such as described by Foote *et al.* (1987), have improved the precision of acoustic survey results both within and between surveys. Thus, when the same vessel and echosounder have been used throughout a sampling series, any observed differences or trends in the results can be attributed convincingly to real changes in a waterbody. For various reasons, it is frequently not possible to use the same echosounder for all surveys in a time series. Furthermore, it is necessary to use a number of vessels for large-scale surveys, each with its own echosounder, to satisfy requirements of synopticity. In addition, the intercomparability of the systems may be called into question when a significant difference is detected between the results from one survey or vessel and another. To accommodate potential criticisms of this type regarding multiship surveys, some form of intercomparison is often included in the survey design.

Simmonds and MacLennan (2005) describe two examples during which survey results from the RV ‘G. O. Sars’ (GOS) were compared with another vessel. As reported by Foote *et al.* (1987), the first survey had GOS sailing 0.5 nautical miles ahead of, and 10 degrees to the port side of, RV ‘Bjarni Saemundsson’ (BS), a difference in sampled track of approximately 160 m. Echo integrators were used to collect the data from two depth strata covering the top 100 m of the water column, which was the depth range of the target species, ‘0’ group capelin, along a 26 nautical mile transect. That transect included a high-density region for part of its length. The results were reanalysed by Simmonds and MacLennan (2005), who noted that although there was a very good correlation between the two data sets (r^2 = 0.99), the slope was 1.21, indicating a small but significant difference between the

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Accepted for publication 13 February 2013.

Doi: 10.1111/lre.12026

vessels. For the second study (described by Simmonds & MacLennan 2005), the results obtained along a transect approximately 45 nautical miles in length by GOS were compared with those from FRV 'Scotia'. That study indicated no significant differences between the results from the two vessels.

Both studies relied on the vessels following close parallel tracks and assumed the sampling conditions were the same for both. This type of sampling arrangement depends on there being similar target densities along the cruise tracks and also that the presence of the lead vessel does not affect the fish distribution on the track of the following vessel. To address part of this concern, Simmonds and MacLennan (2005) describe a design whereby vessels sample several paired parallel transects, changing the lead vessel after each transect pair. Even with this design, however, there are two potential difficulties. First, as the distribution of the fish is likely to change over a timescale of hours, if not minutes, it is essential that the intercalibration exercise is completed within a short period of time. Second, a series of four 20-nautical mile transects done at the normal survey speed of research vessels would likely take over 10 hours of vessel time. It is difficult logistically to schedule research cruises so that all vessels are present simultaneously at the same location, meaning that using the target species of fish as a secondary calibration standard cannot be relied upon to provide unequivocal results. Simply stated, if the results are the same, they are likely to be accepted. However, if results differ significantly, such differences might be attributed with equal justification to the echosounder efficiency, rather than any phenomenon associated with the distribution of fish.

As aggregations are not stable in either space or time, they are not an ideal secondary standard against which to assess echosounder performance. What is required are natural targets subject to minimal change with time. The seabed potentially is a good alternative likely to satisfy this requirement (De Robertis *et al.*).

For large-scale multiship surveys, as noted above, it is logistically inefficient, even impossible, to bring all vessels together simultaneously for intercalibration exercises. During FIBEX (Anon 1982), for example, although the stated aim was to bring all vessels together for such an exercise, it proved impossible. Similarly, this was not achieved for the second large-scale Southern Ocean krill survey (Watkins *et al.* 2004), even though acoustic intercomparison was included in the research plan.

Acoustic surveys have been undertaken over the past decade for Lake Victoria, to estimate the standing stock of Nile perch (*Lates niloticus*). Up to, and including, the survey in February 2007, a Simrad EY500 echosounder had been used. It was replaced with a Simrad EK60 system for the August 2007 survey. The acoustically estimated standing stock of Nile perch in August 2007 decreased to approximately half the value of the February 2007 survey, prompting concerns over the relative effectiveness of the two systems. This was raised at the LVFO Stakeholders Conference, held in Kampala, Uganda, 27–29 October 2008 (LVFO Stakeholder Conference 2008). As these two surveys were completed six months apart, it is not possible to undertake direct comparisons on the backscatter from fish, nor would it be appropriate because it would use the target species as a secondary calibration standard. An alternative source of backscatter likely to be less prone to variation over a six-month period, or even years, is the lake bed.

This paper compares results from a series of lakewide surveys conducted from February 2006 to August 2008, making use of the data from restricted regions within each, wherein the tracks are constrained by the lake structure. This should identify any systematic differences between the effectiveness of the two echosounders. As a further check on the overall system, from echosounder and through post-processing, the acoustic backscatter from the lakebed was analysed on the basis of the same protocols as used for estimating the fish standing stock.

Data were analysed to investigate whether or not, in spite of careful calibration to international standards, there are systematic differences between two different models of echosounder. At the same time, the results were examined to provide some guidance on situations likely to provide information from which to make realistic comparisons of echosounder performance under operational conditions.

MATERIALS AND METHODS

Data were collected, based on the standard LVFO acoustic sampling protocol (LVFO 2008) during lakewide acoustic surveys of Lake Victoria from February 2005 to August 2008, using the RV 'Victoria Explorer' moving at an average speed of 9 knots. A Simrad EY500 echosounder was used for surveys from August 2005 to February 2007. A Simrad EK60 system was used thereafter for the surveys from August 2007 to August 2008. Both echosounders had an operating frequency of 120 kHz. Standard echosounder calibration procedures were used, as recommended by the manufacturer, based on the standard protocol of Foote *et al.* (1987). Calibration values are shown in Table 1.

Analysis was restricted to four regional strata, specifically Emin Pasha Gulf (EP), Sesse Islands (SI), Nyanza Gulf (NG) and Speke Gulf (SG), of the current survey

Table 1. Echosounder calibration values

Echosounder	EY500	EK60	Units
Operating frequency	120	120	kHz
Ping interval	0.5	0.2	Seconds
Absorption coefficient	3	2.5	dB km^{-1}
Two way beam angle	−18.3	−21	dB
Pulse duration	0.3	0.256	ms
Transmit power	63	200	W
TS Gain	22.6	26.1	dB
Beam angle alongships	9.2	6.5	Degrees
Beam angle athwartships	9.3	6.5	Degrees

plan (LVFO 2008). The locations of these regions are illustrated in Figure 1.

The EP and SI strata are on the western side of the lake, being characterized by having significant hills on the surrounding coast, which may indicate a lakebed type that includes exposed rock and boulders, as well as alluvial deposits. In contrast, both NG and SG are shallow, and shoal gently up to the coast where the inland topography is generally low-lying, and may indicate a more uniform lakebed.

Data were analysed in Echoview (Version (R) 4.0.75.6342. www.sonardata.com) and exported in two forms: echo integration and single target detections (STD). The same STD parameters as used for fish counting on the surveys were implemented, including:

- Target strength (TS) Threshold: −50 dB
- Pulse length determination level: 6 dB

Fig. 1. Map of Lake Victoria, East Africa, showing location of the four study strata.

- Minimum normalized pulse length: 0.8
- Maximum normalized pulse length: 1.5
- Maximum beam compensation: 6.0 dB
- Max Std Deviation on minor axis angle: 0.6 degrees
- Max Std Deviation on major axis angle: 0.6 degrees

The echosounder-detected bottom was used to define the integration layer, whose upper limit was the detected bottom, offset by 15 degrees, and whose lower limit was the detected bottom, offset by 30 degrees. This sampling depth range corresponds to the bottom index E1 used by Siwabessy *et al.* (1999) for seabed classification. STD are normally used to identify parts of the signal whose echo envelope closely resembles the transmitted pulse envelope, likely attributable to individual fish. In the context of the present study, STDs for obvious reasons cannot have come from individual fish. They are, however, likely to indicate small locations where there is a sudden change in the sound speed contrast of the lakebed. Thus, STDs are an indication of substrate inhomogeneity.

Survey transects were divided into one-km Elemental Distance Sampling Units (EDSUs), based on GPS positions. Where GPS data were not available, the transects were divided into four-minute (the time taken for a vessel cruising at 9 knots to cover 1 km) EDSUs.

Analysed data were exported from Echoview for each EDSU, and analyses undertaken to estimate the following statistics:

- Sv: Summary statistics of mean and median Sv within each stratum, supported by generalized linear models (GLMs) to test for differences between surveys and echosounders;
- SvSingles: Summary STD statistics, giving Mean TS, number of targets and sampled volume by EDSU, were used to estimate backscatter due to the STDs;
- PercentSingles: In the arithmetic domain, the percentage of the total backscatter attributable to the Sv Singles.

All statistical analyses were undertaken using the statistical package 'R' (R Development Core Team 2007).

RESULTS

Depth correction

A strong relationship in which E1, an equivalent statistics to Sv used in the present study, increased with depth was previously reported by Siwabessy *et al.* (1999), who applied a correction using a simple regression. Such a consistent pattern was not present in the results of the present study. Some examples of the Sv and SvSingles results plotted against depth (Fig. 2a–c) exhibited a

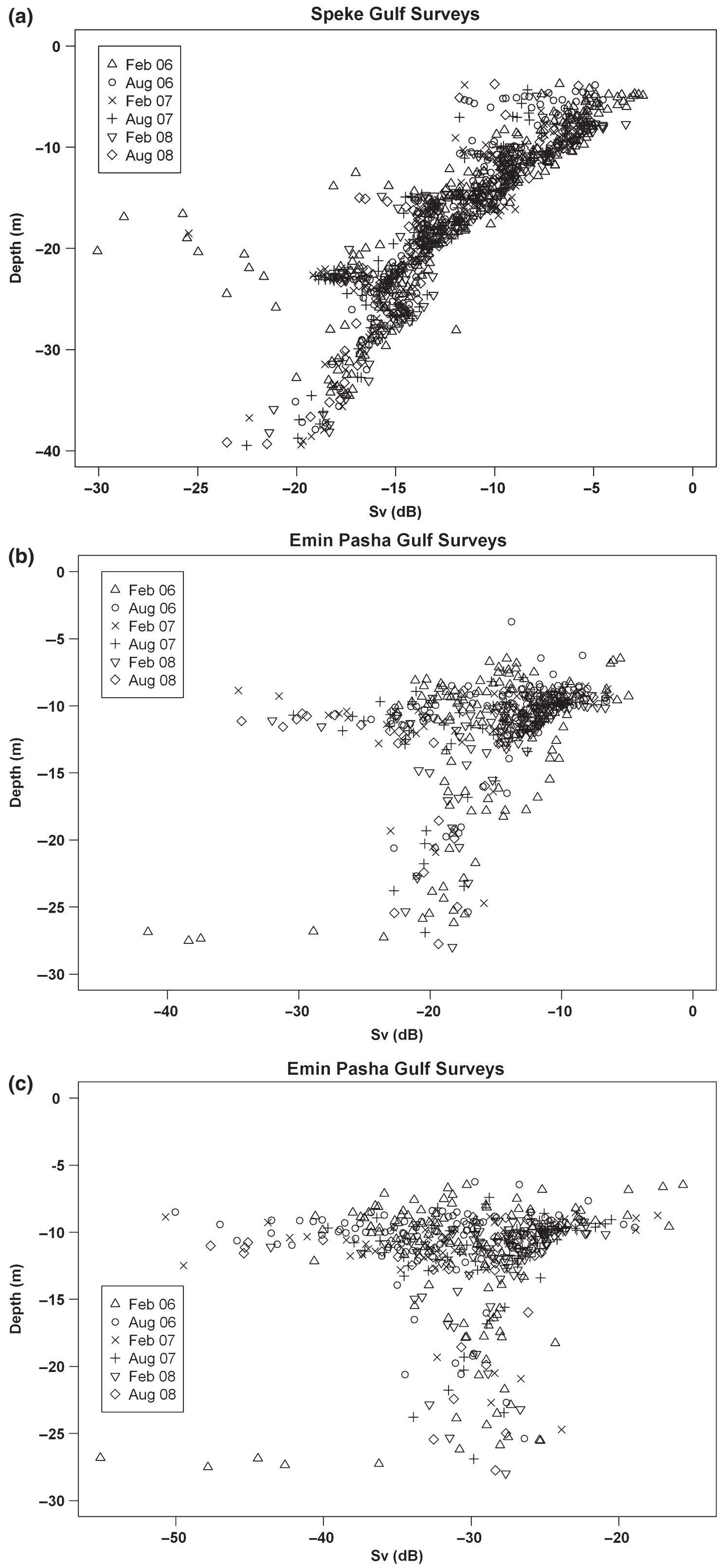

Fig. 2. Scatter plots illustrating relationship between Sv and SvSingles and depth specified in Table 2. (a) Sv versus depth for Speke Gulf, illustrating strongly negative depth-dependent relationship. (b) Sv versus depth for EP, illustrating weakly negative depth-dependent relationship. (c) SvSingles versus depth for EP, indicating no obvious depth-dependent relationship. EP, Emin Pasha Gulf.

Table 2. Qualitative description of depth-dependent responses for Sv and SvSingles

Stratum	Sv	SvSingles
Speke Gulf	Strong –ve	Strong –ve to 10 m, then none
Nyanza Gulf	Strong –ve	Strong –ve
Emin Pasha Gulf	Weak –ve	None
Sesse Islands	Weak –ve	None

decreasing trend with depth. This pattern, however, was not universal, with some strata exhibiting only a weak relationship, while others exhibited none. The type of relationship noted for each stratum and index is presented in Table 2.

In the cases where there was a significant association with depth, it was in the opposite direction to the results reported by Siwabessy *et al.* (1999), who considered it to be due to the effect of the spreading beam pattern causing increased backscatter with increasing depth. The opposite trend found in the present study therefore cannot be due to that effect. In the absence of alternative explanations, therefore, it was concluded that any trend in Sv or SvSingles with depth was probably real, not being an artefact in the sense reported by Siwabessy *et al.* (1999). Thus, no depth corrections were applied to the indices Sv and SvSingles.

Comparisons of echosounders

Exploratory analyses using GLM indicated highly significant differences between surveys strata and echosounders, arising from which it was decided to separately analyse each stratum. Boxplots of Sv, SvSingles and PerCentSingles summary information by survey are presented in Figure 3.

The overall backscatter (Sv) showed little change over the period of the surveys within SG (Fig. 3a), and although there is more variation in the SvSingles within that stratum, there is little overall change in the mean. Similarly, the PerCentSingles boxplot for SG exhibited the same pattern as for the SvSingles (Fig. 3a.). A similar pattern, albeit with greater variation, exists for NG and EP (Fig. 3b,c, respectively.) The boxplots for SI indicate Sv and SvSingles values at the start that decrease through the series, only to increase again on the last survey (Fig. 3d). It is important to note that the highest values of Sv and SvSingles in Figure 3d are similar in magnitude to those of Figure 3a–c (although the scale has had to be adjusted in Figure 3d to accept the lowest values. The GLM (Sv~Echosounder+Survey) gave results indicating no significant differences between the results from the two echosounders for three of the strata:

- SG: d.f. = 1029; $P = 0.792$; medians EY500 = –12.0; EK60 = –12.9;
- NG: d.f. = 1027; $P = 0.705$; medians EY500 = –11.8; EK60 = –15.1;
- EP: d.f. = 500; $P = 0.969$; medians EY500 = –14.1; EK60 = –13.7.

In the case of the SI stratum, the difference was highly significant (SI: d.f. = 318, $P < 0.001$), with the following median echosounder Sv values:

EY500: $N = 138$ and median = –43.6;

EK60: $N = 181$ and median = –54.1.

The Sv values for the SI stratum are extremely low, compared with the other strata. In the context of echo integration of fish schools, they are equivalent to a density of around one or two 10-cm fish m^{-3} of water. Thus, the SI results are probably not representative of the true lakebed.

The SvSingles results, using the same GLM, gave no significant differences between the echosounders for two strata, as follows:

SG: d.f. = 1020; $P = 0.122$; median EY500 = –25.1; EK60 = –25.4;

NG: d.f. = 1018; $P = 0.452$; median EY500 = –31.4; EK60 = –32.7

The EP results, by contrast, were highly significant:

EP: d.f. = 487; $P < 0.001$; medians EY500 = –31.3; EK60 = –27.5, in spite of the fact that the absolute values are similar to those for SG and NG.

For the SI stratum, the difference was highly significant but with values very much lower than for the other three strata as noted for the Sv results.

SI: d.f. = 313, $P < 0.001$, medians EY500 = –57.7 EK60 = –73.3

The results for the PercentSingles index using the GLM model (sqrt(PercentSingles)~Echosounder+Survey) gave the following results:

SG: d.f. = 1020, $P = 0.045$, medians EY500 = 2.44 EK60 = 2.32

NG: d.f. = 1018, $P = 0.066$, medians EY500 = 1.92 EK60 = 1.61

EP: d.f. = 1018, $P < 0.001$, medians EY500 = 1.56 EK60 = 2.03

SI: d.f. = 313, $P < 0.001$, medians EY500 = 0.81 EK60 = 0.64

Although the SG results were just significant at the 5% level, the median values are very close, reflecting the consistency in the SV and SvSingles results. There is a greater difference which, although not significant for the NG stratum, was highly significant for the EP and SI strata, but with different echosounders giving the higher

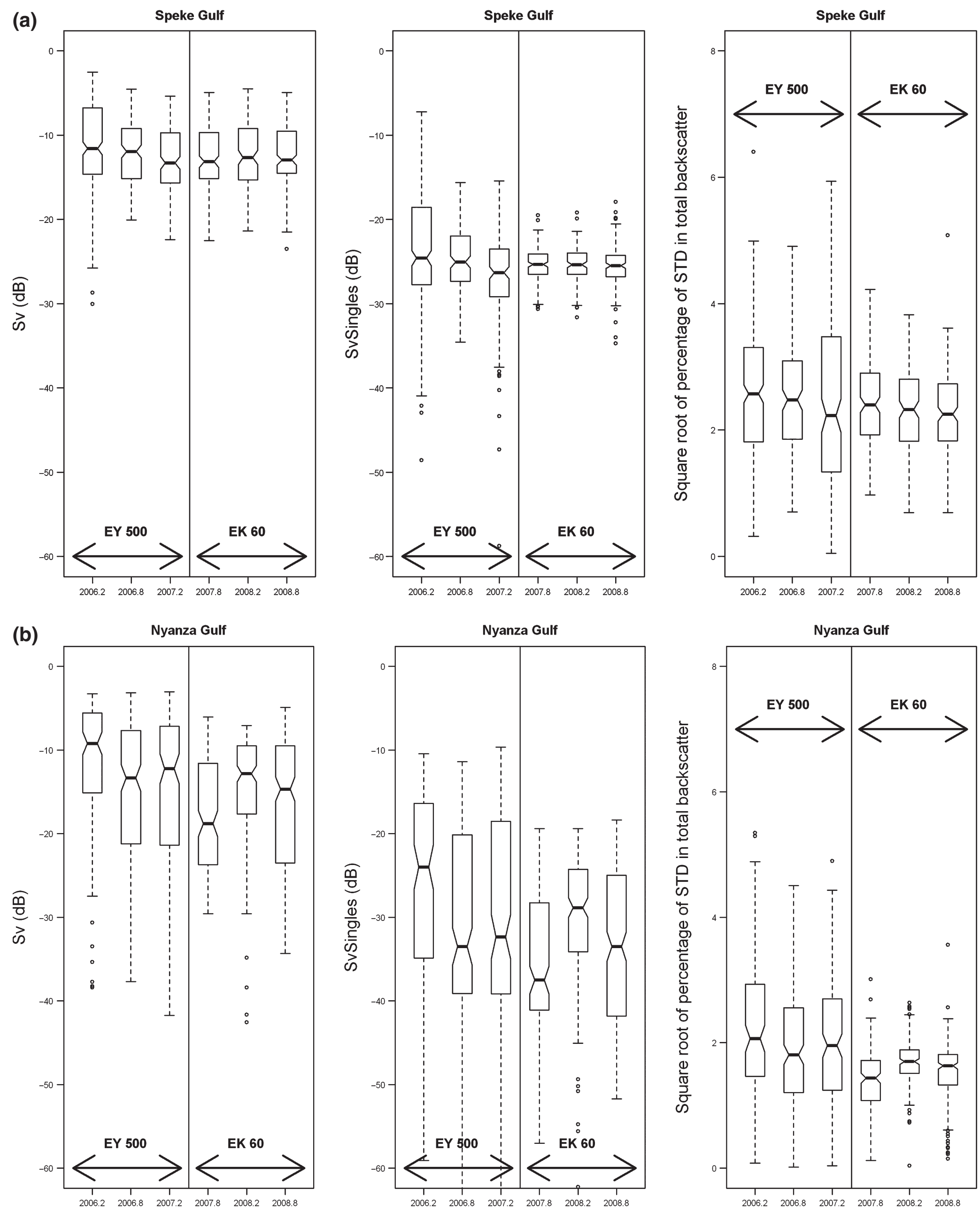

Fig. 3. Box and whisker plots of Sv, SvSingles and Square root of proportion of single target detections in total backscatter (EY500 sounder used for first three surveys; EK 60 used for remainder of surveys).(a) Results for Speke Gulf. (b).Results for Nyanza Gulf. (c) Results for Emin Pasha. (d) Results for Sesse Islands (*y*-axis scales changed for this stratum to accommodate lower results for Sv and SvSingles).

values in these strata. Thus, there is no clear indication for this statistic that one echosounder was performing consistently more effectively than the other.

The SI stratum exhibits major differences from the other three strata in terms of all three indices Such an unusually low series from this stratum is almost certainly unrelated to echosounder performance because the same calibrated system was used for all the other strata within each survey. The SvSingles values for SI are likely to be low because of the above-noted low Sv values. Thus, it is not surprising that relatively few STDs were present in that stratum.

In summary, and excluding the SI stratum results for the reasons stated above, the Sv results indicate no significant difference between the results of the two echosounders. Likewise, the SvSingles results for two strata indicate no significant differences. The only significant difference is for the EP stratum, wherein the EY500

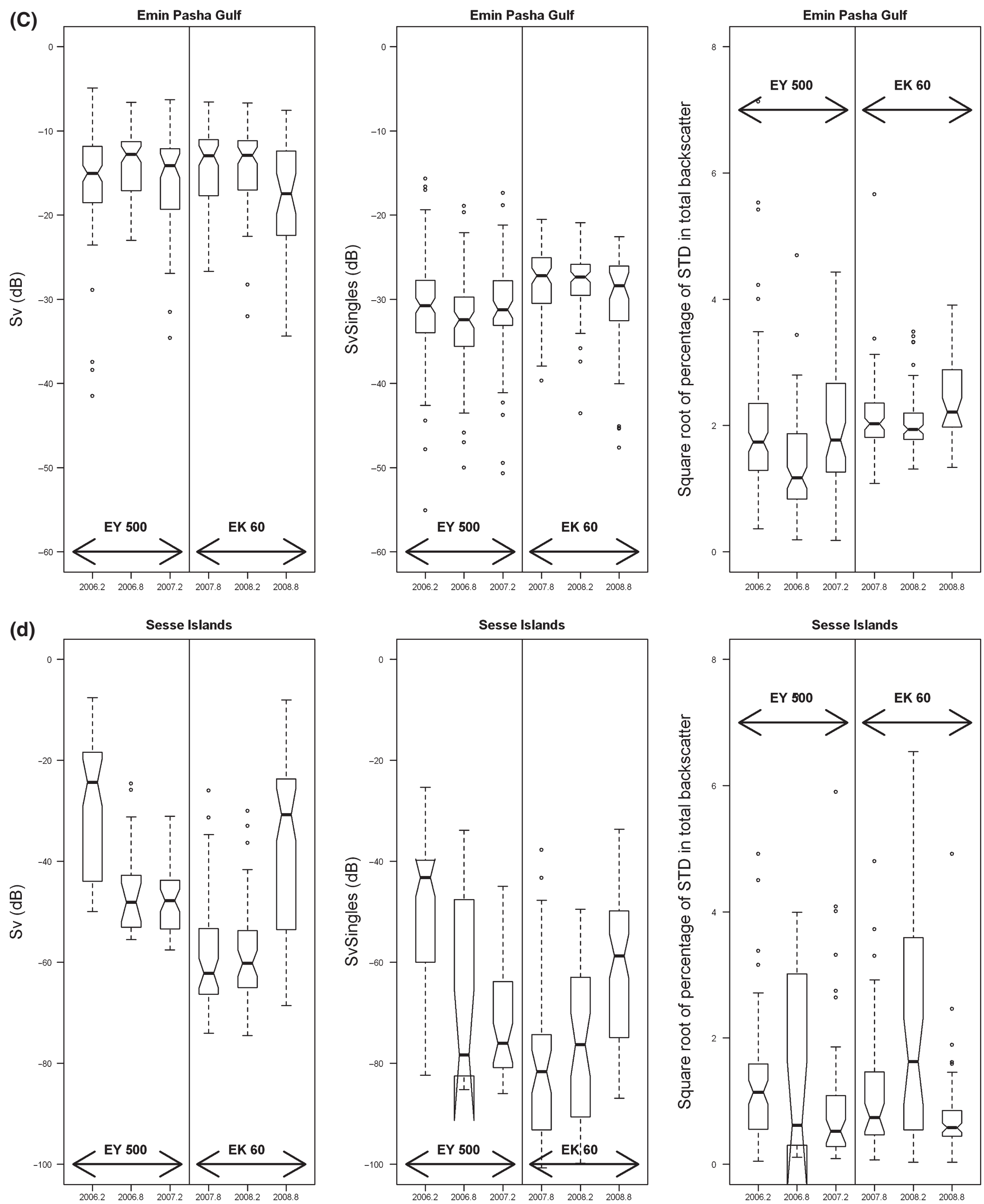

Fig. 3. (Continued).

mean values are lower than those for the EK60. As the original question related to lower fish standing stock estimates, using the EK60 compared with the EY500 echosounder, the difference in the SvSingles result is in the opposite direction. It is reasonable to conclude that the results from that stratum were a result of chance, or else some other unquantified change. Thus, the overall conclusion from both the Sv and SvSingles analyses is that there are no significant differences related to the operational efficiency of the respective echosounders.

Comparison of Sv results for surveys by stratum

The GLM results on the Sv data for each stratum are summarized in Table 3, from which the following points emerge from this analysis:

- There is good consistency in the results from SG, with a variation over the series in the survey median Sv values of less than 2 dB;
- NG and EP have several survey median Sv values similar to those of SG, with the highest value for all

Table 3. Summary generalized linear models results for Sv values

Stratum	d.f.		2006.2	2006.8	2007.2	2007.8	2008.2	2008.8
Speke Gulf	1029	*P*	0.088	0.675	0.040	0.149	0.674	0.538
		Sig	NS	NS	*	NS	NS	NS
		Median	−11.5	−11.3	−12.9	−13.2	−12.6	−12.9
Nyanza Gulf	1027	*P*	<0.001	0.447	0.870	<0.001	0.924	0.013
		Sig	***	NS	NS	***	NS	*
		Median	−9.2	−13.3	−18.8	−12.2	−12.8	−14.6
Emin Pasha Gulf	505	*P*	0.035	0.067	0.077	0.489	0.971	<0.001
		Sig	*	NS	NS	NS	NS	***
		Median	−15.0	−12.8	−14.1	−12.9	−12.9	−17.5
Sesse Islands	576	*P*	<0.001	0.576	0.500	<0.001	<0.001	<0.001
		Sig	***	NS	NS	***	***	**
		Median	−24.4	−48.1	−47.7	−62.2	−60.2	−30.7

Table 4. Summary generalized linear models results for SvSingles

Stratum	d.f.		2006.2	2006.8	2007.2	2007.8	2008.2	2008.8
Speke Gulf	1029	*P*	0.109	0.123	<0.001	0.120	0.122	0.070
		Sig	NS	NS	***	NS	NS	NS
		Median	−24.6	−25.1	−26.3	−25.4	−25.4	−25.5
Nyanza Gulf	1027	*P*	<0.001	0.701	0.439	<0.001	0.451	0.023
		Sig	***	NS	NS	***	NS	*
		Median	−24.0	−33.5	−32.3	−37.5	−28.8	−33.5
Emin Pasha Gulf	505	*P*	<0.001	<0.001	0.030	<0.001	<0.001	0.011
		Sig	**	***	*	***	***	*
		Median	−30.7	−32.4	−31.2	−27.2	−27.3	−28.4
Sesse Islands	576	*P*	<0.001	0.752	0.272	<0.001	0.022	0.153
		Sig	***	NS	NS	***	*	NS
		Median	−42.3	−78.3	−81.6	−76.0	−76.3	−58.8

surveys from NG; overall, the variation between NG and EP surveys is much greater than for SG; and

- The SI results are consistently much lower than for the other three strata and also exhibit a much greater degree of variation between surveys.

Comparison of SvSingles results for surveys by stratum

The GLM results from SvSingles results for each stratum are summarized in Table 4, from which the following points emerge from the analysis:

- There is good consistency in the results from SG, with a variation in the survey median SvSingles values of much less than 2 dB;
- NG and EP, with the exception of the February 2006 survey in the former, have median Sv values similar to, but much lower than for, the SG stratum, with the highest overall value from NG; and
- The SI results are consistently much lower than for the other three strata and also exhibit a very much greater degree of variation between the surveys.

Comparison of the PercentSingles results for surveys by stratum

To normalize the data, a square root transformation was applied. The GLM results for each stratum are summarized in Table 5, from which the following points emerge from this analysis:

- There is good consistency in the results from SG, with a variation in the survey median value of 0.33;
- NG and EP strata have median values lower than the SG stratum, but with greater ranges; and

Table 5. Summary generalized linear models results for PerCentSingles

Stratum	d.f.		2006.2	2006.8	2007.2	2007.8	2008.2	2008.8
Speke Gulf	1029	*P*	0.460	0.312	0.378	0.372	0.045	0.028
		Sig	NS	NS	NS	NS	*	*
		Median	2.56	2.47	2.40	2.23	2.31	2.25
Nyanza Gulf	1027	*P*	<0.001	0.090	0.046	<0.001	0.066	<0.001
		Sig	***	NS	*	***	NS	***
		Median	2.067	1.809	1.952	1.436	1.699	1.632
Emin Pasha Gulf	505	*P*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
		Sig	***	***	***	***	***	***
		Median	1.737	1.171	2.026	1.770	1.940	2.215
Sesse Islands	576	*P*	0.040	0.038	0.126	0.025	0.643	<0.001
		Sig	*	*	NS	*	NS	***
		Median	1.141	0.619	0.521	0.740	1.625	0.579

- The SI results are consistently much lower than for the other three strata and also exhibit a very much greater degree of variation between the surveys. This is largely because there were a very much greater proportion of the EDSUs containing no STDs.

DISCUSSION

Were there differences in performance between the two echosounder?

In analysing the data by stratum, the only one exhibiting a significant difference in the Sv values for the two echosounders was for SI. The overall results within that stratum were unusually low, with Sv values at a level to be expected for moderate concentrations of fish, rather than a true lake substrate. The reason for this occurrence is not clear. It may, however, have been due to an accumulation of detritus, possibly from rotting vegetation, causing the standard bottom detection algorithm, used for each lakewide survey with the same parameter settings throughout, to have been inadvertently triggered above the true lake bottom. This phenomenon obviously warrants further investigation outside of the present study. The results for the other three strata were much more consistent, with no significant differences between the echosounders being detected.

The results from the SvSingles analyses indicate that, except for the SI stratum, differences between echsounders are small, relative to between-survey differences. This finding provides further corroboration for the conclusions based on the Sv analyses. Omitting the SI results because of the low Sv and small numbers of STDs, the PercentSingles analyses provide further confirmation that there were no significant differences between the performances of the two echosounders.

The results from all three analytical approaches point clearly to there being no significant difference between the efficiency of operation of the two echosounders. It is concluded therefore that because both echosounders were calibrated correctly according to the LVFO protocol (LVFO 2008), the results from all the surveys are comparable. Thus, the concerns about possible between-instrument anomalies raised at the previously referenced LVFO 2008 Stakeholders' Conference were without foundation.

Between strata comparisons

The SG results in Table 3 and Figure 3a highlight a consistent pattern in the Sv throughout the time series, with a coefficient of variation (CV) of 34.2%. The pattern also is present for the SvSingles (CV = 18.3%; Table 4), although the range is more compressed for the three most recent surveys. Although that change is coincident with the change in echosounder, it is unlikely to be the cause because the pattern is not present for any of the other strata. A similar situation applies to EP (Tables 3 and 4; Fig. 3c), with CVs for Sv of 35.5% and SvSingles of 18.5%, respectively. The NG results (Tables 3 and 4; Fig. 3b) exhibit a greater degree of variation (CV Sv = 51.8%; CV SvSingles – 33.1%), compared with SG and EP. These differences likely exist because the localities are over 100 km apart, thereby subject to differences in local environmental conditions.

The SI results demonstrate a very different pattern from the other three strata. Overall CVs of 39.0% for Sv and 27.7% for SvSingles, respectively, are masking major differences because the mean values are very much lower, being 30 dB for both Sv and SvSingles. The Sv results in Figure 3d have the highest values in February 2006, which declined in subsequent surveys, but then increased again by August 2008, to values close to the February 2006 result. Although not as clearly evident, the same pattern can be seen for the SvSingles results. These SI results, when compared with the other strata, indicate a change in the substrate that is much greater than any variation between the echosounders.

Unlike the Sv and SvSingles results, the PercentSingles distributions are highly skewed for all four strata, an effect that was corrected using a square root transformation. The SG results exhibit the highest degree of consistency (CV = 35.7%), as might be expected from the Sv and SvSingles results (Table 5; Fig. 3a). The SG results also are consistently the highest PercentSingles results for each survey. More variation is present for NG (CV = 45.5%; Fig. 3b) and EP (CV = 43.8%; Fig. 3c) results.

Whereas the SvSingles index provides an indication of small-scale changes in sound speed contrast, the PercentSingles index provides a measure of the lack of consistency in the substrate between surveys. This inconsistency could arise from changes in a number of sources, such as the proportion of silt to 'hard rock' or, at the other extreme, gas bubbles from rotting vegetation or detritus. Although substrates such as detritus are likely to have a low Sv, compared with rock, it was beyond the scope of the present study to determine the most likely causes.

The SG results are indicative of a substrate consistent within the stratum, showing little variation over the survey series and, as the Sv results are the highest, probably represents the hardest substrate type. Of the four strata selected for this analysis, SG is the obvious candidate for an intercomparison study, although NG and EP also provide adequate results. While the SI results support the conclusion that there is no significant difference related to the echosounder, the variations between surveys within that stratum invite more questions about consistency. Recalling that the four strata were selected because they appeared to offer consistency, the SI results demonstrate that considerable care must be exercised when choosing an intercalibration site.

What are the characteristics of a good intercalibration site?

According to theory, if correctly applied, the accepted international standard protocols (e.g. Foote *et al.* 1987) should ensure survey results are intercomparable. Nevertheless, it is prudent to ensure this is true in the event there happens to be, as in the present study, any controversy arising from a particular survey. Another good reason is that because surveys have to be undertaken from a moving vessel, the possibility exists that some change in efficiency can occur because of either vessel-generated noise or entrained bubbles (Simmonds & MacLennan 2005). The latter problem, however, can be addressed through sampling for short periods under full operational conditions with the echosounder in the passive mode.

Although the seabed has been given as a secondary standard against which to compare the results from different research vessels, the precise protocol is rarely specified. As an example, the text of CCAMLR-2000 Acoustic survey protocol (CCAMLR 2000) says the following:

> Selected shallow water survey transects should be repeated by each vessel; the seafloor scattering can thereby by used as a standard for comparisons. Sea state and ship speed and direction should be concurrently recorded with these measurements.

The results of the present study indicate the choice of a suitable survey site requires very careful consideration. The following criteria could be used to select suitable calibration sites:

- The seabed/lakebed should be characterized by giving uniform backscatter over a sufficiently large area;
- The site should be stable over the timescale of an individual survey or series of surveys; and
- The locality should be accessible and convenient to all vessels and systems participating in the surveys.

Taking each of these criteria in turn, and considering them within the context of the present study, it is clear the SI would not be a good site because of the high degree of variation both within and between the surveys. In terms of Sv and SvSingles SG, NG and EP have fairly consistent results, satisfying the first criterion relatively well.

As the survey design only permits sampling within each of the strata once on each survey, the results of the present study do not reflect changes within the time frame of a single survey. Of the four strata, the most consistent overall survey is SG, although the survey series is presently too small to be able to detect consistent patterns linking the strata.

The third criterion is satisfied for all the Lake Victoria surveys of the present study. As another example, however, there would be a time penalty of several days for the vessel taking the easternmost transects during the

CCAMLR 2000 survey if the chosen locality was on the western side of the waterbody, and vice versa. In that case, it might have been logistically necessary for one or more of the survey vessels to undertake the intercalibration sampling outside of the time period of the actual survey.

To return to the main question of this section, SG, and to a lesser extent, NG and EP come closest to satisfying all three criteria. Both SG and NG are very wide shallow bays, with extensive low ground in the coastal region, and lakebeds that provided a consistent level of backscatter over the survey periods. SI is a complex stratum containing deep channels between islands and shallow flat areas and, as such, has the characteristics of a changing and at the same time highly variable substrate. Such changes may be due to the accumulation of poorly reflecting material on the lake bed, or possibly habitat that is changed by storm effects.

It is concluded that, for the purposes of intercalibration, sites such as SG exhibit the key attributes. However, regions of significant change, such as SI, may provide evidence of environmental change relevant to managing the region.

CONCLUSIONS

This study has demonstrated that when the results from estimating the standing stock of fish acoustically from different surveys or echosounders are questioned, it is possible to check for consistency, using the substrate as a secondary standard. The selection of a suitable intercalibration locality needs to consider potential variations in the chosen survey area. Such an exercise is useful in demonstrating the consistency of the results to ‘non-acousticians’. This does not obviate the need, however, to monitor echosounder efficiency within a system over time and between units engaged in multiship surveys or contributing to a time series of results. Best practice indicates that passive sampling during surveys should provide suitable information. As data will be collected for most surveys, whether on lakes or on the continental shelves at sea, from which indices of substrate type can be calculated, there is merit in including these indices along with the results from the target species, when analysing the results obtained with acoustic surveys.

ACKNOWLEDGEMENTS

The officers and crew of RV Victoria Explorer are thanked for their consistent support during the fieldwork of this study. Drs. J. L. Watkins and S. Fielding of the British Antarctic Survey are thanked for freely participating in discussions on acoustics, as well as in the use of Echoview. We also thank the sceptical critics at the LVFO Stakeholder meeting for questioning the effectiveness of the acoustic method and hope the detailed attention used in this analysis will be carried forward to other methods of abundance estimation. The Leverhulme Foundation is gratefully thanked for its support for part of this work undertaken by Professor Inigo Everson.

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