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ACOUSTICAL ESTIMATION OF FISH ABUNDANCE AND THEIR SPATIAL DISTRIBUTIONS IN LAKE TANGANYIKA

by

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PREFACE

The Research for the Management of the Fisheries on Lake Tanganyika project (LTR) became fully operational in January 1992. It is executed by the Food and Agriculture Organization of the United Nations (FAO) and funded by the Finnish International Development Agency (FINNIDA) and the Arab Gulf Program for the United Nations Development Organization (AGFUND).

LTR's objective is the determination of the biological basis for fish production on Lake Tanganyika, in order to permit the formulation of a coherent lake-wide fisheries management policy for the four riparian States (Burundi, Democratic Republic of Congo, Tanzania, and Zambia).

Particular attention is given to the reinforcement of the skills and physical facilities of the fisheries research units in all four beneficiary countries as well as to the build-up of effective coordination mechanisms to ensure full collaboration between the Governments concerned.

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EXECUTIVE SUMMARY

A total of five fisheries-acoustic surveys were conducted in scope of the LTR Project in the years 1995-1998. They were dedicated to the pelagic fish stock aimed at estimating the total biomass and distribution patterns. The cruises were planned as to cover every time the whole area of Lake Tanganyika, but it not always succeeded (for different reasons - e.g. equipment failure). Complementary fishing operations (midwater trawls), zooplankton sampling and CTD measurements were carried out.
A summary of the surveys with dates and some operational information is given in the Table 1.

Table 1. A summary of the surveys

cruise number	time	mileage	number of acoustic transects	number of trawls	number of CTD stations	number of zoo-vertical stations	number of GULFs
2	15.06. - 30.06.95	978	?	32	32	23	25
5	16.11.-04.12.95	1092	41	41	29	34	26
7	02.04.-12.04.96	?	18	21	21	7	14
17	22.11.-09.12.97	1185	54	26	23	29	15
19	05.02.-20.02.98	1228	41	22	26	0	18

Unfortunately, the data from cruises 5 and 7 were useless for the estimate of absolute fish abundance, because of a very high noise level recorded. In consequence, the analysis concerned only the cruises 2, 17 and 19.

Acoustic measurements could indicate total biomass but could not discriminate between species if their acoustic properties were similar. The fish species of interest: *Stolothrissa tanganicae, Limnothrissa miodon* and *Lates stappersii,* occured in mixed aggregations and their acoustical parameters were almost the same. In that case it was appropriate to consider a broad category which was a mixture of species with similar behaviour, and only the total abundance of the mixture could be estimated on the assumption that one unit weight of all the species reflected the same proprtion of acoustic energy.

The average values of the fish length $<L>$, fish weight $<W>$, target strength $<TS>$, the backscattering cross-section $<\sigma_{bs}>$, backscattering cross-section per unit weight $<\sigma_{1\ kg}>=<\sigma_{bs}>/<W>$ and target strength per unit weight $<TS_{1\ kg}>$, obtained from *TS(L)* regression formula applied to the fish sample caught during three analysed cruises, are presented in Table 2.

Table 2. Mean fisheries and acoustical parameters

cruise number	$<L>$ [mm]	$<W>$ [g]	$<TS>$ [dB]	$<\sigma_{bs}>$ [m^2]	$<\sigma_{bs}>/<W>$ [m^2/kg]	$<TS_{1\ kg}>$ [dB]
2	42.88	2.21	-62.61	$5.48\ 10^{-7}$	$2.48\ 10^{-4}$	-36.06
17	58.07	1.45	-56.30	$2.34\ 10^{-6}$	$1.62\ 10^{-3}$	-27.90
19	71.42	2.54	-56.42	$2.28\ 10^{-6}$	$8.98\ 10^{-4}$	-30.47

It was desired to examine the extent to which diurnal differences could influence a total fish estimate. A comparison of „day” and „night” records of the mean *TS* values and integram values from the surveys 17/97 and 19/98 indicated that the night values were a few dB higher than the day ones. It could be concluded that acoustic measurements performed at night only could result in a bias in the final fish abundance estimate.

In order to estimate the total fish abundance in Lake Tanganyika, the whole its area was divided along the latitudes into 5 regions (Fig.1):

1. 3°20′ - 4°30′ Burundi/Cap Banza
2. 4°30′ - 5°40′ near Kigoma
3. 5°40′ - 6°30′ near Lagosa
4. 6°30′ - 8°00′ Kipili/Karema
5. 8°00′ - 8°45′ Zambia

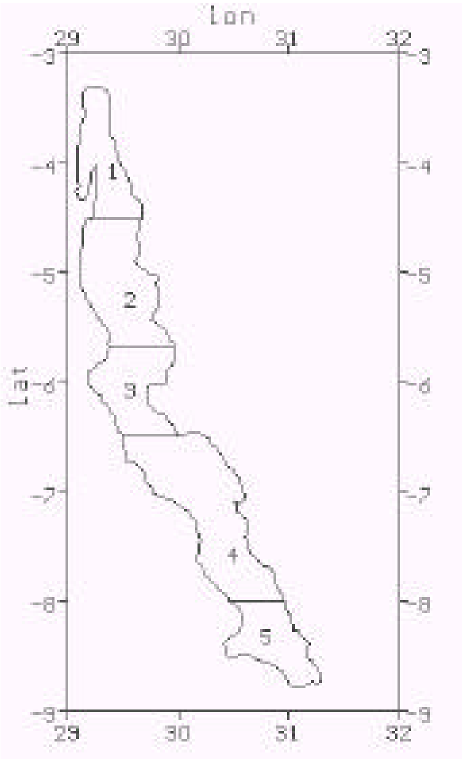


Fig.1. Division of Lake Tanganyika into subregions.

In each section the mean value of fish biomass (in tonnes) and its standard error were evaluated.

Table.3. Mean fish biomass (in tonnes) calculated for 5 sub-regions in surveys 2, 17 and 19

region	area [N.mi.^{2}]	Survey 02/95	Survey 17/97	Survey 19/98
1	1161.70	40137± 13068	8774± 6519	22269± 14120
2	2350.85	42761± 26276	57605± 53249	49787± 40012
3	1774.30	7211± 5452	27154± 16480	64753± 35494
4	3385.43	1085± 218	53614± 20426	104835± 23720
5	1382.35	0	28543± 5663	62819± 32232

Finally, on the basis of the section means and section areas the total abundance and confidence limit for confidence level 95% were calculated. They were as follows:

Table.4. Total fish biomass estimated in surveys 2, 17 and 19

survey	total biomass [tonnes]	confidence limit
02/95	91 193	45 014
17/97	175 681	102 337
19/98	304 463	145 577

It was evident that each of the cruises gave a different distribution of fish biomass. The results of the 02/95 survey could be biased because of the insufficient number of samples, but it was obvious that the majority of fish was concentrated in the northern part of the lake, especially in the layer 60 - 80 m. In December - cruise 17/97 - fish mass was moved toward the south with the maxima in Cap Banza area, Kabimba - Lagosa line, below Cap Kibwesa and the western part of Zambian waters. The depth distribution seemed to be quite uniform. In February - cruise 19/98 - the majority of fish was concentrated in the middle part of the lake, around Cap Kabogo and in the southern part, in Kirando and Kala areas. There was definitely a small amount of fish in the north.

Another division of the whole lake area was made for estimation of fish abundance in waters of the four riparian countries: Burundi, Tanzania, Congo and Zambia. The results are shown in Table 5:

Table.5. Mean fish biomass (in tonnes) calculated for 4 riparian countries in surveys 2, 17 and 19

country	approximate area [N.mi.^{2}]	survey 02/95	survey 17/97	survey 19/98
BURUNDI	580.85	23562	1533	10509
TANZANIA	4241.01	44897	82201	157493
CONGO	4496.78	24482	72130	120121
ZAMBIA	735.99	0	14116	15522

0-value in the lowest row of Tables 3 and 5 for the cruise 02/95 is caused by the lack of acoustic data in the most south part of the lake in that cruise.

It is known from the previous acoustic surveys held on Lake Tanganyika in the years seventies (Johannesson, 1974, Chapman 1974, 1976, Mathisen and Rufli, 1980) that a rough estimate of the total abundance of pelagic fish in Lake Tanganyika was in a range of 0.4 to 2.8 mln tonnes. Our estimates were lower. The extreme estimate obtained by Johannesson (1974) was 4 to 10 times higher than all the others, but the reasons were explained in the main report (paragraph 4.2.1). In regard to variation in the mean density and very large variances, the rest of fish abundance estimates were consistent between themselves.

It must be emphasised in this point that the temporal variations in fish abundance and their spatial distributions are enormous. Johannesson (1974) evidenced more than twice difference in the biomass measured in the interval of a few weeks in Burundian waters. Chapman (1976) found completely different fish distributions in Kigoma waters in two consecutive nights. He concluded: „...the fishery and markets of Kigoma must expect large differences in catch from day to day unless echosounding can reduce them by pinpointing optimum fishing locations”. Such changes should be interpreted in terms of large-scale movement among the nekton components of Lake Tanganyika (the all important fish species are migratory!) and seasonal variations of the environmental conditions. The very low levels of fish biomass can be also a result of a temporary overfishing, especially in the industrial fishing areas - Burundi and Zambia.

The standing stocks of fish in Lake Tanganyika seem to be much less than their annual production (Coulter 1981). According to Hanek and Coenen (1994) the total overall fish catch for 1992 was 167 000 tonnes (Burundi 24 000, Tanzania 80 000, Zaire 50 000, Zambia 13 000). These numbers are comparable with the separate estimates of fish biomass. With increasing dependence on a species with a 1-year life cycle, the fishery probably will become more seasonal and also more susceptible to environmental fluctuations.

1.INTRODUCTION

Lake Tanganyika is unusual among lakes for its trophic efficiency and is unique in the proportion of fish biomass to phytoplankton biomass. What is interesting, Tanganyika's food web has a decidedly marine nature (Coulter, 1991).

The pelagic fish community of Lake Tanganyika is composed of six endemic species: two sardine-like clupeids, *Stolothrissa tanganicae* and *Limnothrissa miodon*, and four members of the genus *Lates* commonly known as *Nile perch* ,*Lates stappersi, Lates mariae, Lares microlepsis* and *Lates angustifrons.* Only three of them are of industrial meaning: *Stolothrissa tanganicae, Limnothrissa miodon* and *Lates stappersi.* All they are migratory. Clupeids are small, numerous, short-living and highly productive. They are ususally key members of pelagic food chain, linking planktonic and piscivorous trophic levels. Adult *Lates* species are predators and their relatively high biomass is supported by highly productive prey.

Acoustic techniques lend themselves very well to counting fish relatively easily. Acoustic surveys are conducted to investigate a large volume of water in a relatively short time, but, in practice, only a small proportion of this volume can be observed. Thus the acoustic measurements are samples which are assumed to be representative of the wider distribution.

The first acoustic attempt in fish investigations were made on Lake Tanganyika by Capart during 1946-1947 (Capart, 1955). Echosounder Hughes MS 21F was employed in the region of Baraka (D.R.C.) and four fish species were detected, but no estimates were given.

The first complete acoustic estimate of total fish biomass with calibrated equipment was made by Johannesson in October-November 1973 (Johannesson, 1974). Echosounder SIMRAD EK120 working at a frequency 120 kHz was used. The survey track was designed as a parallel grid with a total of 48 transects across the width of the lake in 6-nautical mile intervals for the northern part and at 10-nautical mile for the southern half. The estimate of fish abundance was very high - <u>2.8 mln tonnes</u> in the whole lake. At the same time two other types of echosounders were tested side by side and intercalibrated with SIMRAD EK120. Furuno Mark IIB was used by Chapman (1974, 1976) and ELAC-CASTOR was calibrated by Enderlein (1974). In both cases no independent estimates of fish abundance were performed.

A limited survey was made in May 1975. The echosounder Ross-A Fineline working at a frequency 105 kHz was used. A series of stations were taken along the longitudinal axis of the lake and area densities of pelagic fish at separate transects were evaluated. The normal mode of operation was to start surveying right after dusk and continue transecting to dawn, a period in which the fish schools disperse and when they present single targets. A value of *TS*=-57 dB was chosen as a target strength for a 75 mm long *Stolothrissa*. In general the center part of the lake contained more biomass than observed laterally along the sides. The total biomass was estimated at a level of <u>0.467 mln tonnes</u>.

The next survey took place in May 1976 but no results were available due to excessive attenuation of the signals during the tape recording. Finally a second survey was held in November-December 1976 (Mathisen and Rufli, 1980). The echosounder was a

SIMRAD EK120 working at a frequency 120 kHz. A systematic parallel transects were taken at night only. Part of the data was not usable due to intrusion of secondary bottom echoes in the integrated water column and another part of the data was lost due to the system noise. A mean density was calculated for each 5-minute transect interval and a definite increasing trend was observed from north to south (from Burundi to Zambia). The net result was a standing nektonic biomass of 0.674-0.868 mln tonnes.

As it can be seen different estimates of fish abundance in Lake Tanganyika were obtained in the years 1946-1975. There was therefore a need for fisheries development and management purposes for further stock estimates in different seasons as a basis for determining fishing policy in the whole area. Over a period of 3 years (1995-1998) five combined fisheries-acoustic surveys were conducted in scope of the LTR Project and the results of the analysis of the collected acoustic data are presented in this report.

2. SURVEY PROCEDURES

The objectives in designing the survey patterns are to provide maximum coverage for a given survey length and to ensure that the survey adequately represents the characteristics of the total area. The individual cruises out of five combined fisheries-acoustic surveys on Lake Tanganyika were designed in slightly different way, but principally a zig-zag grid of cruise tracks has been followed. The sampling patterns of separate surveys are not presented now, they can be seen in various figures located in the next chapters. The transects were generally confined to water depths exceeding 100 m, for safety reasons, particularly because of the uncertainty of the bathymetric chart (produced in a rather primitive way in 1947-48) and the presence of small fishing boats and nets in the inshore waters. There were some difficulties in proper designing of the cruise track especially because of the obligation to shelter on the east side of the lake (safety reasons again). The acoustic transects were carried out at an average vessel speed of 8 knots, which was a reasonable compromise between the operational requirements and the influence of noise. Acoustic sampling was carried out in a continual way by the SIMRAD EY-500 split-beam echosounder working at a frequency of 120 kHz. Potentially, the values of sound scattering strength, integration values and target strength distributions in 10 arbitrarily chosen water layers up to a depth of 700 m could be recorded.

Concurrent fishing activities were performed with the pelagic trawl at a vessel speed of about 4 knots. The samples were taken and processed according to standard procedures (Aro, 1993, Mannini, 1993). The fish sample data from control trawl catches were used for determining the species composition and length distributions, and additionally for determining sex and maturity of the three fundamental pelagic species: *Stolothrissa tanganicae, Limnothrissa miodon* and *Lates stappersii* and 3 other nile perch species.

Zooplankton samples were taken both by vertical sampling up to 100 m of depth (100 µm mesh size) and towed torpedoes (50 µm mesh size) attached to the trawl wing tips. Large zooplankton and fish larvae were collected by a towed GULF torpedo (250 µm and 100 µm mesh size) from the 250 m water column. The sampling procedure was according to Vuorinen (1993), Kurki (1993).

Temperature and oxygen profiles were measured at the stations by a CTD-12 sonde up to 300 m of depth.

During the first three cruises mainly night measurements were carried out. It was caused by the fact of higher integration values obtained at night. Also local fishermen operate at night, attracting fish by artificial lights. After considering a bias caused by this procedure in abundance estimate it was decided to change the survey strategy in the last two cruises and the measurements were performed both at night and during the day.

3. ACOUSTIC MATERIAL AND METHODS

3.1. Methodology

Fish abundance evaluation by means of SIMRAD echosounder EY500 is based on the linearity principle (Foote, 1983). The fish density is supposed to be proportional to the integral of the echo energy returned from the depth channel of interest. The EY500 performs echo integration in the vertical direction within chosen layers and averages in the horizontal direction along the vessel path. For each EDSU (Elementary Distance Sampling Unit) we have the integration value S_A $[m^2/N.mi.^2]$ and the *TS*-distribution in the integration layer, so we automatically have N_A - the fish number per unit area (1 square nautical mile) for the layer of interest:

$$N_A = \frac{S_a}{\sum_i f_i \sigma_{bs,i}} = \frac{S_a}{\langle \sigma_{bs} \rangle} \qquad (1)$$

where $S_a = S_A / 4\pi$,

$\sigma_{bs,i} = 10^{TS_i/10}$ - backscattering cross-section of the *i-th* fish category,

f_i - frequency of the occurence of the *i-th* category in the TS-distribution.

The dimension of N_A is $1/N.mi^2$.

The main interest is, however, in calculating not the fish number N_A, but the fish density

$$\rho_A = N_A \langle W \rangle \equiv \frac{S_A}{4\pi} \frac{\langle W \rangle}{\langle \sigma_{bs} \rangle} \qquad (2)$$

where $<W>$ is a mean weight of ensonified fish. The dimension of ρ_A is $weight/N.mi^2$. In order to calculate the total biomass we additionally need a relationship between the target strength *TS* of the individual fish and its weight:

$$TS = m \log W + b \qquad (3)$$

In the case we don’t have any direct calibration measurements (on encaged fish, for example), the simplest way to get such a relationship is to correlate the fish catch data (length or weight distribution) with acoustic data - *TS* distribution measured simultaneously by the split beam echosounder in the same trawling layer. The statistically meaningful set of such measurements allows to get the relationship $W(\sigma_{bs})$, valid for the homogeneous region where the fish size distributions are similar.

3.2. Equipment

The echo-integration split-beam system of SIMRAD EY-500 Echosounder, working at a frequency of 120 kHz, installed on board of r/v „Tanganyika Explorer” is capable of real-time integrator values and target strength output. It allows estimates of the absolute fish concentrations in up to 10 layers to be made. The split-beam processor identifies and measures single and multiple target echoes, giving *in situ* target strength estimation. The component acoustic parameters (integrator data, TS distributions, layer settings) together with complementary information (date, time, log, geographical coordinates, etc.) and parameter telegrams from an echo integrator were logged on a PC for post-processing. Separate files, mainly of a size 2 Mbytes, were produced. All the time the echograms were recorded by plotter for subsequent comparative analysis (scatterers identification, zooplankton elimination, bottom influence, noise correction and data interpretation).

The standard control settings of the echosounder used during the last two surveys are described in the Appendix 1.

The acoustic system was calibrated in November 1995, March 1996 and November 1997. Before the fourth cruise, in November 1997, the echosounder was calibrated by means of a standard method described in SIMRAD MANUAL using a 23 mm copper sphere as a standard target with a TS of -40.6 dB. No significant changes in calibration parameters were noticed. Calibration sheet made up on 19.11.1997 is attached in Appendix 2.

3.3. Environmental parameters

The proper values of sound speed in water and sound absorption coefficient are significant in echosounder operation. They depend on depth (hydrostatic pressure), temperature and salinity, and frequency (absorption only). They can be calculated from the following formulae:

Sound speed in pure water (Del Grosso and Mader, 1972):

$$c = 1402.388 + 5.03711\,T - 0.0580852\,T^2 + 0.3342\,10^{-3}\,T^3 + - 0.1478\,10^{-5}\,T^4 + 0.315\,T^5 + 0.16\,z \quad (4)$$

where temperature T is in degrees centigrade and depth z in metres, temperature interval 0°C < T < 95°C and accuracy 0.015 m/s. Sound speed c is in m/s.

Sound absorption (Foote, 1981):

$$\alpha = 8.686\,\{a_1 f_1 f^2/(f_1^2+f^2) + a_2 p_2 f_2 f^2/(f_2^2+f^2) + a_3 p_3 f^2\} \quad (5)$$

where the coefficients are:
$a_1 = 1.03\,10^{-8} + 2.36\,10^{-10}\,T - 5.52\,10^{-12}\,T^2$
$f_1 = 1.32\,10^3\,(T+Tk)\,\exp(-1700/(T+Tk))$
$a_2 = (5.62\,10^{-8} + 7.52\,10^{-10}\,T)\,S/35$
$f_2 = 1.55\,10^7\,(T+Tk)\,\exp(-3052/(\underline{T+Tk}))$
$p_2 = 1 - 1.03\,10^{-3}\,p + 3.7\,10^{-7}\,p^2$
$a_3 = (55.9 - 2.37\,T + 4.77\,10^{-2}\,T^2 - 3.48\,10^{-4}\,T^3)\,10^{-15}$
$p_3 = 1 - 3.84\,10^{-4}\,p + 7.57\,10^{-8}\,p^2$
$Tk = 273.1$
p=0.1z - hydrostatic pressure,
z - depth in metres,
f - sound frequency in Hz,
T - temperature in degrees centigrade,
Sound absorption coefficient α is expressed in dB/m.

Fig.2 presents sound speed dependence on temperature and Fig.3 - sound absorption dependence on frequency, both as recommended by SIMRAD. Values α= 4 dB/km and c=1500 m/s were applied for Lake Tanganyika.

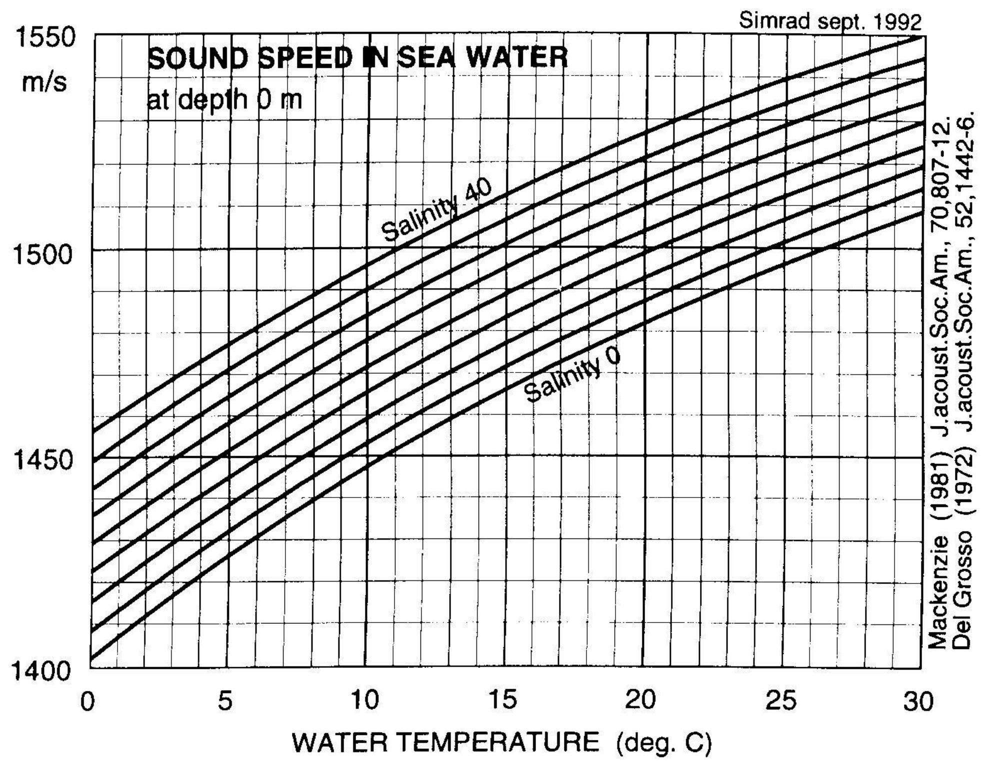


Fig.2. Temperature dependence of sound speed in water.

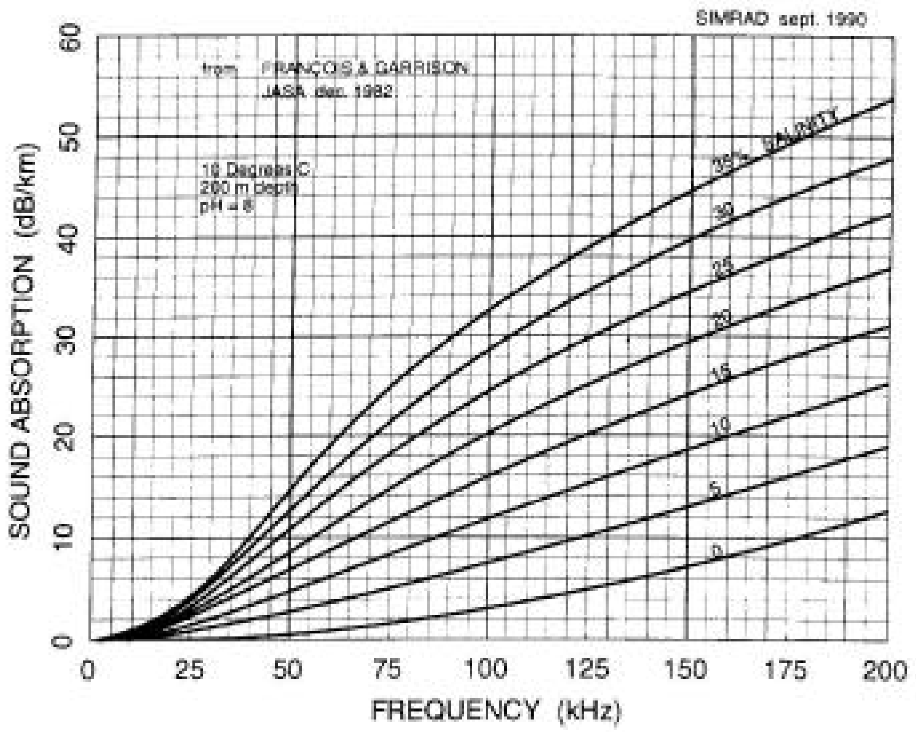


Fig.3. Frequency dependence of sound absorption.

3.4. Pinging rate

The choice of the interval between consecutive pings determines the number of samples. The smaller the ping interval is, the more samples can be collected in a given time. On the other hand, when the pinging rate is too small, there is a danger of recording the secondary bottom reflection from the previous ping. Its contribution, if not corrected, can produce a significant error. Hence the choice of proper interval between the consecutive pings is very important.

If the acoustic data are recorded in the depth window $\Delta x = 0 \sim X_{max}$ and a ping interval is Δt, then the *n-th* reflection from the bottom of a depth d occurs when

$$\frac{c\Delta t}{2n} \leq d \leq \frac{c\Delta t}{2n} + \frac{\Delta x}{n} \qquad (6)$$

where c is a sound speed.

Fig.4 shows the interval of bottom depth that interfere with the fish echoes from the depth *0 ˜ 200 m* versus pinging rate. It can be seen that in the case of ping interval less than 2 s, the second bottom reflection from a depth less than 700 m will interfere with the useful echo signal recorded in a 200 m scale. The depth 700 m is close to the maximum range of the EY-500 echosounder. Big differences in depth across Lake Tanganyika make setting of an optimum value of ping interval rather dificult. In order to avoid problems with secondary bottom reflection, in the last two cruises the ping interval of 2 s was chosen.

On the other hand, the computer needs some determined time for executing all the software procedures, recording data, communicating with several devices (plotter, hard disc) and whereas the upper 200 m layer was sampled, the minimum ping interval chosen automatically by the computer, was about 1.5 s, even if it was set by the operator to be shorter.

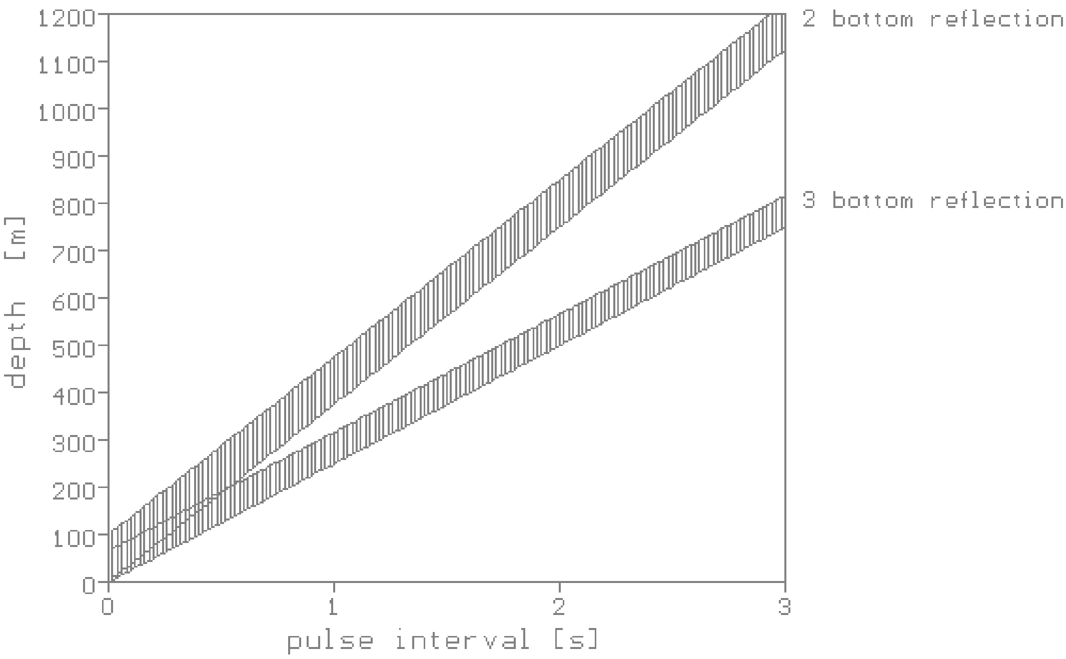


Fig.4. Dependence of the „second bottom" and „third bottom" interferention on pulse interval.

3.5. Layer settings

The algorithm of echo integration depends on layer declaration. In the case of "surface" layer the integration is performed till the detected bottom depth, not including the bottom itself, but when the bottom is not detected, nothing is integrated. On the other hand, when the layer is declared as a "pelagic" one, the integration is not sensitive to bottom detection, is carried out in the whole layer, including the unneeded bottom, when it occurs. In order not to lose any data concerning near shore areas, the most important layer from 10 to 100 m was chosen twice: as a surface layer and as a pelagic one. It was dictated by the fact of very rapid bottom depth variations in the coastal zone. The operation of changing layer settings needs some time and it was often impossible to do it in time. Having two integram values from the layer 10-100 m, as a surface layer and as a pelagic one, allowed choosing the proper value during data post-processing and not losing any piece of information.

The layer 0-10 m was not measured because of the transducer deployment depth, its dead zone (blinking range) and disturbances introduced by near surface bubble layer.

3.6. Format of acoustic data

There were conducted five combined hydroacoustic-trawl surveys on Lake Tanganyika:
1.survey 02/95 held from 15.06.95 till 01.07.95
2.survey 02/95 held from 16.11.95 till 04.12.95
3.survey 07/96 held from 02.04.96 till 12.04.96
4.survey 17/97 held from 22.11.97 till 09.12.97
5.survey 19/98 held from 05.02.98 till 20.02.98

The data gained from the first three surveys are IN DIFFERENT FORM and are INCOMPLETE.

survey 02/95:
· 535 EDSU’s in form of EY500 files *.dg5 spanning the time period from 15.06.95, 20:28 to 23.06.95, 09:47.

survey 05/95:
· 1 large EXCEL file produced by punching echogram data, consisting of 1368 EDSUs and covering the whole cruise

survey 07/96:
· 219 EDSU’s in form of EY500 files *.dg6 spanning the time period from 04.04.96, 20:53 to 09.04.96, 03:52. SIMRAD echosounder stopped working in Kigoma!

The data collected during the last two surveys are the following:

survey 17/97:
· 1245 EDSU’s in form of EY500 files *.dg7 spanning the time period from 22.11.97, 23:15 to 08.12.97, 23:38.

survey 19/98:
· 1229 EDSU’s in form of EY500 files *.dg8 spanning the time period from 05.02.98, 10:06 to 20.02.98, 06:22 .

As it was already mentioned, acoustic data from the first three surveys have a different form. They exist either as the computer files created at the end of each EDSU by the echosounder, or as the EXCEL file, constructed on the basis of the data extracted from the paper echograms, containing: date, time, geographical position, TS distribution in the layer 10-200 m, integrator records for 12 layers. Computer files with extention .dgx contain the full information about each EDSU in the following telegrams:
VL - log data,
GL - geographical position,
D1 - depth,
LL - layering,
A1 - integrator data in all declared layers
H1 - *TS*-distibutions in all declared layeres of integration
Q1 - the whole matrix of backscattering strength, allowing the reconstruction of the echogram on the computer screen.

Surveys 02/95 and 07/95 are represented by *.dgx type of data, but unfortunately, only some parts of those cruises. Data from surveys 17/97 and 19/98 are complete. The tracks of all five surveys are presented in Fig.5. It can be clearly seen that the acoustic coverage in surveys 02/95 and 07/96 are insufficient for the full analysis.

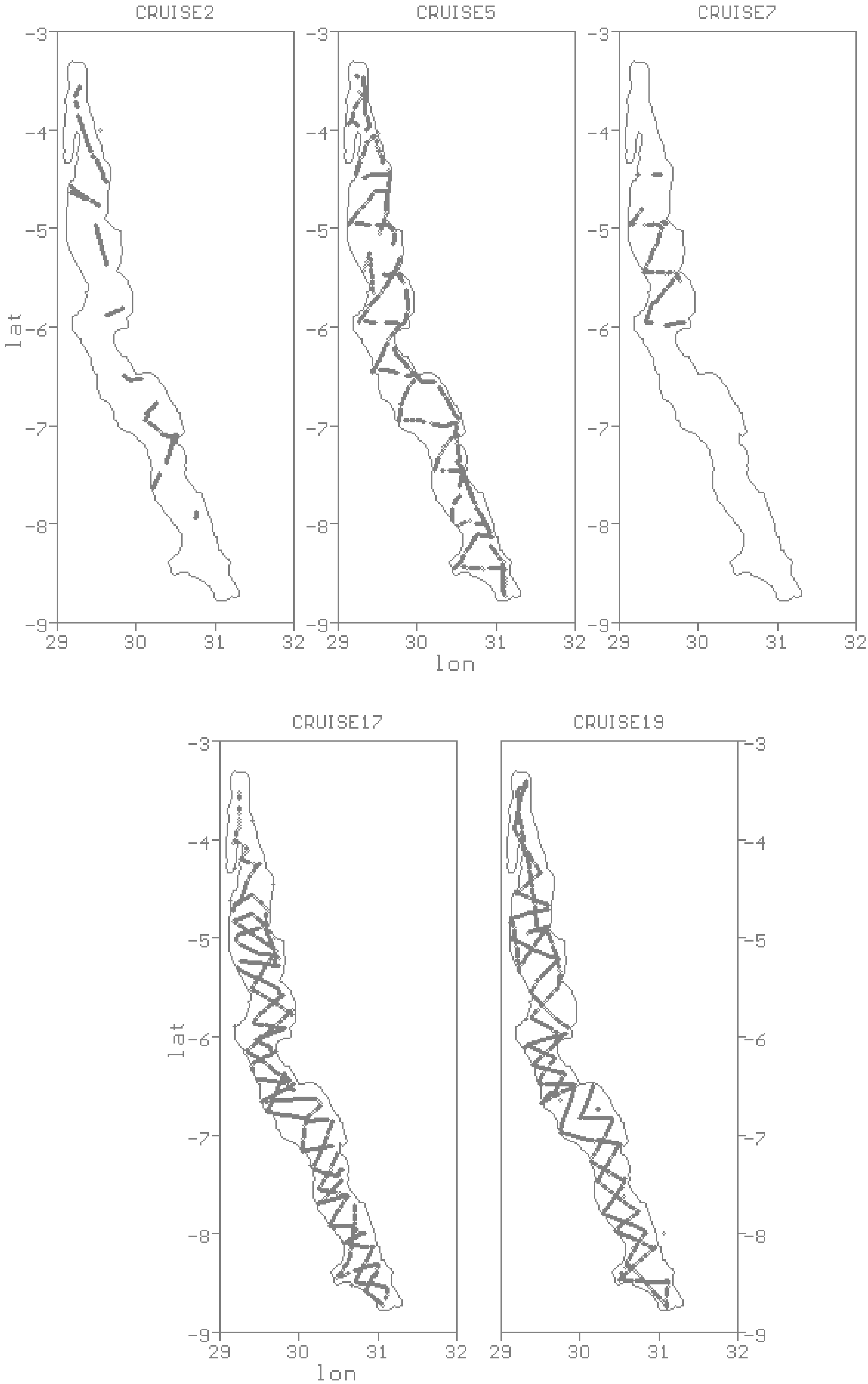


Fig.5. Survey tracks

4. DATA ANALYSIS

4.1. Fisheries

4.1.1. Fish length distributions

Complete fisheries data from all surveys are in a form of EXCEL files with fish length distribution separately for each species: *Limnothrissa miodon, Stolothrissa tanganicae* and *Lates stappersii*. There was a determined number of trawls conducted, but not each species was represented in each trawl.

· survey 02/95 - 32 trawl hauls, 67 individual distributions
· survey 05/95 - 41 trawl hauls, 90 individual distributions
· survey 07/96 - 21 trawl hauls, 46 individual distributions
· survey 17/97 - 26 trawl hauls, 48 individual distributions
· survey 19/98 - 22 trawl hauls, 30 individual distributions

For calculations of average fish length and average fish weight, the fish length distibutions for 3 species (*Limnothrissa miodon, Stolothrissa tanganicae* and *Lates stappersii*) have been merged into the collective fish length distributions for each trawl. The length distribution for species *Stolo* and *Limno* is given in 1 mm intervals, whereas for *Lates* it is in 10 mm intervals. Consequently, the collective distribution has been constructed in 10 mm intervals. Some examples of this procedure are illustrated in Fig.6. They concern the situation when all three species were taken and analysed in a given catch (it was not always the case). As it could be expected there were various distribution shapes for different catches.

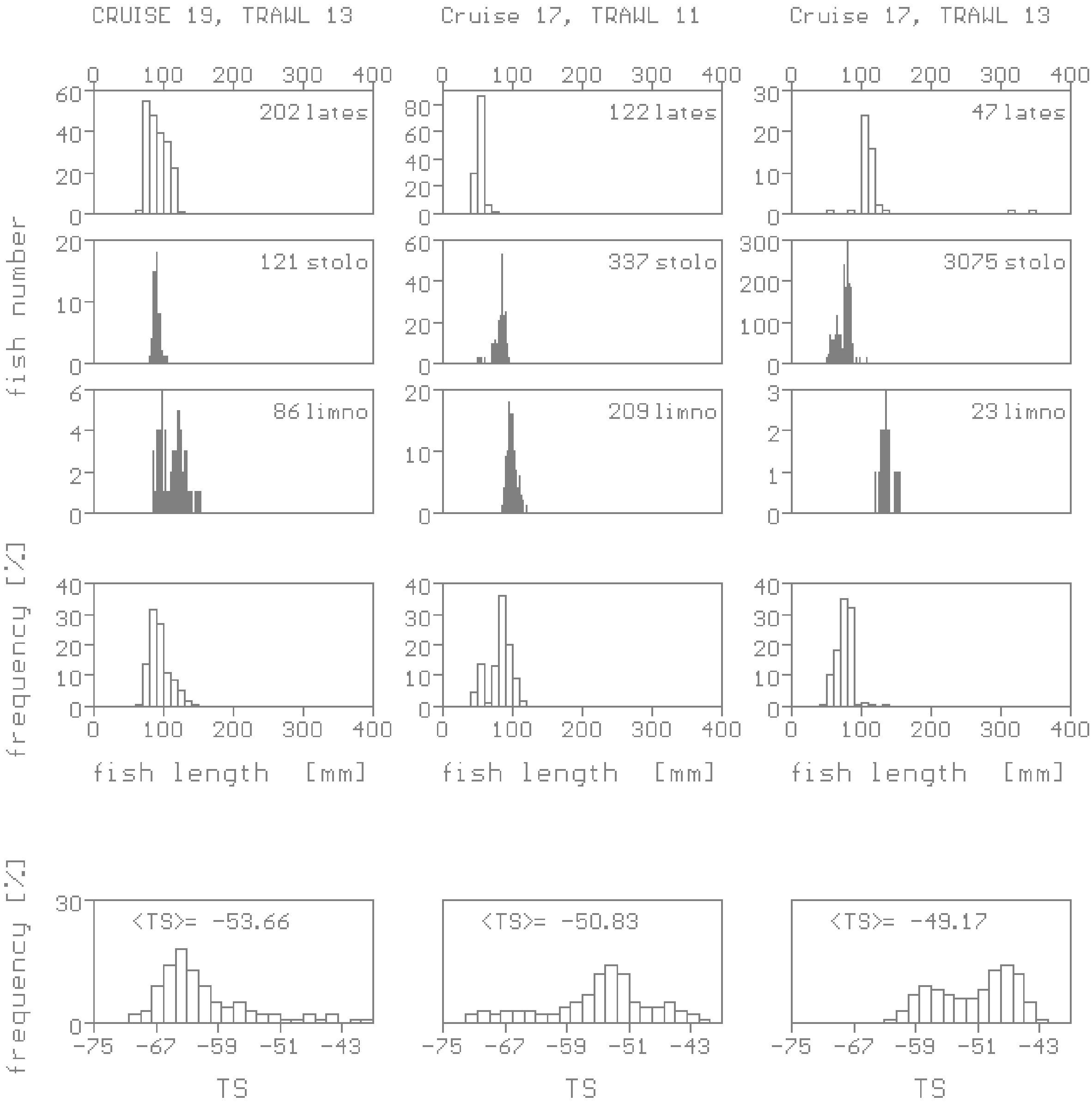


Fig.6. Some examples of individual species length distributions (three upper histograms) and collective distribution together with *TS* distribution in the trawling depth (lower histogram).

4.1.2. Length - weight relationship

For fish weight computation purposes the functional formula has been used:

$$W = AL^B \tag{7}$$

where *W* is expressed in grams and *L* in milimetres. The coefficients *A* and *B* for separate species have been determined by the linear regression method in two ways: (i) calculating the relationship (7) using mean weight at length class (Aro, Mannini, 1995) and (ii) calculating the relationship (7) using individual body weight and total length from a good size range (Mannini, 1997, personal information). The coefficients are as follows:

(Aro, Mannini)		
for *Limnothrissa miodon*	$A = 4.252\ 10^{-6}$	$B = 3.124$
for *Stolothrissa tanganicae*	$A = 4.692\ 10^{-6}$	$B = 3.073$
for *Lates stappersii*	$A = 4.682\ 10^{-6}$	$B = 3.053$
(Mannini)		
for *Limnothrissa miodon*	$A = 3.979\ 10^{-6}$	$B = 3.13$
for *Stolothrissa tanganicae*	$A = 4.049\ 10^{-6}$	$B = 3.11$
for *Lates stappersii*	$A = 6.798\ 10^{-6}$	$B = 2.99$

The weight-length dependence obtained by both methods for three separate species is shown in Fig.7.

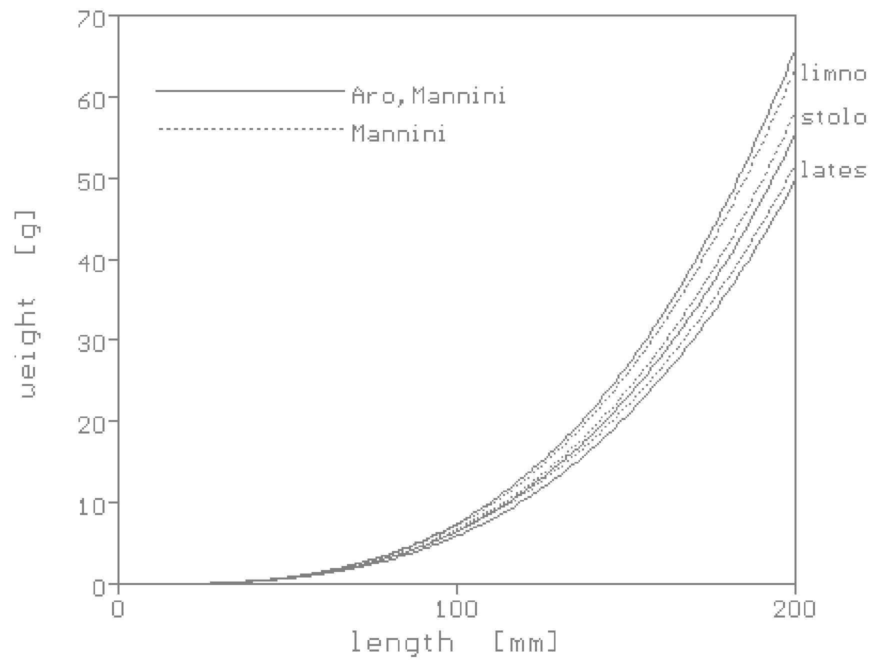


Fig.7. Weight - length dependence due to Aro and Mannini (1995) and Mannini (1997).

A comparison of both methods with total catch in separate trawls of the cruises 17 and 19 is presented in the Table 5 and 6. The calculations were carried out by applying the formula (7) to the individual species distributions gained in separate trawls. In most cases the accuracy of both types of the relationship *W(L)* is sufficiently good.

Table 5. Total catch compared to total weight of separate catches calculated by two methods. Cruise 17

trawl number	total catch	total weight (Aro,Mannini)	total weight (Mannini)
1	0.775	0.773	0.758
2	0.575	0.538	0.545
3	2.112	2.372	2.303
4	0.270	0.321	0.309
5			
6	2.695	2.816	2.839
7	0.055	0.056	0.055
8	1.135	1.213	1.211
9**	1.620	1.515	1.543
10	4.015	2.825	2.838
11	3.045	2.869	2.847
12	594.700	638.756	642.998
13	10.135	9.852	9.984
14	6.990	6.498	6.605
15	1.090	0.824	0.828
16	40.555	39.146	40.127
17	0.280	0.276	0.279
18			
19	0.060	0.048	0.050
20			
21	0.175	0.162	0.156
22			
23			
24	1.235	1.098	1.112
25	0.045	0.122	0.125

Table 6. Total catch compared to total weight of separate catches calculated by two methods. Cruise 19

trawl number	total catch	total weight (Aro,Mannini)	total weight (Mannini)
1	21.875	20.524	20.864
2	0.615	0.660	.673
3	38.890	39.593	39.822
4			
5			
6			
7	3.020	3.038	3.091
8	0.030	0.011	0.012
9	23.425	17.263	16.578
10			
11	20.000	16.260	16.406
12			
13	2.400	2.478	2.540
14	0.400	0.341	0.349
15	1023.800	1249.483	1265.256
16	68.400	71.678	70.395
17	0.030	0.039	0.038
18	21.600	26.514	25.492
19	9.400	11.862	12.001
20	12.600	11.430	11.631
21	38.600	38.341	36.865
22	89.800	91.527	87.955

On the basis of individual and collective fish length distributions the mean fish length and mean fish weight for each catch have been computed:

$$< L >= \sum_i \phi_i l_i \qquad (8)$$

$$< W >= \sum_j a_j \sum_i N_{i,j} L_{i,j}^{b_j} \qquad (9)$$

where ϕ_i - frequency of length class i in collective distribution,

l_i - mean length of class i in collective distribution,

$L_{i,j}$ - mean length of species j in class i in individual distribution,

$N_{i,j}$ - number of fish of species j in length class i (individual distribution)

a_j, b_j - coefficients of formula (7) for species j

Finally, the mean fish length and mean fish weight for each survey have been determined :

$$< L >_{survey} = \sum_k \sum_i \phi_{i,k} l_i \qquad (10)$$

$$< W >_{survey} = \frac{1}{\sum_{i,j,k} N_{i,j,k}} \sum_k \sum_j a_j \sum_i N_{i,j,k} L_{i,j}^{b_j} \qquad (11)$$

where $\phi_{i,k}$ - frequency of length class i in trawl k in collective distribution,

a_j, b_j - coefficients of formula (7) for species j,

$L_{i,j}$ - mean length of fish of species j in length class i

$N_{i,j,k}$ - number of species j in length class i in trawl k

The calculated values of <*L*> and <*W*> for all trawls taken in all five cruises are displayed in Fig.8 a-e.

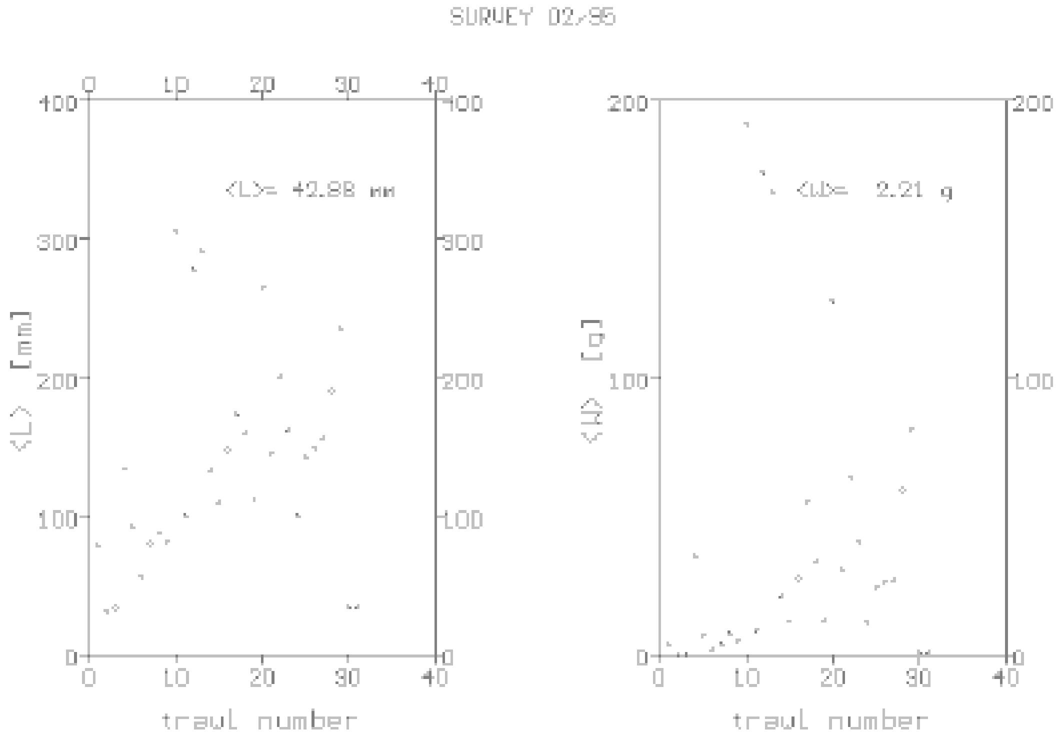


Fig.8a. Mean length and mean weight of a single fish in consecutive trawls. Survey 02/95

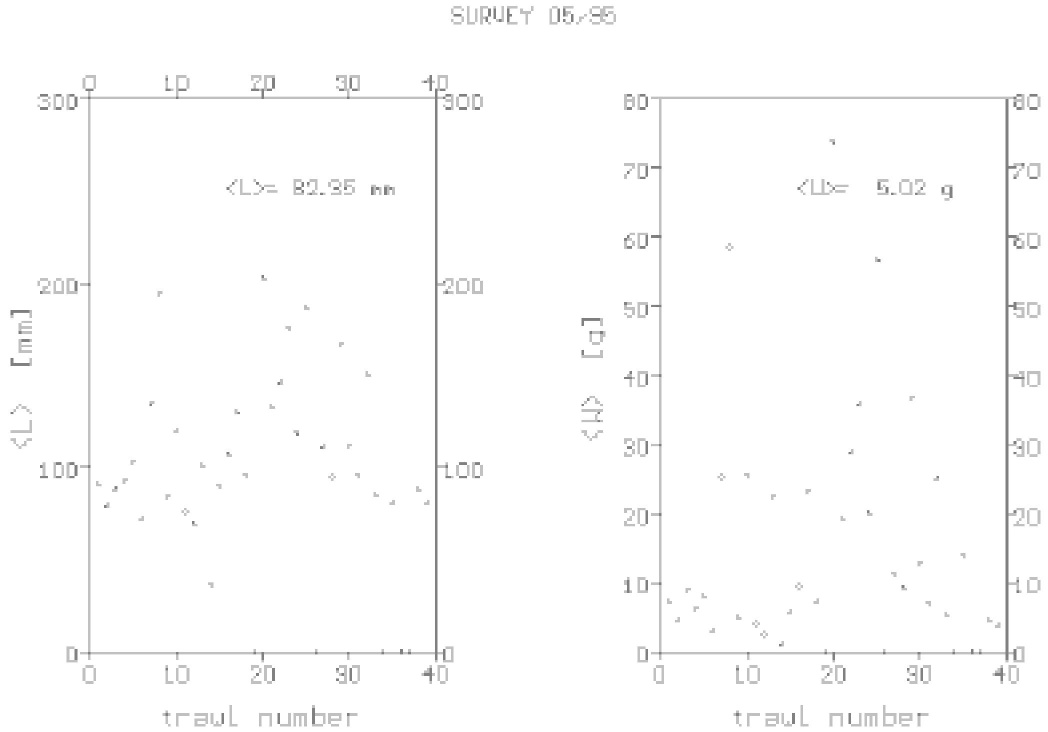


Fig.8b. Mean length and mean weight of a single fish in consecutive trawls. Survey 05/95

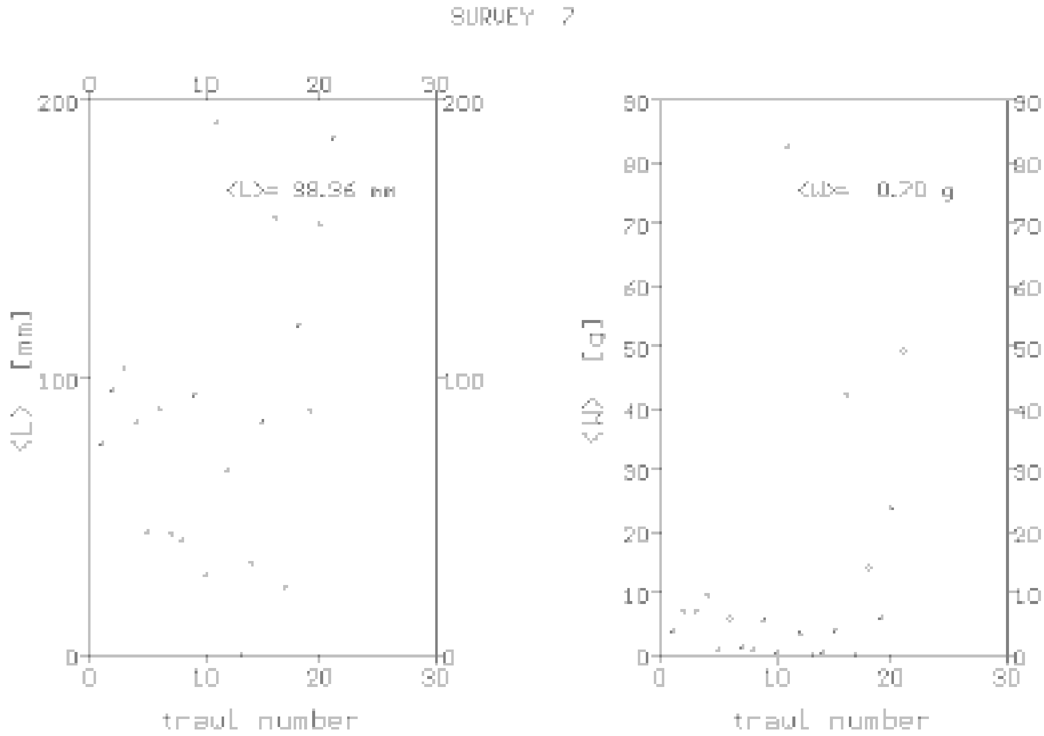


Fig.8c. Mean length and mean weight of a single fish in consecutive trawls. Survey 07/96

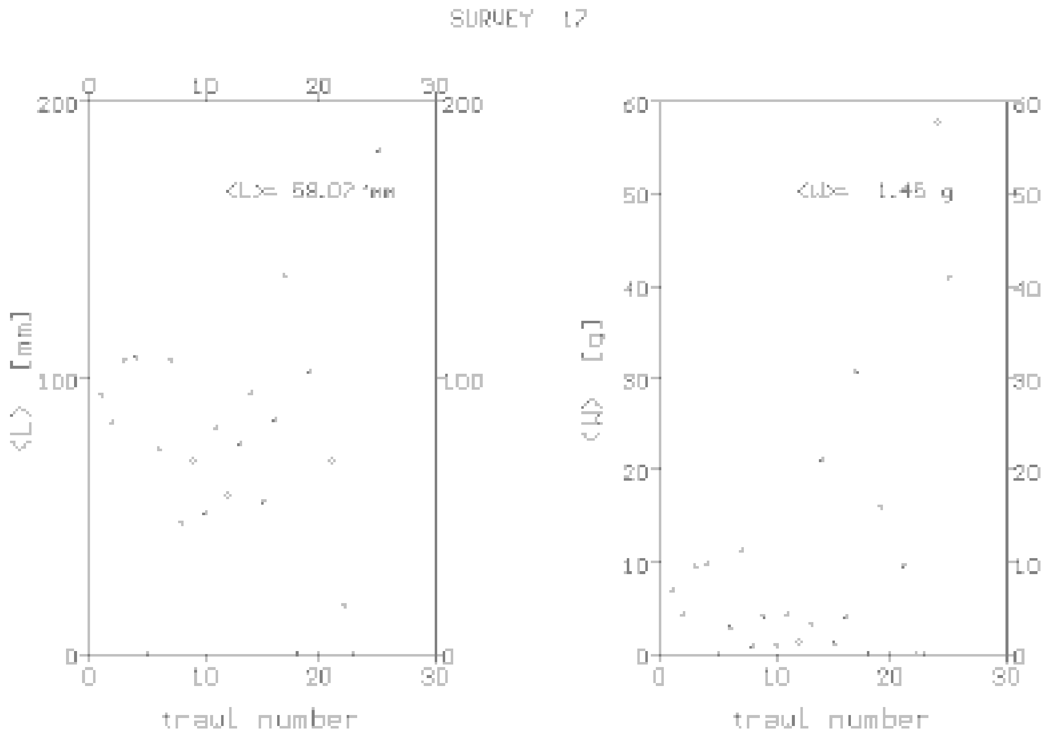


Fig.8d. Mean length and mean weight of a single fish in consecutive trawls. Survey 17/97

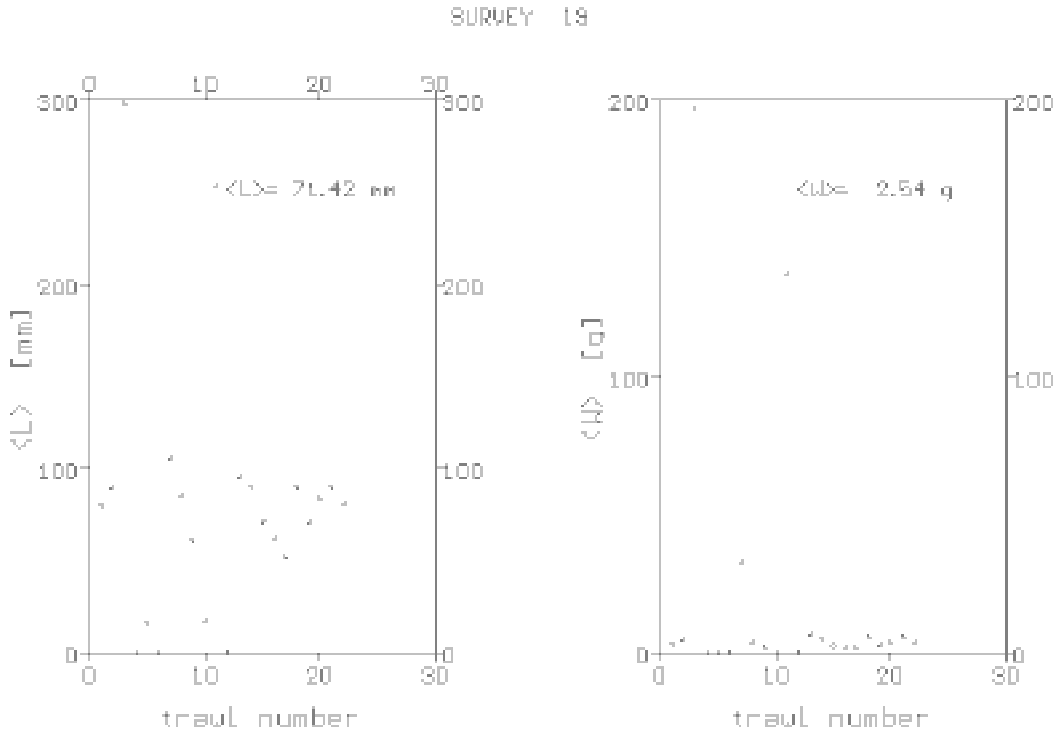


Fig.8e. Mean length and mean weight of a single fish in consecutive trawls. Survey 19/98

4.2. ACOUSTICS

4.2.1. Target strength

Target strength is a scaling factor required to convert echo intensity to fish density (formulae 1 and 2). It is clear that the fish target strength is a complex variable depending on fish size, morphology, behaviour, tilt angle, and on sound frequency. Mean target strength may be estimated as a function of fish length or weight by comparing in situ acoustic measurements with the fish size distribution from trawl catches. The only direct measurements of Tanganyika species target strength (caged fish) were made by Johannesson (Johannesson, 1974). His results are displayed in Fig.9. It must be noted that they concern the maximum target strength in dorsal aspect. In average they are about 7-8 dB higher than the values obtained by split-beam technique during our cruises. Similar problems were encountered by Mitson (1992) in his analysis of Tanganyika fish stock assessment. He presented a chart comparing different *TS* - length curves (Fig.10). In this situation, it seemed sensible to use results based on fish of similar morphology and physiology. It is known that Tanganyika pelagic species are as a group strikingly marine-like in general character (Coulter, 1991). In common practice the target strength dependence on the fish body length is used

$$TS = m \log L_f + b \qquad (12)$$

where m and b are constants for a given species and frequency. The formula of Degnbol et al. (1985) calculated by use of the regression method for the mixture of sprat and herring measured at 120 kHz seems to match our results very well. It looks as follows:

$$TS = 20 \log L_f - 73.1 \qquad (12a)$$

It coincides with a curve of Mathiesen and Rufli (1980) shown in Fig.10. It is also in the range determined by Nakken and Olsen (1977) for small clupeids.

In situ measurements with split-beam system show a wide range of *TS* values that are generally more uniformly distributed than samples caught by fishing (see Fig.6). This can be explained by the stochastic nature of *TS*, which is highly variable even for the same species and size of fish (Foote, 1994). The variability of the mean value of the target strength measured in the layer 10-100 m in consecutive EDSUs during the surveys 02/95, 17/97 and 19/98 will be shown in Fig.14 a-c together with simultaneously recorded integration values. Mean value of *TS* is computed according to formula:

$$\langle TS \rangle = 10 \log \langle \sigma_{bs} \rangle = 10 \log \left(\sum_i f_i \sigma_{bs,i} \right) \qquad (13)$$

where

$\sigma_{bsi} = 10^{TS_i/10}$ - backscattering cross-section of the i-th fish category,

f_i - frequency of the occurence of the *i*-th category in the *TS*-distribution.

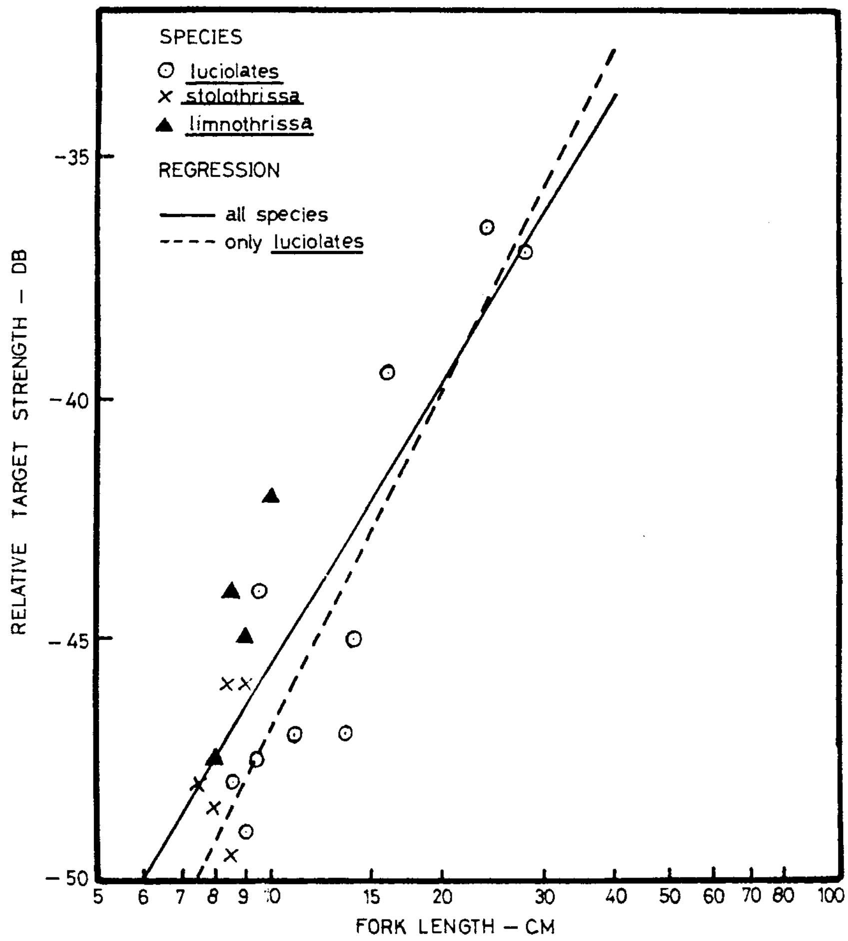


Fig.9. Target strength versus fork length for three main species obtained by Johannessen (1974)

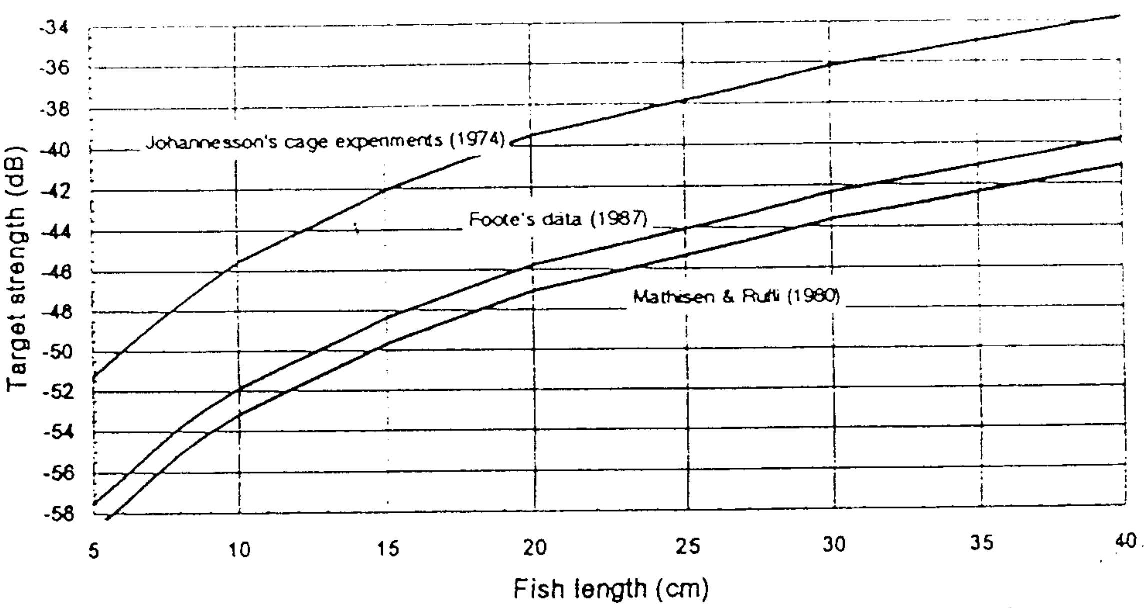


Fig.10. Comparison of different *TS* - length relationships (after Mitson, 1992)

4.2.2. Weight - target strength relationship

If abundance is required as a weight while the target strength function is given for individual fish, the latter must be converted to compatible units. Backscattering cross section per unit weight is length dependent. Usually we know the target strength-length relationship (12) and weigth-length relationship (7):

$$TS = m \log L_f + b$$

where TS is expressed in dB rel 1 m^2 and L_f in centimetres.

$$W = AL^B$$

where W is expressed in grams and L in milimetres.
A simple transformation of (12) gives:

$$L_f = 10^{\frac{TS-b}{m}}$$

and transformation of (7) gives (L=10 L_f):

$$W(TS) = A\left[10^{\left(\frac{TS-b}{m}+1\right)}\right]^B$$

For the coefficients of formula (12a), m = 20 and b=-73.1 we get: $W(\sigma) = A\sigma^{B/2}10^{4.655\,B}$ (14)
The above dependence is shown in Fig.11. To facilitate the calculations and to make the picture clear, only one set of parameters A and B was chosen, namely the middle values for *Stolothrissa tanganicae* : A = 4.692 10^{-6} and B = 3.073 (Aro, Mannini, 1995). The relationship (14), displayed in Fig.12, has been used throughout the analysis as a scaling factor W/σ necessary to obtain values of the area fish density.

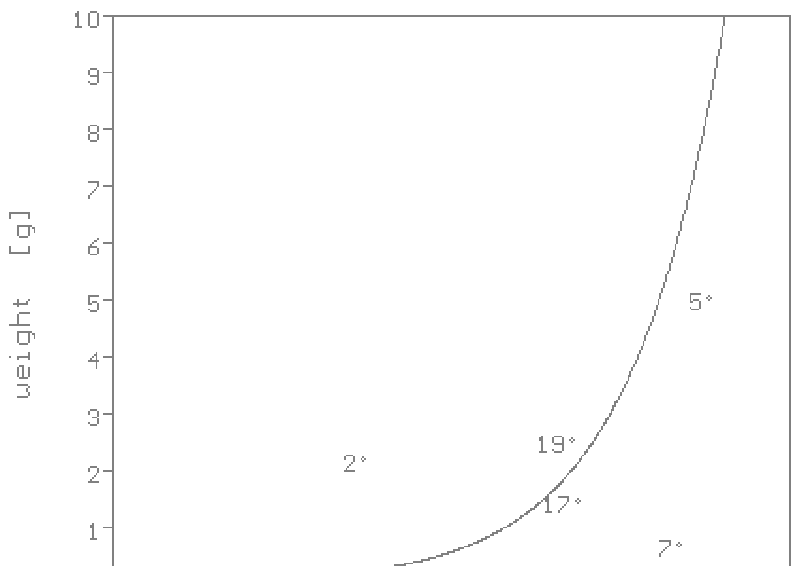


Fig.11. Dependence of fish weight on its target strength calculated from formula (13) and average values obtained for individual cruises

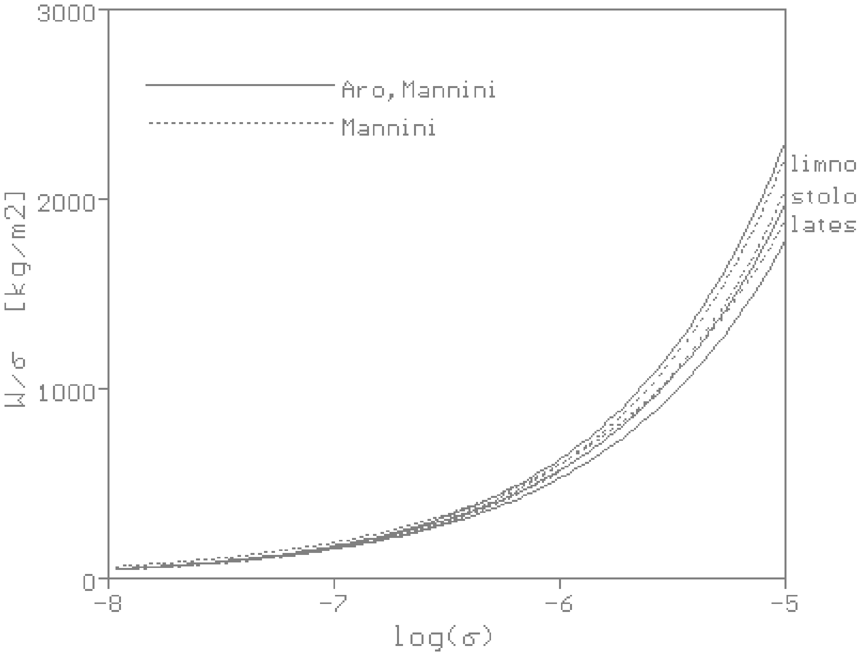


Fig.12. Diagram of scaling factor *W/*σ

The average values of the fish length *<L>*, fish weight *<W>*, target strength *<TS>,* the backscattering cross-section $<\sigma_{bs}>$, backscattering cross-section per unit weight $<\sigma_{1\ kg}>=<\sigma_{bs}>/<W>$ and target strength per unit weight $<TS_{1\ kg}>$, obtained from *TS(L)* regression formula applied to the fish sample caught during all five cruises, are presented in Table 7.

Table 7. Mean fisheries and acoustical parameters for all five cruises

cruise number	<L> [mm]	<W> [g]	<TS> [dB]	$<\sigma_{bs}>$ [m^2]	$<\sigma_{bs}>/<W>$ [m^2/kg]	$<W>/<\sigma_{bs}>$ [g/m^2]	$<TS_{1\ kg}>$ [dB]
2	42.88	2.21	-62.61	$5.48\ 10^{-7}$	$2.48\ 10^{-4}$	4032	-36.06
5	82.35	5.02	-52.37	$5.79\ 10^{-6}$	$1.15\ 10^{-3}$	869	-29.39
7	38.36	0.70	-53.30	$4.68\ 10^{-6}$	$6.68\ 10^{-3}$	150	-21.75
17	58.07	1.45	-56.30	$2.34\ 10^{-6}$	$1.62\ 10^{-3}$	617	-27.90
19	71.42	2.54	-56.42	$2.28\ 10^{-6}$	$8.98\ 10^{-4}$	1114	-30.47

4.2.3. Integrator values

Acoustic survey generates large amounts of integrator data (integrams) which must be manually verified and the wrong ones eliminated. This process is hardly automatized. It is unavoidable to include checks with human intervention to ensure the results coming from the automatic data collection and analysis are sensible.

The preliminary selection of integrams embraced the elimination of bottom integration, plankton influence and noise. It was already mentioned (paragraph 3.5) that in order to minimize troubles with bottom integration, the layer 10 to 100 m was chosen twice: as a surface layer and as a pelagic one. At this stage of tidying data the proper layers were chosen by comparing printed echograms with the depth read from the computer files. Also a gradual appearance of a zooplankton layer at dawn was investigated. In this case, careful examination of changes in echogram and integrator output, made it possible to extract the unwanted influence of plankton, which at some point became mixed with the fish of interest. A similar approach has also been applied to sporadic secondary bottom-echo interference and surface noise produced by ship movement and air bubbles. A successful completion of the introductory data processing resulted in a „clean" set of integrams. Unfortunately, the data from cruises 5 and 7 were useless for the estimate of absolute fish abundance, because of a very high noise level recorded (see Fig.13 for a comparison of S_A values recorded in all five cruises). The probable reason was in using the improper UPS. Only one of the three UPSs onboard „Tanganyika Explorer" was useful for cooperation with SIMRAD, two other were characterized by too high level of the electrical noise. Due to TVG compensation the constant level of electrical noise was amplified with the measured depth and the acoustic data from the deeper layers (over 40 m) were totally useless. Subtracting the noise from the data collected during the second and third cruise was possible, but it was definitely out of scope of this work. It's a question of time and number of people involved in a thorough analysis of echograms. FURTHER ANALYSIS WILL CONCERN ONLY THE CRUISES 2, 17 AND 19.

Figures 14 a-c display the pre-selected integrams recorded in consecutive EDSUs during the three surveys - 2, 17 and 19.

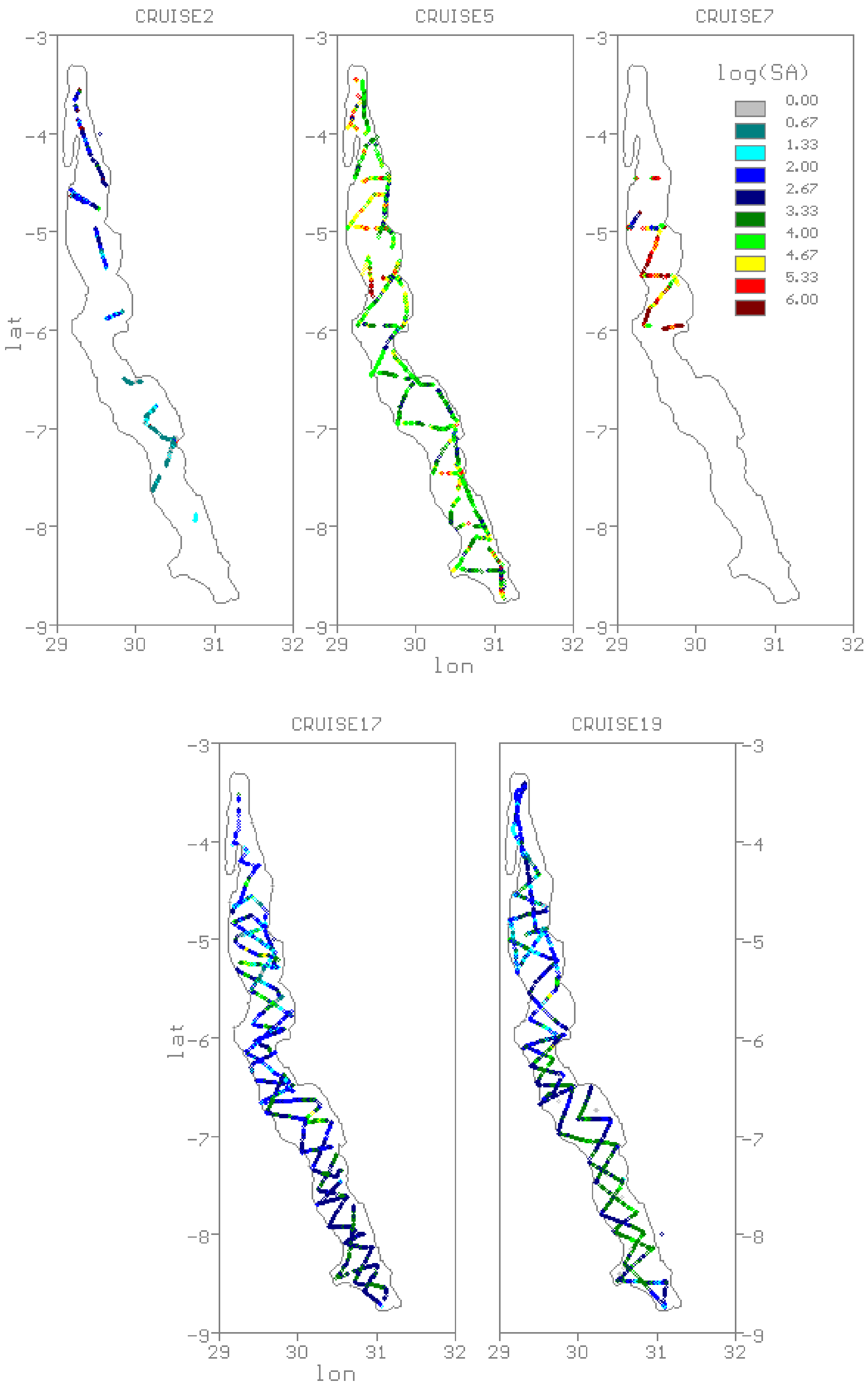
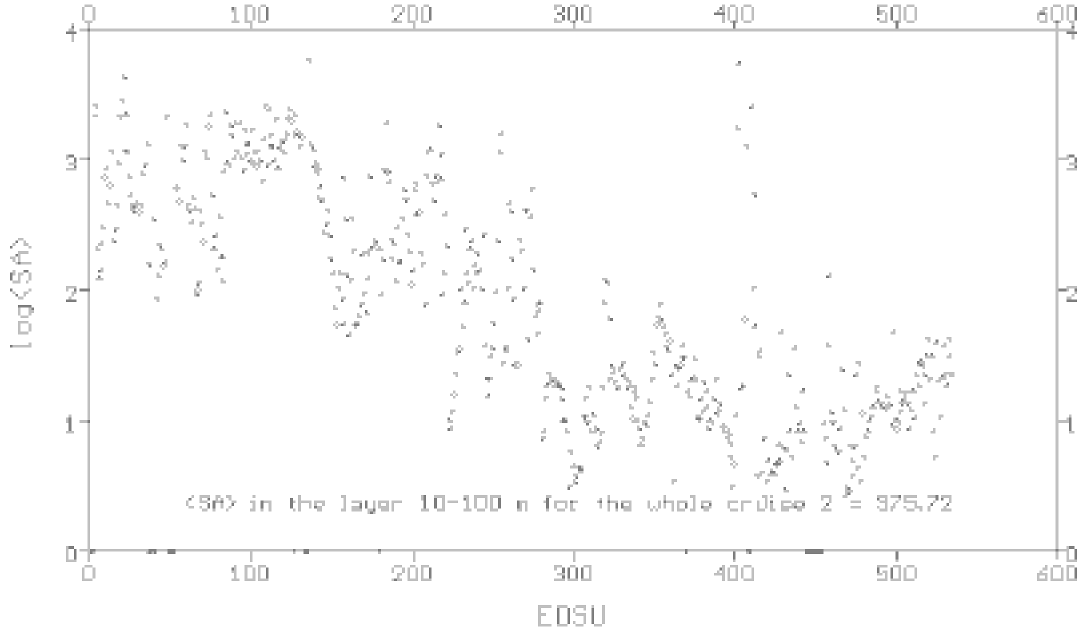


Fig.13. S_A values along tansects for all surveys.



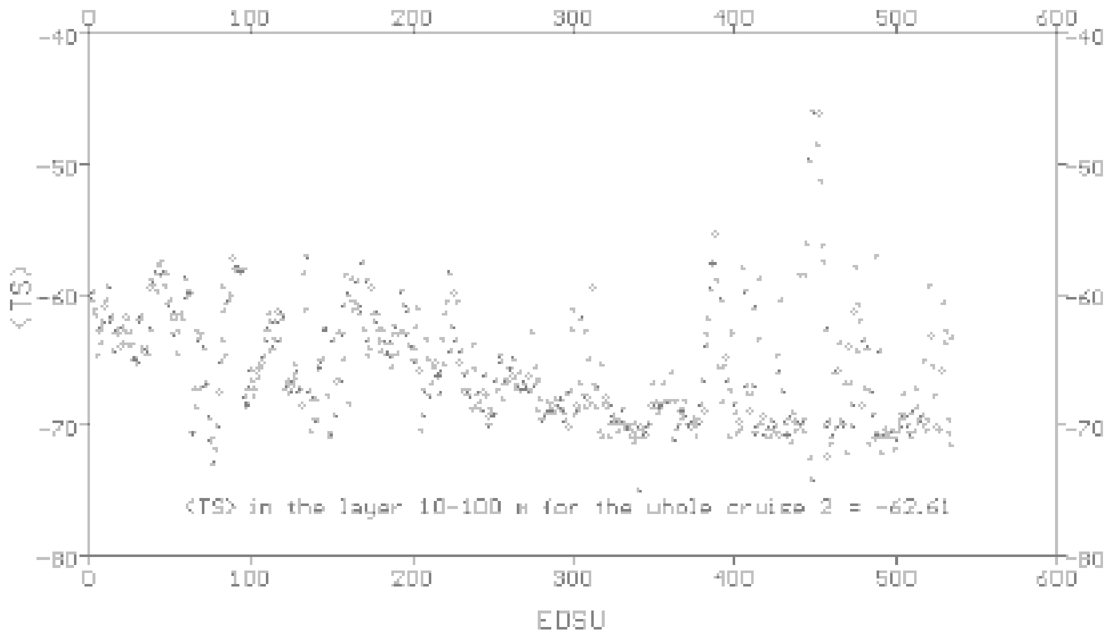
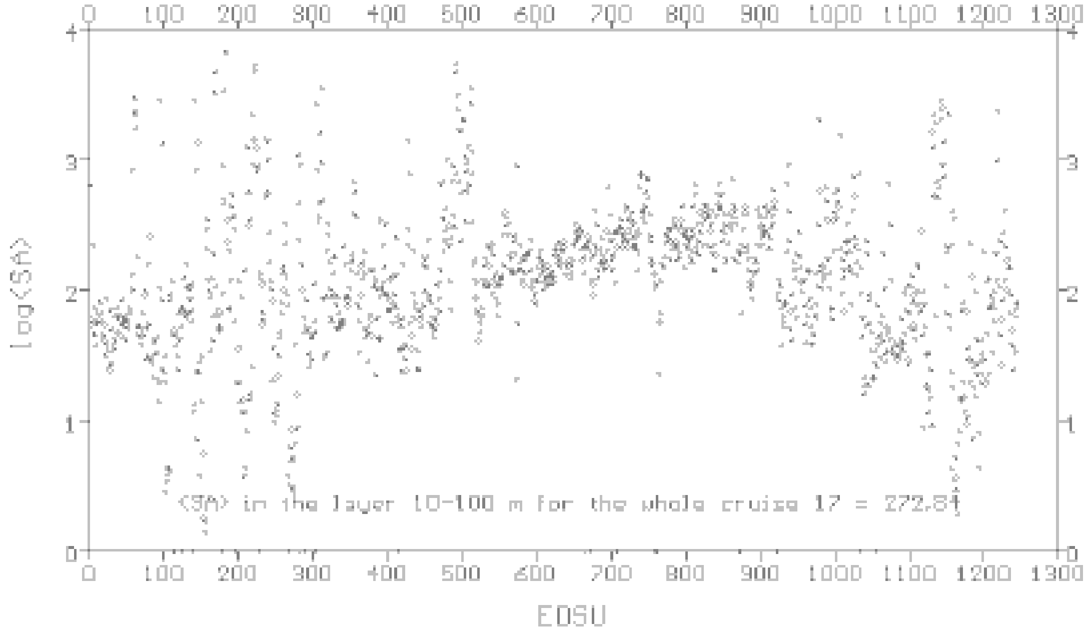


Fig.14a. Integrator values for the layer 10-100 m in consecutive sampling units and mean values of target strength measured by split beam method in the water layer 10-100 m. Survey 02/95.



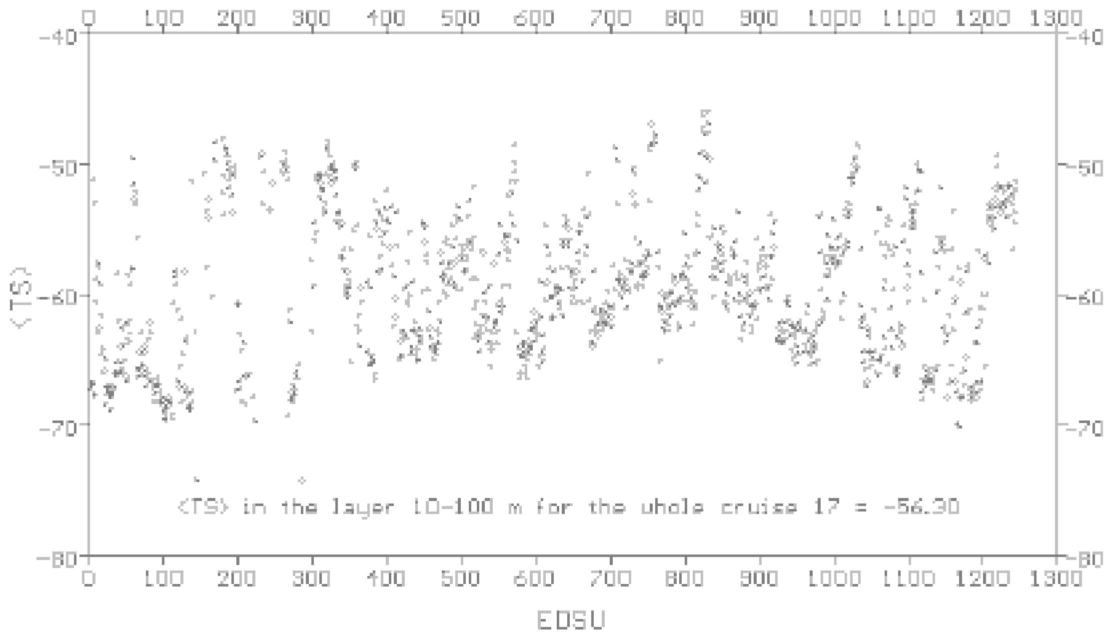
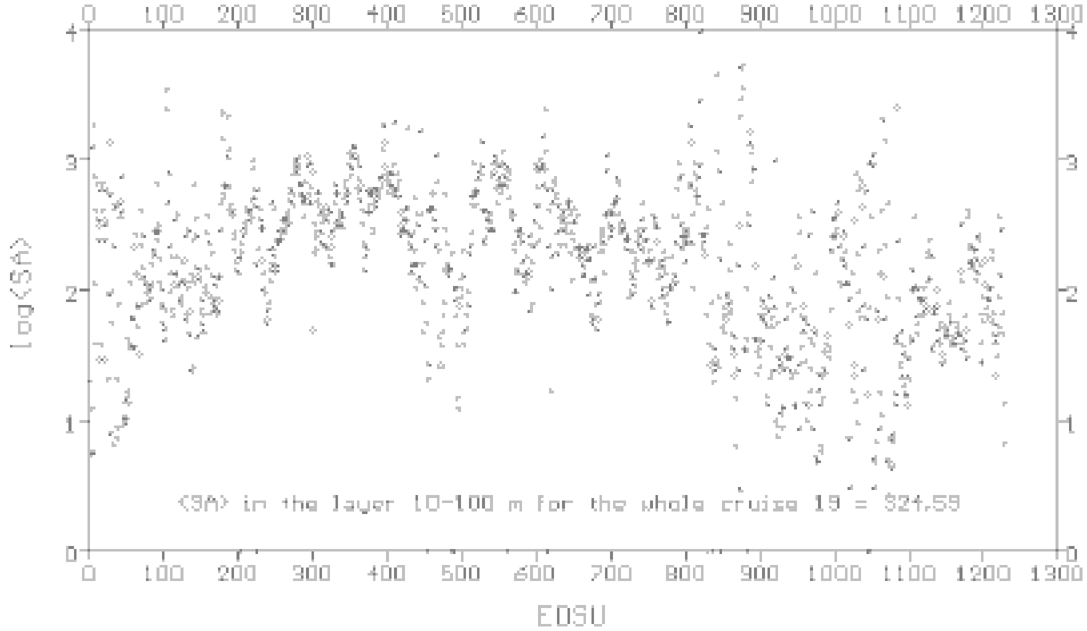


Fig.14b. Integrator values for the layer 10-100 m in consecutive sampling units and mean values of target strength measured by split beam method in the water layer 10-100 m. Survey 17/97.



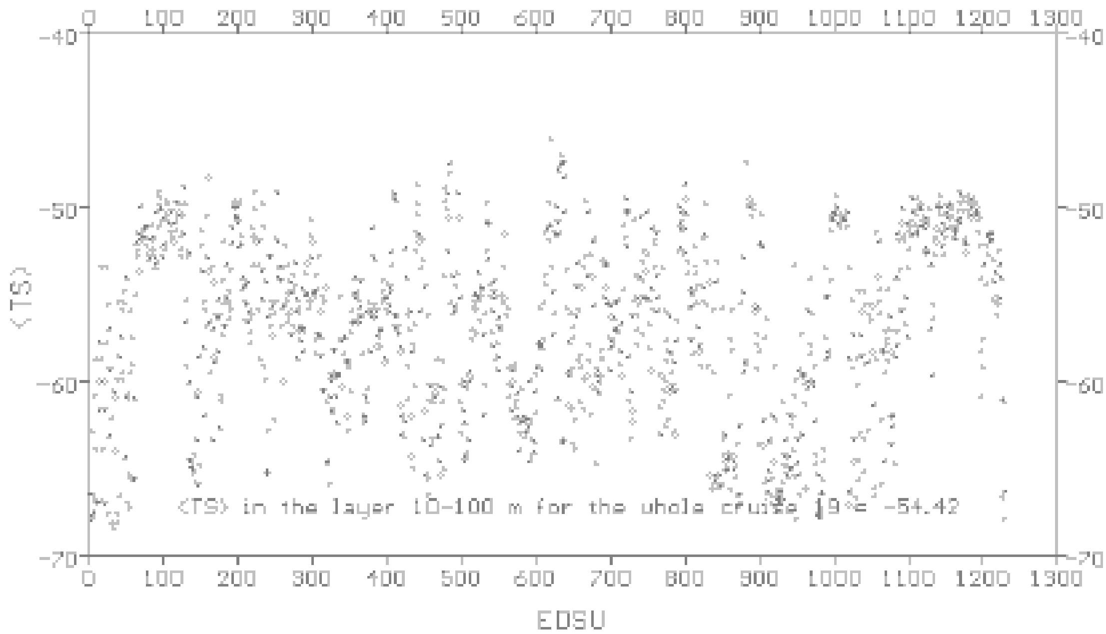


Fig.14c. Integrator values for the layer 10-100 m in consecutive sampling units and mean values of target strength measured by split beam method in the water layer 10-100 m. Survey 19/98.

The values of integrated energy recorded by echosounder are bearing the clue information on area fish number and density. The problem of determination of the mean value for chosen part of the surveyed area lies in sensible averaging of the obtained data. There are two statistical complications with the data: firstly, succesive observations are not randomly distributed over the area but are made along specific lines and can be serially correlated, and, secondly, the statistical distribution of measured integrator values (Probability Density Function) is usually not Gaussian distribution and needs a proper transformation.

The first step in integram analysis was to examine the serial correlation in the sample sequence considered as a time series (MacLennan and MacKenzie, 1988). The examples of auto-correlation functions for two last surveys are presented in Fig.15. In each case the calculations were performed for lags up to 25% of the total record length. It can be concluded that there is no significant autocorrelation and that the samples can be treated as the independent ones.

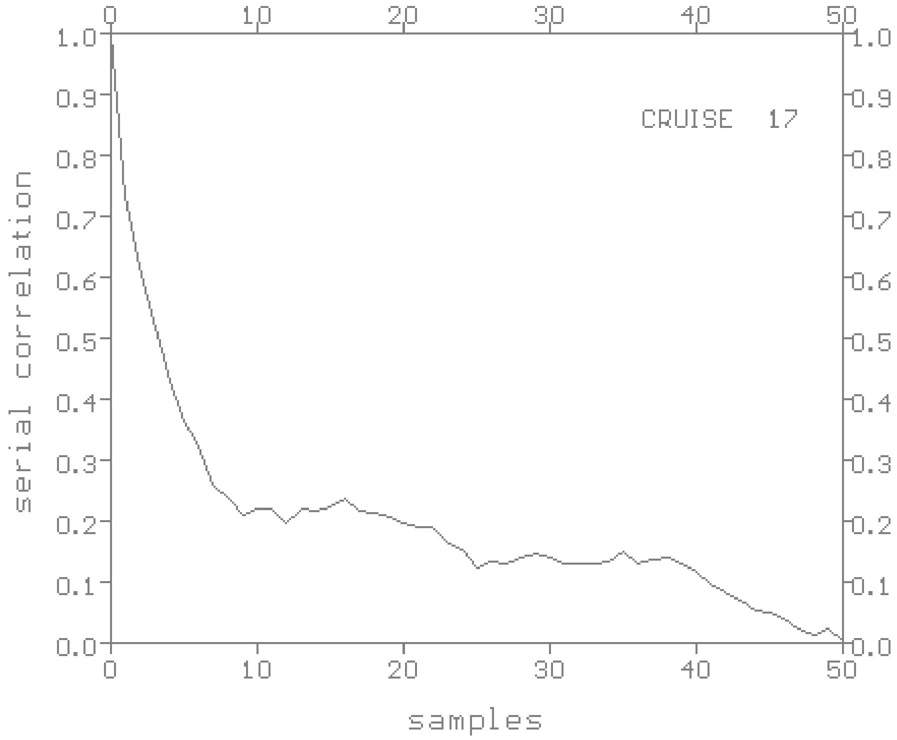


Fig.15a. Correlograms of integrator data from the survey 17.

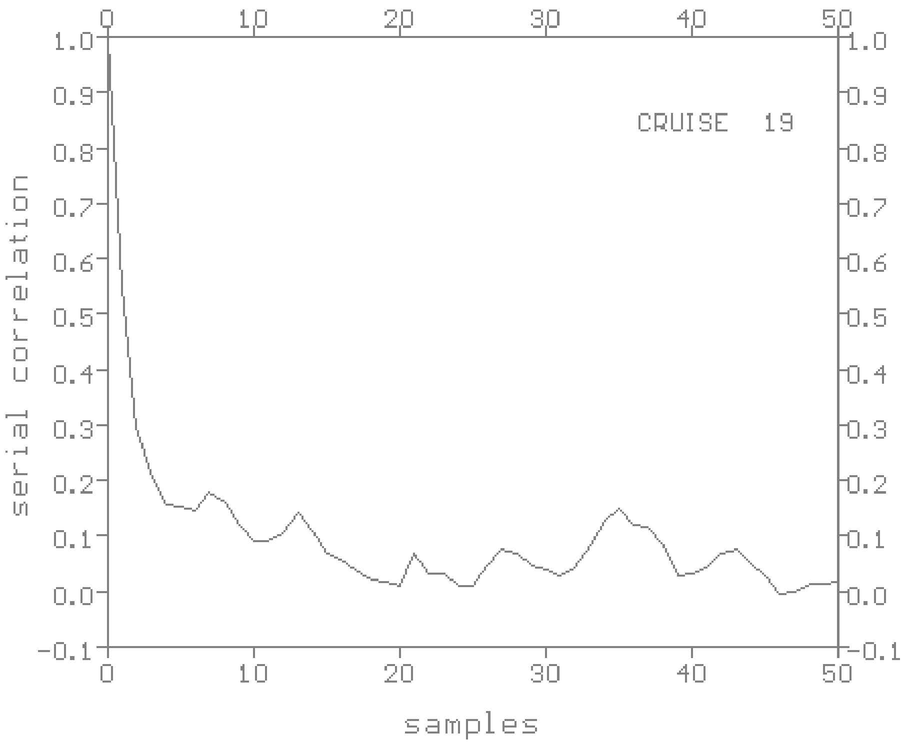


Fig.15b. Correlogram of integrator data from the survey 19

The second step was to check the PDF of integrams. As it could be expected it occured to be positively skewed, which means that a large proportion of the observations yield small values (Fig.16). This type of PDF is very different from the symmetrical normal (Gaussian) probability function on which much of the sampling theory is based.

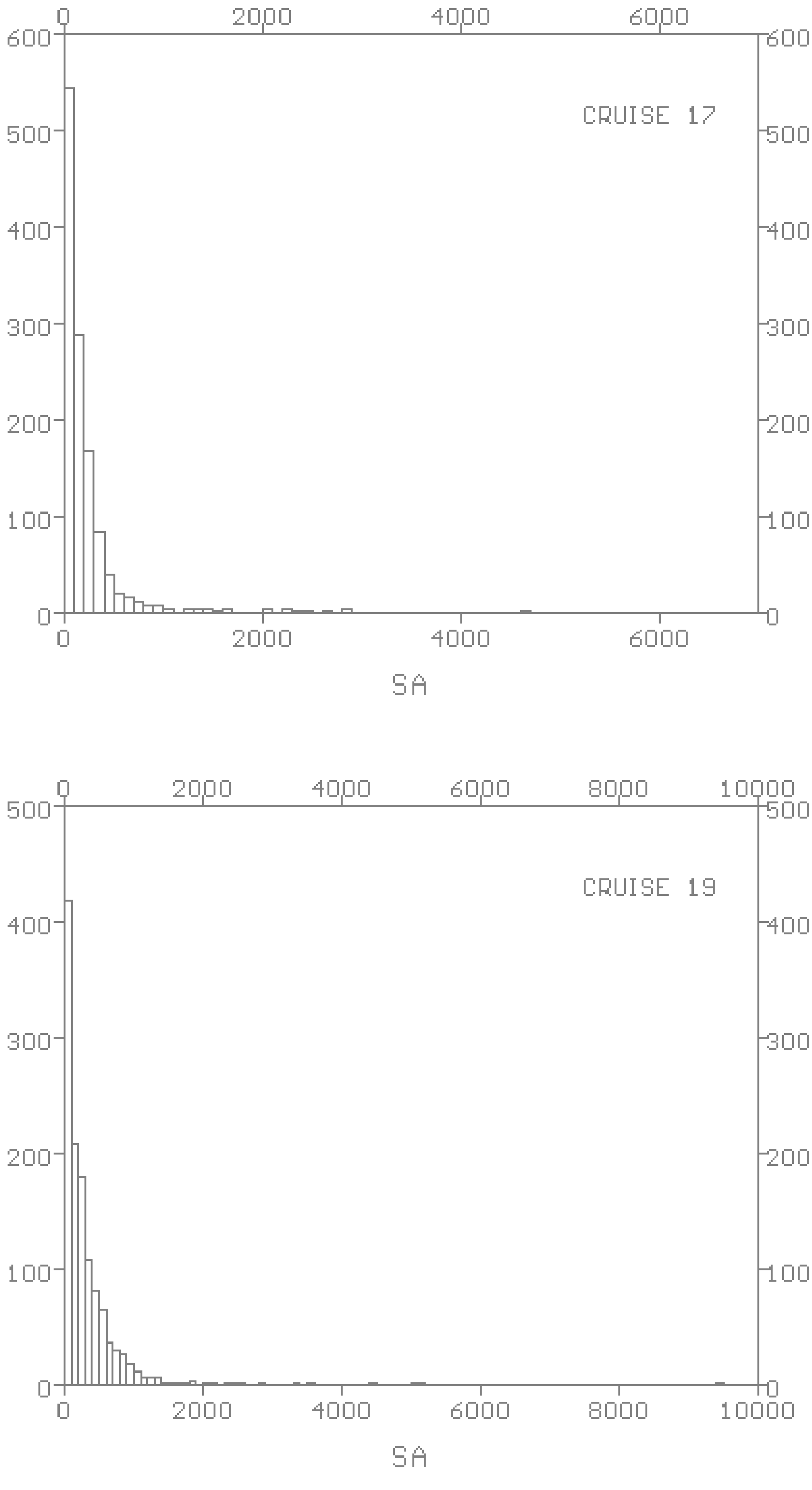


Fig.16. Histograms of S_A values for the last two surveys for the integration layer 10-100 m.

4.2.4. Fish abundance

According to formula (1), the mean area density of fish for the individual EDSU is expressed as:

$$\rho_A = N_A < W > = \frac{1}{4\pi} \frac{S_A}{\sum_i f_i \sigma_{bs,i}} W(\sigma_{bs})$$

The fish abundance estimates were obtained from the echo integration data S_A in depth strata, $<\sigma_{bs}>$ values and scaling formula (14). $S_A/<\sigma_{bs}>$ was not the same for all cases, it depended upon the size distribution of the insonified targets. Consecutive stages of data processing leading to the final results ρ_A are shown in Fig.17 a-c.

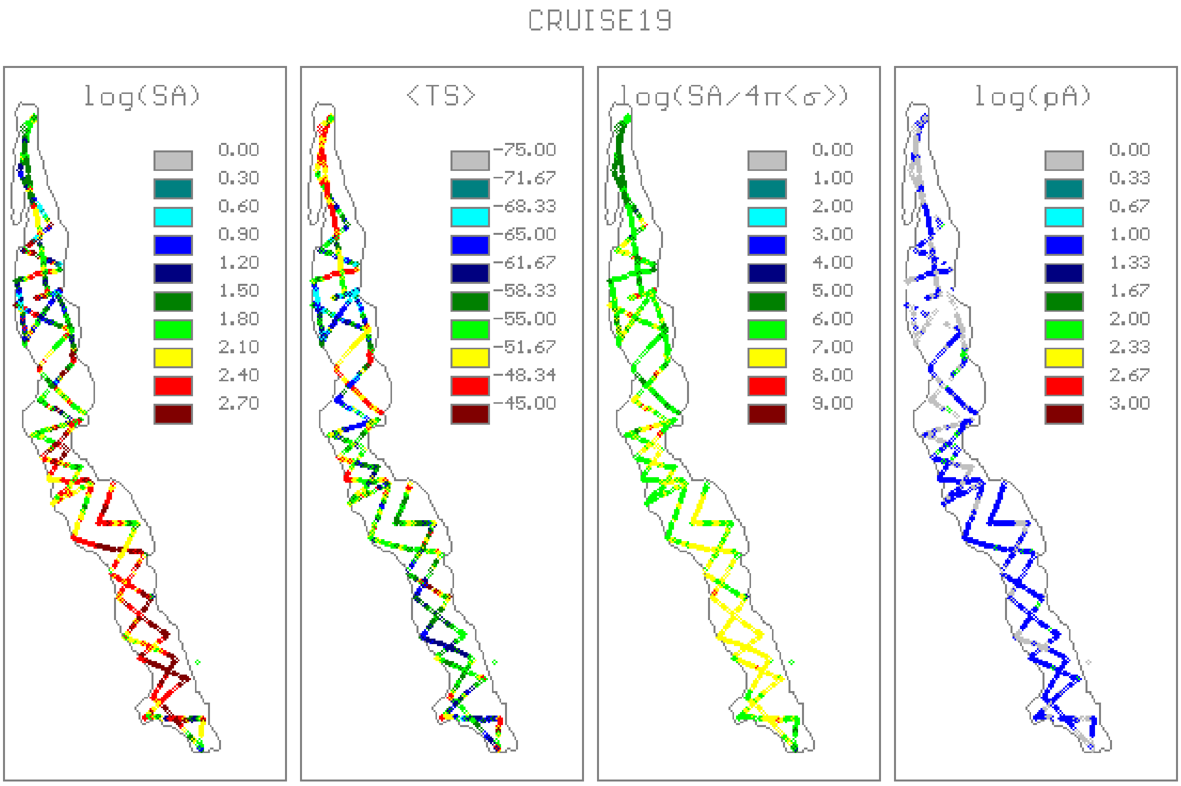


Fig.17a. Values of integrams, average target strength and successive stages of data processing put on a map for survey 19. Layer 10-100 m.

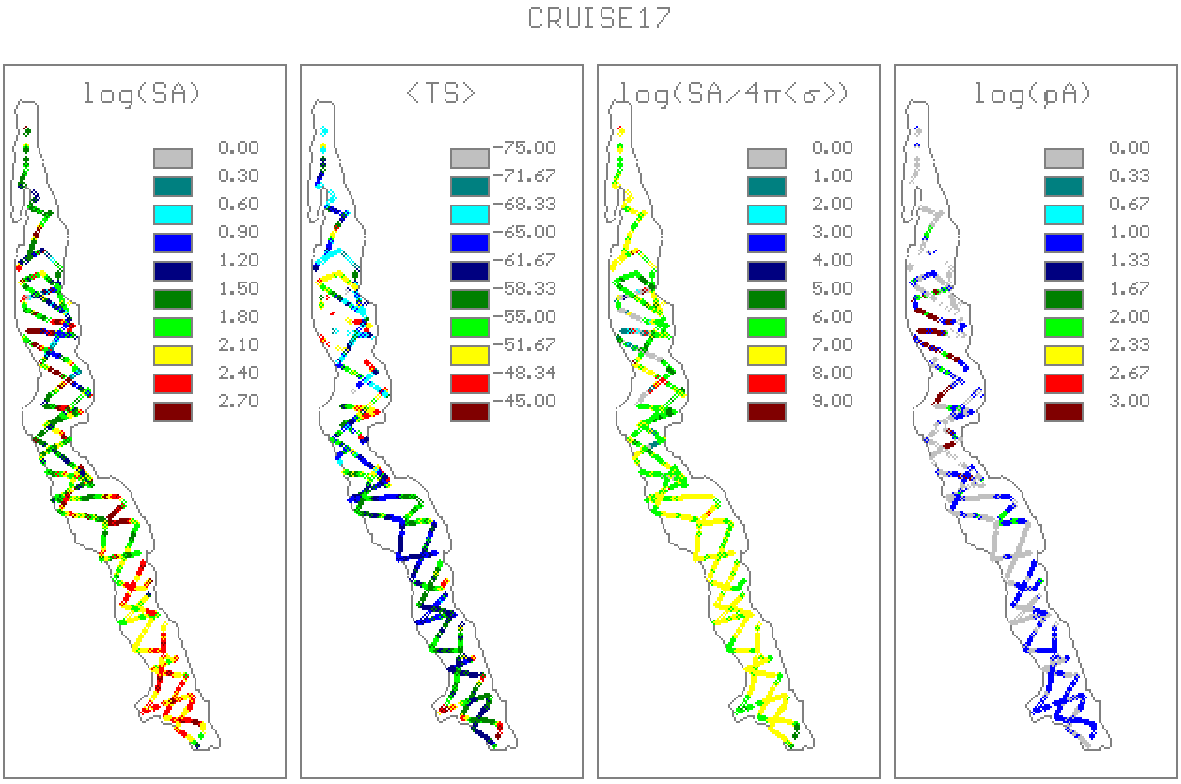


Fig.17b. Values of integrams, average target strength and successive stages of data processing put on a map for survey 17. Layer 10-100 m.

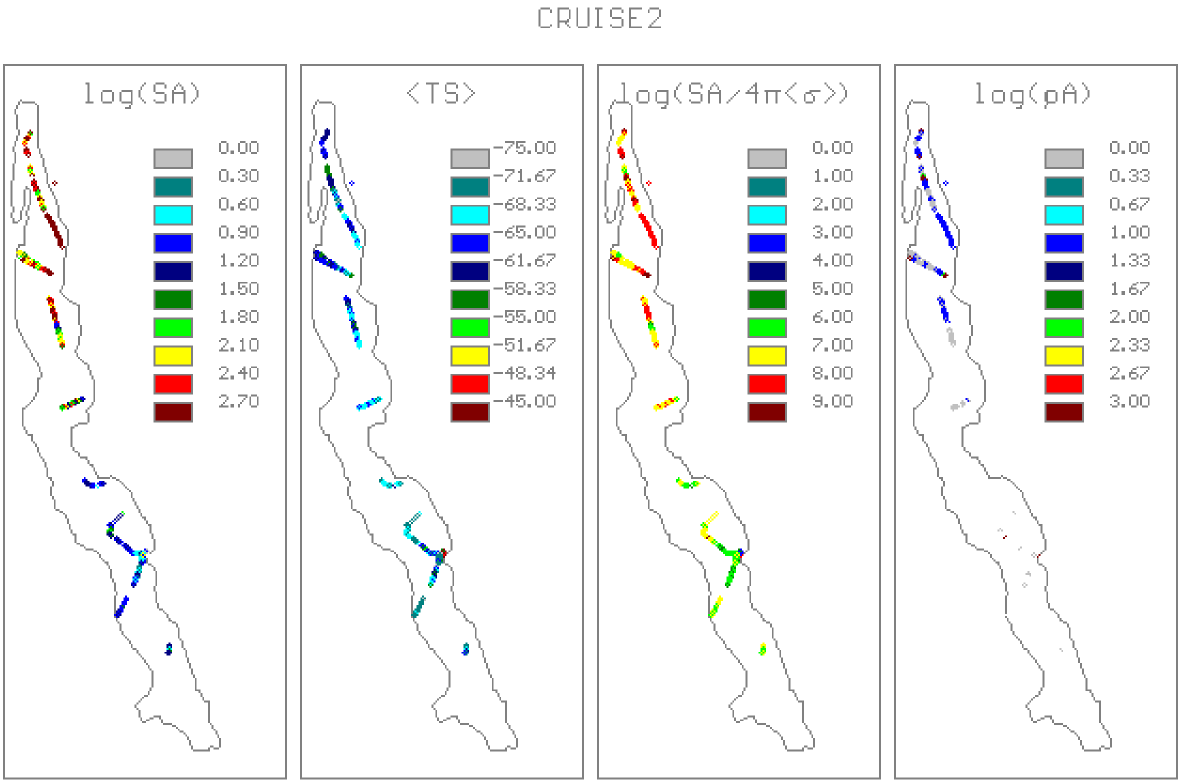


Fig.17c. Values of integrams, average target strength and successive stages of data processing put on a map for survey 2. Layer 10-100 m.

The next step of the analysis was to obtain spatial distibution of fish biomass in the whole lake. Calculated values of area density ρ_A for surveys 2, 17 and 19 have been interpolated by use of EchoBase software. It incorporates the kriging method in the area spanning all EDSU positions between the most west, east, north and south points of the acoustic measurements, giving the interpolated mass distribution over the whole lake.

The last step was to determine $\langle\rho_A\rangle$, the mean value of fish density in the whole lake, using the point observations Y_1, Y_2, ..., Y_N. A straightforward procedure would be to calculate the mean from the formula

$$\langle \rho_A \rangle = \frac{1}{N}\sum_{i=1}^{N} Y_i \qquad (15)$$

The arithmetic mean is valid if a set of Y_i exhibits a probability density function which can be reasonably well approximated by the normal distribution. However, in our case like in most cases of large scale acoustic surveys, data PDF is positively skewed (Fig.16). Distributions which depart seriously from the Gaussian one require correct transformation. There are various types of such transformations described in the literature (MacLennan and Simmonds, 1992, MacLennan and MacKenzie, 1988). One of them is a natural logarithm transformation that has been applied to our data.

$$X_i = \ln(Y_i) \quad (16)$$

$$\langle X \rangle = \frac{1}{N}\sum_{i=1}^{N} X_i \qquad \text{sample mean} \quad (17)$$

$$S = \sum_{i=1}^{N} \left(X_i - \langle X \rangle\right)^2 \qquad \text{residual sum of squares} \quad (18)$$

The true mean Q of the sample and the variance V of this mean were estimated in the following way (MacLennan, MacKenzie, 1988):

$$Q = \exp(\langle X \rangle) G_N \left[0.5S/(N-1)\right] \quad (19)$$

$$V = Q^2 - \exp(2\langle X \rangle) G_N \left[S(N-2)/(N-1)^2\right] \quad (20)$$

The function G_N is computed from the recursive algorithm:

$$G_N(u) = 1 + \frac{(N-1)u}{N} \quad (21)$$

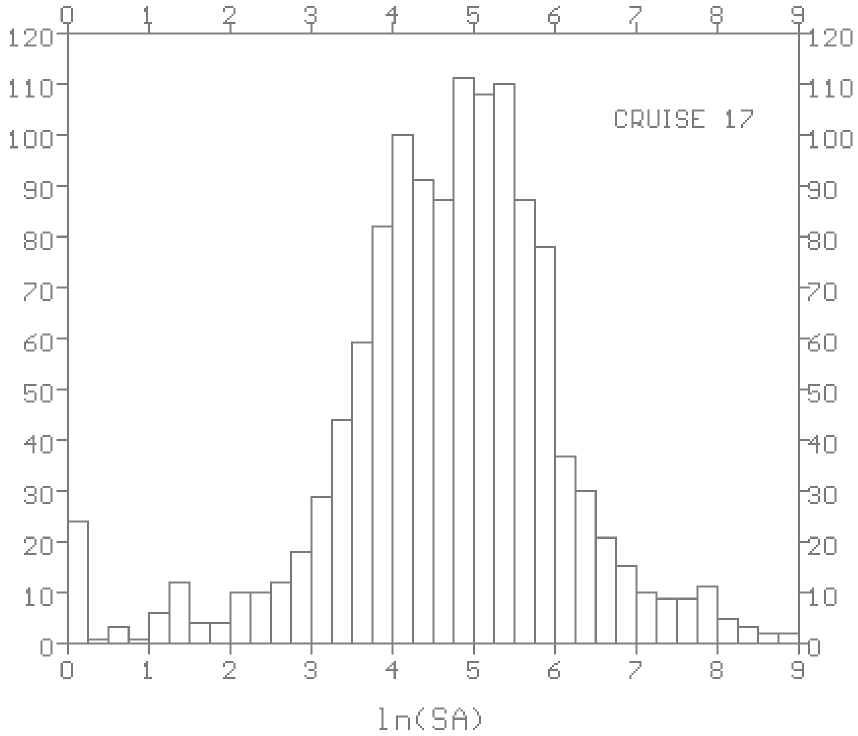
$$g = \frac{(N-1)^3 u^2}{2N^2 (N+1)} \qquad j = 3 \quad (22)$$

$$G_N(u) \rightarrow G_N(u) + g \quad (21a)$$

$$g \rightarrow g \frac{(N-1)^2 u}{jN(N+2j-3)} \quad (22a)$$

$$j \rightarrow j + 1$$

Calculations of G_N (21a) and g (22a) are repeated until convergence, when g is very close to zero.
Transformed integrams for the last two cruises are shown in Fig.18.



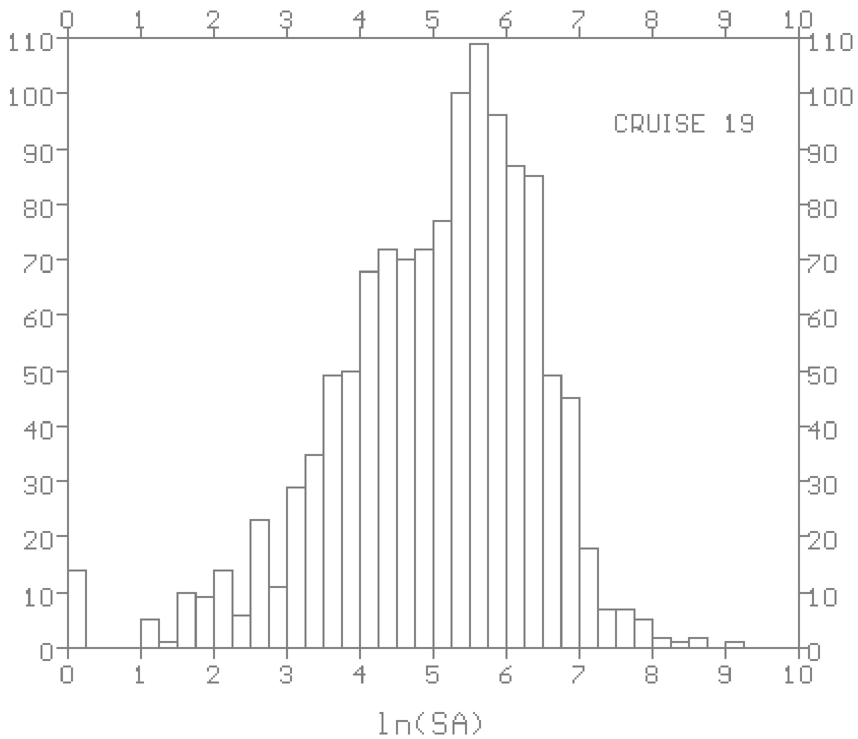


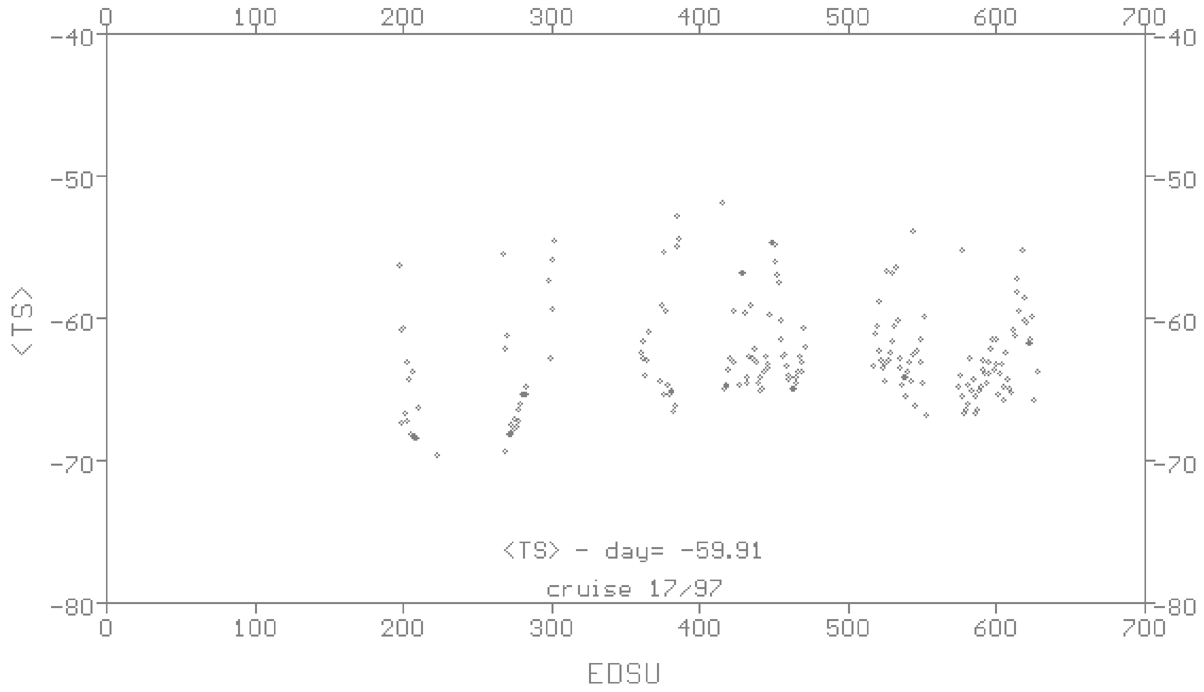
Fig.18. Histograms of the logarithmic values of S_A for the last two surveys for the integration layer 10-100 m.

5. RESULTS

5.1. Diurnal variability

It is known that significant differences occur in the day-night ratio of integrated echo intensities returned from the same fish stock in the same area. Schools observed during the day disperse at night forming a relatively dense layer in the subsurface area. This diurnal vertical migration of fish and zooplankton is described as an optimization of the relation between predation risk and food availability, triggered by changes in light intensity. Hence, it was desired to examine the extent to which such differences could influence a total fish estimate.

A comparison of „day" and „night" records of the mean *TS* values from the surveys 17/97 and 19/98 is presented in Fig.19 a-b. It can be seen that the night values are a few dB higher than the day ones. Similar tendency is observed while comparing the histograms of the day and night integram values (Fig. 20 a-b). It means that acoustic measurements performed only at night can result in a bias in the final fish abundance estimate.



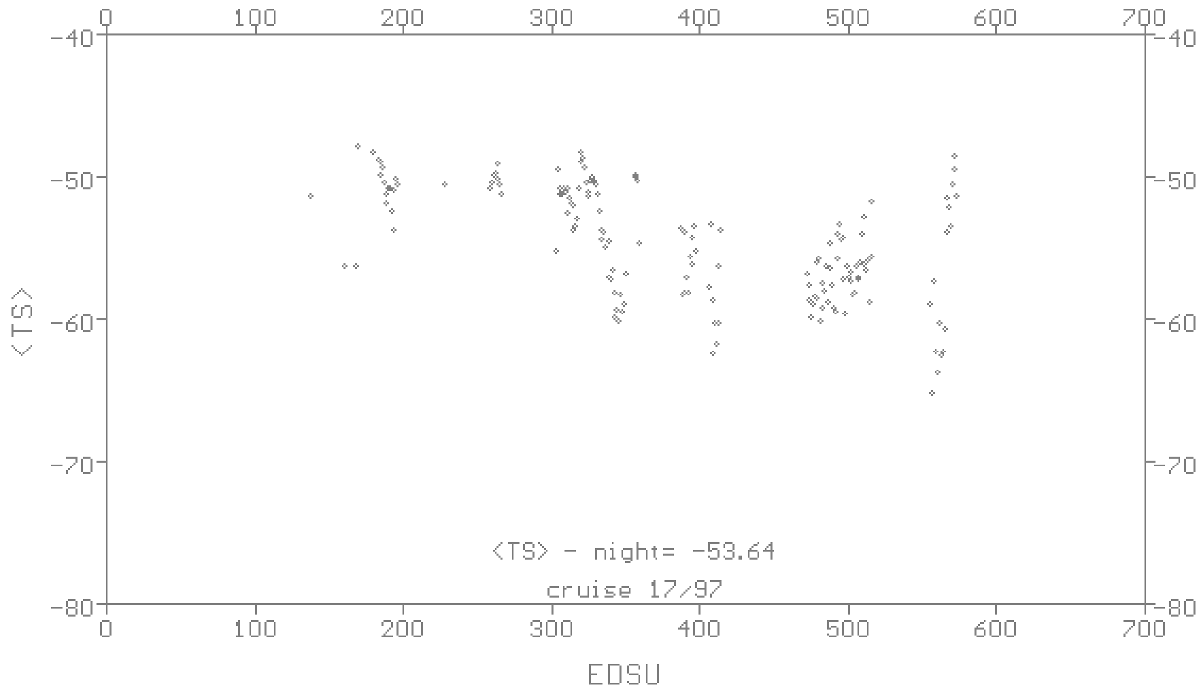


Fig.19a. Mean values of target strength for day and night records in the water layer 10-100 m. Survey 17/97.

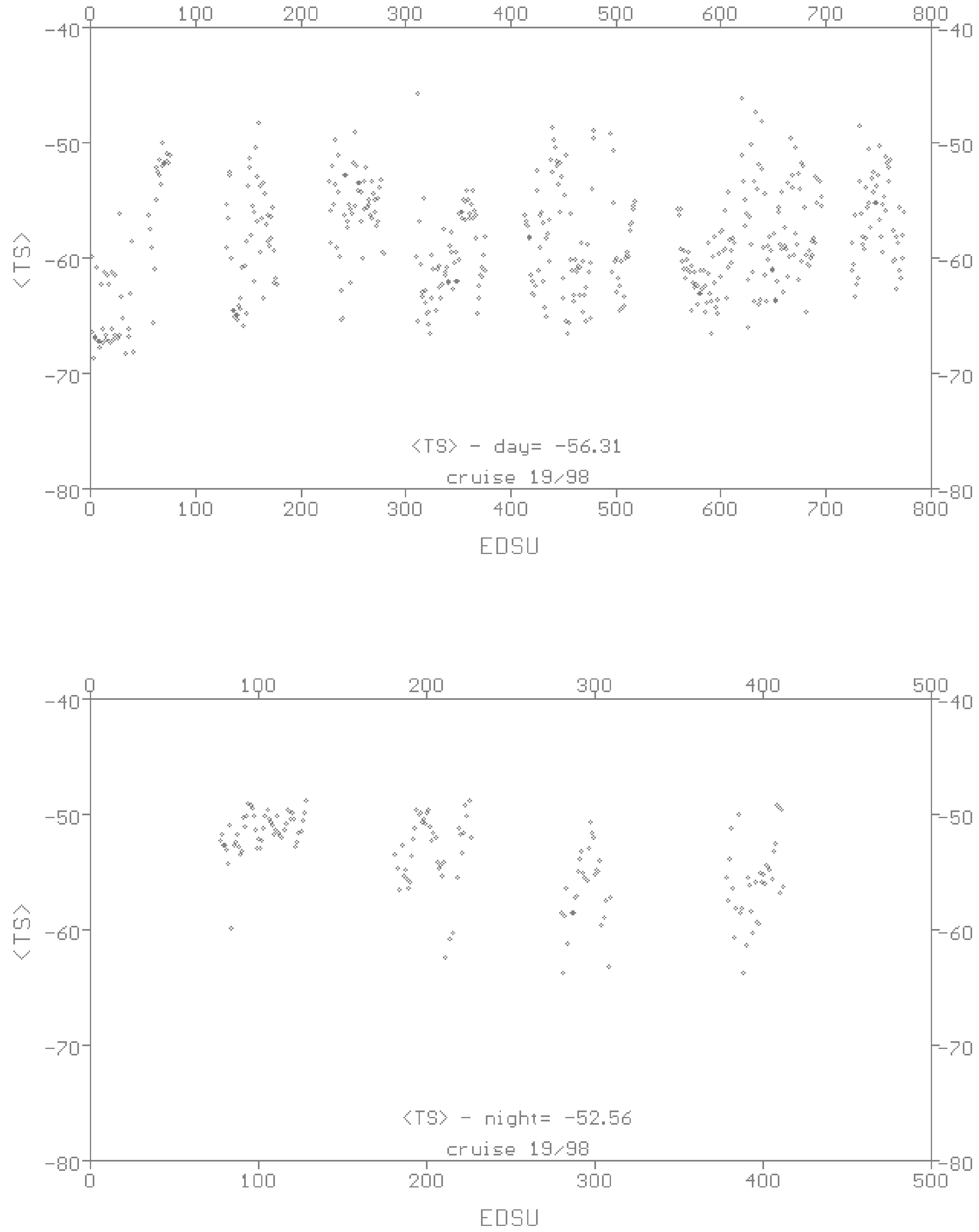


Fig.19b. Mean values of target strength for day and night records in the water layer 10-100 m. Survey 19/98.

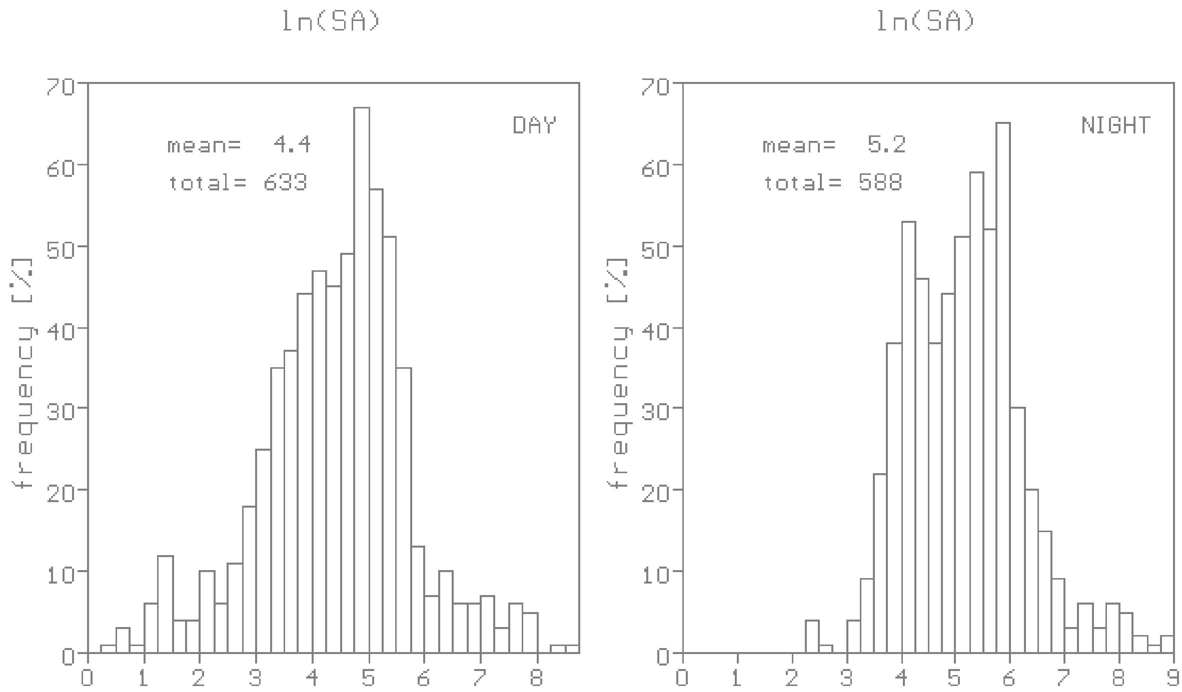


Fig.20a. Distribution of integram values recorded during the day and at night in the water layer 10-100 m. Survey 17/97.

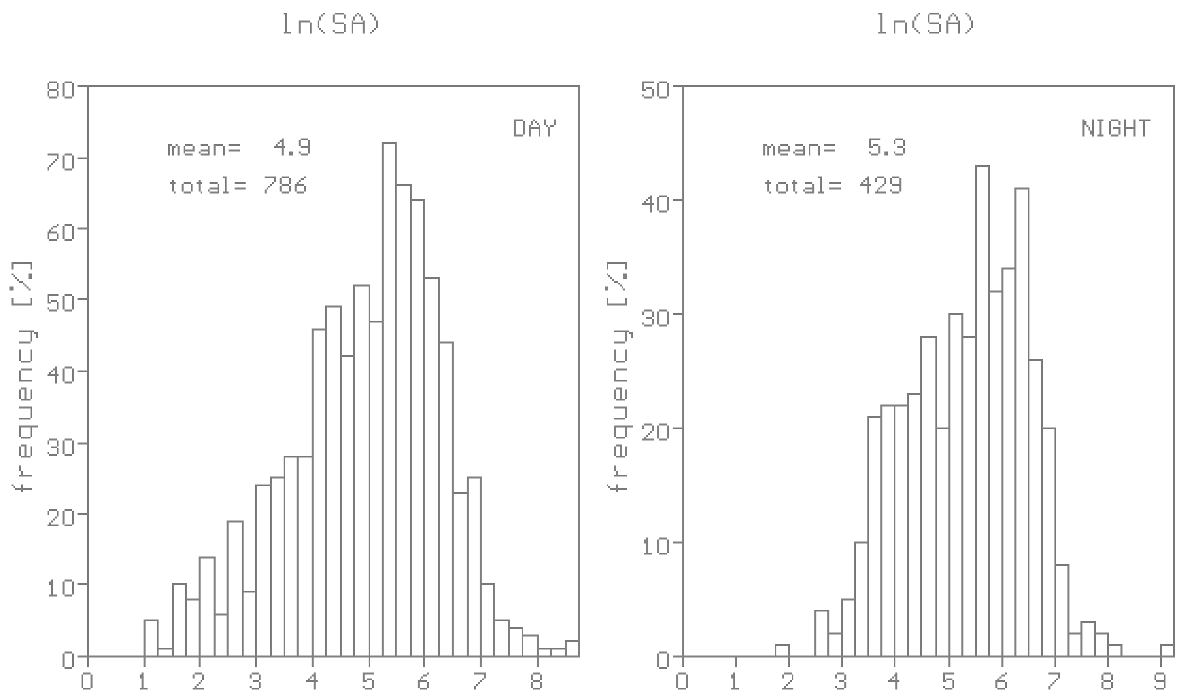


Fig.20b. Distribution of integram values recorded during the day and at night in the water layer 10-100 m. Survey 19/98.

5.2. Fish abundance distributions

The results obtained during the cruises 02/95, 17/97 and 19/98 for the water layer 10-100 m are shown in Fig.21 and for separate water layers for each of these cruises in Figures 22 a-c. The following water layers are shown:

layer 1 : 10- 20 m
layer 2 : 20- 40 m
layer 3 : 40- 60 m
layer 4 : 60- 80 m
layer 5 : 80-100 m
layer 6 :100-125 m

Fig.21 is constructed in the same scale for all cruises - for clear comparison, whereas Figures 22 use the dynamic scale for each picture, spanning the whole interval of calculated values, so that the separate images cannot be compared directly.

It is striking that each of the cruises gives a different distribution of fish biomass. The results of the 02/95 survey can be biased because of the insufficient number of samples, but it is obvious that the majority of fish is concentrated in the northern part of the lake, especially in the layer 60 - 80 m. In December - cruise 17/97 - fish mass is moved toward the south with the maxima in Cap Banza area, Kabimba - Lagosa line, below Cap Kibwesa and the western part of Zambian waters. The depth distribution seems to be quite uniform. In February - cruise 19/98 - the majority of fish is concentrated in the middle part of the lake, around Cap Kabogo and in the southern part, in Kirando and Kala areas. There is definitely a small amount of fish in the north.

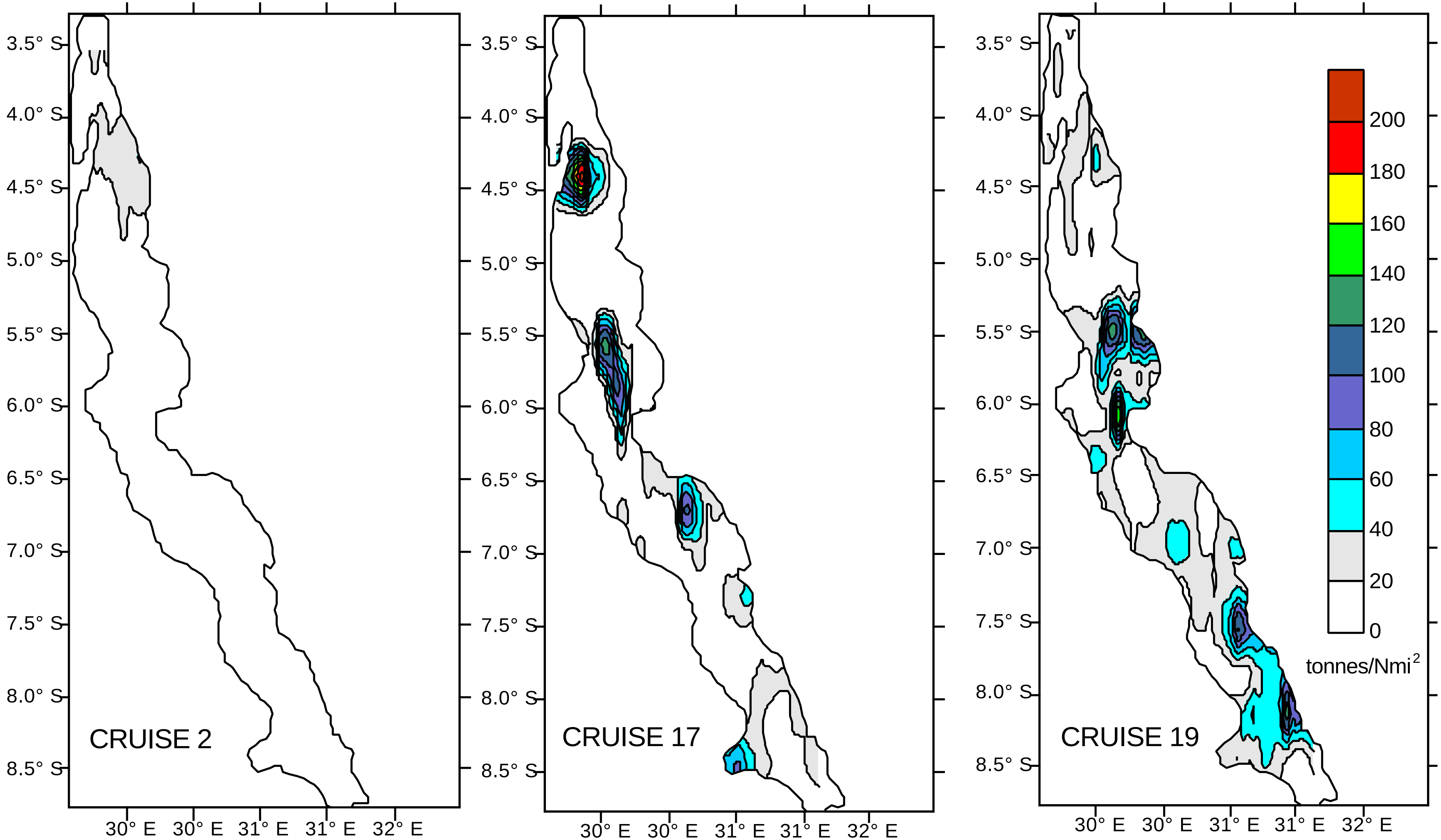


Fig.21. Spatial distributions of the area fish density in the layer 10-100 m from the surveys 2, 17 and 19.

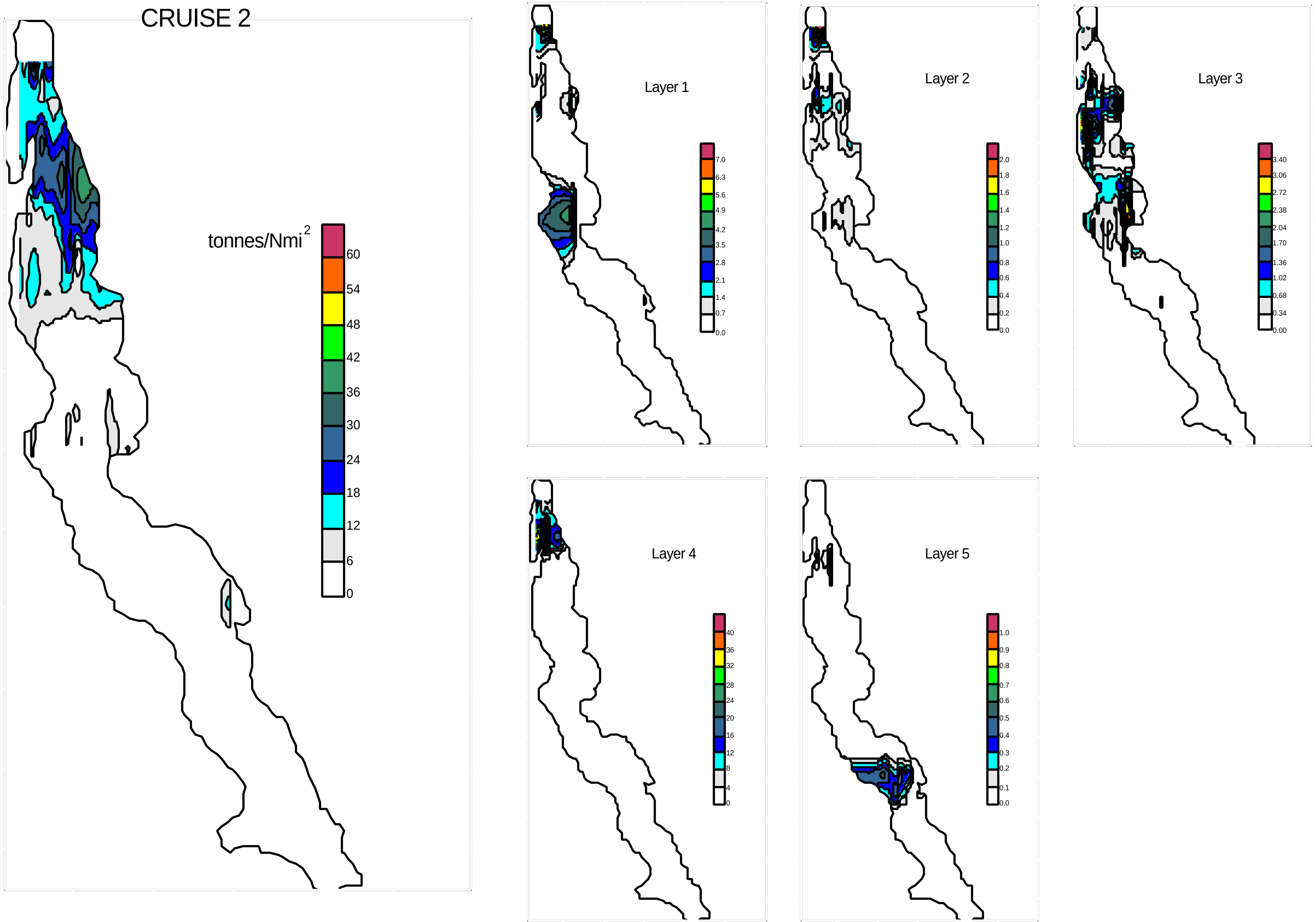


Fig.22a.Spatial distribution of the area fish density in the layer 10-100 m together with sublayers from the survey 2 (June 1995)

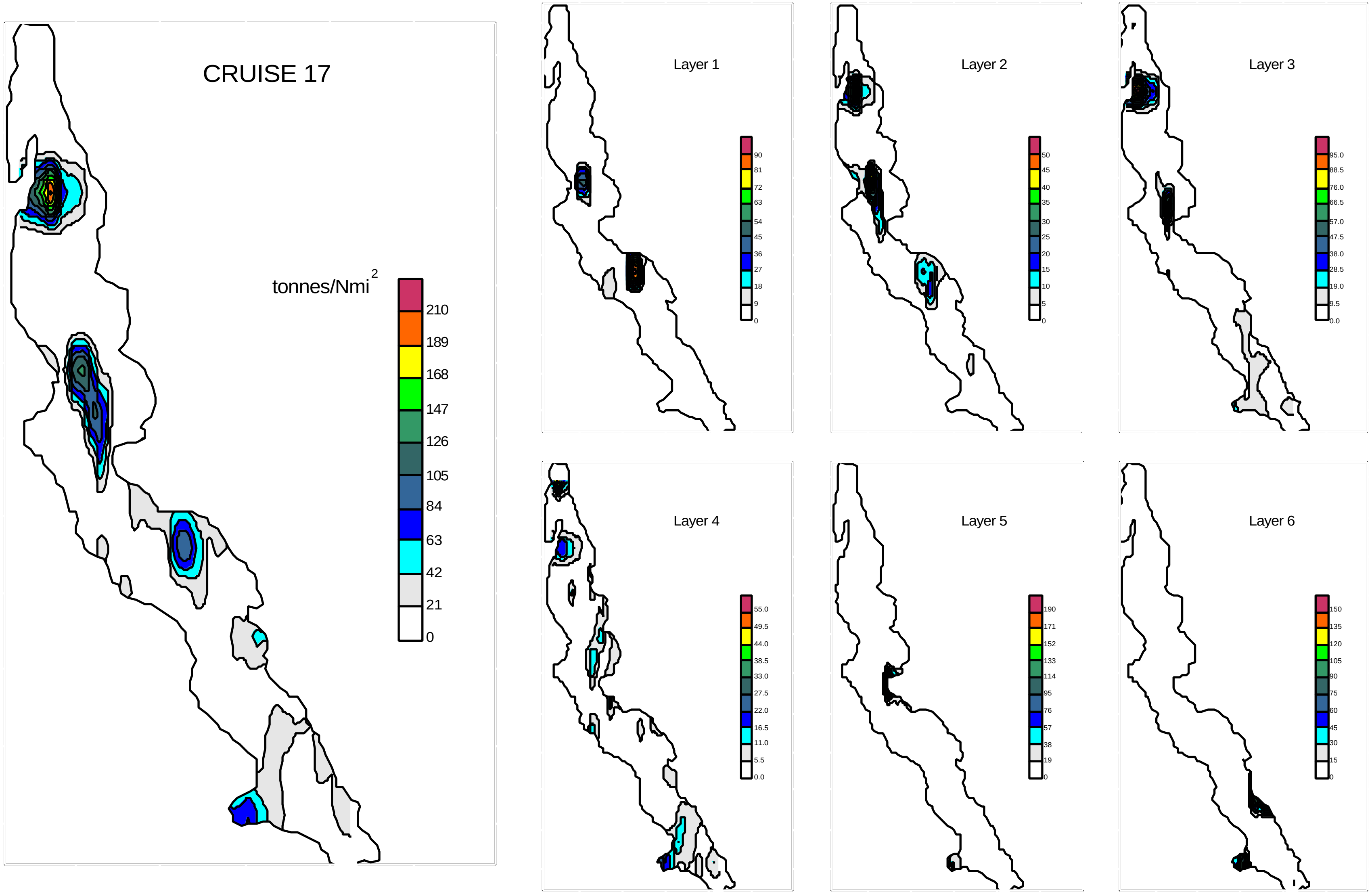


Fig.22b.Spatial distribution of the area fish density in the layer 10-100 m together with sublayers from the survey 17 (November-December 1997)

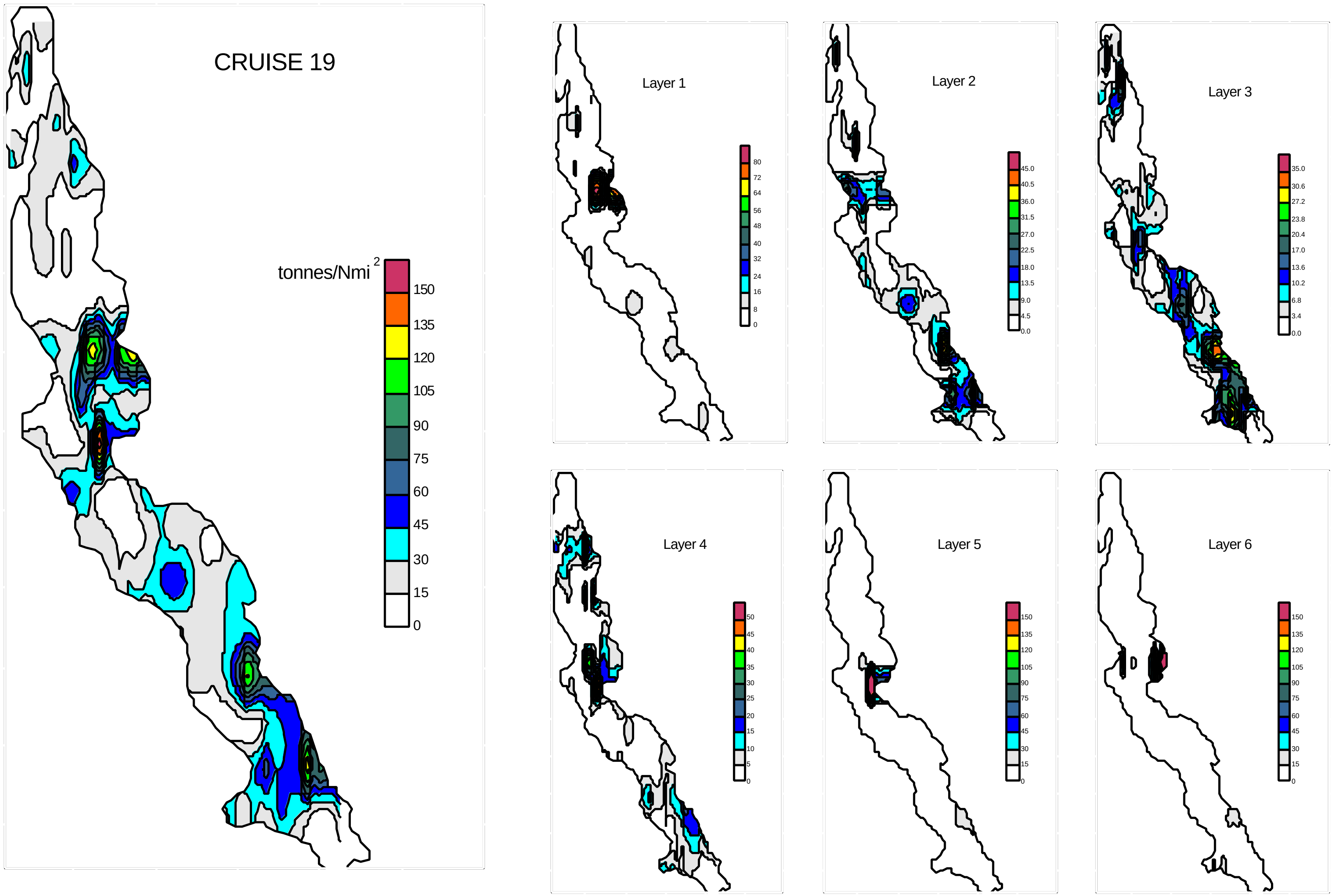


Fig.22c.Spatial distribution of the area fish density in the layer 10-100 m together with sublayers from the survey 19 (February 1998)

5.3. Total abundance

As it was mentioned above, a standard statistical analysis can be applied when integram values Y_i follow a normal (Gaussian) distribution and hence a symmetrical confidence intervals about the estimated mean value $<Y>$ exist. It was not the case, however, so the integram values were transformed to the natural logarithm values. Statistical independence of the samples was proved, thus the effects of possible serial correlation could be ignored.

The whole area of Lake Tanganyika was divided along the latitudes into 5 regions:

1. 3°20′ - 4°30′ Burundi/Cap Banza
2. 4°30′ - 5°40′ near Kigoma
3. 5°40′ - 6°30′ near Lagosa
4. 6°30′ - 8°00′ Kipili/Karema
5. 8°00′ - 8°45′ Zambia

It was the same division as one made by Johannesson (1974) and followed by Mathisen and Rufli (1980). In each section the mean value of the area fish density (in tonnes/N.mi.^{2}), its variance and standard deviation were computed according to the algorithm described in paragraph 4.2.3. The convergence of the recursive procedure (21a) and (22a) was achieved in the 8th-9th step. The results of calculations are presented in Tables 9-11.

Table 9. Mean values of the area fish density, variance and standard deviation for survey 02/95

region	area [N.mi.^{2}]	mean [tonnes/Nmi^2]	variance	standard deviation
1	1161.70	34.55	32.94	5.74
2	2350.85	18.19	32.52	5.70
3	1774.30	4.06	2.46	1.57
4	3385.43	0.32	0.00	0.03
5	1382.35	0	0	0

Table 10. Mean values of the area fish density, variance and standard deviation for survey 17/97

region	area [N.mi.^{2}]	mean [tonnes/Nmi^2]	variance	standard deviation
1	1161.70	7.55	8.20	2.86
2	2350.85	24.50	133.56	11.56
3	1774.30	15.30	22.46	4.74
4	3385.43	15.84	9.48	3.08
5	1382.35	20.64	4.37	2.09

Table 11. Mean values of the area fish density, variance and standard deviation for survey 19/98

region	area [N.mi.^{2}]	mean [tonnes/Nmi^2]	variance	standard deviation
1	1161.70	19.17	38.46	6.20
2	2350.85	21.18	75.41	8.68
3	1774.30	36.50	104.17	10.21
4	3385.43	30.97	12.78	3.57
5	1382.35	45.44	141.52	11.90

Finally, on the basis of the section means and section areas the total abundance and confidence limit for confidence level 95% were calculated. They are as follows:

Table 12. Total fish biomass estimated in surveys 2, 17 and 19

survey	total biomass [tonnes]	confidence limit
02/95	91 193	45 014
17/97	175 681	102 337
19/98	304 463	145 577

From a statistical point of view the results are not very satisfactory. Confidence limit stands on average for about 50% of the estimated value. It can be the result of the fact that the fish density is a stochastic variable described by a statistical distribution whose mean is estimated as the average of a large number of measurements. It is apparent that fish were not randomly distributed in any given area of survey but tended toward contagious aggregation, often in small areas. When the distribution is contagious, the calculated variance must be very high.

6. DISCUSSION

Acoustic methods in fish stock assessment offer some significant advantages like:

· relatively large area coverage
· rapidity of data collection and data processing
· high degree of automatization
· relatively high accuracy and reliability.

The error of the abundance estimate may be considered as the sum of two components, the sampling error (precision) caused by the measurements being stochastic samples of the true mean density and the systematic error (bias) which effects all the observations equally. The first component has already been estimated, the second one is negligible provided the following conditions are satisfied:

1. The equipment is calibrated properly.
2. The stock is not inextricably mixed with other populations (zooplankton!).
3. The fish are neither too deep nor too shallow to be detected by hydroacoustic system.
4. The fish avoidance effect is negligible.
5. The target strength-weight relationship is reliable.

It is difficult to say which of the above asumptions are fulfilled. Practically, only the conditions 1 and 2 can be considered as satisfied in full. If the calibration is performed carefully in accordance with the recommended procedure (as it was in our case), the precision of converting factor is very good. Also zooplankton impact has been eliminated from the echograms. A particularly difficult parameter is the target strength and the target strength - weight dependence. The *TS* measurements depend on the detection of isolated targets which may not be representative of the ensonified population. Errors may occur through the false detection of multiple targets. Such effect can result in the estimated *TS* being biased high. It seems that in situ target strength data should be critically interpretted, as the bias due to failure to reject multiple echoes can be very significant (Foote, 1994). This is especially noticeable in the case of small pelagic fish species, whose packing densities can be extremely large. The target strength - weight relationship depends on fishing results, too. The catching efficiency of the trawl was highly variable. The main problem arisen during the last 2 cruises was the fishing net which had been completely destroyed during the 17/97 cruise what made fishing in the second half of that survey impossible. It was ripped from the opening to codend and we were lucky to retrieve all parts of the net while pulling it up. After being repaired in between two cruises it was subject to be damaged again several times. In consequence, trawling efficiency was rather poor. In addition, the net rope was marked in 50 metres intervals, hence the upper trawling depth was limited to the following values: 10, 22.5, 35, 45, 58, 70 and 80 m, according to the calibration curve obtained for the ship speed 4 knots. In my opinion the assumed depth of trawling was not reliable.

It is known from the previous acoustic surveys held in the years seventies that a rough estimate of the total abundance of pelagic fish in Lake Tanganyika is in a range of 0.4 to 2.8 mln tonnes. Our estimates are lower. Nevertheless, if we exclude the results of Johannesson (1974) of the reasons mentioned in paragraph 4.2.1, the rest of estimates is comparable.

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Also, I wish to appreciate the collaboration with a scientific team on board of “Tanganyika Explorer”.

Special thanks are addressed to Els Bosma for her enthusiastic help in survey organizing and warm hospitality in Kigoma.

APPENDIX 1. EY-500 standard settings

Operation menu:
Ping mode: Normal
Ping auto start: Off
Ping interval: 2.0 sec

Display menu:
Colour set: Light
Event marker: On
Echogram speed: 1:1
Echogram: On

Echogram menu:
Transd. number:1
Range: 150 m
Range start: 10 m
Auto range: Off
Bottom range: 10 m
Bot. range start: 5 m
Bot. range pres: Off
Sub. bottom Gain 0.0 dB/m
Presentation: Normal
TVG: 20logR
Scale lines: 0
Bot. det. line: On
Layer lines: On
Integration line: Off
TS Colour min. : -75 dB
Sv colour min.: -70 dB

Printer menu:
Model type: Paint Jet
Navigation interval: 120 sec
Event marker: On
Annotation: On
Naut. mile marker: On
TS distribution: On
Integr. tables: On
Echogram speed: 1:2
Echogram: Slave

Echogram menu:
Transd. number:1
Range: 150 m
Range start: 10 m
Auto range: Off
Bottom range: 10 m
Bot. range start: 5 m
Bot. range pres: Off
Sub. bottom Gain 0.0 dB/m
Presentation: Normal
TVG: 20logR
Scale lines: 10
Bot. det. line: On
Layer lines: On
Integration line: Off
TS Colour min. : -75 dB
Sv colour min.: -70 dB

Transceiver menu:
Mode: Active
Transducer type: ES120-7

Transd. Sequence: Off
Transducer depth: 0.00 m
Absorption coef.: 4 db/km
Pulse length: Medium
Bandwidth: Wide
Max power: 252 W
2-way-beam angle: -20.6 dB
Sv transducer gain: 25.82 dB
TS transducer gain: 26.30 dB
Angle Sens. Along: 21.0
Angle Sens. Athw.: 21.0
3 dB Beamw. Along: 7.2 dg
3 dB Beamw. Athw.: 7.1 dg
Alongship Offset: -0.20 dg
Athw.ship Offset -0.11 dg

Bottom detection menu:
Minimum depth: 10.0 m
Maximum depth: 750 m
Min. depth alarm: 10.0 m
Max. depth alarm. 0 m
Bottom lost alarm: Off
Minimum level -50dB

Log menu:
Mode: Speed
Ping interval: 100
Time interval: 60 sec.
Distance interval: 1.0 nm
Distance:

Layer menu:
Super layer: 8
Layer-1 Menu:
Type: Surface or Pelagic
Range: 10 m.
Range start: 10 m
Margin: 1.0 m
Sv Threshold: -75 dB
Layer-2 Menu:
Type: Surface or Pelagic
Range: 20 m
Range start: 20 m.
Margin: 1.0 m
Sv Threshold: -75 dB
Layer-3 Menu:
Type: Surface or Pelagic
Range: 20 m.
Range start: 40 m.
Margin: 1.0 m
Sv Threshold: -75 dB
Layer-4 Menu:
Type: Surface or Pelagic
Range: 20 m
Range start: 60 m.
Margin: 1.0 m
Sv Threshold: -75 dB
Layer-5 Menu:

Type: Surface or Pelagic
Range: 20 m.
Range start: 80 m.
Margin: 1.0 m
Sv Threshold: -75 dB

Layer-6 Menu:

Type: Surface or Pelagic
Range: 25 m
Range start: 100 m.
Margin: 1.0 m
Sv Threshold: -75 dB

Layer-7 Menu:

Type: Surface or Pelagic
Range: 25 m.
Range start: 125 m.
Margin: 1.0 m
Sv Threshold: -75 dB

Layer-8 Menu:

Type: Pelagic
Range: 90 m
Range start: 10 m.
Margin: 1.0 m
Sv Threshold: -75 dB

Layer-9 Menu:

Type: Surface or Pelagic
Range: 190 m.
Range start: 10 m.
Margin: 1.0 m
Sv Threshold: -75 dB

Layer-10 Menu:

Type: Surface
Range: 90
Range start: 10 m.
Margin: 1.0 m
Sv Threshold: -75 dB

TS-detection menu:

Min. value: -75dB
Min. Echo Length: 0.8
Max. Echo Length: 1.5
Max. Gain Comp. 4.0 dB
Max Phase Dev.: 4.0

Disk menu:

Log: On
Max. File Size : 2Mb
Drive : C
Directory : /JOA/
Replay : Off

Telegram menu:

Sample Range: 150 m
Status: Off
Parameter : Off
Annotation: On
Navigation: On
Depth: On
Echogram: On
Echo-Trace: On
Sv: On

Sample Angle: Off
Sample Power: Off
Sample Sv: Off
Sample TS: Off
Vessel-Log: On
Layer: On
Integrator: On
TS Distribution: On

Echogram menu:

Range: 250 m
Range start: 10 m
Auto range: Off
Bottom range: 0 m
Bot. range start: 0 m
No. of Main Val. :500
No. of Bottom Val. :0
TVG: 20logR

Serial Com. Menu:

Not used

Annotation menu:

Event counter: 1
Counter Mode: Increase
Time interval: 0 min.
Text:

Navigation menu:

Navig. Input : Serial
Start Sequence: $GPGLL
Separation Char. : 002C
Stop char.: 000D
First Field No. : 2
Speed Input : Serial
Manual speed: 9.0 knt
Baud Rate: 4800
Bits Per Char.: 8
Stop Bits: 1
Parity: None

Utility menu:

Beeper: On
Status Messages : On
Date: yy.mm.dd
Time: hh.mm.ss
External Clock: Off
Password: 0
Default setting: No
Language: English
Sound velocity: 1500 m/s
COM1/COM2 Switch: Off

Test Menu:

Serial Port: COM-1

APPENDIX 2. SIMRAD calibration report

CALIBRATION REPORT EK/EY 500.

VESSEL: LAKE TANGANYIKA EXPLORER DATE: 97-11-19
PLACE: KIGOMA, TANZANIA SOUNDER TYPE: EY500 SERIAL NO: 107
TRANSDUCER TYPE: ES120-7 SERIAL NO: 25741 FREQUENCY: 120 KHZ
WATER TEMP.: 26,5 °C SALINITY: ‰ SOUND VELOCITY: 1500 M/SEC.
TEST MENU - Transceiver - Ampl. TX in Test Mode, with transd: -54 dB, without transd: - 49 dB
TEST MENU - Transceiver - Noise, TX in Passive Mode, Wide Bandwidth and with transd: - 147 dB

Ping Interval	1	1	1	sec.
Absorption Coefficient		4		dB//km
Pulse Length	SHORT	MEDIUM	LONG	
Bandwidth	WIDE	WIDE	WIDE	
Maximum Power		252		W
Transmit Power		252		
Angle Sensitivity Fore - Aft.*		21,0		
Angle Sensitivity Athwartship*		21,0		
TS of Sphere		-40,6		dB
Default TS Transducer Gain		26,10		dB
Measured TS		-40,2		dB
Calibrated TS Transducer Gain		26,30		dB
Calibrated TS		-40,6		dB
Default 2-Way Beam Angle		-20,8		dB
Transducer data 2-Way Beam Angle		-20,6		dB
Measured dist. Transducer - Sphere		5,7		m
Default Sv Transducer Gain		26,10		dB
Theoretical Sa		13266		m^2/nm^2
Measured Sa		11646		m^2/nm^2
Calibrated Sv Transducer Gain		25,82		dB
Calibrated Sa		13220		m^2/nm^2
Default -3dB Beamwidth Fore-Aft.*		7,0		degrees
Default -3dB Beamwidth Athw. *		7,0		degrees
Calibr. -3dB Beamwidth Fore-Aft.*		7,2		degrees
Calibrated -3dB Beamwidth Athw.*		7,1		degrees
Fore - Aft. Offset*		- 0,20		degrees
Athwartship Offset*		- 0,11		degrees

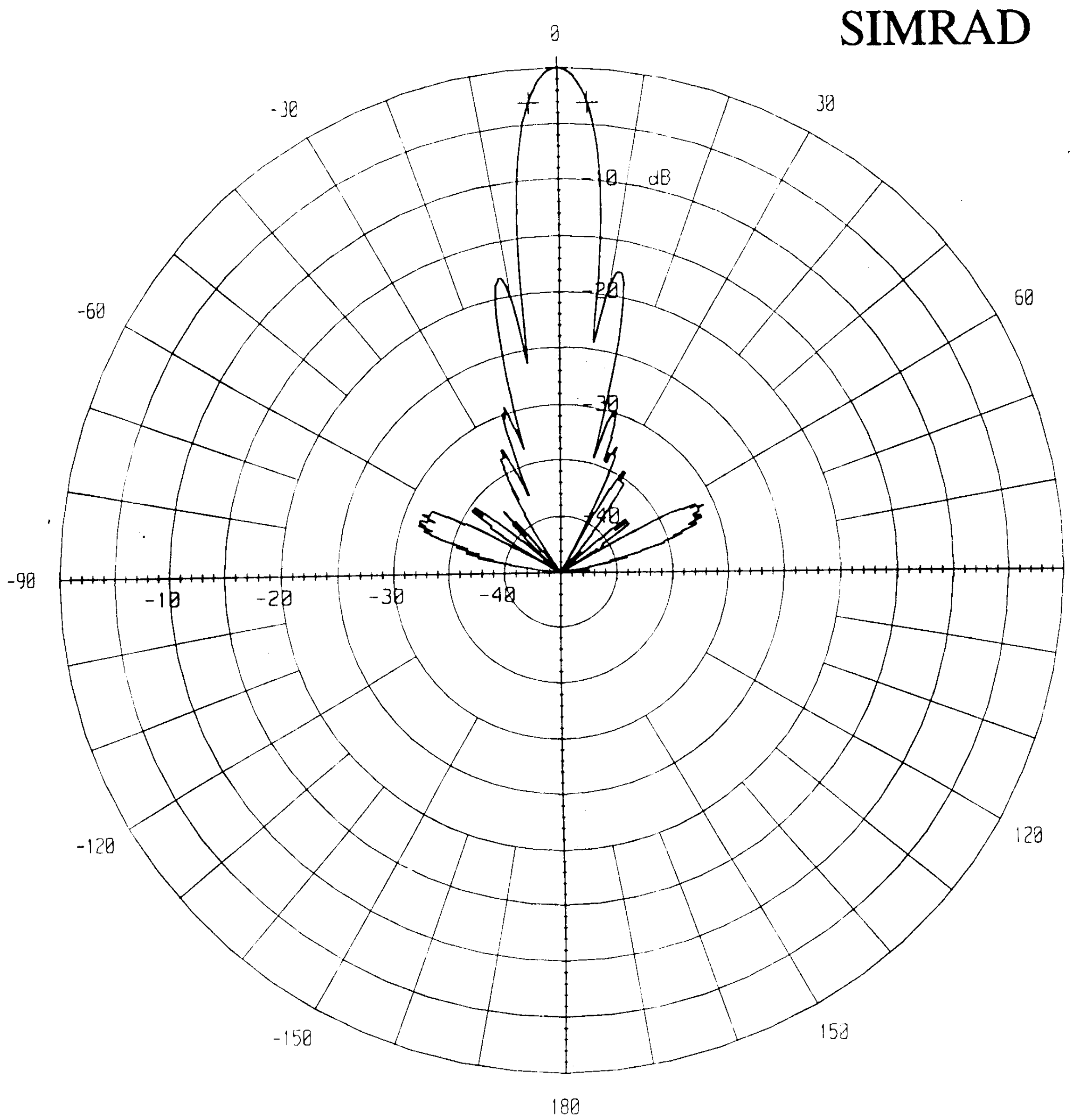
* Valid for split-beam transducers only HORTEN 97.10.08. C:\EK500\EK500GEN.doc

TRANSDUCER MEASUREMENTS

	Part: 1	Part: 2	Part: 3	Part: 4	All par
Measured at : f (kHz)	120.0	120.0	120.0	120.0	120.0
Beamwidth Longitudinal: ß1 (deg)					7.1
Transversal: ß2 (deg)					7.1
Directivity index (dB) 10 log(2.5/(sin(ß1/2)*sin(ß2/2))					28.1
Equivalent two way beam angle (dB): 10 log((ß1*ß2)/5800)					-20.6
Impedance |Z| (ohm) :	74	70	66	77	20
Phase (deg) :	-9	-10	-14	-7	-8
Transmitting response Si (dB re 1 uPa/A):	210.3	210.0	209.7	210.3	210.1
Su (dB re 1 uPa/V): (at 1 metre)	172.9	173.1	173.3	172.5	183.9
Receiving sensitivity Theoretical open circuit (Si-354.1-20 log f) : (dB re V/uPA)	-185.4	-185.7	-186.0	-185.4	-185.6
Electro acoustic efficiency (%): (10 log n= Sw-170.8- DI)					64
Leakage resistance : (Mohm)	OK	OK	OK	OK	OK

Page 1 of 1	Type: ES120_7	SIMRAD
	Serial no: 25741	
	Watertemp.: 187 deg. C	
	Tested by : AB Date: 8 Nov1993	

(slutt01.H4 93.08.09mw)



Beam Pattern

Transducer type	: ES120_7	Beamwidth	: 7.2 deg.
Serial no.	: 25741	Beam	: All parts
Measured at	: 120 kHz	Distance to hydrophone	: 3 m
Plane	: Longitudinal	Water temp.	: 187 ° C
Tested by	: AB	retn01.H4 93.08.09mw	
Date	: 8 Nov1993		

Appendix 3.

Project GCP/RAF/271/FIN – Attachment A to Authors Contract

Terms of Reference for Preparation of a

Report on Hydroacoustics Estimation of Fishmass in Lake Tanganyika

Based on hydroacoustics data and other biological/physical data collected during five pelagic fish resources appraisal surveys carried out on Lake Tanganyika (in June 1995; November-December 1995; April 1996; November-December 1997 and February 1998) the report shall address the following aspects:

presentation of an Executive Summary;
description of material and methodology used;
a thorough review of the existing literature bearing on the results obtained in earlier H/A cruises;
presentation of hydroacoustics data and other related data in order to interpret species fish size distribution and 3-D distribution (all using EchoBase software);
presentation of fish density by expressing data in physical units (biomass in tons/km2, by seasons, depth layers, by area, by country, etc);
formulation of practical proposals/suggestions for the Fisheries Management Plan of Lake Tanganyika.

Language: English

Length: 75 to 100 pages

Format: One hard copy, together with copy on diskette in Microsoft Word 6.0/95 (A4 size paper, all margins 2.54 cm, Courier 10 cpi font)

Timing: to be submitted not latter than 30 May 1998