Determination of the Age of Antarctic Blue and Fin Whales by the Colour Changes in Crystalline Lens

Masaharu Nishiwaki

CHAPTER I. FOREWORD

While on board a whaling factory ship as a research biologist in the 1947 - 1948 Antarctic whaling season, I noticed variation in the shade of of yellow colour in whale eyes. It reminded me of those ancient folk tales where "old badgers" and "ghostly cats" always had golden eyes that shone brightly in the dark. It finally led me to the discovery of a presence of a certain relationship between the colour changes of crystalline lens and the age of whales.

After returning to Tokyo in 1948, I looked up some literature and found some reference made already in 1883 to the lenticoular colour changes according to age in humans. However, no references as to the existence of this relationship in animals were found. None of the bibliographies contained any numerical data of the colour changes in these references.

In order to express numerically such colour changes. I estimated the colour changes, i. e. the degree of colouration, during the whaling season of 1948-1949 when I was again on board a whaling factory ship in charge of biological research, by the method described in proceeding chapters. These were examined with data on age estimation in whales by some other methods.

CHAPTER II. Method of Determining Colouration, or Colour Changes in Crystalline Lens

During the 1947-1948 whaling season, lenses from 32 blue whales and 69 fin whales were studied. It was found that macroscopic examinations reveal varieties in colour ranging from colourless or clear, to light yellow and deep yellow. The development of colour was found to become darker

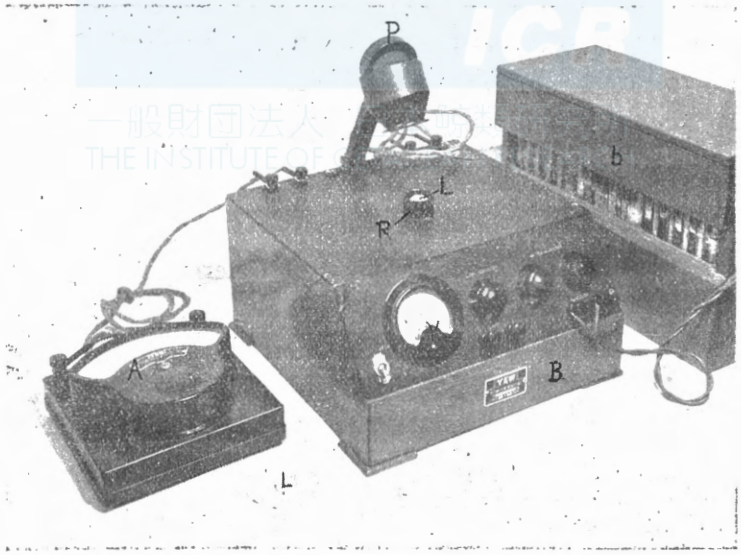
with the increase in body length and the number of corpora lutea or the weight of testes, In order to express these colour changes in numerical values. An apparatus as shown in Figs. 1a and 1b were devised.

Deep thanks are expressed to Mr. Seiji Matsui, Mr. Yoshiaki Nakayama, Mr. Yoshio Sawaji, Mr. Mieyoshi Matsuzaki, Tokyo Shibaura Electric Company Ltd. and Mr, Takeshi Takei and Mr, Yoshitomi Harada, Yokogawa Electric works for their guidance and assistance for the deviee of this apparatus.

Fig. 1a. Absorption Measuring Apparatus.

The glass cylinder shown in Fig. 1a contains some crystalline lens already measured.

Fig. 1b. Miniature of Absorption Measuring Apparatus



The apparatus were based on the fact that stronger the colour, more absorption of light would take place. Therefore, a definite amount of light is passed through a crystalline lens, and the amount of light filtered therefrom, is received by a photocell by which the intensity of light would be recorded by an ammeter.

In Fig. 1, the electric current from the battery (b) is measured by the voltmeter (V) and reaches the light source (1) (contained in the central machine (B)) after voltage is made constant by a resistance. A light of definite intensity from the light source (1) is passed through a lens to become a parallel light, passes through a slit (S) to be radiated to upper part of the machine. At this place, the light passes through the crystalline lens (L) contained in a vessel (R) and is received by the photocell (P), the amount of current received there of being shown by the ammeter (A). The ammeter is graded from 0 to 100, 0 being at a point where no current is passing, and 100, when a definite intensity of current is registered. Prior to actual use (every time the crystalline lens is measured), this needle is set to 100 by the use of a resistance in the apparatus(B). A light passing through a lens would give a certain value in percentage minus the amount of light absorbed by the crystalline lens. The amount of light registered in percentage is the amount of light that has passed through the crystalline lens and, therefore, the amount of light obstructed and absorbed by the coloring in crystalline lens is the value obtained by substracting the value of percentage obtained on the ammeter from 100. This value is designated as the degree of lenticular colouration (light absorption by crystalline lens).

The crystalline lens become slightly larger (increase in diameter and height) with the increase of body length (i. e. age). It becomes slightly clouded with passage of time after the death of a whale so that the lens does not show absorption ratio proper to the degree of colouration.

The fact of an increase in the size of crystalline lens was not taken into consideration in checking the values. There may be some question of how a parallel light from a slit definite size would be affected by the difference in curvature due to size of a crystalline lens but it was found negligible and no correction was made on this account.

The turbidity of the lens was corrected by the values determined from the curve of rate of change after death described later. Table I shows the change in light absorption rate according to passage of time after killing.

Table I. Change in Light Absorption Rate According to Elapse of Time from Killing.

No.	Species of Whale	Sex	Time			Elapsed time from killing to measuring		1st Value %
			Killed at	Treated at	Measured at	hr.	min.	
46	Fin	Male	0330	0420	0450	1	20	88.5
200	〃	Female	1530	1600	1620	0	50	93.5
265	〃	Male	1800	1850	1900	1	00	77.0
294	Blue	Male	1515	2015	2130	6	15	84.0
311	Fin	Male	1615	1745	1755	1	40	79.5
379	〃	Female	1350	1425	1435	0	45	72.0
451	Blue	Male	1820	1850	1900	0	40	92.0
578	〃	Female	0800	0845	0900	1	00	82.0

No.	Measurements made after									
	30 min %	1 hr. %	1.5 hrs. %	2 hrs. %	2.5 hrs. %	3 hrs. %	4 hrs. %	5 hrs. %	6 hrs. %	7 hrs. %
46	86.0	86.0	83.5	83.5	—	—	—	—	—	—
200	93.0	91.0	—	89.0	—	87.5	—	88.0	—	—
265	76.5	76.0	—	—	74.0	—	73.0	—	—	—
294	83.0	—	82.5	—	—	82.5				
311	79.5	—	77.5	—	75.5	—	—	—	—	—
379	—	70.0	—	68.0	—	66.0	66.5	66.0	—	65.0
451	92.0	—	90.5	88.0	87.0	—	86.5	—	—	—
578	81.5	—	81.5	79.5	—	77.5	76.5	—	76.5	

No.	Measurements made after					Marks on Graph	Colouration (Living Index) %
	8 hrs. %	9 hrs. %	10 hrs. %	11 hrs. %	12 hrs. %		
46	83.5					•	90.0
200	—		87.5			○	94.0
265	72.0					△	78.0
294						□	89.0
311	75.0	—	—	—		★	82.0
379	—	—	—	—	65.5	*	73.0
451	—	86.0	—	—	85.5	不	92.5
578						×	83.5

The values in Table I was turned into a graph and a curve was obtained of the change in colouration by passage of time, as shown in Fig. 2. The solid line is the ratio of colour change after death. All the data contained in the present paper have been corrected by this curve.

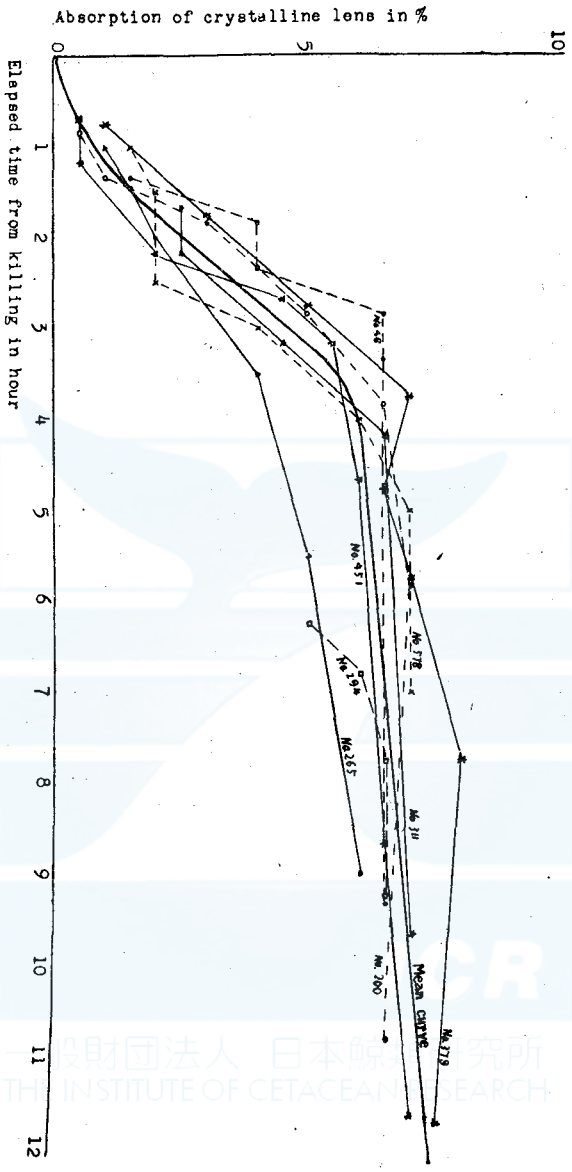


Fig. 2.
Variation of Absorption of Crystalline Lens according to time elapsed from killing

CHAPTER III. Material of Investigation and Individual Data

Crystalline lens of both eyes were measured by the method previously described with all the whales caught by the Hashidate-maru fleet in the

Antarctic during the whaling season of 1948-1949. The number of whales caught were 291 heads of blue whales (183 males and 108 females) and 425 heads of fin whales (203 males and 222 females), of which 3 male blue whales, 3 male fin whales and 3 female fin whales were excluded owing to cataracts and other diseases of the eye. Individual data of whales are given in the Supplement according to the species and sex of whales.

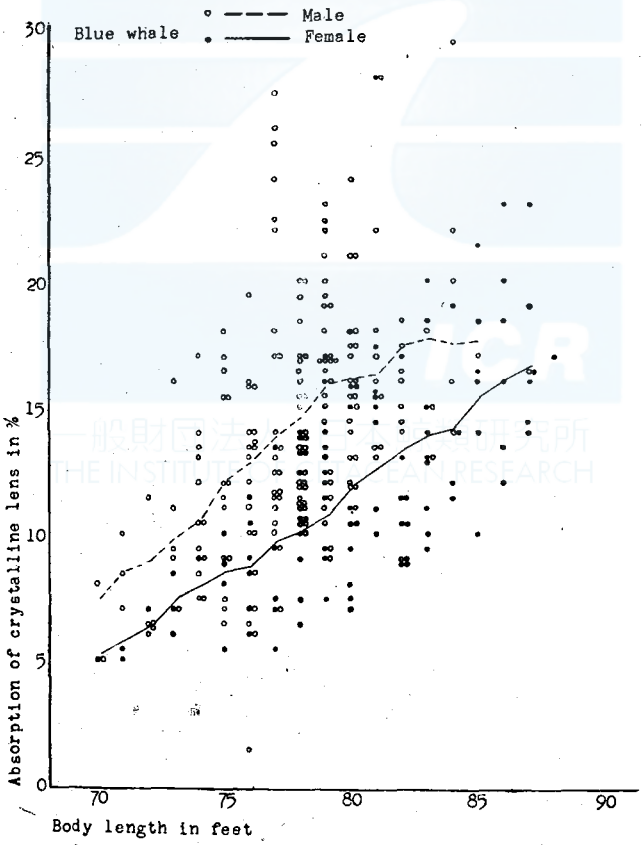
For printing reasons, measurement table of each whale was only sent to those who desired it, without appending to this report.

—(Compiler)—

Grateful thanks are expressed to General Manager Hiroshi Kurebayashi and the crew of the Hashidate-maru, Nihon Suisan Co. Ltd. for cooperation and to Mr. Masayuki Nakajima and Noboru Kanasaki for assistance.

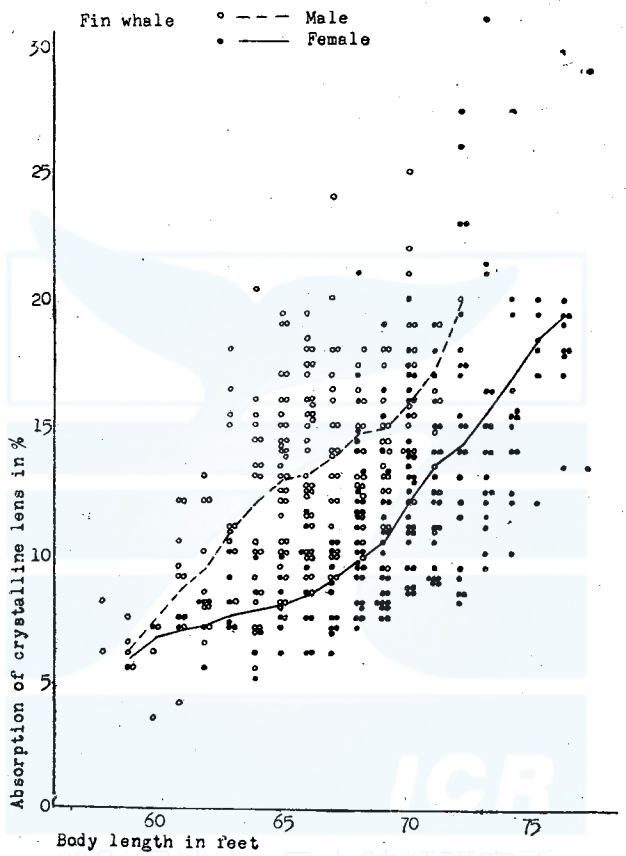
CHAPTER IV. Relationship between Lenticular Colouration and Body Length

Fig. 3. The Degree of Lenticular Colouration According to Body Length



The body length, naturally, increases with growth. Since the degree of lenticular colouration is one of the data showing growth, examination was made as to the presence of any relationship between body length and degree of colouration.

Fig. 4. The Degree of Lenticular Colouration According to Body Length

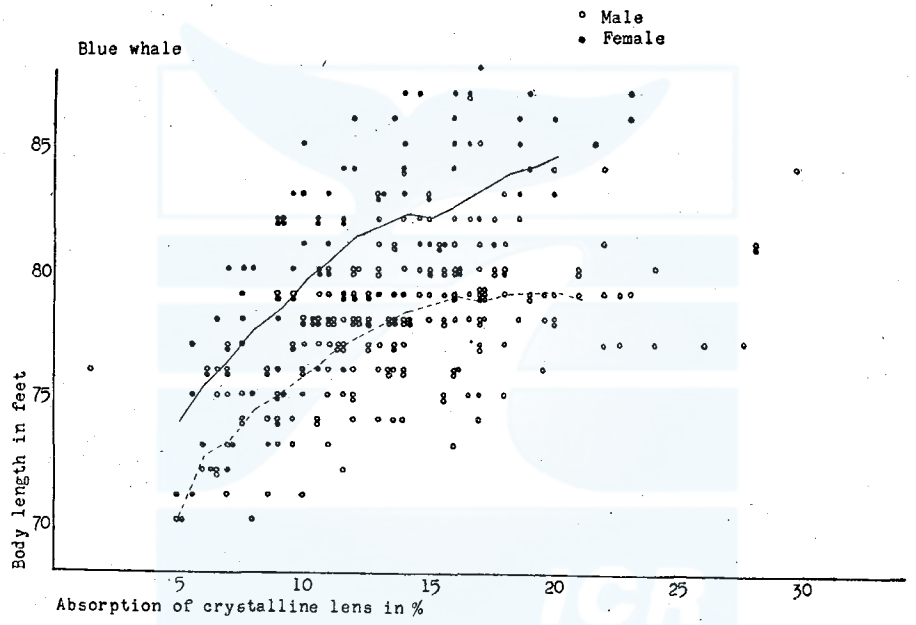


Figs. 3 and 4 show the distribution of the degree of lenticular colouration according to body length in blue and fin whales, respectively. White circles denote those of male whales, and black dots, those of females. It can be seen that both males and females show definite increase of colouration with the increase in body length. The broken lines in both Figs. 3 and 4 show the curve of average degree of lenticular colouration according to body length in male whales, and the solid lines show those of females. Average of male and female whales did not seem to show an average of whales in general and were, therefore, excluded. Both average lines show linear tendency. The colour of crystalline lens becomes darker with elongation of

the body, i. e. with the elapse of time after birth.

The curve data for age estimation in whales in which male and female data could be combined include those for body weight and body length. In baleen whales, data for males generally come out below those of females. However, the curve for average degree of colouration in females are smaller than those for males. This must show that, in comparing male and female of the same lengths, females are generally younger than the males.

Fig. 5. Average Length of Whales According to Degree of Lenticular Light Absorption



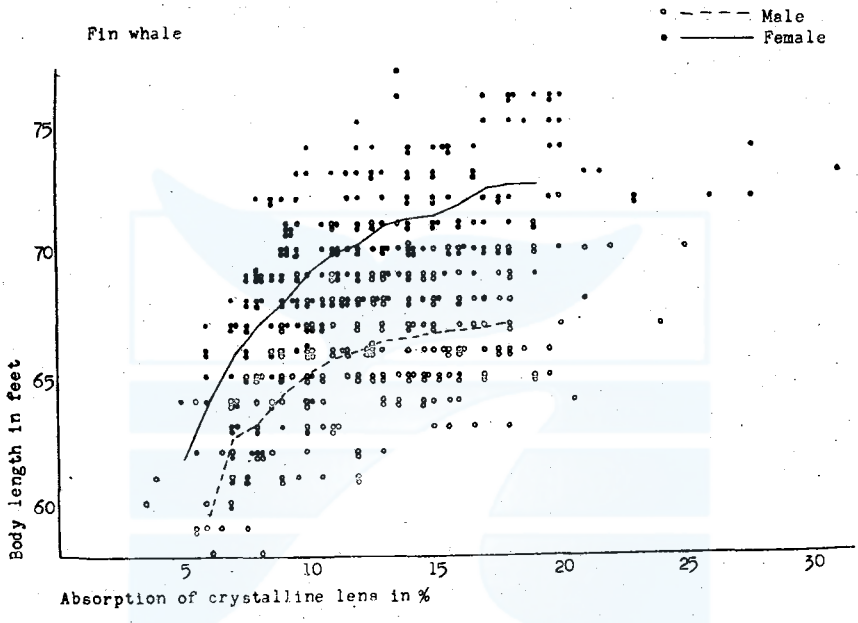
Figs. 5 and 6 show the distribution of body lengths according to degree of lenticular colouration in blue and fin whales, respectively. Notations on the graph are the same as those for Figs. 3 and 4.

The curve for average body lengths according to the degree of lenticular colouration shows that the increase in body length is rapid when colouration is slight, the increase becoming slow when colouration becomes deeper. The curves for male and female whales show about the same degree of colouration although that in female of sexual maturity is slightly below those of males. In other words, this shows the difference in average body length of male and female whales of similar age.

The trend of these curves are very similar to the growth curve ob-

tained by Mackintosh and Wheeler ("Southern Blue and Fin Whales". Discovery Reports. Vol. I, pp. 442-443).

Fig. 6. Average Length of Whales According to Degree of Lenticular Light Absorption



Mackintosh and Wheeler determined an average growth curve in the pregnancy and lactating periods by the combination of standard monthly body growth curve obtained from the body length of whale foetus and the young, and of standard pregnancy period obtained in a similar manner. The growth curve mentioned above was obtained by the combination of this growth curve, body length of sexual maturity and the period needed for the attainment of sexual maturity obtained by other means, such as the relationship between body length and the number of corpora lutea, or between body length and volume of testis. Mackintosh and Wheeler's growth curve is the one most trusted as showing standard growth of whales up to the age of sexual maturity. I am also the one who has followed it as a text.

The average body length curve according to the degree of colouration was obtained according to individual data of each whale and no such curves

for males and females could be drawn by any other data for the determination of age. It is easy enough to obtain separate curves for male and female. Same length of baleens in male and female whales do not denote that their ages are the same. Therefore, combined curve for male and female whales cannot be obtained from the relationship between body length and weight, or from body length and baleen length. Relationship becomes evident only after these data are combined with that of the degree of lenticular colouration.

The only data available for relating male and female whales was the fact that the ankylosis in centrum and epiphyses of vertebrae shows the degree of physical maturity. Many scientists have proved the reliability of this method, and I, too, believe that this is theoretically correct, and have used the data in the following chapters in the same degree of reliability as the relationship between the number of corpora lutea and sexual maturity in female whales. However, it has remained unknown whether the degree of sexual maturity occured at the same age level in male and female whales.

Figs. 5 and 6 can explain both the sexual and physical maturity, and they will often be referred to in the coming chapters.

CHAPTER V. Comparison of the Distributions in Degree of Lenticular Colouration and Number of Corpora Lutea According to Body Length in Female Whales.

Comparison of the distribution of the degree of lenticular colouration according to body length in female whales and that of the number of corpora lutea according to body length in same animals are shown in Fig. 7 for blue whales, and in Fig. 8 for fin whales. The latter data are considered to be the most reliable in estimating the age of whales at present.

The white circles in the two Figures show the number of corpora lutea, and black dots, the degree of colouration, both with respect to body length. In whales where colouration measurement could not be made due to cataract and other eye diseases, corresponding data for number of corpora lutea have been omitted. Therefore, the number of white circles and black dots are the same. Although the diagram was obtained by superimposing one diagram on the other, comparative graph cannot be obtained by ignor-

ing a relationship between the number of corpora lutea and degree of colouration. The manner of obtaining coordinates by calculating the relationship between the two are explained below.

Fig. 7. Relationship between the Degree of Lenticular Colouration and Number of Corpora Lutea According to Body Length

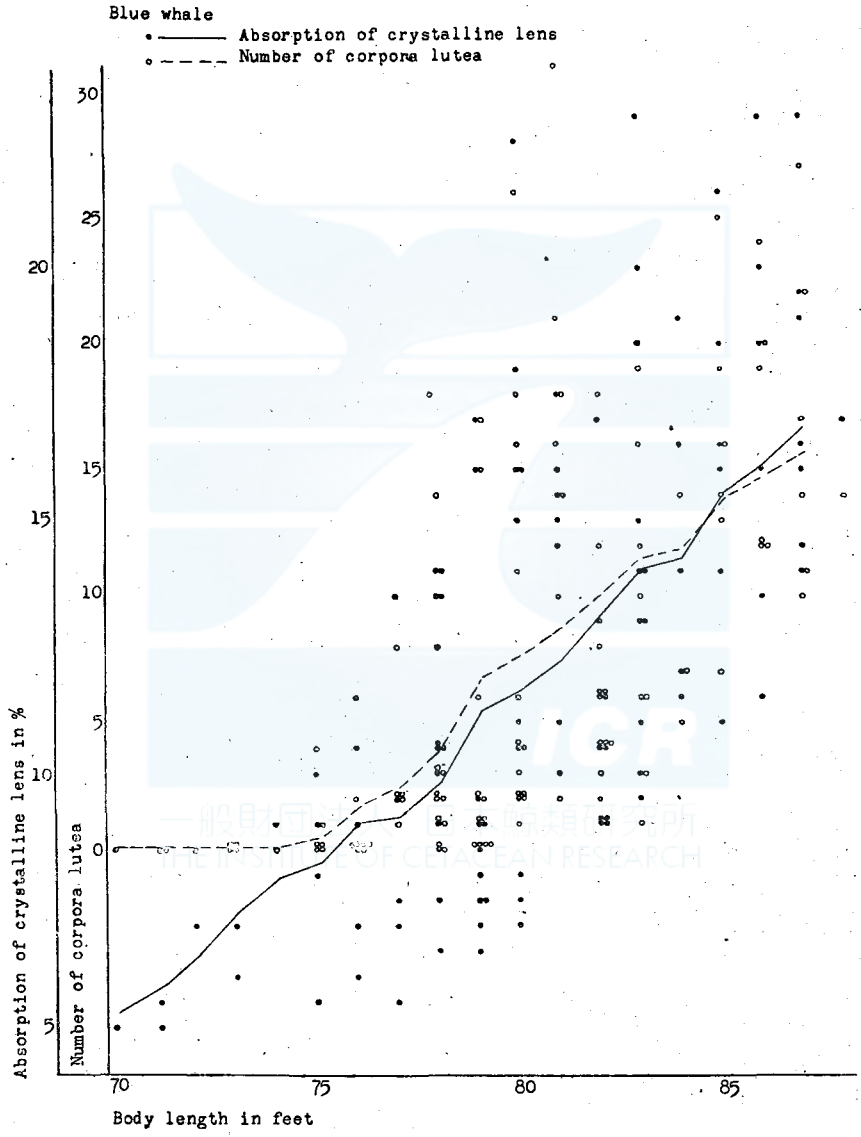
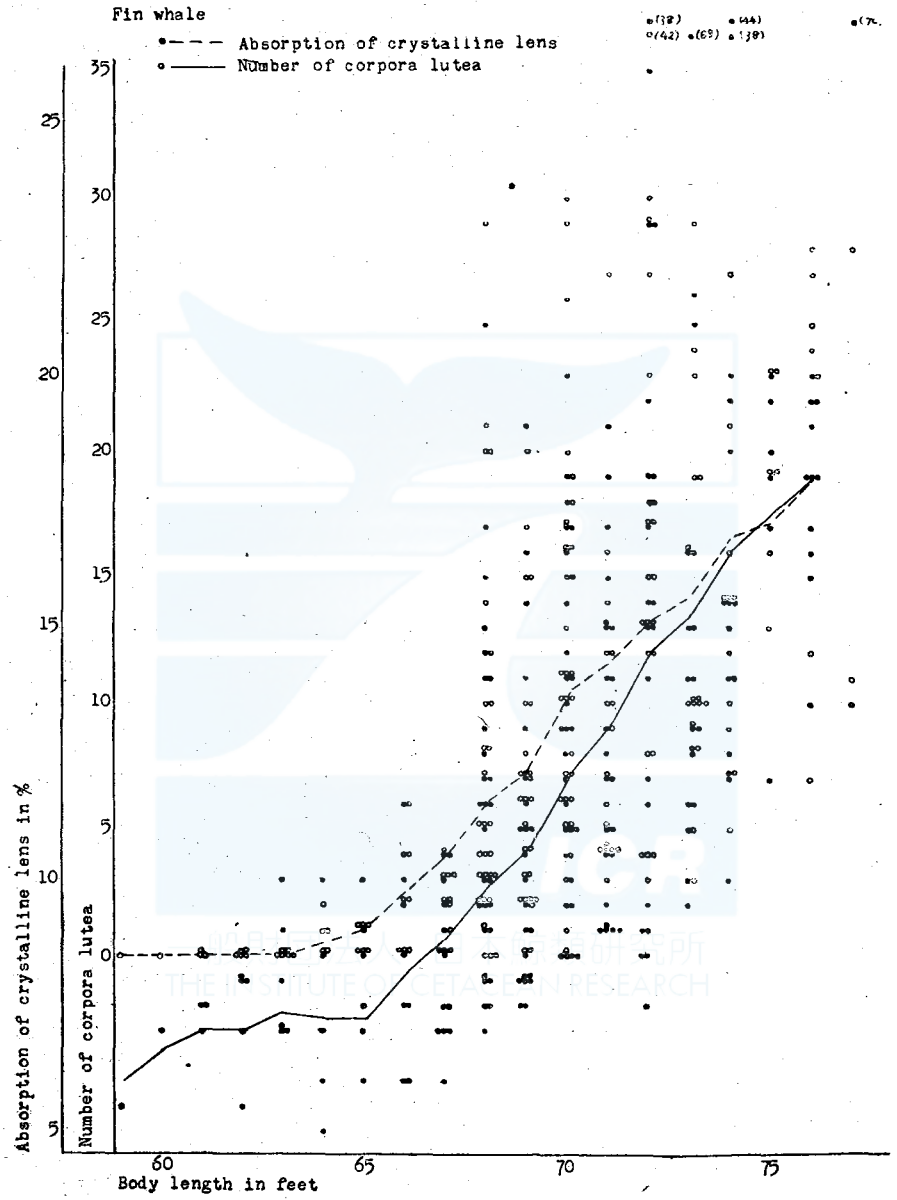


Fig. 8. Relationship between the Degree of Lenticular Colouration and Number of Corpora Lutea According to Body Length



The average number of corpora lutea in blue whales according to their body length is as follows:

(1)

Degree of Colouration*	5%	10%	15%	20%
Average No. of Corp. Lutea	0.7	3.1	12.6	14.8
No. of Whales examined	7	31	18	5

* Degree of colouration, as explained in Chapt. II, is the rate of light absorption by crystalline lens.

Average degree of colouration according to the number of corpora lutea is as follows:

(2)

No. of Corp. lutea	0	1	5	10	15
Average deg. of colouration	7.75%	9.86%	11.20%	14.20%	15.36%
No. of Whales examined	7	7	7	5	12

According to Table (1), the number of corpus luteum corresponding to 1 % of colouration is 0.94 , (A), and to Table (2), an average 5 corpora lutea corresponds to 1.67% of change in the degree of colouration (B).

By averaging (A) and (B), it is seen that 5 % of colouration corresponds to 9.85 of corpora lutea.

To obtain a common base-line for the number of corpus luteum and degree of colouration, what combination of the percentage of colouration and how many number of corpus luteum to be taken was derived as follows:

Since there are no number of corpus luteum smaller than 0, the age of whales having no luteal body cannot be defined. In other words, whales of the group having no corpus luteum contain many which should be in a group below that. On the other hand, degree of colouration classify whales in the group having no corpus luteum. It follows, therefore, that the base line would line at a point of 1 corpus luteum which, from Table (1), would give the colouration of 9.84 %. According to this, 10 corpora lutea would correspond to 13 % of colouration, and 15 % colouration, to 11 corpora lutea.

In the same manner, following data can be obtained for fin whales:

(1)

Degree of colouration:	5%	10%	15%	20%
Average No. of Corp. lut.:	0	4.0	9.8	22.5
No. of whales examined:	7	52	33	13

(2)

No. of Corp. lutea.:	0	1	5	10	15
Average Colouration:	7.12%	8.60%	10.65%	13.45%	13.42%
No. of whales examined:	33	9	30	19	20

From the above Table (1), the number of corpora lutea corresponding to 1 % of colouration is 1.5, (A), and from the above Table (2), the colouration of 2.27 % corresponds to 5 corpora lutea (B).

By averaging (A) and (B), it is seen that 5 % of colouration corresponds to 9.25 corpora lutea. The common base-line, calculated as for blue whales, is at about 9 %, since the colouration of 8.4 % corresponds to 1 corpus luteum. Accordingly, 10 corpora lutea would correspond to 14 % of colouration, and 15 % of colouration, to 9.2 of corpora lutea.

This difference between blue and fin whales can be assumed as difference in the number of ovulation in different species of whales. However, it seemed that there has been a slight difficulty in actual calculations so that the following basis was obtained by averaging the resulte of the two.

In order to facilitate preparation of a graph with 5 % of colouration corresponding to 9.55 corpora lutea, it was made in uniform intervals of 2 corpora lutea corresponding to 1 % of colouration.

The base line was taken at a point of 1 corpus luteum, and, since its colouration is at 9.18 %, colouration of 9 % was combined with one corpus luteum.

According to this, 15 % of colouration corresponds to 13, and 20 % of colouration to 23 of corpora lutea, or 5 corpora to 11.5 % of colouration or 10 corpora to 14 % of colouration. These values satisfy the conditions for both species of whales.

The trends in Figs. 7 and 8 are both entirely the same.

Generally speaking, the dispersion or white circles, i. e. showing the number of corpora lutea, is more scattered than the black dots, i. e. showing degree of lenticular colouration. It appears that the degree of coloura-

tion is present more in the lower part of the graph. However, this trend must be due to the fact that there are no presentation of figures below that of 0 for corpus lutea whereas those for colouration below that are present. In Fig. 8, showing values for fin whales, the group of black dots seem to lie slightly below that of white circles. This is in accordance with the explanation given in the paragraph on calculation of base-line and since 1 corpus luteum corresponds to 8.4 % of colouration, it should have been made to 8.5 % to facilitate perception, but it had been made to correspond to 9 % in averaging with data for blue whales. This was left as it was in this Chapter since it could not be determined whether the difference was due to the difference in the number of ovulation according to the species of whales, or whether this was obtained accidentally in calculation. As explained in Chapter VII, the relationship between the degree of colouration and the number of corpora lutea is definitely different in species of whales. However, no correction will be made in this chapter.

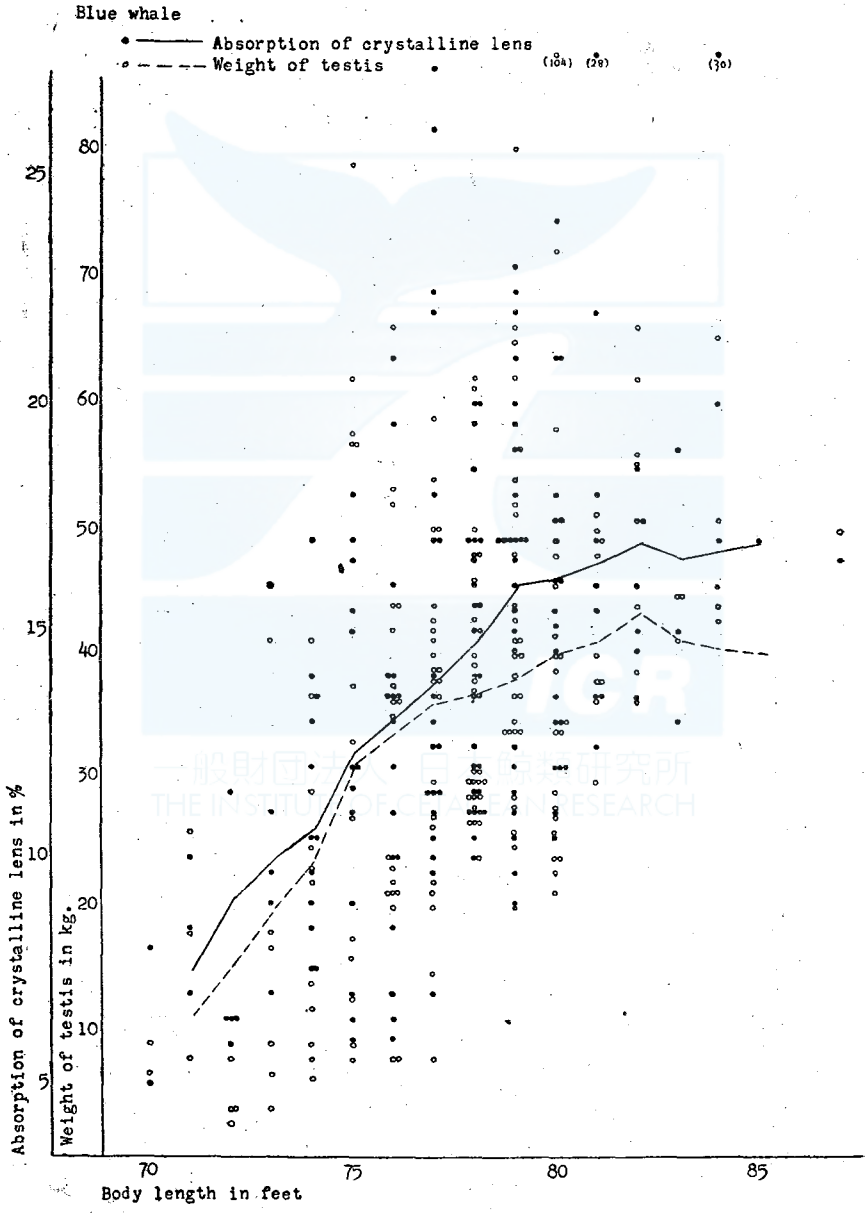
The average body length curves for both blue and fin whales coincide with each other in both calculated from the number of corpora lutea and from the degree of colouration. In those defined according to the number of corpora lutea, the number 0 is the minimum number, giving a lower limit, but the colouration was given for young whales in the group of those having no corpus luteum. This shows the definite advantage of employing the degree of colouration. The curves for the number of corpora lutea and the degree of colouration coincide well in parts where larger number of corpora lutea are present, i. e. where colouration is deeper. Where the number of corpora lutea is smaller, i. e. where the degree of colouration is low, the two curves are slightly set apart, and this may be due to the effect of aforementioned separation of some bodies in the group having no corpus luteum.

Differing from the data of male whales, the increase in the number of corpora lutea is supposed to change in accordance with the passage of time, so that the change in the degree of colouration should also change regularly with passage of time, i. e. with age.

CHAPTER VI. Comparison of the Distributions in the Degree of Colouration and the Weight of Tests according to Body Lengths in Male Whales.

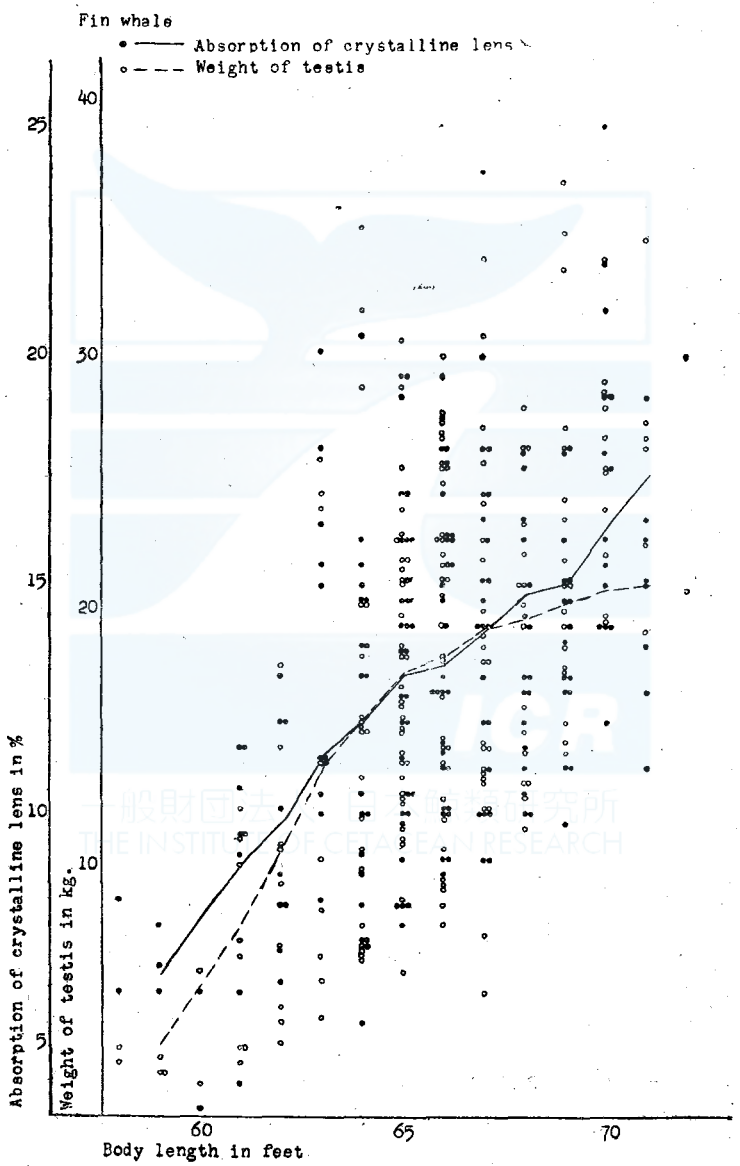
The consideration given to female whales in Chapter V was applied to male whales and the distribution of the degree of colouration and the

Fig. 9. Relationship between the Degree of Colouration and Weight of Testes According to Body Length



weight of testes according to body lengths were compared in one graph. Fig. 9 shows that of blue whales, and Fig. 10, that of fin whales. The reason why the weight of testes was used instead o its size that the former seemed to show values closer to actual figures than the latter.

Fig. 10. Relationship between the Degree of Colouration and Weight of Testes According to Body Length.



The white circles in the graphs denote the weight of testes, and black dots, the degree of colouration. As in the case of female whales, those having cataracts and other eye diseases necessitated removal of white circles corresponding to them, making the number of white circles and black dots the same.

The relationship between the weight of testes and the degree of colouration was calculated as in the case of female whales.

Average weight of testes in blue whales according to the degree of colouration were as follows:

(1)

Degree of Colouration:	5%	10%	15%	20%
Average Weight of Testes:	7.0	25.5	40.9	25.4
No. of Whales examined:	3	26	27	12

Average degree of colouration according to the weight of testes is as follows:

(2)

Weight of Testes:	10 kg.	20 kg.	30 kg.	40 kg.	50 kg.
Average degree of Colouration:	7.0%	9.5%	14.3%	15.3%	16.4%
No. of Whales examined:	3	8	12	17	9

In fin whales, values obtained were as follows:

(3)

Degree of Colouration:	5%	10%	15%	20%
Average Weight of Testes:	3.7	11.5	20.9	26.1
No. of Whales examined:	5	41	52	(11)

(4)

Weight of Testes:	5 kg.	10 kg.	20 kg.	30 kg.
Average Degree of Colouration:	9.8%	10.3	15.1	16.7
No. of Whales examined:	8	15	21	5

Values for blue and fin whales were obtained individually, and were used by averaging them in the first datum. Generally, the weight of the testes of blue whales is about twice that of fin whales, so that the values

for fin whales were doubled to obtain an average value.

Average of data obtained by $\{(1)+(3)\times 2\}\div 2$ gave 13.9 kg. in weight of testes as corresponding to 5 % change in the degree of colouration (A). Average of data obtained by $\{(2)+(4)\times 2\}\div 2$ gave 0.2225 % of degree of colouration as corresponding to 1 kg. change in the weight of testes(B).

By averaging (A) and (B), it was found that 5 % of colouration corresponds to 18.2 kg. (taken as 18 kg.) of the weight of testes, in blue whales. In fin whales, the values are one-half of this, being 9 kg. of testicular weight corresponding to 5 % of colouration.

The base-line was obtained by the following method of calculation taking the weight of testes at 10 % of colouration. Blue whales = (Testicular weight of blue whales at 10% of colouration + testicular weight of fin whales at 10% colouration × 2) ÷2.

Fin whales = (Testicular weight of blue whales at 10% of colouration + testicular weight of fin whales at 10% of colouration × 2) ÷4.

By this method of calculation, it was seen that 24 kg. of testicular weight in blue whales, and 12 kg. of weight in fin whales correspond to 10% of colouration. This was taken as the common base-line.

According to this, 15% of colouration corresponds to 41.3 kg. of testicular weight in blue whales and 20.7 kg in fin whales. The coordinates in blue whales would then be at 42 kg., and that in fin whales, 21 kg., which would satisfy both values. The average colouration at 40 kg. of testicular weight in blue whales is 15.3%, that at 20 kg. in fin whales, 15.1%, giving values that satisfy conditions in both species of whales.

Curves in Figs. 9 and 10 show similar tendencies. As a whole, the white circles, i. e. the weight of testes, show greater degree of dispersion. The average curve for weight shows rapid development at sexually mature stage, after which, the increase in testicular weight has little relation to body length. The same can be said of the size of testes. The testicular weight curve, therefore, begins to slant off as the animals reach sexually mature body length.

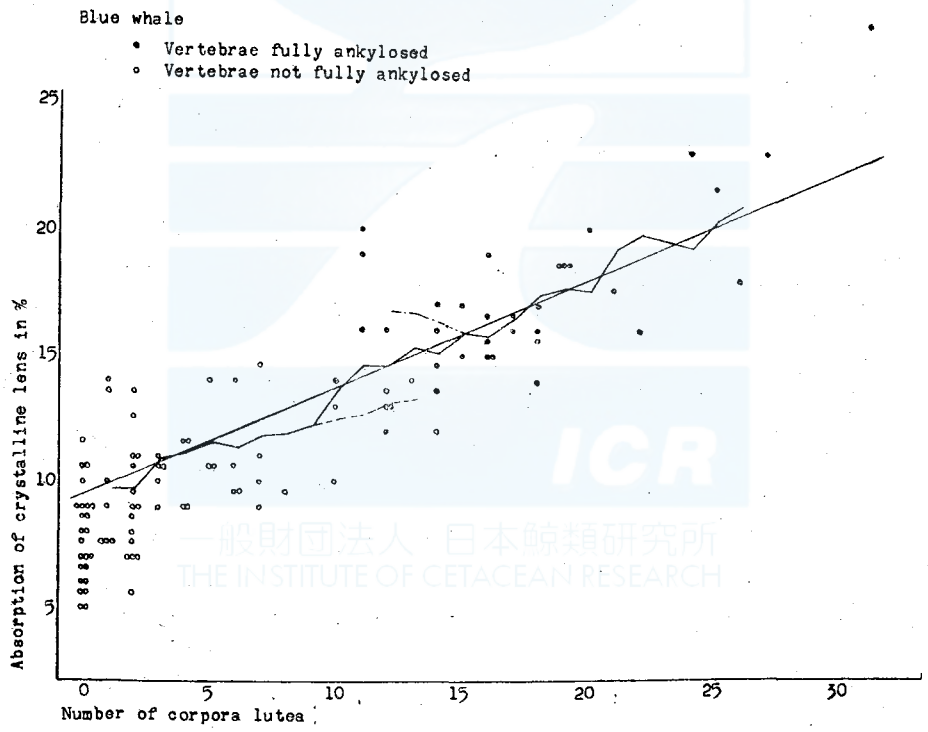
As was explained in the chapter for female whales, the degree of colouration dose not seem to show any special development or declination with sexual maturity. It should change in relation only to passage of time, i. e. by age. It is natural, therefore, that these two curves should be separated at the beginning and the end of these graphs, coming close as a tangent at

one point. This point should correspond to the neighborhood of the sexually mature body length. All these are borne out in Figs. 5 and 10.

CHARTER VII. Relationship between the Degree of Lenticular Colouration and Number of Corpora Lutea,

In preparing the graphs shown in Chapter V, some references were made as to the relationship between the degree of lenticular colouration and number of corpora lutea, These are shown in Fig. 11 for blue whales and in Fig. 12 for fin whales.

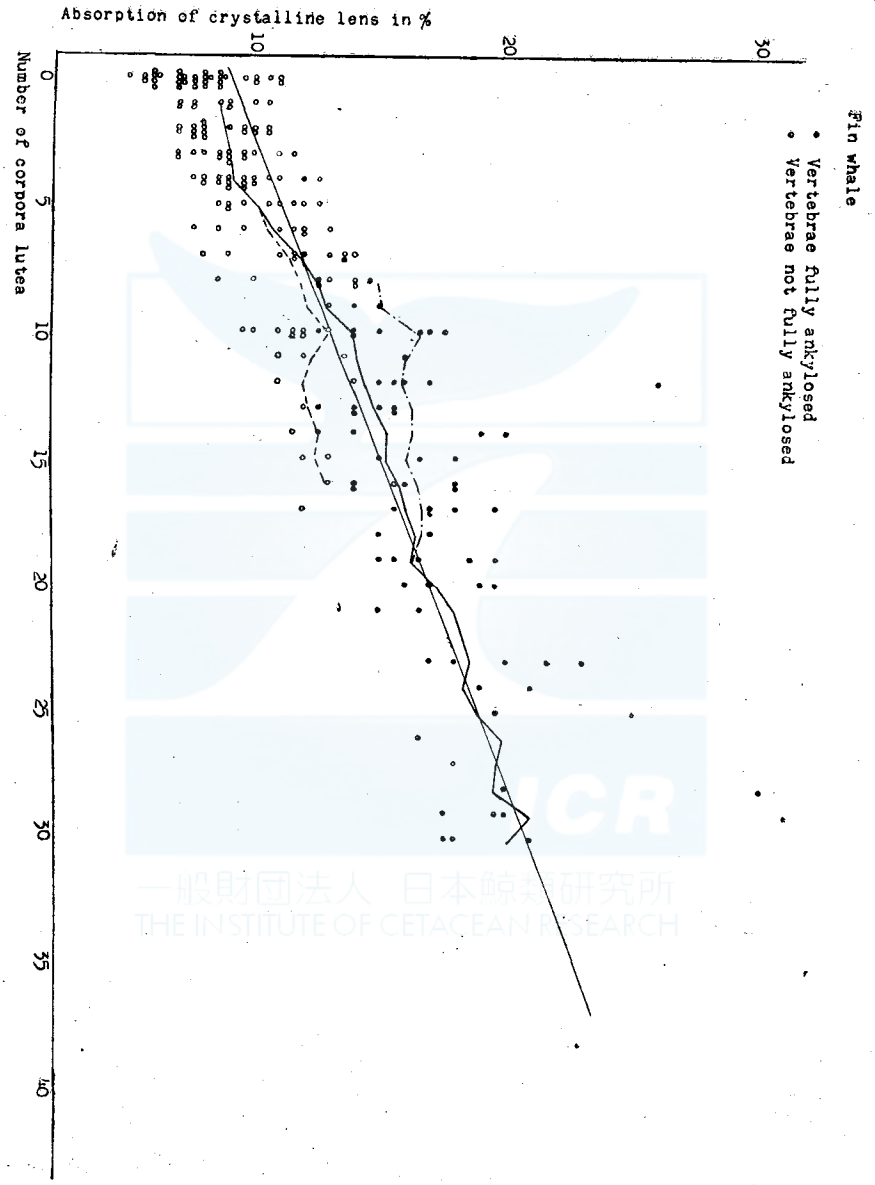
Fig. 11 The Degree of Lenticular Colouration According to Number of Corpora Lutea.



The black dots denote whales of physically mature, and the white circles those of physically immature. The solid line shows an average curve for the degree of colouration according to number of corpora lutea, and the broken line, an average curve for physically immature whales. The question of the maturity of whales will be discussed in the chapter under

that heading, and only the relationship between the degree of colouration and number of corpora lutea will be discussed here.

Fig. 12 The Degree of Lenticular Colouration According to Number of Corpora Luter

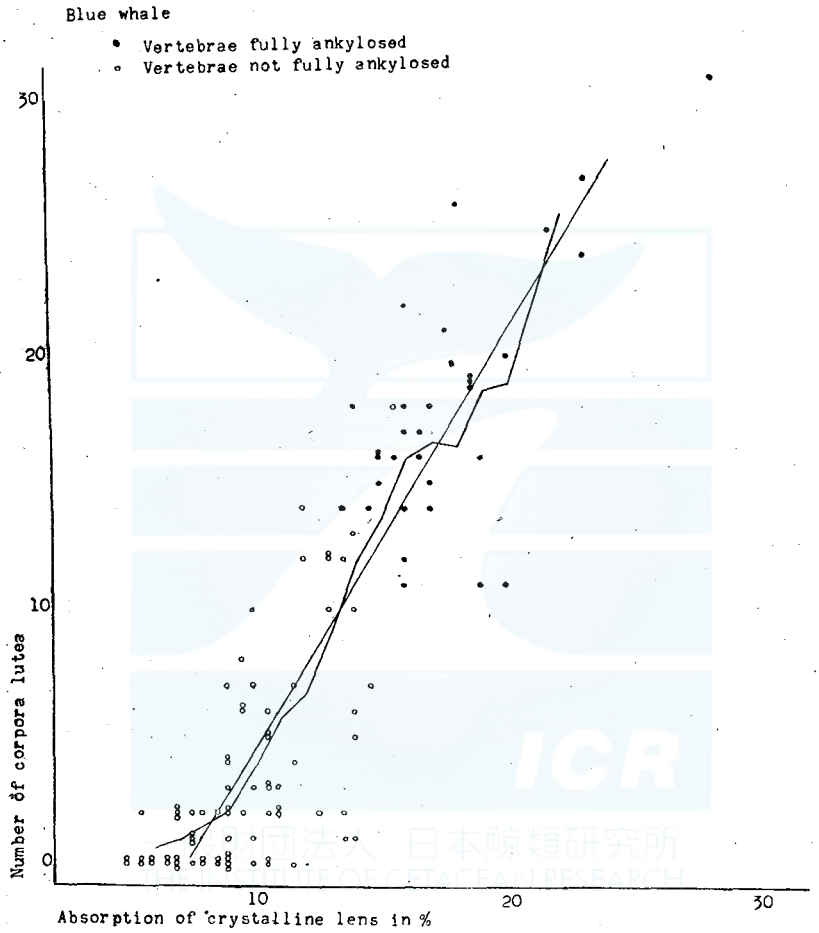


Average curves for both species of whales change lineally which must mean that there is a proportionate relationship between the colouration and number of corpora lutea. In blue whales, the ratio is 2.2% of colouration

against an average of 5 corpora lutea in fin whales.

Figs. 13 and 14 show curves for the number of corpora lutea according to the degree of colouration in blue and fin whales, respectively.

Fig. 13. Number of Corpora Lutea According to the Degree of Lenticular Colouration.



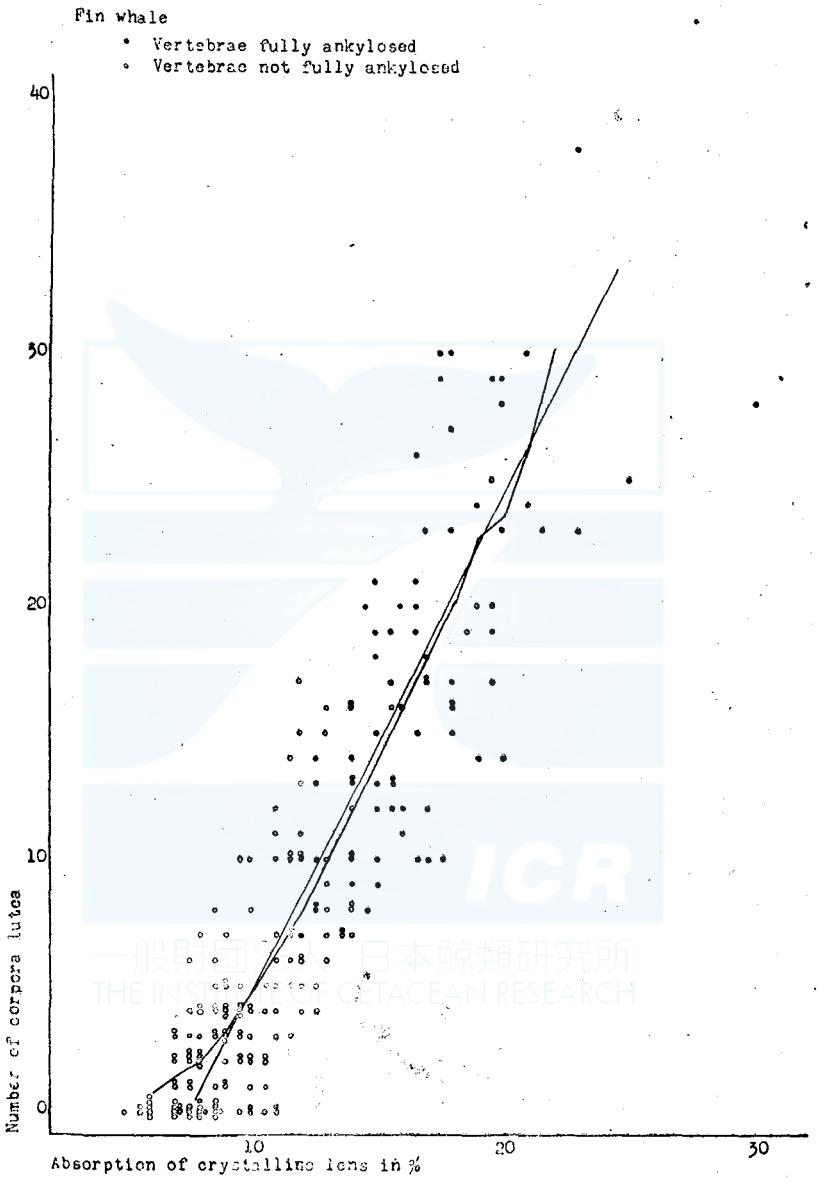
The relation of physical maturity is the same as for Figs. 11 and 12.

It can be seen from Figs. 13 and 14, that the curves for the two kinds of whales change lineally showing that there is a proportionate relationship between the degree of colouration and number of corpora lutea, the ratio being 17 corpora lutea in blue whales and 19 in fin whales against 10% change in the degree of colouration.

These values also approximately coincide with values described in Chapter V. It follows, therefore, that there must exist a certain difference in

number of ovulation in blue and fin whales.

Fig. 14. Number of Corpora Lutea Accordind to the Degree of Lenticular Colouration



CHAPTER VIII. Relationship between the Degree of Lenticular Colouration and Weight of Testes.

Figs. 15 and 16 show the relationship between the degree of lenticular

colouration and weight of testes in blue and fin whales, respectively. The latter values are thought to be the representative data for age determination of male whales.

Fig. 15. The Degree of Lenticular Colouration According to Weight of Testes.

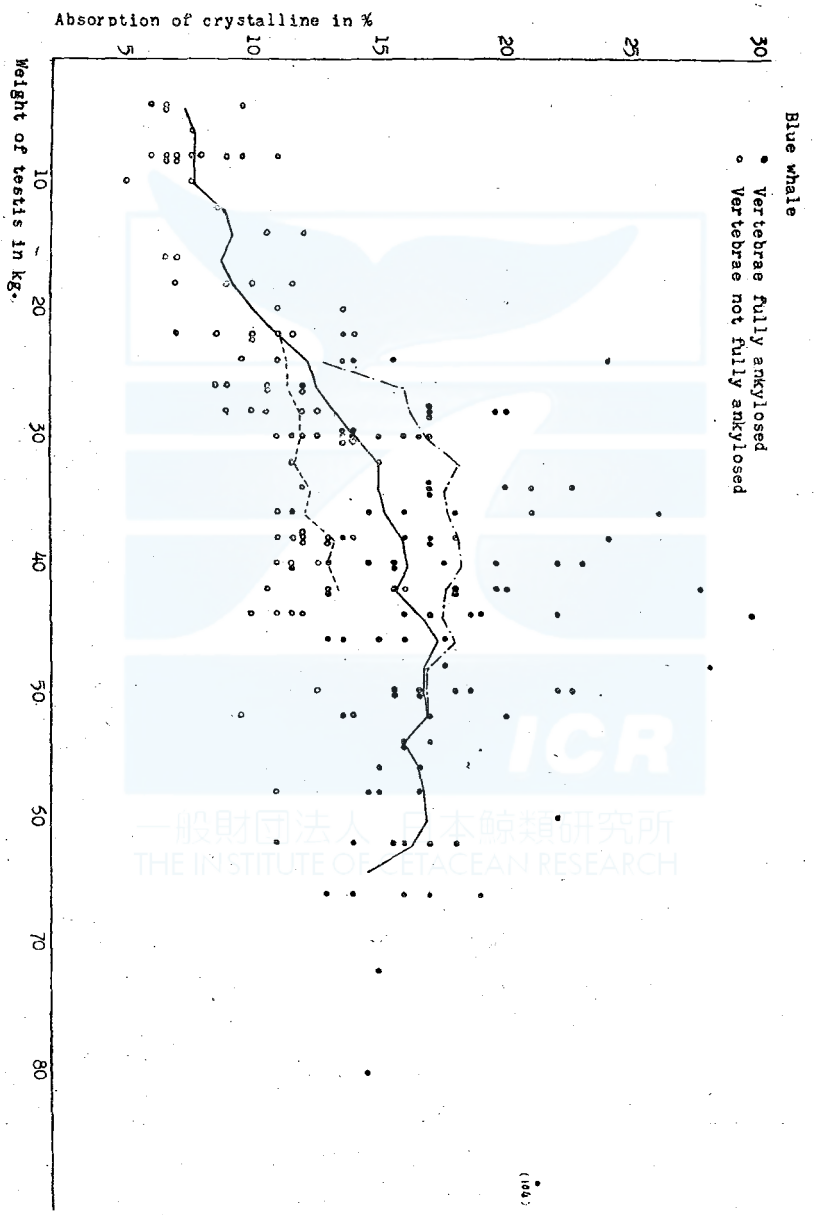
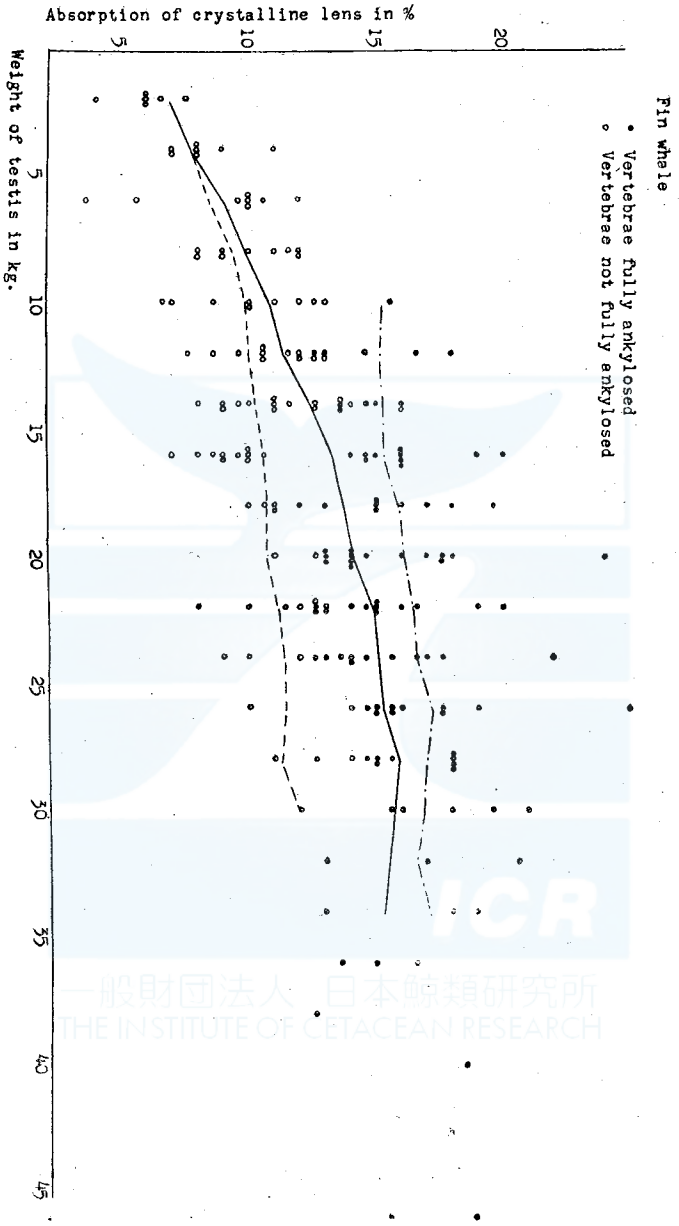


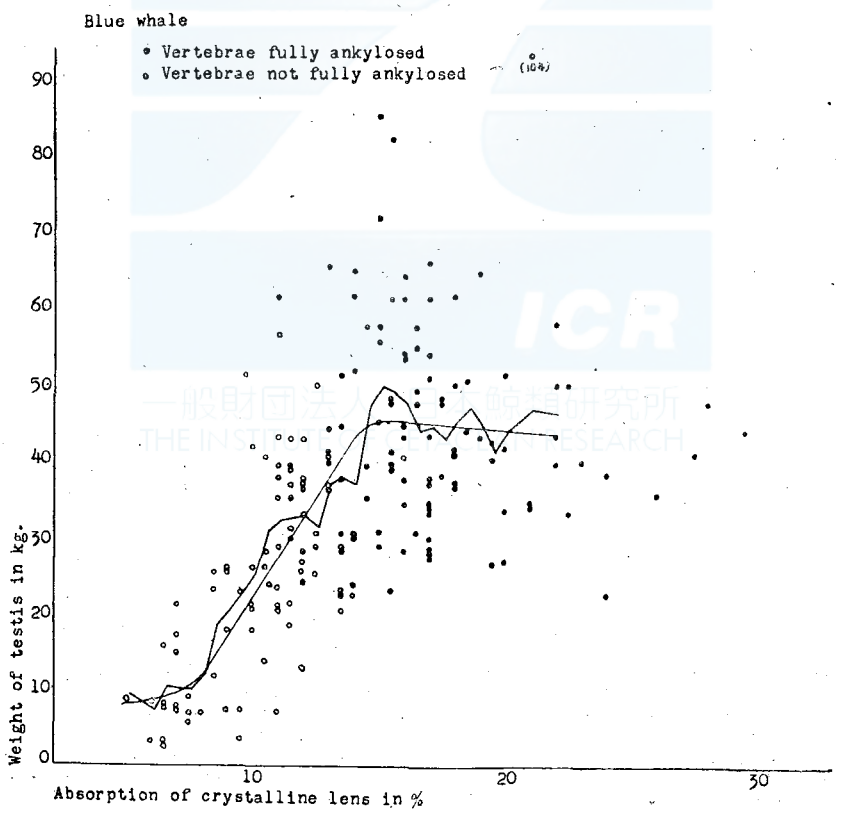
Fig. 16. The Degree of Lenticular Colouration According to Weight of Testes.



In these graphs, the white circles denote physically immature whales and the black dots, the physically mature. Broken and solid lines are the average degree of colouration according to testicular weight in physically mature and immature whales, respectively.

Contrary to the linear relationship existing between the degree of colouration and number of corpora lutea, the relationship between the degree of colouration and the weight of testes appear lineal at first but, after a certain testicular weight, it becomes irregular, and the line gose downward. This must mean that the testis develops regularly with age up to a certain point after which, its weight changes irrespective of age. The largest testis is found in a full-grown whales and testis of aged animals is lighter. Same tendency was observed in a relationship between body length and testicular weight, although it is dangerous to make any definite statement since body length itself is not always in direct proportion to passage of time. However, the degree of colouration seemed to be in direct proportion to the number of corpora lutea which changes regularly with passage of time, and its application to male whales must be taken definite unless

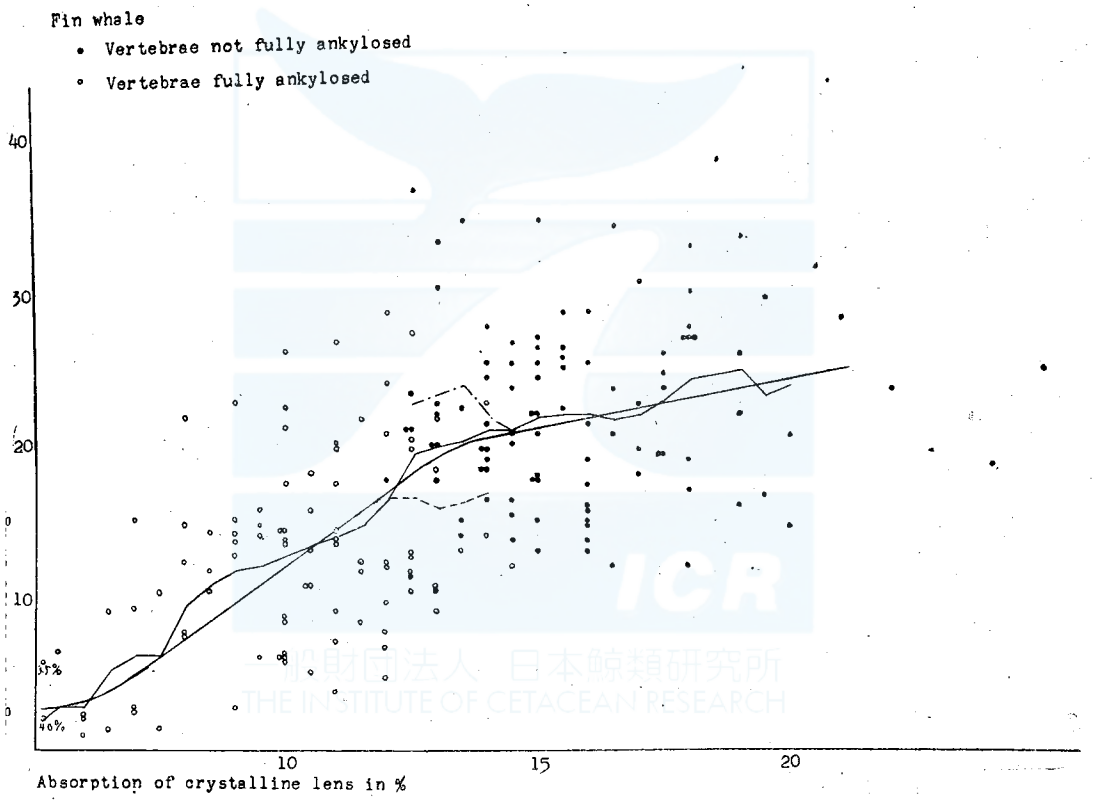
Fig. 17. Weight of Testes According to the Degree of Lenticular Colouration.



there exists a difference in the degree of colouration between the male and female whales. This was one of the phenomena found to differ in the male and female.

The same idea can be seen in the curve of testicular weight according to the degree of colouration which are shown in Fig. 17 for blue whales, and in Fig. 18 for fin whales.

Fig. 18. Weight of Testes According to the Degree of Lenticular Colouration.



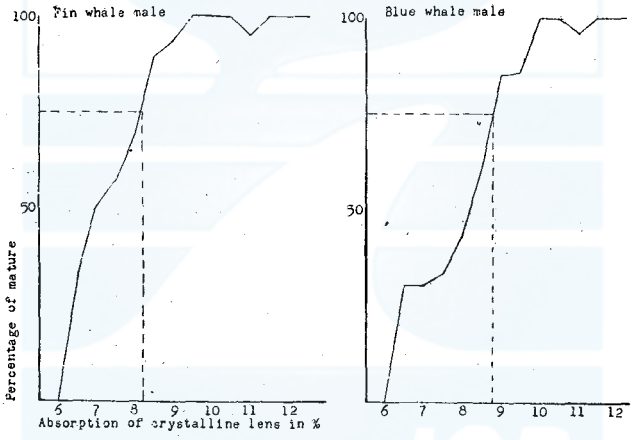
It is interesting to note that in the testicular weight curve according to the degree of colouration, the lower point of change corresponds to the testicular weight at sexual maturity, while that at the higher point corresponds approximately to the degree of colouration at physical maturity which is descrided in the next chapter.

CHAPTER IX. Relationship between the Degree of Lenticular Colouration and Sexual Maturity

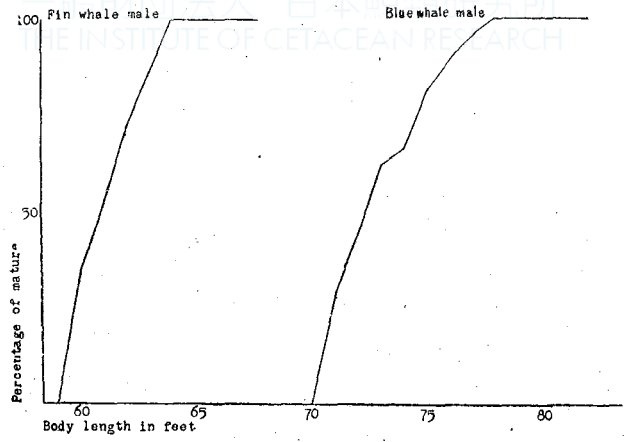
The degree of sexual maturity in female whales is easily determined by the existence of corpus luteum, but it is very difficult in the males. It has tentatively been presumed that sexual maturity has been attained in whales which has a combined testicular weight of 10 kg. in blue whales and 15 kg. in fin whales (This method of determining sexual maturity will be published in a separate paper).

Fig. 19. Percentage of Sexual Maturity in Male Whales

a) Degree of Maturity According to the Degree of Lenticular Colouration



b) Degree of Maturity According to Body Length



Male whales were classified into mature and immature animals according to this classification and the percentage of the number of mature animals according to the degree of colouration is shown in Fig. 19 a. The same percentage according to body length is shown in Fig. 19 b.

From these graphs, it can be seen that the degree of colouration at 75% of maturity is 8.8% in blue whales and 8.2% in fin whales. The body length at this percentage of colouration, calculated from the average body length curves according to colouration as shown in Figs. 5 and 6, are 75 feet in blue, and 64 feet in fin whales. The sexually mature body lengths derived from that at 75% maturity in Fig. 19b, are 75 feet in blue, and 64 feet in fin whales, showing a good coincidence.

An outstanding feature in the testicular weight curve according to the degree of colouration as shown in Fig. 17, as described in the previous chapter, is the fact that the point at which the weight increases suddenly corresponds to the percentage of maturity when the curve has been converted into a smooth one disregarding small, irregular increase and decrease. The testicular weight in blue whales at this point is approximately 10 kg. The same point in fin whales, as shown in Fig. 18, is at the testicular weight of about 5 kg., the degree of colouration being approximately 8%.

Outstanding features of curves in Figs. 15 and 16, are the facts that the point of change in curvature occurs at 10 kg. of weight and about 8% colouration in blue whales, and at 5 kg., and about 8% in fin whales, and these can be taken as the sexual maturity. However, these are curves for the degree of colouration according to testicular weight so that the change in weight according to passage of time (by age) as shown in Figs. 17 and 18, are more suitable to this theory.

Fig. 20 shows the average body length curve for sexually mature and immature whales according to the degree of colouration. This was obtained, first, by classifying the animals into the sexually mature and immature, and then by calculating average body lengths in each group by the degree of lenticular colouration. The curve for sexually mature whales show increase apporximately in accordance with changes as a whole. In immature whales, especially in fin whales, the curves show a remarkable change in body lengths against changes in the degree of colouration.

Fig. 20~. Average Body Length of Male Whales According to the Degree of Lenticular Colouration, divided into sexual Maturity.

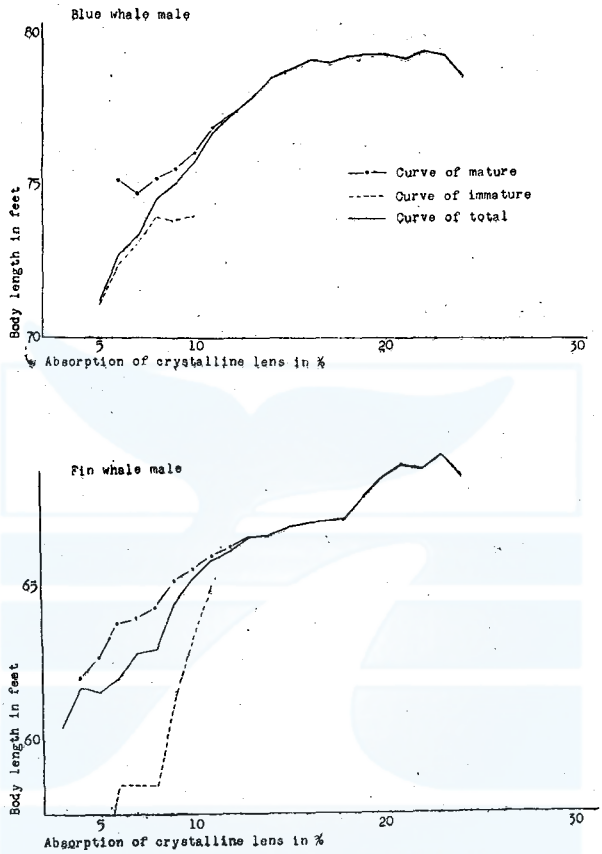
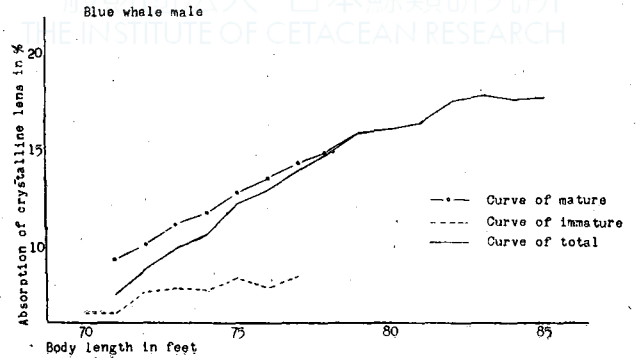


Fig. 21. Average Degree of Lenticular Colouration According to body Lengths, divided into the Sexual Maturity.



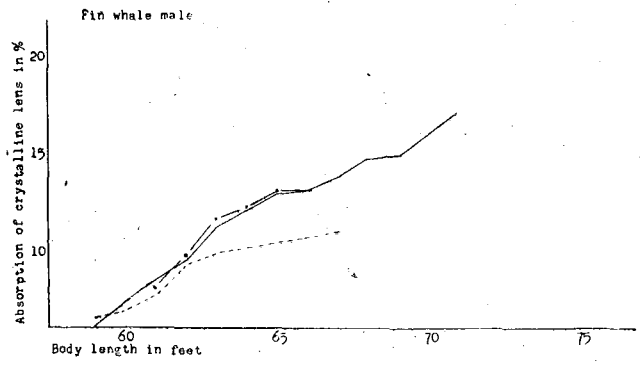
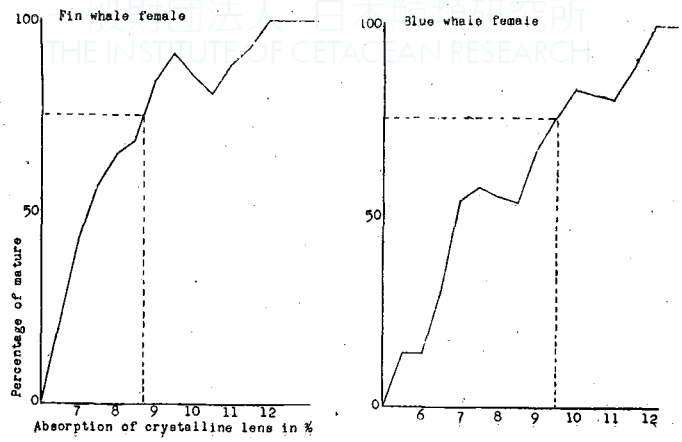


Fig. 21 gives the curve for the degree of colouration according to body length, the average values for which were obtained from whales classified by sexual maturity. In both the fin and blue whales, the changes in mature whales is the same as described for Fig. 20. The curve for immature whales varies in accordance with body length to a certain point in body growth. This point corresponds to the time when the body length and the degree of colouration change to those of mature whale. After this point, the curve levels off for immature whales. This must mean that, in baleen whales, the sexual maturity is attained at a certain age irrespective of the length of its body. Since the number of immature whales examined was small, it might not be correct to adopt this theory as being absolute but the immature whales represented in Fig. 20 would probably be explained by this reasoning.

Fig. 22. Percentage of Sexual Maturity in Female Whale
a) Degree of Maturity According to Lenticular Colouration



b) Degree Maturity According to Body Length.

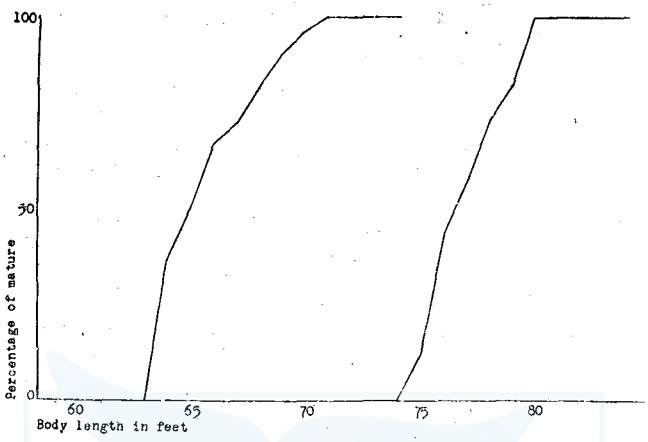


Fig. 22 shows the percentage of mature whales according to the degree of colouration, and Fig. 23, that according to body length, examined in female whales the sexual maturity of which was classified by the existence of corpora lutea.

From Fig. 22a, it can be learned that the degree of colouration at 75% of maturity is 9.5% in blue whales and 8.7% in fin whales. The body length of female whales at this colouration level, as calculated from Figs. 5 and 6, give 79 ft. for blue whales and 68 feet for fin whales. These values, obtained directly from Fig. 22b, 78 ft. for blue, and 67 ft. for fin whales.

Since the development of testes does not go parallel with age, this must constitute a point of argument in the question of sexual maturity in male whales. It is natural, therefore, that there should be a point of abrupt change in the curves for testicular weight by lenticular colouration and for average colouration by testicular weight. On the contrary, ovulation go parallel with age so that the curves for the average number of corpora lutea by lenticular colouration and for average colouration by number of corpora lutea are linear and there are no breaks. If the latter is present, it must be due to lack of the number of whales examined and will not be of a fundamental change. As has been described in Chapter V and VII, the curve change for whales having 0 to 1 corpus luteum cannot be considered on the same line. Classification by colouration was made on whales having no corpora lutea.

From this view-point, the lenticular colouration of whales having 1 corpus luteum as viewed in Figs. 11 to 14, is about 9.5% in blue whales and about 9% in fin whales, which coincides well with the results shown in Fig. 22.

Average body length of whales classified by sexual maturity as calculated from the degree of lenticular colouration is shown in Fig. 23. Average degree of lenticular colouration in whales classified by the degree of sexual maturity as calculated from body length is shown in Fig. 24. Since these figures are for female whales, they are further classified into stages

Fig. 23. Average Body Lengths of Female Whales According to Lenticular Colouration divided into Sexual Maturity.

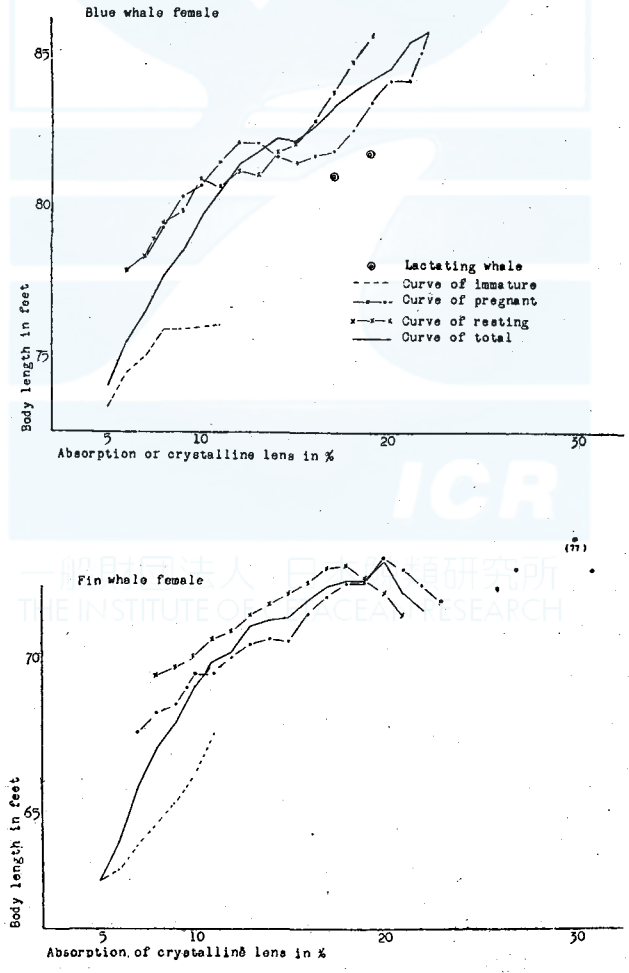
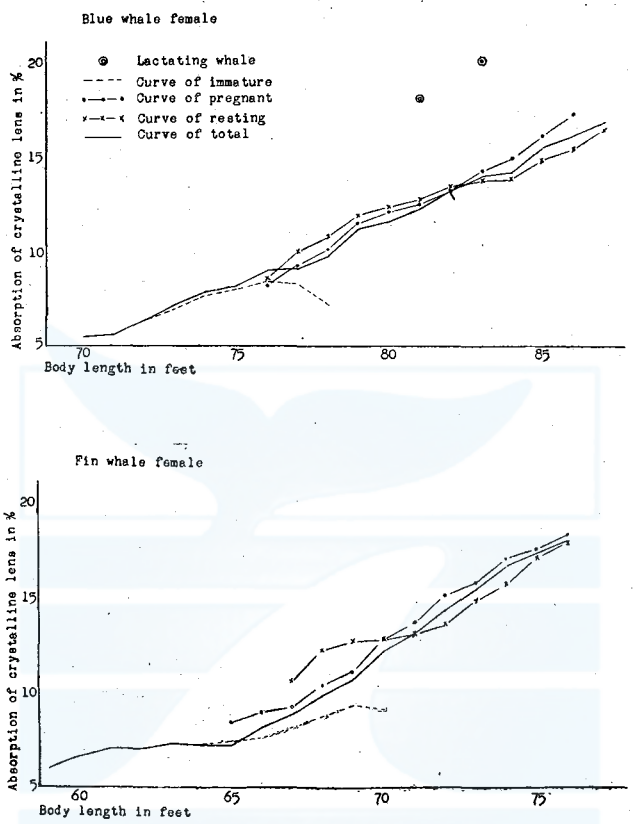


Fig. 24. Average Degree of Lenticular Colouration Female Whales According to Body Lengths Sexual Maturity.



of pregnancy, resting and lactating. Exactly the same idea as was found with the males is applicable here. Immature whales become sexually mature after a elapse of certain time, i. e. at a certain age, irrespective of body length. Of course, there is a basic body length for the sexually mature but, when a female whale passes a certain length of time from birth, it becomes sexually mature, whether it is large or small. No particular change can be learned from the classification of mature females into various stages of pregnancy resting and lactating. It seemed that blue whales of lactating stage apparently had higher degree of lenticular colouration but there had been only two heads of them so that it would be dangerous to draw any conclusion from just these two. At any rate, there are many other whales in pregnant and resting stages around this point.

CHAPTER X. Relationship between the Degree of Lenticular Colouration and Physical Maturity

In all the graphs given from Chapter VII to IX, in which the degree of lenticular colouration was combined with other data on age estimation, black dots denoted physically mature, and white circles, the physically immature whales.

As was explained earlier, physically mature whales are those in which the vertebrae were fully ankylosed, both in thoracic and lumbar series. If one or the other of these was not ankylosed, the whale was considered physically immature.

All theories to present date had it that in female whales, physical maturity was not related to body length but only to the number of corpora lutea. What then, can one find of a relationship between the degree of lenticular colouration and number of corpora lutea. Following could be learned from Figs. 11 and 12.

In blue whale females, 4 out of 78 whales having less than 12 corpora lutea were found to be physically mature, and 3 out of 30 whales having more than 13 corpora lutea were physically immature. Considered from lenticular colouration, 2 out of 77 whales with less than 14% colouration were found mature, and 2 out of 31 whales above 14.5% colouration were immature.

In fin whale females, 16 out of 146 having less than 11 corpora lutea were found mature, and 9 out of 74 having more than 12 corpora lutea were immature. In classification according to the degree of lenticular colouration, 7 out of 130 with less than 13% colouration were found to be mature, while 7 out of 81 with more than 13.5% colouration were found immature.

The range of mixed appearance of mature and immature whales in blue whale females was between 11 to 14 corpora lutea, or between 13.5 to 15.5% of colouration. In fin whale females, this was between 4 to 17 corpora lutea, or between 12 to 15.5% of colouration.

On both counts, physical maturity is more sharply related to the degree of lenticular colouration rather than to the number of corpora lutea. One of the reasons for this seems to lie in the fact that the degree of lentic-

ular colouration changes more regularly with age than the number of corpora lutea, just as the number of corpora lutea changes more regularly with age than the body length.

Fig. 25. Average Body Length of Female Whales According to the Degree of Lenticular Colouration

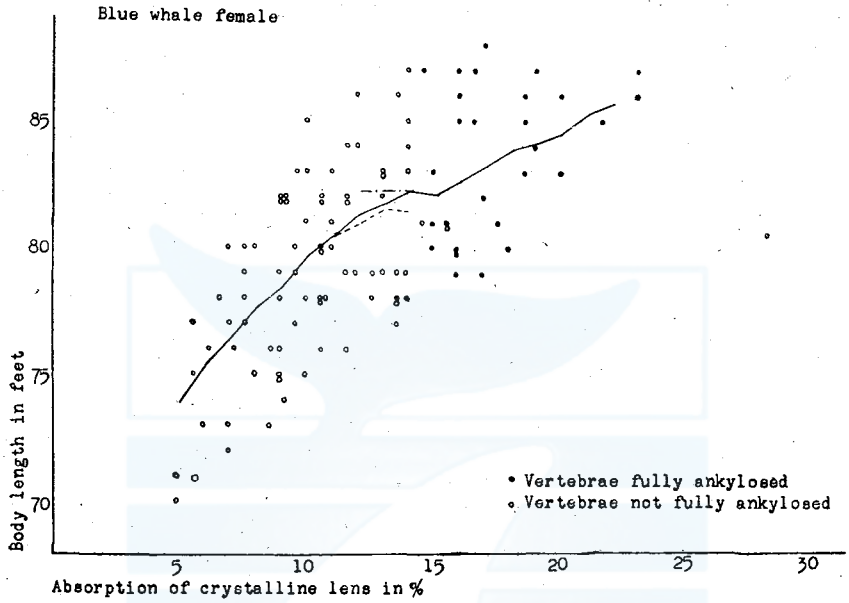
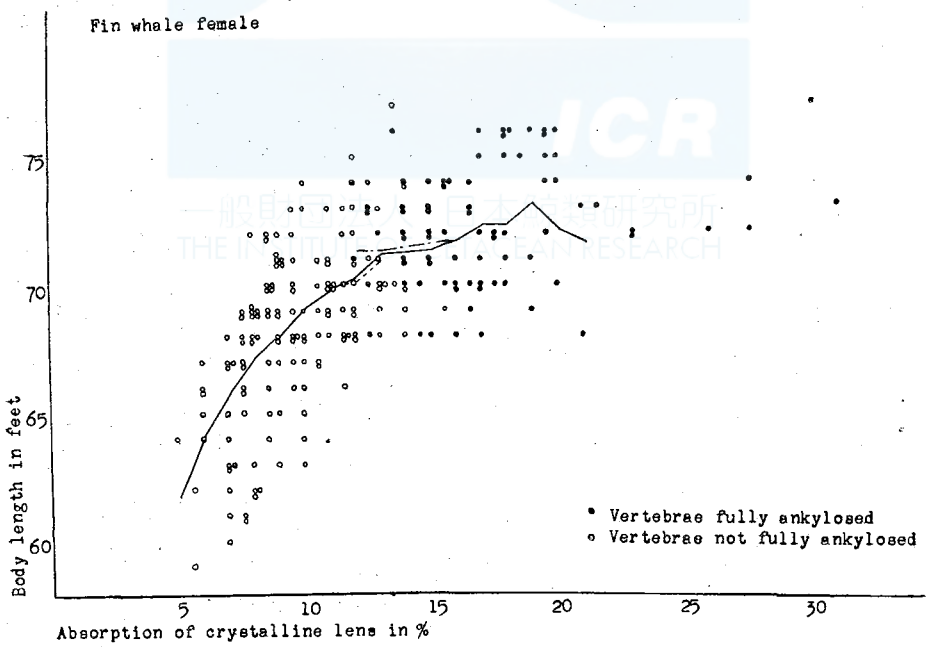


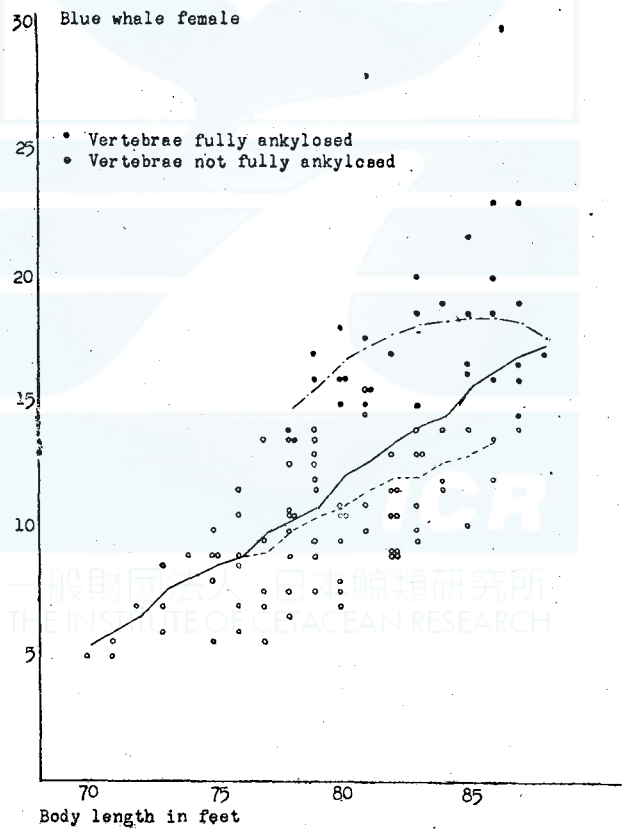
Fig. 26. Average Body Length of Female Whales According to the Degree of Lenticular Colouration



Figs. 25 and 26 show the relationship of sexual maturity to the degree of lenticular colouration and body length in female blue whales and fin whales, respectively.

Both graphs clearly show that physical maturity is not related to body length but to the degree of colouration. The boundary between physically mature and immature in blue whales can be drawn at 14 to 14.5% of colouration and in fin whales, at 13 to 13.5%. The overall average curves in these graphs show the increase in body length with age, as explained in Chapter IV.

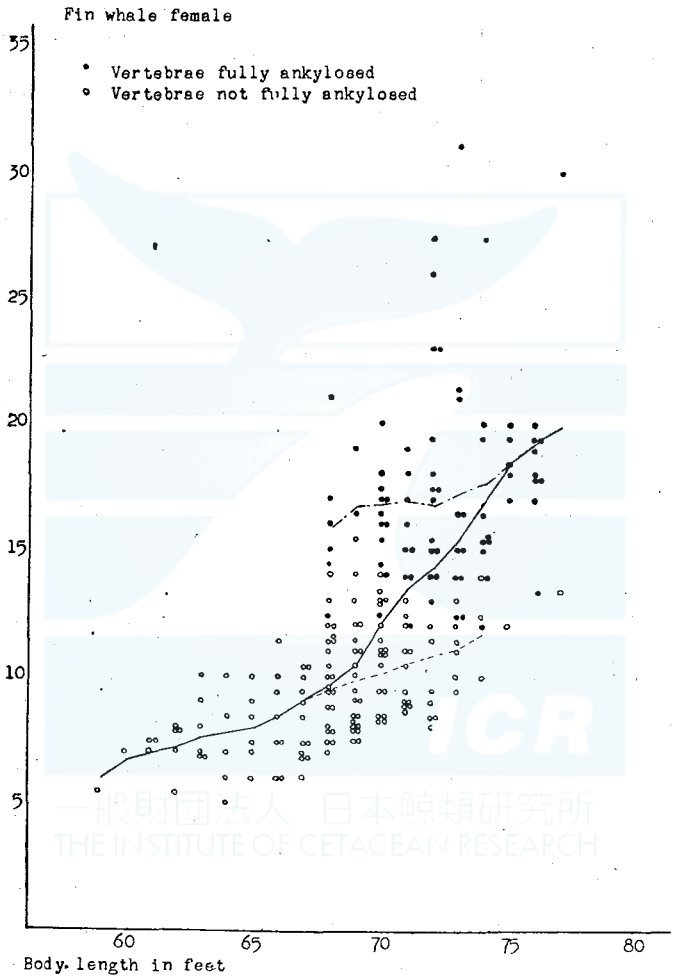
Fig. 27.. Average Degree of Lenticular Colouration According to Body Lengths in Female Whales



There is not particular features in the average body length curve for physically mature and immature whales. Figs. 27 and 28 show average degree of colouration in blue and fin whales of physically mature and im-

mature stages according to their body lengths. Although it is not as linear as those obtained by combination with the number of corpora lutea, yet the three curves for immature, mature and total whales show linear increase, with good coincidence between the three.

Fig. 28. Average Degree of Lenticular Colouration According to Body Lengths in Female Whales



From these results, it can be said that the physical maturity of female whales is not related to body lengths but to the number of corpora lutea and the degree of lenticular colouration. The boundary between maturity and immaturity lies at 14 to 14.5% of colouration in blue whale females, and at 13 to 13.5% colouration in fin whale females.

Same observations made on male whales from Figs. 17 and 18 give imperssion that, without using the data on the degree of lenticular colouration, it would be very difficult to determine the physical maturity of male whales. Solely from their body length. Calculations had heretofore been made from the percentage curve of physical maturity by body length which is explained in later chapters. However, it has been found that the sexual maturity of male whales was closely related to the degree of lenticular colouration and had little connection with their testicular weight.

In blue whale males, classification of sexual maturity by testicular weight, however well it is made, resulted in an inclusion of about 20% immature whales in the mature group, and about 30% of mature whales in the immature group. The range in which both mature and immature whales appear is usually very wide, being from 22 to 56 kg. of testicular weight.

Classified according to the degree of lenticular colouration, 8 out of 80 whales with less than 13% of colouration were found mature, and only 7 out of 100 heads with over 13.5% of colouration were immature. The range of mixed appearance was between 11.5% to 16% of colouration.

Classification of fin whale males according to their testicular weight resulted in an inclusion of about 20% each of immature in mature groups, and vice versa. The range of mixed appearance was between 8.5 and 29 kg. of testicular weight.

Classifying these according to the degree of lenticular colouration, 6 out of 93 whales with less than 12.5% of colouration is found to be mature, and only 8 out of 106 whales with more than 13% of colouration to be immature. The range of their mixed appearance was between 12 to 14.5% of colouration.

From these results, it can be said that, even in male whales, the physical maturity is more related to the degree of lenticular colouration rather than to their testicular weight.

Relationship between body lengths and the degree of lenticular colouration in male whales is shown in Figs. 29 to 32.

In all these graphs, it can clearly be seen that physical maturity has no relationship to body length but is connected with the degree of lenticular colouration.

Fig. 29. Average Body Length of Blue Whales Males According to the Degree of Lenticular Colouration.

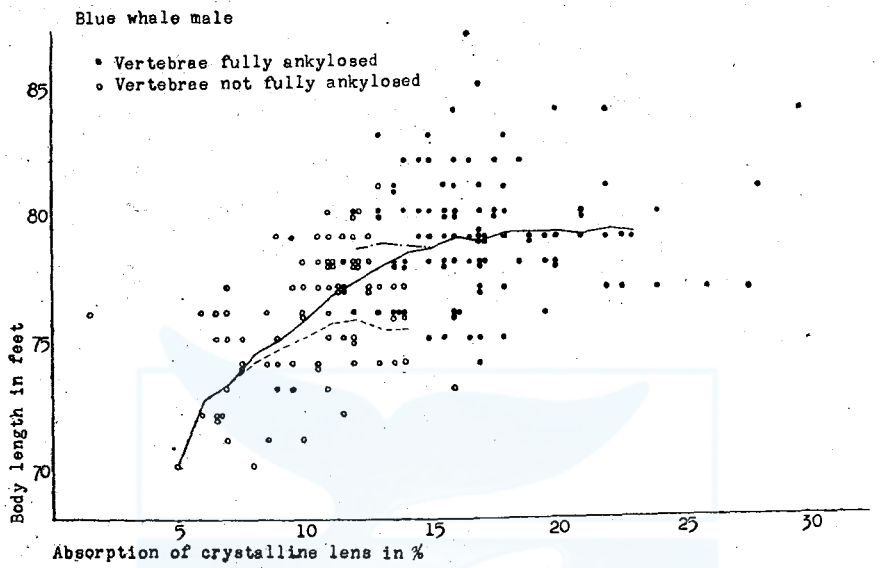


Fig. 30. Average Body Length of Fin Whale Males According to the Degree of Lenticular Colouration.

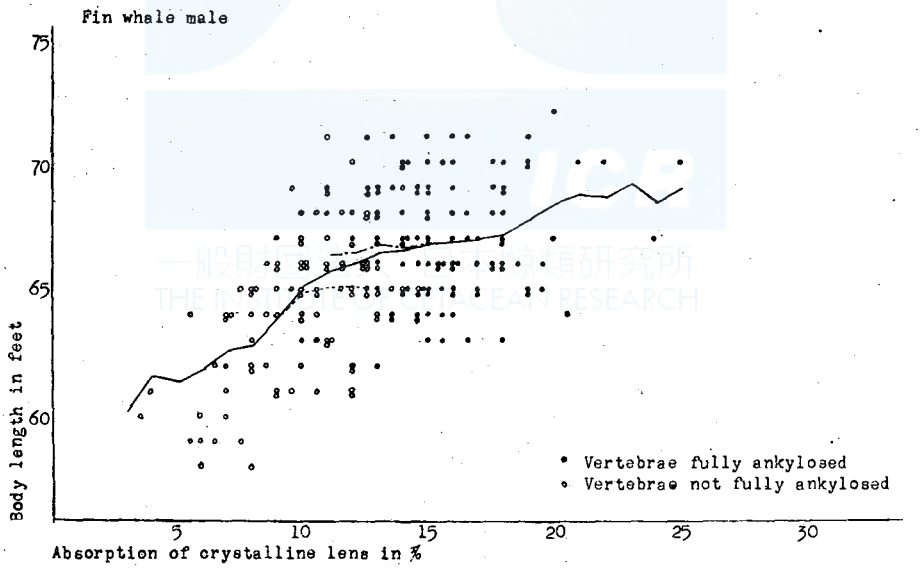
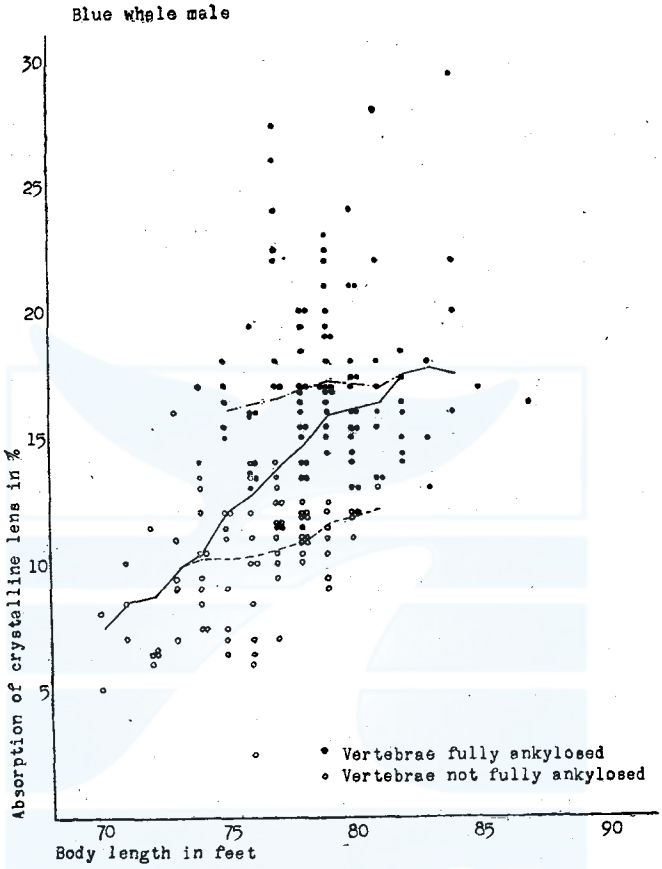


Fig. 31. Average Degree of Lenticular Colouration in Blue Whale Males According to Body Length.



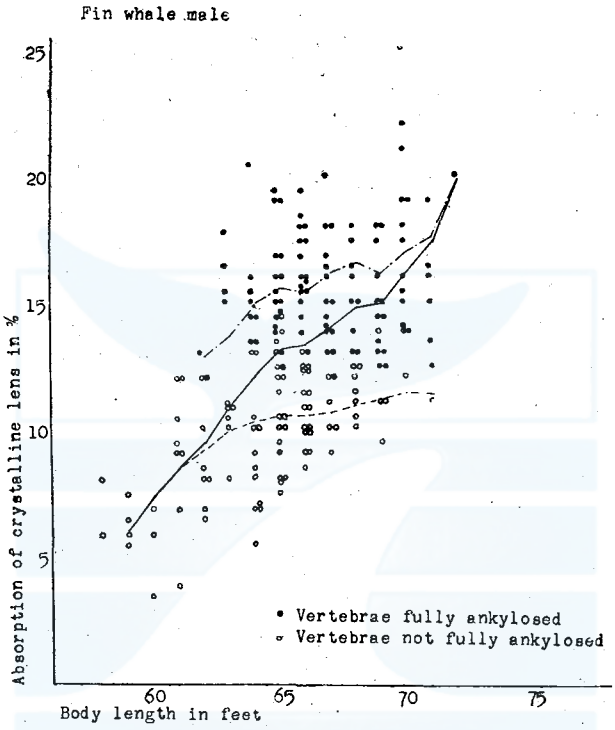
In blue whale males, 8 out of 80 whales with less than 13% of colouration are found to be mature, while only 7 out of 100 whales with more than 13.5% of colouration to be immature. The range of mixed appearance is between 11.5 and 16% of colouration.

In fin whale males, 6 out of 93 whales with less than 12.5% of colouration is found to be mature, while only 8 out of 106 whales with more than 13% of colouration to be immature. The range of mixed appearance is between 12 and 14.5% of colouration.

The average body length curve for physically mature and immature male whales according to the degree of their lenticular colouration, and the average degree of lenticular colouration of mature and immature ani-

mals by their body length, show the same tendencies as for female whales and no particular features can be found.

Fig. 32. Average Degree of Lenticular Colouration in Fin Whale Males According to Body Lengths.



From these results, it can be said that the physical maturity of male whales is more related to the degree of their lenticular colouration and not to either body length or their testicular weight. The boundary between the physically mature and the immature lies at 13.5 to 14% of colouration in blue whale males, and at 12.5 to 13% of colouration in fin whale males.

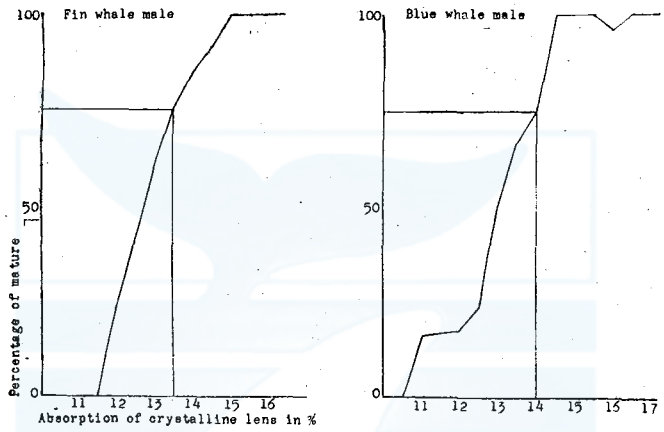
Percentage of maturity according to the degree of lenticular colouration in whales classified by physical maturity is shown in Fig. 33a for males and in Fig. 34a for females. Percentage of maturity according to body length in whales classified by physical maturity is given in Fig. 33b for male whales, and Fig. 34b for females.

The point at which the maturity is 75% on the maturity curve by the degree of lenticular colouration show lenticular colouration of 14% for blue whale males, 13.5% for fin whale males, 14.8% for blue whale females

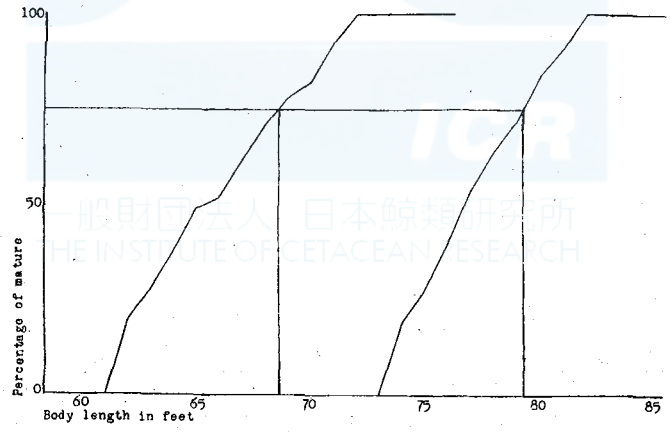
and 14.2(14.15)% for fin whale females. Applying these values to the average body length curves by the degree of lenticular colouration given in Figs. 5 and 6, they correspond to body length of 78 feet in blue whale males, 67 feet in fin whale males, 82 feet in blue whale females and 71 feet in fin whale females.

Fig. 33. Percentage of Physical Maturity.

a) Maturity According to the Degree of Lenticular Colouration.



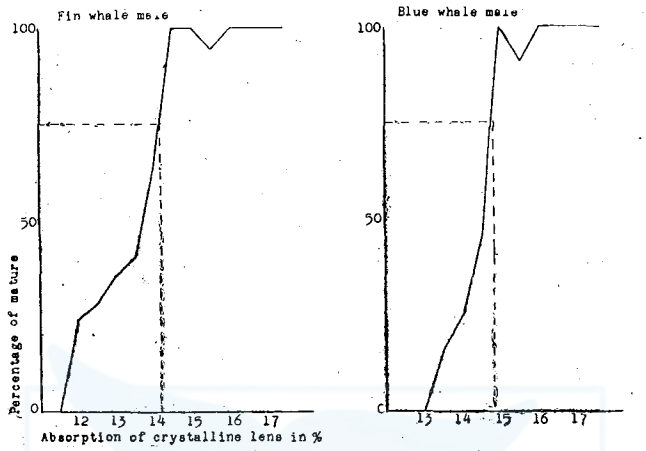
b) Maturity According to Body Lengths.



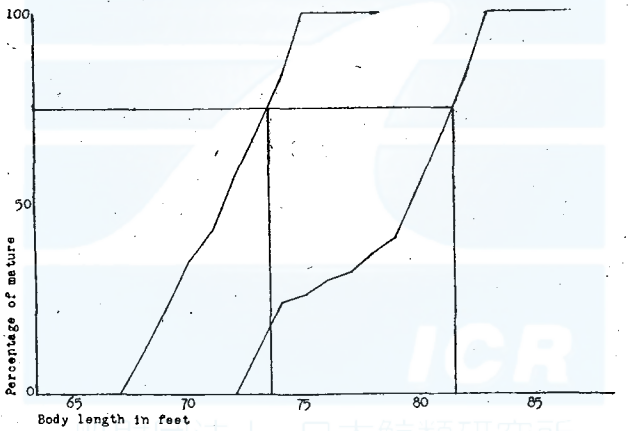
The point at which is 75% on the maturity curve according to body length in Figs. 33b and 34b is at 79 feet for blue whale males, 68.5 feet for fin whale males, 81.5 feet for blue whale females and 73.5 feet for fin whale females, showing good coincidence between the two figures.

Fig. 34. Percentage of Physical Maturity.

a) Maturity According to the Degree of Lenticular Colouration.



b) Maturity According to Body Lengths.



The question now is which figure is more nearer the actual. The values of lenticular colouration from the point of 75% of maturity in the curves in Figs. 33a and 34a, compared with the dividing lines for the range of mixed appearances as described before, give following results:

	(1) 75%on curve	(2) Dividing line	Difference in (1) and (2)
Blue Whale - Male	14.0%	14.0%	none
Female	14.8%	14.5%	none
Fin Whale - Male	13.5%	13.0%	none
Female	14.2%	13.5%	1 inch

The difference in the degree of colouration as obtained from Figs. 5 and 6 correspond to the difference of (1) and (2) above.

These results show that the difference, if at all present, is very small and is in a negligible range. On the other hand, the curves in Figs. 33b and 34b, in which the physically mature body length was directly obtained, offer no data for comparison or examination. These had to be deemed satisfactory up to the present in the absence of other and better methods but it can clearly be seen that the degree of lenticular colouration, or the absorption of light by crystalline lens present values which are more close to actuality.

CHAPTER XI. Conclusion

The foregoing discussions can be summarized as follows:

1) The colouration of crystalline lens increases with passage of time (age) from birth, and the rate of increase in colouration does not change at different stages of life from infancy to old age.
2) Curves showing the change in age and body lengths according to change in the degree of lenticular colouration can be given for both male and female whales at the same time (Figs. 5 & 6), thereby making is possible to compare the body lengths of male and female whales of the same age.
3) Relationship of the degree of lenticular colouration is in direct proportion to the number of corpora lutea which is given by the curve showing increase in the number of corpora lutea according to age. From graphs giving such data (Figs. 13 & 14), the number of ovulations between sexual and physical maturity are found to be 10 in blue whales and 9.5 in fin whales.
4) A relationship exists between the degree of lenticular colouration and testicular weight similar to the one between body length and testicular weight. This can be considered as the curve showing increase in testicular weight according to age.
5) The sexually mature body lengths, as calculated from lenticular colouration ar as follows:

	Lenticular Colour	Body Length	Body Length as calcd. by previous methods
Blue Whale – Male	8.8%	74.9 ft.	74.6 ft.
– Female	9.5%	79.1 ft.	78.2 ft.
Fin Whale – Male	8.2%	63.5 ft.	62.4 ft.
– Femal	8.7%	67.8 ft.	67.3 ft.

6) By consideration of the degree of lenticular colouration, it has become possible for the first time to consider the physically mature body lengths of male whales in the same degree of accuracy as for the female whales. The physically mature body lengths as calculated from lenticular colouration are as follows:

	Lenticular Colouration	Body Length	Body Length as calcd. by previous methods
Blue Whale – Male	14.0%	77.9 ft.	79.3 ft.
– Female	14.8%	82.2 ft.	81.5 ft.
Fin Whale – Male	13.5%	66.6 ft.	68.6 ft.
– Female	14.2%	71.3 ft.	74.5 ft.

These values do not constitute final and decisive factors from the point of the number of whales examined. Some corrections are likely, both theoretically and numerically, by future studies. Only by then, they will become final and decisive.

This paper deals with the change in the degree of lenticular colouration (light absorption by crystalline lens) by passage of time since birth, and changes in colouration during one year will have to wait for future studies.

It is the belief of this author that the change in the colouration of crystalline lens is not only convenient but is far more accurate and reliable than any other data heretofore offered for estimation of age in whales.

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References

N. A. Mackintosh & J. F. G. Wheeler: Southern Blue and Fin Whales. Discovery Reports. Vol. I. (1929).

J. F. G. Wheeler: The Age of Fin Whales at Physical Maturity. Discovery Repoorts. Vol. II. (1930).

A. H. Laurie: The Age of Female Blue Whales and the Effect of Whaling on the Stock. Discovery Reports. Vol. XV. (1937).

L. H. Matthews: The Sperm Whale, Physeter Catodon. Discovery Reports. Vol. XVI. (1938).

L. H. Matthews: The Humpback Whale, Megaptera nodosa. Discovery Reports. Vol. XVII. (1937).

L. H. Matthews: The Sei Whales, Balaenoptera borealis. Discovery Reports. Vol. XVII. (1938).

N. Peters: Ueber Grösse Wachstum und Alter des Blau Wales und Finn Wales. Zool. Anz. Bd. 127(1939).

Helmholtz: Handbuch der physiologischen Optik. 140(1896).

Priestley-Smith: Statistics of the Weight, Volume and Specific Gravity of the Crystalline Lens at Different Times of Life. Transact. Ophth. Soc. (1883).

Collins: The Composition of the Lens in Health and in Cataract. Ophth. Review, 8, 324 (1889).

Hess: Messends Untersuchungen über die Gelbfärbung der menschlichen Linse. Arch. f. Augenh. 63, 164(1909).

J. F. G. Wheeler: On the Stock of Whales at South Georgia. Discovery Reports. Vol. IX. (1934).

S. Kemp and A. G. Bennett: On the Distribution and Movements of Whales on the South Georgia and South Shetland Whaling Grounds. Discovery Reports. Vol. VI. (1932).

A. H. Laurie: Some Aspects of Respiration in Blue and Fin Whales. Discovery Reports. Vol. VII. (1933).

J. J. Ruud: The Surface Structure of the Baleen Plates as a Possible Clue to Age. Hvalradets Skrifter. Nr. 23 (1940).

H. Omura, Y. Matsuura and I. Miyazaki: Science of Whales and the Whaling. (1942).

Japan Trade Institute: Whaling (Hogei). (1943).

Japan Whaling & Marine Industry Union: Whaling Handbook. Vols. I to IV. (1943).

Hideo Omura: Whales. Technology of Marine Products. 7 (1944).

Masanori Nakaizumi: Colour of Crystalline Lens, its Change by Age. Jap. J. Ophth. 30, 701 (1926).

Yoshiharu Shoji: Diseases of Crystalline Lens. Japan Ophth. Review. Vol. XVIII. (1937).

Hiroaki Aikawa: Marine Resources. (1949).

Komao Baba: Whaling. (1943).

Yoshio Matsuura: Whaling. (1943).

Motosaburo Masuyama: How to arrange a few data and to plan an experiment. (1949).

Motosaburo Masuyama: How to plan an experiment. (1948).