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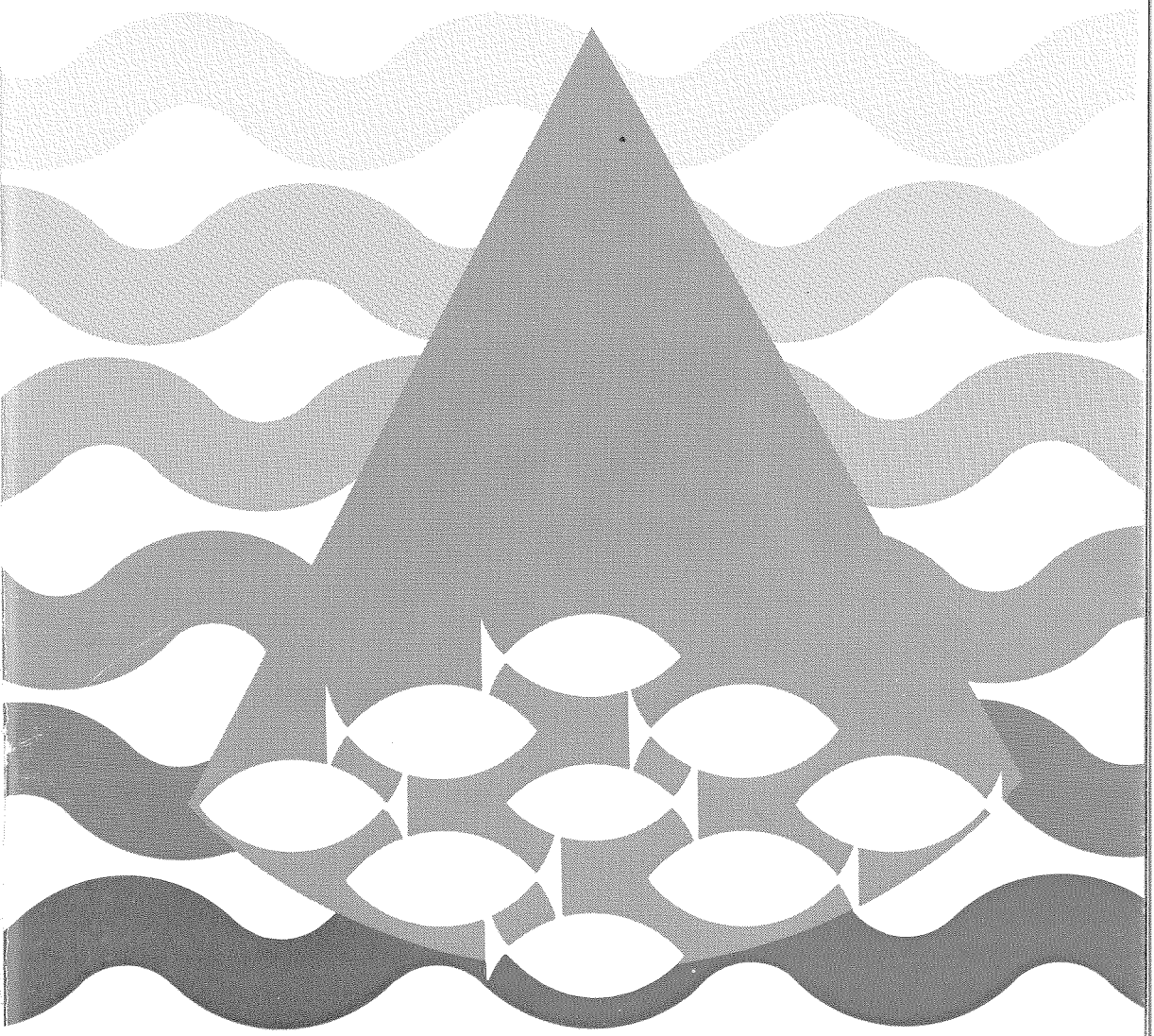

DIRECTORATE OF FISHERIES, BERGEN, NORWAY
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STUDIES ON THE LONG TERM STORAGE OF LIVING SAITHE, *Pollachius virens* Linnaeus, 1758*

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ABSTRACT

Bratland, P., Krishnan, S. and Sundnes, G. 1976. Studies on the long term storage of living saithe, *Pollachius virens* Linnaeus, 1758. *FiskDir. Skr. Ser. HavUnders.*, 16: 279—300.

In order to observe how far muscle nutrition is affected during long term starvation, saithe were stored under natural and laboratory conditions. The results show that changes in the liver and condition indices were similar under both conditions. The analyses of protein, water, lipids, carbohydrates and ash content indicate that in the white muscle there is a loss of protein during starvation. The protein loss is replaced by water. Such a correlation was not found in red mucsle. There was no definite trend in carbohydrate and ash content of muscles with advance of starvation. The overall picture of the various chemical analyses shows that the organic material from white muscle is mobilised when the saithe are starved, whereas there is little change in the red muscle.

INTRODUCTION

Ever since the beginning of this century live saithe have been transported and stored and live animals have been sold on the domestic market. In recent years the annual catch of saithe has increased considerably and the fillet industry has grown to be one of the largest purchaser of live saithe.

The catch quantity of saithe fluctuates seasonally and these fluctuations affect the fillet industry's production. During the summer season the offer (supply) of saithe to the fillet industry is greater than the processing capacity. Therefore, in order to obtain an optimum use of the resource a buffer between the catching and the processing sectors is required. In practice, buffering is effected by storing the surplus quantity of saithe and

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using this surplus to supply the fillet industry during those periods when the catch level is lower than the industry's receiving capacity. It is of great importance, therefore, to store saithe efficiently during these times of large surplus catches either as frozen fish or as living fish held in seines.

One of the chief aims in developing an efficient storage technique is to keep the cost to a minimum. In this respect storage of living saithe has appreciable advantage over freezing, especially when the animals are stored without feeding. Such conditions do not impose unnatural stress as fish in the wild experience starvation in the course of natural cycles of food availability. In our latitudes fish usually have a good supply of food during the summer months while during the winter months they live chiefly on stored nutrition in the body tissues, especially the liver. It is this cycle which is desired to exploit. Under a well planned storage programme it should be possible to hold saithe in seines for periods of up to three months with little detriment to musculature, or in other words, the fillet.

It is normal to find that fish in poor condition have greater water content in the tissue than healthy fish (LOVE 1960, JOHNSTON and GOLDSPINK 1973). This cannot be registered by measurement of the fish's condition based on a length-weight relationship alone. For examphe, salmon migrating up-stream have the same conditon factor during the entire journey, however, protein is successively replaced by water as the fish swim up-river (GREENE 1919, PARKER and VANSTONE 1966).

It was of interest to know whether a similar change in quality would occur in saithe during a complete absence of feeding.

The experiments described here were carried out to investigate biochemical changes in musculature of living saithe stored under various conditions.

MATERIALS AND METHODS

The experiments were performed on purse seine caught saithe.

The experimental conditions of storage in fjords and laboratory tanks with circulation of sea water of constant temperature and salinity were chosen to determine the effects of storage. Table 1 gives the details of experimental conditions. Fig. 1 shows the locations of the field experiments.

Ten samples were taken at intervals of ten days from the fjords (except at Lepsøy where samples were taken weekly), and in the laboratory experiments samples were taken each week. Samples from Leines and Sørøy were frozen for transportation. Samples from Lepsøy and from

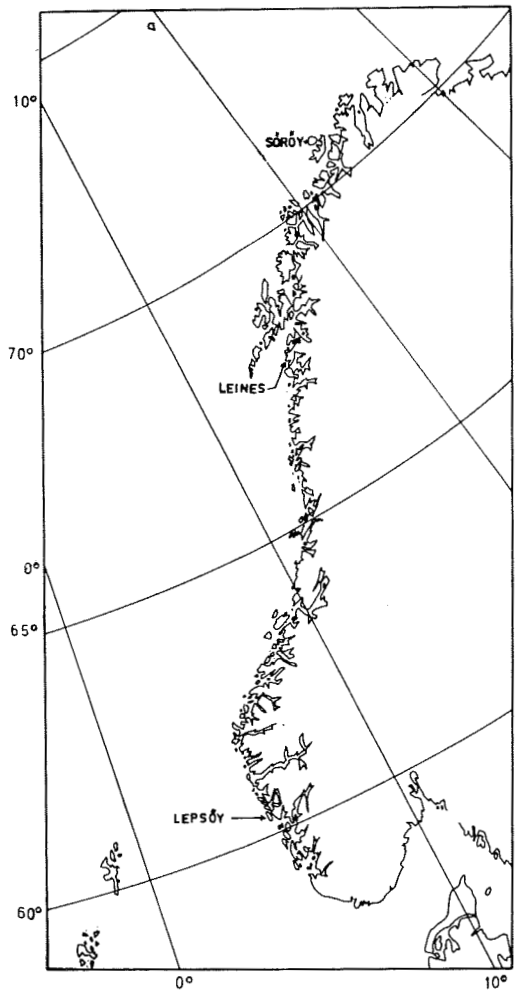

Fig. 1. Localities of saithe storing experiments.

the laboratory experiments were analysed fresh. In order to observe the rate of recovery after starvation the fish were fed for four weeks after twelve weeks of starvation in the lab. '74 set of experiments.

Pieces of muscle for the biochemical analyses were cut from the lateral side just above the ventral fin. Red and white muscles were analysed separately in samples from Sørøy fjord and from the lab. '74 experiment.

The water content was measured by weighing the samples before and after drying at 75°C in a hot air oven. Biochemical analyses were carried out on dry tissue samples.

Table 1. Storage conditions during the starvation experiments on saithe.

Locality and time of year	Storage time	Temperature range and mean temperature (°C)	Salinity (‰)	Quantity stored (Q) (Kg)	Seine volume (S) (m^3)	Density factor (Q/S)	Weight range and mean weight (g)
Lepsøy (Bergen)	25 Nov 1972—	7.2—4.7	31.00	500	100	5.00	300— 600
Winter	28 Feb 1973	6					410
Leines (Bodø)	15 Aug 1973—	9.0—4.0	32.60	80.000	1.700	4.80	350— 700
Fall	11 May 1974	6.7					470
Sørøy (Hammerfest)		6.4—4.0	33.25	170.000	31.820	5.30	4000—2000
Fall		5.1					1550
Lab. exp. (Bergen)		8.5	34.00	75	750*	10.00	300— 400
Spring							340
Lab. exp. (Bergen)		8.5	34.00	350	3.500*	10.00	300—1100
Spring							700

* In case of laboratory experiments the volume of the tank was taken to calculate the density factor (Q/S).

The muscle samples were analysed for total protein, carbohydrate and lipid content. Protein was analysed either by the KJELDHAL or by the modified BIURET method (RAYMONT, AUSTIN and LINFORD 1964). Total sugars were estimated by the phenol-sulphuric acid method (DUBOIS *et al.* 1956). Total lipids were extracted using a mixture of methanolchloroform (RAYMONT *et al.* 1964). Ash was measured by burning the tissues in a muffle furnace at 600°C for ten to twelve hours.

The condition of the fish was measured in terms of liver index (L) where

$L = \frac{\text{wet weight of liver}}{\text{wet weight of body}} \times 100$, and conditon index (C) where

$C = \frac{\text{weight}}{\text{weight}^3} \times 1000$. The liver index was also compared with water, protein and lipid content of muscle. Water content of muscle was compared with the protein and lipid content, and protein was compared with lipids.

RESULTS

The data for the condition index show that there was slight decrease in condition in all fish except for those from Sørøy. These were in the best conditon at the beginning of the experiment as indicated by data for both condition index and liver index (Fig. 2 and 3). Liver index was directly correlated with conditon index except for Sørøy fish (Fig. 4).

In fish stored in the fjord at Sørøy and Lepsøy there was a negligible increase of water in the white muscle compared to the fish stored at Leines where there was heavy increase. Also in the laboratory experiments there was an increase of water in white muscle (Fig. 5). Red muscle on the other hand showed a decreasing water content during the experiment.

In three of the five experiments (i.e. lab. '73, lab. '74 and Leines) there was an inverse correlation between water content of white muscle and liver index (Fig. 6). This is also reflected when compared with condition index (Fig. 7).

Protein content of white muscle in fish stored in the fjords decreased by less than 1.5% during starvation, except for the fish from Leines (Fig. 8), where the decrease was highly pronounced. There was direct correlation between protein content of white muscle and liver index (Fig. 9) and between protein and water content (Fig. 10). The protein content of red muscle decreased during starvation in Sørøy fish, but increased in lab. '74 fish.

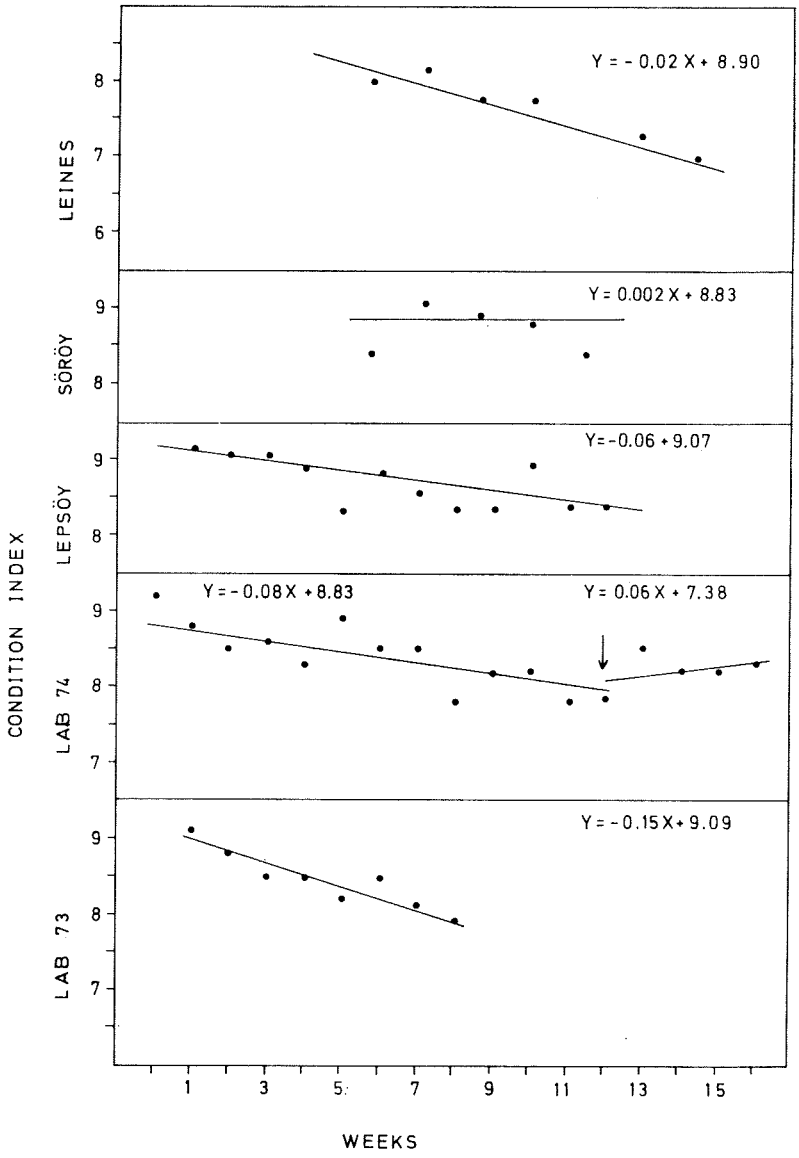

Fig. 2. Saithe condition index (C) during prolonged starvation. Arrow indicates the start of feeding.

Changes in carbohydrate content of white muscle did not show the same trend in all the experiments. There was a decrease in carbohydrate for fish from Leines and from the lab. '73 experiment, an increase in Sørøy fish and no significant change in fish from Lepsøy and in the lab. '74 experiment (Fig. 11).

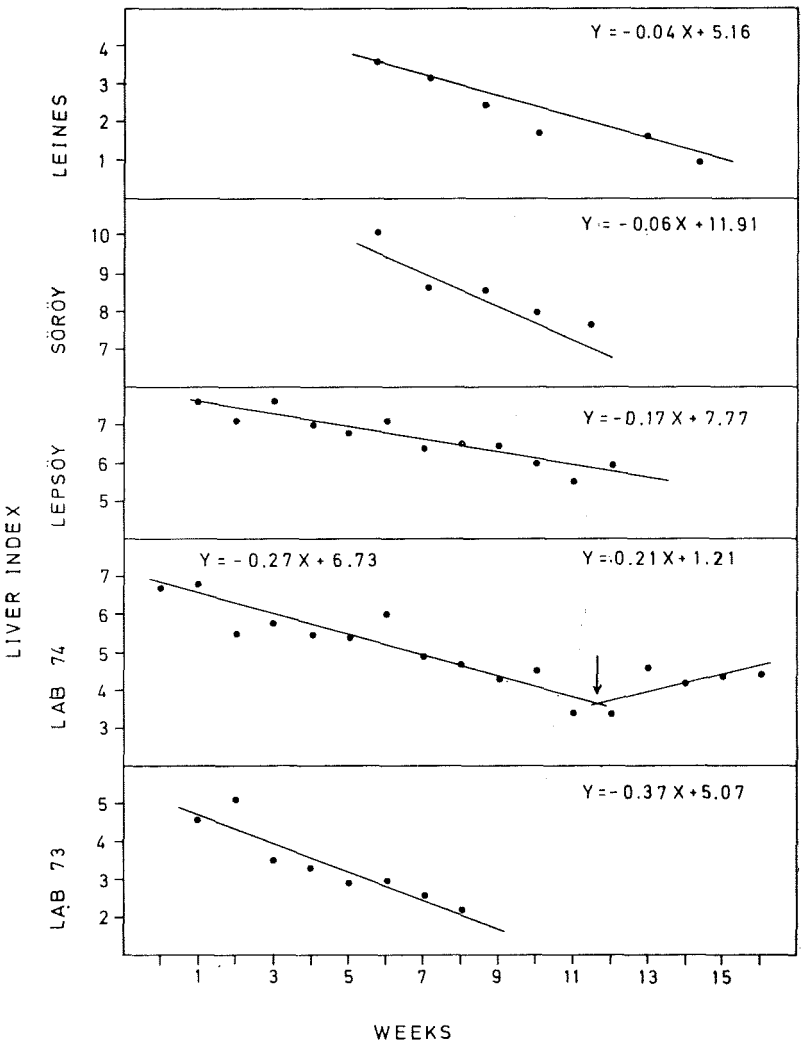

Fig. 3. Changes in liver index (L) during starvation. Arrow indicates the start of feeding.

Lipid content of both white and red muscles increased in all cases, except for white muscle lipid in fish from Sørøy and the lab. '74 experiment (Fig. 12). The precentage increase of lipid in red muscle was greater than for white muscle and was inversely correlated with water content (Fig. 13). An inverse correlation was observed when a comparative graph was made with liver index versus lipid in the case of red muscle and in the case of white muscle from Lepsøy fish (Fig. 14).

The ash content of the fish from Leines, Lepsøy and the lab. '73 experiment decreased during starvation. In the lab. '74 experiment there

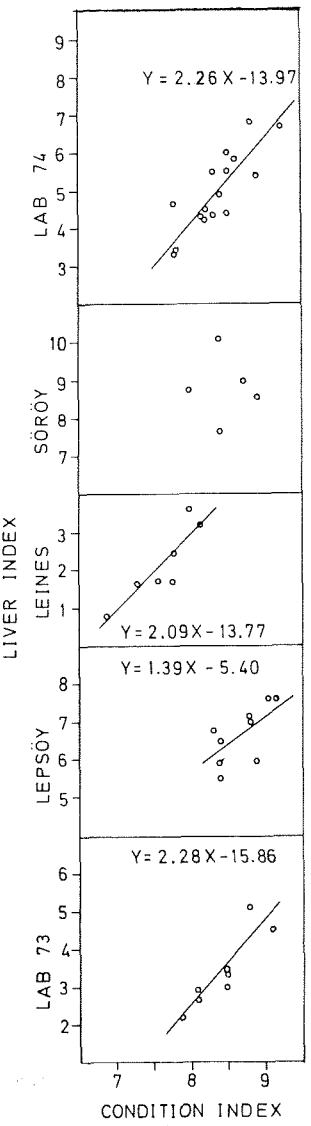

Fig. 4. Relationship between liver index and condition index.

was no significant change in percentage ash content of either red or white muscle during starvation, or when feeding was started after twelve weeks of starvation. In fish from Sørøy ash content of white muscle increased whereas ash content of red muscle decreased (Fig. 15.) Water content was inversely correlated with ash content only in the case of fish from Leines and the lab. '73 experiment (Fig. 16).

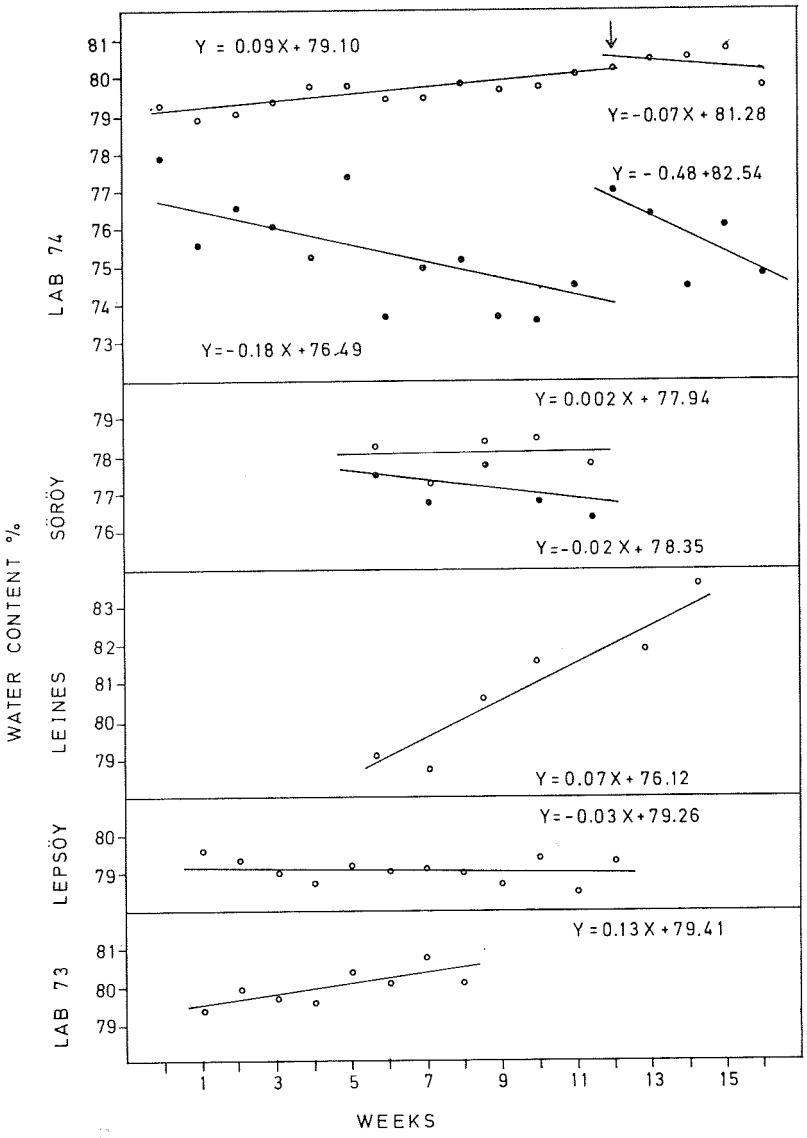

Fig. 5. Changes in water content of white (open circles) and red (solid circles) muscles. Arrow indicates the start of feeding.

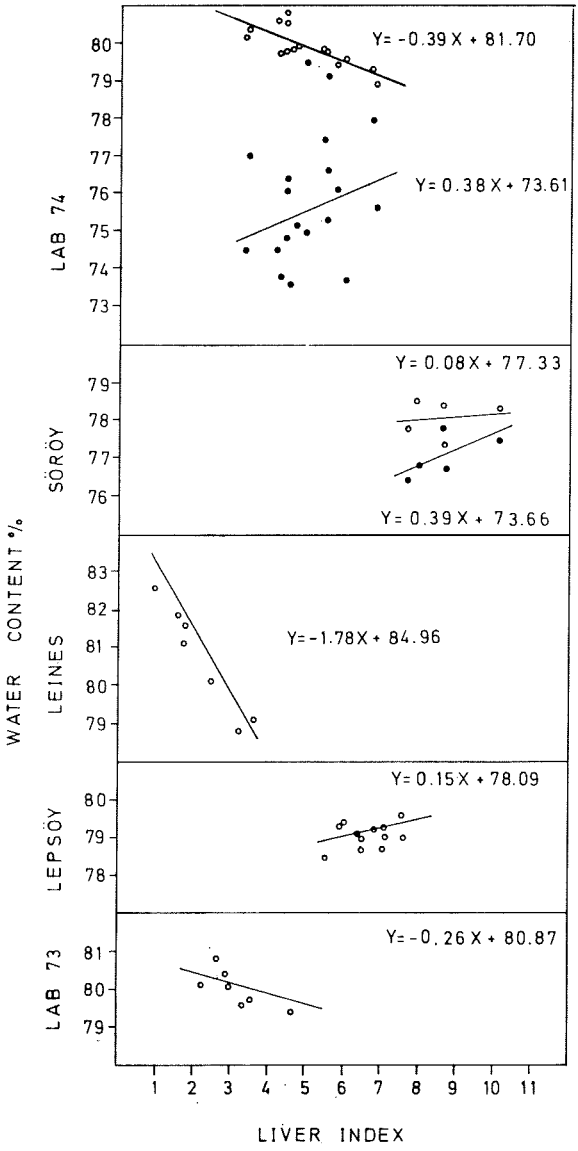

Fig. 6. Relationship between water content and liver index. White muscle: open circles; red muscle: solid circles.

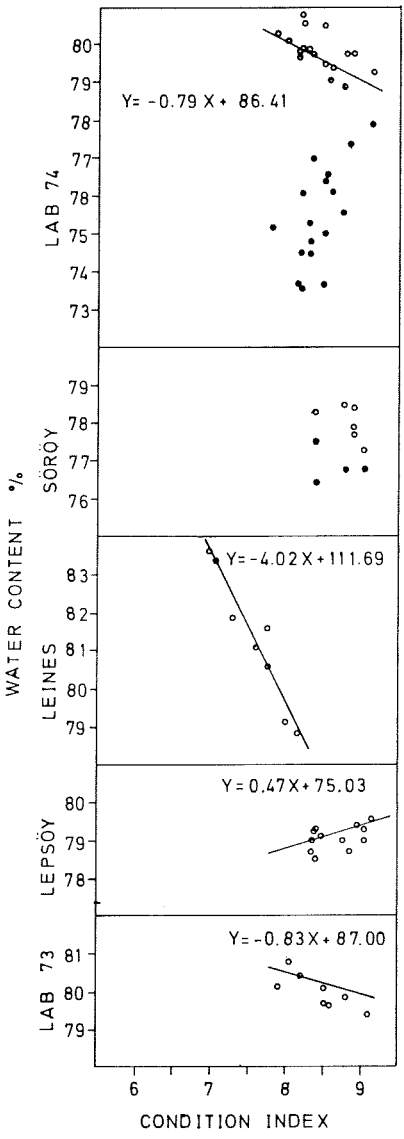

Fig. 7. Relationship between water content and condition index. White muscle: open circles; red muscle: solid circles.

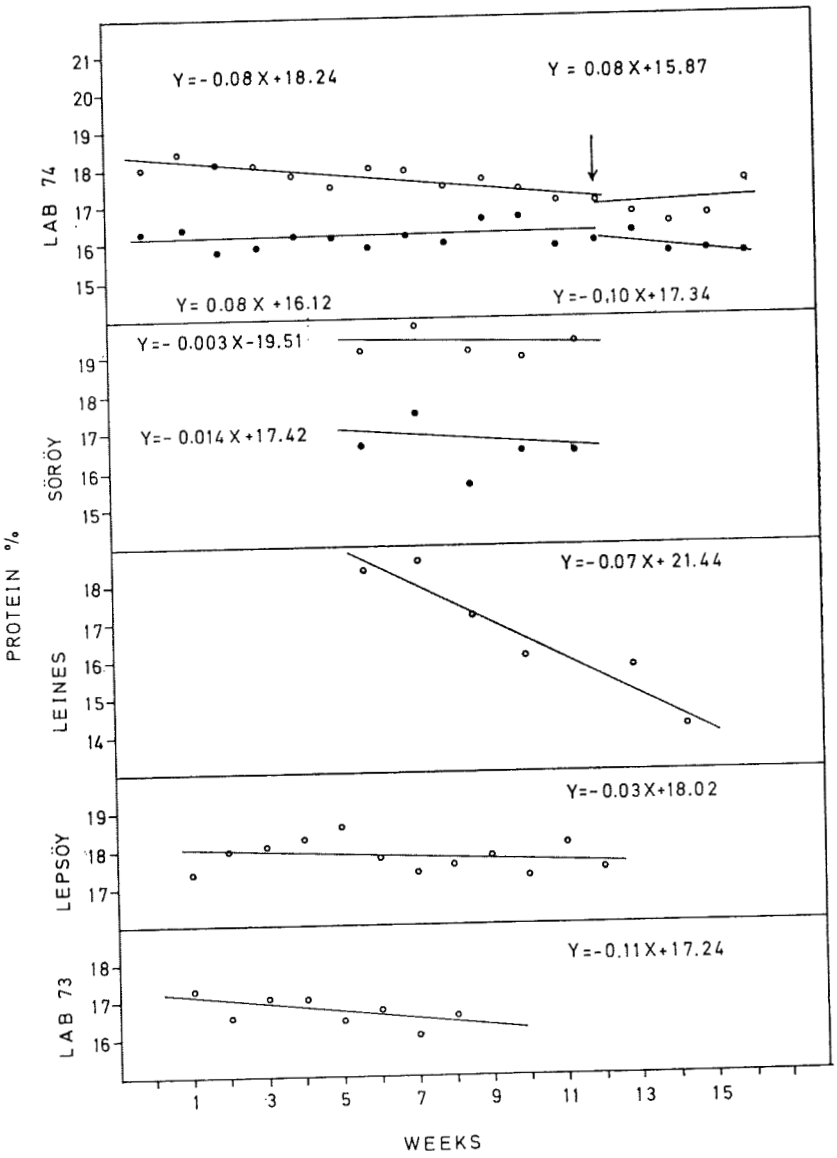

Fig. 8. Changes in total protein in white (open circles) and red (solid circles) muscles during starvation. Arrow indicates the start of feeding.

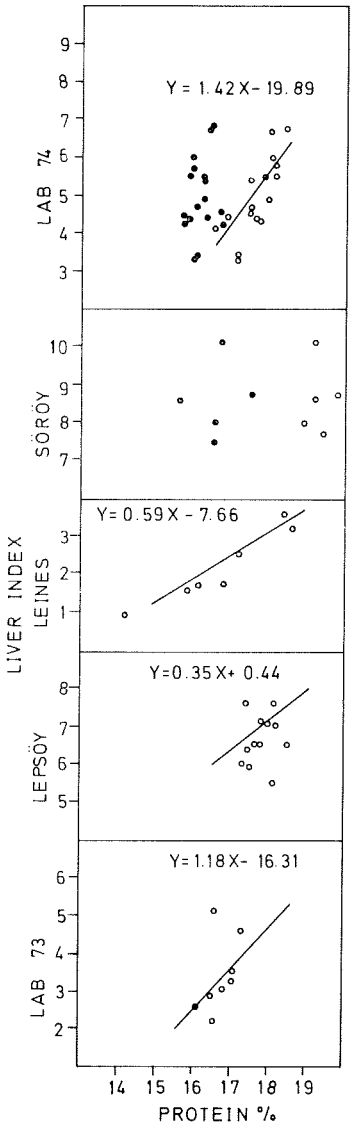

Fig. 9. Relationship between liver index and protein content in white (open circles) and red (solid circles) muscles during prolonged starvation.

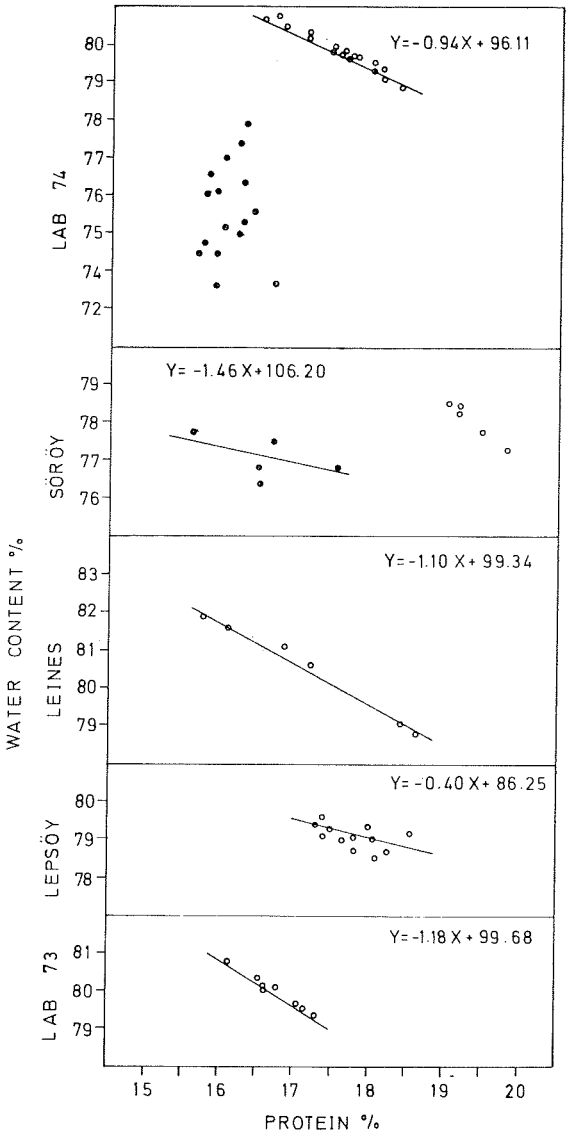

Fig. 10. Relationship between water content and total protein in white (open circles) and red (solid circles) muscles.

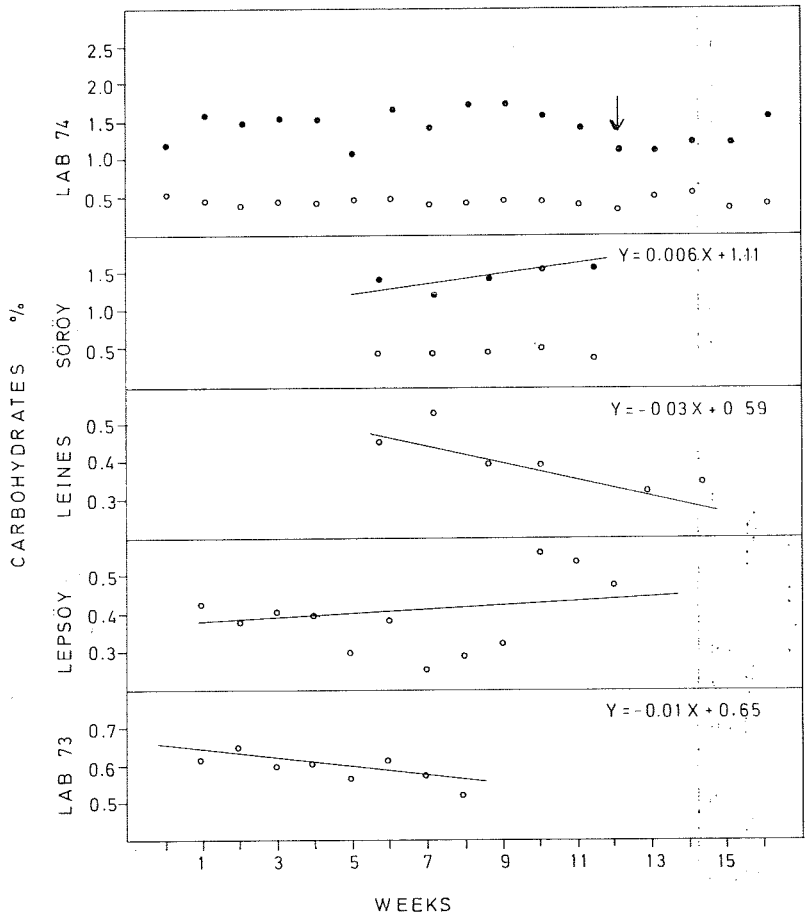

Fig. 11. Changes in carbohydrates in white (open circles) and red (solid circles) muscles during starvation. Arrow indicates the start of feeding.

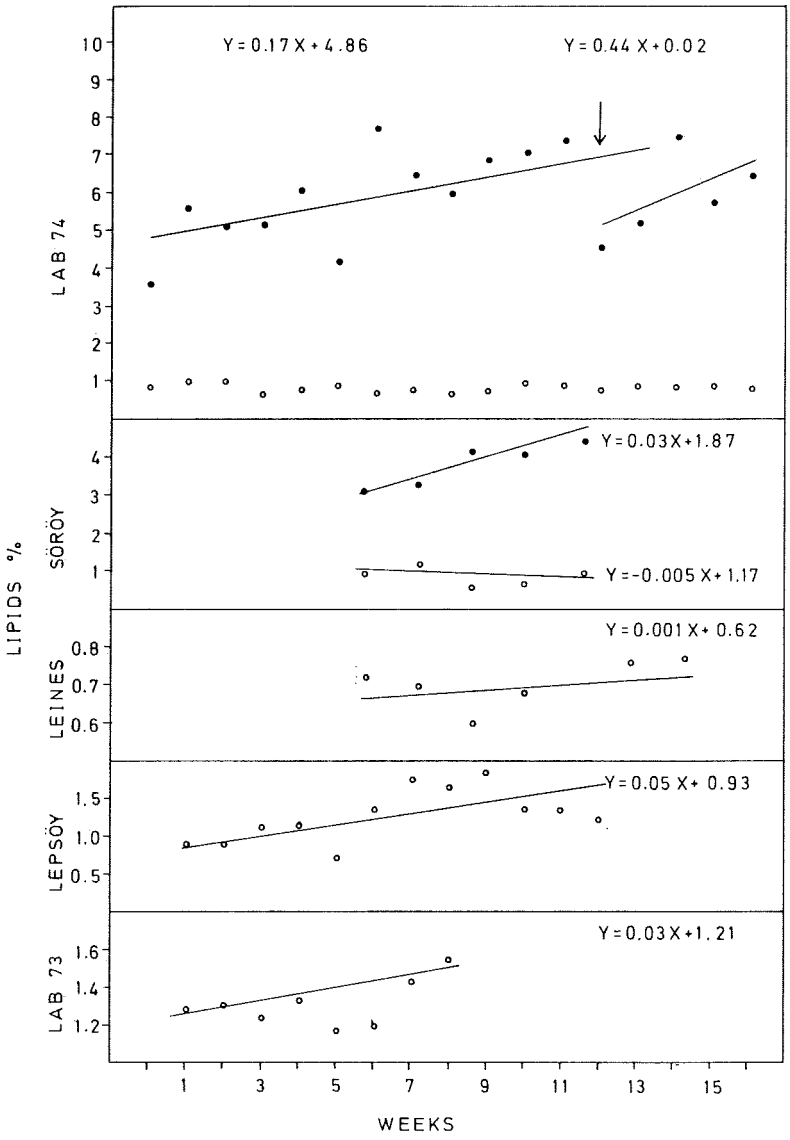

Fig. 12. Changes in lipid content of white (open circles) and red (solid circles) muscles during starvation. Arrow indicates the start of feeding.

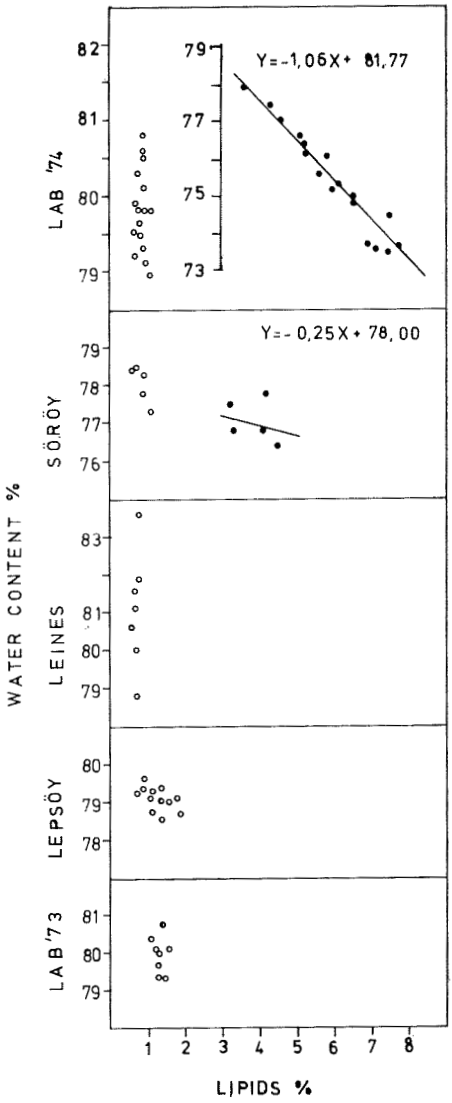

Fig. 13. Relationship between water content and lipids in white (open circles) and red (solid circles) muscles during long term storage.

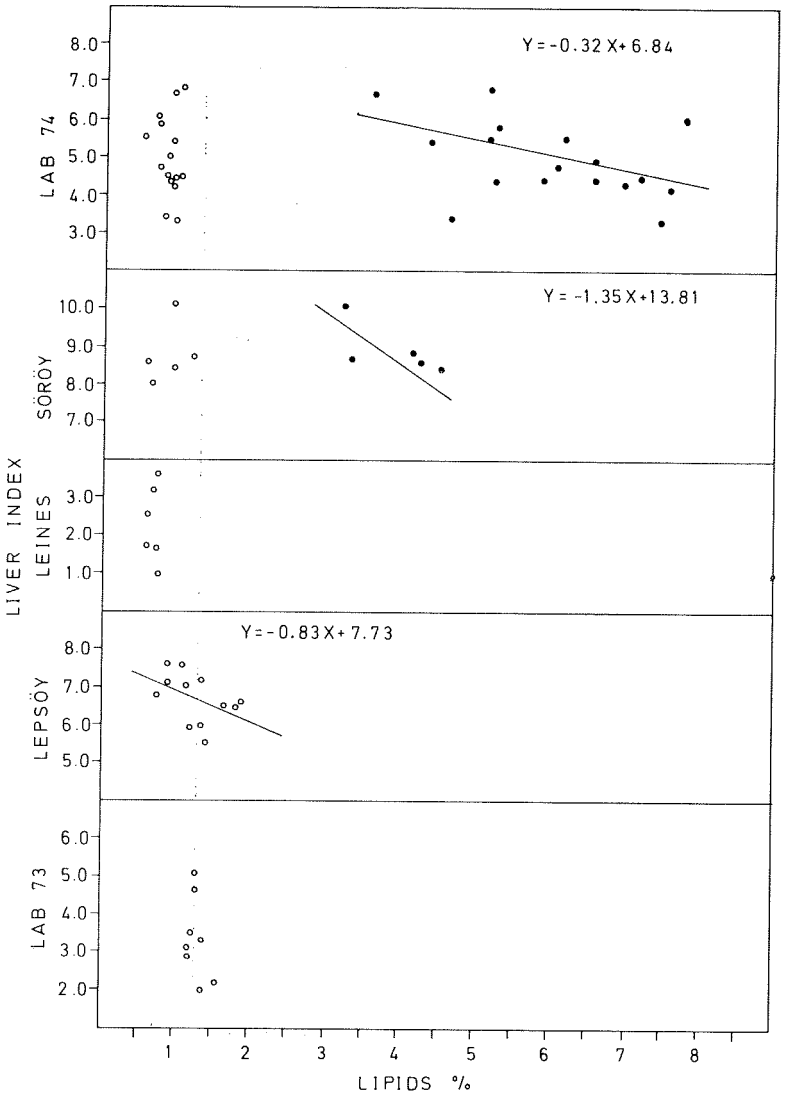

Fig. 14. Relationship of liver index and lipid content in white (open circles) and red (solid circles) muscles during starvation.

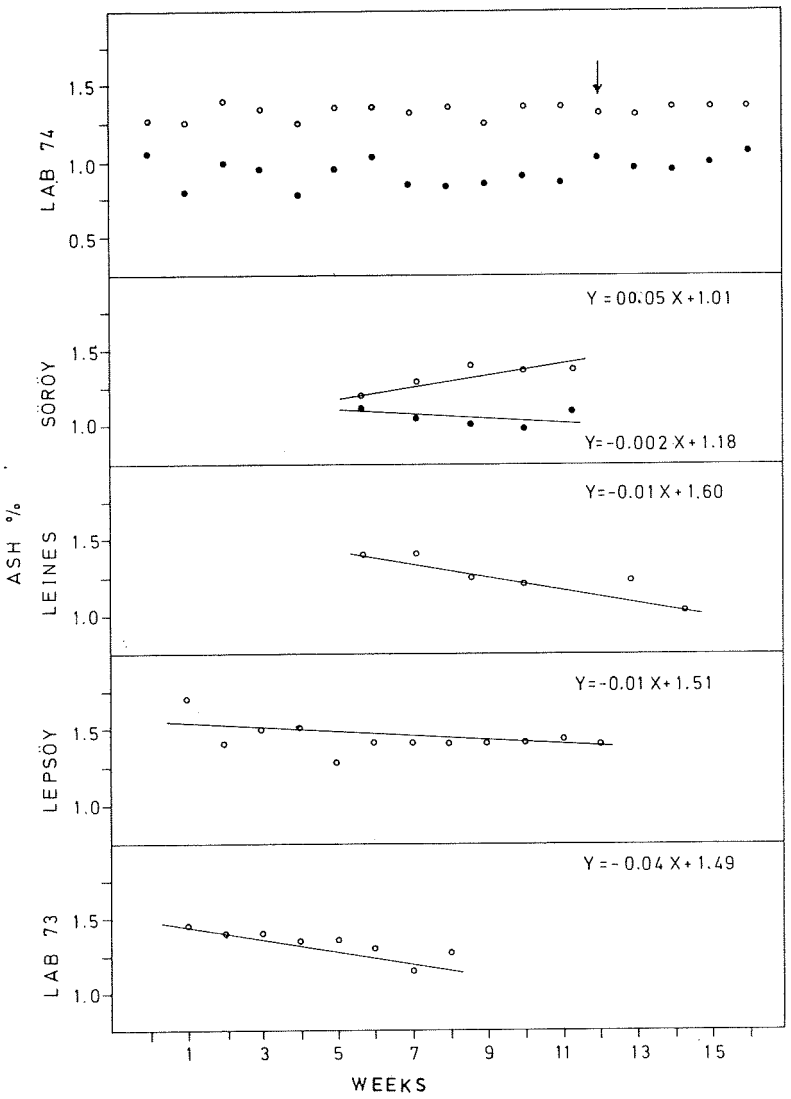

Fig. 15. Changes in ash content of white (open circles) and red (solid circles) muscles during starvation. Arrow indicates the start of feeding.

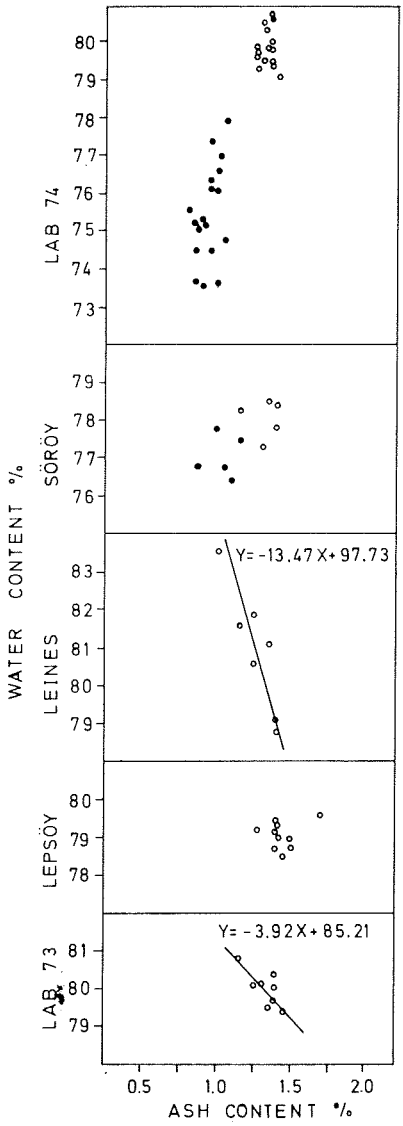

Fig. 16. Relationship between ash and water content in white (open circles) and red (solid circles) muscles during starvation.

DISCUSSION

These experiments on the prolonged starvation of saithe under natural and laboratory conditions have given diversified results. Considering the fish stored in fjords, there was a marked decline in the liver index in all three fjords. Fish stored at Sørøy had the highest liver index (8—10) at the start of the experiment, and in this group the rate of decline of liver index was greatest. This cannot be attributed to temperature since the mean temperature was the same (± 1°C) in all experiments. There was a similar decline in the liver index among fish held in the laboratory during summer 1973 and spring 1974, and this was slightly more marked in the summer. Even though the fish were fed after twelve weeks of starvation, after four weeks of feeding they still did not recover their original liver condition.

The change in condition index during starvation was similar in all fish except for those stored at Sørøy. This discrepancy in Sørøy fish may be due to sampling error in the first Sørøy sample. Both liver and condition indexes of fish in the lab. '74 experiment did not seem to reach the original level after four weeks of feeding.

The earlier works on fatty and non-fatty fish show that water content of muscle increases during starvation and migration. It has been reported by IDLER and BINTERS (1959) that the water content of the muscle of sockeye salmon (*Onchorhynchus nerka*) increases by about 20% during up-stream migration. During starvation 86—88% water has been recorded in the muscle of the non-fatty fish cod (*Gadus morhua*) (LOVE 1958, SUTTON 1968), and 96% water was reported in the muscle of *Hippoglossus platessoides* (TEMPLEMAN and ANDREWS 1956). Compared to these values the increase of water in muscle tissue of saithe during starvation is less than the levels reported previously for non-fatty fish. In normal saithe the water content ranges from 78—82%, in these experiments it rose by only 2—4%. The water content seemed to be steady only in the Lepsøy stock of fish. This may be due to a low water temperature prevailing in that region (6°C) during the experimentation period or the metabolic rate of the fish being at a minimum. Due to the latter, the requirement for mobilization of protein from the muscle would have been less and hence the increase of water would appear to be small.

The analyses of red muscle showed a decrease in water content of 2—4%. This result is not in agreement with findings of JOHNSTONE and GOLDSPINK (1973), who reported an increase in the water content of red muscles of plaice (*Pleuronectes platessa*) during starvation.

Reviewing the changes in the chemical constituents of fish during starvation and migration, LOVE (1970) states that the impact of starvation

is felt sooner in active than in sluggish fish. Such an effect is seen in saithe which are active fish. In the experiments in Leines fjord the protein level fell by 4.5% wet flesh. The protein content decreased from 18.5% to 14.0%. A rapid decline in protein was also recorded in the laboratory fish experiments. The reason for the rapid decline in the laboratory fish protein may be the higher mean temperature in the laboratory experiments which probably resulted in a higher metabolic rate. The rapid decline in protein content of the fish stored at Leines may be due to the fact that these fish were smaller in size than those stored at Sørøy and Lepsøy, and therefore the metabolic rate per unit weight could have been higher than in the larger fish, and depletion of reserves would therefore be more rapid.

The main conclusion is that the low liver index at the beginning of the experiment in Leines fjord indicated that these fish were unsuitable for storage (BRATLAND, KRISHNAN and SUNDNES 1974). The liver is the energy resource to a certain level beyond which the depletion of the muscular tissue increases.

A correlation was also observed between white muscle protein and liver index though no such correlation was found for red muscle. In the Sørøy fish the results were similar to those for white muscle, whereas in the laboratory experiments the trends were in reverse. The reason may be that protein is not released from red muscle during starvation. This was observed by JOHNSTON and GOLDPINK (1973) on plaice. A protein-water relationship was found only in the red muscle of the Sørøy stock, but the liver index-red muscle relationship of this stock was found in neither group. In general there seems to be a good protein-water relationship for both the types of muscle. This observation agrees with that of LOVE (1970).

There was no significant change in carbohydrate content of red or white muscle during starvation, which indicates that the carbohydrates in the muscle tissue of saithe do not serve as a source of energy during starvation. Similarly, the results for lipid content show that muscle lipid is not mobilized during starvation.

The fact that cod, as stated by LOVE (1970) utilize liver lipids during starvation could also refer to saithe. Even though a higher quantity of lipids was recorded in the red muscle, the amount did not seem to decrease with advancing starvation. However, a good fat-water relationship was observed for the red muscle. There were inverse relationships for which no explanations were found between liver index and lipid in the red muscle and between liver index and lipid in white muscle of the Sørøy fish.

From chemical analyses carried out on red and white muscles it becomes obvious that the former contribute less organic material during

starvation than the latter. WALKER (1971), working on the effect of starvation on the skeletal muscle fibres of cod (*Gadus morhua*) and saithe (*Gadus Pollachius virens*), concluded that "during such periods or at times of food shortage, it is the white fibres that atrophy, the red fibres remaining nearly intact". This view has been supported by JOHNSTON and GOLDSPINK (1973). ROBERTS (1969) and PRITCHARD, HUNTER and LASKER (1971) have shown in dogfish (*Scyliorhinus canicula*) and in mackerel (*Symmetricus sp.*) respectively that the red muscle is used almost continuously for locomotor activity while the white muscle is used only for high speed swimming. Hence under captivity little use would be made of the white, tissue and mobilization of material from this tissue could be expected during starvation.

It has been reported for various species that ash content of muscle tissue falls as water content increases during starvation; TILLIK (1932) reported this in Atlantic salmon (*Salmo salar*), and KORDYL (1951) gave a similar result for cod (*Gadus morhua*). There was a similar decrease in ash content with the advance of starvation in three of the five experiments described here (Leines, Lepsøy and lab.'73). However, an ash-water correlation was not found in all groups (Fig. 15).

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ON THE RELATION BETWEEN ECHO INTENSITY AND FISH DENSITY

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ABSTRACT

Røttingen, I. 1976. On the relation between echo intensity and fish density. *FiskDir. Skr.Ser.HavUnders.*, *16*: 301—314.

Integrated echo intensities for a wide range of fish densities were measured. The experiments were carried out on live saithe (*Pollachius virens*) and sprat (*Sprattus sprattus*) which were kept in a net cage. Echo intensities were measured at 38 kHz and 120 kHz and pulse lengths ranging from 0.1 ms to 0.6 ms. The echo intensity was proportional to fish density below certain density limits. At high fish density a shadowing effect was observed. Factors encountered during survey work on schooling fish which indicate shadowing are also discussed.

The exact density values at which shadowing occurs, appear to depend on parameters such as fish species, size, orientation, and probably also the vertical extention of the school.

INTRODUCTION

The basic principle of acoustic fish stock estimation when using echo integration is that the relation between the integrated echo intensity, M, and the fish density, ϱ, is (Midttun and Nakken 1971)

$$\varrho = C \cdot M$$

where C is the density coefficient. It expresses the number of fish per unit area which contributes to one unit of the integrated echo intensity. It is dependent upon fish species and size and the characteristics of the sounder and integration system (Nakken 1975). In dense schools one may expect, due to acoustic interaction of the individual fish, that the members of the deeper part of the school are shadowed by the members which are nearer the transducer. This may take form of scattering and absorption of sound energy by the nearer members, and consequently the lower fishes will reflect less sound energy per density unit. This will lead to an underestimation of fish density.

Little is known about the effects of acoustic interaction of fish in a school (McCartney, Stubbs and Tucker 1965). Some teoretical work

on scatterers have been done, the scatterers usually being point scatterers or small bubbles, and WESTON (1967) has applied the results for bubbles to fish schools. However, little experimental work has been done in this field (LOVE 1971).

The aim of the present investigation has been, by means of acoustic measurements of live fish, to examine if the proportionality between fish density and integrated echo intensity is valid at all fish densities.

MATERIALS AND METHODS

The materials treated in this investigation is:

1) Echograms and oscilloscope readings obtained during survey on schooling fish with a research vessel.
2) Fully controlled measurements of echo intensity from known densities of fish.

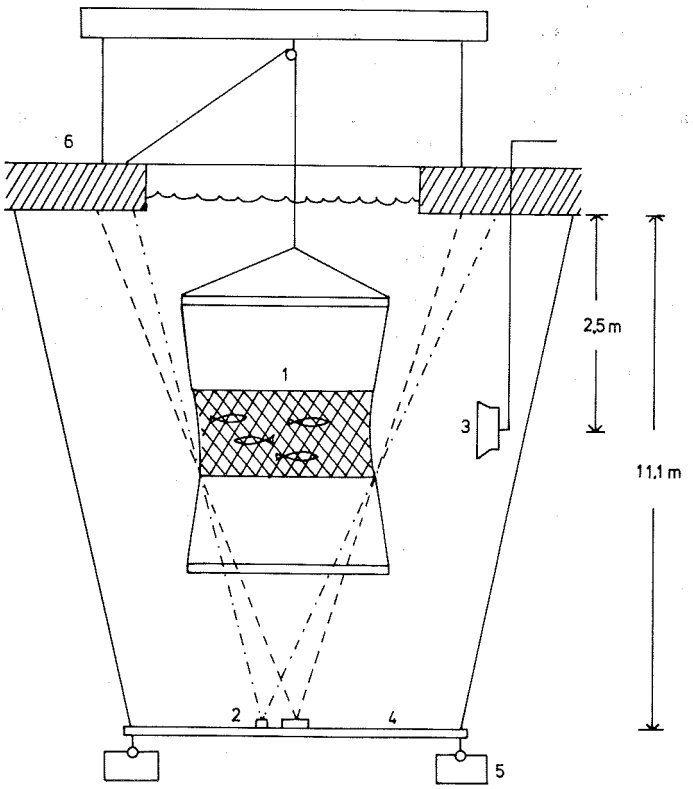

Fig. 1. Experimental arrangement (not to scale). 1) Net cage, 2) transducers, 3) camera, 4) transducer base, 5) load, 6) raft.

Table 1. Data for the net cages.

	Distance between supporting rings (m)	Height of net cage (m)	Diameter of net cage at top and bottom (m)	Diameter of net cage at the centre (m)	Mesh size (mm)	Volume of net cage (m^3)
Net cage 1 (saithe)	3.80	1.80	1.45	1.40	14	2.87
Net cage 2 (sprat)	3.40	2.40	1.50	1.40	26	3.96

Table 2. Mean length ($\bar{l}$), standard deviation (SD), mean weight ($\bar{w}$) of fish used during the acoustic measurements.

Species	$\bar{l}$ (cm)	SD (cm)	$\bar{w}$ (g)
Saithe	35.1	0.6	375
Sprat	12.1	1.7	12

The controlled measurements were carried out from an anchored raft. A diagram (not to scale) of the experimental arrangement is shown in Fig. 1. The upward looking transducers were mounted on a heavily loaded steel frame submerged from the raft in adjustable wires. The net cage was suspended on a line on the acoustic axis of the sound beam at a mean depth of 2.5 m. Table 1 gives data for the two net cages. The upper and lower metal supporting rings were placed at some distance from the net cage; thus the echoes from these rings were not included in the integration interval. Before an acoustic measurement was made, the net cage was hoisted to the surface, and the desired amount of fish was transferred through an opening on the top of the net cage. Then the net cage was lowered to the desired depth.

The acoustic measurements were carried out on two species, saithe (*Pollachius virens*) and sprat (*Sprattus sprattus*). Length and weight data of the fish are shown in Table 2. Before the measurements the fish were kept in floating pens where the fish were acclimatized to the depth at which the measurements were made.

The mean depth of the net cages during the measurements was 2.50 m. At the mean depth the diameter of the net cages was 1.40 m (Table 1), and the sound level at the rim of the cage was measured to be approximately one dB down compared with the sound level at the acoustic axis.

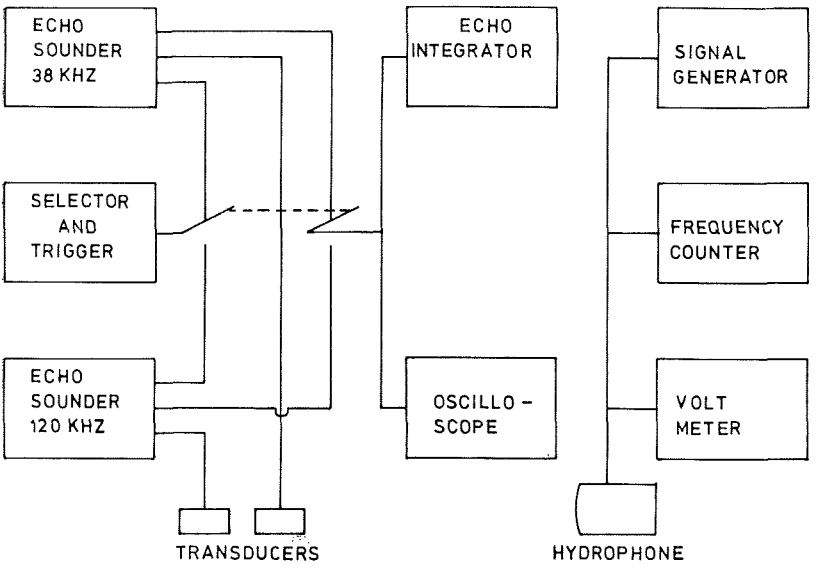

Fig. 2. Block diagram of instrumentation.

A block diagram of the instrumentation is shown in Fig. 2, and Table 3 gives instrument data and control settings.

RESULTS

Fig. 3 shows drawings of four oscilloscope readings of capelin (*Mallotus villosus*) schools. The volt scale is horisontal and the time scale vertical, the vertical extention of the schools being in the order of 30—40 m.

Fig. 4 shows a echogram recording of large schools of spawning capelin on the coast of Finnmark, Northern Norway. The vertical extention of the schools varies from 25 m to 70 m.

Fig. 5—8 show the integrated echo intensities (sum of 1200 pulse transmissions) obtained during the controlled experiments for the different fish densities. In order to compare the different frequencies and pulse lengths, the echo intensities are given in relative values, i.e. the maximum value for each series is set at 1.0. The densities at which the proportionality between integrated echo intensity and fish density is no longer valid, here called shadowing densities, are summarized in Table 4.

For saithe there was only one series of measurements, but for sprat the series was repeated. The values in Fig. 5 and 6 are mean values. The variation of the integrated echo intensities of single pulse transmissions from constant fish densities will be discussed in a later paper.

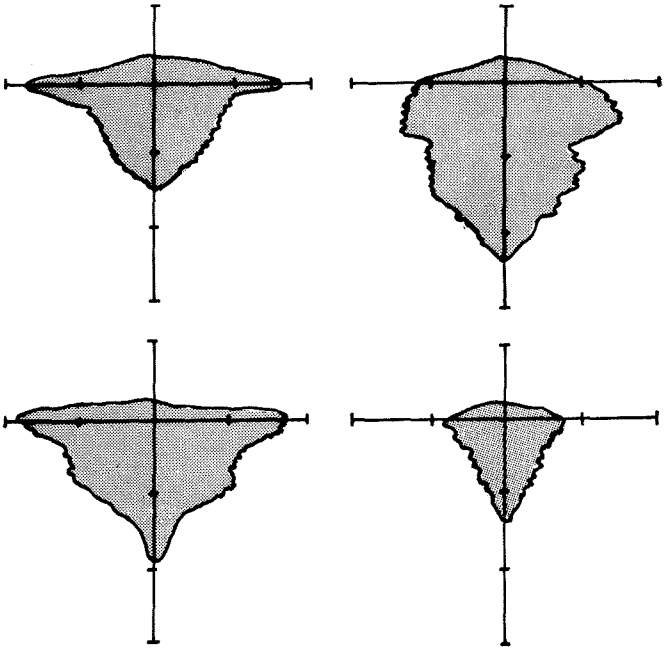

Fig. 3. Oscilloscope readings of capelin schools, Barents Sea, February 1974. 38 kHz 0.6 ms. Volt scale horisontally, time scale vertically.

Table 3. Instrument data and control settings.

Echo sounder:	
Type:	Simrad EK 38A and EK 120A
Frequency:	38 kHz and 120 kHz
Transducers:	10 cm × 10 cm (38 kHz). Circular, diameter 5 cm (120 kHz)
Mode:	WL
Discriminator:	1
Pulse lengths:	0.3 ms and 0.6 ms (38 kHz), 0.1 ms and 0.6 ms (120 kHz)
Bandwidth:	Wide
Output power:	1/10
Repetition rate:	4 pulses per second
Echo integrator:	
Type:	Simrad QM Mk II
Mode:	1 (Channel A. Sounding, Channel B. Nautical mile)
Speed Comp.:	10 knots
Reset:	Manually after 5 minutes (1200 pulses)

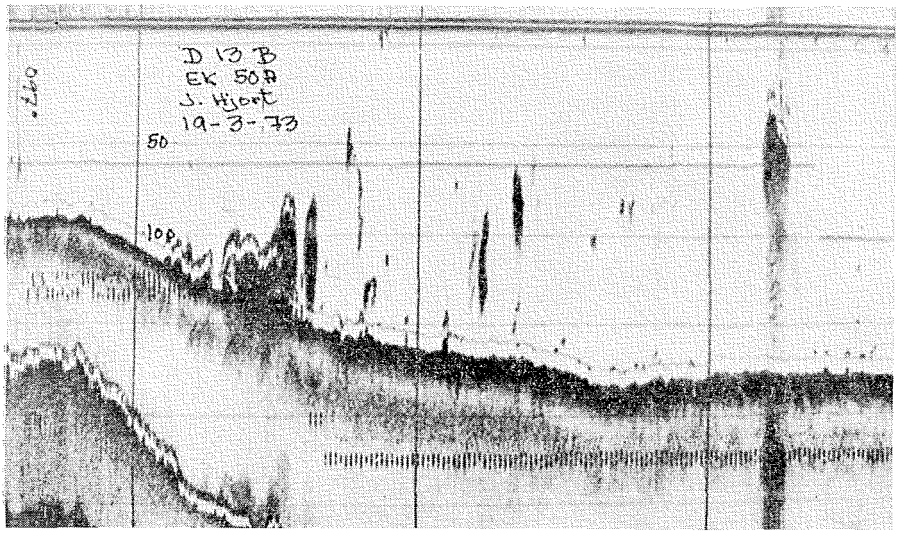

Fig. 4. Echogram of school of spawning capelin, Finnmark coast, March 1973. Depth scale in meters.

Table 4. Shadowing densities for saithe and sprat.

Species	Frequency (kHz)	Pulse length (ms)	Shadowing density	
			Fish/m³	kg/m³
Saithe	38	0.3	110 — 130	41 — 49
	38	0.6	100 — 120	38 — 45
	120	0.1	130 — 140	49 — 53
	120	0.6	120 — 130	45 — 49
Sprat	38	0.3	1800 — 2100	22 — 25
	38	0.6	1800 — 2000	22 — 24
	120	0.1	2700 — 2900	32 — 35
	120	0.6	2400 — 2600	29 — 31

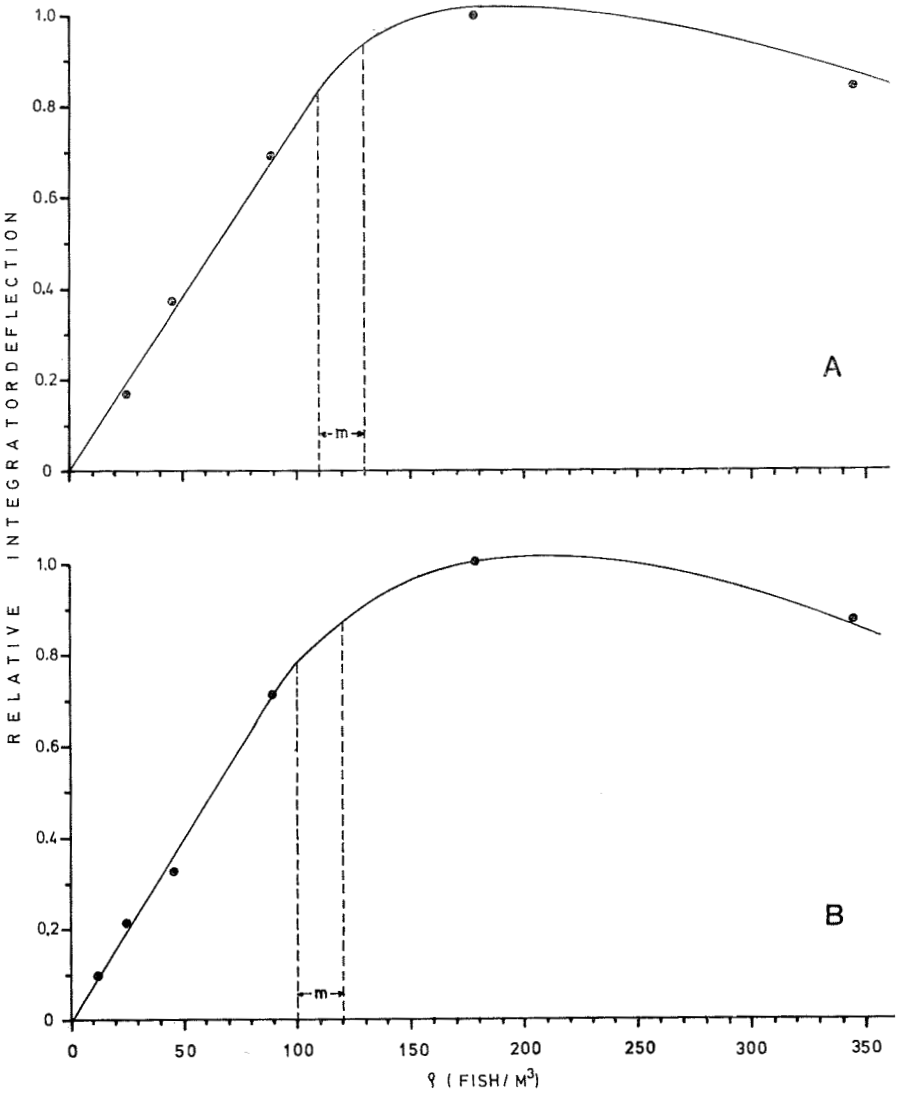

Fig. 5. Observations of relative integrator deflection on densities of saithe at 38 kHz. A) 0.3 ms, B) 0.6 ms, m) density values at which shadowing was encountered.

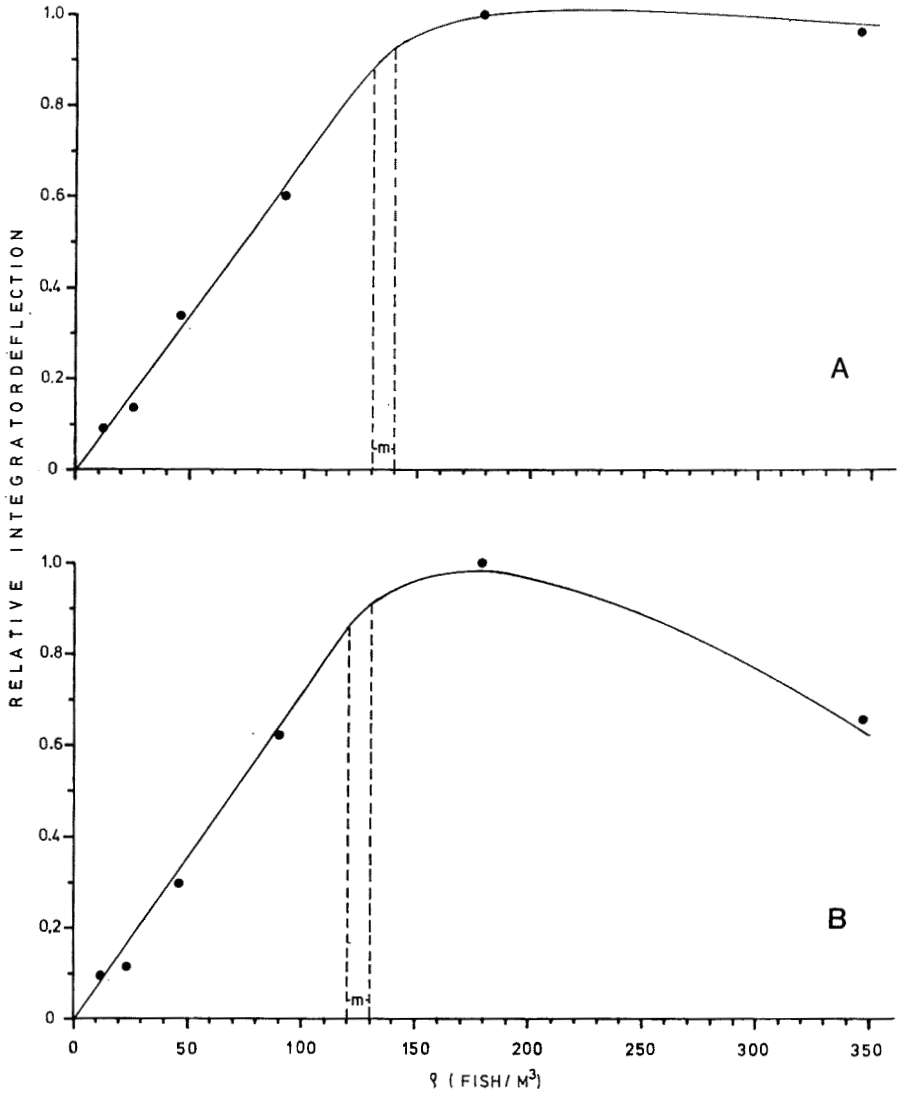

Fig. 6. Observations of relative integrator deflection on densities of saithe at 120 kHz. A) 0.1 ms, B) 0.6 ms, m) density values at which shadowing was encountered.

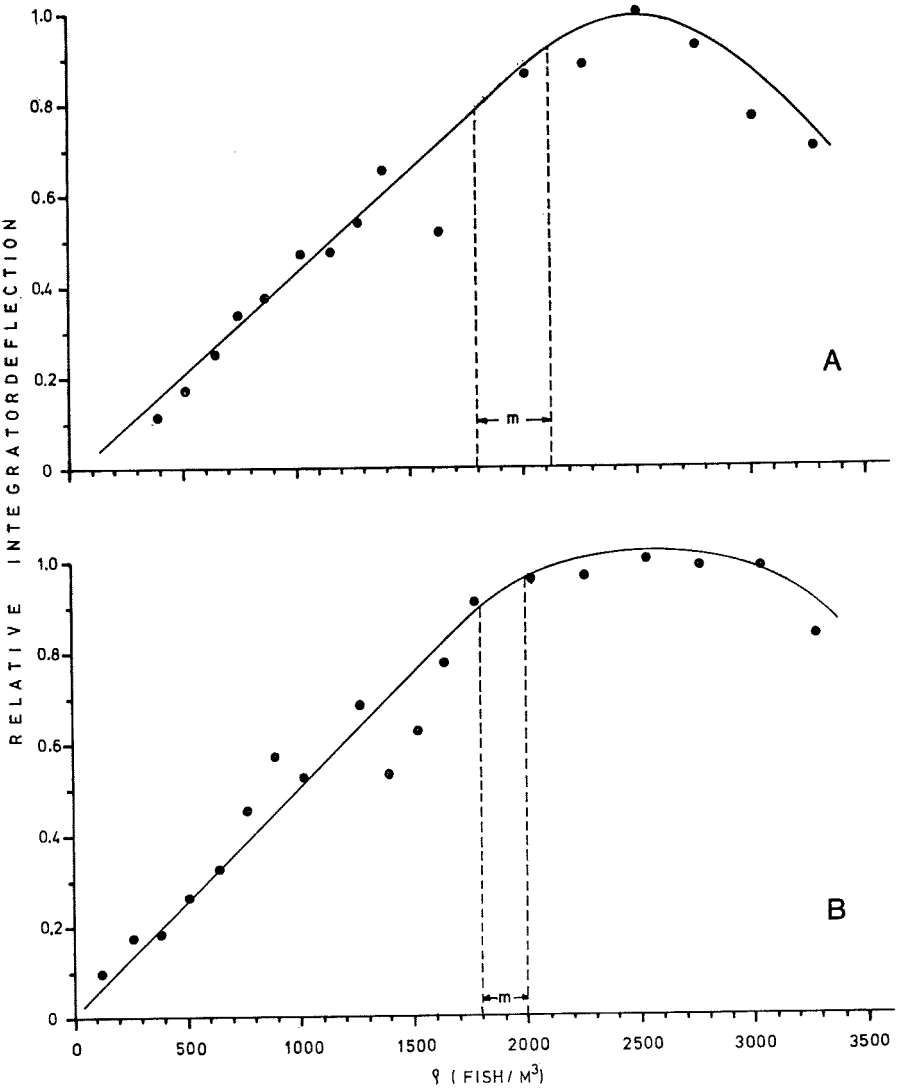

Fig. 7. Observations of relative integrator deflection on densities of sprat at 38 kHz. Legend as in Fig. 5.

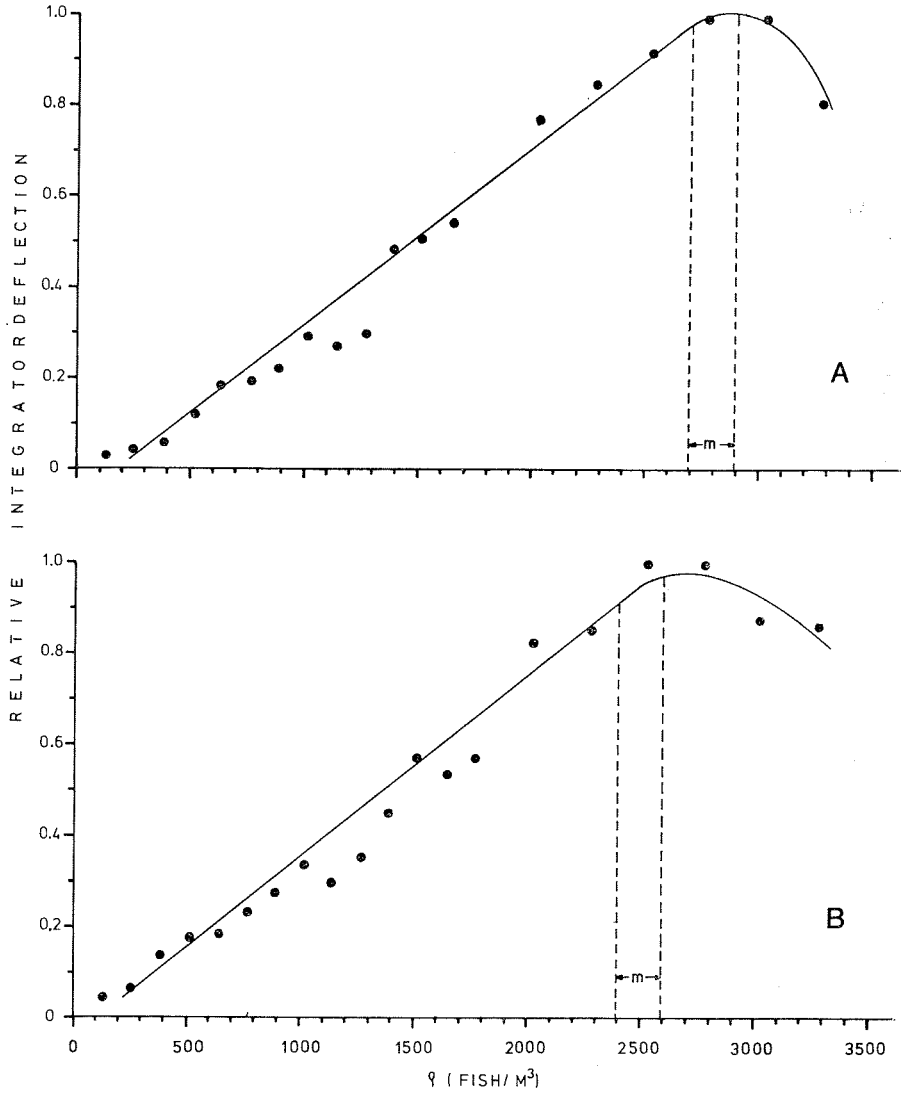

Fig. 8. Observations of relative integrator deflection on densities of sprat at 120 kHz. Legend as in Fig. 6.

DISCUSSION

There are strong reasons to believe that shadowing effects are encountered during surveys on fish schools. The schools in Fig. 3 all show less sound reflection from the deeper layers. The echo sounder has an automatic depth compensator, and it is doubtful if the oscilloscope readings show the actual physical structure of the school, i.e. with greater fish density in the upper layers of the school. A more plausible explanation would be that sound energy is attenuated within the school.

The modern echo sounder is equipped with a white line function. The purpose of this function is to make it easier to discriminate fish which are close to the bottom, and, of great importance when making fish stock assessments with integrator techniques, to prevent strong bottom signals from being integrated. The bottom has a clear white line in areas with no capelin in Fig. 4. However, below the capelin school this bottom white line disappears. This means that the strength of the bottom echo is considerably reduced, and it is therefore probable that the echo of lower fishes will also be reduced. This is the shadowing effect which was discussed in the introduction of this paper. The figure shows also that the echo from the upper part of the schools is so strong that it is blocked.

By using integrator technique the density in the capelin school will be considerably underestimated due to

A. Blocking of the uppermost layer;
B. Shadowing of the lower fishes by the members of the school which are nearer the transducer.

A can be avoided by an appropriate altering of the discriminator level, while the quantitative effects of B are much more difficult to estimate.

The large school in Fig. 4 is a spawning school of capelin. The structure of these spawning schools has been well studied by direct observation by SCUBA divers (BAKKE and BJØRKE 1973, SÆTRE and GJØSÆTER 1975). The densities of these schools are tabulated in Table 5 together with other direct or indirect observations of fish density.

As discussed earlier there is a reduction of the bottom signal below the large capelin school in Fig. 4. This type of spawning school is what SÆTRE and GJØSÆTER (1975) call a "first type school", and these schools consisted of more or less regularly oriented capelin swimming forward or in circles. BAKKE and BJØRKE (1973) and SÆTRE and GJØSÆTER (1975) give densities in distances between fishes. A distance of 15 cm (Table 5) between capelin of 15 cm length will give a density of about 150—200 fish/m^3. This is considerably lower than the shadowing densities given for sprat in Table 4. The sprat is only a little smaller than capelin, and this

Table 5. Natural fish densities.

Species	fish/m³	kg/m³	Interfish distance (cm)	References
Mallotus villosus			40—80 Spawning schools (first type)	BAKKE and BJØRKE (1970)
M. villosus			10 Spawning schools (second type)	BAKKE and BJØRKE (1970)
M. villosus			15—30 Spawning schools (first type)	SÆTRE and GJØSÆTER (1975)
M. villosus			5 Spawning schools (second type)	SÆTRE and GJØSÆTER (1975)
Clupea harengus.....	0.7—1.0			TRUSKANOV and SCHERBINO (1966)
C. pallasi		0.2—0.8		RADAKOV (1973)
C. pallasi		30—32 (2—3 days before spawning)		RADAKOV (1973)
C. pallasi	9.0—10.4 (day)			THORNE (1973)
C. pallasi	0.012—1.0 (night)			THORNE (1973)
Engraulis encrasicholus	650			JOHANNESSON and LOSSE (1973)
E. mordax	50—75			MAIS (1973)
Sardina pilchardus	2		80	CUSHING (1957)
Merluccius productus ..		0.04—0.05		THORNE (1973)
Gadus morhua	$1.0—8.0 \cdot 10^{-5}$			TRUSKANOV and SCHERBINO (1966)
Trachurus mediteranus	110			JOHANNESSON and LOSSE (1973)
Scomber japonicus	20			VAN OLST and HUNTER (1970)

seems to suggest that the shadowing effect is not due to density as such, but rather to the total number of fish or scatterers within the sound beam. In schools with a great vertical extention, such as the spawning school in Fig. 8, shadowing effects may then well be encountered at lower densities than in schools with a short vertical extention like those observed during the experiment.

The problem of estimating densities at which shadowing occurs at different school extentions may be approached by an application of the mathematical theory of multiple scattering. By using the same number of fish which gave a shadowing effect during the experiments, one could make a density reduction by analysing reflection from the same number of scatterers at different fictive extentions of the net cage.

To apply such results to field work, one would probably need exact information of species, sizes of the schools, length distribution, absorption patterns of the fish etc. In addition, behavioral information would be needed, such as orientation and mobility of the fish. At present, much of this information is lacking.

The curves obtained by using different pulse lengths and frequencies do not seem to have significant differences within the same species. There may be a tendency that the shadowing effect first occurs at higher densities when using higher frequencies (Table 4). The curves show decreasing echo intensity for the highest densities. The exact reason for this is unknown.

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