Antarctic Krill (*Euphausia superba*) as an acoustic target

by

Inigo Everson

Natural Environment Research Council,

BRITISH ANTARCTIC SURVEY

Madingley Road, Cambridge CB3 OET.

The steady increase in total world fish catches in recent years has put increased pressure on established fisheries with the result that many nations are now investigating resources in other areas. The Southern Ocean is such an area. In the past whales and seals in the Southern Ocean formed the basis for major fisheries whereas nowadays the emphasis has completely changed and the fishing fleets are now searching for krill and fish.

Antarctic krill occupies a key position in the Southern Ocean ecosystem since it forms the dominant dietary component of baleen whales, many seals, birds and probably also squid and fish. Information on krill abundance is therefore of importance both for krill stock assessment as well as in understanding ecosystem dynamics. The SCAR/SCOR/ IABO/ACMRR Group of Specialists on Living Resources of the Southern Ocean has selected this as one of the topics for intensive study during its Biological Investigation of Marine Antarctic Systems and Stocks (BIOMASS) (SCAR/SCOR 1977).

This paper reviews available information on krill biology which would be of use in determining its target strength and also in designing an acoustic survey.

TARGET STRENGTH

There is very little quantitative data on target strengths of marine organisms other than fish and since krill has entered the fishery scene relatively recently it has received little attention. It has been known for some time that krill can be detected by echosounders; this paper provides information which should be of use in improving echosounder design characteristics and plans for acoustic surveys. The important features relating to krill may be subdivided into those characteristics of individual krill (chemical and physical characteristics) and those relating to their distribution and aggregation (behavioural characteristics).

Chemical and physical characteristics

The Antarcitc krill (*Euphausia superba*) is a euphausiid crustacean which grows to a maximum size of about 6 cm. There is disagreement concerning its lifespan although it is clear that it must be at least two years. The result of this is that krill of size ranging from 2 cm to 6 cm may be found over most of the geographical range throughout most of the summer season. Sexual maturity occurs when the krill are 45-50 mm long.

Two further characteristics that are important for target strength determination are the compressibility and density of the acoustic scatterers. There is no published information on compressibility of *E. superba* although Enright (1963) found that another euphausiid (preserved *E. pacifica*) was approximately 15% less compressible than seawater.

The density of marine organisms is governed by a variety of factors the most important of which are the extent of skeletal structures, oil globules and gas bladders. Being a euphausiid krill does not possess a gas bladder although it does have a chitinous exoskeleton and also has significant lipid stores. The exoskeleton makes up some 10% of the dry weight (Mauchline and Fisher 1969) and this has a high chitin content (up to 40% of the dry weight (Yanase 1976, Clarke 1976)). The net content of chitin in whole krill is about 4% (Grantham 1977) (average based on four separate sources but excluding one value of 12.3%). These figures for chitin content are within the general range of pelagic crustacea. Selected values are summarised in Table 1.

The moulting cycle, during which a significant proportion of chitin is lost and replaced, is likely to have a significant effect on krill in the same way that it does for other crustacea (Penrose this symposium). During the summer the moult cycle has a periodicity of approximately two weeks (Mackintosh 1967, Clarke 1976).

As might be expected the lipid content of _E. superba_ varies considerably during the season and there are also sexual differences particularly around the breeding season (Table 11).

The great difference in lipid content between ripe male and female krill could introduce a significant error factor if this characteristic is a major cause of the density difference from seawater. Furthermore Clarke (pers. comm.)

estimates that 60% of the lipid in gravid females is present as globules in the ovary it is to be expected that this would be considerably reduced at spawning time.

There is no published information on direct estimation of density and it is therefore not possible to determine target strength of E. superba empirically from physical and chemical data. Some research has been done on Euphausia pacifica from which acoustic area (A) estimates have been made and these can be used to give an indication of target strength (T) by applying the formula

$$T = 10 \log_{10} \frac{A}{4\pi}$$

In addition Cram (1978) has calculated an approximate target strength for E. superba from information from net hauls made during an acoustic survey along with other biological information. These results are summarised in Table III.

Behavioural characteristics

There are two behavioural features about which some knowledge and understanding is necessary in planning and analysing results from acoustic surveys of krill. These are the bathymetric distribution and swarming behaviour.

In general krill are restricted to the top 100 m of the Antarctic surface water during the summer months. Although it is frequently stated that they are in the surface water during the winter also there are insufficient data to confirm this. In areas where there is no marked temperature discontinuity krill have been found down to depths of four hundred metres (Shevtso and Makarov 1969, Fischer 1976).

Within this narrow band of distribution there is strong evidence to indicate a diurnal vertical migration pattern (Fig. 1). However this migration pattern is probably linked to factors other than just time of day (and by implication, light) since surface concentrations have been reported for a wide variety of light conditions (Shevtsov and Makarov 1969 and Fischer and Mohr 1978). (Shust (1969) suggests that there is a diurnal migration pattern whereby swarms tend to be near the surface in the morning; however, his observations were based on visual estimation of swarms, a method dependent on good illumination).

There is strong evidence to suggest that the migration pattern is dependent to a great extent on the feeding cycle. Makarov and Shevtsov (1969), Shust (1969) and Pavlov (1969) all suggest that krill tend to feed near the surface and when they are replete they sink down whilst the food in the gut is digested. This same cycle is considered by Pavlov (1969) to have a controlling influence on swarm formation. He suggests that whilst they are feeding the krill are dispersed. When they are replete they aggregate into swarms and slowly sink whilst digestion takes place. After this they return to the surface and disperse to feed again.

On this theory, providing the food concentration is less than the individual krill can filter to maintain maximum ingestion rate then the time spent dispersed and feeding will be dependent on food concentration. The result of this will be that in areas of low phytoplankton concentration the krill will spend a large proportion of their time actively feeding and therefore not in swarms. Also assuming that for krill of a given size digestion rate is more or less constant then the frequency of swarm formation will be dependent on food concentration up to the non-limiting food level, and from this it may be inferred that it would be independent of time of day.

Pavlov (1969), from observations on the time taken for food to pass along the gut suggests that the time for complete digestion of the food increases with the size of the animal. In his paper, however, he gives insufficient information on the size of krill used in his studies. His observations would however suggest that swarms composed of larger krill will be maintained for longer and also, since larger krill will almost certainly take longer to feed to repletion than small krill (for a given food concentration), then the frequency of swarm formation by the former is likely to be lower. On the assumption that swarms composed of larger krill remain for longer than those composed of smaller krill then during the digestion phase of the cycle the former would be expected to sink further. Thus in localities where krill of two distinct size classes occur there is likely to be some degree of stratification. Such a phenomenon has been reported by Shevtsov and Makarov (1969) Fig. 2.

In this discussion food has been the only primary factor considered as an influence on swarming. This is clearly not the whole story since other factors such as light and reproduction almost certainly play an important but as yet unquantified part.

There are two further features concerned with krill swarms that are important for abundance estimation. These are the overall dimensions of the swarms and the density (numbers per cubic metre) of krill within them. There are several published descriptions of the shape of krill swarms (e.g. Marr 1962, Shust 1969) and all comment on their continuously changing amorphous shape. The actual dimensions of the swarms vary greatly; in the horizontal plane they have been reported as less than one metre across to up to one kilometer, the latter described as super-swarms (Cram 1978). Swarms have been classified into three broad types. These are:

(a) Layers (Cram 1978) or Clouds (Shevtsov and Makarov 1969) in which the density is low; such aggregations may extend for several kilometres.

(b) Compact swarms. These contain the highest densities of krill and are generally a few metres to some tens of metres across.

(c) Super-swarms (Cram 1978). These are continuous vertically thick (about 10 m) swarms with a horizontal dimension of up to one kilometer.

Several workers have attempted to estimate the density of krill in swarms and these are summarised in Table IV.

The high density of krill in swarms which at the highest levels indicate that each individual will be no more than one animal length in all directions from its neighbours indicates that the high degree of organisation within the swarms described by Hardy and Gunther (1935

p. 210) and Ragulin (1969) must be the general rule. It may thus be inferred that for the most part the attitude of krill in the swarm relative to the surface (and thus an acoustic source) would be more or less constant.

Returning to the problem of target strength of krill, although individually krill are relatively poor targets, when aggregated in the dense swarms described above they do form good acoustic targets and can be easily detected by echosounders (Fig. 3). Cram (1978) has made some preliminary estimates that the volume back-scattering strength at 120 kHz of swarms ranged from a maximum of -20 dB to a minimum of about -40 dB. These results suggest that estimation of krill abundance in swarms presents no great technical difficulties.

Discussion

Experience has shown that the densest swarms of krill represent very good acoustic targets which can be detected with relative ease by fishing vessels. However at the highest density levels there is considerable instrument saturation which may prove to be an important source of error in abundance estimation. At the other extreme since individual krill are relatively small and are not particularly strong back-scatterers when they are present in swarms they are relatively poor targets. This is of no great consequence to fishermen who would not be interested in such low concentrations; however it could be of enormous importance in abundance estimation if significant amounts of krill are not present in swarms.

No information is available to indicate what proportion of the krill population is present in swarms but it is very likely that it does vary according to the prevailing conditions. Swarming is considered to have some relationship to food availability (discussed in an earlier section). For a situation of constant food concentration (F) a simplistic association can be postulated.

Let:

F = Food concentration (assumed constant)

K = Initial krill stock

α = Proportion of initial krill stock present in swarms

Then αK = Initial krill stock present in swarms

$(1 - \alpha) K$ = " " " dispersed

Fishing and predation on swarms causes a change which may be represented as:

$$\alpha K \rightarrow \alpha K_1$$

With the result that:

$$\alpha K_1 + (1 - \alpha)K \quad < K$$

Relative to food concentrations:

$$\frac{\alpha K_1 + (1 - \alpha)K}{F} \quad > \frac{K}{F}$$

This would increase the tendency to swarm and thus α would therefore tend to increase to a new value β.

This would result eventually in:

$$\frac{\alpha\ K}{F} = \frac{\beta K_1}{F}$$

Since F is constant:

$$\alpha K = \beta K_1$$

Since $K > K_1$

Then $(1 - \alpha)K > (1 - \beta)K_1$

In other words the effect of fishing and natural predation on krill swarms could arguably have its greatest effect on the krill that are dispersed.

Although this model is a gross simplification it does indicate that abundance estimations of krill should take account of the very wide range of concentrations that naturally occur and that low concentrations over large areas may be as important as the dense swarms when it comes to monitoring abundance changes.

Acknowledgements

I am very grateful to Dr. David Cram for his help in the early preparation of this paper and to Dr. Andrew Clarke for allowing me to use some of his unpublished biochemical results. I would also like to thank Prof. Dr. D. Sahrhage of the Federal Research Centre for fisheries, Hamburg for permission to publish the echogram photographs and also for providing information relating to them.

References

Beamish P. 1971
Quantitative measurements of acoustic scattering from zooplankton organisms
Deep-sea Research 18 811 - 822

Clarke A. 1976
Some observations on krill (*Euphausia superba* Dana) maintained alive in the laboratory
British Antarctic Survey Bulletin No 43 111 - 118

Cram D.L. 1978
Preliminary results of the 1978 Krill acoustics and remote sensing study and their relevance to FIBEX
Draft paper submitted to the SCAR/SCOR Group of Specialists on Living Resources of the Southern Ocean. May 1978 17pp

Enright J.T. 1963
Estimates of the compressibility of some marine crustaceans
Limnology and Oceanography 8 (4) 382 - 387

Fischer W. 1976
Tagesperiodische Wanderungen des Antarktischen Krill
Informationen fur die Fischwirtschaft 23 (3) 90 - 92

Fischer W. and H. Mohr. 1978
Verhaltensbeobachungen an Krill (*Euphausia superba* Dana)
Archiv fur Fischereiwissenschaft 29 (1) 71 - 79

Grantham G.J. 1977
The utilization of krill

FAO Report GLO/SO/77/3 Southern Ocean Fisheries Survey
Programme, Rome

Greenlaw C.F. 1977
Backscattering spectra of preserved zooplankton
Journal of the Acoustical Society of America 62 44 - 52

Hardy A.C. and E.R. Gunther 1935
The plankton of the South Georgia whaling grounds and
adjacent waters 1926 - 27
Discovery Reports 11 1 - 456

McCartney B.S. 1976
Comparison of the acoustic and biological sampling of the
sonic scattering layers: R.R.S. Discovery SOND cruise 1965
Journal of the Marine Biological Association (UK) 56 (1)
161 - 178

Mackintosh N.A. 1967
Maintenance of living *Euphausia superba* and frequency of
moults
Norsk Hvalfangst-Tidende 1967 56 (5) 97 - 102

Makarov R.R. and V.V. Shevtsov 1971
Some aspects of the distribution and biology of Antarctic Krill
In: Osnovy biologicheskoy produktivnosti okeani i yeyo
izpol'zivaniye (Basis of the biological productivity of the
ocean and exploitation of it). Moscow, Nauka 1971 81 - 88

Makarov R.R., A.G. Naumov and V.V. Shevtsov 1970
The biology and the distribution of the Antarctic Krill
In: Antarctic Ecology 1 173 - 176

Marr J.W.S. 1962
The natural history and geography of the Antarctic Krill
(Euphausia superba Dana) Discovery Reports 32 33 - 464

Mauchline J.R. and L.R. Fisher 1969
The biology of Euphausiids
Advances in Marine Biology 7 454p

Moiseev P.A. 1970
Some aspects of the commercial use of the krill resources of the Antarctic seas.
In: Antarctic Ecology 1 213 - 216,
Ed: M.W. Holdgate, Academic Press, London and New York

Nemoto T. and K. Nasu 1975
Present status of exploitation and biology of krill in the
Antarctic Oceanology International 1975
Conference papers, Brighton England 353 - 360
Publ BPS Exhibitions Ltd London

Pavlov V. Ya 1969
The feeding of krill and some features of its behaviour
Trudy VNIRO 66 207 - 222
Translated into English; MAFF Translation No NS 94

Pieper R.E. 1971
A study of the relationship between zooplankton and high

frequency scattering underwater sound
PhD Thesis, University of British Columbia

Ragulin A.G. 1969
Underwater observations of krill
Trudy VNIRO 66 231 - 234
Translated into English; MAFF Translation NS 92, 3p

Raymont J.E.G., Srinivasagam R.T. and J.K.B. Raymont 1969a
Biochemical studies on marine zooplankton VII Observations on certain deep sea zooplankton
In: Rev. Hydrobiol 54 (3) 357 - 365

Raymont J.E.G., Srinivasagam R.T. and J.D.B. Raymont 1969b
Biochemical studies on marine zooplankton IV Investigations on *Meganyctiphanes norvegica*
Deep-Sea Research 16 (2) 141 - 156

Raymont J.E.G., Srinivasagam R.T. and J.E.G. Raymont 1971
Biochemical studies on marine zooplankton IX The biochemical composition of *Euphausia superba*
Journal of the Marine Biological Association (UK) 51 (3) 581 - 588

SCAR/SCOR 1977
Biological Investigations of Marine Antarctic Systems and Stocks
BIOMASS 1 Research Proposals 79p

Shevtsov V.V. and R.R. Makarov 1969
On the biology of Antarctic Krill
Trudy VNIRO 66 177 - 206
Translated into English; MAFF Translation No NS 91

Shust K.V. 1969
Visual observations of krill from R/VAkademik Knipovich
Trudy VNIRO 66 223 - 230
Translated into English; National Lending Library Translation
No RTS 5588

Yanase M. 1976
Chemical composition of the exoskeleton of Antarctic Krill
Bull. Tokai Reg. Fish. Res. Lab. (83) 1 - 6
(In Japanese with English summary)

Species	Chitin Content % Dry weight	Reference
Various Deep Sea Crustacea (Decapoda, Mysidacea, Euphausiacea)	2.4 - 6.4	Raymont *et al.* 1969(a)
Meganyctiphanes norvegica	2.8 - 4.4	Raymont *et al.* 1969(b)
E. superba	2.3 - 6.1	Grantham 1977

TABLE I. Chitin content of various planktonic crustacea.

	Lipid % Wet Weight Mean ± Standard Error
Immature	4.09 ± 0.46
Mature Male	2.41 ± 0.40 (exceptionally 4 - 5%)
Gravid Female	6.01 ± 0.46 (exceptionally up to 9%)
Spent Female	2.79 ± 0.3

TABLE II. Lipid Content of <u>E. superba</u> (Unpublished results of A. Clarke, British Antarctic Survey)

Species	Length (cm)	Acoustic Area (m^2)	Target Strength (dB)	Frequency (kHz)	Reference
E. pacifica	2	1.4×10^{-8}	(-90)	102	Beamish 1971
E. pacifica	2.3	---	-65 to -90	60 - 1000	Greenlaw 1977
(Dorsal aspect					
(Anterior aspect)			-100 to -75	200 - 1000	Greenlaw 1977
Euphausiid	1-2	5.5×10^{-10} to	(-95)	107	Pieper 1971 cited by McCartney 1976
E. superba	(1-5)		-70	120	Cram 1978

TABLE III. Target strength information for individual Euphausiids. Figures in parenthesis have been estimated from data in the cited papers.

Numerical	Density by weight	Notes	Reference
1 per in^3 1 per 8 in^3		Visual estimate	Marr 1962
50,000 per m^3		Visual (diving)	Ragulin 1969
	10 - 16 kg/-^{3}	Echosounder	Moiseev 1970
	up to 15 kg/m^3	+ net hauls (?)	Makarov _et_ _al_ 1970
	Generally up to 5 kg/m^3. Max 6 - 33 kg/m^3	"	Nemoto and Nasu 1975
2000 - 8000/m^3 Max 40,000/m^3	mean 1.5 kg/m^3	"	Nemoto _et_ _al_. (in press)
	0.3 - 30 kg/m^3	Layers (Echointegrator and net hauls)	Cram 1978
	1 - 100 kg/m^3	Swarms (Echointegrator and net hauls)	Cram 1978

TABLE IV. Estimates of krill density in swarms

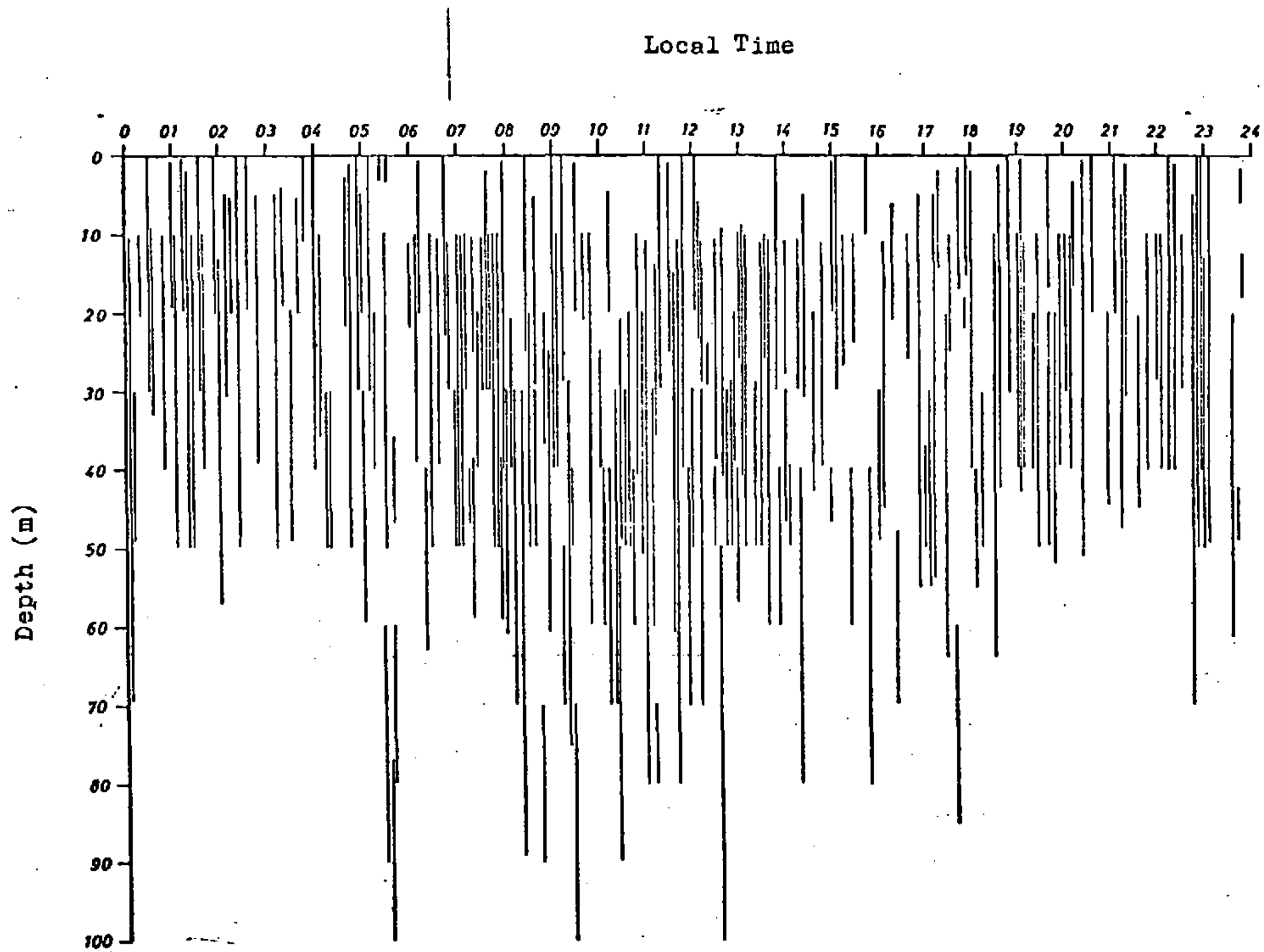


Fig 1 Bathymetric distribution of krill concentrations during the period November 1975 - April 1976. (Fischer and Mohr 1978, Federal Republic of Germany Antarctic Expedition)

Fig (1)

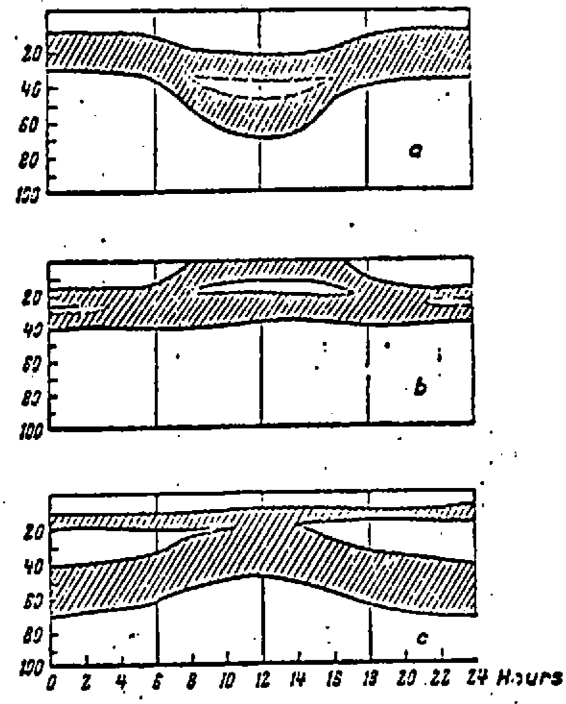


Fig 2 Diurnal vertical migration patterns of krill swarms as depicted by Shevtsov and Makarov (1969) showing formation of layers.

a diurnal movement of the layers with no patches at the surface

b diurnal movement of the layers when patches of krill form at at the surface

c diurnal movement of the layers with temporarily no patches at the surface.

Fig. 3. Echosounder indications of krill from Federal Republic of Germany Antarctic Expedition 1975/76.

(a) + (b) Single discrete swarm which resulted in a catch of 250 baskets of krill as recorded on a 210 kHz sounder with range set at 0-100 m (a) and simultaneously on a 33 kHz instrument with range set at 0-200 m (b) ships speed 3.2 km.

(c) + (d) Series of dense krill swarms near to the surface as recorded by 33 kHz echosounder with range set at 0-200 m (c) and the simultaneous record from a 210 kHz echosounder with range set at 0-100 m sharing a 'cloud' type swarm (d) catch 60 baskets krill, ship's speed 2.7 - 3.0 km.

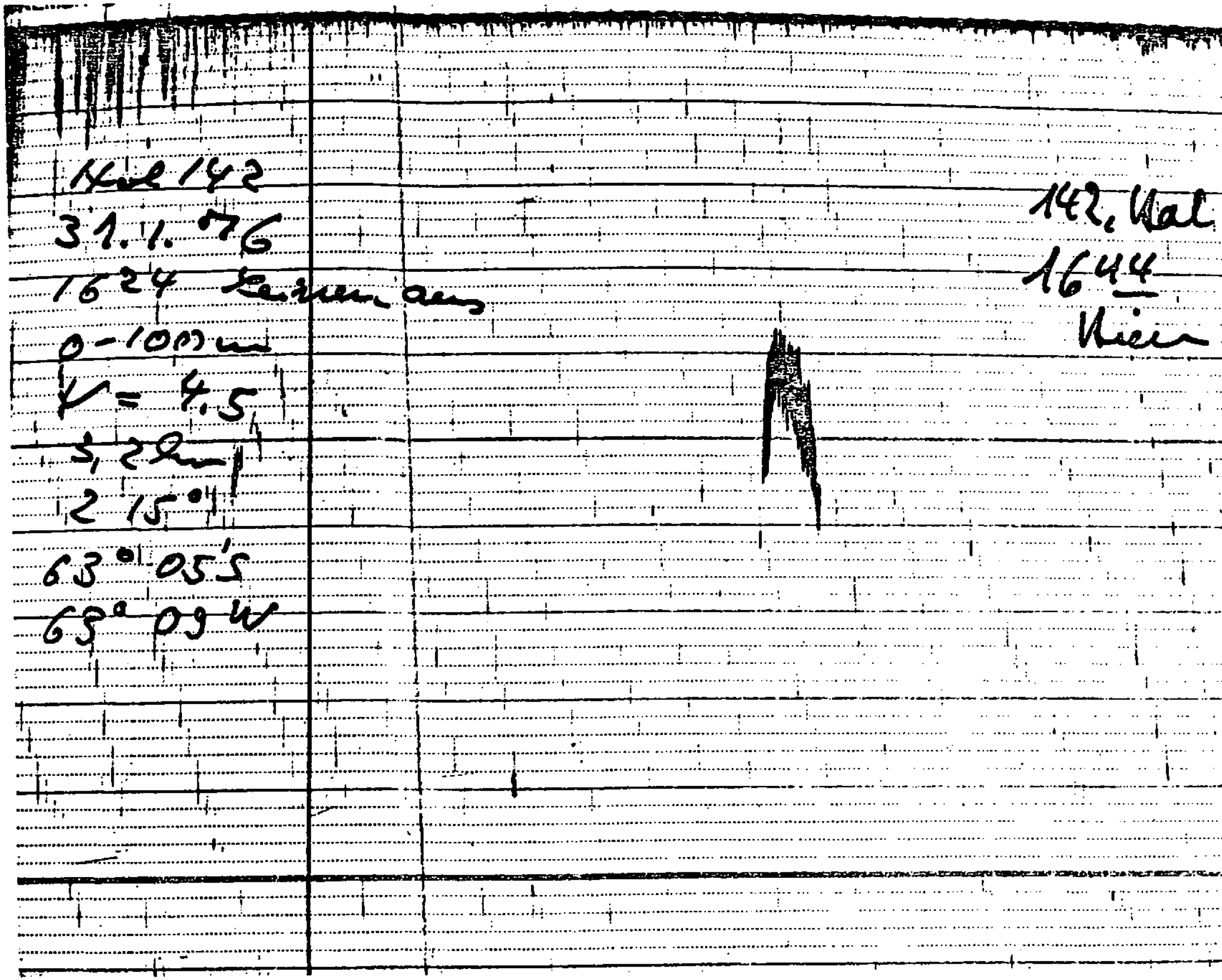
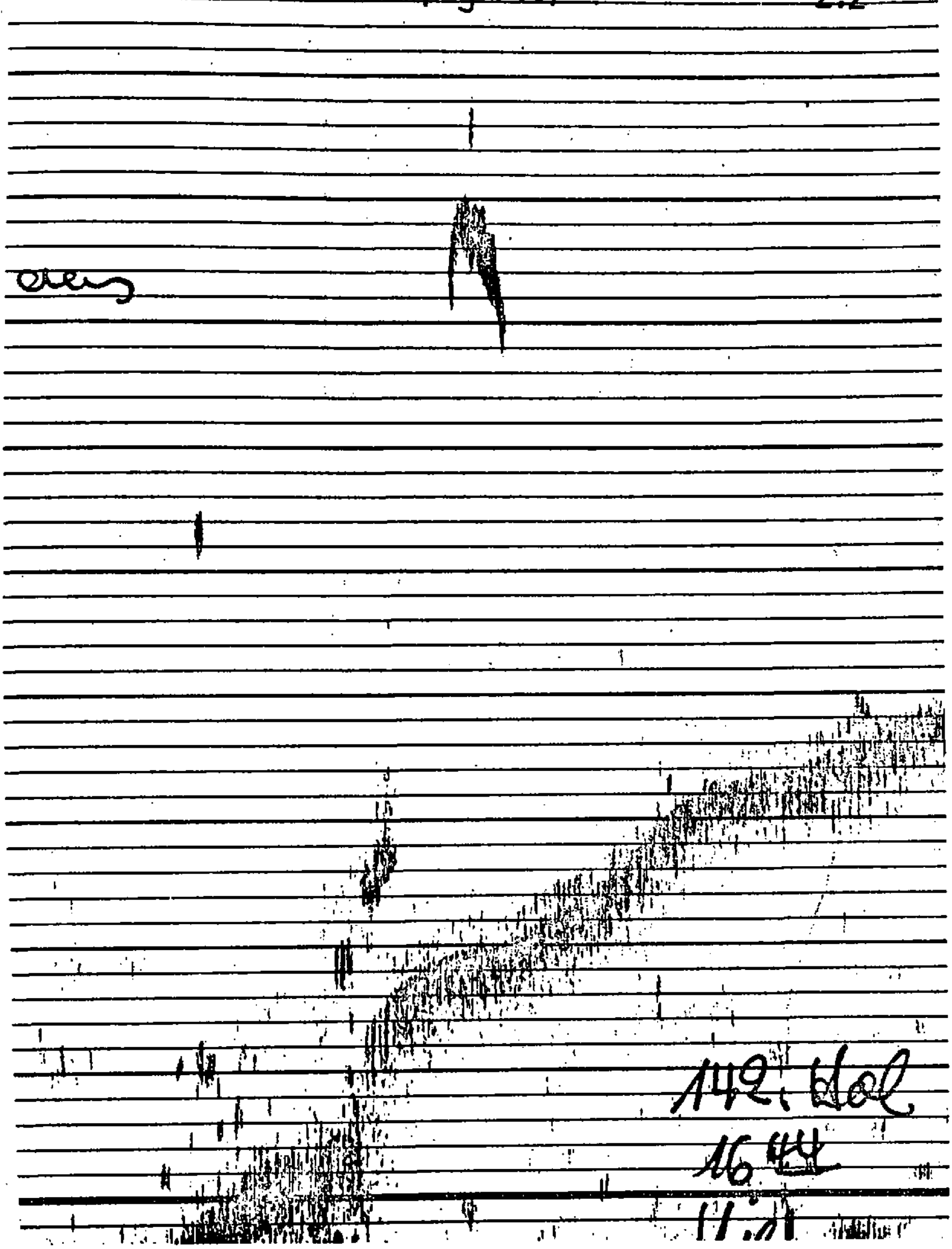

Wal 142
31.1.76
1624
0-100 m
V = 4.5
3,2 km
215°
63° 05' S
65° 09 W
142. Wal
1644

Fig 3(a)

2.2

Fig 3 (b) 2.2



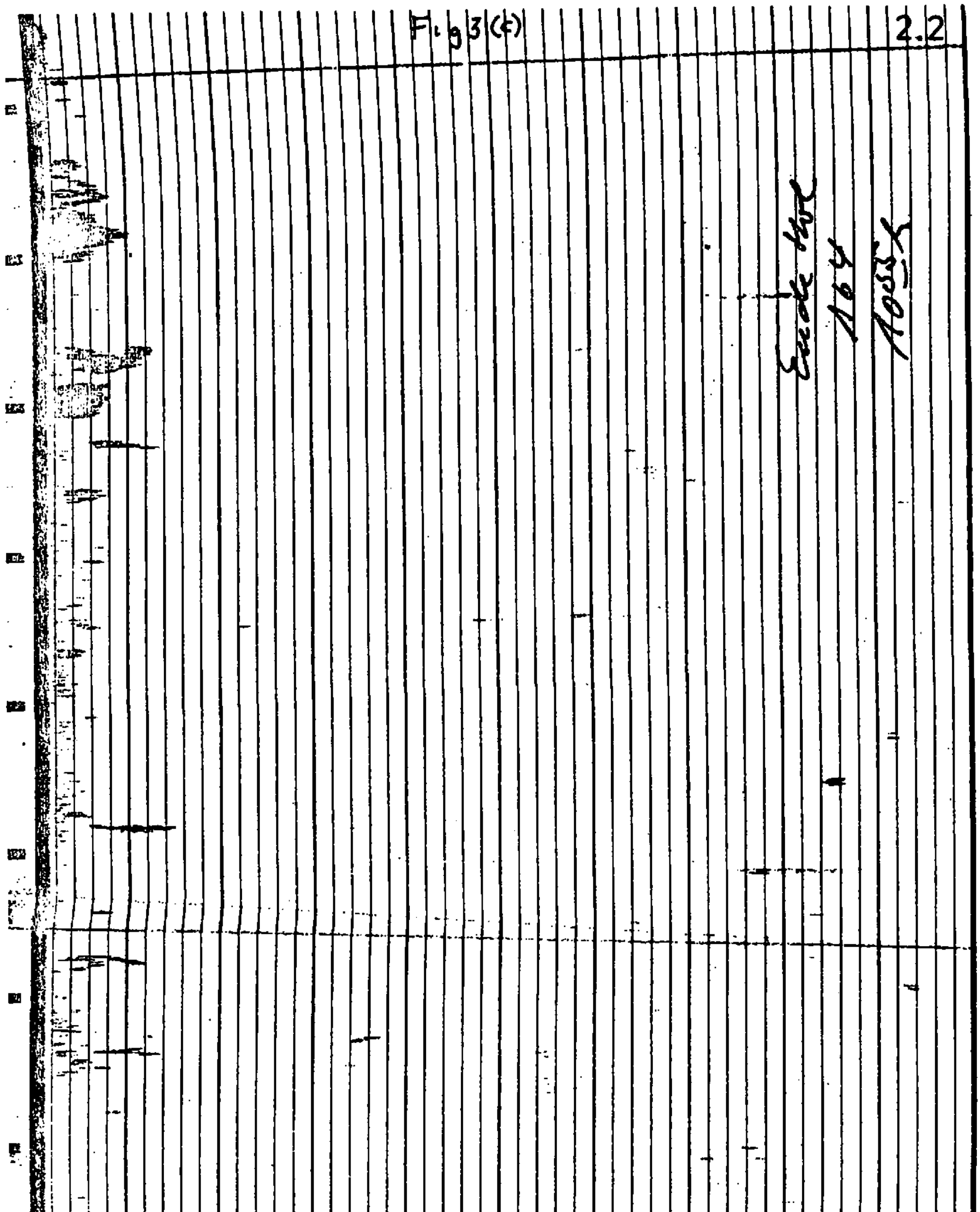


Fig 3(c) 2.2

Fig 3(d)

2.2