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Histological analysis of fibres in myotomes of antarctic fish (Admiralty Bay, King George Island, South Shetland Islands) I. Comparative analysis of muscle fibres size *)

ABSTRACT: Studies were performed on two species of fish from family *Chaenichthyidae* and on seven species of family *Nototheniidae*. Statistical analysis of the subcutaneous and trunk muscle fibres diameter from the trunk and tail area allowed to state that the thickness of these fibres is inversely proportional to the metabolism level of fish. The inter-species similarities were found, but they were not found within families, if their representatives differed in metabolic level.

Key words: Antarctic fishes, ice-fishes, muscle fibres

1. Introduction

Established range of the cell size is one of the cytological features of each class of vertebrates (Szarski 1976). Animals of large variety of sizes are met within each class, but their size does not often correlate to the size of their cells. Suggestions that the size of cells, thus also of muscle fibres were genetically controlled, were published in the middle of XIX century (Bowman, acc. to Joubert 1956). Observations carried out on muscle fibres of mammals indicated, on one hand, lack of correlation between the size of the fibres and the size of the animal (Warringsholz acc. to Joubert 1956). but on the other hand, the investigations of Gauthier and Padykula (1966) showed clearly the existence of such relation.

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Observations made for the class of birds by George and Naik (acc. to Stickland 1975) show that thickness of the muscle fibre increases with the increase of the bird's weight.

The class of fish, similarly to birds (Nitecki 1972), has small cells, with the simultaneous wide range of size. While studying the correlation of the size of muscle fibres of various animal species, their body weight was generally used as an index of their size. Fairly uncomplicated silhouette of fish enables to use also other size parameters, such as volume and slimness (Stickland 1975), which determine more precisely the behaviour of studied species.

The comparison of the volume and slimness of fish with the size of their muscle fibres appears to show that the diameter of fibres increases with the increase of body volume, but decreases with the increase of fish slimness (Stickland 1975). Considerable slimness of the fish body is usually characteristic for quick swimming fish and, what follows, for those with high metabolic activity. The presence of small muscle fibres in such fish seems understandable, and has been also confirmed by studies of mammals (Gauthier and Padykula 1966).

Apart from the existence of the obvious correlation between the ratio of red to white fibres, and the way of fish swim (Boddeke, Slijper and van der Stelt 1959, Mosse and Hudson 1977) we assumed the existence of correlation between the thickness of muscle fibres and fish metabolism.

Up to now no studies of the above correlations have been done on antarctic fish, which are the object of our research. The purpose of the present paper is to establish to what extent the size of muscle fibres is related to fish metabolism and to what extent it is genetically conditioned.

2. Material and methods

Nine species of antarctic fish were selected for studies, including two species of ice-fish from family *Chaenichthyidae: Chaenocephalus aceratus* (Lönnberg) and *Champsocephalus gunnari* Lönnberg, and seven species from family *Nototheniidae: Notothenia nudifrons* Lönnberg, *Notothenia gibberifrons* Lönnberg, *Notothenia rossi marmorata* Fischer, *Notothenia corriceps neglecta* Nybelin, *Trematomus bernacchii* Boulenger, *Trematomus hansoni* Boulenger and *Dissostichus eleginoides* Smitt.

The fish were caught with a dip-net in Admiralty Bay, King George Island (South Shetland Islands) at the turn of 1978/1979.

Adult individuals in good condition and of size approximating maximum for a given species were chosen for investigations. After they had been restored from the net the fish were weighed and measured, and muscle samples were excised from the trunk — from the area in front of the dorsal fin, and from the tail. Muscle samples were fixed in 5% glutaraldehyde in phosphate buffer pH 7.4 at 4° C for about three hours, then rinsed in this buffer and in running water for about 24 hours, and embedded in gelatine. The gelatine blocks, prepared in the above way, were stored in 2% formalin. The blocks were then frozen in the liquid nitrogen and

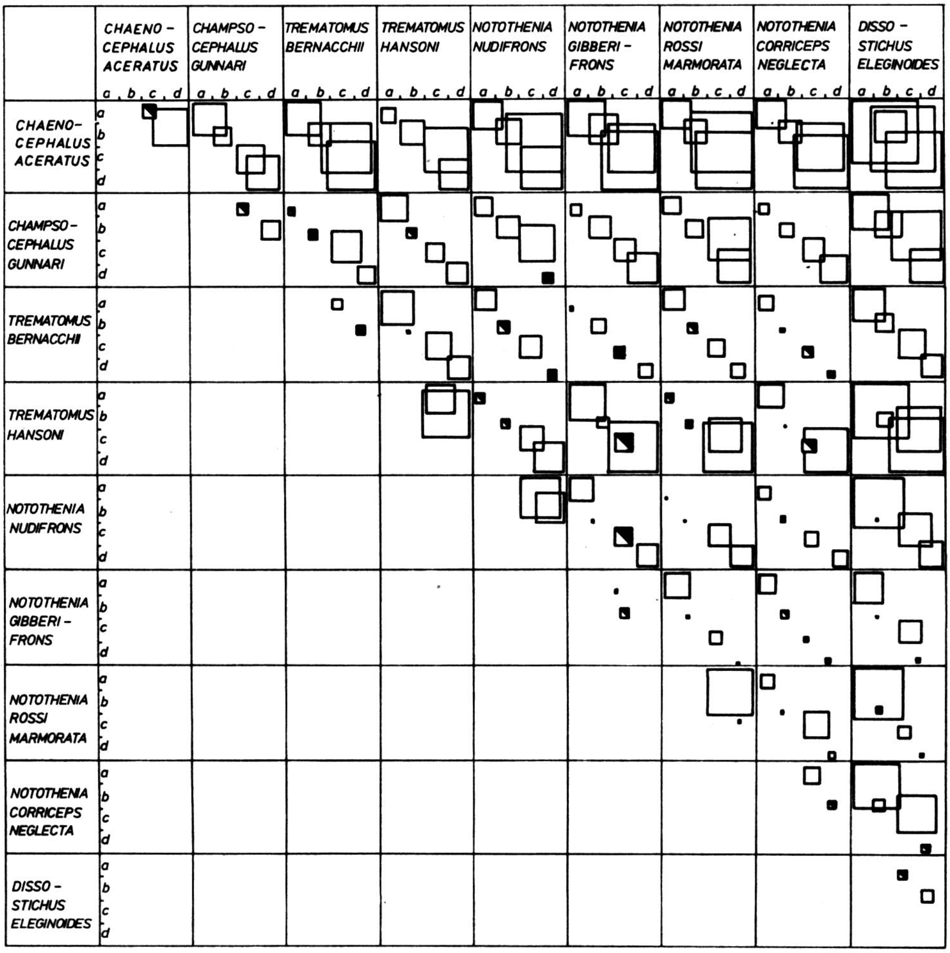

Fig. 1. Values of muscle fibres diameters of nine species of antarctic fish compared with the φ^2 index (χ^2/N)

a — *musculus lateralis magnus* from the trunk, *b* — *musculus rectus lateralis* from the trunk, *c* — *musculus lateralis magnus* from the tail part, *d* — *musculus rectus lateralis* from the tail part. The corresponding muscles of each fish were compared with each other (e.g. *a* — *musculus lateralis magnus* of *Champsocephalus gunnari* with *a* — the same muscle of *Chaenocephalus aceratus*, the obtained value of φ^2 is shown as a square located on the intersection of lines drawn from "*a*" in column of *Champsocephalus gunnari* and from "*a*" in column of *Chaenocephalus aceratus*), also both trunk muscles with two tail muscles of each fish were compared and the obtained φ^2 values were presented as areas of squares. Index φ^2 is close to 0 if species are very similar, thus small squares indicate large similarities of fibre diameters, and large squares — small similarities, suggesting a considerable diversity of fish species.

10 μm sections were cut on a cryostat. Staining with Sudan black B allowed to show the presence of sudanophilic and sudanophobic fibres, making possible the distinguishing of the layer of subcutaneous red fibres and the deeper layer of the white fibres.

Several pictures were taken of histological sections in the light microscope of both analysed muscles (*musculus lateralis magnus* and *musculus rectus lateralis*) from trunk and tail parts of the fish body. The diameter of fibres was measured from the films with a measuring magnifier. For each fibre two diameters at the right angle to each other were measured and then the average was calculated. 45 to 600 fibres of each studied muscle were measured. The size distribution of fibres diameters was established for each layer, the means and medians, also the χ^2 statistical analysis was performed. The strength of interrelations of corresponding muscle layers of all studied fish species was calculated with the φ^2 index, to show the similarity of these species. The obtained values of φ^2 are presented graphically (Fig. 1) as squares, whose areas represent the strength of the interrelation (φ^2) of corresponding muscles.

The volume and slimness of seven fish species were calculated: $V = \frac{1}{3}\,\frac{h \cdot w \cdot l}{4}$ and using the coefficient l/h, where: h — the greatest height of fish, w — the greatest width of fish, l — length measured from the snout to the base of the tail. The measurements were performed on preserved fish. It was assumed that the ratio h : w : l is constant for each species (Stickland 1975) (Table I).

Table I

List of studied fish and their measurements

Species	Lenght l (mm)	Hight h (mm)	Width w (mm)	Slimness l/h	Weight (g)
Chaenocephalus aceratus	530	120	92	4.41	2380
Champsocephalus gunnari	375	65	46	5.76	504
Trematomus bernacchii	165	41	27	4.02	110
Trematomus hansoni	305 *)	—	—	—	455
Notothenia nudifrons	160	42	27	3.80	80
Notothenia gibberifrons	250	52	47	4.80	370
Notothenia rossi marmorata	295	70	56	4.21	615
Notothenia corriceps neglecta	315	87	72	3.62	780
Dissostichus eleginoides	630 *)	—	—	—	3500

*) Measurements of alive fish

Diameters of the muscle fibres of both muscles from the trunk and tail of the seven species of fish were related to their volume and slimness using the regression equation and correlation coefficient.

3. Results

The studied muscles, *musculus lateralis magnus* and *musculus rectus lateralis* make up the biggest portion of the mass of fish muscles. The first of these muscles is composed of white fibres, the second one — of red ones, in the majority of fish. Layers or groups of muscles of intermediary character, or not fitting any histological criteria of metabolic classification of fibres (Bone 1978, Willemse and de Ruiter 1979) can also be frequently found.

The fish muscles are built of myomers laying next to each other and containing both types of fibres. The course of muscle fibres and their thickness differs in two areas of the fish body under examination — in trunk and tail parts. Our observations show that the diameters of cross-sections of *musculus rectus lateralis* are larger in the tail part than those in the trunk part. The white fibres of *musculus lateralis magnus* from the trunk are larger than those from the tail part, except for one species (*Champsocephalus gunnari*).

Chaenichthyidae

Two species of this family were analysed.

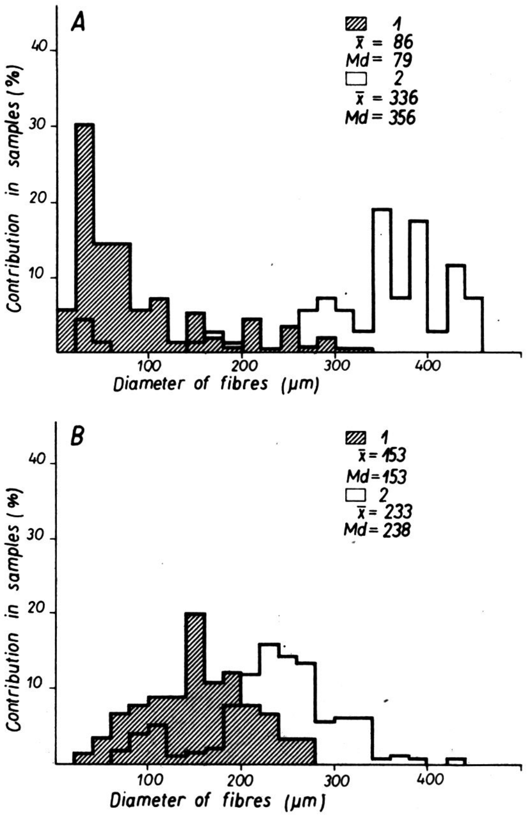

Fig. 2. The size distribution of muscle fibres diameters from the trunk (*A*) and tail part (*B*) of *Chaenocephalus aceratus*

1 — *musculus rectus lateralis*, 2 — *musculus lateralis magnus*. Fibre diameters in 20 μm classes.

Chaenocephalus aceratus

Musculus rectus lateralis of the trunk part consists in 1/3 of small diameter fibres (40 μm), although muscle fibre diameters over 300 μm can also be found (Figs. 2 A and 3). *Musculus lateralis magnus* fibres in the trunk demonstrate high diversity of diameters (20—450 μm). There is about 75% of large diameter fibres (Fig. 4), but there are also fibres of very small diameters (20—50 μm).

The red fibres of the *musculus rectus lateralis* in the tail of this species have higher mean diameter (153 μm) than those in the trunk (Fig. 2 B).

Majority of *musculus lateralis magnus* fibres have diameters nearly half as small as (mean 233 μm) those in the trunk (Fig. 2 B).

The size distribution of red fibre diameters from the trunk is positively oblique, from the tail symmetric, and the size distribution of white fibres from both regions of fish body is negatively oblique.

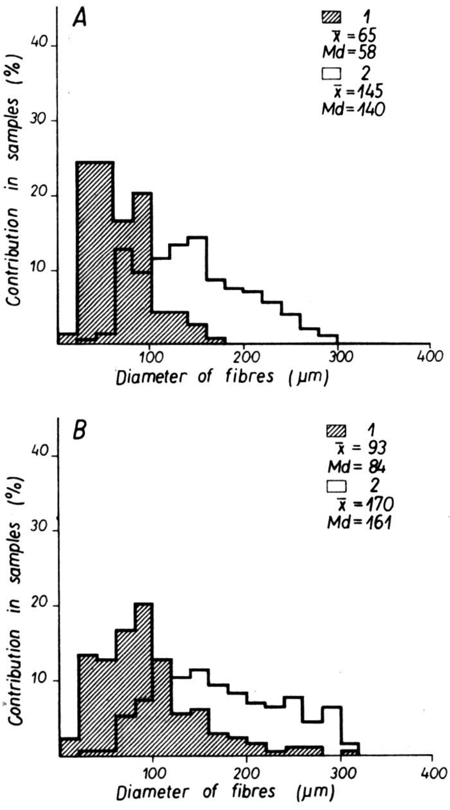

Fig. 5. The size distribution of muscle fibres diameters from the trunk (*A*) and tail part (*B*) of *Champsocephalus gunnari*
Explanation see Fig. 2.

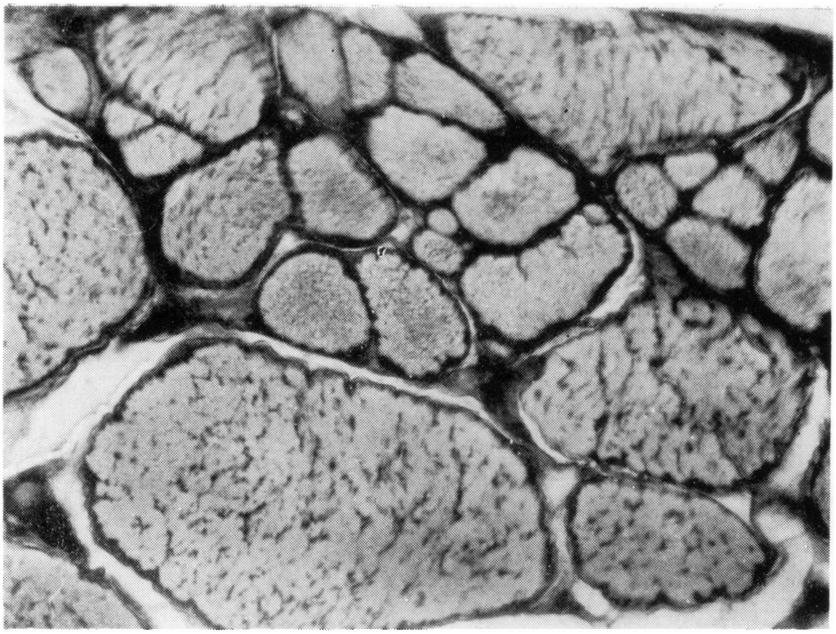

Fig. 3. The cross-section of *musculus rectus lateralis* of *Chaenocephalus aceratus* from the trunk

The majority of fibre population is composed of thin fibres, although thick fibres are also present. Thick and medium fibres are more heavily stained by Sudan black B than thin fibres. Magnification 220x

(Photo E. Śmiałowska)

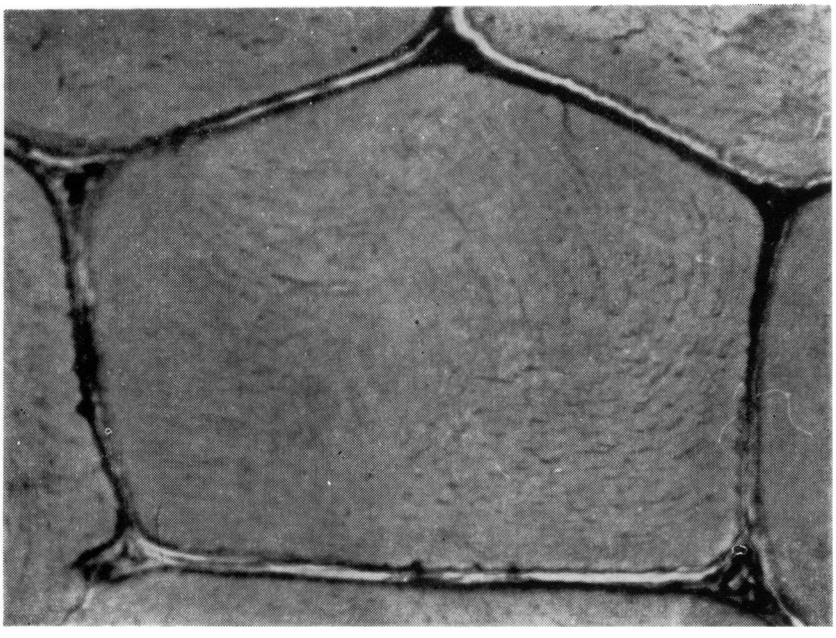

Fig. 4. The cross-section of *musculus lateralis magnus* from the trunk of *Chaenocephalus aceratus*

This muscle is composed of fibres of very large diameters and small content of mitochondria. Magnification 220 x

(Photo E. Śmiałowska)

Champsocephalus gunnari

The second species investigated which has a small amount of erythrocytes was *Champsocephalus gunnari*. Like *Chaenocephalus aceratus* it is characterized by fairly large sizes of cross-sections diameters of muscle fibres.

The diameters of the *musculus rectus lateralis* red fibres from the trunk are 20—100 µm in nearly 90%, although thicker fibres, with diameters up to 180 µm can also be found (Fig. 5 A).

The average fibre diameter of *musculus lateralis magnus* is 145 µm, there are also some fibres in size classes 20—60 µm, and 280—300 µm. Two fractions of fibres can be distinguished. The first, small, includes the fibres of diameters up to 80 µm, the second amounting 40% of all fibre population contains fibres up to 160 µm in diameter, about 30% — from 160 to 300 µm (Fig. 5 A).

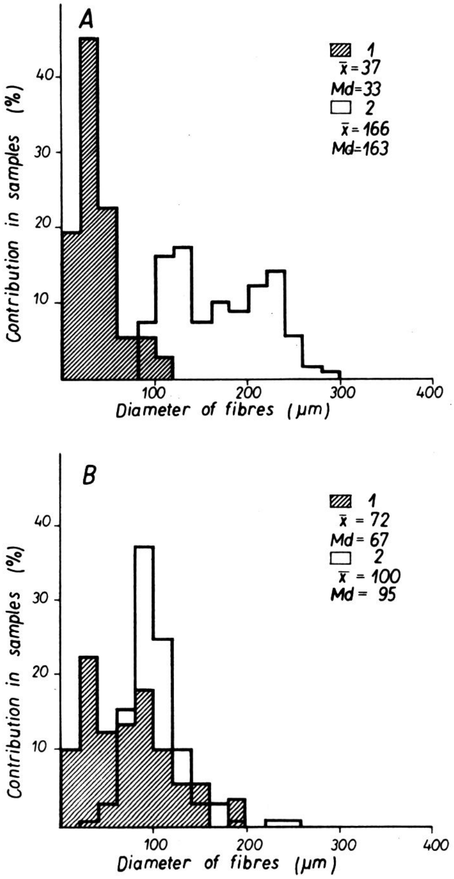

Fig. 6. The size distribution of muscle fibres diameters from the trunk (*A*) and tail part (*B*) of *Notothenia nudifrons*
Explanation see Fig. 2.

The *musculus rectus lateralis* from the tail part of *Champsocephalus gunnari* consists of sudanophilic fibres of more differentiated diameter sizes than in the trunk. About 75% fibres are within the size class 20—120 μm, the rest consists of much thicker fibres reaching up to 300 μm (Fig. 5 B).

Musculus lateralis magnus of the tail part has a large variety of fibres diameters (20—320 μm), and nearly equal presence of all size classes of fibres (except the two first and the last class) in the muscle (Fig. 5 B).

The size distributions of fibre diameters of the studied muscles are positively oblique for both trunk and tail parts.

Nototheniidae

The analysis of the muscle fibre size distributions of four species of the genus *Notothenia*: *Notothenia nudifrons* (Fig. 6), *Notothenia gibberifrons* (Fig. 7),

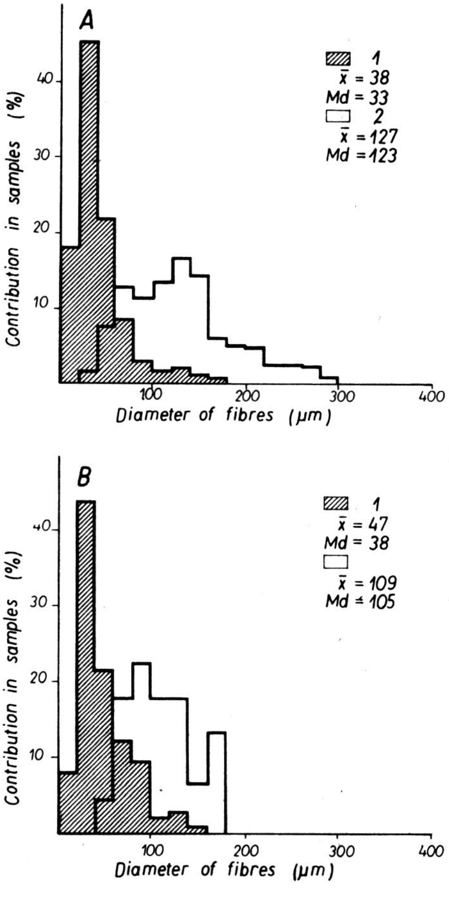

Fig. 7. The size distribution of muscle fibres diameters from the trunk (*A*) and tail part (*B*) of *Notothenia gibberifrons*
Explanation see Fig. 2.

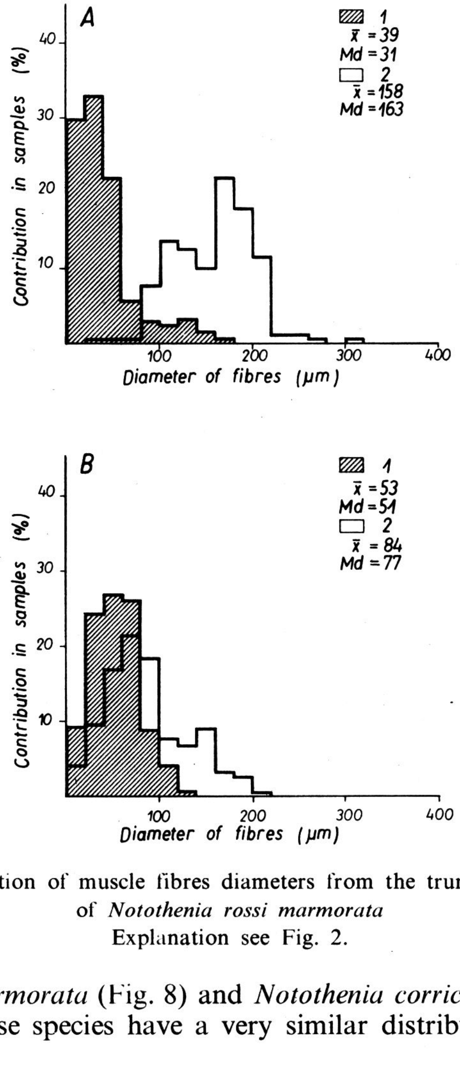

Fig. 8. The size distribution of muscle fibres diameters from the trunk (*A*) and tail part (*B*) of *Notothenia rossi marmorata*
Explanation see Fig. 2.

Notothenia rossi marmorata (Fig. 8) and *Notothenia corriceps neglecta* (Fig. 9) showed that all these species have a very similar distribution of the muscle fibre diameters.

Notothenia nudifrons

Small fibres (10—40 μm) dominate among the red fibres of the trunk, and amount to 65% of the all fibres; the diameter of the thicker fibres does not exceed 120 μm (Fig. 6 A).

The white fibre population of the *musculus lateralis magnus* consists of two fractions, one with the fibres 100—140 μm in diameter, the other with diameters 200—300 μm (Fig. 10). The number of fibres in both fractions is about the same (Fig. 6 A).

The size distribution of fibres in the tail part is quite different. The red fibres in this body region form two distinct fractions (contrary to the trunk part). One of the fractions consists of fibres of small diameters

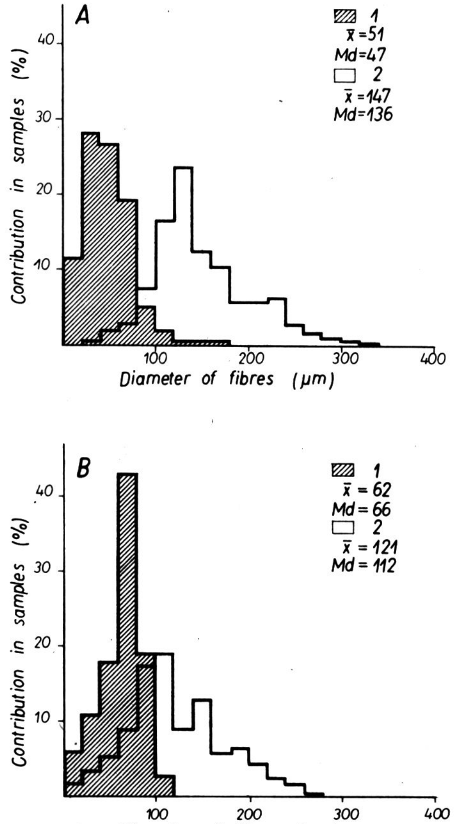

Fig. 9. The size distribution of muscle fibres diameters from the trunk (*A*) and tail part (*B*) of *Notothenia corriceps neglecta*
Explanation see Fig. 2.

(12—40 μm) and make up 32% of the fibres, the other (42%) contains fibres 80—200 μm in diameter (Fig. 6 B).

The white fibres of the *musculus lateralis magnus* show a significant uniformity of diameters (100 μm) (Figs. 6 B and 11).

All size distributions of the fibre diameters of both fibre types in both regions of body are positively oblique.

Notothenia gibberifrons

The structure of the *musculus lateralis magnus* is quite homogenous, since as much as 85% of fibres are within the size classes 0—60 μm, although fibres of larger diameters (up to 180 μm) are sporadically found (Fig. 7 A).

Musculus lateralis magnus of this part of the body is made mainly of white fibres (nearly in 70%) of 60—160 μm in diameter. The larger fibres (diameters up to 180 μm) also make up a fairly large (30%) part of its structure (Fig. 7 A).

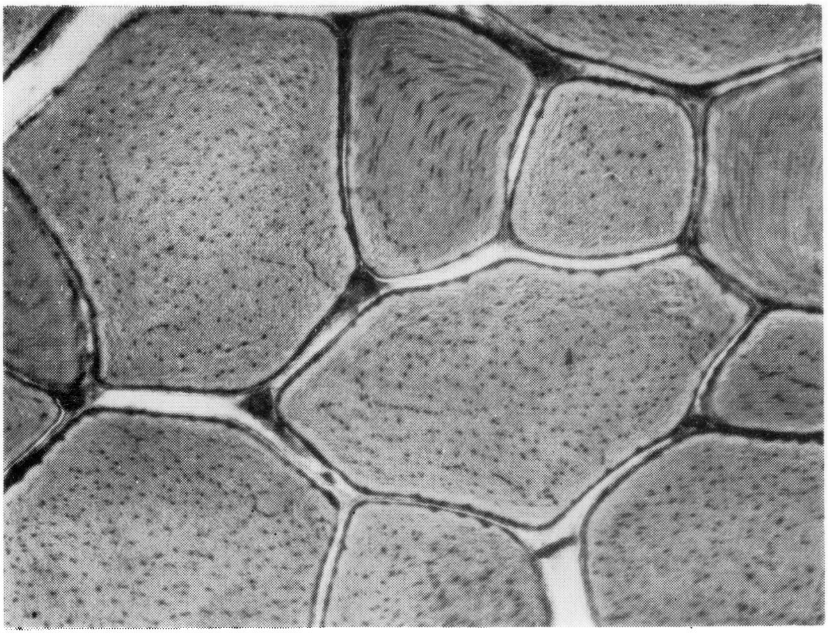

Fig. 10. The cross-section of *musculus lateralis magnus* of *Notothenia nudifrons* from the trunk

The picture presents a large diversity of the size of muscle fibres. Groups of lipid droplets and mitochondria are evenly distributed on the whole section. Magnification 220 x

(Photo E. Śmiałowska)

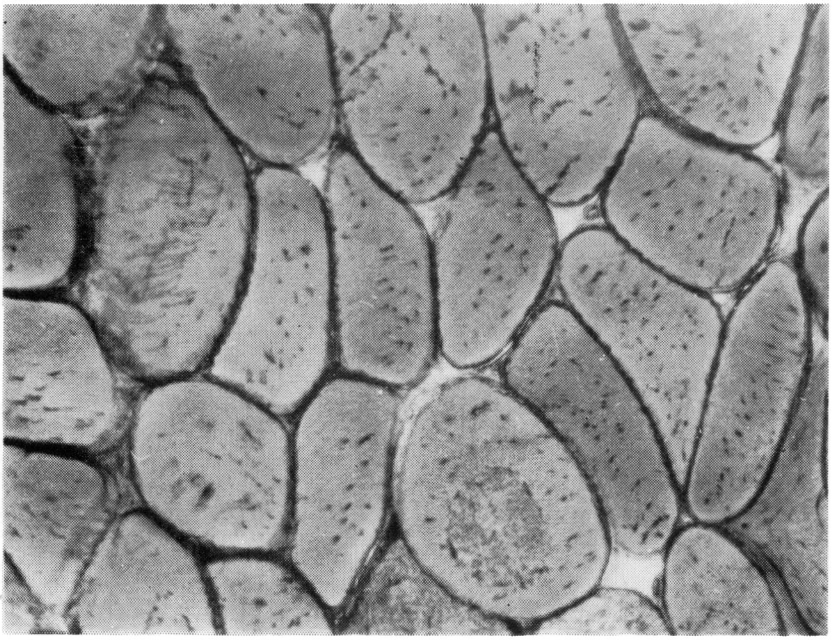

Fig. 11. The cross-section of *musculus lateralis magnus* of *Notothenia nudifrons from the tail part of body*

This muscle is composed of uniform, relatively small fibres (100 μm in diameter). The lipid droplets and mitochondria groups are visible in fibres. Magnification 220 x

(Photo E. Śmiałowska)

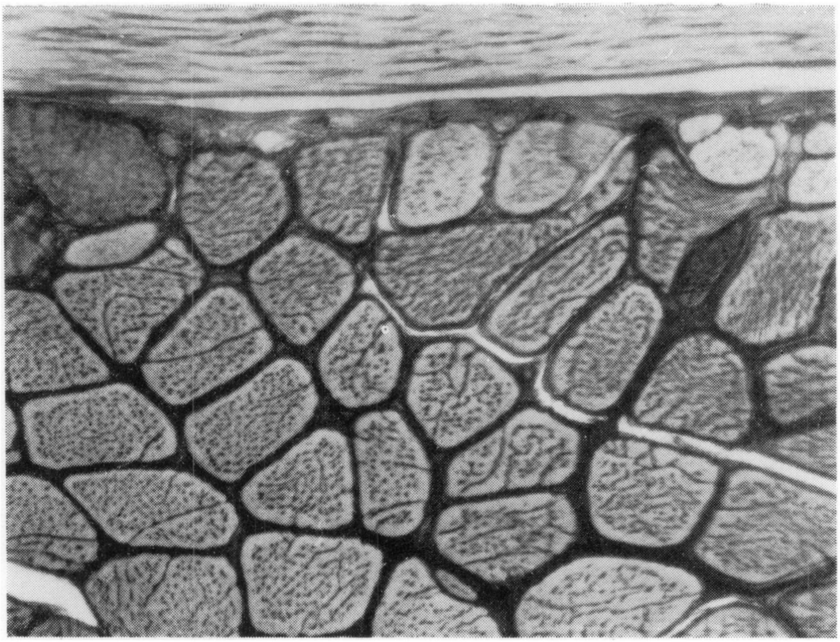

Fig. 12. The cross-section of *musculus rectus lateralis* of *Notothenia corriceps neglecta* from the tail part of body
This muscle is composed of thin fibres with large content of lipid droplets and mitochondria. The fibres reveal small variation of diameters. Magnification 220 x
(Photo E. Śmiałowska)

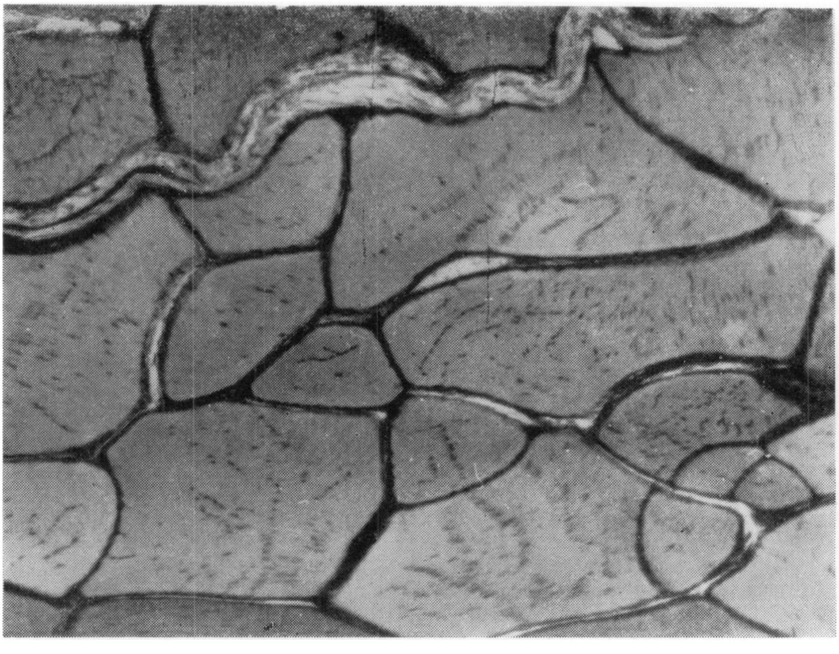

Fig. 14. The cross-section of *musculus lateralis magnus* of *Trematomus barnacchii* from the tail part
This muscle is composed of two distinct fractions of fibres — thin and thick fibres. Magnification 220 x
(Photo E. Śmiałowska)

The subcutaneous fibres in the tail part have the size distribution very similar to the corresponding fibres in the trunk, although their mean diameter is bigger (47 μm) (Fig. 7 B).

The structure of the *musculus lateralis magnus* of the tail is characterised by small range of the fibre diameters (40—160 μm), with 35% of fibres 60—140 μm in diameter (Fig. 7 B).

The size distribution of fibre diameters in size classes in both fibre types, in both studied part of fish body are positively oblique.

Notothenia rossi marmorata

The trunk red fibres of this species are characterised by a large uniformity of fibre sizes, just as in the species described above. About 84% of fibres are within the size classes of diameters 0—60 μm, although there is also a small percentage of fibres up to 180 μm in diameter (Fig. 8 A).

The white fibres of the *musculus lateralis magnus* of the trunk can be devided into two fractions. The first, the smaller one (about 33%), is composed of fibres of 80—140 μm in diameter, the second, composed of fibres of 100—220 μm in diameter makes up 51% of all the fibres. Much smaller (30 μm) and much larger (302 μm) single fibres were sporadically found (Fig. 8 A).

The subcutaneous fibres of *musculus lateralis magnus* have on the average a larger diameter in the tail part of the body (53 μm), than in the trunk (39 μm), but the diameters of the thickest fibres do not exceed 120 μm. The majority of fibres (77%) are within the size classes of diameters 20—80 μm (Fig. 8 B).

The white fibres of the *musculus lateralis magnus* in this region of body have their diameters nearly twice as small as those of the fibres of the same muscle in the trunk. Besides, distinct fractions of fibres, observed in the trunk do not appear here. The majority of fibres (60%) measure 40—100 μm in diameter, although there are also nearly 29% of fibres measuring 100—220 μm in diameter (Fig. 8 B).

The size distribution of the *musculus rectus lateralis* fibres of both analysed regions of *Notothenia rossi marmorata* body are positively oblique. The distribution of the white fibres diameters in the trunk is negatively oblique, and in the tail part — positively oblique.

Notothenia corriceps neglecta

Musculus rectus lateralis of the trunk consists of muscle fibres of 20—80 μm in diameter of cross-section, which amount to 73% of all fibres. Single fibres up to 180 μm in diameter can also be found (Fig. 9 A).

Musculus lateralis magnus contains fibres of diverse diameters in size classes 20—340 μm, although those with diameters 120—240 μm dominate (23% of all fibres) (Fig. 9 A).

The fibres of *musculus rectus lateralis* of the tail part are uniform in their diameters. Fibres of 60—80 μm (Fig. 12) in diameter make up

43% of this muscle, 37% of fibres belong to two neighbouring size classes (Fig. 9 B).

The diameters of white muscle fibres in the tail part are within size classes 0—280 μm, their mean diameter of cross-sections being 121 μm. About 36% of the fibres is contained in size classes 80—120 μm (Fig. 9 B).

The size distribution of fibre diameters of *musculus rectus lateralis* is positively oblique for the trunk, while for the tail part it is negatively oblique. The size distribution of fibre diameters of *musculus lateralis magnus* the two areas investigated is positively oblique.

Genus *Trematomus* also belongs to the family *Nototheniidae*. Specimens of two species of this genus were also an object of analysis of muscle fibres composition. Both these species differ significantly as to fibre diameters and the configuration of the fibre size distribution.

Trematomus bernacchii

Musculus rectus lateralis is composed in 60% of fibres 20—80 μm in cross-section diameter. Diameters of the thickest fibres are below 140 μm,

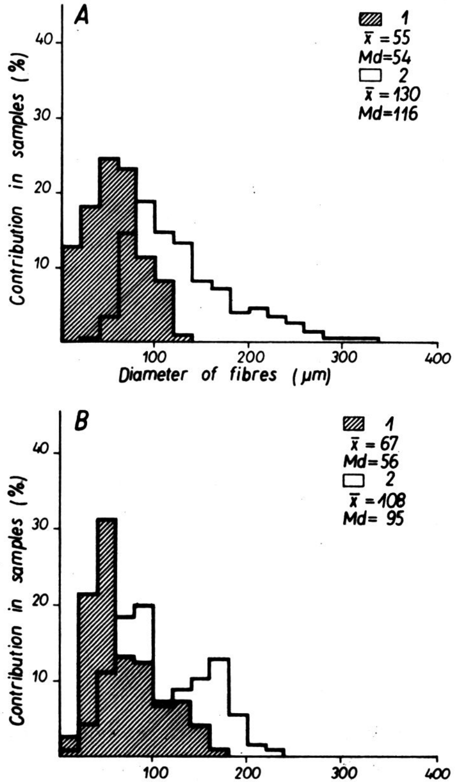

Fig. 13. The size distribution of muscle fibres diameters from the trunk (*A*) and tail part (*B*) of *Trematomus bernacchii*
Explanation see Fig. 2.

but they form a fraction of a percent; fibres of the class 0—20 µm, though, form nearly 13% of the muscle (Fig. 13 A).

Musculus lateralis magnus in the trunk contains the fibres of 20—340 µm in diameter. Fibres of the size class 80—100 µm form 19% of all fibres, the number of fibres in succesive ten classes decreases gradually (Fig. 13 A).

Contrary to the trunk, in the tail part of *musculus rectus lateralis* there are two clearly distinct classes of fibres (20—60 µm). Small fibres are scarce, fibres of diameter over 60 µm are quite numerous (44%), the largest reach 163 µm in diameter (Fig. 13 B).

The white fibres population in the tail part are composed of two quite different fractions (Fig. 14). The first consists of fibres of 40—100 µm in diameter (49% of all fibres), the second — less numerous (30% of all fibres) — of fibres in diameter classes 120—180 µm. Larger fibres, even up to 240 µm, can also be found and few very small fibres (0—40 µm), too (Fig. 13 B).

The size distribution of muscle fibres diameters in the two muscles investigated for both regions of fish body are positively oblique.

Trematomus hansoni

The fibres of the *musculus rectus lateralis* with diameters in size class 20—40 µm make up nearly 38% of all fibres in this muscle in the trunk. The mean diameter of the fibre cross-sections equals, however, 51 µm as numerous fibres have larger diameters, even up to 152 µm (Fig. 15 A).

Musculus lateralis magnus in the trunk is composed of thick fibres. The highest number of fibres (23% of all fibres) is in the size class 140—160 µm, and in subsequent classes their number gradually decreases. Fibres with diameter over 300 µm can also be found, but none were observed below 80 µm in diameter (Fig. 15 A).

The subcutaneous fibres of *musculus rectus lateralis* are over twice as large in the tail part as in the trunk. They are also more varied in their size (20—280 µm), but 61% of all fibres measure 80—140 µm in diameter. This feature clearly distinguishes *Trematomus hansoni* from *Trematomus bernacchii*, and from all other species in the family *Nototheniidae* (Fig. 15 B).

Muscle fibres of *musculus lateralis magnus* are characterised by slightly larger variety of diameters in the tail part (60—340 µm), than in the trunk. The majority of fibres of this muscle (57%) measures 100—160 µm in diameter. The subsequent size classes of fibres (160—300 µm) are nearly equally numerous (3—5% of all fibres each) (Fig. 15 B).

The size distributions of fibre diameters of muscles in the two investigated parts of fish body were positively oblique.

Dissostichus eleginoides

This was the only available representative of genus *Dissostichus*. Both muscles under investigation are characterised by small diameters of their fibres in trunk as well as in tail parts.

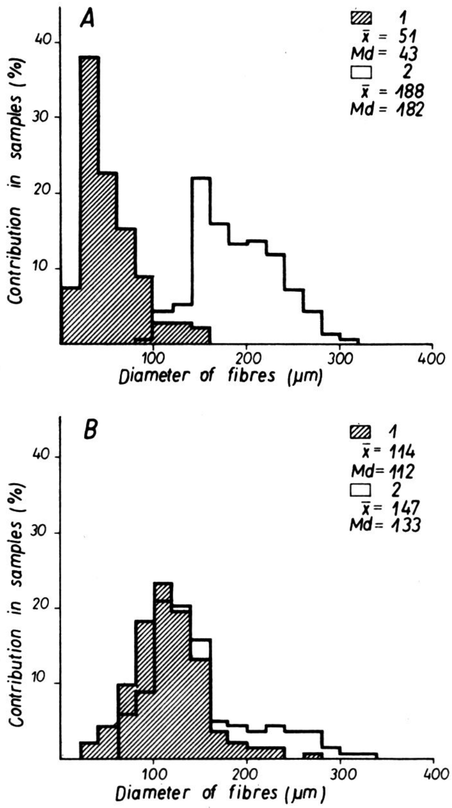

Fig. 15. The size distribution of muscle fibres diameters from the trunk (*A*) and tail part (*B*) of *Trematomus hansoni*
Explanation see Fig. 2.

Fibres diameters of *musculus rectus lateralis* in the trunk measure in single cases up to 121 μm, but the majority of them (68%) does not exceed 40 μm (Fig. 16 A).

Fibre diameters of *musculus lateralis magnus* of this body region are in classes 0—200 μm with the majority of them (69%) of 40—100 μm in diameter (Fig. 16 A).

A very similar distribution of the fibres diameters of both muscles was found in the tail part of fish body. Fibres 20—60 μm in diameter make 74% of all fibres in *musculus rectus lateralis*, so its structure is quite uniform, although six subsequent classes (80—200 μm) occur there, too (Fig. 16 B).

The white fibres are in size classes 0—240 μm and their average diameter is 68 μm. Fibres 20—80 μm in diameter form about 66% of all fibres (Fig. 16 B).

The size distributions of muscle fibre diameters of both muscles investigated in the trunk as well as in the tail are positively oblique.

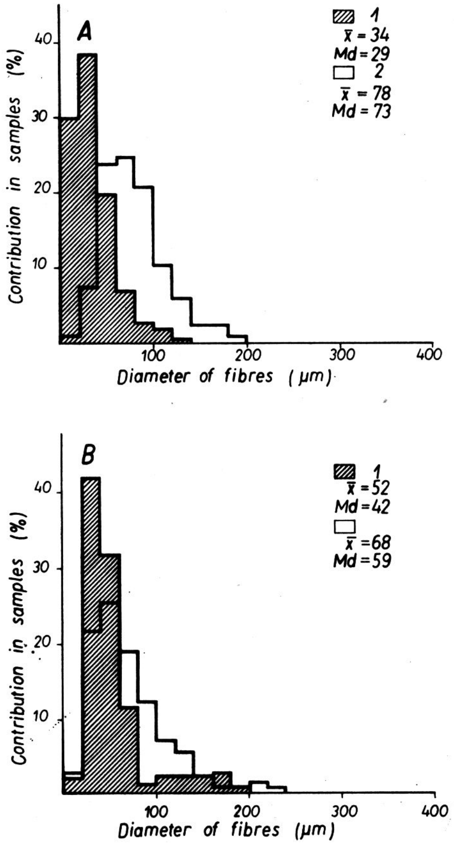

Fig. 16. The size distribution of muscle fibres diameters from the trunk (*A*) and tail part (*B*) of *Dissostichus eleginoides*
Explanation see Fig. 2.

4. Discussion

The fish of the Antarctic Ocean basin live in specific physico-chemical conditions of their environment. The low water temperature, close to 0° C, does not change much (± 1.5° C) during the year. Simultaneously the oxygen saturation of water is close to maximum values and attains 0.7% (Ruud 1965). Uniform oxygen content and water temperature are maintained in even large depths due to the strong water circulation caused by various factors. These unique conditions made possible the forming of numerous endemic species, or even families. One of the main physiological features of described endemites is relatively low metabolism (Hureau et al. 1977), which in the case of family *Chaenichthyidae* reached extreme low values (Ralph and Everson 1968, Hemmingsen, Douglas and Grigg 1969). This was followed by numerous biochemical and morphological adaptations, which led among others, to the lowering of hemoglobin and myoglobin content (e.g. genus *Trematomus* — Hureau et al. 1977), to the reduction of the number of erythrocytes to less than 1 mln in 1 cm^3 of blood in comparison to other non antarctic *Teleostei* (e.g. genus *Notothenia* — less than $1 \times 10^6/1$ cm^3, other *Teleostei* — $1—2 \times 10^6/1$ cm^3, Tyler 1960).

The family *Chaenichthyidae* members contain the lowest number of erythrocytes ever found (e.g. *Chaenocephalus aceratus* — 40 in 1 cm^3 of blood, Hureau et al. 1977), the lowest hemoglobin content, the lowest metabolism (Hemmingsen, Douglas and Grigg 1969) and they lack myoglobin in skeletal muscles (Hamoir 1978). Against this background certain dependencies between the size of muscle fibres and fish metabolism could be outlined.

The presence of the largest fibres was observed for both species of ice-fish, which are also characterised by the lowest metabolism of all fish studied. This is so especially for *Chaenocephalus aceratus* (Hureau et al. 1977), a typical near bottom species, feeding mainly on krill, and hunting only sporadically (Holeton 1970). Slightly smaller fibres were found in *Champsocephalus gunnari*, which, although a white blooded species, is a pelagic one (Holeton 1970) and therefore its metabolism should be higher (lack of data). The subcutaneous fibres of both species are also large (Figs. 2 and 5) when compared to other species investigated, thus also these fibres have low metabolism. However, the presence of mitochondria (red fibres) (Fig. 3) indicates the oxygen type of metabolism contrary to that of white fibres (Fig. 4). These fibres are located close to the skin well supplied with blood vessels (Jakubowski, Byczkowska-Smyk and Michalev 1969), which makes easier the direct and fast supply of oxygen and does not limit their growth in thickness.

The exchange of oxygen in these fish takes place without mediation of hemoglobin, thus the importance of capillary bed is not as great as for red blooded fish. It was found that respiration occurs to a large extent through the skin (Hemmingsen and Douglas 1970), well supplied with blood vessels (Steen and Berg 1966, Jakubowski, Byczkowska-Smyk and Michalev 1969), from which oxygen can reach the tissues through the body fluids. Our preliminary observations have also shown, that the few capillary vessels in muscles are minute and have a thick walls, thus their importance in the distribution of the oxygenated plasma is disputable. As compared with other fish a considerably lowered content of lactic acid was found (Hemmingsen, Douglas and Grigg 1969) and only a small difference in its content in arterial and venous blood. This results from the low muscle metabolism of these fish, which is based mainly on the aerobic decomposition of carbohydrates. In this situation a high ratio of the surface to the volume of muscle fibre would not be an indispensable condition for its proper functioning. Therefore, it seems that natural selection favoured thick fibres of muscles. With such a low metabolism characteristic for these fish every decrease in energy expenditure is particularly favoured by natural selection. Szarski (1968, 1976) formulated a hypothesis, that the increase of cell size, which took place several times during evolution of vertebrates, was caused by energy savings. A low ratio of the surface to the volume of fibres is advantageous from the energetic point of view, as less energy is used for preserving the electrochemical gradient of the cell membranes of the smaller number of thick fibres, than of the larger number of thin fibres, when the mass of muscle remains the same. The differences in the size of fibres of both ice-fishes investigated mirror, as we think, the differences in their behaviour. This is also supported by differences in the shapes of their body, the ratio 1/h (length to height) indicates the larger slimness of *Champsocephalus gunnari* body. Finally factor φ^2 indicates a small similarity of *Chaenocephalus aceratus* to *Champsocephalus gunnari* (Fig. 1).

Genus *Trematomus* differs from the remaining species of family *Nototheniidae* as to the size of fibres. Both species of this genus have the thickest fibres, which is connected with relatively low metabolism and small content of erythrocytes (Hureau et al. 1977). In that respect both these species are more similar to the ice-fish than to the remaining membres of family *Nototheniidae*. But *Trematomus bernacchii* and *Trematomus hansoni* are much more similar to the four remaining species of the genus *Notothenia* as far as the thickness of their muscle fibres is concerned. This results probably from the closer family relation within *Nototheniidae* and from similar near bottom way of life.

The fish of the genus *Notothenia* are characterised by metabolism

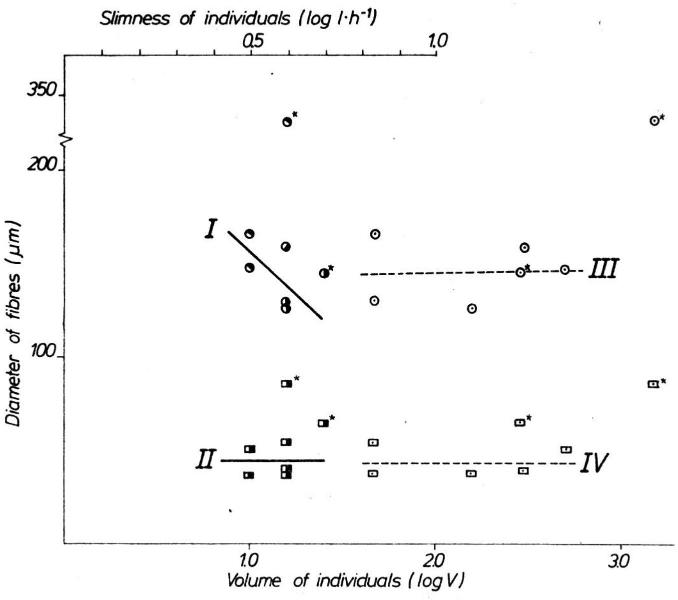

Fig. 17. The correlation of slimness (log $l \cdot h^{-1}$) and volume (log V) of five species from family *Nototheniidae* (*Notothenia nudifrons*, *Notothenia gibberifrons*, *Notothenia rossi marmorata*, *Notothenia corriceps neglecta* and *Trematomus bernacchii*) with their muscle fibre diameters (in the trunk)
I — *musculus lateralis magnus* — equation of regression: $D = 247.2 - 181.6 \times \log l \cdot h^{-1}$.
II — *musculus rectus lateralis* — equation of regression: $D = 44$; III — *musculus lateralis magnus* — equation of regression: $D = 141.6 + 1.85 \times \log V$; IV — *musculus rectus lateralis* — equation of regression: $D = 43.89 + 0.05 \times \log V$. * ice-fish (*Chaenocephalus aceratus* and *Champsocephalus gunnari*) were omitted in correlation calculation as it appears to be very different in fibre diameter size from the other fish.

relatively high for antarctic fish (Hureau et al. 1977), and also by the highest content of erythrocytes. Both these features are lineary related, and influence the very similar distribution of muscle fibres of these fish. On the basis of calculations it can be said, that the slimness of these fish is inversely correlated with the size of diameters of muscle fibres. The correlation coefficients do not confirm such correlation, which may be caused by small number of studied species, but regression analysis indicates the possibility of the existence of such tendency (Figs. 17 and 18). No correlation between the fish volume and diameter of fibres, observed by Stickland (1975) for coral reef fish, was found.

The analysis of the diameter distribution of muscle fibres of *Dissostichus eleginoides* confirms our previous expectations concerning the dependence of the thickness of fibres from the behaviour of fish. *Dissostichus eleginoides* is a predatory pelagic fish, thus its metabolism is possibly highest among all species studied by us, which is confirmed by the studies of de Vries et al. (1974) on *Dissostichus mawsoni*. The presence of small muscle fibres clearly distinguishes this species from family *Chaenichthyidae*, also from the genus *Trematomus*, but there is a similarity to fish of the genus

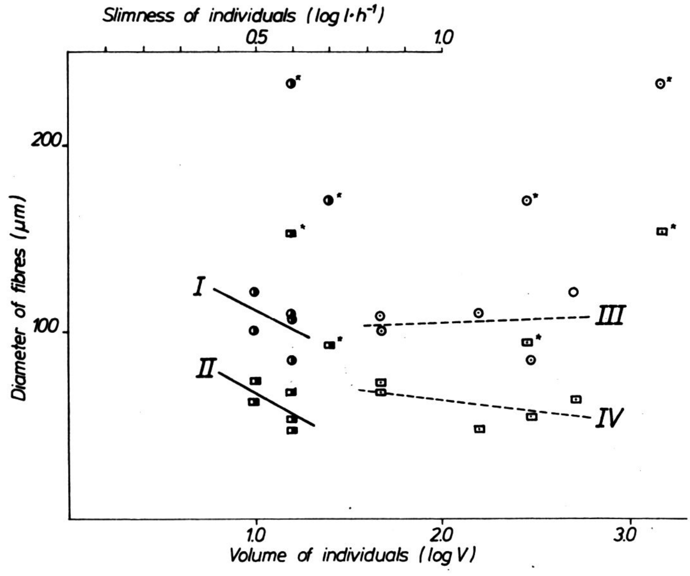

Fig. 18. The correlation of slimness ($\log l \cdot h^{-1}$) and volume ($\log V$) of five species from family *Nototheniidae* (*Notothenia nudifrons*, *Notothenia gibberifrons*, *Notothenia rossi marmorata*, *Notothenia corriceps neglecta*, *Trematomus bernacchii*) with their muscle fibre diameters (in the tail)

I — *musculus lateralis magnus* — equation of regression: $D = 161.2 - 101.6 \times \log l \cdot h^{-1}$,

II — *musculus rectus lateralis* — equation of regression: $D = 123.6 - 113.3 \times \log l \cdot h^{-1}$,

III — *musculus lateralis magnus* — equation of regression: $D = 96.6 + 3.59 \times \log V$;

IV — *musculus rectus lateralis* — equation of regression: $D = 86.78 - 12.39 \times \log V$.

* ice-fish (*Chaenocephalus aceratus* and *Champsocephalus gunnari*) not considered in correlation calculations.

Notothenia, especially in the size distribution of fibres of *musculus rectus lateralis* in the trunk and tail part of body (Fig. 1).

The discussion presented above concerning the mechanism regulating the size of muscle fibres shows unmistakenly, that the only, most plausible factor, which decides upon their size is metabolism. It can be expected that low metabolism will result in thick fibres, and vice-versa. The hight ratio of the surface to the volume of small fibres is advantageous with high metabolism, as it assures quick exchange of lactic acid with capillary vessels surrounding the fibre. When metabolism is low, the amount of lactic acid produced is small and does not require the development of blood vessels to such an extent as in the case of high metabolism, possibly limiting the diagonal growth of a fibre. A large differentiation of the sizes of muscle fibres within such compact families as *Nototheniidae* and *Chaenichthyidae* seems to eliminate the influence of the genetic relation factor.

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5. Summary

Histological analysis of *musculus lateralis magnus* and *musculus rectus lateralis* in the trunk and tail part of body was performed on nine species of fish: *Chaenocephalus aceratus*, *Champsocephalus gunnari*, *Notothenia nudifrons*, *Notothenia gibberifrons*, *Notothenia rossi marmorata*, *Notothenia corriceps neglecta*, *Trematomus bernacchii*, *Trematomus hansoni* and *Dissostichus eleginoides* (Table I). The types of fibres, red or white, were determined on the basis of their affinity to Sudan black B (Figs. 3, 4, 10, 11, 12 and 14). Diameters of fibres were measured on histological slices, and full statistical analysis was made.

The largest diameters of both red and white fibres was found for family *Chaenichthyidae* (Figs. 2—5) (ice-fish), whose representatives do not contain hemoglobin nor myoglobin. Fish of this family are characterised by very low metabolism. Fibres of medium sizes occurred in representatives of genus *Trematomus* (Figs. 13—15). This genus is characterised by lowered hemoglobin and myoglobin content and by lowered metabolism. The remaining representatives of family *Nototheniidae* have the smallest fibres (Figs. 6—9 and 16). Fish of genus *Notothenia* and *Dissostichus* have the highest content of hemoglobin in blood and of myoglobin in muscles, and the highest metabolism among the fish in antarctic waters. Similarities were found within a genus *Notothenia* but there were no similarities found within a family, if their representatives differed in metabolism level.

6. Резюме

Гистологический анализ мышцев (*musculus lateralis magnus* и *musculus rectus lateralis*) туловищных и хвостновых проведено на девяти видах рыб: *Chaenocephalus aceratus*, *Champsocephalus gunnari*, *Notothenia nudifrons*, *Notothehia gibberifrons*, *Notothenia rossi marmorata*, *Notothenia corriceps neglecta*, *Trematomus bernacchii*, *Trematomus hansoni* и *Dissostichus eleginoides* (таблица I). Классификацию типов волокон на красные и белые проведено на основании родства с Суданом чёрным Б (рис. 3, 4, 10, 11, 12 и 14). Измерения диаметров волокон сделано на гистологических обрезках и проведено полный статистический анализ.

Высшую величину диаметров так белых как и красных волокон найдено в семье

Chaenichthyidae (рис. 2—5), (белокравные рыбы), представители которой не имеют гемоглобина и миоглобина.

Рыбы етой семьи характеризуются низкими метаболизмами. Волокна со средними размерами выступали у представителей роста *Trematomus* (рис. 13—15). Этот род отличается пониженным содержанием гемоглобина и миоглобина, а также пониженным метаболизмом. Остальные представители семьи *Nototheniidae* имеют в сравнении с выше приведёнными видами более мелкие мышцевые волокна (рис. 6—9 и 16). Рыбы рода *Notothenia* и *Dissostichus* характеризуются высшим содержанием гемоглобина в крови и миоглобина в мышцах среди рыб выступающих в водах Антарктики, а также ответствено до антарктических условий высоким метаболизмом.

Для рыб вида *Notothenia* характерны сходства зато отдельные семьи отличаются друг от друга уровнем метаболизма.

7. Streszczenie

Analizę histologiczną mięśni (*musculus lateralis magnus* i *musculus rectus lateralis*) tułowiowych i ogonowych przeprowadzono na dziewięciu gatunkach ryb: *Chaenocephalus aceratus*, *Champsocephalus gunnari*, *Notothenia nudifrons*, *Notothenia gibberifrons*, *Notothenia rossi marmorata*, *Notothenia corriceps neglecta*, *Trematomus bernacchii*, *Trematomus hansoni* i *Dissostichus eleginoides* (tabela I). Klasyfikację typów włókien na czerwone i białe przeprowadzono na podstawie ich powinowactwa do Sudanu czarnego B (rys. 3, 4, 10, 11, 12 i 14). Pomiary średnic włókien wykonano na skrawkach histologicznych i przeprowadzono pełną analizę statystyczną.

Najwyższą wartość średnic tak włókien białych, jak i czerwonych znaleziono w rodzinie *Chaenichthyidae* (rys. 2—5) (ryby białokrwiste), której przedstawiciele nie posiadają hemoglobiny i mioglobiny. Ryby z tej rodziny cechuje bardzo niski metabolizm. Włókna o pośrednich wymiarach występowały u przedstawicieli rodzaju *Trematomus* (rys. 13—15). Rodzaj ten charakteryzuje się obniżoną zawartością hemoglobiny i mioglobiny oraz obniżonym metabolizmem. Pozostali przedstawiciele rodziny *Nototheniidae* mają, w porównaniu do wyżej wymienionych gatunków, najdrobniejsze włókna mięśniowe (rys. 6—9 i 16). Ryby z rodzaju *Notothenia* i *Dissostichus* mają najwyższą zawartość hemoglobiny we krwi i mioglobiny w mięśniach spośród ryb występujących w wodach Antarktyki, jak również, odpowiednio do warunków antarktycznych, wysoki metabolizm. Znaleziono podobieństwa wewnątrz-rodzajowe (*Notothenia*), natomiast nie stwierdzono podobieństw w obrębie rodziny, jeżeli jej przedstawiciele różnili się poziomem metabolizmu.

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