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SHORT NOTE

VARIATIONS IN ECHOSOUNDER CALIBRATION WITH TEMPERATURE, AND SOME POSSIBLE IMPLICATIONS FOR ACOUSTIC SURVEYS OF KRILL BIOMASS

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Abstract

Accurate estimation of krill biomass by acoustic techniques is dependent on a number of factors of which one of the most fundamental is accurate echosounder calibration. The Simrad EK500 scientific echosounder used aboard RRS *James Clark Ross* is calibrated regularly at South Georgia before and after krill surveys there, and exhibits temporal stability in system gain settings. Between Antarctic seasons this echosounder has also been calibrated in temperate European waters. Under these warmer conditions, calibrated gain settings differ markedly from those applied in the Antarctic, even after adjustments have been made to account for differences in sound speed between locations. Here we present results from multiple Antarctic and European calibrations which suggest that echosounder transducer performance is dependent on ambient water temperature. Highly significant differences in volume backscattering (S_v) and target strength (TS) transducer gains were detected at both 38 and 120 kHz between calibrations conducted at the two locations. At 120 kHz, the required S_v transducer gains at South Georgia (sea temperature at depth of transducer = 2.3°C) were on average 1.4 dB less than in European waters (16.6°C), and a similar trend was detected at 38 kHz. If European calibration parameters were to be employed during surveys around South Georgia, and no account were taken of the differences in gain settings, then integrated 120 kHz echo signals would be under-reported by 2.8 dB, leading in turn to an under-estimation of krill biomass by 52.5%. Every effort should therefore be made to ensure that echosounders are calibrated at temperatures as close as possible to those prevailing within the area in which surveys are conducted. In addition, the implications for biomass estimation of temperature variation across a survey area should be considered carefully.

Résumé

L'estimation précise de la biomasse de krill au moyen de techniques acoustiques est fonction de plusieurs facteurs, dont un des plus fondamentaux est l'étalonnage précis de l'écho-sondeur. Le sonar scientifique Simrad EK500 utilisé à bord du navire de recherche *James Clark Ross* est étalonné régulièrement en Géorgie du Sud avant et après les campagnes d'évaluation du krill menées dans ce secteur, et démontre la stabilité temporelle du réglage de l'amplification du système. Ce sonar a d'ailleurs été étalonné dans des eaux tempérées européennes entre les saisons de recherche en Antarctique. Dans ces eaux plus chaudes, le réglage étalonné de l'amplification diffère considérablement de celui utilisé en Antarctique, même en ayant effectué des ajustements pour tenir compte des différences de vitesse sonique entre ces sites. Nous présentons ici des résultats provenant d'étalonnages multiples réalisés dans les eaux antarctiques et européennes. Ceci semble démontrer que le fonctionnement du transducteur de l'écho-sondeur est fonction de la température ambiante de l'eau. Des différences très significatives de l'amplification du transducteur en ce qui concerne la rétrodiffusion par volume (S_v) et l'intensité de la réponse acoustique (TS) ont été décelées tant à 38 qu'à 120 kHz entre les étalonnages effectués dans les deux sites. À 120 kHz, l'amplification S_v requise du transducteur dans le secteur de la Géorgie du Sud (température de la mer à la profondeur du transducteur = 2,3°C) était inférieure d'environ 1,4 dB à celle des eaux européennes (16,6°C). Une tendance similaire a été décelée à 38 kHz. Si les paramètres d'étalonnage européens devaient être utilisées dans les campagnes d'évaluation menées autour de la Géorgie du Sud sans tenir compte des différences du réglage de l'amplification, les signaux acoustiques intégrés à 120 kHz seraient sous-évalués de 2,8 dB, ce qui aboutirait à une sous-évaluation de la biomasse du krill de 52,5 %. Il est par conséquent impératif de s'assurer que les écho-sondeurs soient étalonnés aux températures les plus proches possible de celles prédominantes dans le secteur dans lesquels les campagnes d'évaluation sont réalisées. Il faut par ailleurs examiner de près les implications, pour l'estimation de la biomasse, des variations de température dans le secteur faisant l'objet d'une campagne d'évaluation.

Резюме

Для получения точной оценки биомассы криля с помощью акустических методов необходима точная калибровка эхолота. Эхолот Симрад EK500, который используется на научно-исследовательском судне *James Clark Ross*, подвергается регулярной калибровке на Южной Георгии до и после съемок криля в этом районе и характеризуется временной стабильностью параметров усиления. Между периодами работы а Антарктике данный прибор калибровали и в европейской части умеренных вод. В этих более теплых условиях откалиброванная регулировка усиления существенно отличается от таковой в антарктических водах, даже после внесения изменений для учета межрегиональных различий в скорости звука. В данной работе представлены результаты ряда калибровок, проведенных как в Антарктике, так и в водах Европы, которые указывают на то, что работа преобразователя эхолота зависит от температуры окружающей воды. Между калибровками, проведенными в этих двух регионах, были выявлены существенные расхождения в усилении преобразователя, в объеме обратного рассеяния (S_v) и силе цели (TS) как на 38 кГц, так и на 120 кГц. Требуемые величины усиления преобразователя S_v на 120 кГц в районе Южной Георгии (температура моря на глубине преобразователя = 2,3°C) в среднем были на 1,4 дБ меньше таковых в европейских водах (16,6°C); подобная картина наблюдалась на 38 кГц. Если бы при съемках в районе Южной Георгии для калибровки применялись европейские параметры и не учитывались расхождения в регулировке усиления, то величины интегрированных эхосигналов на 120 кГц были бы на 2,8 дБ меньше, что, в свою очередь, привело бы к недооценке биомассы криля на 52,5%. В связи с этим следует проводить калибровку эхолотов при температурах, как можно ближе к температурам, преобладающим в районе съемки. Кроме этого, необходимо тщательно изучить вопрос о влиянии изменчивости температуры в районе съемки на результаты оценки биомассы.

Resumen

La estimación exacta de la biomasa del kril mediante técnicas acústicas depende de varios factores, de los cuales uno de los más importantes es la calibración correcta del ecosonda. El ecosonda Simrad EK500 utilizado a bordo del RRS *James Clark Ross* se calibra regularmente en Georgia del Sur antes y después de las prospecciones de kril realizadas en esa área, y demuestra estabilidad temporal en el ajuste de ganancias de la amplificación del sistema. El ecosonda en cuestión también ha sido calibrado en las aguas templadas de Europa, durante períodos transcurridos entre las temporadas antárticas. En estas condiciones más templadas, el ajuste de ganancias de la amplificación del sistema difiere notablemente del ajuste aplicado en la Antártida, aún después de hacer los ajustes necesarios para tomar en cuenta las diferencias entre la velocidad del sonido en las dos localidades. Este estudio presenta los resultados de varias calibraciones realizadas en la Antártida y en Europa que indican que el rendimiento del transductor del ecosonda depende de la temperatura ambiental del agua. Se detectaron diferencias altamente significativas en las ganancias del volumen de la retrodispersión (S_v) y de la potencia del blanco (TS) del transductor a 38 y 120 kHz entre las calibraciones realizadas en las dos localidades. A 120 kHz, las ganancias del transductor S_v requeridas en Georgia del Sur (la temperatura del mar a la profundidad del transductor = 2,3°C) fueron menores en un promedio de 1,4 dB que las requeridas en aguas europeas (16,6°C), y se detectó una tendencia similar a 38 kHz. Si los parámetros de la calibración europea fuesen utilizados durante las prospecciones de Georgia del Sur, y no se tomasen en cuenta las diferencias entre las ganancias del transductor del sistema, las señales acústicas integradas a 120 kHz serían subestimadas en 2,8 dB, lo que conduciría a una subestimación de la biomasa del kril de 52,5%. Debe por lo tanto hacerse todo lo posible por asegurar que los ecosondas sean calibrados en temperaturas lo más cercanas posible a las que predominan en el área de las prospecciones. Además, deben considerarse cuidadosamente las implicaciones de la variabilidad de la temperatura dentro del área de la prospección misma para la estimación de la biomasa.

Keywords: Acoustic survey, calibration, gain, transducer performance, water temperature, CCAMLR

INTRODUCTION

Standard-target techniques are generally accepted as being the most accurate and practicable for calibration of ship-borne scientific echosounders (Foote et al., 1987). The influence of water temperature on sound speed, and consequently on the target strength of standard target spheres, is well described (Clay and Medwin, 1977; Foote and MacLennan, 1984a and 1984b), and the importance of taking environmental conditions into account during calibration is clearly recognised (MacLennan and Simmonds, 1992). Although it has been shown that laboratory temperature may have a considerable effect upon the amount of gain applied by system electronics in some echosounders (Simmonds, 1990), the possible effects of ambient water temperature on transducer performance are less well described. While some acoustic Doppler current profilers (ADCPs) have a specific term in their data processing algorithms to compensate for transducer temperature (R.D. Instruments, 1989), we have found no reference to corrections for such effects in manuals for scientific echosounders.

Although some acousticians have demonstrated long-term stability in echosounder calibration (e.g. Simmonds, 1990; Knudsen, 1997), there is a growing body of evidence to suggest that ambient water temperature influences transducer performance. Blue (1984) noted that the materials used to construct transducers made them susceptible to changes in character with temperature, and suggested that many of the transducers then used in fishery acoustics would not be stable to within ±0.5 dB over the range of temperatures of water commonly surveyed by fisheries biologists. Shirakihara et al. (1986) reported that transducers used aboard *Kaiyo Maru* during the FIBEX acoustic survey were 6 dB (four times) less sensitive at 0°C than at 20°C. More recently Demer and colleagues (Demer and Hewitt, 1992; Demer, 1994; Demer and Soule, 1996) have conducted a series of rigorously controlled calibration experiments in tanks, and have demonstrated that, for a Simrad EK500 system operating at 120 kHz, a 0.4 dB decrease in target strength (TS) gain is required as water temperature falls from 5.5 to 0.5°C. Furthermore, Pauly et al. (1996) calibrated their EK500 120 kHz transducer in temperate (sea temperature = 14.3°C) and Antarctic (sea temperature = 2.5°C) waters and found similarly that the required system gain was less (by 1 dB) in the colder water.

It appears therefore that a reduction in system gain may be a consistent requirement on transition from warm to cold water. Here we present calibration data for an EK500 system at 38, 120 and 200 kHz collected over a number of seasons in both Antarctic and European waters, which further support the view that echosounder transducer performance is highly temperature dependent. We also show that, if uncorrected, the influence of temperature upon transducer performance could have a highly significant impact upon acoustic estimates of krill biomass.

MATERIALS AND METHODS

A Simrad EK500 echosounder is used aboard RRS *James Clark Ross* to conduct acoustic estimates of krill biomass (e.g. Brierley and Watkins, 1996; Brierley et al., 1997a). Acoustic data are collected using hull-mounted Simrad 38 (type ES38-B) and 120 kHz (ES120) split-beam transducers and a single-beam 200 kHz (200-28) transducer. To prevent damage by ice, the transducers are housed within oil-filled recesses in the ship's hull, behind polycarbonate windows. These windows are cleaned annually in dry-dock during refit.

Routine standard-target calibrations of each transducer are carried out using both frequency-specific copper target spheres (60.0, 23.0, and 13.7 mm diameter for 38, 120 and

Table 1: Transducer descriptions and transceiver settings used during calibration exercises.

Nominal frequency, kHz	38	120	200
Transducer type	Simrad ES38B	Simrad ES120	Simrad 200-28
Beam type	Split	Split	Single
Transmit power, kW	2	1	1
Maximum power, kW	2	1	1
Pulse duration, ms*	1.0 (medium)	1.0 (long)	0.6 (long)
Band width, kHz*	3.8 (wide)	1.2 (narrow)	2.0 (narrow)
Ping interval, s	1	1	1
Two-way beam angle, dB	-20.7	-18.3	-20.9
Noise margin, dB	0	0	0
Cu sphere diameter [WC], mm	60.0 [38.1]	23.1 [38.1]	13.7 [38.1]

* Adjectives in curved brackets are the descriptions of these parameters as they appear in the EK500 menu.

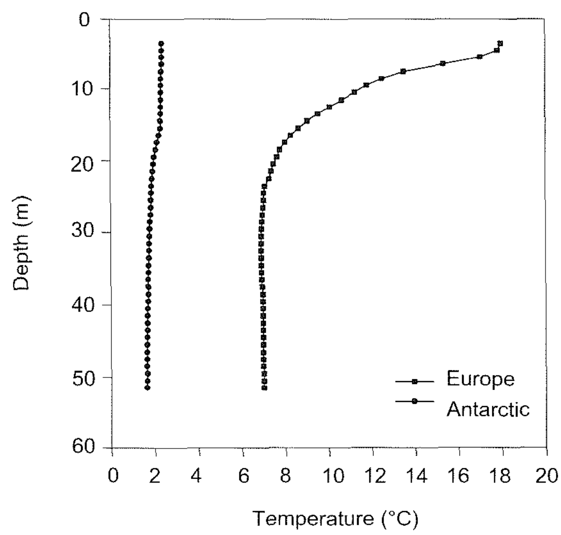

Figure 1: Typical temperature profiles at the European and Antarctic calibration sites.

200 kHz respectively) and a single tungsten carbide sphere (38.1 mm). Transceiver settings used during the calibration exercises (and on survey) are given in Table 1. Calibrated TS and volume backscattering (S_v) transducer gains are determined by adjusting gain settings in accordance with equations given by Simrad (1993) until the observed peak TS and integrated-area backscattering (S_a) values respectively from each sphere match theoretical expectations. Theoretical sphere TS values are determined with reference to tables provided by the sphere manufacturers, which give information on TS variation with sound speed. Conductivity temperature/depth probe (CTD) casts are made before each calibration event to obtain profiles of temperature and salinity through the water column. These are used in conjunction with pH 8 (as recommended by MacLennan and Simmonds, 1992) to calculate profiles of sound speed according to the equation of Francois and Garrison (1982), and from these a mean sound velocity through the water column between the transducers and the sphere is determined. In addition to TS and S_v transducer calibrations, beam patterns of the two split-beam transducers are routinely mapped using the Simrad programme *lobe*, and are corrected accordingly.

Calibrations are usually performed in Stromness Bay, South Georgia, prior to and after most krill surveys. A number of calibrations have also been undertaken in temperate European waters. The most recent of these took place in August 1995 at Uggdalseidet Fjord, Norway, under the supervision of Simrad engineers. Both Stromness Bay and Uggdalseidet Fjord are sheltered locations with deep water close inshore. Each therefore provides the calm sea conditions necessary for calibration, and has the additional advantage of facilities enabling the ship to be moored securely both stern and aft. Prior to every calibration event, the echosounder had been in continuous operation for at least two days on transit between the point of embarkation for the respective research cruises and the calibration site.

Table 2: Summary of mean S_V and TS transducer gains (and their standard deviations) at 38, 120 and 200 kHz derived from multiple calibrations of the EK500 aboard RRS *James Clark Ross* carried out in both Antarctic and European waters.

Frequency and Gain Type	Number of Calibrations		Mean Calibrated Transducer Gain, dB (SD)		Europe cf. Antarctic *t*-test *P*
	Europe	Antarctic	Europe	Antarctic	
38 kHz S_V	7	16	26.6 (0.1)	26.0 (0.2)	<< 0.001
38 kHz TS	7	17	27.0 (0.1)	26.1 (0.1)	<< 0.001
120 kHz S_V	5	15	22.1 (0.1)	20.7 (0.4)	<< 0.001
120 kHz TS	5	15	22.0 (0.1)	20.6 (0.3)	<< 0.001
200 kHz S_V	4	15	22.8 (0.1)	23.2 (0.4)	0.052
200 kHz TS	4	15	22.8 (0.4)	23.2 (0.4)	0.086

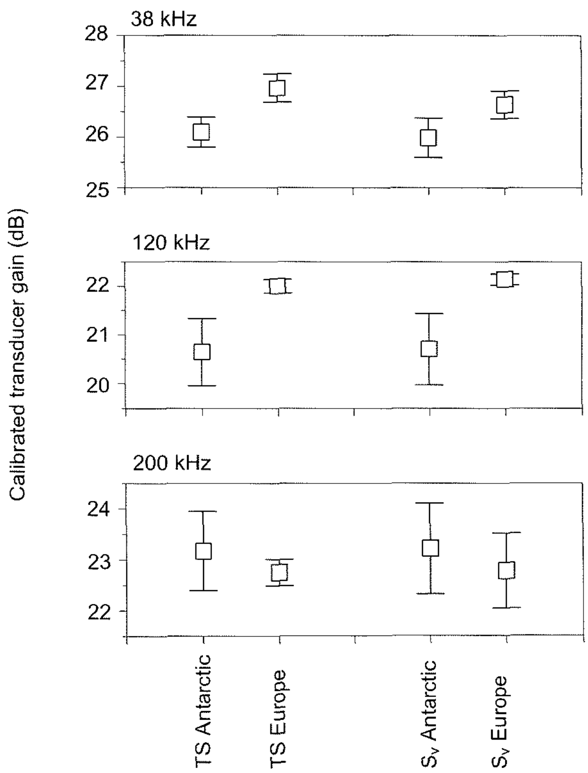

Figure 2: 38, 120 and 200 kHz calibrated S_v and TS transducer gain settings for the EK500 aboard RRS *James Clark Ross* in Antarctic and European waters. Error bars are ±2 standard deviations.

RESULTS

Since February 1994 the EK500 aboard RRS *James Clark Ross* has been calibrated on six separate occasions at Stromness, South Georgia, and on one occasion in warmer Norwegian waters. Typical temperature/depth profiles for each location are given in Figure 1. Multiple calibrations of each transducer were conducted on each of these occasions. Mean S_v and TS transducer gains for each frequency derived from all individual calibrations conducted over this time (including data from Cu and WC spheres, which gave indistinguishable results: *t*-test $P > 0.05$) are given in Table 2. The data are summarised graphically in Figure 2. It is clear from these data that repeat calibrations carried out within each region give consistently similar results. This is so even for calibrations performed at various depths with the target spheres both above and below thermoclines, and demonstrates temporal echosounder stability. Calibrated gains appear most stable at 38 kHz, whilst the variances associated with calibrated gain values at 120 and 200 kHz increase slightly with increasing frequency. This increase in variance with frequency is probably due to the greater practical difficulty experienced in keeping the increasingly smaller (diameter and mass) calibration spheres required for the higher frequencies stationary in the beam and on axis. In addition, the single-beam 200 kHz transducer is unable to compensate for the instances when the sphere swings off axis. On these occasions measured sphere TS will inevitably be lower than expected.

Although repeat calibrations at each of the two locations varied little (see Table 2 and Figure 2) over the study period, calibrations conducted in Antarctic waters yield significantly different results to those conducted in European waters. The difference in sea temperature between locations is illustrated in Figure 1. In Stromness Bay, the sea temperature at the depth of the transducers (approximately 6 m) was typically 2.3°C, whereas in Uggdalseidet Fjord it was 16.6°C. Mean temperature through the water column from the transducers to the calibration sphere (approximately 20 m) was 2.3°C at Stromness and 11.2°C in Uggdalseidet Fjord. At 38 and 120 kHz, calibrated S_v and TS transducer gain values were significantly lower (t-test $P << 0.001$) in Antarctic waters than in the warmer Norwegian Fjord. Calibrations at 200 kHz did not differ significantly between locations, although the failure to detect any difference at this frequency may simply be a function of the increased variance associated with the 200 kHz calibrations, rather than a real departure from the trend exhibited at 38 and 120 kHz.

DISCUSSION

Repeat echosounder calibrations carried out at South Georgia over a number of seasons demonstrate a high degree of self consistency, especially at 38 and 120 kHz, suggesting that within a particular geographic location/ oceanographic regime the EK500 system aboard RRS *James Clark Ross* remains stable over time (see Simmonds, 1990). Despite having taken every precaution to correct for local environmental differences (water temperature, salinity), however, there are significant differences between calibrations at 38 and 120 kHz undertaken at South Georgia and in Europe. We believe the cause of these observed differences to be the difference in temperature at the two locations of the transducers, of the oil in which they are housed and/or of the windows by which they are protected, all of which are influenced directly by the temperature of the sea at that depth (approximately 6 m). The physical and/or electrical properties of each of these components may vary with temperature. The water temperature at 6 m in Stromness Bay, South Georgia, has typically been around 2.3°C during our calibration exercises there, whereas the equivalent temperature in Uggdalseidet Fjord, Norway, was 16.6°C. Although our results apply to a single configuration of echosounder, transducer, recess window material and oil type, other acousticians operating in the Antarctic (Shirakihara et al., 1986; Demer and Hewitt, 1993; Demer, 1994; Pauly et al., 1996) have noted a change in echosounder performance on transition between water masses with differing surface temperatures. In common with this study, all report that gain settings need to be reduced in colder water.

At present we use the difference in volume scattering strength at 120 and 38 kHz to identify echoes caused by krill (e.g. Brierley et al., 1997a). As both these frequencies appear to respond in a broadly similar manner to changes in temperature, it is unlikely that temperature fluctuation across our survey areas would compromise our ability to correctly apportion krill biomass. Our calibrations at 200 kHz, however, show no clear pattern of variation with temperature. If this is a true representation of the performance of the 200 kHz transducer, discrimination of other zooplankton species on the basis of the relative differences in their backscattering strength at 38, 120 and 200 kHz (see Brierley et al., 1997b) may be affected by regional temperature change.

Variation in the efficiency of the 120 kHz transducer with temperature may be a source of error in calculation of biomass. All data available to date point to the potential for underestimation of biomass in cold water because of a reduced transducer efficiency. If our S_v gain parameters determined in the warm European waters, for example, were used during survey of the cold waters around South Georgia, and no correction were made for the difference, then integrated 120 kHz signals would be under-reported by 2.8 dB ($2 \times [S_v\ gain_{Antarctic} - S_v\ gain_{Europe}]$, since gain is applied to both transmitted and received signals – see Simrad, 1993 section P2260E, pp. 15–16), which would equate to a 52.5% underestimation of krill biomass. This demonstrates clearly the potential for bias in acoustic surveys due to temperature effects alone. In a review of the FIBEX acoustic survey, Miller and Hampton (1989) point out that calibration error due to temperature could have led to a general underestimation of krill abundance because most echosounders used during that survey were calibrated at temperatures substantially higher than those of Antarctic surface waters.

For most workers the effect of temperature fluctuation on survey accuracy will probably be minor in comparison to the total error likely to be introduced throughout the survey (see Demer, 1995). For our own annual surveys to the north of South Georgia, for example (see Brierley et al., 1997a), mean sea surface temperature differs by less than 1°C between the calibration site and the two survey regions (British Antarctic Survey, unpublished data). The effect could, however, be important for studies conducted in the vicinity of strong thermal discontinuities, e.g. around fronts. With a growing body of evidence to suggest that thermal transducer instability is a real phenomenon, rather than an isolated system error, it would be prudent to consider this source of error in the design and implementation of the new proposed synoptic acoustic survey of krill abundance throughout the oceanographically diverse CCAMLR Area 48.

CONCLUSIONS

The performance of Simrad ES38-B and ES120 echosounder transducers has been shown here to be significantly temperature-dependent. Our findings of a requirement for a reduction in both S_v and TS transducer gains on transition from warm to cold water are consistent with observations reported previously by other acousticians, and as such may be illustrative of a general effect.

Failure to adjust echosounder gain settings in response to possible changes in ambient water temperature between the calibration site and the survey area could potentially lead to the introduction of significant bias in acoustic survey results. If, for example, calibration is conducted in waters warmer than those of the survey area, then acoustic surveys may significantly underestimate biomass because of temperature effects alone.

We suggest that echosounder calibration be undertaken in an area as close as possible to the intended survey region, and that water temperature throughout the survey area be monitored, especially in proximity to regions of strong thermal discontinuity, for example around fronts.

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