REPRODUCTION OF THE SPERM WHALE IN THE NORTH—WEST PACIFIC

SEIJI OHSUMI

It is need to establish the countermeasure for the control of the sperm whale population as well as some baleen whales. For reasonable control of the population, we must make a correct diagnosis of the population size. The problem on the reproduction is one of the needful factors in the stock assessment.

On the reproduction of the sperm whale, there are some reports—Matsuura (1936, 1940), Matthews (1938), Omura (1950), Nishiwaki & Hibiya (1951), Clarke (1956), Nishiwaki, Hibiya & Ohsumi (1969), Chuzhakina (1961), etc. However, on the sexual cycle which is need to stock assessment, we have only few knowledges yet.

Recently, age studies of the sperm whale have been developing (Nishiwaki, Hibiya & Ohsumi, 1958; Ohsumi, Kasuya & Nishiwaki, 1963), and many materials for the reproduction of the sperm whales in the adjacent waters to Japan have been collected with connection to age. Present report is chiefly based on the materials, and the results will be added new informations in some points to poor knowledges on the sperm whale.

To our regrets, we have not yet succeeded to keep sperm whale to study reproductive physiology, and it is very deficult to get true knowledge. We must develope the study on this problem furthermore.

MATERIALS AND METHODS

Whales Research Institute has continued to investigate the whales in adjacent waters to Japan, and present paper is based on the biological data and materials collected in the investigations during the seasons from 1960 to 1962.

Age of sperm whale was shown as the number of growth layers in dentine of maxillary tooth which was prepared with the same method as described by Ohsumi *et al.* (1963).

Sexual maturity of the female was judged with ovaries, that is to say, the female which has one or more than one *corpus luteum* or *corpus albicans* in ovaries was judged as sexually mature. Pregnant female was also judged with ovaries, because in Japanese coastal whaling, whales are opened their belly before they are towed to a land station and foetuses are often lost at that time. The female with *corpora lutea* in ovaries was judged as pregnant, although there will be a possibility to exist some females which is not pregnant with *corpora lutea* in the ovaries. Lactation of the sperm whale was determined by examining mammary gland. Cutting the mammary grand, secretion of white milk was judged as lactation. Number of *corpora lutea* and *corp. albicantia* in the ovaries was counted for the purpose to know number of ovulation of a whale by naked eye, and on some individuals, diametre of the *corpora* were measured to study the involution of corpus albicans.

The records of foetuses in International Whaling Statistics 1937–1961 were used to count the sex ratio of the sperm whale in foetal stage and to draw growth curves of foetuses.

BREEDING SEASON

The breeding season is here defined as the period of pairing. because, in the sperm whale, gestation period extends for 16–17 months, and pairing takes plase in different season with the parturition season as shown in the following chapter.

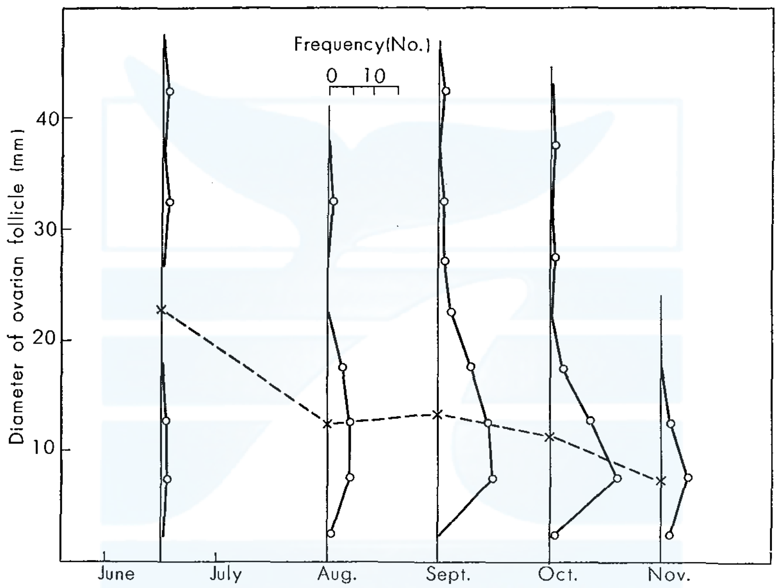

Fig. 1. Frequency distribution of diametre of ovarian follicles in resting and pubertal sperm whales caught in the waters adjacent to Japan.
Cross and broken line: mean diametre.

Seasonal change of genital organ

Males: Matthews (1938) reported that there was no definit reproductive activity in the males examining histologically the testes of the sperm whale in the southern hemisphere. That is to say, testes are active in the all seasons. Nishiwaki & Hibiya (1951, 1952) examined the testis tissue of the sperm whale in Japanese coastal waters, and described the possibility of a periodicity in the activity of testis. Clarke (1956) examined the seasonal change of diameter of semineferous tubules in the testes of the sperm whale in the Azores waters, and stated that there was sexual cycle in the male of sperm whale, and the breeding season existed during October to June.

According to Chittleborough (1955), there is quite difference in the weight between testes in feeding season and breeding season for the humpback whale. Meek (1918) reported that weight of testes of *Phocaena communis* increased remarkably in summer. On the contrary, Mackintosh & Wheeler (1929) describe that amount of sperm is more in breeding season than in feeding season, but there is no seasonal change in the weight of testes for the southern blue and fin whales.

Comparing the relations between age and weight of testes for the sperm whales caught in adjacent waters to Japan during the months April-June and September-November, there is no difference between them, although it is not yet concluded because of scanty of the materials of the former.

Further investigation will be need on this problem in the sperm whale.

TABLE 1. FERTILIZED DATES (MONTH/DECADE) OF SPERM WHALE FOETUSES ACCORDING TO THE FOETAL LENGTHS AND MONTHS KILLED

Body length (feet)	Gestation month	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0	1.0	12/2	1/2	2/2	3/2	4/2	5/2	6/2	7/2	8/2	9/2	10/2	11/2
1	2.3	11/1	12/1	1/1	2/1	3/1	4/1	5/1	6/1	7/1	8/1	9/1	10/1
2	3.4	10/1	11/1	12/1	1/1	2/1	3/1	4/1	5/1	6/1	7/1	8/1	9/1
3	4.5	8/3	9/3	10/3	11/3	12/3	1/3	2/3	3/3	4/3	5/3	6/3	7/3
4	5.8	7/3	8/3	9/3	10/3	11/3	12/3	1/3	2/3	3/3	4/3	5/3	6/3
5	6.9	6/2	7/2	8/2	9/2	10/2	11/2	12/2	1/2	2/2	3/2	4/2	5/2
6	8.0	5/2	6/2	7/2	8/2	9/2	10/2	11/2	12/2	1/2	2/2	3/2	4/2
7	9.2	4/1	5/1	6/1	7/1	8/1	9/1	10/1	11/1	12/1	1/1	2/1	3/1
8	10.3	3/1	4/1	5/1	6/1	7/1	8/1	9/1	10/1	11/1	12/1	1/1	2/1
9	11.5	2/1	3/1	4/1	5/1	6/1	7/1	8/1	9/1	10/1	11/1	12/1	1/1
10	12.6	12/3	1/3	2/3	3/3	4/3	5/3	6/3	7/3	8/3	9/3	10/3	11/3
11	13.8	11/3	12/3	1/3	2/3	3/3	4/3	5/3	6/3	7/3	8/3	9/3	10/3
12	14.9	10/2	11/2	12/2	1/2	2/2	3/2	4/2	5/2	6/2	7/2	8/2	9/2
13	16.1	9/2	10/2	11/2	12/2	1/2	2/2	3/2	4/2	5/2	6/2	7/2	8/2
14	17.2	8/1	9/1	10/1	11/1	12/1	1/1	2/1	3/1	4/1	5/1	6/1	7/1
15	18.4	7/1	8/1	9/1	10/1	11/1	12/1	1/1	2/1	3/1	4/1	5/1	6/1
16	19.5	5/3	6/3	7/3	8/3	9/3	10/3	11/3	12/3	1/3	2/3	3/3	4/3
17	20.7	4/3	5/3	6/3	7/3	8/3	9/3	10/3	11/3	12/3	1/3	2/3	3/3

Females: Diameters of the largest graafian follicles were measured for 89 sperm whales in resting and pubertal stages. They were caught in the adjacent waters to Japan during the months June-November. Monthly frequencies of the diameters are shown in Fig. 1. Mean diameter has a tendency to decrease with the increase of month. Although there is no data on the measurement in other months, it is estimated that there is a periodic change in the diameter of graafian follicle. If the season when the whale has the largest graafin follicle agrees with breeding season, it is estimated to be before June. In the other hand, in the frequency distribution of the size of graafian follicles there are two modes. If the ovarian follicle over 25 mm in diameter is near the maturity, such follicles are observed during June-Ocotober. This phenomenon will show a possibility that there are some individuals which ovulate during the seasons.

TABLE 2. RECORDS OF FOETAL LENGTHS OF THE NORTHERN HEMISPHERE SPERM WHALES GIVEN IN THE INTERNATIONAL WHALING STATISTICS 1937-61

Foetal length (feet)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
0	—	—	1	5	—	2	2	4	—	—	—	—	14
1	—	—	1	—	3	8	23	22	22	8	2	—	89
2	—	—	—	2	—	2	9	47	45	16	7	3	131
3	—	1	—	1	1	1	3	27	50	25	16	1	126
4	1	—	—	—	7	3	4	11	30	29	13	2	100
5	—	2	3	4	2	4	—	5	11	30	14	1	76
6	1	1	1	1	5	6	3	9	7	7	8	7	56
7	2	—	1	5	7	3	2	3	2	1	7	3	36
8	4	1	6	6	8	4	3	5	2	—	—	1	40
9	1	3	2	16	12	6	4	7	4	5	—	—	60
10	2	6	9	16	20	3	8	6	5	2	1	3	81
11	—	1	4	18	14	5	10	9	11	3	—	—	75
12	—	1	6	19	19	6	17	18	13	2	—	—	101
13	—	—	1	4	13	10	16	14	9	1	—	—	68
14	—	—	—	—	3	4	11	10	4	3	—	—	35
15	—	—	—	1	2	1	2	2	4	1	—	—	13
16	—	—	—	—	1	—	—	—	1	—	—	—	2
17	—	—	—	—	—	—	—	—	—	—	—	—	—
20	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	11	16	35	98	117	68	117	199	220	133	68	21	1,103

TABLE 3. RECORDS OF FOETAL LENGTHS OF SOUTHERN HEMISPHERE SPERM WHALES GIVEN IN THE INTERNATIONAL WHALING STATISTICS, 1937-61

Foetal length (feet)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
0	—	1	1	—	—	—	—	—	—	1	5	—	8
1	1	5	6	7	3	—	—	1	—	4	2	—	29
2	2	6	11	14	13	—	1	—	2	2	1	1	53
3	5	7	22	22	23	12	4	3	4	4	2	—	100
4	2	5	13	21	38	29	8	11	3	4	—	—	134
5	1	3	7	19	34	27	13	10	14	8	8	1	145
6	2	1	1	14	22	19	22	29	19	29	10	2	170
7	2	3	4	7	14	12	17	24	24	24	14	3	148
8	5	2	—	4	2	16	21	44	41	45	32	1	213
9	5	1	2	—	—	8	11	26	36	35	20	4	148
10	5	2	2	1	2	1	7	14	19	37	35	8	133
11	8	3	2	1	—	—	4	2	20	26	17	8	91
12	14	3	2	5	3	1	2	6	7	27	27	6	103
13	13	4	5	—	3	1	—	—	3	13	19	6	67
14	3	1	2	—	2	—	1	—	3	4	6	5	27
15	3	—	1	—	1	—	—	—	—	4	1	—	10
16	—	—	—	—	—	—	—	—	—	—	—	1	1
17	—	—	—	—	—	—	—	—	1	—	—	2	3
20	—	—	1	—	—	—	—	—	—	—	—	—	1
Total	71	47	82	115	160	126	111	170	196	267	199	48	1,592

Estimation of pairing season from body lengths of foetuses

In the following chapter, growth curves in the gestation period will be shown. In Fig. 7, the growth curves of foetuses in northern and southern sperm whales agree with each other sliding the time axis to 6 months. This means that the pairing season in the northern and southern hemispheres are opposite in time but the same in season of the year as shown by Clarke (1956).

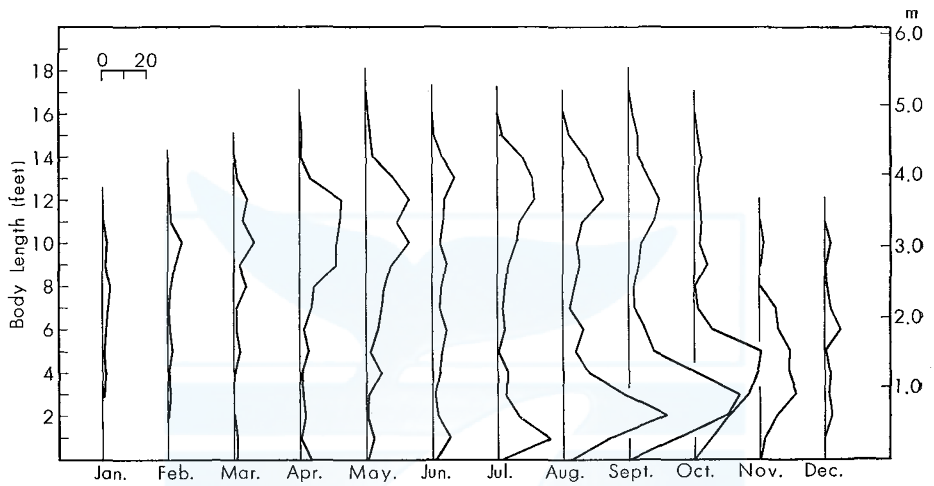

Fig. 2. Monthly foetal length frequencies of the northern hemisphere sperm whale.

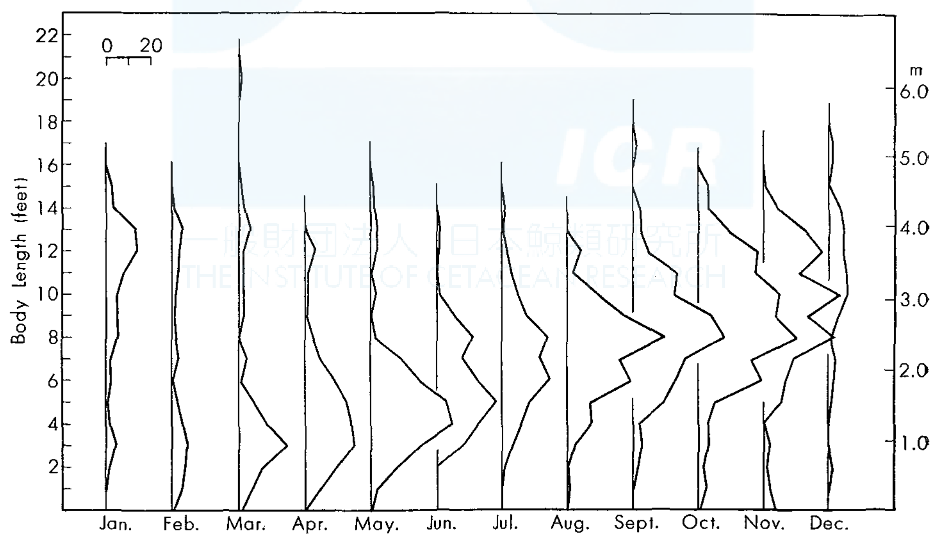

Fig. 3. Monthly foetal length frequencies of the southern hemisphere sperm whale.

Conception date will be calculated with the method of Huggett & Widdas (1951) in the following chapter. According the result, peak of conception date is middle-late decade of April in the northern hemisphere, and middle-late decade of October in the southern hemisphere. However, as shown in Figs. 2 and 3, breeding will last fairly long time. Basing the growth curve, conception dates and gestation months are calculated in each foetal length of each month as shown in Table 1. And Tables 2 & 3 are the frequency of foetal size distribution in each month for the sperm whales of which data were given from the International Whaling Statistics, 1937–1961.

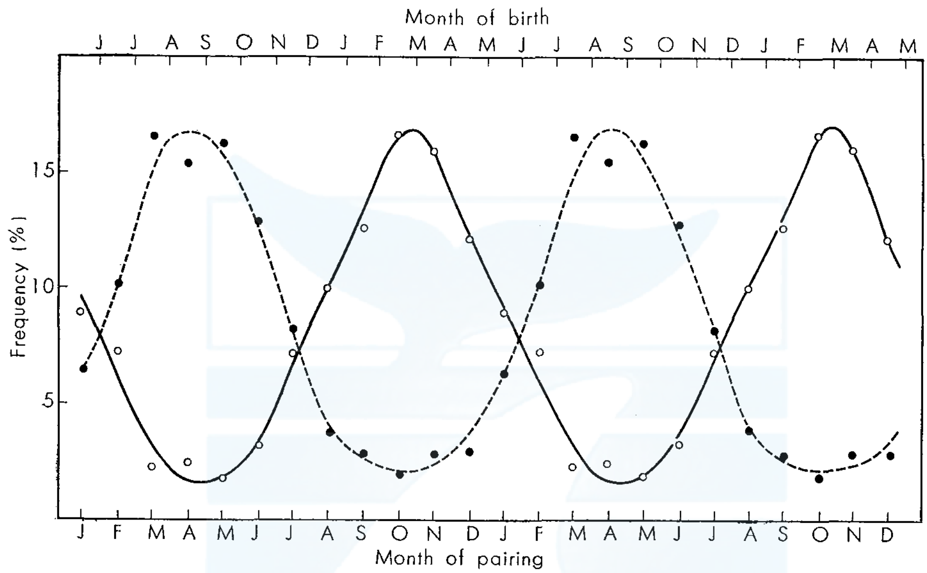

Fig. 4. Pairing and parturition frequencies calculated from foetal lengths for the southern and northern sperm whales.
Open circles and solid line: southern hemisphere, Closed circles and broken line: northern hemispnere.

Frequency of conception dates were calculated from Tables 1, 2, and 3. Pairing extends all seasons of the year as shown in Fig. 4. But the mode of pairing is April and October in the northern and southern hemisphere respectively, and most conception extends between February to June in the northern hemisphere, and between August to December in the southern hemisphere. The months are late winter to late spring in both hemispheres, and during the months, 71 and 67 per cent of total conceptions of the year are considered to take plase in the northern and southern hemisphere respectively. Bimodal frequency distribution of the pairing season is not seen in the sperm whale as reported by Naaktgeboren *et al.* (1960) for the fin whale.

Change of pairing season according to the age of the mother whale

Laws (1961) reports that pairing seasons are different between primiparous and multiparous fin whales, the former is about one month later than the latter, and pairing season becomes earlier with the increase of age of the mother whale.

Body lengths of foetuses were measured and maxillary teeth of the mothers were collected for 110 sperm whales in Japanese coast during 1960 to 1962 seasons. The conception dates were calculated from foetal lengths, and the ages were counted on the growth layers in the dentine of maxillary teeth. Fig. 5 shows the average conception date in the age classes of the whales. Average conception date in under 10 years class which is estimated to be almost primiparous is 6th of June, on the contrary, average conception dates of over 11 years classes which are estimated to be almost multiparous are early decade or middle decade of May. Furthermore, there is a tendency that pairing date becomes gradually earlier accompanying with the increase of age in the sperm whale.

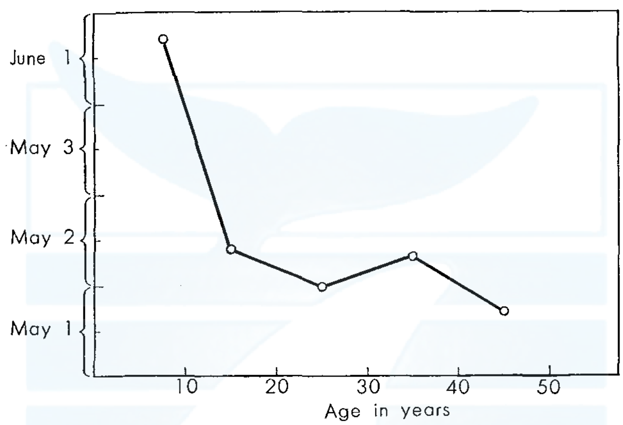

Fig. 5. Change of average conception dates according to the age of sperm whales in the waters adjacent to Japan.

In Japanese coastal whaling, composition of younger female sperm whales in the catch increases gradually from spring to fall. This phenomenon means older group migrates northward ealier. And it is estimated that whales having early pairing season leave their breeding ground earlier than the others. Further investigation will need on the ecology of schools especially " harem " in the sperm whale for the solution of this problem.

Yearly fluctuation of pairing season

Conception dates were calculated from the records of foetal lengths of the sperm whales caught in adjacent waters to Japan during 17 years from 1946 to 1962, and average conception date was calculated in each year. Fig. 6 shows the result. During these years conception took plase earliest in 1947, and average date was 6th of April, and the latest year was 1958. The average date was 20th of May. Range of yearly fluctuations is one month and a half.

Recently pairing season seems to become later from Fig. 6, but we must remember that recently the catch season removes to fall in Japanese coastal whaling. And as described in the previous section, composition of younger whales in the catch increases from spring to fall. The younger females have later pairing season.

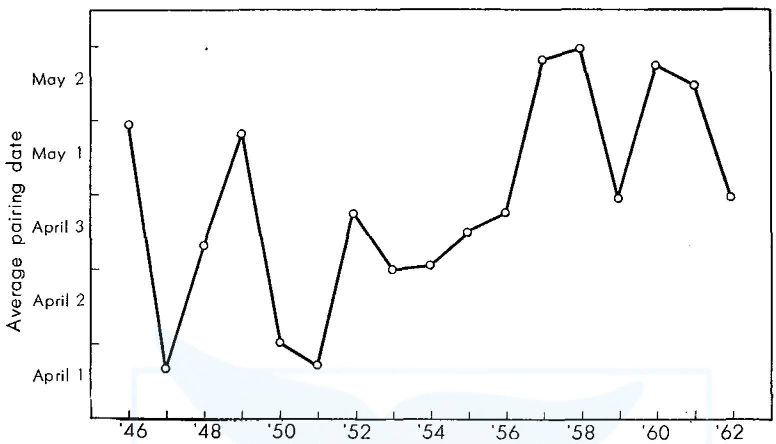

Fig. 6. Yearly fluctuation of conception dates for the sperm whales in adjacent waters to Japan during 1946 to 1962, based on foetal lengths in each month.

GESTATION, PARTURITION AND LACTATION

Monthly foetal length frequency

Using the records on the foetal lengths given in the International Whaling Statistics, 1937–1961, monthly foetal length frequencies are summarized in Tables 2 and 3 for the northern and southern sperm whales respectively. In Figs. 2 and 3 the monthly foetal length frequency distributions are set out. Comparing the two figures, we can find that monthly frequency distributions are different each other between the northern and southern sperm whales. It is clear that they are separated to different stocks. On the contrary, in the northern sperm whales, the monthly frequency distributions do not show significant difference among the whales taken in the waters of Japan, Kuril Islands, Pacific coast of North America and the North Atlantic. In the same way, the monthly length distributions do not show the significant difference among the whales caught in the waters of Chile, Peru and South Africa. That is to say, if there are several stocks in the same hemisphere, they will show the same growth pattern in their gestation periods.

In some months there are two peaks of the length distribution. Bimodal distributions are evidently seen in July, August and September in the northern hemisphere and January, February and March in the southern hemisphere. The monthly peaks move continuously to the peak in the next month. These phenomena suggest that modal period of conception is one a year, and the gestation period lasts over one year.

Growth curve of the foetus

Fig. 7 shows the relation between the mean foetal lengths in each decade for the northern and southern sperm whales. The data are due to the International Whaling Statistics, 1937–1961. In this figure, growth curves of both hemisphere sperm whales fit each other when one of them slide the axis of abscissa to 6 months. This means that the growth rates are almost the same between the both hemisphere sperm whales. Excluding the earlier and later stages, the given figures are recognized as straight lines. In early stage the figures are seemed to be higher than the actual one, for very small embryos are apt to be overlook and are not recorded occasionally. On the contrary, in the late stage of gestation we must consider that the given figures are seemed to be lower than the actual, because in this season there are some individuals which are already born, and they bring down the true figure.

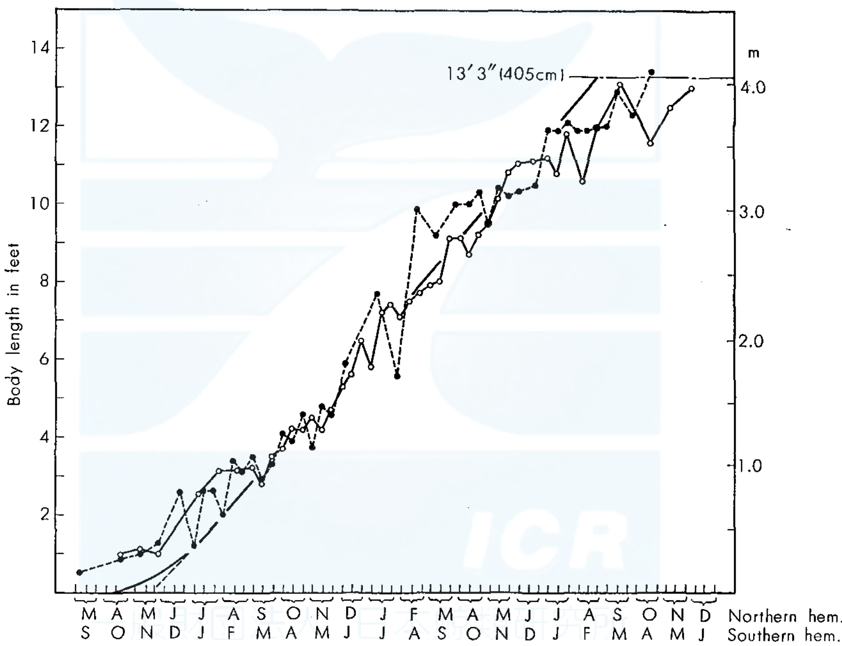

Fig. 7. Mean foetal lengths in each decade and foetal growth in length of both hemisphere sperm whales.
Broken line and closed circles: Northern hemisphere, Solid line and open circles: Southern hemisphere, Broad line: growth curve.

Two regression lines are calculated using the mean foetal lengths in each decade during the months September to June in the northern hemisphere and March to December in the southern hemisphere. Cross point between the regression line and the axis of abscissa is the last decade of May and the last decade of November for the northern and southern hemisphere respectively. And the cross point between the body length at birth (405 cm or 13 feet 3 inches, as shown in the following section) and the regression line is the last decade of August and the last decade of February in the northern and southern hemisphere respectively. Therefore, the period between the two points is 15 months and one decade (468 days) in the both hemisphere.

Laws (1959) showed that the foetal growth in toothed whales could be described by a linear plot of length except non-linear early part of pregnancy. And I agree with his theory for the case of the sperm whale.

The mean conception date was calculated by means of the method of Huggett & Widdas (1951) and Laws (1959):

$$Lt_0 = 468 \text{ days} \times 0.07/0.93$$
$$= 35 \text{ days}$$

Therefore, the conception date is estimated to be middle to last decade of April and middle to last decade of October in the northern and southern hemisphere sperm whales.

Thus, the growth curve of the foetus of the sperm whale is drawn as broad line in Fig. 7, and the both hemisphere sperm whales will show the same growth curve in gestation period.

TABLE 4. FOETAL LENGTHS OF SPERM WHALE IN EACH GESTATION MONTH

Gestation month	Foetal length feet	Foetal length cm	Month	Foetal length feet	Foetal length cm
1	0.2	6	9	6.9	210
2	0.8	24	10	7.7	234
3	1.7	52	11	8.6	262
4	2.5	76	12	9.5	289
5	3.4	103	13	10.3	314
6	4.2	127	14	11.2	341
7	5.1	155	15	12.1	369
8	6.0	183	16	12.9	393

Table 4 shows the average foetal length in each gestation month.

Growth rate of foetus in males seems to be slightly greater than that in females, but the difference will be very small.

Sex ratio in gestation period

Sex ratio in foetal stage is one of the needful factors for the stock assessment of sperm whale.

Summarizing 2677 foetal records in the International Whaling Statistics, 1937–1961, calculated sex ratios of males are shown in Table 5. They are 48.1, 56.2 and 45.6 per cent in the waters of the North Pacific, Chile & Peru and Africa respectively. The average sex ratio of males is calculated as 51.03 per cent. Therefore, it will be concluded that the sex ratios of males and females are almost equal in the sperm whale.

Body length at birth

On the body length birth in the sperm whales, several authors described as shown in Table 6.

TABLE 5. SEX RATIOS OF THE SPERM WHALE IN THE FOETAL STAGE

	North Pacific	Chile & Peru	Africa	Total
Males	514	628	224	1,366
Females	554	490	267	1,311
Both sexes	1,068	1,118	491	2,677
% of males	48.13	56.17	45.62	51.03

After the International Whaling Statistics 1937–1961

TABLE 6. DESCRIPTIONS ON THE BODY LENGTHS AT BIRTH IN THE SPERM WHALE BY SEVERAL AUTHORS

Authors	Body length at the brith	Locality
Bennett (1840)	14 ft	
Melville (1851)	14–15 ft	
Matsuura (1936)	13–14 shiaku	Japan
—— (1940)	14–15 shiaku	Japan
Matthews (1938)	4 m or little more	Southern hemisphere
Mizue & Jimbo (1940)	14–15 ft	Japan
Clarke (1956)	3.92 m	Azores
Laws (1959)	4.15 m	Southern hemisphere

TABLE 7. RECORDS OF NEWLY BORN SPERM WHALES

Body length		Date	Locality	Author
3.71 m	(12′ 8″)	14, VIII	Azores	Clarke (1956)
3.86 „	(12′ 8″)	12, VIII	„	„
3.89 „	(12′ 9″)	12, VIII	„	„
4.04 „	(13′ 3″)	11, VIII	„	„
4.04 „	(13′ 3″)	? IX	Barmuda	Wheeler (1933)
5.00 „	(16′ 5″)	27, VII	Japan	Ohsumi *et al* (1963)
5.2 „	(17′)	19, VIII	„	Matsuura (1940)
5.2 „	(17′)	27, X	„	„
5.5 „	(18′)	?	North Atlantic	Harmer (1933)

Observation of parturition for the cetacea is very rare chanses for us, and so measurement of body length at birth is almost impossible. Neonatal body length must be determined with larger foetal lengths and body length of calves which are estimated as soon after birth. However, whale calves are protected from catch, and we have only few data on the measurements of the calves as shown in Table 7.

The shortest calf was 3.71 m (12′ 2″) in this Table. According to Ohsumi *et al.* (1963), a calf stranded in a Japanese beach on 27th July, 1957. This calf was 5.00 m (16′ 5″) in body length, and had no growth layer in dentine of teeth. Examining the deposition of dentine, the calf was at least 4 months old, then the neonatal length is clearly estimated to be under 5 m.

The maximum foetal length is 19 feet 6 inches in the records on the sperm whale foetuses in International Whaling Statistics. But it is exceptional, and I wonder whether it was foetus actually or not. In the records of 2,695 sperm whale foetuses, there are 6 (0.22%) foetuses of which body lengths are 17 and 16 feet.

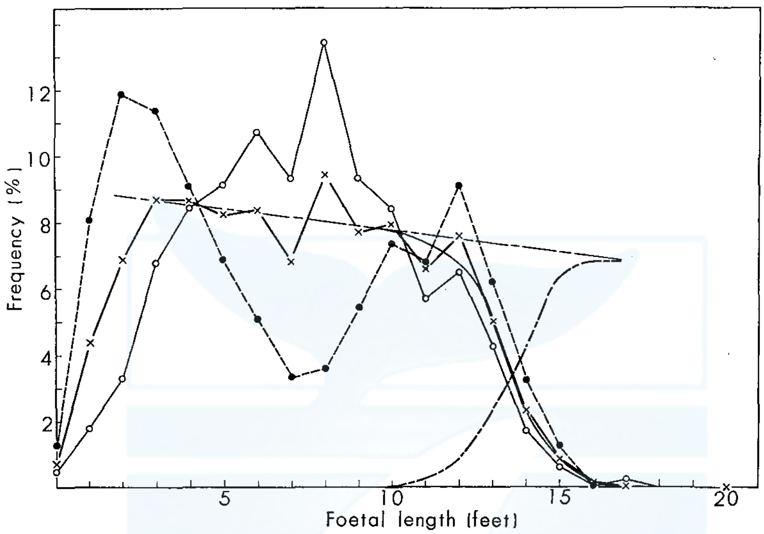

Fig. 8. Size distributions of the sperm whale foetuses, and estimation of the length at birth.

Open circles and solid line: Southern hemisphere, Closed circles and broken line: Northern hemisphere, Crosses and broad line: Both hemisphere, Straight Chain line: Estimated change of frequency from broad line, Broad chain line: Estimated size distribution of calves (Straight line minus broad line).

Fig. 8 shows the size distributions of sperm whale foetuses. Pattern of the distribution in the northern hemisphere is different with that in the southern hemisphere. It is caused with the difference of whaling season between the both hemisphere (foetus data are many in summer-fall seasons in the northern hemisphere, and they are many in spring season in the southern hemisphere). Summing up the data in the both hemisphere, the combined frequency distribution gradually decreases from 3 to 12 feet, after then the frequency decreases suddenly. Comparing size distributions over 8 feet long in the summer season (July-September in northern hemisphere and January-March in southern hemisphere) when is the parturition season of the sperm whale as described in the following section, the distribution patterns of the both hemisphere are nearly the same each other, although modal lengths are 13 and 12 feet in the southern and northern hemisphere respectively as shown in Fig. 9. Average foetal lengths are 11.67 and 11.78 feet in southern and northen hemisphere sperm whales. These results mean that there is no difference of body lengths at birth between the both hemisphere sperm whales. The neonatal length should be larger than the average foetal length at the season, because the individuals which have been born at that season are of course excluded from the size distribution of foetuses, and they drop the really average body length in this season.

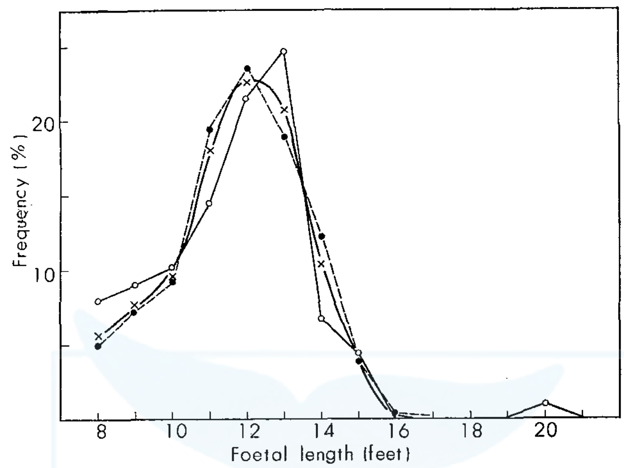

Fig. 9. Foetal size distribution of the sperm whales in parturition months.

Open circles and solid line: Southern hemisphere in January, February and March, Closed circles and broken line: Northern hemisphere in July, August and September, Crosses and broad line: Both hemisphere.

Regression line was drawn in Fig. 8, and estimating that the distance between the line and smoothed broad curve is the frequency of calves, the size distribution of calves are shown as a broad chain line in Fig. 8. Cross point between chain line and smoothed foetal line is 13.6 feet (4.15 m). It is estimated the length is the average body length at birth in the sperm whale. However, considering the records that there are 5 calves of wich body langths are under 4.15 m among the few data in Table 7, the given neonatal length will be little larger than the real one. The body lengths of the 5 calves are between 3.71 and 4.04 m, and the average is 3.98 m. In conclution I estimate that 4.05 m (13 feet 3 inches) is the average body length at birth in the sperm whale of both hemispheres.

Parturition season

Table 8 shows the parturition season in the sperm whales described by several authors.

In the previous section, the average body length at birth was given as 13 feet 3 inches. The mean parturition date will be got from a cross point between the growth curve and the body length of 13 feet 3 inches in Fig. 7. It is last decade of August in the northern hemisphere, and last decade of February in the southern hemisphere. They are both late-summer season. Catch dates of the calves which are considered to be soon after birth are during middle decade of August to September as shown in Table 7. This will support the above result.

Fig. 4 shows periodical change of parturition dates in addition to the periodical change of conception dates calculated by means of growth curve and foetal size frequencies in each month. In the northern sperm whales, 71 per cent of the year's parturition takes plase during June to October, and in the peak month August 20.8 per cent of parturitoion. Parturition lasts through the year, but during January to April the proportion of parturition is only 11 per cent. In the southern hemisphere, 67 per cent of parturition will take plase during December to April, and 9 per cent during July to October.

TABLE 8. DESCRIPTIONS ON THE PARTURITION SEASONS IN THE SPERM WHALE BY SEVERAL AUTHORS

Authors Northern hemisphere	Parturiton season	Location
Beale (1839)	Not limited	
Bennett (1840)	Ditto	Japan
Tago (1922)	Ditto	Japan
Harmer (1933)	June～December	Bormuda Is.
Matsuura (1936)	May～August	Japan
—— (1940)	May～September	Japan
Mizue & Jimbo (1950)	July～October	Japan
Clarke (1956)	May～November (peak : July～August)	Azores Is.
Chuzhakina (1961)	May～October (peak : July～August)	Kuril Is.
Southern hemisphere Matthews (1938)	September～April (peak : February)	Africa

Gestation period

On the gestation period for the sperm whale, Scammon (1874) described as 10 months. Harmer (1933) and Matsuura (1936) estimated to be 12 months. Later authors all reported longer gestation periods. Matthews (1938), Matsuura (1940) and Clarke (1956) got a result of 16 months, Mizue & Jimbo (1950) 17 months, and Chuzhakina (1961) 16–17 months respectively for the gestation period of the sperm whale. Laws (1959) studied foetal growths for several cetaceans, and calculated the gestation period of the sperm whale to be 491 days or 16 months.

As described in the former sections, average conception date is middle decade of April, and the average parturition date is last decade of August in the next year for the northern sperm whale. For the southern sperm whale, they slide just 6 months from those in the northern hemisphere. Therefore, gestation period is calculated to be 16.4 months (about 503 days). Of course we must estimate that there is individual variation in the gestation period in the sperm whale.

Body length at weaning

We have scanty knowledges on the lactation of the sperm whale.

Matsuura (1936) estimated the lactation period to be about 6 months, but he did not describe on the body length at weaning. Matthews (1938) thought lactating period was 7 months, and length at weaning was estimated with growth curve and lactating period to be 6.5 m (21 feet). Clarke (1956) examined the stomach contents of 15 small sperm whales caught in the waters to adjacent Azores Islands. And he found that milk was contained in the stomach of whales under 6.6 m in length, but food animals were found in those of whales over 6.8 m in length. Then he determined weaning length of the sperm whale would be between 6.6 and 6.8 m, probablly 6.7 m (22 feet).

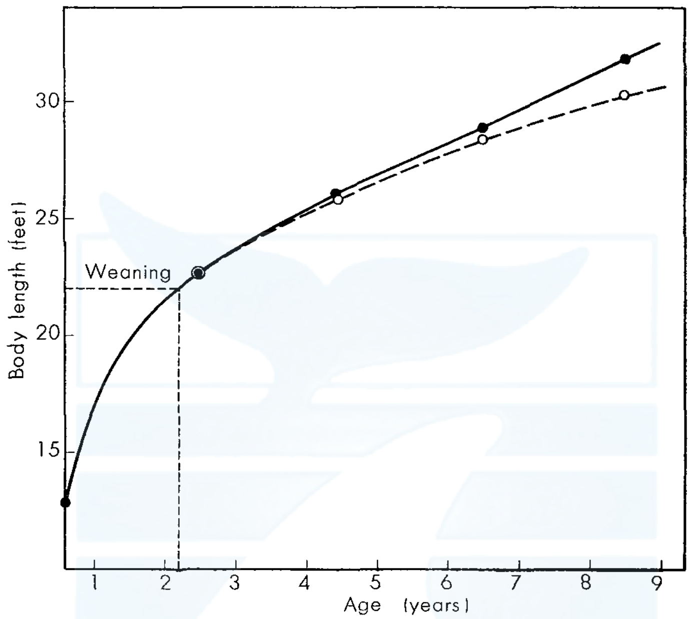

Fig. 10. Growth curves of male and female sperm whales based on the growth layers in dentine of maxillary tooth, and estimation of weaning period from body length at weaning.

Open circle and broken line: Females, Closed circle and solid line: Males.

There was nothing in the stomach of a 5.0 m long sperm whale which stranded on Japanese coast. This whale was estimated to be suckling, although milk was not confirmed in the stomach.

According to some observations on feeding of small sized toothed whales in aquariums, infants begin to eat food simultaneously suck mother's milk after some months from birth (Tavolga & Essapian, 1957; etc.).

At the present time, there is no datum to be added to the information by Clarke (1956) on the problem of body length at weaning for the sperm whale, and so I also employ his theory for the length at weaning in the present paper.

Weaning season and lactation period

Matsuura (1936) estimated lactation period was 6 months, and in his paper parturition season was May-August. Then weaning season is December-February in his theory. Matthews (1936) estimated that weaning season was August for southern sperm whale. Clarke (1956) determined the season was September, for the whales of weaning body length appeared during July-October in Azores. And he also estimated the lactation period to be 13 months after correction with weaning season of the calculated 15 months from the composition of lactating and pregnant whales.

As described in former sections we have few chanses to investigate calves, and so to pursue a growth in length seasonally is impossible for the sperm whale. Another method is to use growth curve as examined by Matthews (1938).

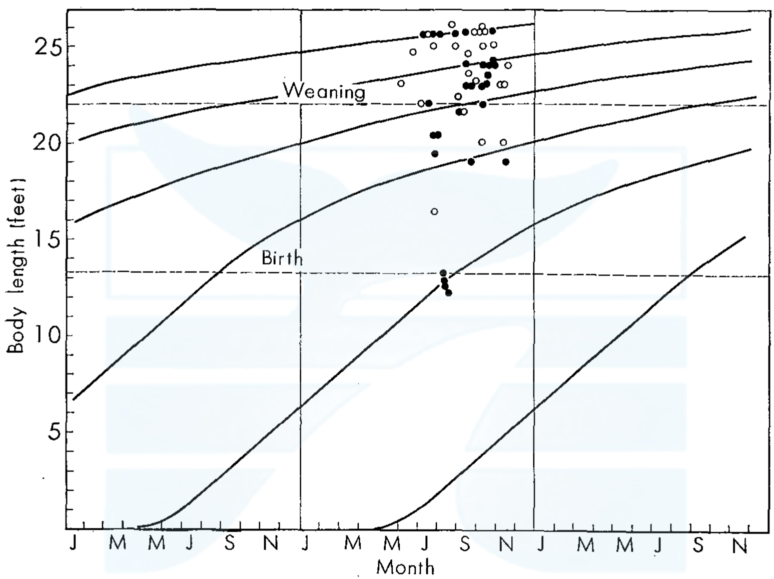

Fig. 11. Growth curve of foetuses and calves for the sperm whales in the northern hemisphere, and the records of date and body length of calves.
Open circle: Female, Closed circle: Male.

Recently age determination of the sperm whale has developed by reading growth layers in the dentine of maxillary teeth (Nishiwaki *et al.*, 1958; Ohsumi *et al.*, 1963). Fig. 10 shows a growth curve based on reading the growth layers in young sperm whales. According to Ohsumi *et al.*, dark band in dentine appears in winter, and mean parturition season is August. Therefore, a time from birth to formation of the first dark band is about 4 months in average. In Fig. 10, graduations on the axis of abssisa show winter (January 1st).

If the weaning length is 22 feet, lactation period is estimated from Fig. 10 as 1.6 years (2.3–0.7=1.6). If lactation period is 1.6 years (=19 months), weaning season becomes March-April in the northern hemisphere. However, Clarke states weaning season is September considering the appearence of weaning whales, and as shown in later chapter, proportion of resting whales increase after August. Therefore, I determine weaning season is August or September in the northern hemisphere. Then the lactation period is more suitable to estimate as 24–25 months than 19 months.

Fig. 11 shows growth curve in gestation and calving ages and some plots of calves by date and length. As there are individual variations in growth rate and conception date, plotted points ride not always on the growth curve.

In the present paper, lactation period becomes much longer than the previous theory. On this problem, bottle-nosed dolphin (*Tursiops truncatus*) which were kept alive in an aquarium suckle for 18 months (Tavolga & Essapian, 1957), and a mother bottle-nosed dolphin (*Tursiops gilli*) which died at 2 years and 6 months after parturition secreted milk still at its death (Nakajima, 1963). According to Sergeant (1962), pilot whale (*Globicephala melaena*) has 22 months of lcatation period. Above reports seem to support my result.

OVULATION

Relation between the number of ovulation and age

Age of the sperm whale is present in the dentine of the maxillary tooth as a growth layer (Nishiwaki *et al.*, 1958). And the annual accumulation rate of the growth layer is studied by Ohsumi *et al.* (1963).

The relation between the age (number of growth layers in the dentine) and the number of corpora lutea and corpora albicantia in the ovaries were given for 892 female sperm whales which were investigated in the coast of Japan during the seasons from 1960 to 1962. Fig. 12 shows the above relation on each individual. Individual variation is relatively remarkable, but correlation coefficient is calculated as +0.76 for the ages more than 6 years old. There is an intensity that the deviation spreads accompanied with the increase of the age. This seems to show that there is individual variation in the ovulation cycle of the sperm whale. On the other hand, the ages at one ovulation distribute from 6 to 18 years. This shows that there is an individual variation in the age at sexual maturity. Then, the variance of the relation between age and number of ovulation is caused by the above two factors.

Fig. 13 shows the mean number of ovulations in each age (solid line) and the mean age in each number of ovulation (broken line). Two lines are both likely straight. This shows that there is close relation between age and number of ovulation, and the ovulation cycle is constant as the avarage. However, examining in detail, the gradient of the line is larger in the young ages than that in the older ages, and in old ages, the deviation between solid line and broken line spread each other. The ovulation is seemed to become gradually to lessen in the relation with the age.

Average annual number of ovulation and average ovulation cycle

Average annual number of ovulation was given calculating the coefficient of regression line from relation table. In above section we found that gradient of the

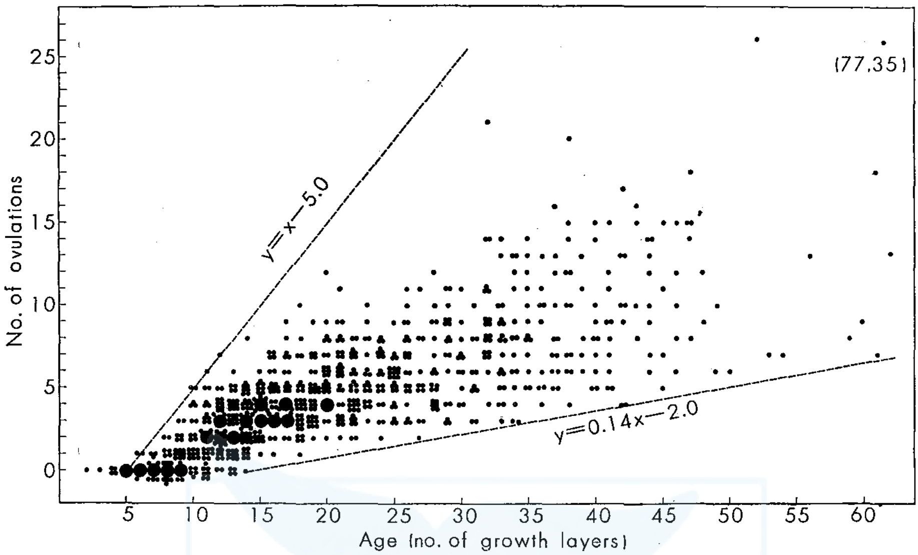

Fig. 12. Relation between age and number of ovulations for the sperm whales caught in the waters adjacent to Japan (1960–1962).

Small circle: One whale, Large circle: Ten whales, Broken lines: Upper and lower limits.

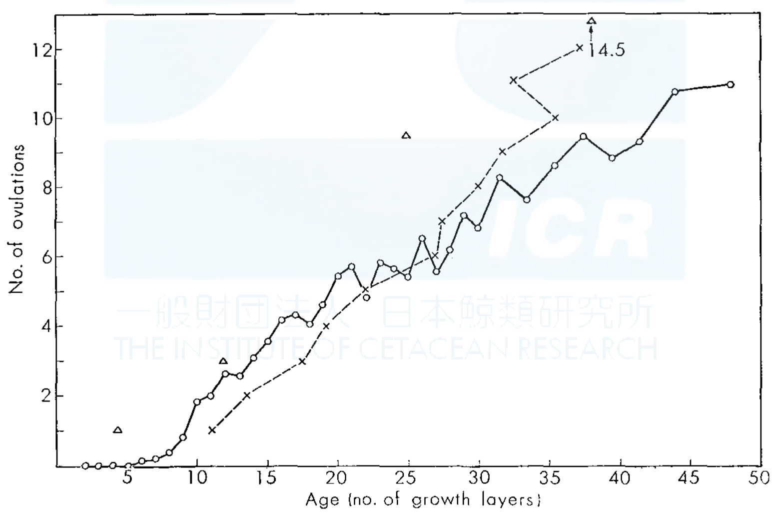

Fig. 13. Mean number of ovulations in each age and mean age in each number of ovulations for the sperm whales in the waters adjacent to Japan (1960–1962).

Open circles and solid line: Mean number of ovulations in each age, Crosses and broken line: mean age in each number of ovulations, Triangle: Result in the paper by Chuzakina (1961).

line in younger ages is different from that in older ages, then two coefficients were given separated at the age of 20 years as shown in the following:

Age	Average annual number of ovulation
6–20	0.308
21–48	0.255
6–48	0.265

In the older ages average annual number of ovulation is low, and 3 factors will be considered on this subject. The first is a possibility that ovulation cycle becomes prolonged as the increment of the age. The second factor is a ploblem whether old corpus albicans is not able to be distinguished or not. On this problem I will examine in the following section. The third factor is a artificial error on the counting of corpora albicantia. As the increase of accumulation of corpora albicantia in the ovaries, we are apt to miss counting the corpora number.

TABLE 9. BIOLOGICAL DATA ON FOUR MARKED SPERM WHALES RECAPTURED IN THE NORTH PACIFIC BY 1962

Mark no.	Elapsed time(A) (Years-Months)	No. of growth layers at recapture(B)	No. of corp lut. & alb. in ovaries(C)	Estimated age at marking(B-A)	Estimated age from sexual mat.(D)	Annual no. of ovulation(C/D)
J2871	10–1 1/3	18	0–2, 0–1	8	9	0.33
J2883, 2984	10–1 1/3	20	1–2, 0–3	10	11	0.54
J3166	9–1	30	0–3, lost	21	21	(0.29)
J3237	8–2 1/2	14	0–0, 0–2	6	5	0.40

As shown in Fig. 12, the deviation of corpora number are relatively large, but the ranges are limitted within two broken lines. Average annual number of ovulalation given from the upper limitted line is 1.00, and this value is considered to show the maximum vulation rate. On the contrary, annual ovulation number given from the lower limitted line is 0.14, and this will show the minimum ovulation rate of the sperm whale. Therefore, annual ovulation number is included within the range from 0.14 to 1.00, and the average annual rate is considered to be 0.27 in the sperm whale caught in the waters adjacent to Japan.

Calculating the ovulation cycle from the annual number of ovulation, it distributes from one year to 7.1 years, and the average ovulation cycle is 3.7 years. Then, the ovulation cycle of the sperm whale is considered to be fairly long, and connecting with the reproductive cycle as shown in the following chapter, the sperm whale is estimated to be mono-oestrous.

Examination of annual number of ovulation by means of whale marking

Amoung the marked sperm whales recaptured in the North Pacific by the end of 1962, there were 4 individuals of which maxillary tooth was collected for the age counting and in the same time the corpora number in the ovaries were counted. The biological data on the 4 individuals are shown in Table 9. We can not know the age at the time of marking of the recaptured whales, but it is able to be estimated by the elapsed time from marking till recapture and the growth layers in the dentine of upper tooth.

Now, the age at sexual maturity was estimated to be 9 years (Ohsumi *et al.*, 1963). In the present paper also shows the similar result, for cross point of solid line at lovulation level in Fig. 12 is 9.2 years. Age at marking of J 2871 whale is estimated to be 8 years, then this individual was near the age at sexual maturity at that time. Using the average age at sexual maturity, it will be estimated to become sexual maturity after 1 year from marking. As elapsed time is 10 years, this individual is estimated to be 9 years from sexual maturity. Finally, average annual number of ovulation is calculated from the number of ovulations devided by the age from sexual maturity, and it is 0.33. In the same way, average annual number of ovulation on other 3 recaptured whales are 0.54, 0.29, and 0.40 respectively for J 2883, J 3166, and J 3237. The average of 4 whales is 0.39. This value is similar to those which calculated in the above section.

Persistence of corpus albicans

It is believed that the involution speed of corpus albicans is very slow in the cetacea, and it does not vanish for the life span. On this problem, Laws (1961) studied thouroughly for the ovaries of the fin whale, and he supported the theory.

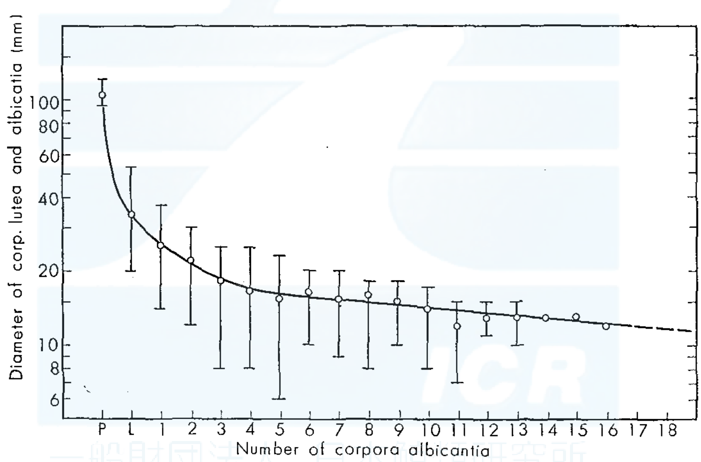

Fig. 14. Regression of mean diametre of corpora lutea and albicantia with increment of corpora numbers.
P: Corpora lutea of pregnancy, L: Corpora albicantia of lactation, Open circle: Mean value, Bar: Range of diametre.

Nishiwaki, Hibiya & Ohsumi (1958) measured the diametre of corpora lutea and corpora albicantia in the ovaries of 18 sperm whales, and reported preliminally that corpus albicans persisted for life span in the sperm whale. Then, Chuzhakina (1961) examined the ovaries of the sperm whale histologically, and got the same result as Nishiwaki *et al.*, because a corpus albicans which was disappearing partly or completely in the ovary was not observed at all.

In the present paper, diametres of corpora lutea and c. albicantia were measured for 29 sperm whales caught in the adjacent waters to Japan, and they were arrenged according to their size for each individual, to get the change of diametre accompanied with the increase in number of corpora albicantia in the ovaries. Corpus albicans of lactation was separated from other corpora albicantia.

As shown in Fig. 14, corpora lutea of pregnancy were 95–120 mm in diametre for 10 individuals, and the mean diametre of them was 105.0 mm. On the change of size in corpus luteum during gestation period, Chuzhakina (1961) reported that diameter of the body did not involute during the period. Laws (1961) describes the same result in the fin whale.

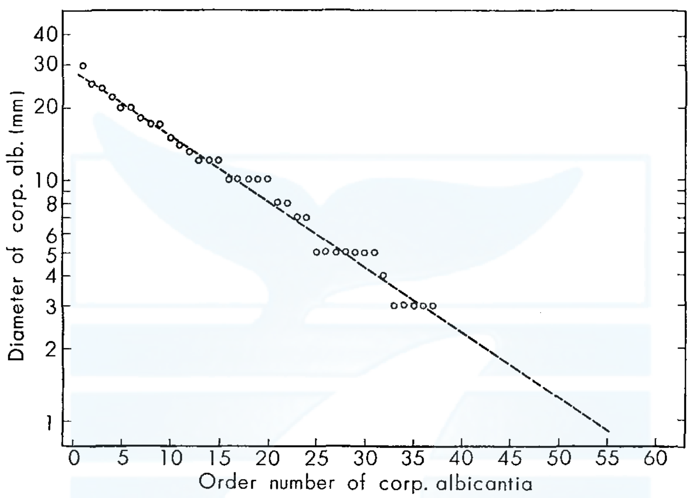

Fig. 15. Arrangement of diametre of 37 corpora albicantia in the ovaries of a sperm whale caught in the coastal waters of Japan.
Open circle: Actual diametre, Broken line: Regression curve.

After parturition corpus luteum reduses suddenly its size into corpus albicans. Corpora albicantia of lactation were 20 to 53 mm in diameter for 18 lactating sperm whales, and the mean diameter was 33.6 mm. The diameters of corpora albicantia except corpora albicantia of lactation were 3–37 mm. Arrenging them according to their size, it is found that the speed of involution gradually decreases, and the mean diameter of the corpora is 12 mm in the corpora number of 16. This size is easily recognized by naked eyes. However, the size of corpora albicantia in old stage is not constant as described by Laws (1961) for the fin whale, and seems to continue to decrease as shown in Fig. 14.

Fig. 15 shows the arrengement of diameters of 37 corpora albicantia in the ovaries of an individual which has the most corpora number in our materials. According to the Figure, the process of involution of corpus albicans is drawn as a hypabola, and the smallest corpus was 3 mm in diameter. If we are difficult to distinguish the size under 2 mm by naked eyes, the number of corpora will be 42 from the Figure. Considering from the frequency distribution of corpora number in the sperm whale, the composition of individuals of which number of corpora are over 20 is very small, and the maximum is 37. The age of the individual in Fig. 15 is 56+ from dentinal growth layers, and it is estimated to be very old.

It will be concluded that corpus albicans in the ovaries of the sperm whale continues to decrease in its size, but persists in ovary through the life.

Multiple-ovulation and multiplets

More than one ovum ovulate in the same time or simultaniously to the previous ovulation in an oestrus and at least one ovum furtilize in the oestrous, all Graafian follicles which have ovulated into oestrous should remain as *corpora lutea* during the gestation period. Then, the number of corpora lutea in the ovaries of a pregnant whale is considered to show the number of ovulations in the same oestrous period, although there are rare cases in which more than one ovum ovulate from one graafian follicle in cetacea (Bannister, 1963).

Of the total of 446 sperm whales which were investigated their both ovaries and had corpora lutea in the ovaries, 442 whales (99.11%) had only one copus luteum, 3 whales (0.67%) had 2 corpora lutea and one whale (0.22%) had 3 corpora lutea in the ovaries. Therefore, the frequency of multiple ovulation is considered to be extreamly low.

A frequency of multiplets is also an indication of multiple ovulations. However, the frequency of multiplets should be lower than that of multiple ovulation, because all ovulations do not always succeed to the furtilization. On the occurrence of twins in the sperm whales, Bennett (1840), Beneden & Gervais (1880), Matsuura (1936) and Matthews (1938) reported. And the frequency of twins is calculated as 0.66% from the data in the papers of the latter two authors. Using the records of foetuses of sperm whale in the International Whaling Statistics, of total 2,664 pregnant whales only 12 whales (0.45%) had twins. There is no record on the multiplets more than twin in the sperm whale. The frequency occurrence of multiplets will be lower than that of baleen whales (Kimura, 1956).

The frequency of the multiplets (0.45%) is lower than that of multiple ovulations (0.8%). But, it is dangerous to connect the figures to the fertilization rate of ovums, because the sperm whales are usually flensed in land stations where equipments are often worse than those in factory ships, and it will be apt to miss the finding of foetuses in the flensing at land stations.

PREGNANCY RATE

Seasonal change of pregnancy rate and the true pregnancy rate

Pregnancy rate is expressed as the rate of pregnant whales in the sexually mature females which have one or more than one corpus luteum or corpus albicans in the ovaries. Matsuura (1936) described that the occurrence of pregnant sperm whales varied with seasons in Japanese coast, but the total pregnancy rate was calculated as 34 per cent through the year. Matthews (1938) reported on the sperm whales in South Africa that of the total of 14 females which had been investigated during the seasons June to September 7 were pregnant and 5 were desided as soon after ovulation or early stage of pregnancy. Then the pregnancy rate is calculated as 86 per cent. Clarke (1956) stated that the pregnancy rate was 27 per cent during the seasons June to December in Azores Islands area, although he suggested the possibility of the phenomenon that some pregnant and lactating sperm whales did not approach to the area.

TABLE 10. MONTHLY CHANGE OF PREGNANCY RATES OF THE SPERM WHALFS CAUGHT IN THE ADJACENT WATERS TO JAPAN, 1960-62, AND THE CORRECTION FOR THE TRUE PREGNANCY RATE

	May & June	July	Aug.	Sept.	Oct.	Nov.	Total
Pregnant whales	26	31	117	280	98	21	573
Total mature whales	41	48	221	658	346	85	1,399
Pregnancy rate (%)	63.5	64.6	53.0	42.6	28.3	24.7	40.9
Exchange ratio 1	0.29	0.38	0.65	0.77	0.91	1.00	
True pregnancy rate 1 (%)	18.4	24.5	34.5	32.8	25.8	24.7	26.8
Exchange ratio 2	0.50	0.50	0.50	0.67	1.00	1.00	
True pregnancy rate 2 (%)	31.8	32.3	26.5	28.4	28.3	24.7	28.7

In the sexually mature females caught in the coastal waters of Japan from May to November during 1960–1962, the number of whales of which both ovaries were examined and number of whales which had corpus luteum in the ovaries among the above whales are shown in Table 10. Cutting the abdorminal part of whales for the purpose of cooling the carcas, foetuses are often lost in Japanese coastal whaling. However, I think that we have no objection to regard the whale which has corpus luteum in ovaries as the pregnant whale. It is because that pregnant whale has always corpus luteum, and when an ovum does not furtilize, corpus luteum involute fastly into corpus albicans. As the peak of pairing season is April in the northern hemisphere, the cases of occurrence of corpus luteum without furtilization will be scarse in the season of our investigation.

As shown in the Table, the pregnancy rate varies remarkably according to season. During the months from May to August, the rates are over 50 per cent, but it becomes to 42 per cent in September, and the rates are under 30 per cent in October and November.

Now, in the former chapter, gestation period of the sperm whale was estimated to be 16.4 months, and two groups exist in some seasons of the year. They are individuals which have been pregnant since the last year, and the other group includes the individuals which conceived in the next year during the seasons April to August, and after then, most pregnant whales were conceived in the year. Therefore, the pregnancy rates which were got according to each month during April to August are pretence ones.

For the purpose of calculation of the true pregnancy rate, the following two methods were employed. The first method is to get the ratios of the pregnant whales conceived in the year to total pregnant whales from size frequency of foetuses in Table 3, and the pretent pregnancy rates are recounted into the true rates by the above ratios. The ratios and the true pregnancy rates are shown in Table 10 as exchange ratio 1 and true pregnancy rate 1. As the result, the calculated pregnancy rates in each month become nearly constant and ranged between 18 and 35 per cent, and the average is 26.8 per cent.

However, in Table 10, small embryos are often difficult to be found and so it is considerable that some of the small embryos are not recorded by fishermen. Then, the second method is employed for calculation of the true pregnancy rate. In the northern hemisphere, the peak of parturition season is about August, and the peak of pairing season is considered to be April. Then, during 5 months from April to August, half of the pregnant whales should be conceived in the last year. In September I considered that 2/3 of the total pregnant whales are conceived in the year, because the large foetuses exist fairly in this month. The pregnant whales which appear in October and November are considered to be conceived in the same year. This method was preliminally emploied in the paper of Ohsumi *et al.* (1963). True pregnancy rate 2 is given in Table 10, using the above exchange ratio 2. The exchanged pregnancy rate 2 are almost constant in each month as similar as the true pregnancy rate 1, and they distribute between 24 and 32 per cent, and the average is calculated to be 28.7 per cent. In conclution, the true pregnancy rate of the sperm whale in the waters adjacent to Japan is estimated to be 26–29 per cent.

Previous reports on the pregnancy rate of the sperm whale did not consider the ratio of the whales which had been conceived in the last year. For instance, Matsuura (1936) reported the pregnancy rate as 34 per cent, but in his paper the average pregnancy rate during the months September to March was 28.6 per cent. This figure is very near to my result.

On this subject, a question is occured whether the materials which had been caught in the coast of Japan represent the total population of mature females in the ocean or not. Clarke (1956) suggested a segregation in the migration of pregnant and lactating females in Azores Islands waters. Ecological study on the schools of the sperm whale has not been developed, and the investigation on this problem should be done in future, but I want to pay attention on the result that the pregnancy rate fairly coincides with the annual number of ovulations which obtained in previous chapter. I consider that this coincidation shows the figures obtained as the true pregnancy rate representing those which in the mother population.

Change of pregnancy rate accompanied with age

Change of pregnancy rate accompanied with age is known in general mammals. But there are few reports on this subject for the cetacea.

Table 11 shows the age distribution of the pregnant whales (individuals which have corpus luteum in the ovaries) and the total females (individuals of which both ovaries were examined) caught in the coastal waters of Japan during 1960–1962 seasons. The ages are based on the number of growth layers in the dentine of maxillary tooth. Fig. 16 shows the change of pregnancy rate accompanied with age. These rates are of course pretent as described in previous section. Pregnancy rate increases suddenly after the age at sexual maturity, and it attains to maximum at 15–20 years. After then, the rate begins to decrease gradually with increment of age. However, the rate at 50 years of age is still 75 per cent of the figure at maximum rate. In Table 11, there is no pregnant whale over 61 years old. But the materials are few, and so it is not concluded from this phenomenon that there is menopause in the sperm whale.

TABLE 11. AGE COMPOSITION OF FEMALE SPERM WHALES, PREGNANT SPERM WHALES AND THE PERCENTAGE OF PREGMANT WHALES IN THE TOTAL FEMALES, JAPANESE COAST, 1960-62

Age (year)	Pregnant whales	Total whales	% of pregnant whales	
1- 2	—	1	0.0	
3- 4	—	3	0.0	
5- 6	2	29	6.9	
7- 8	6	52	11.5	
9-10	22	69	31.9	
11-12	46	101	45.5	
13-14	40	119	33.6	
15-16	35	82	42.7	
17-18	32	81	39.5	
19-20	41	76	53.9	
21-22	23	67	34.4	
23-24	16	43	37.2	
25-26	18	54	33.4	
27-28	12	33	36.4	
29-30	14	35	40.0	
31-32	12	35	34.3	
33-34	13	37	35.2	
35-36	12	31	38.8	
37-38	7	29	24.1	31.1
39-40	8	19	42.1	
41-42	7	19	36.8	37.5
43-44	5	13	38.5	
45-46	4	13	30.8	31.6
47-48	2	6	33.3	
49-50	2	4		28.6
51-52		3		
53-54	2	3		50.0
55-56	—	1		
57-58	1	4		33.3
59-60	1	2		
61-62	—	3	0.0	
63-64	—	2	0.0	
Total	383	1,069		

Number of corpora albicantia in the ovaries is also one of age characters in the cetacea, and as shown in Fig. 12, there is close relation between the age based on number of growth layers in the dentine and number of corpora in the ovaries.

Table 12 shows two frequency distributions of corpora numbers. One is the whales with corpus luteum and the other one is the total whales of which both ovaries were examined. And Fig. 17 shows the pregnancy rate in each corpora class calculated from Table 12. The given curve has the same tendency as Fig. 16,

TABLE 12. NUMBER OF PREGNANT SPERM WHALES AND THE PERCENTAGE OF THE PREGNANT WHALES IN EACH NO. OF CORPORA IN THE OVAVIES. COAST OF JAPAN, 1960–62

No. of corpora	Pregnant whales	Total whales	% pregnant
1	36	103	35.0
2	42	108	38.8
3	66	188	35.1
4	78	157	49.1
5	62	156	39.7
6	43	99	43.4
7	39	97	40.2
8	28	68	41.1
9	23	57	40.4
10	15	39	38.5
11	10	29	34.5
12	5	18	27.8
13	4	16	25.0
14	2	12	16.7
15	3	11	} 21.4
16	—	3	
17	1	4	} 16.7
18	—	2	
19	—	—	
20	—	1	
21	—	1	
22	—	—	
23	—	—	
24	1	1	
25	—	1	
30	—	1	
35	—	1	
37	—	1	
Total	458	1,174	

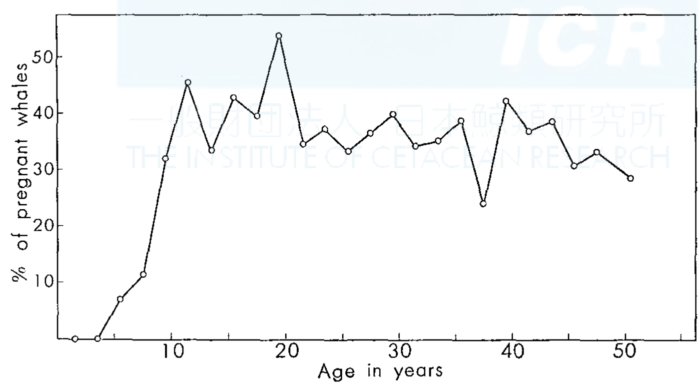

Fig. 16. Change of pregnancy rates according to the age in the female sperm whales.

that is to say, in earlier stage, pregnancy rate increases with increment of corpora number, and the rate attains to maximum value at 4 of corpora numbers. After then the rate decreases gradually, but the tendency of the decrement is more remarkable than the case in Fig. 16. In Table 12, there is no pregnant whale over 25 of corpora numbers. However, an individual with 37 corpora in the ovaries was lactating. This example shows that the sperm whale can conceive in older age.

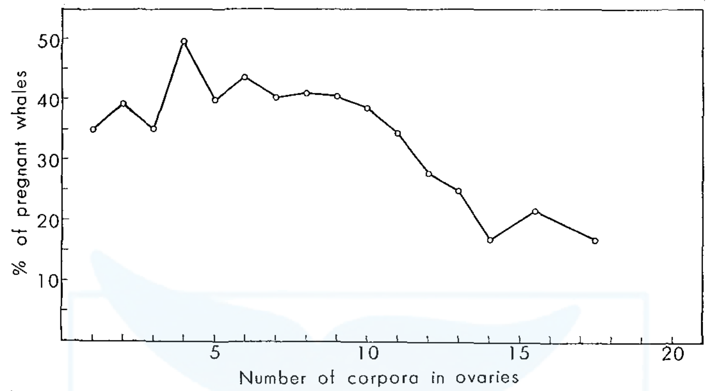

Fig. 17. Change of pregnancy rates according to the number of corpora in the ovaries of the sperm whales.

The difference of the tendency of decrease between Figs. 16 and 17 is able to be explained that annual number of ovulations decreases accompanied with increment of age as shown in the previous chapter, and the older ages based on number of ovulations concentlates the true ages, on the other hand, the individuals of which annual number of ovulations is higher than the normal have a tendency to have Type D of reproductive cycle as examine in the following chapter. The whales which have this type of reproductive cycle have low pregnancy rate.

REPRODUCTIVE CYCLE

Patterns of reproductive cycle and a review on the previous papers

The sperm whale is mono-oestrous as discussed in the previous chapter of the present paper. In general, oestrous period is classified as follows:

1. Post-partum oestrus.
2. Inter-lactation oestrus.
3. Post-lactation oestrus.
4. Post-resting oestrus.

The first case of oestrus is considered to exist in the sperm whale. However, as shown in the following section, the frequency of this case will be low. Clarke (1956) reported on this kind of oestrus for the sperm whale in Azores. Chittleborough (1958) and Laws (1961) also described on this case for the baleen whales.

The second case has a possibility to exist in the sperm whale, for the lactation period is considered to be very long in this kind of whale. The fact that there are some individuals which are simultaniously pregnant and lactating will support the existence of the second case as well as the first case. Chuzhakina (1961) mentioned on the possibility of this case in the sperm whale.

Matthews (1938) described that ovulation occured immediately at the end of lactation for the sperm whale, and resting period was short even if it was existed. However, as Clarke pointed out, the season when Matthews investigated was the former half of the pairing and it is proper that there is no resting whales in this season. Clarke did not recognize the post-lactation oestrus. If the sperm whale ovulate immediately to weaning, the season will be mostly August or September in the northern hemisphere. But, the frequency of conception is the lowest of the year in this season. Laws (1961) showed a theory that most of the female fin whale ovulate at weaning, but they do not conceive in this time because of the decline of sexual activity in the males in the season. Laws's theory will not be applied to the sperm whale. Because, the occurrence of mature ovarian follicles or corpora lutea just after ovulation in the ovaries is not recognized in the sperm whales caught in summer season in Japanese coastal waters. On the contrary, Sergeant (1962) reported that in the pilot whale (*Globicephala melaena*) there is no resting period, and it generally ovlates just after the weaning.

Clarke considers that post-resting oestrus is the most normal case in the sperm whale. I agree with his consideration from the investigation of reproductive cycle for the sperm whale.

Concerning to the reproductive cycle of the sperm whale, Matsuura (1936) first estimated two-years cycle (gestation period: 12 months, lactation period: 6 months, and resting period: 6 months). However, today this theory is not given our approval, for it is clear that his estimation on the gestion period is not true. Matthews (1938) also showed two-years reproductive cycle for the southern sperm whale. He estimated gestation period as 16 months and lactation period as 7 months. But, his theory is contradictory to the real phenomena in two points that lactaing period is too short and there is no resting period in his theory. Clarke (1956) advocated 3 years, reproductive cycle for the sperm whale in Azores. It includes 16 months gestation, 13 months lactation and 7 months resting periods. And Chuzhakina (1961) reported that the reproductive cycle was 2.5 years, that is, gestation was 16–17 months, lactation lasted to 10–11 months, and resting was 3–4 months.

Calculation of reproductive cycle

From the relation between age and number of ovulations, mean number of ovulations per year decrease slightly with the increment of age, and it is 0.31 by 20 years of age, 0.26 between 21 and 48 years, and 0.27 in total ages. From these figures, the ovulation cycle is calculated as 3.2, 3.9, and 3.7 years respectively in above ages. That is to say, the reproductive cycle is considered to be 3–4 years calculated with number of ovulations per year.

In the previous chapter, the true pregnancy rate was given as 26–29 per cent. Then the pregnancy cycle is calculated as follows:

$$1 \text{ year}/0.26\text{–}0.29 = 3.4\text{–}3.8 \text{ years}$$

This value coincides fairly with the reproductive cycle calculated from annual rate of ovulations. I consider that pregnancy cycle supports that reproductive cycle is 3–4 years for the sperm whale.

Establishment of several types of reproductive patterns

Pattern of reproductive cycle and the number of ovulations in each pattern are shown in Fig. 18, considering from gestation and lactation periods. Type A is a case that ovulation does not occure after parturition and weaning, and the resting stage lasts for more than one year. In this case mean annual rate of ovulation is less than 0.25. The possibility of existing of such individuals is deemed by the result that the lower limit of annual ovulation is 0.14 in the relation between age and number of ovulations. The longer resting stage is, the smaller annual ovulation becomes. The longest reproductive cycle is calculated as 7.2 years from the lower limit of above relation. Considering the ageal change of pregnancy rate, the frequency occurrence of Type A will increase with age.

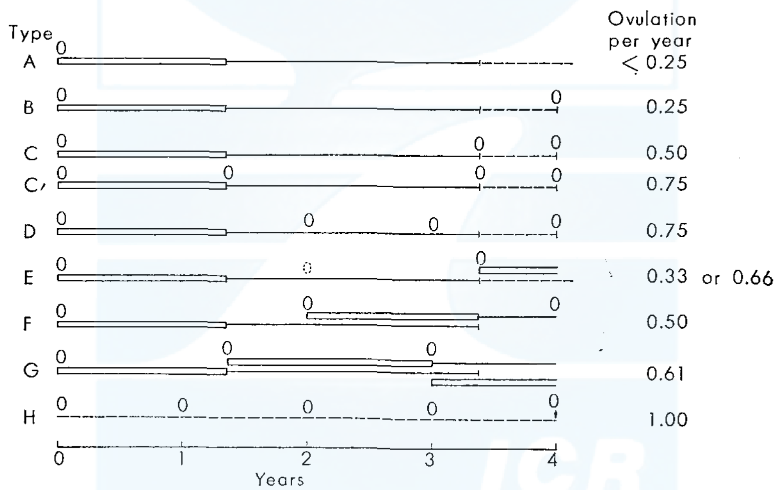

Fig. 18. Types of reproductive cycles in the female sperm whale.
Square: Pregnant period, Solid line: Lactating period, Broken line: Resting period, O: Ovulation.

Type B is a 4 years reproductive cycle which ovulate after 8 months' resting period. Annual rate of ovulation of this type is 0.25, it is the most near the mean number of annual ovulations, and it is regarded as the most normal reproductive cycle for the sperm whale, estimating with other reproductive phenomena. Type C is a reproductive cycle in which an unsuccessful ovulation occures immediately to the weaning, and the whale conceives in the time of the next ovulation after resting period. The mean number of ovulations per year is 0.50. In Type C', the first ovulation takes plase immediately to parturition in addition to Type C. Annual rate of ovulations is 0.75 in this case. However, according to the investigation of the ovaries during August to October when is considered as the season of parturition and weaning in Japanese coastal waters, appearence of corpora lutea of ovulation or mature graafian follicles is rare in this season, and Clarke (1956) got the similar result for the sperm whales in Azores. Therefore, the possibility of existing of Types C and C′ is considered to be small in the sperm whale.

TABLE 13. REPRODUCTIVE STAGES OF FEMALE SPERM WHALES IN EACH MONTH IN THE WATERS OF JAPAN, (1960-62)

Actual figure	May and June	July	Aug.	Sept.	Oct.	Nov.	Total
Pregnant	3	13	54	107	41	7	225
Pregnant and Lactating	1	2	14	26	15	1	59
Lacating	4	11	28	100	72	8	223
Resting	—	3	28	104	78	12	225
Total	8	39	124	337	206	28	732
Percent							
Pregnant	37.5	44.9	43.6	31.7	19.9	25.0	30.7
Pregnant and Lactating	12.5	6.9	11.3	7.7	7.3	3.6	8.1
Lactating	50.0	37.9	22.6	29.7	35.0	28.6	30.4
Resting	0.0	10.3	22.6	30.9	37.9	42.9	30.7

Type D is a 4 years reproductive cycle in which unsuccessful ovulation is taken plase in a pairing season and the next ovulation lead to conception after the resting period. The reproductive cycle of Type D has a possibility to remove into Type E or F explained in the following, and it is considered to exist according to the seasonal change of graafian follicles. Average number of ovulations per year in this type is calculated as 0.75, and it is under the upper limit of the relation between age and number of ovulations. It is considered that there is a possibility to exist such a type of sexual cycle, especially in younger ages. Type E is a 3 years reproductive cycle in which whale does not ovulate or does not conceive if it ovulates at the first breeding season during lactating period, and it conceives at the next breeding season. The possibility of existing of this type will be supported by the fact that there are individuals which are pregnant and lactating. Annual number of ovulations is 0.33 or 0.67. In the reproductive cycle of Type F, whale conceives at the first breeding season, and the next parturition takes plase at weaning. The existence of this type is supported with the same fact as shown in Type E, and a phenomenon that there is a record that a sperm whale with a foetus of 340 cm in length was still lactating is explained more easily by Type F than by Type E. Type F is a 2 years reproductive cycle, and annual ovulation is 0.50. The whales of about 20 years of age have Types E and F of sexual cycle more frequently than other ages judging with ageal change of pregnancy rate. Type G is a 16–17 months sexual cycle which conceives immediately to parturition. This type has the same contradiction as explained in Types C and C', and a whale of this type must continue to suckle the last calf after the next parturition. Therefore, the possibility of existing of this kind of type will be negligible. Type H is a sterile sexual cycle in which whales repeat an nusuccessful ovulation in every breeding season. The annual number of ovulations is 1.00, and this agrees with the upper limit of Fig. 12. This type of reproductive cycle will be more frequently in pubertal or young ages.

Summarizing the above considerations, Type B will be typicl reproductive cycle for the sperm whale, and Type A will be also common in the species. Types D, E, F and H also have possibility to exist, especially Types E and F will be 8 per cent of the reproductive cycle in the sperm whales in adjacent waters to Japan as shown in the following section.

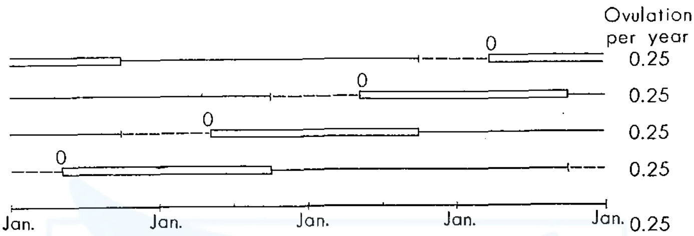

Fig. 19. A pattern of reproductive cycle for the female northern sperm whale (A), based on Type B in Fig. 18. Marks are the same as in Fig. 18.

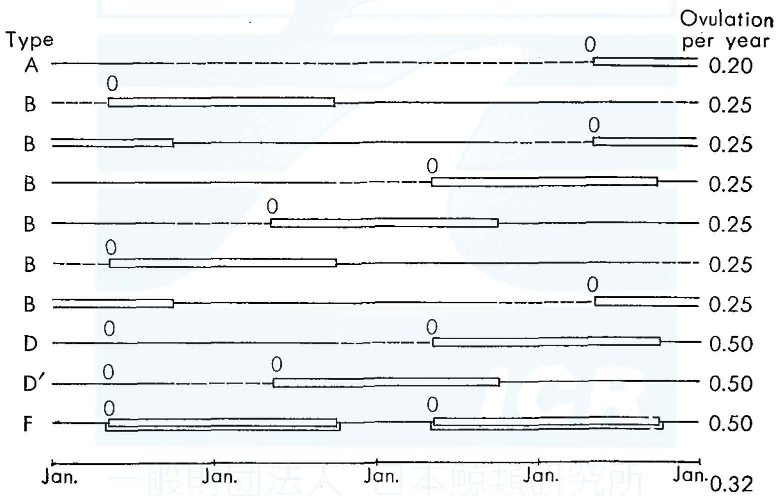

Fig. 20. A combined pattern of reproductive cycles for the female northern sperm whale (B), based on Types A, B, D and F in Fig. 18. Marks are the same as in Fig. 18.

Examination of reproductive cycle by means of seasonal change in reproductive conditions

Reproductive conditions were grouped into pregnant, simultaniously pregnant and lactating, lactating and resting stages for 732 female mature sperm whales of which both ovaries and mammary gland were examined in the coast of Japan. The result is shown in Table 13. And seasonal change of the compositions of the above reproductive conditions is also shown in Fig. 21-C.

The composition of individuals which were simultaniously pregnant and lactating is 3.6–12.5 per cent, and 8.1 per cent in average. The frequency does not vary so remarkably, although there is slight tendency to decrease with season. The ratio of resting individuals is low until August, and then it increases. This phenomenon is concerned with that weaning season is about August in the northern hemisphere sperm whale. It was already studied that the frequency of pregnant individuals decreases after August. Lactating individuals are almost constant in the composition seasonally, and the ratio is about 30 per cent.

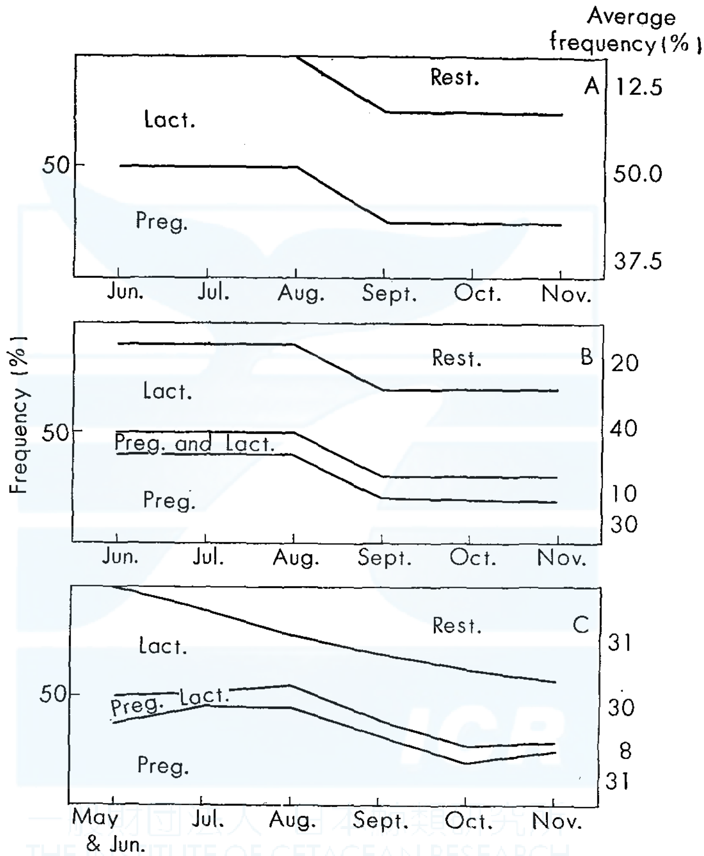

Fig. 21. Seasonal change of estimated and actual composition of reproductive stages for the female sperm whales caught in adjacent waters to Japan.
Data are based on Figs. 19, 20 and Table 12.

Fig. 19 shows a pattern of reproductive cycle for the female northern sperm whale. This pattern is composed with only Type B which is considered as the typical reproductive cycle in the sperm whale. And the seasonal change of ratios of reproductive conditions is shown in Fig. 21–A. Comparing the seasonal change of Pattern A with the actual one (C) in Fig. 21, the ratio of resting stage of the former is smaller than the latter, on the contrary, ratio of lactating stage is larger than the latter. Furthermore, Pattern A can not explain the actual composition, for there is no pregnant whales with lactation in Pattern A. Therefore, the reproductive cycle for the sperm whale is not composed of only single type of Type B, but it will be composed of complex types of reproductive cycles.

Making a combined pattern (B) of reproductive cycle with Types A, B,D, and F as shown in Fig. 20, the seasonal change of composition of reproductive conditions is calculated as shown in Fig. 21–B. This seasonal change fairly agrees with the actual one (Fig. 21–C). The combination of reproductive types in this pattern is 60 per cent of Type B, 20 per cent of Type D (D'), 10 per cent of Type A and 10 per cent of Type F. And the annual rate of ovulations is calculated as 0.32. This rate is near that of young ages.

In practice, the reproductive cycle in the sperm whale will be a complex pattern which is composed more types than the pattern which was shown in Fig. 20. In Type A, there will be Types A', A", . . . in which resting period is longer than that in Type A, and it is estimated that Type E will add in the actual reproductive cycle in the sperm whale. Accompanying with the increment of the age, proportion of Types A, A', A", . . . is considered to increase, on the contrary, the proportion of Types D and F will decrease in the reproductive cycle in the sperm whale.

From the above consideration, it was found that the types of reproductive cycle which were established in the previous section are able to explain the seasonal change of composition of reproductive conditions by a combination of the types. And the estimated pattern is supported to be near the actual eombination of reproductive cycle in the sperm whale in the adjacent waters to Japan.

SUMMARY

1. Some problems concerning to the reproduction of the sperm whale chiefly in the north-west Pacific were studied.

2. Diameter of graafian follicle changes seasonally, and it is estimated to become largest in spring season in average.

3. Pairing season was estimated from monthly frequency of foetal lengths. Pairing extends all season of the year, but the mode of pairing is in April and October in the northern and southern hemisphere respectively. There is a tendency that pairing date becomes gradually earlier accompanying with increase of age.

4. Sex ratio of the males is 51.0 par cent in gestation period.

5. Body lengths at birth is estimated as 4.05 m (13 feet 3 inches). There is no difference of the lengths between the both hemisphere whales.

6. Parturition chiefly takes plase during June to October, and December to April in the northern and southern hemisphere respectively.

7. Gestation period is calculated to be 16.4 months in both hemisphere.

8. Lactation period is suitable to estimate as 24–25 months, and the weaning season is determined to be August or September in the northern hemisphere.

9. Annual rate of ovulation is calculated from the relation between age and number of ovulations. It is 0.27. The rate decreases gradually accompanied with increase of ages.

10. Process of involution of corpus albicans is drawn as like a hypabola, but it persists in ovary through the life.

11. Frequency occurrence of multiple ovulations and multiplets are very low in the sperm whale. It is estimated to be 0.89 and 0.45 per cent for multiple ovulation and multiplets respectively.

12. Pretence pregnancy rate varies remarkably according to season, and the true pregnancy rate is calculated to be 26–29 per cent for the sperm whale in the waters adjacent to Japan.

13. Pregnancy rate changes accompanied with the age, and the age of maximum pregnancy is 15–20 years and 4 corpora.

14. Average duration of reproductive cycle is calculated to be 3–4 years for the sperm whale. Eight types of reproductive cycles were established considering gestation and lactation periods and annual rate of ovulation.

15. Examining the reproductive cycle by means of seasonal change in reproductive conditions, it is found that the actual reproductive cycle is composed of many types of the cycle.

ACKNOWLEDGEMENT

The materials used in the present paper were collected by the efforts of biologists who investigated, collected and examined the material under the leading by Dr. H. Omura, Director of the Whales Research Institute. My sincere thanks are due to them.

I am much indebted to many members of the Japanese whaling companies for the help in investigation and collection of the materials.

REFERENCES

Beale, T. (1839). The natural history of the sperm whale. (Cited by Matthews, 1938).

Benneett, F. D. (1840). Narrative of a whaling voyage round the grove. (Cited by Matthews, 1938).

Chittleborough, R. G. (1954). Studies on the ovaries of the humpback whale, *Megaptera nodosa* (Bonnaterre), on the western Australian coast. *Aust. J. Mar. Fresh-water Res.*, 5 (1) : 35–63.

—— (1955). Aspects of reproduction in the male humpback whale, *Megaptera nodosa* (Bonnaterre). *ibid.* 6 (1) : 1–29.

—— (1958). The breeding cycle of the female humpback whale, *Megaptera nodosa* (Bonnaterre). *ibid.* 9 (1) : 1–18.

Chuzhakina, E. S. (1961). Morfologicheskaya kharakteristika yaichnikov samok Cashalota (*Physeter catodon*) v svyazi s opredeleniem vozraska. *Trudi Inst. Nor. Zhivotnilth A. N. SSSR.*, 34 : 33–55.

Clarke, R. (1956). Sperm whales of the Azores. *Discovery Reps.* 28 : 237–98.

Committee for International Whaling Statistics (1938–1962). *International Whaling Statistics* 1937–1961.

Huggett, A. St. G. & Widdas, W. F. (1951). The relation between mammalian foetal weight and conception age. *J. Physiol.*, 114 (3) : 306–17.

Kimura, S. (1956). The twinning in southern fin whales. *Sci. Rep. Whales Res. Inst.*, 12 : 103–25.

Laws, R. M. (1959). The foetal growth rate of whales with special reference to the fin whale, *Balaenoptera physalus* Linn. *Discovery Reps.*, 29 : 281–308.

—— (1961). Reproduction, growth and age of southern fin whales. *ibid.*, 31 : 327–486.

Matsuura, Y. (1936). Breeding habits of the sperm whale in the adjacent waters of Japan. *Zool. Mag. (Japan)*, 48 (5) : 260–6 (In Japanese).

—— (1940). Statistical study on whale foetuses-III. Sperm whales in the adjacent waters of Japan. *Bull. Jap. Soc. Sci. Fish.*, 9 (4) : 142–4.

Matthews, L. H. (1938). The sperm whale, *Physeter catodon. Discovery Reps.*, 17 : 93–168.

Melville, H. (1851). *Moby Dick, or the whale.* Collins Classics, London 1953, 478 p.

Mizue, K. & Jimbo, H. 1(950). Statistic study of foetuses of whales. *Sci. Rep. Whales. Res. Inst.*, 3 : 119–31.

Naaktgeboren, C., Slijper, E. J. & van Utrecht, W. L. (1960). Research on the period of conseption, duration of gestation and growth of the faetus in the fin whale, based on data from International Whaling Statistics. *Norsk Hvalfaugst-tid.*, 49 (3) : 113–9.

Nakajima, M. (1963). Death of Echo, a female bottlenose dolphin. *Geikentsushin.*, 145 : 6–12 (In Japanese).

Nakajima, M., Takahashi, K., Ogura, M. & Sawaura, K. (1963). On the growth of infants of small size toothed whales. *J. Jap. Soc. Zoo Aquarium*, 5 (1) : 16–22 (In Japanese).

Nishiwaki, M. & Hibiya, H. (1951). On the sexual maturity of the sperm whale found in the adjacent waters of Japan (I). *Sci. Rep. Whales Res. Inst.* 6 : 153–66.

—— (1952). Sexual maturity of the sperm whale found in the adjacent waters of Japan (II). *ibid.*, 7 : 121–4.

Nishiwaki, M., Hibiya, T. & Ohsumi, S. (1958). Age study of sperm whale based on reading of tooth laminations. *ibid.*, 13 : 135–53.

Omura, H. (1950). Whales in the adjacent waters of Japan. *ibid.*, 4 : 27–113.

Ohsumi, S., Kasuya, T. & Nishiwaki, M. (1963). Accumulation rate of dentinal growth layers in the maxillary tooth of the sperm whale. *ibid.*, 17 : 15–35.

Sergeant, D. E. (1962). The biology of the pilot or pothead whale *Globicephala melaena* (Traill) in Newfoundland waters. *Bull. Fish. Res. Board Canada*, 132 : 1–84.

Sleptsov, M. M. (1955). Biologia i promisel kitov dalnevostozuih morei (Translated into Japanese by H. Sakiura).

Tago, K. (1922). [On the whales in the adjacent waters to Japan]. *Zool. Mag. (Japan)* 34 (401) : 446–79 (In Japanese).

Tavolga, M. C. & Essapian, E. S. (1957). The beheavior of the bottle-nosed dolphin (*Tursiops truncatus*) : Mating, pregnancy, parturition and mother-infant beheavior. *Zoologica*, 42 (1) : 11–31.

Wheeler, J. F. G. (1933). Note on a young sperm whale from the Bermude Islands. *Proc. Zool. Soc. London*, 1933 : 407–10.