Zoology. — *Preliminary researches on the fat-content of meat and bone of Blue and Fin whales.* By C. F. FELTMANN (Netherlands Whaling Company Ltd., Amsterdam), E. J. SLIJPER (Institute of Veterinary Anatomy, State University, Utrecht) and W. VERVOORT (Netherlands Whaling Company Ltd., Amsterdam). (Communicated by Prof. G. KREDIET.)

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According to article 12a of the Schedule attached to the International Convention for the Regulation of Whaling (Washington, December, 2d, 1946) all parts of Baleen whales taken by the catchers of a factory ship or a land station must be processed by boiling or otherwise, except the internal organs, the whalebone and the flippers. In his remarks on the resolutions of the Washington Conference KNUDTZON (1947) demonstrates that a part of the whale-meat is so lean that boiling oil from it is not only useless but also highly uneconomical. It can only be used for human consumption (frozen meat, canned meat, meat extract), for animal food (whale meal etc.) or as raw material for synthetic textile fibres (BRANDT, 1940).

Very few exact data, however, are known about the distribution of the fat and lean meat in the body of big whales. Up to the present time the only source of information about this subject was the publication by HEYERDAHL (1932), whose descriptions of the muscular anatomy of whales are quite unsatisfactory. Moreover in his table 12 he does not give any particulars from which part of the animal the samples originated and the data in table 13 are very incomplete. HEYERDAHL's researches about the content of fat in different parts of the whale-skeleton are also very incomplete and partly incomprehensible, whilst not a single statement in literature can be found on which the directions of the International Convention about the flippers can be based. Consequently the modern whaling industry still badly needs exact data about the fat-content of meat and bone in the different parts of the whale, at the different times of the season, on the various whaling grounds and in whales of different sex, size and condition. We therefore made some preliminary researches about this subject during the first antarctic season of the Dutch floating factory "Willem Barendsz". The operations of this ship were carried on from December 17th 1946 until April 7th 1947 in the Southern Atlantic Ocean (Bouvet- and Weddell-sector of the Antarctic Whaling grounds; Area III and II) between 55° and 67° S. and between 7° E. and 26° W. Our data, unfortunately are comparatively scarce but the conclusions that can be drawn may serve as a basis for further and more extensive investigations.

I. *The meat.*

A large portion of the whale meat originates from the musculature of the back. This musculature can be divided in three different longitudinal strands (fig. 1, 2). The upper or epaxial strand fills the space between

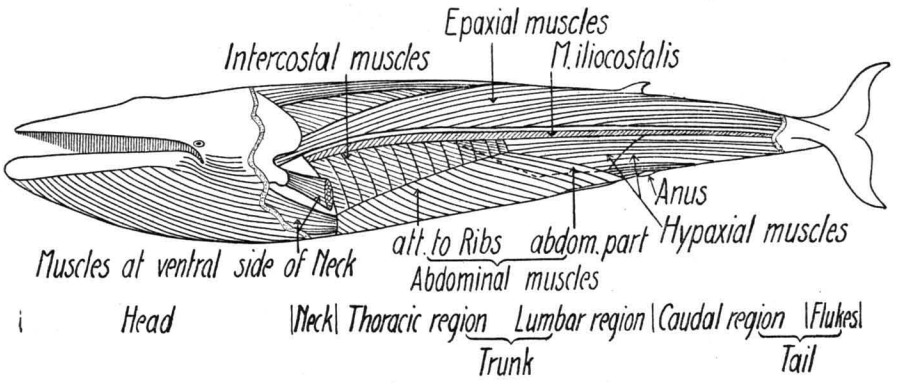

Fig. 1. Schematic drawing of the musculature of the trunk and tail in the big whales.

the neural spines and the transverse processes. It consists of the m. spinalis, semispinalis capitis, transverso-spinalis, longissimus dorsi, extensor caudae medialis and lateralis (see SLIJPER, 1936, p. 217; 1946, p. 73), but in adult animals all these muscles are so intimately fused that only one single huge muscular complex can be distinguished from the occipital part of the skull up to the tail-fin. The lower or hypaxial strand in the lumbar region fills the space between the transverse processes and the vertebral bodies and in the tail the space between the transverse processes and the chevron bones. It consists of the m. hypaxialis lumborum, the m. flexor caudae medialis and lateralis and the m. levator ani. The small intermediate strand lies along the angles of the ribs in the thoracic and along the summits of the transverse processes in the lumbar and caudal region. This muscular strand

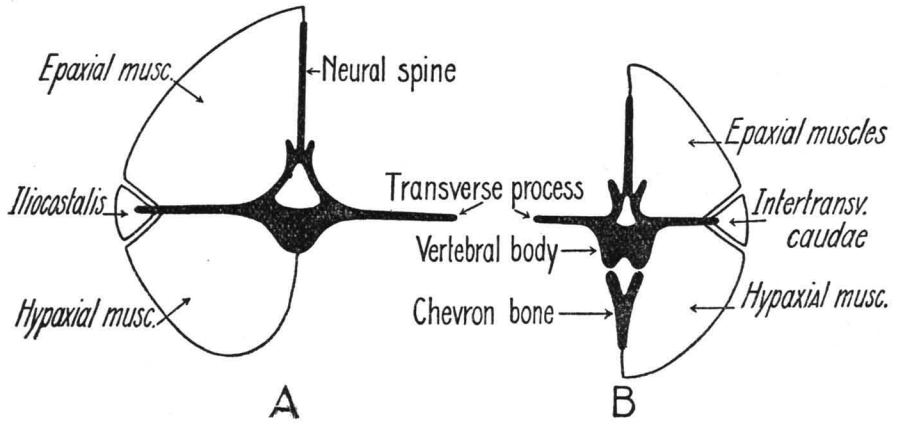

Fig. 2. Very schematic transverse sections through the vertebral column and the spinal musculature of the big whales. *A*, lumbar region. *B*, caudal region.

has arisen from the fusion of an epaxial (m. iliocostalis dorsi et lumb.) and a hypaxial (m. intertransv. caudae) component (SLIJPER, 1936, p. 245). The original line of demarcation lies at the lumbo-caudal border, i.e. at the level of the anus. A description of the other musculature can be found in the publications by SCHULTE (1916) and SLIJPER (1936).

Microscopic examination of sections stained with Sudan III showed that the fat of meat is only found in the connective tissue and not in the muscle-fibres, just as might be expected. Therefore by microscopic examination already a rough impression about the percentage of fat may be obtained from the quantitative relation between the red muscular and the white fatty connective tissue.

The data in table 1 and 2 show that by far the largest quantity of fat among the musculature of the back, is found in the meat of the tail, i.e. the part of the back behind the anus. Here the fat-content averages 20 % (Fin whale) and 37 % (Blue whale). The fat-percentage increases from the anus to the flukes. Moreover, there are three longitudinal strands in the musculature with a higher content of fat than the other meat, viz. along the summits of the neural spines (dorsal part of the epaxial musculature), along the summits of the transverse processes (m. intertransversarius caudae) and along the summits of the chevron bones (ventral part of the hypaxial musculature). Only the first and last strands have been described by HEYERDAHL (1932), whose fat-percentages are quite in accordance with our findings if one takes into account that his samples were taken at the level of the anus.

With regard to the thoracic region, HEYERDAHL (1932, pl. IV, fig. 10) distinguishes between an outer and an inner layer of the epaxial musculature, the outer layer being much fatter than the inner. In our opinion, however, there are in the thoracic and lumbar region only two comparatively small longitudinal strands with a higher percentage of fat (fig. 2), viz. a strand along the summits of the neural spines (dorsal part of epaxial musculature) and a strand along the angles of the ribs and the summits of the lumbar transverse processes (m. iliocostalis dorsi et lumb.). These strands show a fat-percentage which averages 12 %. Macroscopically these strands can be distinguished quite well from the remaining meat. The same may be said about a very thin layer of fat meat along the side of the neural spines and vertebral bodies and along the upper side of the transverse processes. No analyses, however, were made of this layer.

About 90 % of the epaxial and hypaxial musculature of the thoracic and lumbar region consists of very lean meat with a fat-percentage of 4—6 % in the cranial part of the thoracic epaxial musculature and a percentage of 3—4 % in the other parts of the meat of the back.

There is a comparatively great local variability in the fat-content of the abdominal musculature. The parts attached to the ribs are fairly fat (± 17 %), the abdominal wall itself, on the contrary, is lean (± 5 %). The

TABLE 1.

Percentage of fat in the meat of the Blue whale, Balaenoptera musculus L.
In italics: percentage of water.

Number	229	230	524	548	737
Date	26-1-'47	27-1-'47	4-3-'47	7-3-'47	4-4-'47
Length in feet	85	81	83	80	70
Length in meters	25,9	24,7	25,3	24,4	21,3
Sex	♀	♀	♂	♂	♀
Pregnant or not	Pr.	Pr.			Not pr.
Supposed maturity	Almost sex. mat.	Sex. mat.	Sex. mat.	Sex. mat.	Immature
Vertebral epiphyses ankylosed up to	10 Th.	Not	1 L.	Not	Not
Number of hours dead	10	15	15	18	2
Condition of muscles	Fresh		Fresh		Very fresh
1. Muscles of the back					
a. Epaxial muscles					
1. Thoracic region					
Strand along summits of neural spines		9,2 *67,5*			
Interior part			2,6 *73,0*	12,0 *69,0*	4,9 *72,0*
2. Lumbar region					
Strand along summits of neural spines	14,3 *50,0*				
Interior part			3,6 *72,5*	8,6 *70,0*	3,7 *72,5*
3. Caudal region					
Strand along summits of neural spines		45,0 *38,0*			
Interior part			20,4 *60,0*	38,0 *48,0*	43.3 *42,5*
b. M.iliocostalis lumb.			12,8 *64,0*	13,0 *65,0*	
c. Hypaxial muscles					
1. Lumbar region interior part	5,6 *54,0*		3,5 *73,0*	8,4 *71,0*	
2. Caudal region interior part			6,7 *73,0*	17,0 *60,0*	
2. Abdominal muscles (m. obl. abd. ext.)					
a. Part attached to the ribs	17,5 *50,0*				17,0 *61,5*
b. Abdominal part					3,8 *72,0*
3. Intercostal muscles	28,4 *37,0*				
4. Muscles at ventral side of neck (m. brachiocephalicus)					21,4 *59,0*

TABLE 2.

Percentage of fat in the meat of the Fin whale, Balaenoptera physalus L.
In italics: percentage of water.

Number	20	266	375	450	504	744
Date	21-12-'46	3-2-'47	15-2-'47	23-2-'47	1-3-'47	5-4-'47
Length in feet	66	74	70	73	72	68
Length in meters	20,1	22,6	21,3	22,3	22,0	20,7
Sex	♂	♀	♀	♀	♂	♀
Pregnant or not		Pr.	Not	Pr.		Not
Supposed maturity	Sex. mat.	Almost phys. mat.	Sex. mat.	Almost phys. mat.	Sex. mat.	Just sex. mat.
Vertebral epiphyses ankylosed up to		10 L.		10 L.		
Number of hours dead	24	25	5	13	47	1
Condition of muscles	Fairly fresh	Fairly fresh	Fresh	Fresh	Inner parts putrified	Very fresh
1. Muscles of the back						
a. Epaxial muscles						
1. Thoracic region Strand along summits of neural spines		4,0 *68,0*		24,0 *58,0*		
Interior part				7,8 *69,0*	1,9 *72,5*	8,3 *70,0*
2. Lumbar region Strand along summits of neural spines					16,0 *60,0*	
Interior part	3,3			3,0 *71,0*	2,9 *73,0*	3,6 *71,0*
3. Caudal region Strand along summits of neural spines		27,0 *50,5* near the anus				
Interior part					15,5 *57,0*	20,0 *58,0*
b. M. iliocostalis lumb.				26,0 *58,0*		
c. Hypaxial muscles						
1. Lumbar region interior part			2,4 *75,0*	2,5 *72,0*	2,8 *73,0*	
2. Caudal region interior part		6,0 *68,5* near the anus				
2. Abdominal muscles (m. obl. abd. ext.)						
a. Part attached to the ribs	2,8	36,0 *48,0*			4,0 *73,0*	32,6 *49,0*
b. Abdominal part	1,8					10,0 *67,0*
3. Intercostal muscles	2,7					
4. Muscles at ventral side of neck (m. brachiocephalicus).						28,8 *55,0*

musculature of the lower (ventral) side of the neck (chiefly m. brachio-cephalicus) is fat (± 25 %) and the same impression is gained from the other musculature of the pectoral fin (flipper) by macroscopic examination.

There is a comparatively large variability in the fat-content of the meat of various animals and our material is so small that no conclusions can be drawn about correlations with the proceeding of the season or with the condition of the whales. No conclusions about the time of the season can be drawn from the tables by HEYERDAHL (1932), although he gives some data about increase of the fat-content. In his opinion pregnant females should have the fattest, lactating females, on the contrary, the leanest meat. Moreover there is a certain correlation between the fat-content of the meat and that of the layer of blubber. A definite difference in fat-percentage between Blue and Fin whales neither appears from our tables, nor from those of HEYERDAHL (1932), with the exception of the tail-musculature, which is much fatter in the Blue than in the Fin whale. WAGNER (1939) thinks that there is a certain correlation between the fat-percentage of meat and its content of vitamin A. His data, however, show no marked differences between samples that, according to the place where they were taken, must have been very fat and other samples that apparently were lean.

It is a well-known fact that, even in the cold water of the Antarctic, comparatively soon after death a marked decomposition sets in, caused by putrefactive and fermentative processes. These processes are initiated by the hot air blown into the body cavity and the fermentative processes in the stomach, whilst the comparatively small surface of the animal and the thick layer of blubber seriously hamper the exchange of temperatures between the body and its surroundings. These processes cause a rise of the temperature of the meat that in the first hours after the death appears te fall from about 37° C to about 30° C (HEGGENHAUGEN, 1932).

Our data about the temperature of the meat (table 3) are quite in

TABLE 3.

Temperature of the meat of dead Blue and Fin whales.

Number	Species	Sex	Length in m	Number of hours dead	Part of the meat	Temperature in °C.
494	Fin	♂	19,50	27	Inner part of thoracic epaxial muscles	34
496	Fin	♂	20,40	24	Inner part of lumbar epaxial muscles	30
					Abdominal muscles	31
540	Blue	♀	21,65	15	Hypaxial muscles	36

accordance with those of AASER (1944) that were collected at Norvegian land stations, but they are much lower than those of HEYERDAHL (1938), collected in the Antarctic. During decomposition of the meat a part of the

fat is lost, and although no definite correlation between the age of the carcase and the fat-content of the meat appears from our tables, the data about the 47 hours dead Fin whale Nr 504 show a marked decrease in the fat-percentage of the most putrefied inner parts of the musculature.

During the month of December a sample of the residue which is blown off from the oil-separators (the grax) was analysed. This grax contains 3—3,5 % fat and according to HEYERDAHL (1932, p. 68) even in the laboratory it is nearly impossible to extract fat from meat with a fat-percentage under 3—4 %.

From all the above-mentioned facts the conclusion now may be drawn that it is quite useless to process the meat of the back cranial of the lumbo-caudal border (i.e. headwards of the anus) in the boilers. It is almost impossible to separate the small fat strands in this region from the other meat since this would cause a great loss of time. This part of the whale-meat therefore can only be used for the products mentioned on page 604. The same impression is gained from the abdominal parts of the abdominal muscles. The meat of the tail and the other parts of the body, however, is generally fat enough for the production of whale-oil.

II. *The bone.*

According to the International Convention all parts of the skeleton must be processed with the exception of the bones of the pectoral fin (flipper). The only available data in literature about the fat-content of the bones of whales are given by HEYERDAHL (1932). This author distinguishes between red and yellow bone. The red bone now and then would occur in the vertebrae of those whales that were "blodskudd", i.e., in whales that would be struck by the harpoon in such a manner that the pores of the vertebral bone filled with blood. The red bone contains much less fat than yellow.

According to our opinion, however, this explanation of HEYERDAHL (1932, p. 72) is quite incorrect. Certainly there is a very striking difference between red and yellow bone, but just as in other animals this difference is caused by the fact that the meshes of the spongiosa of the red bones contain red bone-marrow, by which the blood-cells are formed. In the spongiosa of the yellow bones almost exclusively fatty tissue is found. These observations were confirmed by microscopic examination of sections stained with Sudan III. The sections showed that, just as in other mammals, in the red bone-marrow also a large quantity of fat cells may be found. We were, however, struck by the fact that the fat is not only found in the fat-cells of the red and yellow bone-marrow, but also in large quantities in the bone-cells (osteocytes) themselves. These cells were completely filled with fat, with the exception of the space occupied by the nucleus. According to WEIDENREICH (1930, p. 395) fat also occurs in the osteocytes of man and other mammals, but only very exceptionally the cells appear to be so crowded with fat as we saw it in the whales. WEIDENREICH (1923,

p. 576) describes such cells in the sesamoid of the m. peronaeus longus of man.

Generally in fetal mammals all the bones contain only red bone-marrow. In man this condition is retained up to the 7th year. Then in the long bones of the limbs the red marrow begins to turn into fat, a process that is finished about the 20th year (PINEY, 1922). In adult men red bone-marrow is present in the bones of the skull, the vertebral column, the ribs (with the exception of the distal $2\frac{1}{2}$ cm), the sternum and the pelvic bone. So about half of the bone-marrow is red, the other half yellow (JAFFÉ, 1936). ACKERKNECHT (1912) has shown that the long bones of the horse already contain yellow bone-marrow at birth. In horses younger than eight years the yellow bone-marrow of the vertebral column is only found in the caudal vertebrae, but in animals older than 15 years the turning into fat has proceeded in a cranial direction up to the first lumbar vertebrae. In these animals also in the thoracic vertebrae, the ribs and the sternum some yellow patches may be found in the red marrow (VARIĆAK, 1938). In the cow the process begins after birth but proceeds very soon up to the middle thoracic vertebrae. The same may be said of the pig, but in the adult cat and dog only the sacral and caudal vertebrae contain yellow marrow (VARIĆAK, 1938). In the vertebral column of the Guinea pig, the rabbit, the rat and the mouse this marrow is only found in the tail. Moreover these small mammals always possess red marrow in the long bones of the limbs, even when they are quite adult (RANVIER, 1889, p. 264; MAXIMOW, 1927, p. 379; STASNEY and HIGGINS, 1935, p. 77). It therefore appears that in growing mammals the red marrow disappears first from the long bones and after that from the vertebrae in a caudo-cranial direction. According to VARIĆAK (1938) the feeding-condition of the animals does not influence their amount of yellow marrow.

The examination of the skeleton of a 503 cm long Blue whale fetus showed that in the big whales shortly before birth all bones contain only red marrow. In the young, probably not yet sexually mature, 21,6 m long Blue whale Nr 452 (table 4) all vertebrae behind the 5th caudal contained only yellow, the vertebrae before the 2d lumbar only red marrow. From 2 L.—5 Ca. scattered patches of red could be observed in the yellow vertebral bodies. Consequently in the vertebral column the red marrow is replaced by yellow, fatty marrow in a cranial direction, just as in other mammals. The yellow marrow first appears in the vertebral processes, after that in the outer layer of the spongiosa of the vertebral bodies and finally in the centre of these bodies, just the reverse as in the big domestic animals (VARIĆAK, 1938). In adult whales generally the cervical and thoracic vertebrae contain only red, the majority of the lumbar and all the caudal vertebrae only yellow marrow. A transitionary condition is found in the first 2—4 lumbar and sometimes also in the last thoracic vertebrae (table 4). The bones of the skull, the ribs, the scapula and the bones of

TABLE 4.

Distribution of red bone-marrow in the Blue whale, Balaenoptera musculus L.
C = cervical, Th = thoracic, L = lumbar, Ca = caudal vertebra.

Number	452	180	185	229	181
Sex	♂	♀	♂	♀	♀
Length in feet	71	79	81	85	86
Length in meters	21,6	24,1	24,7	25,9	26,2
Supposed maturity	Sex. immature	Sex mat.	Sex. mat.	Nearly phys. mat.	Sex. mat.
Epiphyses of vertebrae ankylosed up to	Not ank.	Not ank.	7 L	8 Th	6 L
Vertebral body and processes red	1 C—1 L	3 C—15 Th	1 C—2 L	6 C—8 Th	1 Th—2 L
Body red, processes yellow	2 L			9—12 Th	
Centre of body red, proc. yellow	3—4 L	1 L	3 L	3—15 Th	3—4 L
Body with small red patches	5—7 L		4—5 L	1 L	5—7 L
Body with very small red patches	8 L—5 Ca				

the flipper contain only yellow marrow. Therefore in the big whales the total quantity of red marrow and consequently the quantity of blood-forming tissue in relation to the size of the animal is still much smaller than in the big domestic animals.

In the skull and vertebrae of the whales the layer of compacta is very thin. These bones almost completely consist of spongiosa with comparatively large meshes. The bones of the flipper and the ribs, however, show a fairly thick layer of compacta.

Table 5 shows that the vertebral bone with red marrow shows a fat-content of 3,4—24 % and that with yellow marrow a percentage of 38—67 %. These data are quite in accordance with those of HEYERDAHL (1932, table 15), if his "blodsprengt hvirvel" are identified with vertebrae containing red marrow. With regard to the bones of the skull it may be said that our fat-percentages from the Blue whale (51—84 %) are much higher than those of HEYERDAHL (1932, table 15; 40—35 %), who analysed only the skull-bones of the Fin whale. All the bones of head, trunk and tail of big whales contain enough fat for the extraction of oil in the boilers, although the fat-content of the red cervical and thoracic vertebrae is markedly less than that of the other bones.

About the flippers the following particulars could be obtained:

1. Nr 523, Blue whale, 78 feet, 23,80 m, sexually mature ♂, 15 hours dead, 4-3-'47.

	% fat	% fatty acids
Humerus (spongiosa)	64,0	0,2
Radius and ulna, distal part (spongiosa)	69,0	0,2

TABLE 5.

Percentage of fat in the different parts of the skeleton of Blue and Fin whales.
In italics: percentage of fatty acids.

Species	Blue	Blue	Blue	Blue	Fin
Number	126	169	513	576	374
Date	6—1—'47	15—1—'47	2—3—'47	12—3—'47	15—2—'47
Sex	♂	♀	♀	♀	♂
Length in feet	78	84	89	87	59
Length in meters	23,8	25,6	27,1	26,5	17,7
Pregnant or not		Not	Not	Pr.	
Supposed maturity	Sex. mat.	Phys. mat.	Phys. mat.	Almost phys. mat.	Sex. immat.
Epiphyses of vertebrae ankylosed up to	7 L.	2 Th.	2 Th.	5 L.	Not
Number of hours dead	11	3	52	26	7
Lower jaw	73,4 *0,43*			84,2 *0,1*	
Rostrum of skull	51,4		67,5 *0,8*	81,6 *0,14*	65,4 *0,9*
Proc. coracoideus of scapula	69,3 *0.35*				
Rib					32,0
Anterior thoracic vertebra (red)		24,0	7,2 *61,0*	20,2	3,4
Anterior lumbar vertebra (red)	18,4				
Anterior lumbar vertebra (yellow)		54,0	27,3 *43,0*	49,2	67,0 *0,25*
Posterior lumbar vertebra (yellow)	60,6 *0,23*				
Caudal vertebra (yellow)	53,9		38,5 *20,0*	62,3	52,0 *0,2*

2. Nr 696, Blue whale, 81 feet, 24,7 m, sexually mature ♀, not pregnant, no vertebral epiphyses ankylosed, 3 hours dead, 28-3-'47.

Radius and ulna, proximal part (spongiosa)	51,0
Radius and ulna, distal part (spongiosa)	63,0
Metacarpal bones	60,0
Fibrous connective tissue of distal part of fin	16,0

These data show that the flippers of the Blue whale contain a large amount of oil of good quality. Unfortunately no flippers of the Fin whale were analysed, but in connection with the data of table 5 it may be expected that they will not show great differences with those of the Blue whale. There is no particular difficulty in processing the flippers on the deck of a factory-ship and consequently the conclusion may be drawn that there is no reason why it should be allowed to throw them away.

The data about the 52 hours dead Blue whale Nr 513 show that just as in the meat, the fat-percentage of the bone is unfavourably influenced by heat and decomposition of the tissues. In the thoracic and lumbar vertebra all the bone-marrow has disappeared; the meshes of the spongy bone are

empty. The fat-content of these bones shows a very marked decrease. This decrease is less in the caudal vertebra which is situated nearer to the surface of the body and it is smallest in the rostrum of the skull, where the bones lie just under the comparatively thin skin. The data about this whale show likewise that with decreasing fat-content the amount of fatty acids increases and consequently the quality of the oil decreases as well.

III. *Summary*

All parts of the musculature of Blue and Fin whales generally contain in their connective tissue so much fat, that oil can be extracted from them in the boilers of a factory-ship or land-station, with the exception of the back-musculature cranial of the lumbo-caudal border (i.e. the level of the anus) and probably also of the abdominal part of the abdominal musculature. Therefore the largest part of the whale meat can only be used for human consumption, for feeding animals or for the making of synthetic textile fibres. No definite difference in the fat-content of the meat could be found between Blue and Fin whales, with the exception of the tail-musculature, which generally is much fatter in the Blue whale.

A marked decrease of the fat-content as well as an increase of the percentage of fatty acids was found in the inner parts of the meat and bone of those whales that were processed too long after death. Our material was so small, however, that no definite relation could be found between the number of hours after death and the decrease of the fat-content.

In adult Blue and Fin whales red bone-marrow is practically only found in the cervical and thoracic vertebrae. Consequently they possess relatively less blood-forming tissue than is known from any other mammal.

The fat of the bone of whales is found in the red and yellow bone-marrow as well as in the osteocytes. Although red bones contain less fat than yellow bones, all bones are fat enough to be processed in the boilers. The same may be said about the flippers and consequently there is no reason why the International Convention about the Regulation of Whaling should allow them to be thrown away.

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