Biomass and dispersion of myctophid fishes in the Scotia Sea as detected by multi-frequency echosounders

J.H. Emery[1], S. Ksatkina[2], C. Goss[3], R.P. Hewitt[1], D. Demer[1], J. Watkins[2], M. Naganobu[4], V. Sushin[2], A. Brierley[5], Y. Takao[6]

[1] Southwest Fisheries Science Center, P.O. Box 271, La Jolla, California, USA 92038
[2] AtlantNIRO, 5 Dimitry Donskoy Street, Kaliningrad 236000, Russia
[3] British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, UK
[4] National Research Institute of Far Seas Fisheries, Orido 5-7-1, Shimizu, Shizuoka 424, Japan
[5] Gatty Marine Laboratory, University of St Andrews, St Andrews, Fife, Scotland KY16 8LB
[6] National Research Institute of Fisheries Engineering, Ebidai Hasaki, Kashima-gun, Ibaraki 314-0421, Japan

Abstract

The biomass and dispersion of myctophid fishes across the Scotia Sea was inferred from muli-frequency active acoustic data collected by research vessels from Japan, Russia, UK and USA during January – February 2000. Regions of the echograms were delineated as myctophid fish when the difference between mean volume backscattering strength at 120 kHz and that at 38 kHz was less than 2 dB and greater than -5 dB. No attempt was made to distinguish between genera or species of myctophidae, although the majority of volume backscattering could likely be attributed to *Electrona Antarctica, E.Carlsbergi*, , *Gymnoscopalus nicolsi,* and *Krefftichthys anderssonii*. Integrated volume backscattering area attributed to myctophid fish was converted to biomass density using a range of values for backscattering area per kg of fish (σ_{kg}) derived from *in situ* target strength (TS) measurements and various TS-length and weight-length relationships. Estimated biomass of myctophid fishes across the Scotia Sea ranged from 6.9 to 18.5 million tones,

depending on the TS-length and weight-length relationships used. Transect to transect sampling variability yielded a coefficient of variation of 72%. Comparison of acoustic return from the two frequencies was noise-limited to 300 m depth; visual inspection of the 38 kHz data in the depth range of 300 to 500 m suggested an underestimate of approximately 50% in the ocean stratum off the Antarctic Peninsula, perhaps more in the Scotia Sea stratum. Myctophid distribution varied over the survey area with highest density centered on the Scotia Sea transects just below South Georgia.

Introduction

During January and February 2000 a multi-ship, multi-nation survey of the Scotia Sea (Watkins et al. this volume) was conducted in support of the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR), part of the Antarctic Treaty system. The survey was primarily designed to estimate the biomass of Antarctic krill using active acoustic data collected at 38, 120 and 200 kHz from the upper 500 m of the water column and macro zooplankton samples obtained from the upper 200 m. These data are examined here with the intent of generating an estimate of myctophid fish biomass in the Scotia Sea.

Substantial quantities of meso-pelagic myctophid fishes are known to occur in the Southern Ocean (Filin et al. 1991, Hoddell et al. 2000, Lubimova et al. 1983, Lubimova et al. 1987). Myctophid fish have been noted as important components of vertebrate diets and described as an alternative prey to Antarctic krill. (SC-CAMLR-XIX, 2000). Croxall et al. 1999 demonstrate the ability of macaroni penguins to maintain reproductive performance by switching to other prey sources, such as myctophids, during years of declining krill populations. Casaux et al. 1998 identified myctophids in the stomachs of Cape petrels at the South Shetland and South Orkney Islands. Reid and Arnould 1996 found large amounts of myctophids in fur seal scats between early February and mid-March.

Distributions of *in situ* target strength (TS) measurements obtained during the CCAMLR 2000 survey indicate two major modes apparent in both the 38 kHz and 120 kHz data sets. The lower of these modes is approximately –64 dB at 120 kHz; the corresponding mode at 38 kHz is 8 dB lower at approximately –72 dB (figure 1). These TS measurements were attributed to Antarctic krill (*Euphausia superba*) and for the purposes of estimating krill biomass the data were filtered to include only those regions of the

echograms where the difference between volume backscattering strength at 120 kHz and that at 38 kHz was greater than 2 dB but less than 16 dB (Watkins and Brierley 2000, Hewitt et al. this volume).

The position of the higher of the two modes was more similar between the frequencies with the mode at 120 kHz 2 dB lower than that at 38 kHz (figure 2). We have attributed these target strength measurements to mesopelagic myctophid fishes (of the genera *Electrona, Gymnoscopelus, Protomyctophum* and *Krefftichthys*, but primarily *E. Antarctica, E. carlsbergi, G. Nicholsi,* and *K. andersson,*) (Lubimova et al. 1987, Duhamel et al. 2000). For the purposes of estimating biomass and dispersion of myctophid fishes the data were filtered to include only those regions of the echograms where the difference between volume backscattering strength at 120 kHz and that at 38 kHz was greater than -5 dB but less than 2 dB (Figure 3). This range was selected based on observations made between myctophid scattering layers at 120 kHz and 38 kHz. These layers were confirmed to be myctophids by net sampling.

The possible inclusion of squid in the final estimate was of concern. However, squid produce an acoustic signal that is more easily detected at higher frequencies (Vaughan and Recksiek 1979, Suzuki et al. 1974). Given that myctophids are better detected at lower frequencies, squid are not likely to have been included within the same dB range when considering the difference between 120 kHz and 38 kHz data.

Methods

Acoustic data were collected as part of a four-ship survey conducted during January-February 2000 across the Scotia Sea. The survey area was divided into seven strata each with three to ten randomly spaced parallel transects (Figure 4). Survey transects were

conducted only during daylight hours. On each survey vessel volume backscattering and individual target strength data were collected using a Simrad EK500 echosounder, 38 kHz, 120 kHz and 200 kHz hull-mounted transducers, and SonarData's EchoLog_EK data logging software. Standard sphere calibrations were conducted aboard each vessel before and after the survey. Ping intervals were 2 sec and pulse durations were 1 msec for all frequencies. Samples of volume backscattering strength were obtained every 0.71 m from the surface to 500 m depth after using a survey mean sound velocity profile as a basis for calculating adjustments due to absorption, spherical spreading, acoustic wavelength and equivalent two-way beam angle (Hewitt et al. this volume).

In situ TS measurements were filtered to include only those observations made at the same time in the same location with both the 38 and 120 kHz split beam transducers following the method outlined by Demer et al. 1999.

Backscattering was attributed to myctophid fish when the difference between mean volume backscattering at 120 kHz and 38 kHz was greater than -5 dB but less than 2 dB. The use of this procedure was limited to 300 m depth because of excessive noise in the 120 kHz data. In order to avoid including echoes from non-myctophid fin fishes, data from the surface to 50 m and within 50 m of the bottom were excluded.

Because of the relatively high variability between samples of volume backscattering, strength echograms were resampled. The dimensions of the resampling bins were 5 m in depth by 100 sec in time (approximately 500 m horizontal distance at a survey speed of 10 knots). Each resampled value thus represents the average volume backscattering strength from 350 samples.

SonarData's EchoView post-processing software was used to 1) reconstruct and filter echograms for the transect periods between stations; 2) remove echoes due to surface turbulence, the bottom and secondary bottom returns (false bottom); 3) resample

the echograms; 4) exclude regions of echograms within 50 m of the surface and bottom; 5) subtract noise from the 38 kHz and the 120 kHz echograms; 6) subtract the 38 kHz noise-free resampled echogram from the 120 kHz noise-free resampled echogram; 7) mask portions of the 38 kHz noise-free resampled echogram to exclude regions where the difference between the mean volume backscattering strength at 120 kHz and that at 38 kHz was less than -5 dB or greater than 2 dB; and 8) integrate the masked resampled 38 kHz echogram over 10 m depth layers and average over 1852 m horizontal distance.

The application of these filters is illustrated by the echograms in Figure 5. The first panel is an unfiltered 38 kHz echogram. The second panel is the same echogram filtered to include only krill and the third panel is the same echogram filtered to include only myctophid fishes. Echograms from the entire CCAMLR 2000 survey were processed in a similar fashion.

All echograms (original and resampled, unfiltered and filtered) were visually inspected. In some instances noise apparent on the deeper portions of the 38 kHz echograms resulted in false delineation of myctophids. These instances were investigated and corrected by applying a time-varied threshold to the 38 kHz measurements of volume backscattering strength.

Integrated volume backscattering area (NASC) was converted to myctophid biomass area density (ρ) by dividing NASC by the acoustic backscattering cross-sectional area per kg of fish:

$$\rho = \frac{\mathrm{NASC}}{\sigma_{kg}} \bullet \frac{1000\left(\frac{g}{kg}\right)}{1852^2\left(\frac{m^2}{n.mile^2}\right)}$$

Where ρ is the myctophid biomass area density in units of g m^{-2},

NASC is the integrated volume backscattering area expressed as the Nautical Area Scattering Coefficient in units of m^2 of backscattering cross-sectional area per square n. mile of sea surface, and

σ_{kg} is the acoustic backscattering cross-sectional area per 1 kg of wet fish weight in units of m^2 per kg.

An estimate of $\sigma_{kg} = 0.0105$ ($\pm$ 0.0025) was taken from Filin et al. 1991, as derived from length-dependent expressions of acoustic backscattering cross-sectional area and weight of single fish, such that:

$$\sigma_{kg} = \frac{\sigma(L)}{w(L)}$$

where $\sigma(L) = 4\pi 10^{TS(L)/10}$, $TS(L) = -75.0 + 25.5\log(L)$, and L ranged from 5 to 10 cm. No expression for weight as a function of length (w(L)) was provided by Filin et al. 1991.

Further estimates of σ_{kg} were obtained by converting the distributions of *in situ* TS measurements to a pdf of backscattering cross-sectional area (σ). Distributions of fish lengths (L) were derived from the above expression and a pdf of individual fish weight for both *Electrona* spp and *Gymnoscopelus* spp were calculated from distinct length-weight relationships acquired from measurements taken during the US-AMLR 2001 fish stock assessment survey.

Where $W = 0.016(L)^{2.9178}$ for *Electrona* spp, and
$W = 0.0354(L)^{2.5622}$ for *Gymnoscopelus* spp

Thus:

$$\sigma_{kg} = \frac{\sum f_i \sigma_i}{\sum f_i w_i}$$

Where *i* indexes the TS frequency classes and $\Sigma f_i = 1$. This yields estimates of 0.0185 for *Electrona* spp and 0.0111 for *Gymnosopelus* spp.

A third estimate of σ_{kg} was obtained using the TS-length relationship from Foote 1987, where $TS(L) = -71.9 + 20\log(L)$. Using this algorithm and the length-weight relationships obtained from the AMLR 2001 survey, σ_{kg} for *Electrona* spp and *Gymnoscopelus* spp was estimated at 0.0296 and 0.0161 respectively.

Strata densities and variances were calculated following Jolly and Hampton 1990. Estimates of mean density calculated for each transect represent samples within a stratum. Mean densities of each stratum were equal to the weighted mean of all transects within the stratum, weighted by transect lengths. Stratum variances were also calculated as the weighted variances of all transects within the stratum, weighted by transect length.

Results

After applying the two TS algorithms and related cross-sectional areas, the total biomass of myctophid fish in the Scotia Sea varies (table 1). Given that Filin et al. 1991 assumes one value of σ_{kg} for all myctophid species with a range of ±0.0025, a range in biomass is calculated (15.8-25.6 million tonnes). Utilizing Filin's TS algorithm taken from Mamylov 1988 in combination with the length-weight relationships derived from AMLR 2001, we arrive at 11.1 million tonnes (assuming all to be *Electrona* spp) and 18.4 million tonnes (assuming all to be *Gymnoscopelus* spp). Applying the TS algorithm from Foote 1987 and the same length weight

relationship produces biomass estimates of 6.9 and 12.7 million tones. Variability was greatest in the Scotia Sea region. One of the ten Scotia Sea transects was considerably higher in myctophid abundance compared to the remaining nine.

Fish lengths derived from the TS-length relationship from Filin et al. 1991 ranged from 1.5-6.5 cm with the mode at 2.5 cm (figure 6a). Lengths derived from the TS-length relationship from Foote 1987 ranged from 1-7.5 cm with the mode also at 2.5 cm (figure 6b).

Myctophids were distributed between 25 and 300m with over 70 percent occurring between 200 and 300m (figure 7b). More may have been located below 300m, but were excluded due to noise corruption. Myctophids at this depth were eliminated as a result of the noise subtraction step of the delineation method. Depth distribution varied by strata (fig 8). Myctophids occurred mostly at depths less than 200m for the Antarctic Peninsula, South Georgia, East Scotia Sea, and South Orkney Island but occurred mostly at depths greater than 200m in the South Shetland Island and Scotia Sea strata. Myctophid abundance was nearly uniform with depth in the South Sandwich Islands.

The Antarctic Peninsula Area was analyzed separately in order to determine the amount of myctophids potentially located below 300m. After performing a noise subtraction from the original echogram rather than the resampled echogram, myctophids below 300m were visually delineated. The results indicated that a large portion of these fish were indeed located deeper than the noise corruption barrier (fig 7a). An estimated 44 percent of the total biomass attributed to myctophid fish between 0 and 500m may occur at depths greater than 300m for this region.

The horizontal dispersion of myctophids varied greatly throughout the survey area. The areas of highest densities centered predominately on the Scotia Sea transects, just below South Georgia (fig 9). Other areas of greater abundance were the northern ends of the East Scotia Sea transects, northwest of the Orkneys, and the area north of the South Shetland Islands. These descriptions represent myctophids located between 50 and 300m only, as those at greater depths were not included in the analyses for the entire survey area.

Discussion

The estimate of the biomass of mesopelagic myctophid fishes across the Scotia Sea is fraught with several sources of uncertainty. Sources of uncertainty include the undercounting of myctophid fishes outside of the observation window, the overestimate of myctophid biomass by inclusion of echoes from other organisms, the overestimate of myctophid biomass by inclusion of noise in the 38 kHz volume backscattering data greater than 300m (visual delineation method only), and variability associated with estimates of backscattering cross-sectional areas.

Because of the exclusion of fish below 300m, the possibility of underestimation by approximately 44 percent is likely as shown in the case of the Antarctic Peninsula region. This would lead to an increase in biomass from 19.5 (applying Filin et al. 1991) to 34.8 million tonnes. However, the visual delineation of fish below 300m is highly subjective and could lead to under- or over-estimation in itself. The sampling limitations must also be taken into account. Acoustic backscattering was only recorded as deep as 500m. This will likely lead to additional underestimation of total biomass. Underestimation in the Scotia Sea strata may be greater.

The 250-300m layer contains most of the myctophid biomass for this region. It is probable that more will occur at depths greater than 300m.

The two-frequency delineation method is the most objective means of enhancing acoustic signals from one organism while eliminating that of others. It is not completely flawless, however. It is possible for echoes from other organisms to be included in the estimate due to similarity in value with that of the organism of interest. For example, the window of –5 to 2 dB used to separate myctophids from other organisms could possibly include krill. The expected difference between 120 and 38 kHz for krill ranges between 2 and 16 dB (Watkins and Brierley 2000). Still, larger krill can exhibit a dB difference of 0 to 2 dB, well within the dB range applied when delineating myctophids.

Another source of error in estimating biomass is that of noise corruption. The likely case of over-estimation due to noise inclusion occurs when visually delineating. The two-frequency delineation method is designed to reduce noise amplification and inclusion while bringing out signal attributed to myctophids. This occurs during the resampling portion of the procedure. On the other hand, the visual delineation method does not account for this. In order to prevent total loss of myctophid fish at depths greater than 300m, some noise remains in the echogram. Therefore, some noise may be included when visually delineating the fish aggregations.

Other sources of error are the various TS-length relationships. Myctophids use of the swimbladder is uncertain (Neighbors and Nafpaktitis 1982). Backscattering values are higher at 38 kHz than at 120 kHz, an indication of a swimbladder. However, some myctophids may exhibit swim bladder atrophy. The swim bladder may become surrounded by lipids as they age, rendering it

nonfunctional. Thus, the larger, older fish may become less distinct at lower frequencies, which could explain why the TS algorithm obtained from Foote 1987 yielded smaller fish sizes.

Another source of uncertainty not yet mentioned is that of *in situ* target strength measurements. Most single targets detected occurred between 50 and 150 m. This is a possible explanation for the low length frequency distributions derived from the TS algorithms. Underestimation may have occurred because of the lack of target strength data for fish of adult size or the population is dominated by juvenile and larval fish.

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			a		B		c		d		e		
Stratum	Area (km^2)	NASC m^2/n.mi^2	Density (g/m^2)	Biomass 10^6 tonnes	Density (g/m^2)	Biomass 10^6 tonnes	Density (g/m^2)	Biomass 10^6 tonnes	Density (g/m^2)	Biomass 10^6 tonnes	Density (g/m^2)	Biomass 10^6 tonnes	CV %
AP	473318	36	0.82-1.33	0.38-0.62	0.57	0.27	0.96	0.45	0.36	0.17	0.66	0.31	35
SS	1109789	562	12.60-20.47	13.9-22.7	8.85	9.82	14.75	16.37	5.53	6.14	10.17	11.29	80
ESS	321800	163	3.65-5.93	1.17-1.91	2.56	0.82	4.27	1.37	1.60	0.52	2.95	0.95	34
SSI	48654	174	3.90-6.34	0.19-0.31	2.74	0.13	4.57	0.22	1.71	0.08	3.15	0.15	37
SOI	24409	38	0.84-1.37	0.02-0.03	0.59	0.01	0.99	0.02	0.37	0.01	0.68	0.02	63
SG	25000	4	0.09-0.15	0.002-0.004	0.07	0.00	0.11	0.00	0.04	0.00	0.08	0.00	48
Sand	62274	14	0.32-0.52	0.02-0.03	0.23	0.01	0.38	0.02	0.14	0.01	0.26	0.02	33
ALL	2065244			15.77-25.63		11.08		18.47		6.93		12.73	72

Table 1. Density and biomass estimates by strata derived from:

(a) TS = -75.0 + 25.5log(L) and σ_{kg} = 0.0105 (± 0.0025) from Filin et al. 1991, based on fish lengths from 5-10cm,
(b) TS = -75.0 + 25.5log(L) and length-weight relationship for *Electrona* spp from AMLR2001,
(c) TS = -75.0 + 25.5log(L) and length-weight relationship for *Gymnoscopelus* spp from AMLR2001,
(d) TS = -71.9 + 20.0log (L) from Foote 1987 and length-weight relationship for *Electrona* spp from AMLR2001,
(e) TS = -71.9 + 20.0log (L) from Foote 1987 and length-weight relationship for *Gymnoscopelus* spp from AMLR2001.