THE LIFE HISTORY OF DALL'S PORPOISE WITH SPECIAL REFERENCE TO THE STOCK OFF THE PACIFIC COAST OF JAPAN

TOSHIO KASUYA

Ocean Research Institute, University of Tokyo, Tokyo

ABSTRACT

The geographical variation of the colour types of the species indicates three local stocks in the northwestern North Pacific and western Bering Sea (WNP/BS), off the Pacific coast of Japan (PJ), and in the Sea of Japan and Okhotsk Sea (SJ/OS).

The catches by the salmon gillnet fishery in WNP/BS and the present and past harpoon fishing in PJ and in SJ/OS, and the age structure based on the cemental growth layers give the following estimation of the life history parameters. The calves are born in August to September at the length of 100 cm after the gestation of 11.4 months, and nursed for about 2 years. Sexual maturity is attained in males at the age of 7.9 years and the length of 195.7 cm, and in females at 6.8 years and 186.5 cm. The mean calving interval is about 3 years, and the annual natural mortality rate of the adult female will be below 0.1. Data are insufficient to indicate the degree of between stocks difference of the parameters.

The weaned immature individuals are distributed in the south in the winter (PJ, WNP/BS, and SJ/OS) and possibly in the summer too (WNP/BS). The segregation of pregnant females by the size of the fetus is expected (WNP/BS). The harpoon fishing mainly exploits the weaned immature and newly matured individuals (PJ and SJ/OS), however the salmon gillnet fishery kills the calves of suckling age and newly matured individuals (WNP/BS). The lactating females are underrepresented in the both fisheries.

INTRODUCTION

The Dall's porpoise, *Phocoenoides dalli* (True 1885), is widely distributed in the northern part of the North Pacific. It ranges from the Sea of Japan and Okhotsk Sea to the west coast of North America as far south as 33°N (Norris and Prescott 1961, Nishiwaki 1967a), and the northern limit will be in the Chukchi Sea (Sleptsov 1961). On the other hand the True's porpoise, *P. truei* Andrews 1911, has a limited distribution off the Pacific coast of northern Japan and of the Kuril Islands. Its southern limit is at about 35°N in the winter season. In the summer it seems to be distributed from 42°N to 54°N, and from the east coast of the Kuril Islands to 168°E (Sleptsov 1961, Ohsumi 1975, Kasuya 1976b).

On the systematic relationship of the two kinds of porpoises, Kuroda (1954) considered, based on the probable incomplete genetic isolation suspected from

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the observation of the school structure and the pigmentation of the fetus, that the True's porpoise is a geographical race and a subspecies of *P. dalli*. Houck (1976), however, through the study of the osteology and external morphology of the porpoises found that only the colour variation attained the plausible level of differentiation in the genus. Finally, considering the fact of coexistence of the two types in the western North Pacific, he concluded that *Phocoenoides dalli* seems to be polymorphic in colour pattern with two major colourmorphs *i.e.* the *dalli*-type and *truei*-type. In the same year Kasuya (1976b) analysed the geographical variation of the ratio of the two types in the northwestern North Pacific, and found that the ratio of *truei*-type in the total *Phocoenoides* caught in the winter season off the Pacific coast of northern Japan (southern part of Sanriku region which covers the coastal part from 38°N to 41°30′N) is about 96% and its ratio in the sightings and in the incidental catch by Japanese salmon gillnet fishery decreases in the offshore waters. This led him to conclude that there can be one coastal population of *Phocoenoides* off the Pacific coast of northern Japan and off the east coast of Kuril Islands, which is entirely or mostly composed of the *truei*-type and intermingles at its northeastern boundary with another offshore population composed of only *dalli*-type. From the fact that the Kuril Islands seems to block the migration of *truei*-type into the Okhotsk Sea, he considered that the *dalli*-type found in the Okhotsk Sea will not pass the Kuril Islands and there will be a third population of *Phocoenoides* in the Okhotsk Sea and the Sea of Japan. However, in the study, he retained the conclusion if the *dalli*-type in the catch off Sanriku region is original in the coastal population or the migrant from other population.

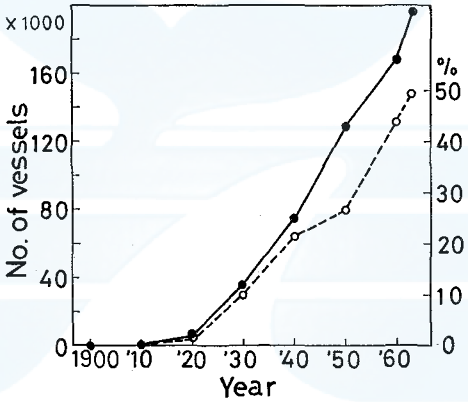

Fig. 1. Number of the Japanese fishing vessels equipped with engine (closed circle and solid line), and its ratio in the total number of fishing vessels (open circle and dotted line), statistics cited from Takagi (1965).

A brief history of the recent exploitation of *Phocoenoides* in the Japanese coastal waters was described by Kasuya (1976b) based on Japanese published records. Some statistics not cited in Kasuya (1976b) and the harpoon fishing gears are reported in Wilke *et al.* (1953). The exploitation of *Phocoenoides*, as well as that of other delphinids, seems to have had a peak in late 1930's to 1940's affected by the social factors during and after the war, and was operated at various part of Japan using the method or fleets introduced from Sanriku coast (Yoshida 1939, Matsui and Uchihashi 1943, Hirashima and Ono 1944, Wilke *et al.* 1953). However, in the recent years, the fishing at most of the places ceased the operation except for the Sanriku coast. The most uncertain is the history of the exploitation in earlier period. It is known that there was operated in the past a driving fishery of dolphins at Oura of Yamada Town on the Sanriku Coast. The operation was made only when the dolphins came close to the entrance of the bay. The species of a catch of 2,385 porpoises made in February 1882 was identified on a photograph as *Lagenorhynchus obliquidens*. However, since the school of *Phocoenoides* is small and usually stays far from the coast, the driving fishery will not have exploited the species. The alternative method taking the species seems to be harpooning the individuals come to the bow wave of the boat. The fishing is most efficient with a vessel with engine. Since the number of the Japanese fishing vessels equipped with engine was negligible before 1920 (Fig. 1), the exploitation of *Phocoenoides* at significant level would have started after late 1920's. This date is almost same with the introduction of motor vessels into the driving fishery of *Stenella coeruleoalba* off Izu coast (Kasuya and Miyazaki 1976a).

The season for the recent porpoise hunting off Sanriku coast is from the last decade of January to the beginning of April when no other fishing is profitable and the market price of the porpoise is high (Kasuya 1976b), and it is operated with hand harpoon and small fishing vessels of about 20 to 30 gross tons. The fishing area ranges approximately between 38°N and 40°N, and between about 10 nautical miles (18 km) and 40 to 50 miles (80 km) off the coast. Accordingly this fishing is mainly harvesting the Japanese east coast population of Kasuya (1976b). The annual catch is about 6,000 individuals. Almost nothing is known about the life history of the individuals of this population.

The offshore population, inhabiting the northwestern North Pacific and western Bering Sea, has been captured incidentally by the Japanese salmon gillnet fishery, which has continued since 1930 with an interruption from 1946 to 1951. The statistics of the incidental catch is not available. Mizue *et al.* (1966) estimated it as about 20,000 individuals in 1964 season (data based on person. comm. of K. Mizue). Though the analysis of the species caught by the salmon gillnet fishery was made by Mizue and Yoshida (1965) and Mizue *et al.* (1966), the absence of the adequate way of age determination limited the accuracy of the studies.

The present study intends to analyse the life history of the porpoise caught by the harpoon fishing off Sanriku coast, together with the supplemental considerations of that of the two other populations distributed in the offshore north-western North Pacific and western Bering Sea and in the Okhotsk Sea and the Sea of Japan.

MATERIALS AND METHOD

The analyses of the school structure are based on the same data used in Kasuya

(1976b). However, few records where the estimation of the school size is less reliable are excluded, and a school observed by Dr Kajihara at the east side of the Soya Straight was added.

TABLE 1. MATERIALS USED IN THIS STUDY

Month*	Jan.	Feb.					Mar.		Apr.	
	B	A	A	B	B	B	A	B	B	Total
Year	'74	'72	'74	'74	'75	'76	'74	'72	'74	
No. examined, males	147	68	52	53	28	127	66	58	9	608
females	75	14	47	50	19	111	69	88	0	473
sex unknown	0	14	0	0	0	4	0	1	0	19
Body length, males	96	53	52	38	28	94	62	53	9	485
females	56	12	47	33	19	93	63	76	0	399
No. aged, males	68	33	4	32	17	87	20	25	8	294
females	42	9	4	26	16	87	35	29	0	248
Testis, histology	55	0	4	27	14	85	14	0	9	208
weight only	0	29	0	0	0	0	0	31	0	60
Females, maturity determined	45	4	17	30	18	78	57	54	0	303

* A: From the 1st to 15th, B: From 16th to the end of month.

The biological information and samples were collected in the years from 1972 to 1976 covering the season from January to April, at the seven landing ports listed below.

Miyako:	39°39′N, 141°57′E
Yamada:	39°28′N, 141°57′E
Funakoshi:	39°27′N, 141°58′E
Otsuchi:	39°19′N, 141°55′E
Kamaishi:	39°14′N, 141°53′E
Ofunato:	39°04′N, 141°43′E
Hosoura:	39°00′N, 141°44′E

Though total of 1,100 individuals were examined, the available informations were variable between the individuals because the internal organs were usually removed before landing.

The body length was measured at nearest 1 cm interval with steel tape on a straight line connecting the tip of snout and bottom of the tail notch. In analysing the body length data, they are usually grouped into 4 cm intervals expressed by $4N \leqq X \leqq 4N+3$, where N indicates a positive integer and X the body length.

The pigmentation was, in the field, classified into the three major categories of *dalli*-type, *truei*-type, and black-type. The pigmentation of randomly selected 537 individuals was recorded on black and white photographs for the further analyses of the individual variation.

The reproductive stage of the female was determined through the observation of mammary gland, ovaries, and the reproductive tract, and recorded as " Immature ", " Pregnant ", " Lactating ", and " Resting ". Since the ovaries and uterus of the immature females are always left on the carcass, the identification of the immature stage is easiest. However, as the ovaries and large portion of uterus of the adult females are often removed by the fishermen, the distinction of the pregnant and resting females is often impossible. In such a case only the maturity was confirmed from the fragments of reproductive tract left in the body cavity.

The ovaries were fixed in 10% formalin solution. The weight and the mean diameter of the corpora and mean diameter of the largest follicle were measured in the laboratory. The mean diameter was calculated as the cube root of the multiple of the three diameters.

One testis and the epididymis were collected from each male and fixed with the same way as ovaries. In the laboratory the smear was taken from the testis tissue at its midlength and from the epididymis at the corresponding position, and the presence and the relative density of spermatozoa were observed after staining with toluidine blue. The histological examination was made on the epididymis, and on the peripheral and central testicular tissues taken from the midlength of the testis. The preparation was made after ordinary way.

The age was determined based on the growth layers in the cementum of the tooth. Several teeth taken from the upper or lower jaw were fixed in 10% formalin. In the laboratory, the tooth was separated from the jaw bone and soft tissue was removed with fingers. Then they were dried and embeded in poliester resin for the convenience of handling. The embeded tooth was ground with whet stones until the center of the pulp cavity was exposed, then it was glued on a clear plastic plate with synthetic resin and the other side was ground to get a thin longitudinal ground section of 10 to 15 μm thickness. The ground section was decalcified in 5% formic acid for several hours, stained with Mayer's haematoxylin for 30 minites, and finally mounted with Canada balsam. The growth layers were counted with a microscope (×150 to ×300).

As mentioned in the next section, at least some of the *dalli*-type individuals caught off the Sanriku region are considered to belong to the offshore population in the northwestern North Pacific and western Bering Sea. However, since there is no way of distinguishing these individuals and the ratio of the total *dalli*-type is so low as 4%, the samples of the two types collected off Sanriku coast were dealt together in the analyses of the growth and reproduction.

Some ancillary materials collected by myself in the southern Okhotsk Sea or by S. Nagahora of the Iwate Prefectural Fisheries Research Laboratory in the northwestern North Pacific are used in this study.

After the analyses of the biological data were nearly completed, Dr A. Takemura of the Nagasaki University provided for me the tooth samples and the biological data of the 107 Dall's porpoises taken by the North Pacific salmon gillnet fishery. Since these materials represent the offshore population in the northwestern North Pacific and western Bering Sea and the age structure of the catch has not been published, they are briefly analysed in the Addendum.

DISTRIBUTION AND SCHOOL STRUCTURE

Distribution of the populations

There is no new information to add the range of the distribution of the three populations of *Phocoenoides* distinguished by Kasuya (1976b). Though Sleptsov (1961) mentions that the *truei*-type is found even in the southern part of the Okhotsk Sea and in the Sea of Japan, it is not supported by other data available to me (Kuzin and Perlov 1975, Kasuya 1976b). However, as it is not impossible to expect few *truei*-types to migrate into the Okhotsk Sea or into the Sea of Japan through the Kuril Islands or the Tsugaru Strait, further study will be needed before arriving at the definite conclusion.

TABLE 2. ANALYSIS OF SCHOOL OF *PHOCOENOIDES DALLI* OFF SANRIKU COAST

School size	Observed no. and %						Probability in %			
	T		TD		D		T	TD[1]	TD[2]	D
1	2	100	0	0	0	0	90.8	—	—	9.2
2	8	61.5	0	0	5	38.5	82.4	8.4	8.4	0.8
3	5	100	0	0	0	0	74.9	22.7	2.3	0.1
4	4	100	0	0	0	0	68.0	29.6	2.4	0.0
5	3	100	0	0	0	0	61.7	37.6	0.7	0.0
6	3	75.0	1[3]	25.0	0	0	56.0	43.3	0.7	0.0
7	3	100	0	0	0	0	50.9	48.9	0.2	0.0
Total	28	82.4	1	2.9	5	14.7	72.4	22.7	4.0	0.9

1): Mixed school *truei*-type exceeding *dalli*-type, 2): Mixed school *dalli*-type exceeding *truei*-type, 3): Five *truei*-types and one *dalli*-type, T: School of *truei*-type, TD: Mixed school, D: School of *dalli*-type.

Wilke *et al.* (1953) stated that the school of *Phocoenoides* containing both *dalli*-type and *truei*-type is not frequent off the southern coast of Hokkaido. Table 2 shows a detailed analysis of the frequency of the two colour types in the schools observed in January, February, May, and June. The location covers the area surrounded by 37°30′N, 41°N, 143°E, and the coast of Japan, which is nearly same with the harpoon fishing ground of the species in the winter season. Only the schools not exceeding 7 individuals are used in the analysis, because the correct estimation of the school size and the identification of the colour types of all the individuals are difficult on the larger schools. Of 34 schools dealt here 5 schools contained only *dalli*-type, 1 school was composed of 5 *truei*-types and 1 *dalli*-type. Other 28 schools classified into the school of *truei*-type includes the two cases, the first is that all the individuals in a school were confirmed as *truei*-type, and the second is the case of 4 schools where only the part of the individuals were confirmed as *truei*-type but the presence of *dalli*-type was not confirmed. The ratio of the *truei*-type in the 34 schools is estimated as 90.8% and that of *dalli*-type 9.2%. The probability of the ratio of the two types in a school was calculated based on the above ratio and on the assumption that the combination of the two types is random. As shown in Table 2, the actual frequency of the mixed schools is much lower than the probability calculated on the assumption of random combination. Especially the discrepancy found for the schools of 3 or less individuals must be significant, because the identification of the individuals is most reliable. If the above calcultion is based on the ratio of *dalli*-type 3.6% observed in the catch off the Sanriku coast, the disagreement with the actual sightings is more exaggerated. This indicates that the school formation of *Phocoenoides* off Sanriku coast is, at least in some degree, dependent on the colour pattern.

Though it is not used in the present analysis, a school of about 20 *dalli*-types sighted in September at 38°30′N, 142°30′E (Nishiwaki 1967b) must be considered by the same way. Mr Y. Jinno, the captain of the research vessel *Tansei-maru*, sighted and tagged in November and December 1972 three schools of the species approximately at 42°05′N, 141°05′E. These schools were composed of 5, 7, and 20 to 25 individuals of the *dalli*-type. The correctness of the record of the pigmentation was confirmed on the photographs. And in May 1974 another school of 3 *dalli*-types was sighted by him at the same position mentioned above

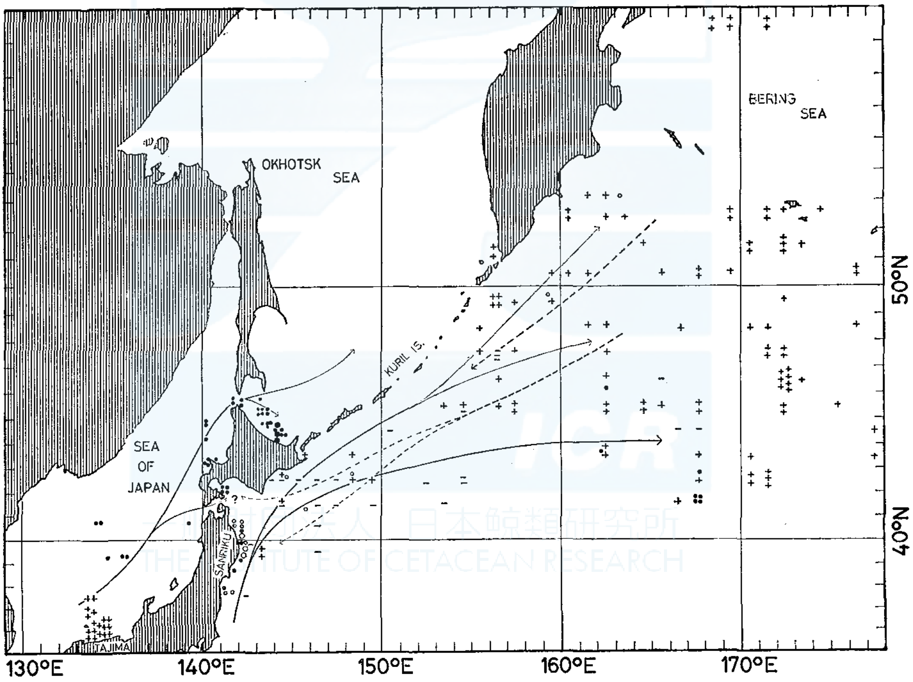

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Fig. 2. Position of sighting or of sporadic catch of *Phocoenoides*. Open circle or bar: *truei*-type, closed circle or cross: *dalli*-type, half closed circle: school with two types. Circle indicates the school used for the analyses of the school size, larger circle 10 schools, the smaller one, solid lines the spring-summer migration of the stock off the Pacific coast of Japan or that of the stock in the Sea of Japan and Okhotsk Sea, and dotted line the autumn-winter migration of the stock in the northwestern North Pacific and western Bering Sea.

(Fig. 2). As already indicated by Kasuya (1976b), it is difficult to explain these schools as caused by the random assemblage of the less frequent *dalli*-type.

It will be reasonable to conclude from the above discussions that all the *dalli*-type individuals found off the Pacific coast of Japan are not the members of the Japanese east coast population, but at least some of them, especially those in the schools not containing the *truei*-type, are migrant from the offshore population in the northwestern North Pacific and western Bering Sea or from the Sea of Japan-Okhotsk Sea population. This is consistent with the informations on the ratio of the three colour types analysed in page 10. The interbreeding between the populations will be more scarce than expected from the apparent coexistence of the two types.

Kuroda (1954) stated that a fetus of *truei*-type pigmentation was obtained from a female of *dalli*-type, and suspected the presence of the interbreeding between the two types. His data is based on one of the two fetuses reported by Wilke *et al.* (1953), where more precise description of the fetuses is available. Wilke

TABLE 3. SCHOOL SIZE OF *PHOCOENOIDES DALLI* IN THE WESTERN NORTH PACIFIC AND ADJACENT SEAS

Area & month	School size														Total schools	Mean size
	1	2	3	4	5	6	7	8	10	13	15	20	22	35		
Coastal Pacific (39°–54°N), *truei*-type																
Jan.						2									2	6.0
Feb.		2	1	1			2		2	1					9	6.4
May			1		1		1		1		1	1			6	10.0
Jun.	2	6	3	3	2	2[1]			2						20	3.9
Jul.			1		2				2						5	6.6
Aug.				1											1	4.0
Total	2	8	6	5	5	4	3	0	7	1	1	1	0	0	43	5.7
Coastal Pacific, *dalli*-type																
Feb.		1													1	2.0
May		2	1												3	2.5
Jun.		2													2	2.0
Nov.					1		1								2	6.0
Dec.													1		1	22.0
Total	0	5	1	0	1	0	1	0	0	0	0	0	1	0	9	5.2
Offshore Pacific (42°–44°N, 162°–168°E), *dalli*-type																
May	0	1	3	0	1	0	0	1	0	0	0	0	0	1	7	8.4
Sea of Japan[2], *dalli*-type																
May	2	5	1	0	0	0	0	0	0	0	0	0	0	0	8	1.9
Okhotsk Sea[3], *dalli*-type																
May		1		1											2	3.0
Jun.		2	1												3	2.3
Jul.		6	5	1	1	1	1					1			16	4.3
Sep.		7	4	8	3		3								25	3.8
Total	0	16	10	10	4	1	4	0	0	0	0	1	0	0	46	3.4

1) One mixed school of 5 *truei*-types and 1 *dalli*-type included, 2) Type unidentified 4 schools (10 individuals) included. 3) Type unidentified 2 schools (6 individuals) included.

et al. (1953) state that a [near term] fetus of 89.5 cm obtained from *dalli*-type female on 16 May was " marked, although in indistinct gray tones, like *truei* " but " the pattern of 10 pound fetus [77.8 cm in body length] taken 24 May [from a *truei*-type female] was indistinct ". The feature of the former fetus seems to be continuous to the pigmentation of the newborn calf of the *dalli*-type, where the anterior lateral region is pigmented in dark gray and changes later into black (Kasuya 1976b). Kasuya (1976b) states on the young *truei*-type that the corresponding part is pigmented in light gray tone but its posterior border is indistinct. Accordingly, the example of the two fetuses described by Wilke *et al.* (1953), can not be a proof of the presence of the interbreeding, but can be a suggestion that the two types are distinguishable at the stage of about 80 to 90 cm in body length.

Table 3 shows the school size frequencies of *Phocoenoides* observed mostly by myself and few by other trained observers. The positions of these sightings are indicated by circles in Fig. 2. Other sporadic records of the catch or of sightings indicated by cross or bar are cited from Kasuya (1976b) and Ohsumi (1975), but are not included in Table 3. Part of the latter data could be overlapping since some of their data sources are same. The schools of *Phocoenoides* are usually composed of less than 7 individuals (87.6% of total number of schools). Since the mode exist at 2 individuals, it is suspected that the basic unit of the school of this species would probably be 2 or 3 individuals and that the schools with 4 to 7 individuals will be formed by the aggregation of the basic units. It is also suspected that the uncommon large schools exceeding 10 individuals is formed by the repeated aggregation of the schools. In the present scanty materials, the seasonal variation of the school size is not indicated.

Between the colour types there is observed a slight difference of the school size. If the 32 schools of the *truei*-type sighted from May to September is compared with 54 schools of *dalli*-type sighted in the same season in the Sea of Japan and Okhotsk Sea, the former gives the mean school size of 5.4 individuals and the latter 3.5. The ratio of the schools composed of 4 or more individuals is 59.4% in the former, and 37.0% in the latter. This is an indication of the presence of the difference of the schooling behavior between the two populations. It is not clear, at present, if this difference is caused by the geographical difference of food availability and of the density of porpoise population, or by the difference of the hereditarily decided schooling behavior. However, the fact that the school size of the *dalli*-type in the area where the *truei*-type is dominantly distributed is also sligtly small may suggest the latter possibility.

VARIATION OF PIGMENTATION

Ratio of the three colour types

Table 4 shows the ratio of the three colour types in the catch off Sanriku coast. If all the available data are combined, the ratio of *truei*-, *dalli*-, and black-types in the catch is given as 96.3%, 3.4%, and 0.3% respectively. The ratio of *truei*-type fluctuates between 90.9% and 98.6% in half month groups. And there

TABLE 4. SEASONAL FLUCTUATION OF THE RATIO OF THREE COLOUR TYPES OF *PHOCOENOIDES* IN THE CATCH OFF SANRIKU COAST, IN NUMBER AND PERCENT

Colour types	Jan.		Feb.				Mar.				Apr.		Total	
	B		A		B		A		B		B			
Males														
truei-type	145	98.6	113	94.4	203	97.6	60	90.9	54	93.1	9	100.0	584	96.1
dalli-type	2	1.4	6	4.8	5	2.4	6	9.1	3	5.2	0	0.0	22	3.6
black-type	0	0.0	1	0.8	0	0.0	0	0.0	1	1.7	0	0.0	2	0.3
total	147	100	120	100	208	100	66	100	58	100	9	100	608	100
Females														
truei-type	72	96.0	59	96.7	174	96.7	66	95.7	86	97.7	0		457	96.6
dalli-type	2	2.7	2	3.3	6	3.3	3	4.3	2	2.3	0		15	3.2
black-type	1	1.3	0	0.0	0	0.0	0	0	0	0	0		1	0.2
total	75	100	61	100	180	100	69	100	88	100	0		473	100

A: 1st to 15th, B: 16th to the end of month.

TABLE 5. RATIO OF THREE COLOUR TYPES OF *PHOCOENOIDES* IN THE CATCH OFF SANRIKU COAST, IN NUMBER AND PERCENT

Body length (cm)	156–175		176–195 (♂) 176–187 (♀)		196–217 (♂) 188–195 (♀)	
Males						
truei-type	104	96.3	164	97.6	118	96.7
dalli-type	4	3.7	4	2.4	4	3.3
black-type	0	0.0	0	0.0	0	0.0
total	108	100	168	100	122	100
Females						
truei-type	81	93.1	310	96.9	80	96.4
dalli-type	6	6.9	9	2.8	2	2.4
black-type	0	0.0	1	0.3	1	1.2
total	87	100	320	100	83	100

is detected a slight increase of the *dalli*-type from 1.8% in January to 3.3% in February, and to 5.0% in March.

The ratios of the three colour types in the growth stages are shown in Table 5, where the body length are grouped from the smallest to 175 cm or the mean length at 2 years of age, from 176 cm to the approximate lengths at sexual maturity, and above them. The ratio of the *dalli*-type is highest in the smallest group. However the seasonal change of the ratio is too large to be explained by the higher ratio of *dalli*-type in the juveniles and the seasonal increase of the ratio of the juveniles (Table 14). It is more reasonable, as already suggested by the analysis of the school structure, to consider that there are *dalli*-type porpoises of other population(s) migrating to the Sanriku coast and intermingling with the stock off the Pacific coast of Japan.

Individual variation of the pigmentation

The detailed analysis of the individual variation of the pigmentation is made based on the black and white photographs of 537 individuals caught by the harpoon fishing off Sanriku coast. The pigmentation of the lateral region is classified into the following 14 minor groups.

1. *Truei*-type, spots in the lateral region absent or scarce (Pl. I, Figs 1–2).
2. *Truei*-type, spots abundant in the anterior lateral region (Pl. I, Figs 3–4).
3. *Truei*-type, spots distributed in the entire white area (Pl. I, Figs 5–6).
4. *Truei*-type, spots restricted to the posterior lateral region, in some individuals a vertical belt of spots may exist at mid-lateral (Pl. I, Figs 7–8).
5. *Truei*-type, a vertical belt of spots at anterior lateral region (Pl. I, Fig. 9).
6. *Truei*-type, two vertical belts of spots at anterior lateral region (Pl. I, Fig. 10).
7. *Truei*-type, three vertical belts of spots at anterior lateral region (Pl. II, Fig. 1).
8. *Truei*-type, four or more vertical belts of spots, or belts unseparable (Pl. II, Fig. 2).
9. *Truei*-type, same as type-8 except for the dark background and fused mottling (Pl. II, Fig. 3).
10. *Truei*-type, same as type-8 except for a belt of spots at center of lateral region (Pl. II, Fig. 4).
11. *Truei*-type, all the lateral area grayish (Pl. II, Fig. 5).
12. Black-type, entire body pigmented almost same darkness (Pl. II, Figs 6, 8).
13. *Dalli*-type, without spot (Pl. II, Fig. 7).
14. *Dalli*-type, spots in the posterior lateral region (Pl. II, Fig. 9).

The above classification is somewhat arbitrary. The distinction of type-1 and type-2 depends on the density of the spots in the anterior lateral region and the variation of the two types is continuous. However, they are clearly distinguished from type-4 with spots in the posterior region or from type-3 with spots in the entire lateral region. All the 6 types, from type-5 through type-10, are characterized by the presence of the dense spots forming one or more vertical belts, and the presence of some common factors is suspected. The type-11 and type-12 (black-type) are separated only by the darkness of the lateral region. Since the density of pigmentation of lateral region, especially that of inguinal region, is variable between the individuals classified into black-type, I suspect that the two types could be found as continuous when more data are accumulated. The presence of the vertical belt of spots at mid-lateral region, type-10 and some of type-4, will perhaps be a variety of the spotting in the anterior or posterior lateral region.

As mentioned in the former section, the young *truei*-type porpoise has pale grayish pigmentation at the chest region. This character is not analysed in the present study because such feature is not correctly recorded on the photograph. There is, except for *dalli*-type, expected no significant difference of the mean body lengths between the various types, and it is considered that the pigmentation patterns dealt here are not the growth characteristics. This is same with the case of

TABLE 6. FREQUENCY OF MINOR PIGMENTATION TYPES OF *PHOCOENOIDES* OFF SANRIKU COAST

Types	Males					Females					Unknown		Total	
	No.	%	Body length (cm)			No.	%	Body length (cm)			No.	%	No.	%
			range	mean	SE			range	mean	SE				
1. *truei*-type	157	53.2	149–214	186.1	1.13	102	47.7	160–204	182.1	1.12	17	60.7	276	51.4
2. ,,	78	26.4	164–217	185.4	1.42	60	28.0	163–205	181.5	1.55	9	32.1	147	27.4
3. ,,	18	6.1	168–201	188.6	3.47	19	8.9	171–194	181.8	2.20	0	0	37	6.9
4. ,,	2	0.7	168	168.0	—	2	0.9	159–185	172.0	13.0	0	0	4	0.7
5. ,,	9	3.1	180–198	191.1	2.58	2	0.9	171–178	174.5	3.50	0	0	11	2.0
6. ,,	1	0.3	182	182.0	—	2	0.9	180–186	183.0	3.00	0	0	3	0.6
7. ,,	2	0.7	177	177.0	—	0	0				0	0	2	0.4
8. ,,	2	0.7	168–192	180.0	12.0	4	1.9	166–193	179.0	7.81	0	0	6	1.1
9. ,,	4	1.4	178–190	183.0	3.00	9	4.2	176–194	183.6	3.04	0	0	13	2.4
10. ,,	3	1.0	199–204	201.5	2.50	1	0.5	190	190.0	—	0	0	4	0.7
11. ,,	5	1.7	176–202	186.0	8.08	4	1.9	175–185	180.0	2.89	2	7.1	11	2.0
12. black-type	2	0.7	179–207	200.0	14.0	0	0				0	0	2	0.4
13. *dalli*-type	12	4.1	163–196	175.4	4.12	7	3.3	168–190	175.8	4.10	0	0	19	3.5
14. ,,	0	0				2	0.9	175	175.0	—	0	0	2	0.4
Total	295	100	149–217	—	—	214	100	159–205	—	—	28	100	537	100

1) For the number and the percentage the length unknown individuals included.

the three major colour types.

Though it is left for the future study, several factors will have to be assumed for the explanation of the presence of the various minor colour types. One of the possible example is shown below, where each factor is represented by a group of gene or genes.

Factor A: promotes the melanization of the anterior lateral region
Factor B: promotes the melanization of the posterior lateral region
Factor C: inhibits the melanization of the anterior lateral region
Factor D: inhibits the melanization of the posterior lateral region

The coexistence of a promoter and inhibitor will result in the various density of spotting in the controlled region. When the capitals indicate the presence of the variable number of genes grouped into one of the 4 factors, and the small letter the absence of the genes, most of the pigmentation types could be explained by the following combination.

Truei-type (no spot, or spots in the anterior region, type-1, 2, and 5 through 10, 86.0%): abcd, abcD, abCd, abCD, AbCd, AbCD
Truei-type (spots in the posterior region, type-4, 0.7%): aBcD, aBCD
Truei-type (spots in the entire lateral region, type-3, 6.9%): ABCD
Black-type and type-11 of *truei*-type (2.4%): ABcd
Dalli-type (without spot, 3.5%): Abcd, AbcD
Dalli-type (with spots, 0.4%): ABcD

However the absence of the individuals expressed by ABCd, aBCd, or aBcd, which are expected to have the black posterior area and white or, spotted anterior flank, will need further investigation.

PRENATAL GROWTH

Neonatal length

Because of the restricted fishing season, no full term fetus nor newborn calf was obtained from the catch off Sanriku coast. Mizue *et al.* (1966) analysed the 24 full term fetuses and 19 newborn calves caught incidentally by the salmon gillnet fishery in the northwestern North Pacific and western Bering Sea. The body lengths of the smallest postnatal individual and of the largest fetus were 92 cm and 109 cm respectively, and they concluded that the mean neonatal length of the species will be about 100 cm. Table 7 shows the length frequencies of fetuses and newborn calves in Mizue *et al.* (1966), in Koga (1969), and few data obtained by the research vessel of the salmon fishery and provided by Mr. S. Nagahora. The least squares regression is shown by

TABLE 7. RATIO OF FETUS AND NEWBORN CALF OF *PHOCOENOIDES* IN THE NORTHWESTERN NORTH PACIFIC AND WESTERN BERING SEA

Body Length (cm)	Published records[1)		Present data		Total in %	
	fetus	postnatal	fetus	postnatal	fetus	postnatal
85	4	0	0	0	100.0	0
90	5	1	1	0	85.7	14.3
95	3	2	0	0	60.0	40.0
100	5	7	0	1	38.5	61.5
105	1	2	0	0	33.3	66.7
110	1	2	0	1	25.0	75.0
115	0	4	0	0	0.0	100.0
Total	19	18	1	2	50.0	50.0

1) Cited from Mizue *et al.* (1966) and Koga (1969).

$$y = 3.201x - 269.0$$

where x indicates the body length in cm, and y the ratio of postnatal individuals in %. The body length where the ratio reaches 50% is 99.7 cm, which is rounded and the mean body length at birth 100 cm is obtained for the population of *Phocoenoides* in the northwestern North Pacific and western Bering Sea.

Fetal growth and length of gestation

The fetal growth was estimated from the seasonal change of the fetal length off Sanriku coast. The body lengths of 39 fetuses plotted against the date of catch show a linear increase (Fig. 3). The straight line calculated by the least squares is shown by the following equation,

$$y = 0.3333x+19.4$$

where x indicates the days from the first of January, and y the fetal length in cm. The fetal growth rate of the Japanese east coast population is about 3.3 mm/day. On 28 August, the extended straight line reaches 100 cm or the mean neonatal length of the population in the northwestern North Pacific and western Bering Sea. This is an approximate estimation of the mean date of birth of *Phocoenoides* off the Pacific coast of Japan. Some inaccuracy must exist in this estimation, because the neonatal length of the offshore population is tentatively used for the Japanese east coast population.

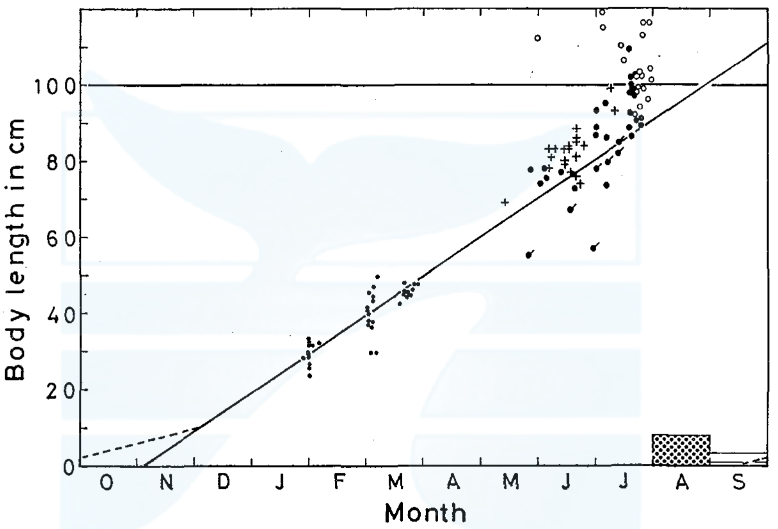

Fig. 3. Seasonal change of the body lengths of fetuses and infants of *Phocoenoides*. Small closed circle and solid line: fetus off Sanriku coast, large closed circle: fetus in the northwestern North Pacific and western Bering Sea (Mizue *et al.* 1966), large closed circle with bar: that in Koga (1969), cross mark: that provided by A. Takemura, open circle: infant in the same area in Mizue *et al.* (1966). Open square indicate the range of two fetuses in the southern Okhotsk Sea (present materials), and dotted square the range of 7 fetuses in the same area in Okada and Hayashi (1951).

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It is known that the growth of mammalian fetus is expressed by the earlier slow growth stage and later linear growth stage (Huggett and Widdas 1951, Laws 1959). The backward extraporation of the above fetal growth line crosses with the axis of time on 3 November of the preceeding year. The length of time from this date to the mean date of birth is 300.1 days. If the value of 0.135 estimated by Perrin *et al.* (1976) for the fetal growth of *Stenella attenuata*, which has the gestation slightly shorter than 1 year, is used, the equation of Laws (1959) is shown as follows.

$$t_g - t_o = 300.1$$
$$t_o = 0.135t_g$$

Where t_0 indicates the length of time from the start of conception to the date when the extended straight line of the growth cuts the axis of time, and t_g the total gestation length. These equations give the total gestation of 346.9 days or 11.4 months (using months of 30.4 days). The mean date of conception is, in the Japanese east coast population, approximately on 17 September.

AGE DETERMINATION

Tooth structure and growth layers

Following observations were made on the thin tooth sections decalcified and stained with haematoxylin. The tooth of the species is constituted of enamel, dentin, and cementum. The enamel does not dissolve in the formic acid, which is different from other delphinids. The decalcified enamel is stained blue with haematoxylin. This is an indication of high content of organic matrix. There are observed many fine growth layers in the decalcified and stained section of enamel.

The neonatal line in dentine is clear as a thin unstainable layer. There are nearly 10 faint minute layers in the prenatal dentine. The growth layers are irregular and unclear in the postnatal dentine laid down after the first layer. Though the pulp cavity is wide on newborn individuals, it is soon filled with postnatal dentine leaving a narrow canal, and the base of the root is finally covered with thick cemental layers. This narrow pulp cavity is connected with the surface of the tooth through canals penetrating the cementum.

The cemental growth layers are, on the longitudinal section, most clearly observed between the level of the proximal end of the fetal dentine and that of the proximal end of the first postnatal dentinal layer. Though the cementum of older individuals is thick at the proximal end of the tooth, the growth layers are not well detected in it.

The individual variation of cementum thickness is large. And there are often observed accessory layers in the thick cementum, which makes the age determination difficult. The accessory layers are usually distinguished through the careful observation of the entire cemental layers of the tooth. The accuracy of age determination of the species by the cemental growth layer is so bat that two independent counts made carefully on a tooth section often give the discrepancy of 20%.

Accumulation rate of the layers

The comparison of the independent counts of the dentinal and cemental layers is shown in Fig. 4, where only the individuals with readable dentinal layers are selected. The number of growth layers in the two tissues is same on the individuals younger than 4 cemental layers. At the older age, however, the accumulation of the dentinal layer seems to cease as in the case of the striped and spotted dolphins suspected by Kasuya (1976a) or the layer becomes indistinguishable.

Mizue *et al.* (1966) estimated the postnatal growth of theo ffshore population in the northwestern North Pacific and western Bering Sea, based on the analysis of the body length and the body weight, that the body length of one year old individual is from 145 to 169 cm and that of the 2 years old is from 170 to 187 cm. Since the breeding season of the species is unimodal and restricted to the summer season, the reliable separation of some young age groups can be done based on the length frequency. An estimation of the accumulation rate of the growth layers is made in comparison with their study. As shown in Table 8, no trace of cemental layer is observed on the teeth of two newborn individuals, 100.5 cm female and 110.0 cm female, caught by the salmon gillnet fishery. The postnatal dentine is not formed in the former individual, but there is observed a very thin postnatal dentine (5 μm in thickness) on the tooth of the latter individual (Pl. III, Figs 1 and 2). On the other hand, the teeth of slightly older individuals, 132 to 159 cm, caught in winter off Sanriku coast have one stainable layer in cementum and the same number of layers in dentine. Most of the 45 aged individuals of the length

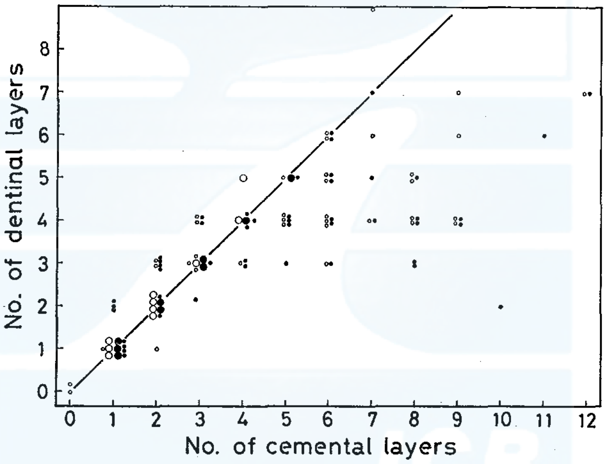

Fig. 4. Scatter diagram of the relationship between the number of dentinal layers and that of cemental layers. Large circle indicates 5 individuals, the small one, open circle female, and closed male. All the available data included.

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TABLE 8. COMPARISON OF DENTINAL AND CEMENTAL GROWTH LAYERS OF NEWBORN AND JUVENILE *PHOCOENOIDES*

Body length (cm)	Sex	No. cemental layers	No. dentinal layers	Date of catch	Remarks
100.5	♀	0	0	21, VII, '73	*dalli*-type, N. Pacific
110.0	♀	0	0	26, VII, '72	,, ,,
132.0	♂	1	1	30, I, '74	*truei*-type, Sanriku
149.0	♂	1	1	3, III, '74	,, ,,
156.0	♀	1	1	27, II, '74	,, ,,
159.0	♀	1	—	19, II, '76	black-type, ,,

from 141 cm to 168 cm caught in late May to early July and dealt in the Addendum of this study are considered, though there might be the inclusion of few older individuals, to have been born in the preceeding summer. Among these 45 juveniles, 38 individuals or 84.4% of the total have only one stainable cemental layer in the tooth, and only 7 or 15.6% have two cemental layers. These informations indicate that the cementum is absent on the tooth of newborn individual but the first stainable cemental layer is completed or being deposited in the first winter, and that the deposition of the next layer is not started in the season from late May to early July. This is a strong suggestion that the stainable cemental layer is deposited in autumn and winter season as in the cases of the striped and spotted dolphins (Kasuya 1976a) or of the Baird's beaked whale (Kasuya 1977). Accordingly, the age of the individual with N cemental layers and caught off Sanriku coast can be approximately N−0.5 years, because the birth in the species occurs in summer and the fishing season is from late January to early April.

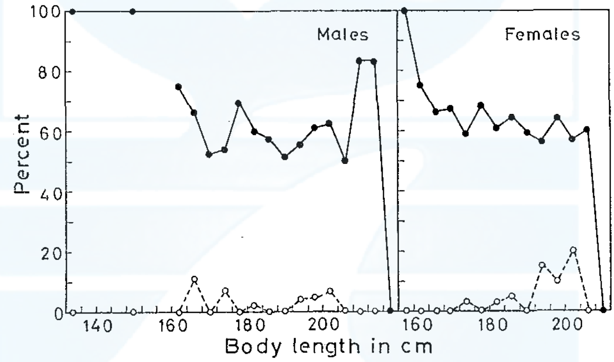

Fig. 5. *Phocoenoides* off Sanriku coast, ratio of the individuals aged (closed circle and solid line), and the ratio of the age indeterminable individuals in the tooth sampled individuals (open circle and dotted line).

The ratio of the individuals aged by the above method is 60.0% of the length known males and 62.4% of the females. As shown in Fig. 5, the ratio is slightly low in the larger individuals, and especially in females. This seems to have been caused by the failure of the preparation, higher frequency of the falling off of the tooth in older individuals, or by the unreadability of tooth layers. However, the bias will not be so large to have significant effect on the analyses in the later sections of this study.

POSTNATAL GROWTH IN THE MALE

Length frequency

The body lengths of 485 males taken off the Pacific coast of Japan ranged from 132 cm to 219 cm, with the mean length of 185.2 cm. Single mode was present at the length group of 180 to 183 cm. As shown in Fig. 6, the ratio of the larger individuals and the mean body length decrease, in both sexes, with the progress of the fishing season. Though the decrease in the half month interval is not significantly large, the change is considered to be significant because the trend continues from late January to late March.

Another important feature of the length frequency is, in both sexes, the scarcity of the individuals below 170 cm and above 200 cm. This will be related, as mentioned in the later sections, with the segregation and the bias caused by the fishing method.

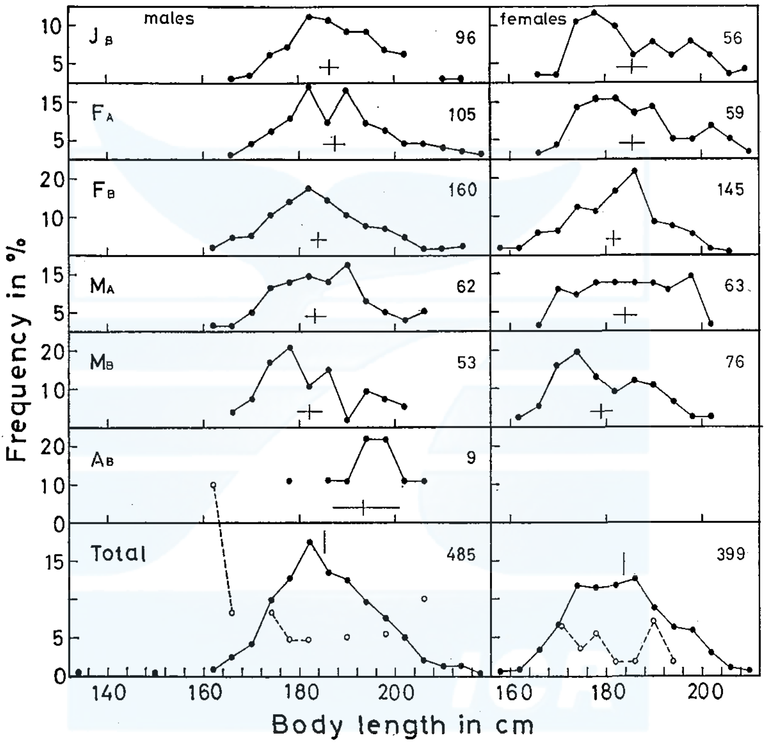

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Fig. 6. Body length frequencies of *Phocoenoides* caught by the harpoon fishing off Sanriku coast. Mean (vertical line) and range of two standard errors (horizontal line) are indicated. Suffix A attached to month indicates from the 1st to 15th of the month, B from 16th to the end, and open circle and dotted line the ratio of *dalli*- and black-type in the total *Phocoenoides*.

Growth curve

The relationship between the body length and the age is shown in Fig. 7. It is known in some delphinids that the mean growth curve of the male at the age between 3 and 10 years is expressed approximately by a straight line (Kasuya *et al.* 1974, Kasuya 1976a). In the present species, the mean body lengths at the age from 1.5 to 6.5 years seems to come on a straight line. The least squares regression of these points gives the following equation,

$$y = 3.30x + 169.58, \quad 1.5 \leqq x \leqq 6.5$$

where x indicates the age in years, and y the mean body length in cm. The gradient 3.30 indicates the mean annual growth rate. The corresponding figures of *Stenella coeruleoalba* and *S. attenuata* are 4.40 cm/year and 4.20 cm/year respectively (Kasuya *et al.* 1974). Accordingly it is suggested that in spite of the similarity of the neonatal length and length at 1 year of age, the growth of the later part of the life is much slower in *Phocoenoides* than *S. coeruleoalba*, and that the asymptotic

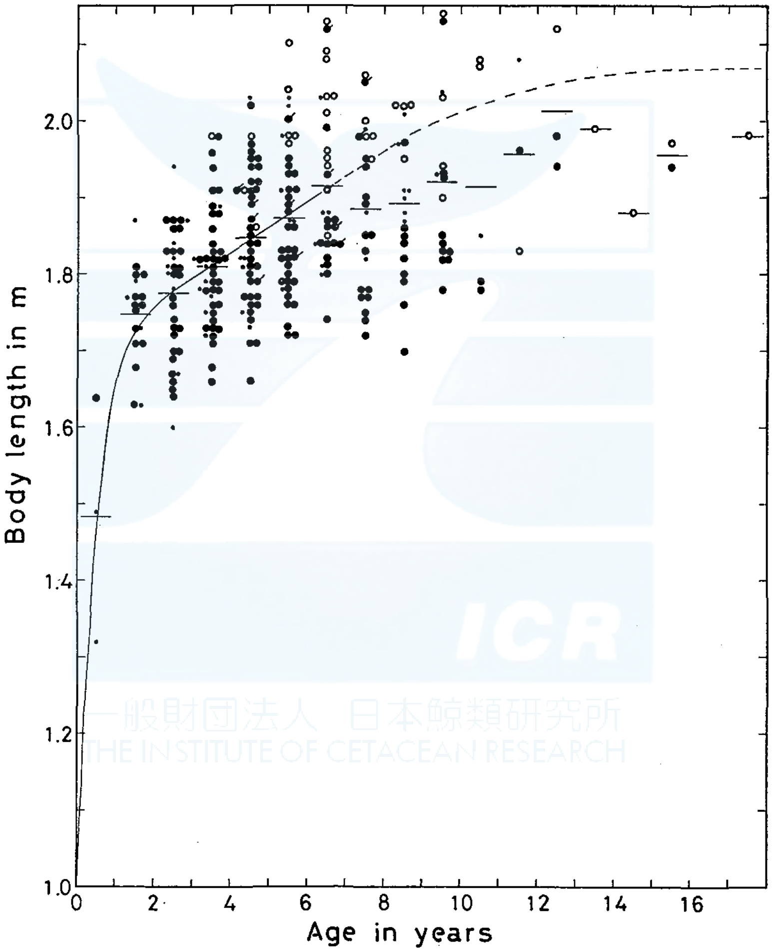

Fig. 7. Male *Phocoenoides* off Sanriku coast, scatter plot of body length on age (N=294). Large closed circle indicates the immature, closed with bar the maturing, open circle the mature, and small closed circle the unidentified individual. Horizontal bar indicates the mean body length.

length of the former species could be much smaller than that of the latter species. Because of the scarcity of the adult individuals, the asymptotic length can not be estimated in the present study. In Fig. 7, it was tentatively assumed to be between 200 and 210 cm and to be attained at or after the age of 15 years as in the case of the female.

Male growth stages

The materials are collected from the catch of harpoon fishing. As the season is limited to January through April, or 5 to 8 months prior to the peak of the mating season estimated in this study, the activity of the male organ will be at the lowest.

For the preliminary examination, the maturity of the male was examined by the following four methods.

1. Epididymal smear: classified into the three stages, " spermatozoon absent ", " scanty ", " copious ".
2. Testicular smear: classified as above
3. Epididymal tissue: classified into the following three stages.
   " Immature ", ductus epididymidis is simple and narrow, and the epithelial cell is low.
   " Maturing ", folds of the ductus epididymidis are developed, but the low epithelial cells are still present at some part.
   " Mature ", folds of the ductus epididymidis are extremely developed, and all the epithelial cells are tall.
4. Testicular tissue: classified into the following three stages by the examination of the peripheral and central testicular tissue.
   " Immature ", both spermatid and spermatocyte absent in the sections examined.
   " Maturing ", central tissue is mature and peripheral tissue immature.
   " Mature ", both central and peripheral tissues are mature [=spermatid or spermatocyte present]

In the above criteria of the maturity of epididymal or testicular tissue, the presence or absence of the spermatozoon is not taken into cosideration, because even in some undoubtedly mature testis the spermatozoon is absent or scanty in the season. The spermatozoon in the testis tissue was, if present, always found with spermatid

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TABLE 9. COMPARISON OF THE MATURITY INDICES OF MALE *PHOCOENOIDES* OFF SANRIKU COAST

Testis (histology)	Epididymal smear			Testicular smear			Ductus epididymidis		
	−	+	++	−	+	++	Im.	M'ing	Mat.
Immature	157	0	0	152	5	0	71	11	0
Maturing	10	1	0	13	1	0	0	3	5
Mature	23	7	3	18	14	1	0	1	6
Total, no.	190	8	3	183	20	1	71	15	11
%	94.5	4.0	1.5	89.7	9.8	0.5	73.2	15.5	11.3

−: no spermatozoon, +: scanty spermatozoa, ++: spermatozoa copious.

or spermatocyte, but the latter two not always with spermatozoon.

Among the 208 individuals examined of the testis tissue, there was no individuals where the peripheral testis is mature in spite of the immaturity of the central testicular tissue. Few individuals had no trace of spermatid nor spermatocyte but showed the presence of scanty spermatozoa in the testicular smear. Though these individuals could have been producing the spermatozoa at some restricted part of the testis, they will safely be considered as not acting as an adult male because the ductus epididymidis is not fully developed and no spermatozoon was found in the epididymal smear (Table 9).

On the other hand the individuals with the " mature " testis can be considered as really attained the sexual maturity, because about one third of the individuals of this category showed the presence of spermatozoa in the epididymal smear, and because the spermatocytes or spermatids in the winter season will grow to the spermatozoa by the next mating season.

The most uncertain is the individuals with " maturing " testis. At least some of the males of this category are suspected to act as adult male, because there is a case of the " maturing " male where the spermatozoa are present in the epididymal smear and more than half of the individuals of this category had the " mature " epididymis. However, it is impossible to consider that all of the males of this category are sexually mature, since many individuals of this category still have the " maturing " epididymis. Accordingly the males with the testis of this category are dealt as the maturing, and the males with the testis of two other categories as the immature and mature.

Attainment of sexual maturity in males

Table 10 shows the relationship between the age and the development of the epididymis. The ductus epididymidis start to develop at various age between 1.5 and 9.5 years. The fully completed stage appears at about 4.5 years. Since as mentioned in the later section, there is an underrepresentation of the mature individuals, Table 10 can not be used for the estimation of the mean age at the

TABLE 10. AGE AND DEVELOPMENT OF DUCTUS EPIDIDYMIDIS OF *PHOCOENOIDES* OFF SANRIKU COAST

Age(yrs)	Immature	Maturing	Mature
0.5	0	0	0
1.5	7	1	0
2.5	10	2	0
3.5	13	3	0
4.5	12	2	2
5.5	9	2	1
6.5	4	0	5
7.5	5	2	1
8.5	5	1	0
9.5	2	0	1
10.5	0	1	0

completion of the development of the epididymis.

If the weight of testis and mean diameter of the seminiferous tubules are plotted on the logarithmic scale, there is observed a linear relationship (Fig. 8). The least squares regression of 201 individuals is shown by

$$y = 33.79x^{0.2284}$$

where y indicates the mean diameter of the tubules in μm at the center of testis, and x the weight of testis in grams. Both the immature and mature individuals are expressed by the single equation. This feature is different from that observed on *S. attenuata* (Kasuya *et al.* 1974), which is possibly related with the length of time from the mating season. The absence of the observable seasonal change in the diameter of tubules will also have direct relationship with the restricted season of the samples. In Fig. 8, the points are clearly separated into two groups at the tubule diameter of about 70 μm, or at the testis weight of 25 g. The group with developed testis is mainly composed of the mature individuals, and the opposite the immature. The individuals with the maturing testis, which is smaller in number, situate at the intermediate position. This feature is shown graphically in Figs 9 and 10. The ratio of sexually immature individuals is 50% at the tubule diameter of about 70 μm, and that of sexually mature male at about 80 μm. As the maturing stage must be passed by all the males before attaining the sexual maturity, the former figure corresponds to the mean tubule diameter at the attainment of the maturing stage, and the latter to that at the attainment of sexual maturity.

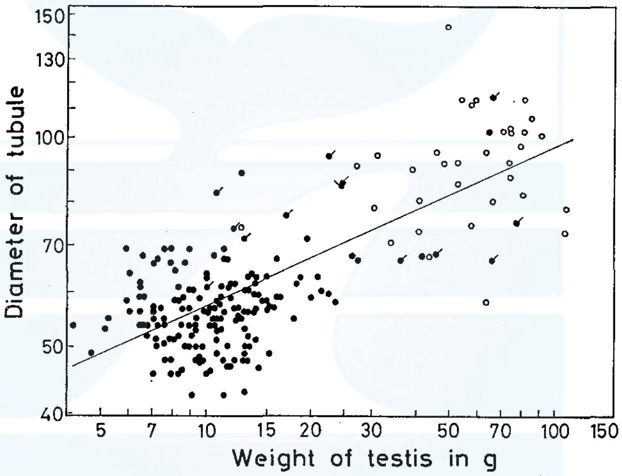

Fig. 8. *Phocoenoides* off Sanriku coast, scatter plot of the mean diameter of seminiferous tubules (μm) on weight of testis (N=201). Closed circle indicates the immature, closed circle with bar the maturing, and open circle the mature.

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For the identification of the maturity of the male, the weight of testis is more

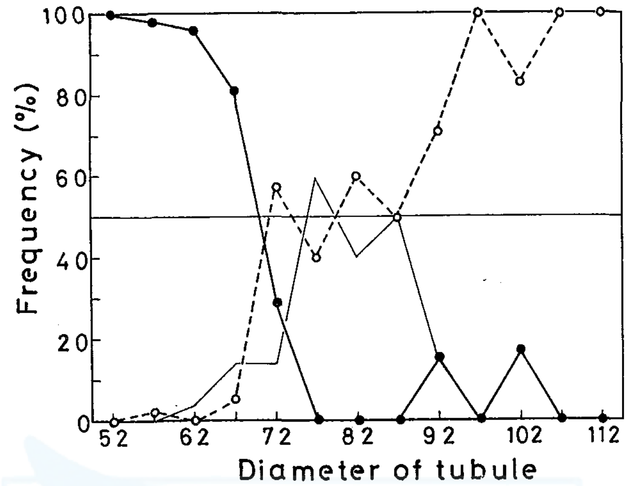

Fig. 9. *Phocoenoides* off Sanriku coast, relationship between the sexual maturity and mean diameter of seminiferous tubules in μm. Closed circle and thick solid line indicate the immature, open circle and dotted line the mature, and thin solid line the maturing.

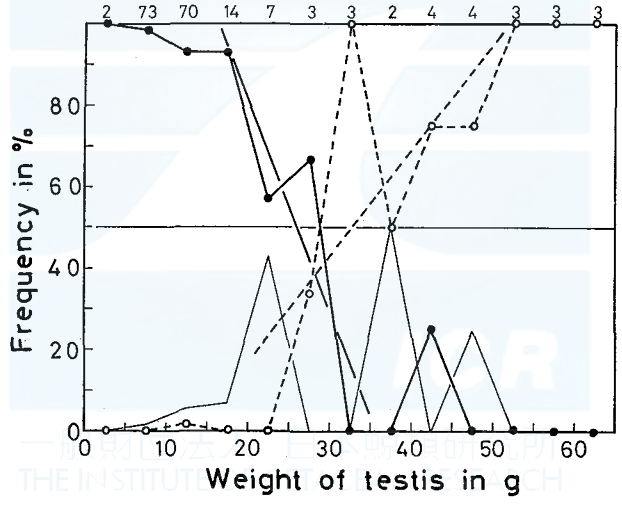

Fig. 10. *Phocoenoides* off Sanriku coast, relationship between sexual maturity and the weight of testis. The numerals at the top indicate the sample size. For symbols see Fig. 9.

practical than the histological examination. The relationship between the maturity and weight of testis is shown in Fig. 10. The ratio of immature individuals decreases in accordance with the increase of the testis weight from 10 g to 45 g. The least squares regression is given by the equation,

$$y = -5.382x + 188.73, \quad 10.0 \leqq x \leqq 34.9$$

where x indicates the weight of one testis, and y the ratio of immature individuals. The value of y becomes 50% at the testis weight of 25.77 g, which is the mean weight of testis at the attainment of the maturing stage. The relationship between the ratio of mature individuals (y in %) and the weight of testis (x in g) is shown by the following equation.

$$y = 2.560x - 34.10, \quad 20.0 \leqq x \leqq 54.9$$

The mean weight of one testis at the attainment of sexual maturity is obtained from this equation as 32.85 g. This estimation is based on the assumption that there is neither segregation nor difference of the catchability between the individuals of the same testis weight and belonging to the different growth stages. Though this question is not solved in this study, if it exists, the above estimation does not indicate the true figure of the population, but only can be applied in estimating the maturity of the harpoon fishing catch.

Mizue *et al.* (1966) examined the testis of 41 Dall's porpoises caught in the offshore waters of the northwestern North Pacific and western Bering Sea in the season from May to July. Though they did not give the weight of testis at the onset of sexual maturity, it is suspected from the relationship between body length and weight of testes (Fig. 3, Mizue *et al.* 1966, and Fig. 27 of this study) that the sexual maturity will be attained between 100 and 200 g in the weight of combined testes. The maximum weight of the combined testes in the summer catch is about 700 g. These values are more than twice larger than those observed in the winter catch off Sanriku coast. This difference is too large to be attributed to the difference of the population, but more reasonably be considered in connection with the annual reproductive cycle of the male. Mizue *et al.* (1966) state based on the histological examination of the testes that there was found no " fully mature " individuals in the season, and considered that the weight of testes will increase in the coming mating season. Though they did not give the definition of the criterion nor explain if the " fully mature " stage indicates one of the growth stages or one of the stages of the annual reproductive cycle of the adult male, I suspect that they indicated the latter. Then more increase of the testis weight is expected in the mating season in August and September.

Age at the attainment of sexual maturity

In calculating the age at the attainment of sexual maturity, the sexual maturity of some individuals was decided by the weight of testis. Namely the testis weighing 25.7 g or less was classified into the immature, that 32.9 g or more the mature, and the intermediate into the maturing.

As shown in Fig. 11, the age of the youngest sexually mature individual is 3.5 years and that of the oldest immature 15.5 years. The maturing individuals are found in the age of 4.5 to 7.5 years. These figures suggest that the mean age of the male at the attainment of sexual maturity is approximately at 5 to 10 years. The facts that the ratio of the mature males exceeds 50% at the age above 13 years and the number of individuals older than this age is extremely scarce, suggest

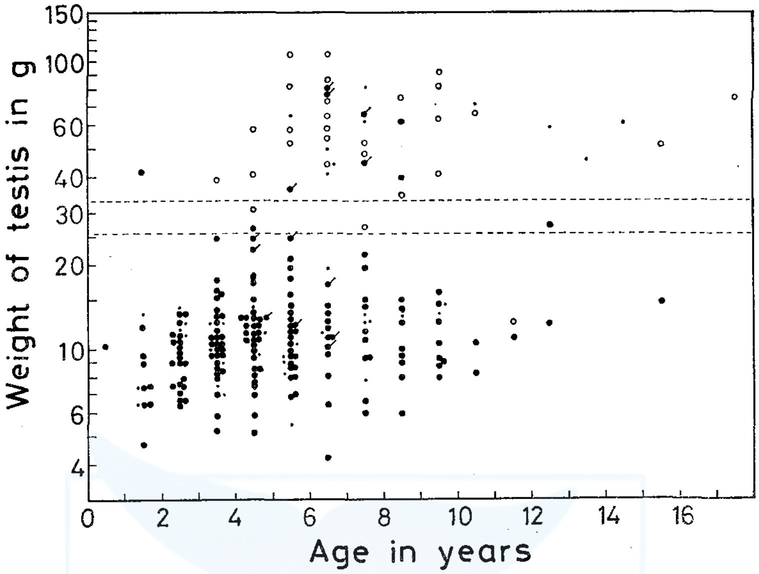

Fig. 11. *Phocoenoides* off Sanriku coast, scatter plot of the weight of testis (logarithmic scale) on age. Dotted lines indicate the mean weights at the attainment of maturing stage and of sexual maturity. For other symbols see Fig. 7.

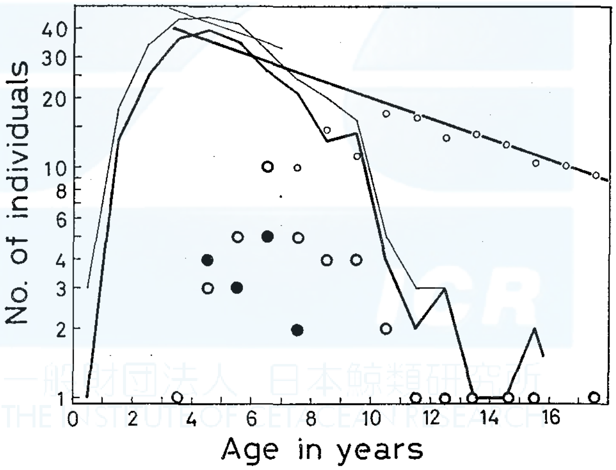

Fig. 12. Age frequency of male *Phocoenoides* in the catch of harpoon fishing off Sanriku coast. Thin solid line indicates all the aged males, thick solid line the maturity known individuals, large open circle the actual number of adult individuals, closed circle that of the maturing, and small open circle number of the adult males corrected for the fishing bias. For further explanations see text.

that the present sample underrepresents the older individuals. Possibly the older males, and especially the adults, will be less attracted by the bow wave of the ship and captured less intensely as in the case of the adult females and suckling calves

TABLE 11. *PHOCOENOIDES* OFF SANRIKU COAST CLASSIFIED BY AGE AND MATURITY, MALES

Age (yrs)	Actual no.			Calculated no. & %					
	Im.	M'ing	Mat.	Im.		M'ing		Mat.	
2.5	25	0	0	25	100.0	0	0	0	0
3.5	35	0	1	35	97.2	0	0	1	2.8
4.5	32	4	3	32	82.0	4	10.3	3	7.7
5.5	27	3	5	27	77.1	3	8.6	5	14.3
6.5	11	5	10	11	42.3	5	19.2	10	38.5
7.5	14	2	5	14	53.8	2	7.7	10.0	38.5
8.5	9	0	4	9	38.3	0	0	14.5	61.7
9.5	10	0	4	10	47.2	0	0	11.2	52.8
10.5	2	0	2	2	10.5	0	0	17.1	89.5
11.5	1	0	1	1	5.8	0	0	16.3	94.2
12.5	2	0	1	2	12.8	0	0	13.4	85.9
13.5	0	0	1	0	0	0	0	14.1	100
14.5	0	0	1	0	0	0	0	12.7	100
15.5	1	0	1	1	8.7	0	0	10.5	91.3
16.5	0	0	0	0	0	0	0	10.4	100

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Fig. 13. *Phocoenoides* off Sanriku coast, the relationship between the sexual maturity and age. Closed circle and thick solid line indicate the frequency of immature individuals, open circle and dotted line that of the adults, and thin solid line that of the maturing invididuals. The larger circle indicates the actual frequency and the smaller the frequency corrected for the fishing bias.

mentioned later.

As the increase of the number of the mature males is almost linear at the ages from 3.5 to 6.5 years, the fishing selection by the maturity seems to be less intense at these ages (Fig. 12). Furthermore, as mentioned in the other section, most of the calves seem to be weaned before 3.5 years and the fishing bias related with the nursing can be negligible in the above range. Then the age frequency of the male in these age classes will indicate the approximate survival rate. The least squares regression for the age range gives the total annual mortality rate of 9.7% or 0.102 in the instantaneous rate. The true ratio of the mature individuals in the age classes above 6.5 years is calculated based on the assumption that the mortality rate is same in the older individuals and the shortage of the frequency above the age is caused by the underrepresentation of the adults (Table 11 and Fig. 12).

The corrected ratio of the mature individuals (y in %) is shown by the following least squares equation, when x indicates the age in years (Fig. 13).

$$y = 10.124x - 32.17, \quad 3.5 \leqq x \leqq 13.5$$

The half of the males are sexually mature at the age of 8.1 years, which is an estimation of the mean age at the onset of sexual maturity of the males. The similar regression calculated for the ratio of immature individuals is shown by the following equation.

$$y = -9.534x + 123.52, \quad 2.5 \leqq x \leqq 13.5$$

The ratio of immature males reaches 50% at the age of 7.7 years. This is the mean age when the male attains the maturing stage. The fact that the difference between the two ages is only 0.4 year suggests that the maturing stage is passed within short period.

Another estimation of the age at the attainment of sexual maturity is obtained as the mean of the age of the youngest mature individual and that of the oldest immature. Though this methods gives a more direct estimation than the former, the accuracy is lower because it is based on the small number of samples at the extremities of the ordinary distribution and because the estimation of the age of individuals is less reliable. This method, excluding the two textreme cases, gives (4.5+12.5)/2=8.5 (years), which is sufficiently close to the estimation obtained by the first method.

Body length at the attainment of sexual maturity

The unbiased estimate of the mean body length at the onset of maturing stage and that at the onset of sexual maturity are obtained from the mean growth curve and the corresponding ages estimated above. They are 195.0 cm and 196.3 cm respectively.

As shown in Fig. 14, the rapid increase of the testis weight starts at the body length of 184 cm. This feature is almost identical with the species in the offshore waters of the northwestern North Pacific and western Bering Sea studied by Mizue *et al.* (1966), or dealt in the Addendum of this study. The relationship between the body length and the ratio of sexually mature individuals is shown in Fig. 15. The largest immature male is found in the length group of 212 cm to 215 cm, and the smallest mature male in that of 180 cm to 183 cm. The males in the maturing stage are found at the body length between 176 cm and 215 cm.

The least squares regression between the body length (x in cm) and the ratio

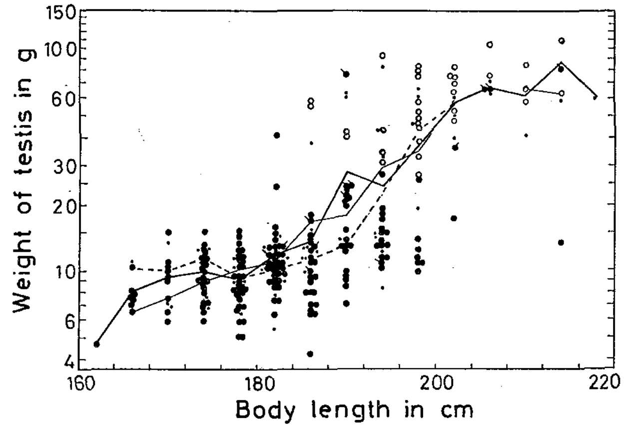

Fig. 14. *Phocoenoides* off Sanriku coast, relationship between weight of testis (logarithmic scale) and body length. Thin solid line indicates the mean in January (n=55), thick solid line that in February (n=157), and dotted line that in March (n=39). For other symbols see Fig. 7. Nine data in April are plotted.

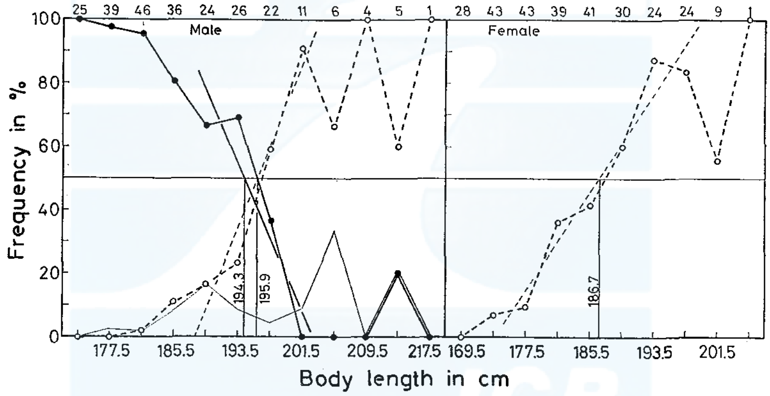

Fig. 15. *Phocoenoides* off Sanriku coast, relationship between sexual maturity and body length. Numerals at the top indicate the sample size. For other symbols see Fig. 13.

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of the immature males (y_1 in %) and that between body length and the ratio of mature males (y_2 in %) are as follows.

$$y_1 = -5.8225x + 1181.37 \quad 188 \leqq x \leqq 203$$

$$y_2 = 6.4850x - 1220.37 \quad 188 \leqq x \leqq 203$$

These equations give 194.3 cm for the body length where half of the individuals are immature, and 195.9 cm for the length where half of the males are mature. The discrepancy between the two lengths is caused by the presence of the males at maturing stage. Since these calculations are not corrected for the fishing bias, the lengths are able to be used only for the purpose to get the unbiased estimate of the maturity of the harpoon fishing catch, but are not applicable to the samples obtained by other method.

Generally speaking, it is not expected even for the Dall's porpoise that the two sets of the body lengths estimated above by the different methods coinside, because the growth of the length seems to be very slow after the attainment of sexual maturity. Similar feature is indicated on *S. coeruleoalba* by Kasuya (1972). The coincidence of the two sets of figures are considered to have been caused by the underrepresentation of older individuals in the present materials.

Conclusion

In the present study the maturity of the male is classified into the three categories of the immature, maturing, and mature. However, this is too complicated for the practical use in the analyses of the life history of the species. For the unbiased classification of the males into two categories of the immature and mature, it will be practical to take the mean of the values at the attainment of the maturing stage and of the mature stage. They are as follows ;

Weight of testis : $(25.77+32.85)/2=29.31$ g
Age : $(7.7+8.1)/2=7.9$ years
Body length : $(195.0+196.3)/2=195.7$ cm

The last figure is practically same with another estimate $(194.3+195.9)/2=195.1$ cm.

POSTNATAL GROWTH IN THE FEMALE

Length frequency

The body lengths of 399 females ranged from 156 cm to 209 cm with the mean length of 183.5 cm (Fig. 6). Single mode will exist at the length group of 184 to 187 cm. The mean length decreases, as in the case of the male, with the progress of the fishing season. The large adult individuals and the juveniles of the suckling age are scarce in the catch.

Growth curve

The relationship between body length and the age in the female is shown in Fig. 16. The mean growth curve seems to be almost identical with that of the male until the age of 3 years, then the growth becomes slower than the male (Fig. 31). Because of the scarcity of the adult females, the growth after the age of 7 years is not directly estimated. Possibly the asymptotic length of between 195 and 205 cm will be attained at about 15 years of age as in the case of *S. coeruleoalba* (Kasuya 1976a). The mean growth curve in Fig. 16 was drawn by eye based on the above assumptions.

Age at the attainment of sexual maturity

As shown in Fig. 17, the combined weight of ovaries is usually smaller than

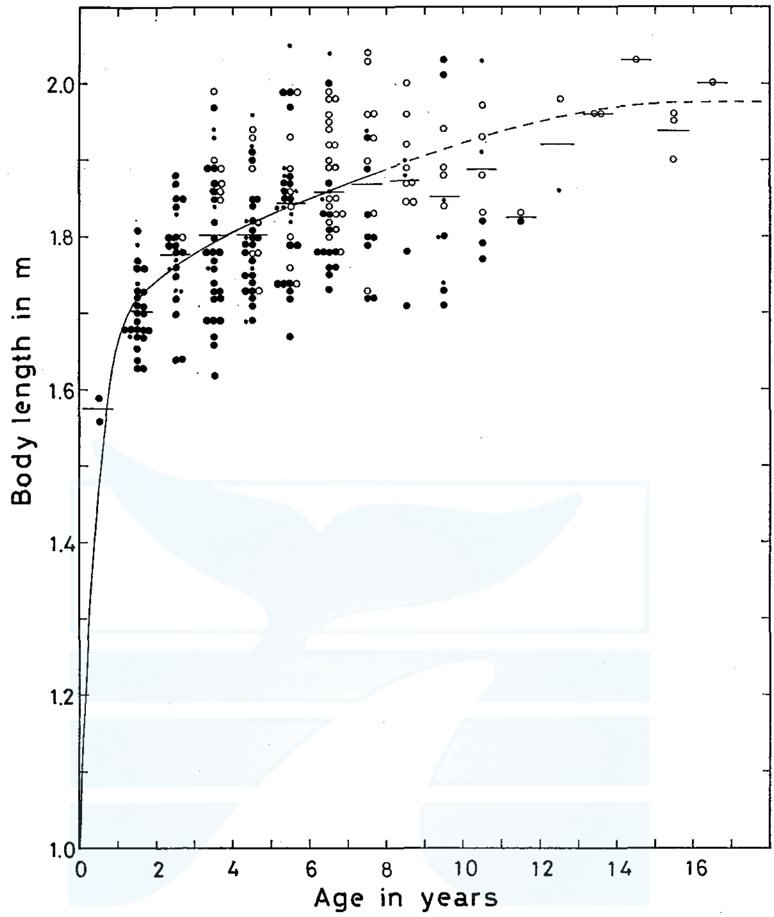

Fig. 16. Female *Phocoenoides* off Sanriku coast, scatter plot of body length on age. Growth curve is drawn by eye. For marks see Fig. 7.

3.5 g in the immature individuals having no follicle measuring 1 mm or more in the mean diameter. However, that of the immature females with the follicle exceeding the size shows heavier weight. The weight of 8 pairs of ovaries with corpus luteum ranged from 6.8 to 14.5 g.

The age of the youngest sexually mature female is 2.5 years, and that of the oldest immature is 11.5 years (Table 12). However, considering the fact that the age determination of this species is less accurate than that of other delphinids and that the ovulation occurs about 0.5 year before or after the fishing season, it will be better to say, excluding the samples at the both limits of the range, that the female attains the sexual maturity at the age between 3 and 11 years. The center of the range situates at 7 years of age, which can be a rough estimate of the mean age of the female at the onset of sexual maturity.

Another estimation of the age at the onset of sexual maturity is calculated

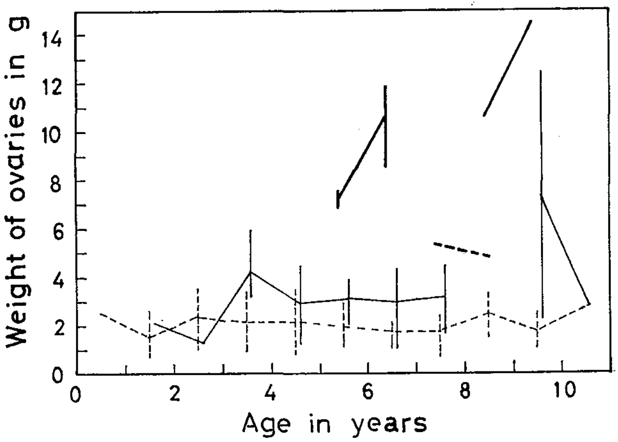

Fig. 17. *Phocoenoides* off Sanriku coast, relationship between combined weight of ovaries and age. Thin dotted line indicates 86 immature females without measurable follicle (≧1 mm), thin solid line 34 immature females with measurable follicle, thick dotted line 2 adult females without corpus luteum, and thick solid line 7 adult females with corpus luteum. Mean and range are indicated.

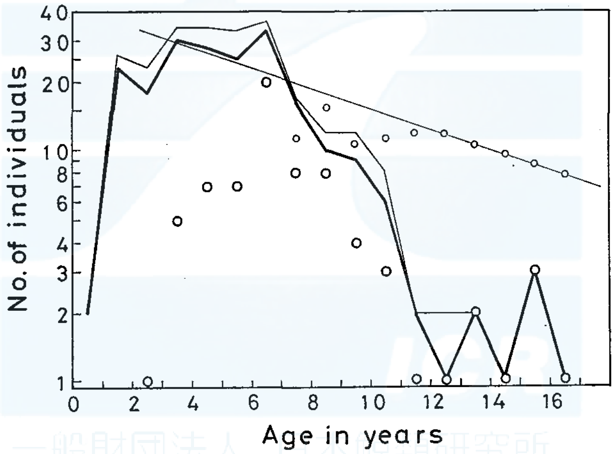

Fig. 18. Age frequency of female *Phocoenoides* in the catch of harpoon fishing off Sanriku coast. For symbols see Fig. 12.

from the ratios of adult females in each age groups. The underrepresentation of the adult females was corrected, using the total annual mortality rate of 9.7%, in the same way as used for the males (Table 12 and Fig. 18). The least squares regression gives the equation

$$y = 9.483x - 14.39, \quad 1.5 \leqq x \leqq 12.5$$

where y indicates the corrected ratio of the adult females in %, and x the age in

TABLE 12. *PHOCOENOIDES* OFF SANRIKU COAST CLASSIFIED BY AGE AND MATURITY, FEMALES

Age (yrs)	Actual no.		Calculated no. & %			
	Im.	Mat.	Im.		Mat.	
1.5	23	0	23	100.0	0	0
2.5	17	1	17	94.4	1	5.6
3.5	25	5	25	83.3	5	16.7
4.5	21	7	21	75.0	7	25.9
5.5	18	7	18	72.0	7	28.0
6.5	13	20	13	39.4	20	60.6
7.5	8	8	8	41.5	11.3	58.5
8.5	2	8	2	11.5	15.4	88.5
9.5	5	4	5	31.8	10.7	68.2
10.5	3	3	3	21.1	11.2	78.9
11.5	1	1	1	7.8	11.8	92.9
12.5	0	1	0	0	11.6	100.0
13.5	0	2	0	0	10.4	100.0

years (Fig. 13). This equation gives 6.8 years for the age when 50% of the females are sexually mature, which is sufficiently close to the figure obtained by the first method.

Body length at the attainment of sexual maturity

The body length at the age of 6.8 years, the mean age at the attainment of sexual maturity, is read on the mean growth curve as about 186.5 cm.

As shown in Fig. 16, the individuals of large body size attain the sexual maturity at an age younger than the smaller. The smallest mature female is found in the length group of 172 to 175 cm, and the largest immature in that of 200 to 203 cm. This range is not significantly different from the values of the stock in the western Bering Sea and northwestern North Pacific (Mizue *et al.* 1966, and Addendum of this study). The least squares regression between the percentage of the adult individuals, y, and the body length, x in cm, is expressed by

$$y = 3.8807x - 674.72, \quad 176 \leqq x \leqq 199$$

and shown in Fig. 15. This equation gives 186.7 cm for the body length where 50% of the females are sexually mature.

REPRODUCTION

Breeding season

Two different opinions have been published on the gestation length of this species. Okada and Hayashi (1951) considered on the Sea of Japan-Okhotsk Sea stock that mating will take place in about one month from the end of June to the beginning of July. However, in the same paragraph, they tell that the copulation must occur in August. The gestation was considered to last for 7 to 9 months.

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One of the reasons for this conclusion is their observation that " Most of the females . . . collected [by them] in August in the Okhotsk Sea were found to be carrying small embryos of about 5.5 mm in length ". Another reason is, though the data source is not clear, that " the adults with embryos of 5 mm in body length were caught commonly in the Okhotsk Sea during the summer from June to August, and the adults caught off Tajima, [southern] Sea of Japan during March and April had either already given birth or had a large fetus of one meter in body length." In their study, no comment was made on the neonatal length.

Mizue *et al.* (1966), on the other hand, estimated the mean neonatal length as about 100 cm from the largest fetus and smallest infant caught by the Japanese salmon gillnet fishery in the western Bering Sea and northwestern North Pacific. They suggested the parturition season in late July to early August, the mating season after the end of salmon fishing season in early August, and consequently the gestation of less than 1 year.

In the present study, the gestation of 11.4 months and the parturition peak in late August were calculated for the population off the Pacific coast of Japan. These conclusions are similar to those estimated by Mizue *et al.* (1966).

The most important difference between the three studies concerns if the peak of parturition of the population in the Okhotsk Sea and Sea of Japan really exists in April as suggested by Okada and Hayashi (1951). If this is correct the length of gestation can be about 7 to 9 months (Okada and Hayashi 1951) and the daily growth rate of the fetus at the linear growth stage can be approximately between $100/30.4(7-7\times0.2)=0.587$ cm/day and $100/30.4(9-9\times0.2)=0.457$ cm/day. On the other hand, Kasuya (1977) showed that there is a linear relationship between the neonatal length of delphinids (x, cm) and the daily fetal growth rate at the linear part of the fetal growth (y, cm/day). The equation was shown as follows.

$$y = 0.001462x+0.1622$$

This equation and the neonatal length of 100 cm give the daily growth rate of *Phocoenoides* as 0.308 cm/day, which is much smaller than the rate calculated above but closer to the value 0.333 cm/day obtained in the former section. This suggests that the parturition season and the gestation length estimated by Okada and Hayashi (1951) is wrong.

The extended line of the fetal growth off the Sanriku coast shows good coincidence with the fetal lengths in May and early June in the western Bering Sea and northwestern North Pacific. However, most of the points in late June and July come above this line. There could be two interpretations for it. One is to consider that the growth of the near term fetus is faster than the previous stage. Another possibility is to expect the segregation of pregnant females in relation to the size of the fetus. Though the precise locations of the samples are not known, the presence of segregation is suggested by the fact that the fetuses in 1968 season (Koga 1969) come below the growth curve and those caught in 1964 and 1965 (Mizue *et al.* 1966) and in 1967 (provided by Dr A. Takemura) come above the line. Possibly the pregnant females of the stock with nearterm fetus will stay, in late June and July, in the waters from the western Aleutian Islands to the east coast of the Kamchatka Peninsula, and the cows with smaller fetus will migrate to further north.

Figure 19 shows the frequency distribution of the estimated date of parturition in the two stocks of the species. The dates were calculated, using the fetal growth curve of the Japanese Pacific coast stock, as the date when calves smaller than 110 cm in body length and all the fetuses might have attained the mean neonatal length of 100 cm. Since the dates and the lengths of fetuses in Mizue *et al.* (1966) were read on their Fig. 2, the accuracy might be worse. An apparent parturition peak exists in late July to early August, or slightly before that of the Japanese Pacific coast population. However, as the larger fetuses are overrepresented in the sample, the real parturition peak will be in late August to early September as in the case of the population off the Pacific coast of Japan.

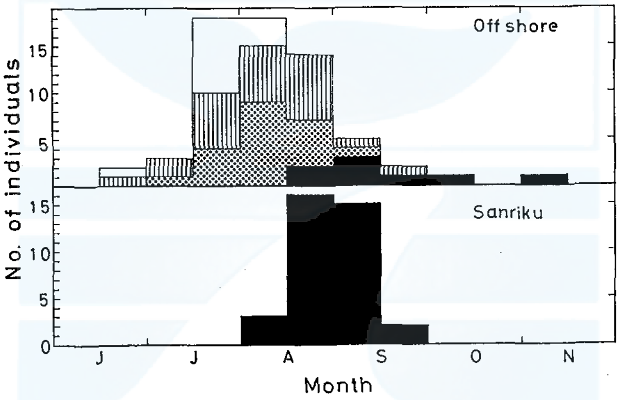

Fig. 19. Frequency of the date of birth calculated from the mean fetal growth curve and fetal length in the catch by salmon gillnet fishery in the western Bering Sea and northwestern North Pacific (Top), and that in the catch of harpoon fishing off Sanriku coast (bottom, based on fetuses). For the offshore stock, white square indicate 12 infants in Mizue *et al.* (1966), square with lines 24 fetuses in the same study, dotted square 20 fetuses provided by A. Takemura, and black square 8 fetuses in Koga (1969).

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The mating season is not precisely known for the stock off the Pacific coast of Japan, because of the restricted fishing season and of the inaccuracy of the estimation of the fetal growth in the early pregnancy. However, rough estimation of the range of the season is made by moving the fetal growth curve back and forth. Then, the mating season from middle August to late October with a peak in September is estimated. Possibly this is consistent with the fact that the development of the follicles in the ovary of immature female starts in March (Fig. 20). On the Sea of Japan-Okhotsk Sea population, the occurrence of small embryos in August was confirmed by Okada and Hayashi (1951) and that in September by myself. Accordingly it is reasonable to expect that the mating season and probably the parturition season of the population is not different from those of the stock off the Pacific coast of Japan. At present there is no data to consider that the mating season of the stock in the western Bering Sea and northwestern North Pacific is different from that of two other populations dealt in this study. The concentrated unimodal breeding season of the species is different from the pattern found in the tropical or subtropical species, but seems to be common in all the boreal delphinids (Kasuya 1972).

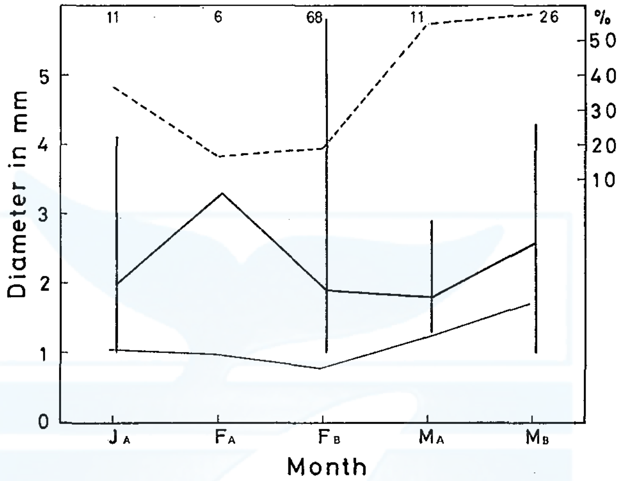

Fig. 20. Seasonal change of the diameters of the largest follicle in the ovaries of immature females off Sanriku coast. Dotted line and right scale indicate the ratio of the females with measurable follicle (≧1 mm), thick solid line the mean diameter and the range of the largest follicles in those individuals, and thin solid line the mean of all the immature females calculated assuming 0.5 mm for the unmeasurable follicles. The suffix A attached to the month indicates from the 1st to 15th of the month, B from 16th to the end, and numerals the sample size.

Sex ratio

Of the 39 fetuses from the Sanriku coast, 21 fetuses or 53.8% of the total were represented by the female. The records of 51 fetuses of the stock in the western Bering Sea and northwestern North Pacific were compiled from 24 fetuses in Mizue *et al.* (1966), 8 fetuses in Koga (1969), and 19 fetuses provided by A. Takemura. They contained 33 females or 64.7% of the total. Though these data suggest the slight excess of the female fetus in the two populations of the Dall's porpoise, further study is needed for the conclusion.

The overall sex ratio of the postnatal individuals seems to be even in the 290 samples captured by the salmon gillnet fishery in the western Bering Sea and northwestern North Pacific (Table 13). However, as shown in Table 14, the feature is slightly complicated in the catch by harpoon fishing off Sanriku coast, if analysed by the season and maturity. The maturity of most of the males was

TABLE 13. SEX RATIO AND MATURITY RATE OF *PHOCOENOIDES* CAUGHT BY SALMON GILLNET IN THE N.W.N. PACIFIC AND W. BERING SEA

Author		1	2	3	Total
Sex ratio[4]					
Adult	N	34	—	—	34
	%	58.8	—	—	58.8
Immature	N	73	—	—	73
	%	42.9	—	—	42.9
Total	N	107	148	35	290
	%	49.5	54.1	40.0	50.7
Maturity[5]					
Male	N	54	—	—	54
	%	25.9	—	—	16.7
Female	N	53	60	14	127
	%	37.7	43.3	57.1	42.5

1) Provided by Takemura, 2) Mizue *et al.* 1966, 3) Koga 1969, 4) Ratio of females, 5) Testes exceeding 150 g in combined weight are dealt as mature.

TABLE 14. SEX RATIO AND MATURITY RATE OF *PHOCOENOIDES* CAUGHT BY THE HARPOON FISHING OFF SANRIKU COAST[1]

Month		Jan.	Feb.		Mar.		Apr.	Total
		B	A	B	A	B	B	
Sex ratio[2]								
Adult	N	44	53	69	35	24	4	229
	%	63.6	49.1	62.3	74.3	66.7	0.0	60.7
Immature	N	108	111	237	90	105	5	656
	%	25.9	29.7	43.0	41.1	57.1	0.0	39.6
Total	N	222	186	488	135	145	9	1,081
	%	33.8	32.8	46.5	51.1	60.7	0.0	43.8
Maturity								
Male	N	96	105	161	62	53	9	486
	%	16.7	25.7	16.1	14.5	15.1	44.4	18.5
Female	N	56	59	145	63	76	0	399
	%	50.0	44.1	29.7	41.3	21.1	—	34.8

A, 1st to 15th. B, 16th to the end of month. 1) Based on body length when genital organ is not studied. 2) Ratio of females.

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identified by the histological examination of the testis, however the males with a testis weighing 29.4 g or more were considered as sexually mature when the testis was " maturing " or testis was not examined histologically. The maturity of some other males was classified by the body length (196 cm or more into the mature). The females measuring 187 cm or more were considered as sexually mature, when the reproductive tract was not examined.

The ratio of females in the immature individuals shows an increase from 26% in late January to 57% in late March. The age classes producing such a seasonal fluctuation is from 4.5 to 7.5 years of age, namely the individuals after the com-

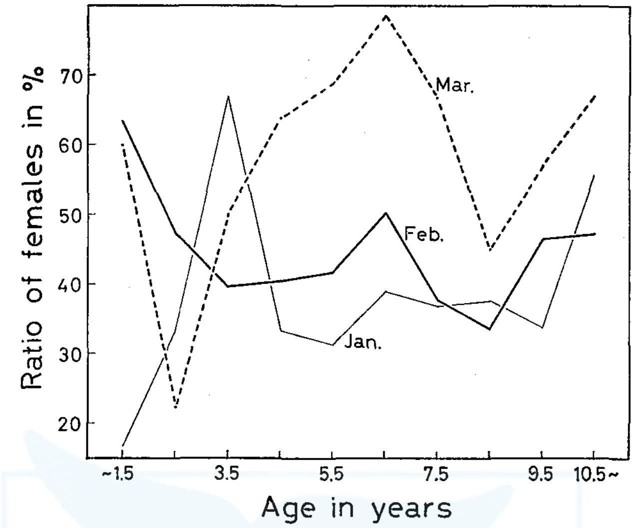

Fig. 21. *Phocoenoides* off Sanriku coast, seasonal change of the sex ratio.

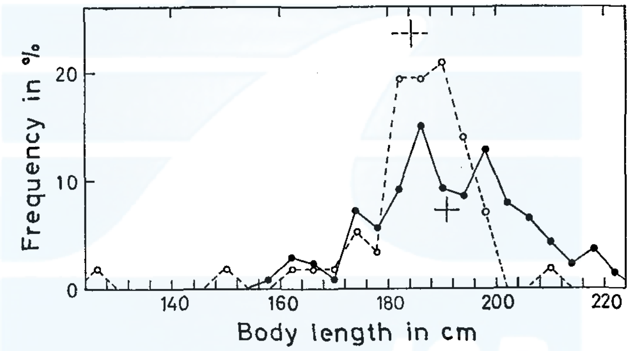

Fig. 22. Body length frequency of *Phocoenoides* caught by the harpoon fishery off Tajima coast compiled from Noguchi (1946). Closed circle and solid line indicate male (n=140), and open circle and dotted line female (n=57). Mean body length and the range of two standard errors are indicated.

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pletion of weaning and before the attainment of sexual maturity (Fig. 21). The decline of the female ratio at the ages of 7.5 and 8.5 years will have a relationship with the fact that the females attain the sexual maturity about one year earlier than the male and the sexually mature individuals are underrepresented in the catch of harpoon fishing. In the adult individuals the number of the females exceeds that of the males in all the months studied. Though the trend of seasonal change of the sex ratio is same with the immature individuals, the seasonal difference is much smaller.

Noguchi (1946) provided the body length measurements of 197 Dall's porpoises caught by the harpoon fishing off Tajima coast (southern Sea of Japan). There is some question if the length was measured by the same way used in this study because both the modal and mean lengths are about 5 cm larger than the present materials collected off the Pacific coast of Japan (Fig. 22). The date of the catch is somewhere between the middle of March and middle of May. The overall sex ratio is so low as 28.9%, and if the maturity is estimated based on the body length criteria obtained in this study, the ratio of the females in the immature individuals is 26.5% (n=117) and that in the mature 32.5% (n=80).

Maturity rate

The ratio of sexually mature individuals in the catch off Sanriku coast is shown in Table 14. The maturity of some individuals is identified by the body length. The ratio shows, in both sexes, a gradual decrease from late January to late March. The change is more conspicuous in the female, and the maturity rate of the sex in late March is about a half of that in late January.

This result, together with the seasonal change of the sex ratio discussed above, indicates the presence of the segregation by the sex and maturity. The immature individuals seem to have tendency to arrive fishing ground off Sanriku coast after the adult individuals. This tendency is much clear in females than in males.

Reproductive cycle

Since the length of gestation is estimated in the former section as 11.4 months, the lengths of lactation and resting period are estimated in this section. The number of females at each reproductive stage in the catch off Sanriku coast is shown in Table 15. Though the stages were decided through the observation of the reproductive tracts, there are many adult females which reproductive stages were not decided obstacled by the removal of the internal organs. Since they, 34 individuals, were not lactating, they should have been classified into pregnant or resting females. Then the more correct estimates of the pregnant and resting females can be from 58 to 92 and 2 to 36 individuals respectively. If the sample correctly represents the ratio in the population and the length of gestation is 11.4

TABLE 15. RERPODUCTIVE STAGES OF ADULT FEMALES OF *PHOCOENOIDES*[1)]

Locality	Season	Preg.	P. & L.	Lact.	Rest.	Unknown
Sanriku	Jan. B	22	1	0	0	2
	Feb. A	3	0	0	0	6
	Feb. B	9	0	3	2	22
	Mar. A	15	4	3	0	3
	Mar. B	9	0	0	0	1
	Total	58	5	6	2	34
N.W.N. Pacific & W. Bering Sea	1	20	0	0	0	0
	2	24	0	1	1	0
	3	8	0	0	0	0
	Total	52	0	1	1	0

1) For abbreviations see Tables 13 and 14.

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months, the mean length of a reproductive stage in months is given by

$$X \cdot 11.4/P$$

where P indicates the number of pregnant females, and X the number of females at one of the reproductive stages.

Above calculation gives the following estimation for the stock off the Pacific coast of Japan.

Simple pregnancy	10.50—10.81 months
Overlapping of pregnancy and lactation	0.90— 0.59 months
Simple lactation	1.09— 0.71 months
Resting	6.51— 0.24 months
Total	19.00—12.35 months

The mean length of calving interval is from 1.0 year to 1.6 years. Though this is extremely short, the cycle is not impossible, if most of the females are conceived in the summer of the parturition. However, the most improbable is the shortness of the lactating period. The overall period of lactation obtained above is only from 1.3 months to 2.0 months. Generally speaking the lactation of the odontoceti last at least for about one year (Brodie 1969, Kasuya 1976a, Perrin *et al.* 1976). It is reasonable to consider, apart from the underrepresentation of the adult individuals, that the lactating females are underrepresented in comparison with the pregnant and resting females.

This is indirectly indicated by the body length frequencies (Fig. 6), where the individuals smaller than 172 cm is scarce and those smaller than 156 cm is almost entirely lacking. The former length corresponds to the age of about 1.5 years on the mean growth curve, and the latter to that of about 0.5 year. Similar

TABLE 16. ESTIMATION OF NURSING PERIOD OF *PHOCOENOIDES* OFF SANRIKU COAST

Age (yrs)	Annual mortality rate			0	0.1	0.15
	No. weaned individuals			Weaning /year	Weaning /year	Weaning /year
	♂	♀	Total			
0.	0	0	0			
0.25				5	5	5
0.5	3	2	5			
1.0				39	39.50	39.75
1.5	18	26	44			
2.0				13	17.40	19.60
2.5	34	23	57			
3.0				21	26.70	29.55
3.5	44	34	78			
4.0				1	8.80	12.70
4.5	45	34	79			
Mean weaning age	—	—	—	1.69	1.96	2.06
Standard error	—	—	—	0.11	0.11	0.11

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feature is seen in the catch by harpoon fishing in the southern Sea of Japan studied by Noguchi (1946). In his data the number of individuals under 172 cm is only 14 or 7.1% of the total. The absence of the juveniles does not seem, as mentioned in the latter section, to be a result of the size selection of harpoon fishermen. It is most reasonable to consider that suckling calf and nursing cow are not effectively captured by the harpoon fishing. In the other words, the gradual increase of the catch of calves at the age from 0.5 to 4.5 years will be related with the completion of weaning. As shown in Table 16, such probably weaned individuals start to appear before the age of 0.5 years and cease at 4.0 years of age, and when the sexes are combined the number is hightest between the ages of 0.5 and 1.5 years. Though another interpretation is discussed at the end of this section, this is an estimation of the range of the weaning age. For the correct estimation of the mean age at weaning, the mortality of weaned calves needs to be considered. When n_x indicates the apparent number of calves weaned at the age x, N_x the number of calves weaned at the age x and corrected for the mortality, and M the annual total mortality rate of the weaned calves, there can be the following approximation.

$$N_x = n_{x+0.5} - (1-M) \cdot n_{x-0.5}$$

Defining the age x as the mean age of the calves which have weaned between x −0.5 and x +0.5 years of age, and assuming the total mortality rate of 0, 0.1, and 0.15. The estimates of the mean age at weaning 1.69, 1.96, and 2.06 are obtained. Though the estimation of the mortality rate at these age classes is difficult, the first assumption is without doubt an underestimate and the last possibly an overestimate.

The above calculation is affected by two kinds of biases. The first is the possible inclusion of some sucklings as indicated by the presence in the catch, of 11 females lactating or lactating and simultaneously pregnant. Possibly at least some of the five individuals dealt, in the above calculation, as weaned by the age of 0.5 year could still being nursed. This bias causes the underestimation of the weaning age. If the youngest 11 calves, the number of lactating females, are excluded, the above calculation gives the mean age of 2.07 years (M=0.10). The other bias is caused by the time lag between the end of lactation and the start of the independent life of the calf. As reasonably expected, if the weaned calves stay by the mother for a considerable length of time and protected from the fishery, the above estimation can be higher than the true weaning age. In case of *Stenella coeruleoalba* off the Pacific coast of Japan, the weaned calves are considered to stay in the nursing school for about 1.5 years in the average (Miyazaki 1977b). However, this will not necessarily mean that the weaned calves of *S. coeruleoalba* accompany the mothers. Since the school size of *Phocoenoides* is usually so small as 2 or 3 individuals, there is not expected such a developed social behavior as observed in *S. coeruleoalba*, and the seasonally restricted breeding season of the present species will help the rapid recombination of the school member. Therefore the time lag in the present species will not be so large as in *S. coeruleoalba*. As the conclusion, because the two kinds of biases must exist at the unknown degrees, it will be safe to say that the length of lactation of *Phocoenoides* off the Pacific coast of Japan have the variation from 0.5 year to 3.5 years with the possible average of about 2 years. Further study is needed for the better estimation.

Though the mean length of the resting period, 0.24 to 6.51 months estimated from the ratio of the number of resting females to that of pregnant females, is within the reasonable range, the accuracy is insufficient. The fact that the lactating females and females pregnant and simultaneously lactating are caught in the later part of the fishing season suggests that these females would have been near the end of lactation and weaning peak will exist in between February and the peak of the next mating season in September (Table 15).

The mean calving interval of the species off the Pacific coast of Japan is not precisely estimated. If the above estimation of the lengths of lactation and of resting period is correct, the mean calving interval will be between $(11.4+24+0.24)/12=3.0$ years and $(11.4+24+6.51)/12=3.5$ years. Another estimation is made by assuming that the calves are usually separated from the mother when the mother starts the next gestation. This means, in other words, that the length of lactation estimated above is the sum of the lactating and resting periods. Then the claving interval can be $(11.4+24)/12=3.0$ years. However, since such a detailed discussions are impractical at present, it will be possible only to say that the mean calving interval is approximately about 3 years.

The frequency of reproductive stages of the females caught by the salmon gillnet fishery in the western Bering Sea and northwestern North Pacific was calculated from the published and unpublished data (Table 15). The scarcity of lactating or resting females is similar to the catch by harpoon fishing off Sanriku coast. However, the capture of many calves smaller than 130 cm presumably born within 1 year (one in Takemura's sample and 19 in Mizue *et al.* 1966) indicates the presence of many lactating females in the population. Possibly the lactating females are underrepresented in the catch compared with the catch of the pregnant females. At present there is no exact way of estimating the reproductive cycle of the females in the stock, however an attempt is made in Addendum.

Accumulation rate of corpora in the ovaries

Table 17 shows the relationship between the age and the reproductive stages of the females off Sanriku coast. The age compositions of the lactating and resting females, which are few in number, are same with that of pregnant individuals. The frequency of the corpora number shown in Table 18 indicates, together with Table 17, that most of the adult females caught by the fishery are very young with only 1 or 2 ovulations. Possibly, most of the catch of the adult individuals are before the first conception, in their first gestation, or in the lactation followed by the first parturition. If all the 19 pregnant females which have 1 to 3 corpora are considered as being in their first gestation, the mean number of ovulations experienced before the first conception is 1.3. This is close to the figure 1.67 estimated by the same method for an exploited population of *Globicephala melaena* (Sergeant

TABLE 17. RELATIONSHIP BETWEEN AGE AND REPRODUCTIVE STAGES OF FEMALE *PHOCOENOIDES* OFF SANRIKU COAST

Age (yrs)	Immat.	Mature				
		Preg.	P. & L.	Lact.	Rest.	Total[1]
2.5	17	0	0	0	0	1
3.5	25	1	0	0	0	5
4.5	21	2	0	1	0	7
5.5	18	4	0	0	0	7
6.5	11	16	0	0	0	20
7.5	8	1	2	1	1	8
8.5	2	5	0	2	0	8
9.5	5	4	0	0	0	6
10.5	3	1	0	0	0	1
11.5	2	1	0	0	0	1
12.5	0	1	0	0	0	1
13.5	0	0	1	0	0	2
14.5	0	0	1	0	0	1
15.5	0	0	0	0	0	3
16.5	0	1	0	0	0	1

1) Adults of unknown reproductive stage included.

TABLE 18. RELATIONSHIP BETWEEN NO. OF OVULATIONS AND REPRODUCTIVE STAGES IN ADULT *PHOCOENOIDES* OFF SANRIKU COAST

No. corpora	Preg.	P. & L.	Lact.	Rest.
1	14	0	0	1
2	4	0	1	0
3	1	0	0	0
9	1	0	0	0
Total[1]	58	5	6	2

1) Individuals of unknown corpora number included.

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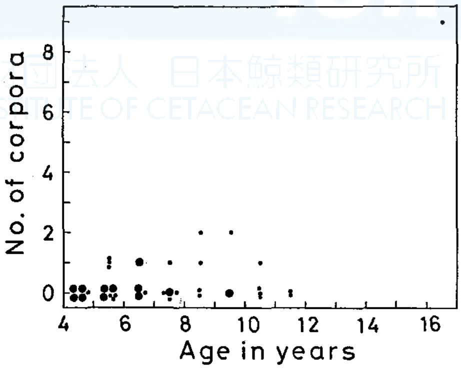

Fig. 23. Scatter plot of the number of copora in the ovaries on age, *Phocoenoides* off Sanriku coast. Large circle indicates 5 individuals, and the small one.

1962), but significantly smaller than the figure 2.08 of an almost unexploited population of *Stenella attenuata* (Kasuya *et al.* 1974).

The scatter plot of the ovulation number on age is shown in Fig. 23. The data is insufficient to estimate the mean annual ovulation rate. The rough estimate of the range is given as from (9−1)/(16.5−5.5)=0.73 to (9−1)/(16.5−11.5)=1.6 per year.

Regression of corpora diameter

The diameters of 20 corpora lutea of pregnancy ranged from 17.2 mm to 24.6 mm, and the mean was 21.7 mm. No accessory corpus luteum was observed. The size distribution of the corpora albicantia of 10 adult females is shown in Fig. 24. There is a group in the size of corpus at the diameter of 6 mm to 8 mm. It is represented by the female nos. 3, 4, 5, 6, 8, caught in the winter season off the Pacific coast of Japan. Since the pregnant individuals are considered to be in their first gestation, these corpora are thought as the corpora of the ovulations in the last summer, namely about 0.5 year after the ovulation or the parturition (no. 3). The larger corpora albicantia of the no. 2 resting female caught in July in the southern Okhotsk Sea are suspected as those of the ovulation in the summer of the capture. The corpus albicans of the no. 1 resting female is considered as derived from the ovulation occurred after the last mating season. Other corpora ablicantia possibly regressed for 1 or more years.

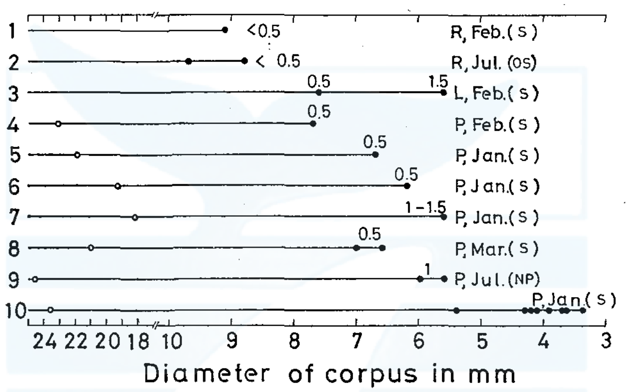

Fig. 24. Distribution of the diameter of corpus luteum (open circle) and of corpus albicans (closed circle). Reproductive stages (R: resting, L: lactating, P: pregnant), Date of catch and location (OS: southern Okhotsk Sea, NP: northwestern North Pacific, S: off Sanriku coast) are indicated. The numerals by the circle indicate the approximate time after the start of regression.

DISCUSSION

The assuption of the nonrandom catch is an important factor in the present study of the life history parameters of the Dall's porpoise. The discussion is made at first step on this problem, then on the segregation of the species and the rates of mortality and recruitment.

The underrepresentation of suckling calves

The scarcity of the juvenile calves at the suckling age is a peculiar feature of the catch by the harpoon fishing off Sanriku coast and in the southern Sea of Japan studied by Noguchi (1946). This is not observed in the incidental catch by the salmon gillnet fishery in the western Bering Sea and northwestern North Pacific. As the cause of this age structure, there can be the following three possibilities.

1. The selection by the fishermen, who generally hopes to get larger individuals.
2. The recent decrease of the recruitment.
3. The scarcity of the cows and suckling calves in the fishing ground, which is caused by the segregation of those individuals.
4. The technical inability of taking the suckling calves.

The first may exist in some degree, because the catch is sold by the weight of the carcass weighed after removing the viscera. However, the effect seems to be almost negligible when the condition of the fishery is considered. Usually the fishing vessels on Sanriku coast arrive at 7 to 8 o'clock at the fishing ground, 10 to 40 or 50 nautical miles (18 to 80 km) off the coast, and search and harpoon the porpoises until 14 to 15 o'clock to return to the port by the evening. Two or less number of porpoises are usually caught from one school. The mean daily catch is only 4 to 6 individuals per ship even when the boats which come back without catch are excluded (Kasuya 1976b). Furthermore, since the porpoises quickly swim around the bow of the boat, there is little chance for 1 to 3 harpooners on the bow to select large individual. If the first hypothesis is correct and the other 3 hypotheses are wrong, there must be more catch of lactating females, because the mean lengths of lactation in odontoceti are at least about 1 year (page 39) and the number of lactating females in a population is expected to be nearly equal to or more than that of pregnant females.

The 2nd hypothesis will be safely denied. Since the exploitation of the Japanese east coast population has continued for more than 30 years and there is detected no indication of the rapid decrease of the population density (Kasuya 1976b), it is difficult to expect a rapid decrease of the recruitment in recent few years.

The 3rd hypothesis will not be denied at present, when it is considered that there is expected a segregation of pregnant females with near term fetus in the summering ground of the offshore stock in the western Bering Sea and northwestern North Pacific, and that the individuals of the Japanese east coast population shows a segregation by the maturity and sex. Further study is needed for the confirmation of segregation of lactating females.

The 4th hypothesis implies that the suckling calves accompanying the mothers migrate to the fishing ground, but are not captured by some ecological or technical reasons. Because the fishermen harpoon only the porpoises riding the bow wave, the above age composition will occur if the mother and calf are less attracted by the boat compared to the weaned juveniles. Actually it is well known that there exist many schools which do not approach the bow of the boat even when fisherwen try to let them do so. According to the personal communication of Mr K. Sasaki, a porpoise hunter, and to my own observations on board of the porpoise hunting boat and on the research vessels, the number of such schools is slightly more than half of the total number of *Phocoenoides* schools sighted. Mr Sasaki tells that even when a school comes to the bow of the ship the presumable mother accompanied by a calf and the very large individuals stay only for a short length of time or stay far from the ship, however, the individuals of the medium size play on the bow wave longer and are the easiest to catch. This is the reason why I consider the 4th hypothesis most probable as the explanation of the scarcity of calves at the suckling age. Therefore the underrepresentation of the calves at the suckling age will be fundamentally ascribed to the behavior of the lactating females discussed in the next section.

The underrepresentation of adult individuals

In the former section, it is shown that the number of adult individuals is scarce, in both sexes, in the catch by harpoon fishing. The analyses of age and of the corpora number in the ovaries of the catch off Sanriku coast suggest that only 6 females have presumably experienced the 2nd gestation and 42 adult females are probably before the 2nd gestation. This could be explained by one of the following two hypotheses.

5. The mortality is high in the population.
6. The older individuals are not captured by the harpoon fishing.

The instantaneous annual total mortality rates of the Dall's porpoise off Sanriku coast tentatively calculated from the right side slope in the age frequencies are as follows.

Male : 0.2185, between 4.5 and 9.5 years of age.
Female : 0.3356, between 6.5 and 10.5 years of age.

As the lactating females are underrepresented in comparison with the pregnant females (page 39), the apparent mortality rate of the females can be expressed slightly higher. If the total mortality rate of the female, M, is same for all the age classes, there can be the following equations, where S_1

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$$S_1 = l_0 \int_0^7 e^{-Mx} dx$$

$$S_2 = l_0 \int_7^{\infty} e^{-Mx} dx$$

$$A = \frac{S_2}{S_1 + S_2}$$

indicates the number of immature females, S_2 that of adult females, l_0 number of females at the age 0, and A the ratio of adult females in the total female population. When 0.2185 the lower figure is taken for M, A is 21.7%. Assuming the sex ratio at birth as 1 : 1, and the length of mean calving interval as 2 years the possible shortest, or 3 years the more reasonable estimate obtained in this study, the gross annual recruitment rate of 5.43% or 3.62% is obtained. Whereas the total annual mortality rate is $(1-e^{-0.2185})\cdot 100=19.6\%$. Accordingly, if there is no bias in the catch, the population must decrease at the rate of about 15% per year. However, the exploitation of the population have continued at least for 13 years at the level of about 6,000 individuals per year (Addendum Table of Kasuya 1976b), and there is detected no indication of rapid decrease of the stock. If the population really decreased at the rate of 15% per year, the stock should have decreased in the 13 years to 12% of the level in 1963. Such a large decrease must have resulted in the decrease of the annual catch and that of the mean daily catch per boat. This is the reason why I consider the 5th hypothesis incorrect.

The indication suggesting the correctness of the 6th hypothesis is obtained by the comparison of the age compositions of *Stenella coeruleoalba* caught by the driving method and by harpoon fishing. The ages were determined based on the dentinal growth layers in case of the individuals younger than 10 to 15 layers, but based on the cemental layers in older individuals (Kasuya 1976a). The age frequencies of 29 males and 35 females in the catch by harpoon fishing were obtained off Taiji (33°35′N, 135°57′E) in the winter of 1971, where the harpoon fishing was operated only for two or three years until the driving fishery of the species started. All the 1388 (564 females and 824 males) samples by driving fishery were obtained off the east coast of Izu Peninsula (34°56′N, 139°09′E) and randomly collected by myself or by Kasuya and N. Miyazaki. They are the catch of following 7 drivings, where only the numbers of the aged individuals are listed. The maturity of the female was decided by the presence of corpus in the ovary and that of the male by the weight of testis (smaller than 15 g immature).

Driving 22: 14, Dec., 1971. Immature school. 62 females (2 to 8 layers, adult absent) and 218 males (2 to 12 layers, adults 2.8%).
Driving 38: 17, Nov., 1972. Nursing school. 101 females (1 to 49 layers, adults 77.0%) and 52 males (1 to 20 layers, adults 53.8%).
Driving 43: 15, Nov., 1973. Nursing school. 89 females (1 to 40 layers, adults 58.1%) and 135 males (1 to 31 layers, adults 62.4%).
Driving 44: 20, Nov., 1973. Nursing school. 111 females (0 to 43 layers, adults 66.7%) and 111 males (1 to 58 layers, adults 68.5%).
Driving 45 and 46: 23 and 24, Nov., 1975. Probably nursing schools, mixed in the harbor. 170 females (0 to 58 layers, adults 59.9%) and 192 males (0 to 58 layers, adults 60.4%).
Driving 47: 3, Nov., 1976. Males dominant. 31 females (2 to 26 layers, adults 29.0%) and 116 males (3 to 46 layers, adults 69.8%).

The fishing grounds of the two fisheries are separated only about 330 km, and considered as being migrated by a single population (Miyazaki *et al.* 1974, Kasuya 1976c). Though the between schools differences of the age composition and of the sex ratio are not small, the population structure will be roughly estimated by combining the 7 schools. The ratio of sexually mature individudals is 55.7%

of the 553 maturity and age known females caught by the driving, and 47.4% of the 816 males. On the other hand, when all the maturity known individuals are included (40 females and 42 males), the corresponding figures of the harpoon fishing are so low as 17.5% and 9.5% respectively, These figures are similar to those of *Phocoenoides* caught by the harpoon fishing both in the amplitude and in the between sexes difference. The bias of the fishing methods is demonstrated more tipically in the age frequencies of Fig. 25. If the instantaneous total mortality rate is calculated from right side slope of the age frequencies of the catch by the driving fishery, the following figures are obtained.

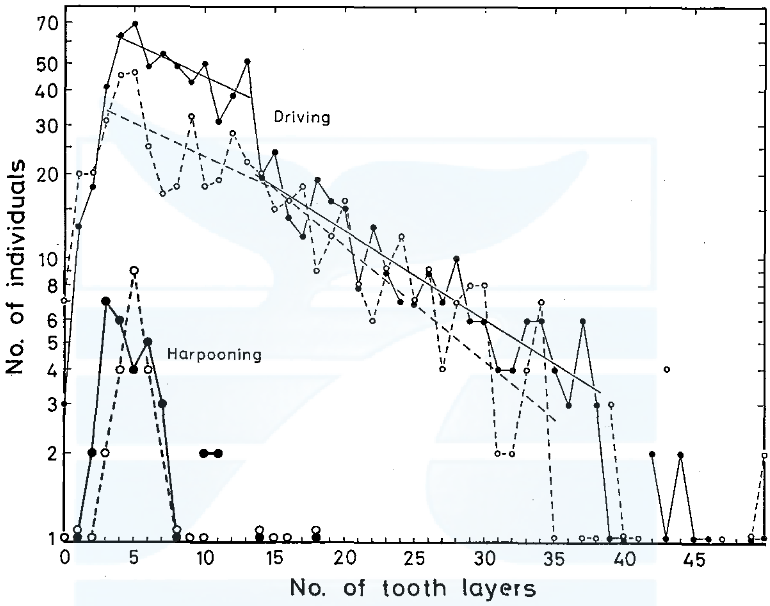

Fig. 25. *Stenella coeruleoalba* off the Pacific coast of Japan, age frequencies of the catch by driving fishery (small circles and thin lines) and that by harpoon fishery (large circles and thick lines). Closed circle and solid line indicate male, and open circle and dotted line female.

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Female: 0.0537, 3 to 14 layers
0.0944, 15 to 35 layers
Male : 0.0529, 4 to 13 layers
0.0726, 14 to 38 layers

When the instantaneous natural mortality rate of the adult female is assumed as 0.06 or 0.07 (Kasuya and Miyazaki 1976), the fishing mortality rate of from 0.0244 to 0.0344 is estimated, and then the natural mortality rate of the females before the maturation 0.0193 to 0.0293. The left side slope of the age frequency of the catch by driving fishery seems to be caused by the loss of juvenile calves (Kasuya 1972) and by the segregation of the immature individuals. Especially the inclusion of the data of the immature school, driving no. 22, causes the high frequency of the juvenile females of the ages between 3 and 6 layers and males between 3 and 10 layers.

Though the above age frequency of the catch by the driving are extremely different from the age structure of *Phocoenoides* off Sanriku coast, that of the *Stenella coeruleoalba* caught by the harpoon fishing is similar to the latter in the predominance of the individuals below 9 years of age, the mean age at the attainment of sexual maturity (Kasuya 1972, Miyazaki 1977a).

From these reasons I consider that the 6th hypothesis will be close to the truth. Though the possibility of the segregation is not perfectly denied, it seems to be more reasonable to consider that the Dall's porpoise, as well as the striped dolphin, becomes less attracted by the bow wave of the ship or becomes more cautious of danger soon after the onset of sexual maturity. This change of the behavior has a effect to lower the fishing mortality rates of the adults and suckling calves accompanying the mother. The underrepresentation of the lactating females (page 39) will be explained by the enhancement of the behavior during the lactation in relation to the limited swimming ability of infant, or by a simple fact that lactating females are generally older than the pregnant. The possibility of the segregation of the lactating females is still left to be studied.

The discussions on the age structure of the Dall's porpoise incidentally captured by the salmon gillnet fishery is made in Addendum.

Segregation by age and maturity

In the former sections, the following phenomena are indicated through the analyses of the catch by harpoon fishing off Sanriku coast.

1. In the adult, the female ratio is high and stable throughout the season.
2. In the immature, the ratio of females is low, but increases from late January to late March.
3. In the male, the ratio of the adult is low, and changes little.
4. In the female, the ratio of the adult is high, but decreases from late January to late March.

The different analysis of the same material is shown in Table 19, where the seasonal increase of the ratio of the immature females is clearly demonstrated. These seasonal fluctuations of the composition are difficult to be explained by the catch bias of the fishing, but is reasonable to be considered that the migration of the immature individuals, especially of the female, increases from January to March.

Kasuya (1976b) showed on the catch of the species off Sanriku coast that the catch per day's work of the harpoon fishing boat has a peak in April when the value is about twice of that in January, and concluded that the fishing season closes in April, by the decrease of the demand of the porpoise meat and the migration of other profitable fishing objects, before the peak of the north bound migration of the species. The seasonal change of the catch per fishing boat described by Kasuya (1976b) will indicate, in a strict sence, that of the abundance of the young exploitable age classes, and coincides well with the above feature of the seasonal

TABLE 19. COMPOSITION OF *PHOCOENOIDES* CATCH OFF SANRIKU COAST, SHOWN BY SEX AND SEASON

Sex and Maturity[1]		Jan.	Feb.		Mar.		Apr.	Total
		B	A	B	A	B	B	
Males								
Adult	no.	16	27	26	9	8	4	90
	%	10.5	16.5	8.5	7.2	6.2	44.4	10.2
Immature	no.	80	78	135	53	45	5	396
	%	52.7	47.5	44.1	42.4	39.4	55.6	44.8
Total	no.	96	105	161[2]	62	53	9	486
	%	63.2	64.0	52.6	49.6	45.6	100	55.0
Females								
Adult	no.	28	26	43	26	16	0	139
	%	18.4	15.9	14.1	20.8	12.4	0	15.7
Immature	no.	28	33	102	37	60	0	260
	%	18.4	20.1	33.1	29.6	46.5	0	29.4
Total	no.	56	59	145	63	76	0	399
	%	36.8	36.0	47.4	50.4	58.9	0	45.1
Grand total	no.	152	164	306	125	129	9	885
	%	100	100	100	100	100	100	100

1) Based on body length when genital organ is not studied.
2) One length unknown individual included. For abbreviations see Table 1.

change of the catch composition.

In the Japanese coastal waters the Dall's porpoise is distributed mainly in the waters north of the 17°C isothermal line, and in the waters above this surface water temperature the temperate and subtropical dolphins are dominant (Kasuya 1976b). The 17°C isothermal line moves seasonally from southernmost point at 35°N in February to the northernmost point of 42°N in August along the Pacific coast of Japan (Fig. 26). The surface water temperature at the fishing ground is lowest in February, and it becomes gradually higher in March and April. They will offer a suggestion on the seasonal change of the distribution of the species off the Pacific coast of Japan.

Other indication of the seasonal migration of the population is found in the sighting records of dolphins (Kasuya and Miyazaki 1976b, Kasuya unpub.). The Dall's porpoise arrives off Sanriku coast (38°N to 41°N) in September, but it does not arrive south of 37°N in November. The observation outside of the fishing ground in winter is lacking. In May there migrate many *Lagenorhynchus obliquidens* and few *Grampus griseus* and *Orcinus orca* off Sanriku coast, but there are still found many *Phocoenoides*. The southern limit of *Phocoenoides* in this month is approximately at 37°N on the Pacific coast of Japan, and *Lagenorhynchus* is recorded between 36°N and 42°N. In June *Phocoenoides* retreat to 38°30′ and *Orcinus, Grampus*, and *Globicephala* are recorded south of 39°30′N. However, no Dall's porpoise is recorded south of 42°N in July in spite of the presence of *Lagenorhynchus*, *Orcinus*, *Grampus*, *Delphinus*, and *Tursiops* in the area. The facts that the southernmost sightings of *Phocoenoides* were made in May at about 37°N and that the catch of the species could not be comfirmed at Choshi fish market situating at 35°45′N (Kasuya 1976b) suggest that the southern limit of the ordinary distribution of the species in winter season will be about 36°N in the Pacific coast of Japan.

Possibly the species will arrive at the southernmost range in early February, and be followed by the retreat to the north in February through August. Accordingly the start of the fishing season in the last decade of January coincides nearly with the end of the southbound migration and the begining of northbound migration. The seasonal change of the ratio of the immature females suggests that these individuals migrate to the Pacific coast of Japan earlier than the adults and possibly spend the winter in the southern waters. The adult females, on the other hand, will arrive later and stay in the northern region. The males, possibly the adult too, seems to winter in the further south near the southern limit of the distribution. This is suggested from the catch off Sanriku coast in April (Table 14) and from the catch off Tajima coast studied by Noguchi (1946). The porpoise hunting off Tajima coast (southern Sea of Japan) was operated from late March to early June, and the catch of *Phocoenoides* was replaced in late April by *Lagenorhynchus* the temperate species. Namely the hunting was operated near the southern limit of the dis-

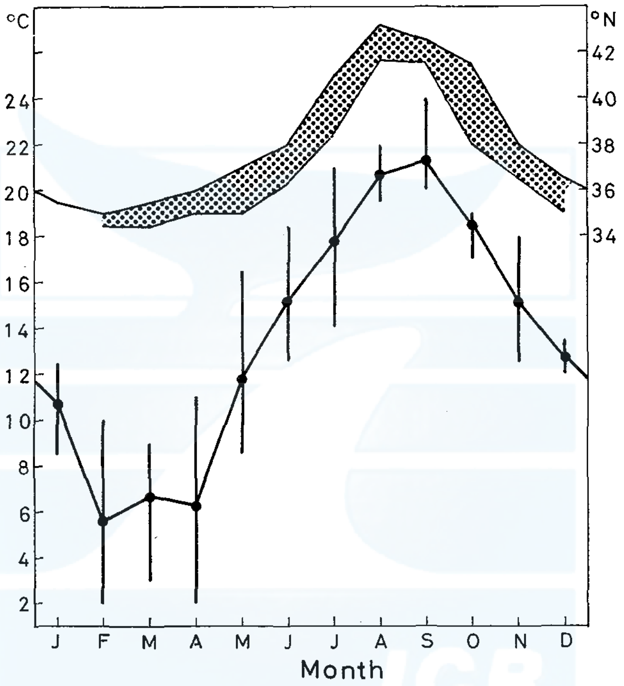

Fig. 26. Surface water temperature off the Pacific coast of Japan. Closed circle and solid line the range and mean at 39°30′N, 142°30′E off Sanriku coast in the five years from 1972 to 1976, and the dotted area the range of the latitude of the 17°C isothermal line at 20 to 30 nautical miles off the coast in the same period (data based on Anon. 1972–1976).

tribution of the stock in the season. If the maturity is determined by the body length there are 140 males of 54 adults and 86 immatures, and 57 females of 26 adults and 31 immatures. The ratio of the males is 71.1% and the maturity rate is 38.6%, and both of these figures are higher than those off Sanriku coast. The maturity rate of the female is similar to the catch off Sanriku coast.

The tendency of the immature individuals being distributed near the southern periphery of the wintering ground seems to exist even in the stock in the northwestern North Pacific and western Bering Sea. This is suspected from the fact that the ratio of *dalli*-type is higher in the juveniles in the catch off Sanriku coast (page 10).

Rates of mortality and reproduction

The total mortality rate of the male at the pubertal ages was estimated as 0.102 in instantaneous rate or 9.7% per year (page 27). However the accuracy of the estimation is doubtful, because it is based on the age frequency of the restricted age classes and limited number of samples. The annual changes of the population structure and of the timing of migration and sampling will cause the bias of unknown degree. The following mathematical approach is made in order to have a suggestion on the possible range of these parameters.

When the abbreviations are defined as follows,

M_1, M_2, M_3: Instantaneous natural mortality rate at the ages between 0 and 2 years, 2 and 7 years, and above 7 years respectively.
F_1, F_2, F_3: Instantaneous fishing mortality rates of the above age groups.
S_1, S_2, S_3: Number of females of the above three age groups.
R: Ratio of females at birth, assumed as 0.5.
C: Calving interval, assumed as 2 or 3 years.

the number of females at each age groups in a stational population is shown by the following approximations.

$$S_1 = l_0 \int_0^2 e^{-(M_1+F_1)x} dx$$

$$S_2 = l_0 \cdot e^{-2(M_1+F_1)} \int_0^5 e^{-M_2+F_2)x} dx$$

$$S_3 = l_0 \cdot e^{-2(M_1+F_1)} \cdot e^{-5(M_2+F_2)} \int_0^\infty e^{-(M_3+F_3)x} dx$$

$$l_0 = S_3 \cdot R/C$$

Then the ratio of the adults in the population is calculated by $S_3/(S_1+S_2+S_3)$, and the net production rate by $S(1-e^{-F})/(S_1+S_2+S_3)$, where S indicates the stock size of the exploited age classes and F the sustainable fishing mortality rate of the same age classes. F is calculated from the 3rd and 4th equations by assuming the natural mortality rate. The calculation was made based on the following three hypotheses.

Hypothesis 1: $M_1=M_2=M_3>0$, $F_1=F_2=F_3>0$, nonselective catch and constant mortality rate.

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Hypothesis 2: $M_1=M_2=M_3$, $F_1=F_3=0$, $F_2>0$, selective catch and constant natural mortality.

Hypothesis 3: $M_1=2 \cdot M_3$ up to 1 year, then $0.25 \cdot M_3$, $M_2=0.25 \cdot M_3$, $M_3>0$, $F_1=F_3=0$, $F_2>0$, selective catch, natural mortality rate variable.

The first hypothesis is not supported by the results of the present study. The 3rd hypothesis, the most optimistic, is based on the result of the present study indicating the selective exploitation of the juveniles between the weaning and sexual maturity, and on the natural mortality rate of *Stenella attenuata* analysed by Kasuya (1976a). Kasuya (1976a) showed that the mean natural mortality rate of female *S. attenuata* in the entire immature period could be less than a half of that of the adult female, but he suggested that the mortality of the newborn claves could be higher. The low mortality rate before the attainment of sexual maturity is also suggested in the age frequency of *S. coeruleoalba* shown in Fig. 25. This is in the good resemblance with the mortality of the human race, where the mortality rates of the women at the ages between 4 years and 19 years is shown to be at the minimum in the life (Anon. 1976). Possibly this feature will be common in some of the high trophic k-selective mammal species, and is expected for the Dall's porpoise. Accordingly, the natural mortality rates in the 3rd hypothesis are so assumed that the mean annual natural mortality rate in the entire immature stage is a half of that of the adult period and the rate is highest in the early suckling age of 0 to 1 year. The 2nd hypothesis is the intermediate of the first and the 3rd. The natural mortality rate of the adult female, M_3, is assumed as 0.05, 0.075, and 0.10, and the calving interval as 2 years and 3 years. The former cycle is attained when the gestation occures, in most of the adult females, with the interval of one year, and seems to be shorter than the cycle of the Dall's porpoise off the Pacific coast of Japan. The latter cycle, 3 years, is estimated in the present study and seems to be more reasonable.

The results of the calculations are shown in Table 20. It indicates that the

TABLE 20. POPULATION PARAMETERS IN HYPOTHETICAL STATIONAL POPULATION OF *PHOCOENOIDES*

M_3, assumed	0.050		0.075		0.100	
C, calving interval	3 years	2 years	3 years	2 years	3 years	2 years
Nonselective catch, hypothesis-1						
$F_1=F_2=F_3$	0.039	0.063	0.014	0.038	<0	0.013
Net production	3.8%	6.1%	1.4%	3.7%	<0	1.3%
Ratio of adult	53.6%	45.3%	53.6%	45.3%	—	45.3%
Selective catch, hypothesis-2						
F_2	0.171	0.252	0.055	0.136	<0	0.043
Net production	4.0%	6.3%	1.5%	4.0%	<0	1.4%
Ratio of adult	56.4%	48.5%	54.4%	46.9%	—	45.8%
Slective catch, hypothesis-3						
F_2	0.206	0.287	0.107	0.188	0.032	0.113
Net production	4.8%	7.1%	2.9%	5.4%	1.0%	3.6%
Ratio of adult	56.7%	49.0%	55.0%	47.6%	53.6%	46.5%

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selective catch of the immature individuals gives slightly higher net production. The fact that the net production is negligible under the assumption of $M_3=0.10$ and $C=3$, suggests that the actual natural mortality rate of the adult female will be below 0.10. If the population off the Pacific coast of Japan is stational with the annual catch of 6,000 individuals, the population need to be between 6,000/0.048= 125 thousands and 6,000/0.015=400 thousands (2nd and 3rd hypotheses with $M=0.05$ or 0.075, and $C=3$).

ADDENDUM

Dr A. Takemura of the Faculty of Fisheries, Nagasaki University provided for the present study the biological data and tooth samples of *Phocoenoides* of *dalli*-type caught incidentally by the mother ship salmon gillnet fishery in the western Bering Sea and northwestern North Pacific. Since these samples belong to a stock different from Japanese Pacific coast population, and its biological informations are still very limited, some brief analyses are made in comparison with the results obtained on the latter population.

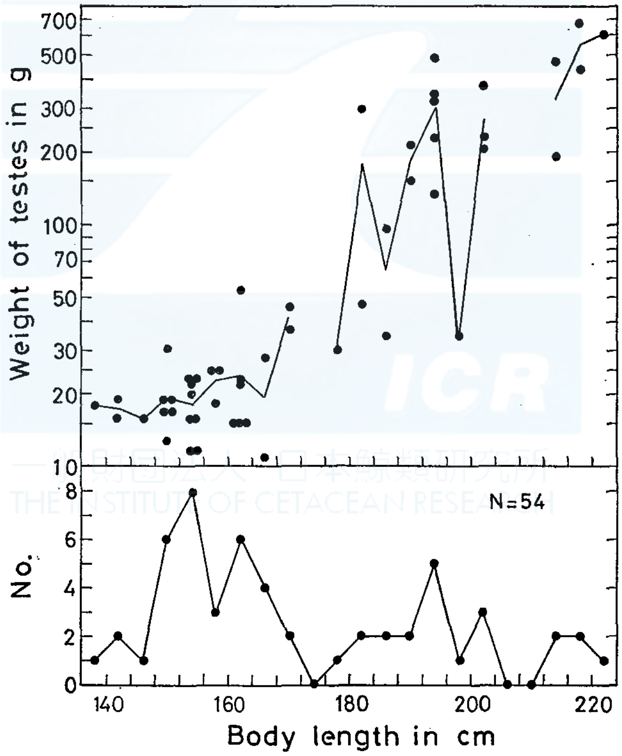

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Fig. 27. Male *Phocoenoides* in the western Bering Sea and northwestern North Pacific. Body length frequency (bottom) and scatter plot of the weight of combined testes (logarithmic scale) on body length (top).

The samples were collected in the period from May 23, 1967 to July 9, 1967 on board of a mother ship. The ordinary biological observations were made and recorded by A. Takemura.

Age determination

The age was determined by myself with the same method as used in the former sections. Since the accumulation of the cemental layers is considered as annual and the parturition peak as from late August to early September, the number of stainable cemental layers will approximately coincide with the age of the porpoise in years. However, the length of time from the mean date of catch of the aged individuals, 15th of June, and the expected peak of the parturition in early September will cause some signigicant bias in the estimation of the growth of juveniles. This is the reason why the body length of the porpoise with N stainable layers is plotted in Fig. 27 at the age of (N—1/4) years.

Length and age frequencies

The body lengths ranged from 139 cm to 220 cm in males, and from 144 cm to 212 cm in females. The calf smaller than 130 cm, which is considered as born in the year (Mizue *et al.* 1966), is only one individual in spite of the same sampling

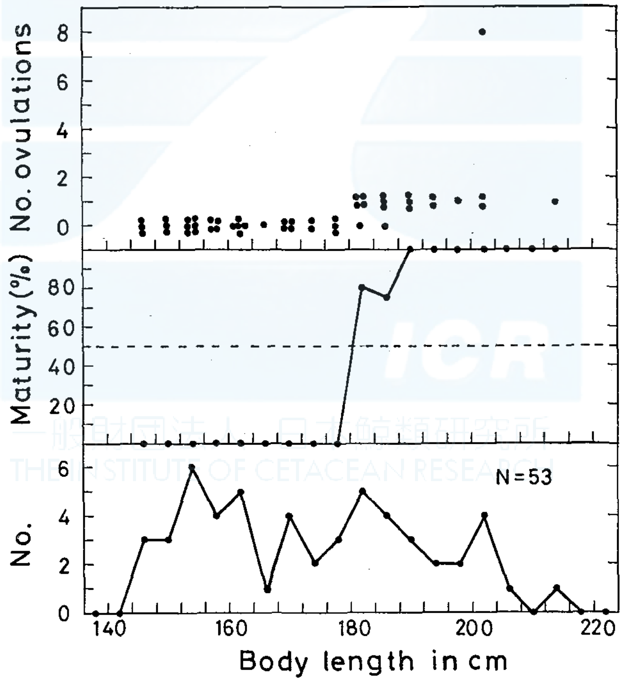

Fig. 28. Female *Phocoenoides* in the western Bering Sea and northwestern North Pacific. Body length frequency (bottom), relationship between body length and the ratio of the sexually mature individuals (middle), and the scatter plot of the number of corpora in the ovaries on body length (top).

TABLE 21. LIFE HISTORY PARAMETERS OF *PHOCOENOIDES* ESTIMATED IN THE PRESENT STUDY

	Parameters		Japanese Pac. Coast	N. W. N. Pac. / B. S.
1.	Length at birth (cm)		—	99.7
2.	Length at 1 year (cm)		165	165
3.	Length at sexual matirity (cm)	♂	195.7	189.1*
		♀	186.5	177.9*
4.	Testis weight at maturity (g)		29.31	50–100
5.	Age at sexaul maturity (years)	♂	7.9	4–5*
		♀	6.8	4–5*
6.	Parturition season		Aug.-Sept.	Aug.-Sept.
7.	Length of gestation (months)		11.4	—
8.	Length of lactation (years)		2	1–2
9.	Calving interval (years)		3	2–3
10.	Prenatal sex ratio (female %)		53.8 (n=39)	64.7 (n=51)

*: Considered as an underestimation of unknown degree caused by the sample bias.

season with Mizue *et al.* (1966), where total of 19 juveniles of the size are recorded. It also need to be noted that the frequency is low, in both sexes, at the lengths about 170 cm to 180 cm. This corresponds with the low frequency at the age of 3 years. The larger individuals are more abundant in the present sample than that from the harpoon fishing.

The presence of a dominant mode at one and two years of age is a feature different from that of the catch by harpoon fishing, where the calves of suckling ages are extremely scarce. The other mode at the older age is nearly same with that of the catch by harpoon fishing.

Sexual maturity

On the males caught by the salmon gillnet fishery, the mean weight of the testis at the attainment of sexual maturity is not estimated. However, the scatter plots of the weight of testes against the body length suggest that the weight would be from 100 to 200 g in the combined weight. Then the sexual maturity seems to be attained at the length from 180 to 200 cm (Fig. 27). This feature is almost same with the data in Mizue *et al.* (1966) and Koga (1969). When the weight of 150 g is tentatively used as the mean weight of testes at sexual maturity, the least squares regression between the ratio of sexually mature individuals and the body length gives 189.1 cm as the length where half of the males are mature (the present data, and those in Mizue *et al.* 1966 and in Koga 1969 included). The half of the males in the present materials are sexually mature at 4 to 5 years of age (Fig. 29).

The present scanty materials suggests that the sexual maturity of the females is attained at a length between 180 and 187 cm (Fig. 27). The corresponding figure read on Fig. 5 of Mizue *et al.* (1966) is from 170 to 190 cm. The least squares regression calculated for the present data and those in Mizue *et al.* (1966) gives 177.9 cm as the length where half of the females are sexually mature. The mean

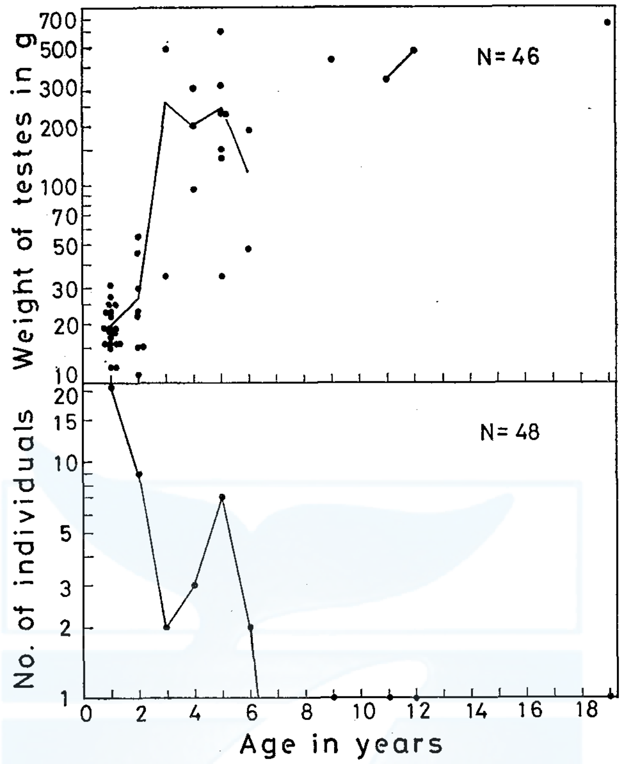

Fig. 29. Male *Phocoenoides* in the western Bering Sea and northwestern North Pacific. Age frequency (bottom) and the scatter plot of the weight of combined testes on age (top). Both are plotted on semi-logarithmic scale.

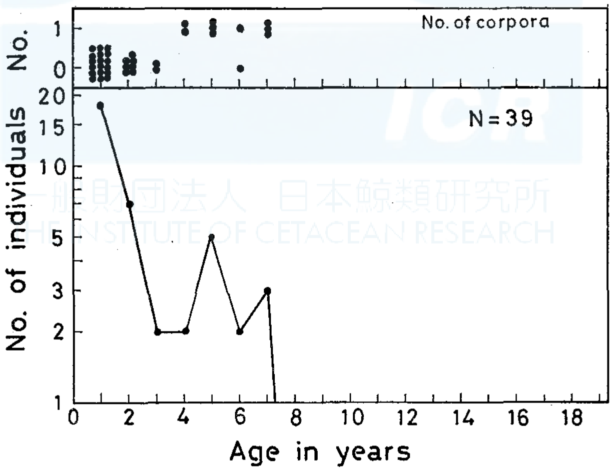

Fig. 30. Female *Phocoenoides* in the western Bering Sea and northwestern North Pacific. Age frequency (bottom) and the scatter plot of the number of corpora in the ovaries on age (top).

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age at the attainment of sexual maturity is between 4 and 5 years in the present materials (Fig. 30).

As mentioned later, the mean ages and lengths at sexual maturity estimated above will in some degree be affected by the bias of the sample.

Reproductive stages

The sex ratio and ratio of the adults in the catch by the salmon gillnet fishery are within the ranges of the corresponding figures of the catch by harpoon fishing off Sanriku coast (Tables 13 and 14).

The adult females are almost exclusively composed of the pregnant females (Table 15). The number of corpora in the ovaries is only one in most of the adult females in the present materials (Fig. 27). However, this feature is different from the catch studied by Mizue *et al.* (1966) in 1964 and 1965.

Growth curve

The age-length relationship of the present materials at the ages below 2 years does not seem to be significantly different from the growth curve fitted for the population off the Pacific coast of Japan. However, the body lengths of the individuals from 3 to 7 years of age situates above it (Fig. 31). Although this will indicate the faster growth in the northwestern North Pacific and western Bering Sea population, the following factor can not be neglected. Some premature individuals attain the sexual maturity, in the two stocks, at the age of 3 or 4 years, and these individuals are usually larger than the immature individuals of the same age (Figs 7, 16, and 31). Since the underrepresentation of the weaned juveniles is indicated in the age frequency, it is reasonably expected that at the age of 3 to 7 years the sexually immature individuals, which are smaller in body length, are underrepresented than the adults of the same age. This bias causes the mean growth curve to be higher than truth.

Discussion and conclusion

The Dall's porpoise caught incidentally by the salmon gillnet fishery are constituted mainly of the possible suckling calves and the young adults of both sexes. The incidental death of many calves and few lactating females are of contrast. Mr S. Nagahora of the Iwate Prefectural Fisheries Research Laboratory informed me several observations where mother stays by a dead or alive calf entangled in the gillnet. The calf is less experienced and will easily be entangled in the gillnet, and perhaps the accident of the calf will indicate for the mother the presence of the gillnet. This can be an explanation of the low mortality of the lactating females. The decrease of the catch of the calves from 1 year through 3 years will be a reflection of the completion of weaning. Some juveniles will already be weaned by the age of 1 year and will be underrepresented in the present material. This age structure suggests the mean nursing period of from 1 year to 2 years, and consequently the mean calving interval of 2 to 3 years.

The reason of the low mortality of the weaned immature individuals is not

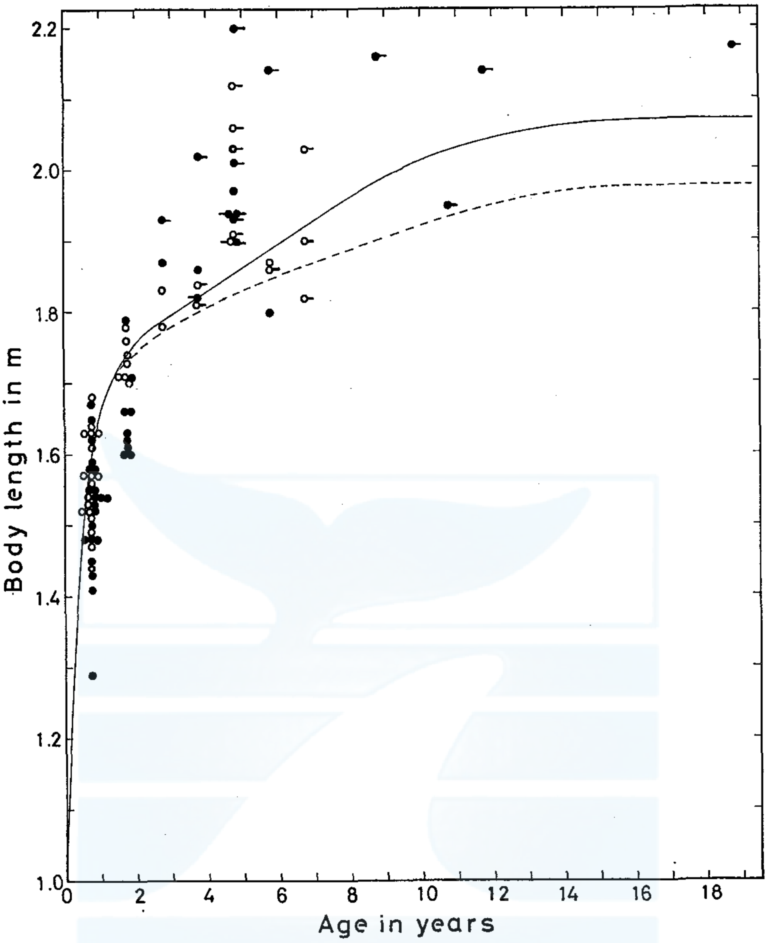

Fig. 31. *Phocoenoides* in the western Bering Sea and northwestern North Pacific. Scatter plot of the body length on age. Closed circle indicates male, and open circle female, and the circle with bar the adult. The solid line (male) and dotted line (female) are growth curves fitted for the species off Sanriku coast.

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clear. Possibly one of the following two reasons is working for it.

1. Presence of segregation, the weaned immature individuals are distributed outside of the sampling area in the season.
2. Change of the behavior at the weaning and at the attainment of sexual maturity.

The difference of the food preference between the growth or reproductive stages is reported by Mizue *et al.* (1966). The nonpregnant females were feeding almost exclusively on squid, but the pregnant females on more variety of food organisms including fish and shrimp. It is not clear in their study if the difference of food items is related to the difference of the location or to that of the real preference.

However, since the segregation by maturity and sex is suggested in the wintering ground off the Japanese coast (pages 10 and 50), it will be more reasonable to support the first hypothesis.

The scarcity of the individuals over 7 years of age will indicate the underrepresentation of the older individuals. Possibly the older and more experienced individuals are not usually entangled in the gillnet.

Since the immature, and probably smaller, individuals at the ages above 4 years are underrepresented compared with the adult larger individuals of the same ages, the mean body lengths and mean ages at the attainment of sexual maturity obtained in the present study can be the underestimations. Therefore it is unreasonable, at present, to conclude that the difference of the growth between the stock off the Pacific coast of Japan and that in the northwestern North Pacific and western Bering Sea is so large as observed in the present materials.

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EXPLANATION OF PLATES

PLATE I

The individual variation of the pigmentation pattern of *Phocoenoides dalli* caught by the harpoon fishing off Sanriku coast.

Fig. 1. Type-1, male.
Fig. 2. Type-1, male.
Fig. 3. Type-2, 195 cm, male.
Fig. 4. Type-2, 177 cm, male.
Fig. 5. Type-3, female.
Fig. 6. Type-3, male.
Fig. 7. Type-4, 168 cm, male.
Fig. 8. Type-4, male.
Fig. 9. Type-5, 178 cm, female.
Fig. 10. Type-6, 182 cm, male.

PLATE II

The individual variation of the pigmentation pattern of *Phocoenoides dalli* caught by the harpoon fishing off Sanriku coast.

Fig. 1. Type-7, male.
Fig. 2. Type-8, 193 cm, female.
Fig. 3. Type-9, 181 cm, female.
Fig. 4. Type-10, 204 cm, male.
Fig. 5. Type-11, female.
Fig. 6. Type-12, 207 cm, male. White patches on dorsal fin and chest region are artifact of the reflection of light.
Fig. 7. Type-13, 168 cm, female.
Fig. 8. Type-12, ventral view of the individual shown in Fig. 6.
Fig. 9. Type-14, 175 cm, female.
Fig. 10. Type-3, male. An individual different from that in Fig. 6, Plate I.

PLATE III

Tooth sections of *Phocoenoides dalli*, decalcified and stained with haematoxmylin. Abbreviations are as follows.

C: Cementum, D: Dentine, E: Enamel, M: Periodontal membrane, N: Neonatal line in dentine, Open circle: Dentino-cemental boundary, Closed circle: Cemental growth layer.

Figs 1 and 2. 110 cm, female, *dalli*-type, 26, July, 1972, 46°43′N, 162°24′E. Born in the year of catch, no cemental layer is deposited.

Figs 3 and 4. 149 cm, male *truei*-type, 3, March 1974, off Sanriku coast. Presumably born in the preceding summer. One unstainable and a stainable cemental layers are deposited. Cementum of this individual is extraordinary thick, and an accessory layer is present.

Figs 5 and 6. 182 cm, male, *truei*-type, 21, Feb., 1976, off Sanriku coast. Sexually immature. 9 stainable layers in cementum.

PLATE IV

Figs 1 and 2. 196 cm, male, *truei*-type, 27, Feb., 1974, off Sanriku coast. 12 stainable layers in cementum. For abbreviations see Plate III.

Fig. 3. Immature testis tissue. 185 cm, *truei*-type, 20, Feb., 1976, off Sanriku coast. Weight of testis 10.8 g.

Fig. 4. Immature testis tissue. 174 cm, *truei*-type, 20, Feb., 1976, off Sanriku coast. Weight of testis 7.2 g.

Fig. 5. Mature testis tissue. 194 cm, *truei*-type, 19, Feb., 1976, off Sanriku coast. Weight of testis 43.9 g.

Fig. 6. Mature testis tissue. 190 cm, *truei*-type, 20, Feb., 1976, off Sanriku coast. Weight of testis 41.4 g.

Tissues in Figs 3 to 6 are taken from the center of the testis.

PLATE V

The growth stages of the epididymal tissue of *Phocoenoides dalli* caught off Sanriku coast. Scale indicates 0.1 mm.

Fig. 1. Immature epididymis. 184 cm, *truei*-type, 18, Feb., 1976. Weight of testis 6.4 g.

Fig. 2. Immature epididymis. 166 cm, *truei*-type, 20, Feb., 1976. Weight of testis 7.3 g.

Fig. 3. Maturing epididymis. 191 cm, *truei*-type, 18, Feb., 1976. Weight of testis 24.7 g.

Fig. 4. Maturing epididymis. 206 cm, *truei*-type, 17, Feb., 1976. Weight of testis 66.2 g.

Fig. 5. Mature epididymis. 194 cm, *truei*-type, 19, Feb., 1976. Weight of testis 43.9 g.

Fig. 6. Mature epididymis. 212 cm, *truei*-type, 19, Feb., 1976. Weight of testis 81. 7 g.

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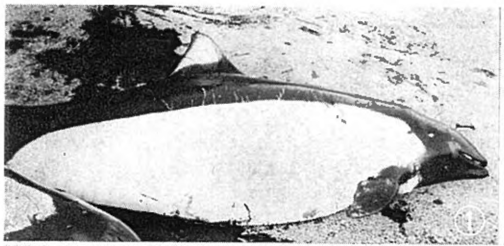
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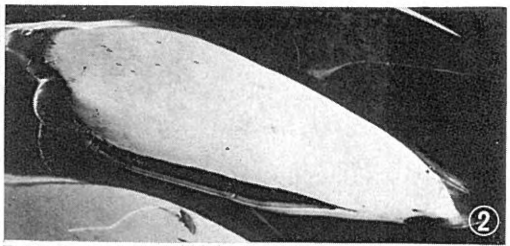
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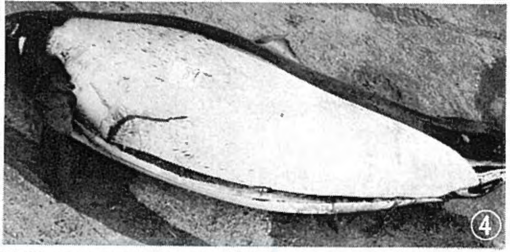
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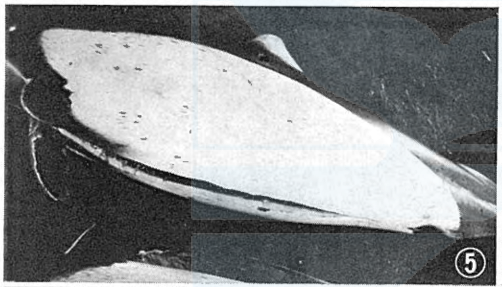
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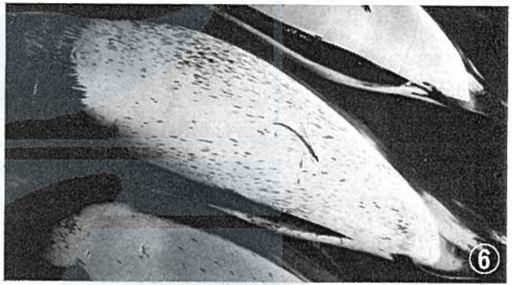
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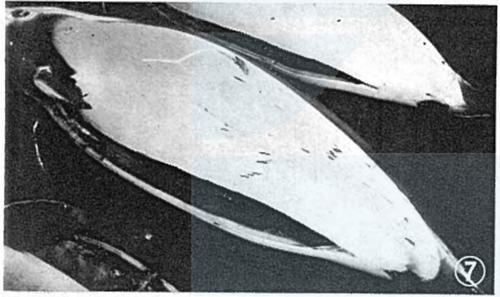
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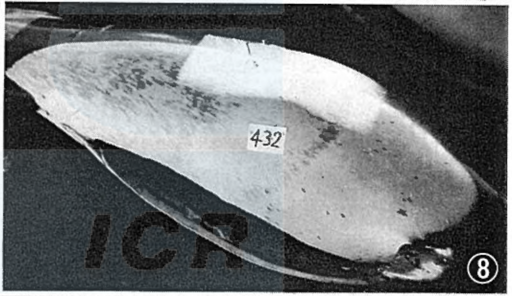

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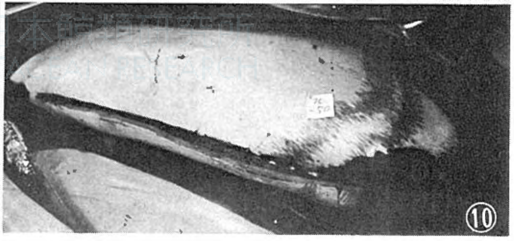
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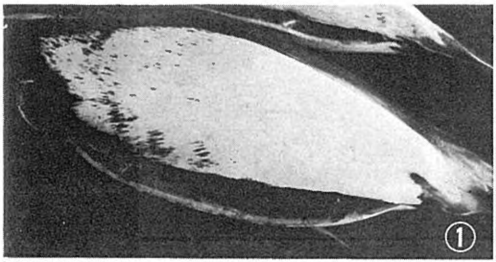
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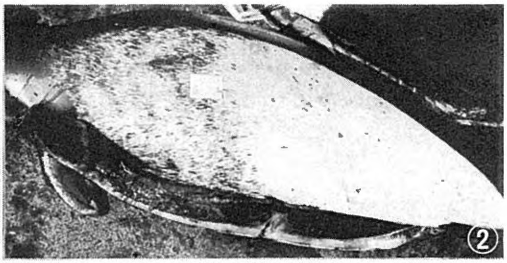
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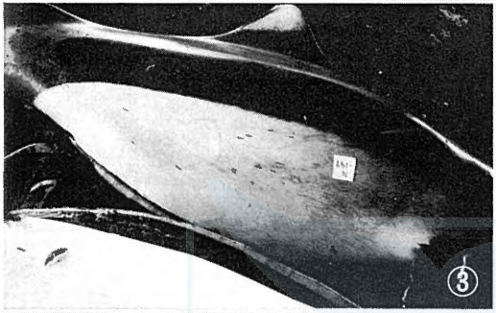
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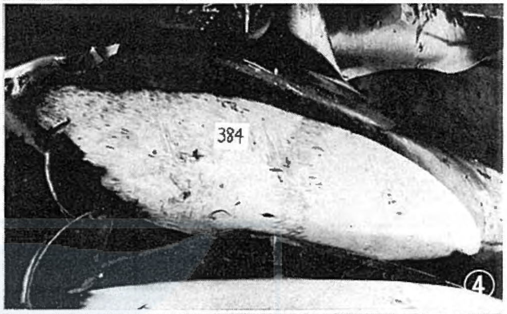

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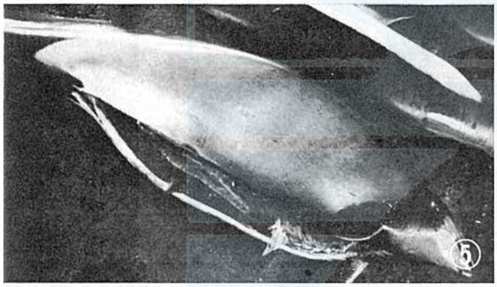
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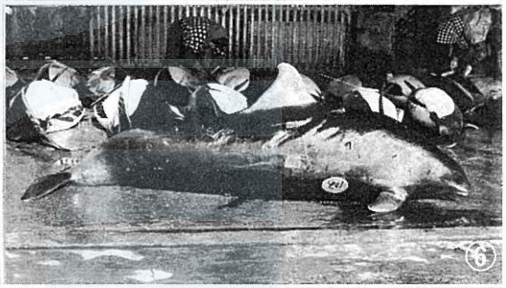
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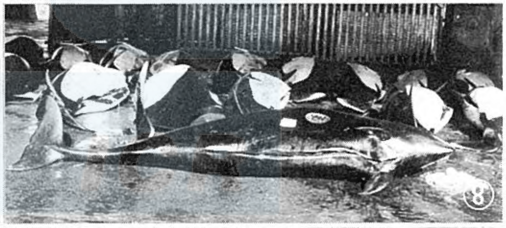
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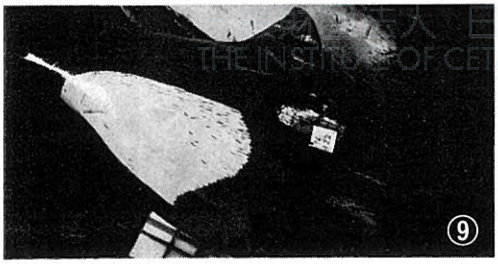
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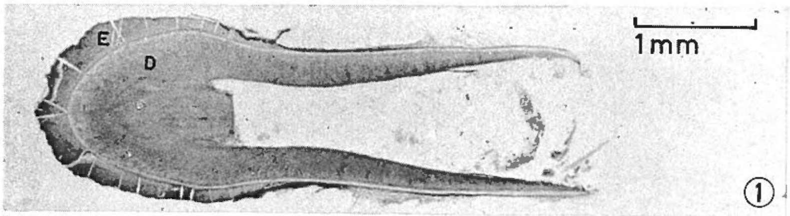
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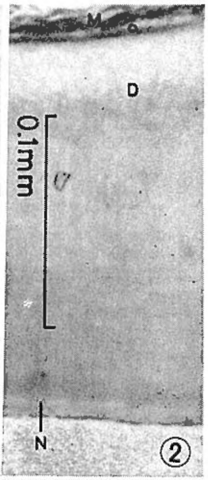
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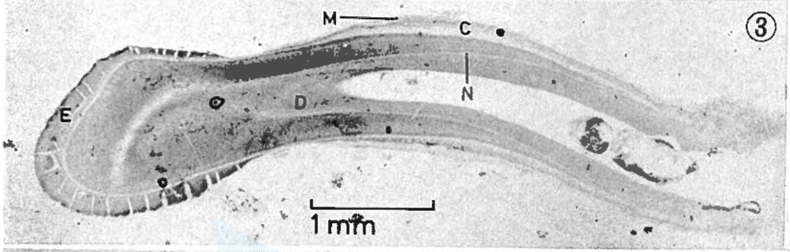
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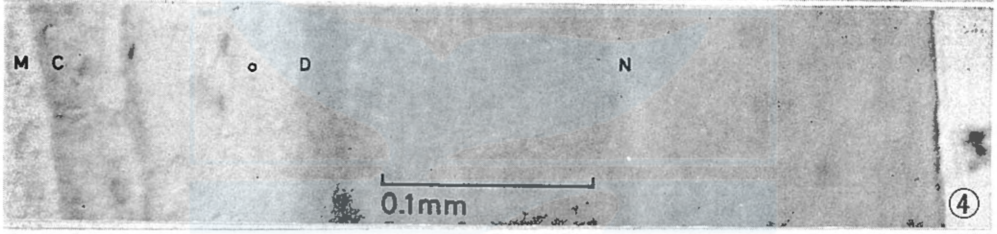
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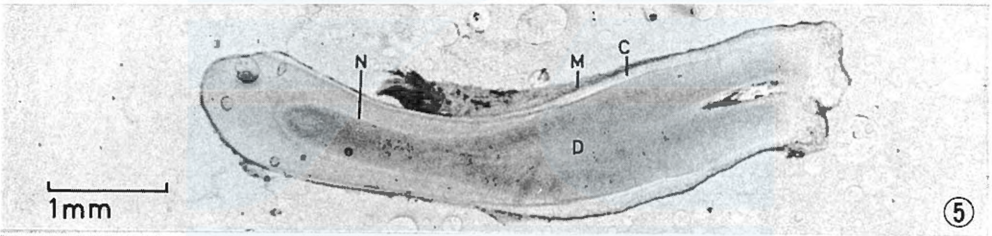
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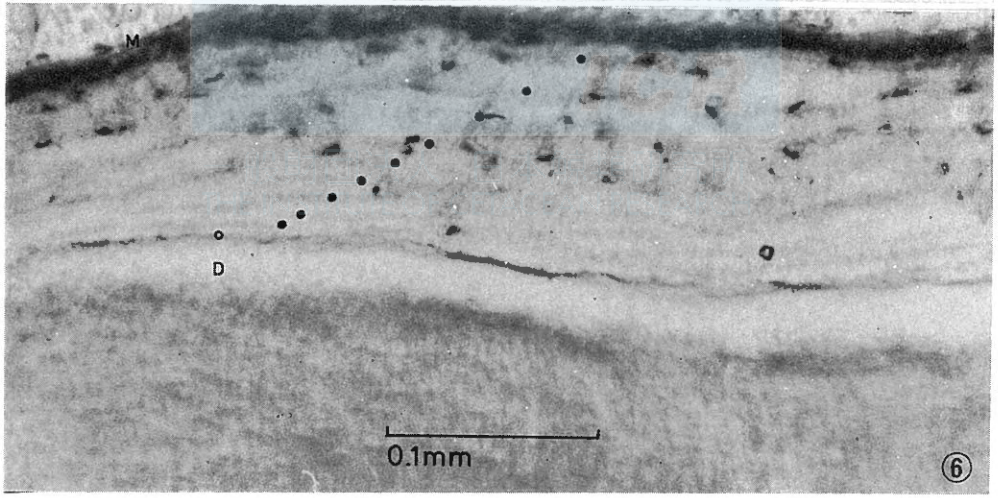
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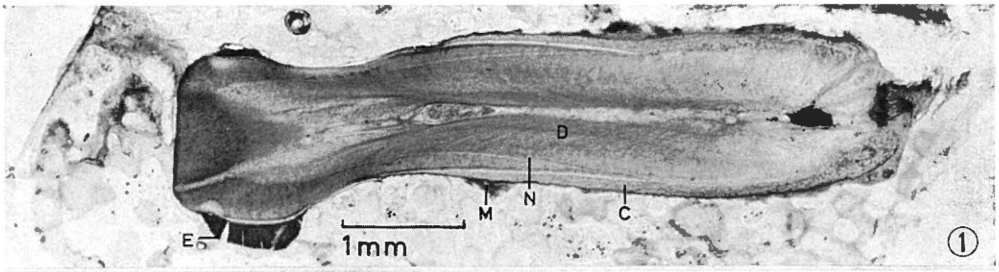
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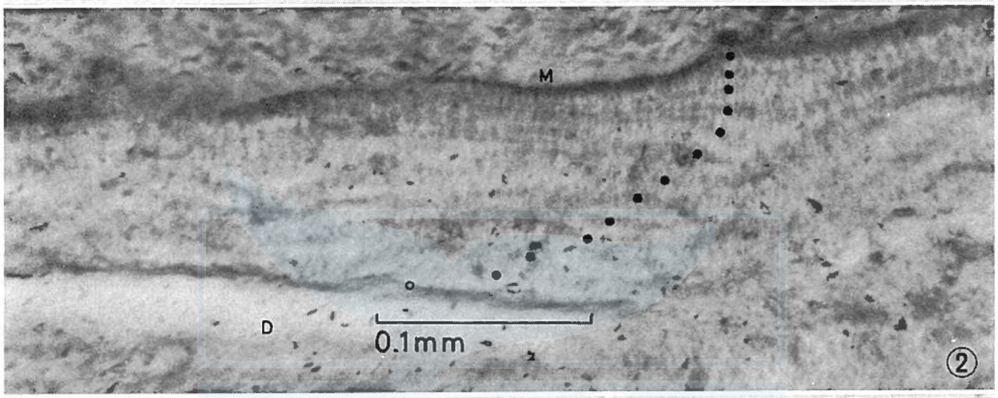
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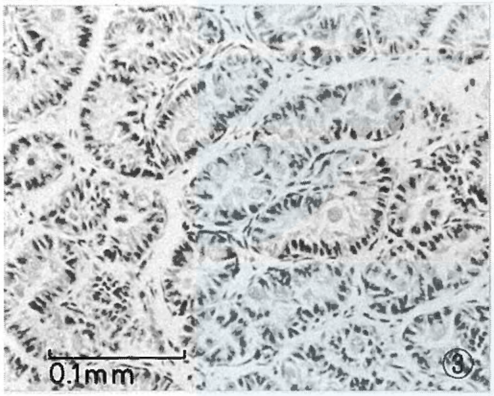
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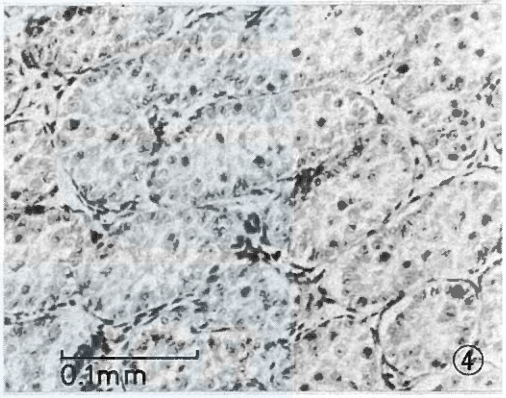
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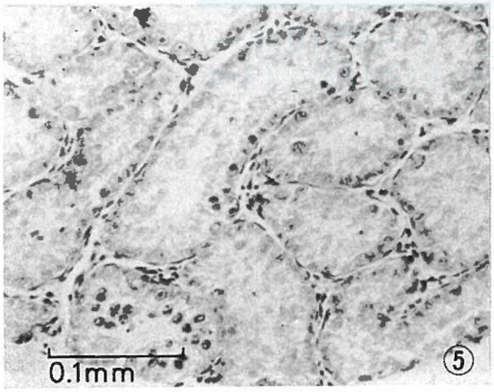
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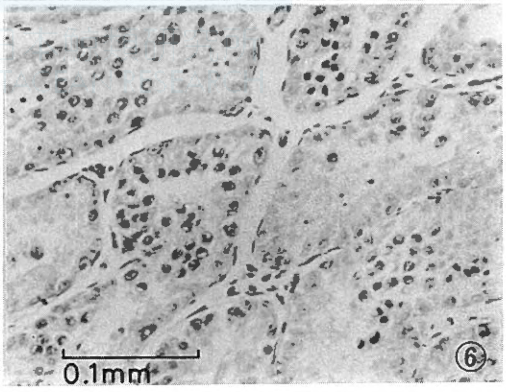
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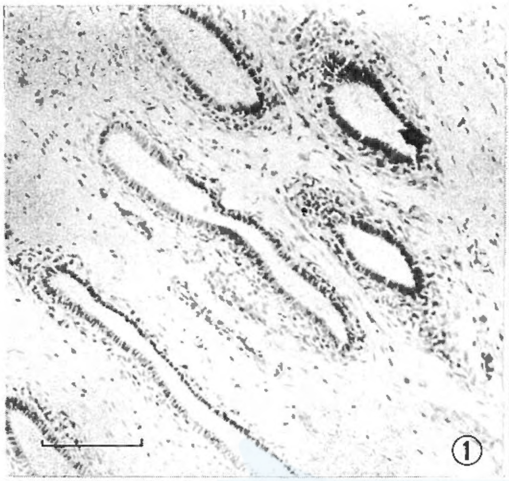
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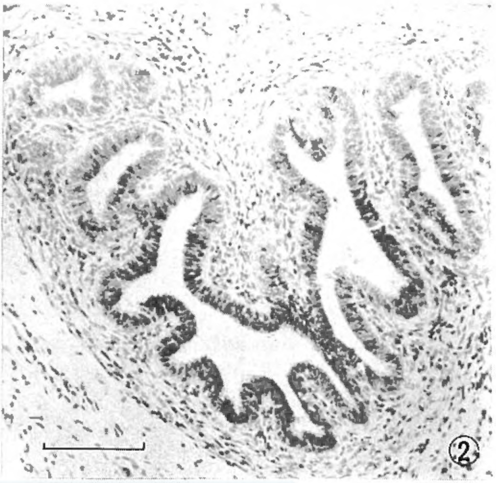
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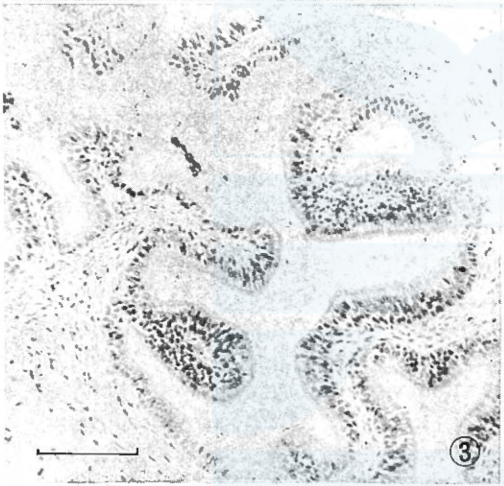
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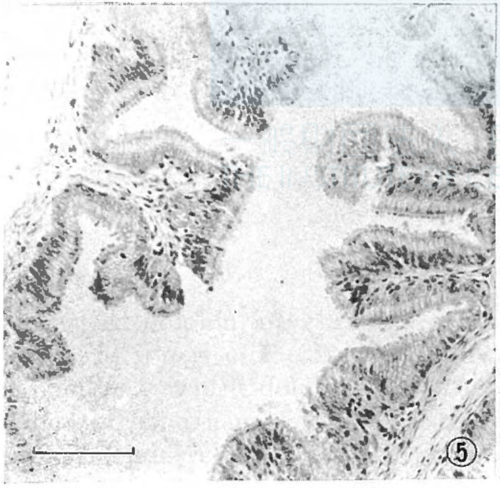
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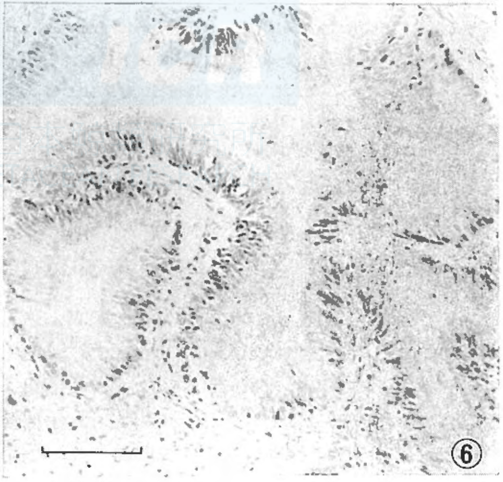
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