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Biological studies on the North Pacific sei whale

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Abstract

The sei whale has been becoming the main objective in the baleen whales of the pelagic whaling in the North Pacific. However, the biological parameters necessary to the stock assessment of the North Pacific sei whales have not been examined thoroughly. This study was done with the intention of contributing the rational management of sei whale stocks, of clarifying their life history, and of separating the stock of them in the North Pacific into units.

The foetal growth curve of the North Pacific sei whales becomes exponential to birth. The mean conception and birth time are the late of December and the beginning of November, respectively. Body length at sexual maturity was calculated to be 13.4 m in females and 12.9 m in males, respectively. Physical maturity is also examined to be 15.2 m in females and 14.3 m in males, respectively. The mean diameter of seminiferous tubules will be over 110 μ in mature whale and less than 90 μ in immature one. The testis tissue does not mature radially, but rather from dead center to the posterior, then to the dorsal perifery and finally the process of testicular maturation is completed with the expansion of mature tissue to the anterior ventrum of the organ. As characters for evaluating sexual maturity of a large number of male whales, penis length, index of testis volume and testis weight are examined, and testis weight is regarded as the best. Testis weight at sexual maturity was estimated to be 0.9 kg. The age at sexual maturity utilizing the transition phase criterion was estimated to be seven years of age in both sexes.

The gestation, lactation and resting periods are estimated to be about ten and half, about seven and about six and half months, respectively. The sex ratio in single birth of the North Pacific sei whales is almost 1 : 1, and the rate of twinning is 0.52%. Body length at sexual maturity, rate of sexual maturity, pregnancy rate and ovulation rate are examined by year, by age and by area, and these results showed the segregation of animals by sexual states. Ovulation rate varies from 1.00 to 0.30 according to the calculation of three methods, and reasonable mean ovulation rate per annum be taken as 0.604. Average recruitment age and natural mortality coefficient are calculated from age composition and the figures differ by area and by season. This phenomena show that the effects of catching pressure on one stock unit may not have influence on the others.

Migrations and movements of the North Pacific sei whales are discussed based on whale marking, whale sighting, the change in the rate of sexual maturity by area, the change in mean body length by sex, by area and by month, and the body length composition. Three

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different migration and movement patterns are recognized in the North Pacific sei whales from above analyses, namely, the waters west of 180°, the waters between 180° and 160°W, and the waters east of 160°W. The sei whales migrate northward in spring and southward in autumn. The first animals to begin the migration are the larger sized mature whales. There are three successive peaks of the migration in the mature females, that is, pregnant, resting and lactating, in order.

The identification of the stock units of the North Pacific sei whales is carried out by use of following four methods; whale marking, catch distribution, whale sighting and the shape of the baleen plates. Recognizable three stock units of the North Pacific sei whales are demarcated by the borders of 175°W and 155°W.

Contents

Introduction

At present, world whaling can be divided into two main divisions, i. e., coastal and pelagic whaling according to the mode of operation. These two divisions, each has two types of whaling based on the target species of the catch.

Large type whaling seeks fin, sei, Bryde's and sperm whales as the main objective. Nowadays, Japanese pelagic whaling aims at the sei whale (*Balaenoptera borealis*). More than 80% of the sei whales (including Bryde's whale) taken in the North Pacific before World War II were captured by Japanese coastal whaling. Yearly fluctuation of the number of sei whales taken at that time was small, and yearly mean of catch was about 450 animals. Since the 1954 season, when USSR and Japan began pelagic factory whaling in the northern part of the North Pacific, the catch for the entire North Pacific increased to about 1, 250 sei whales a year, until 1963 season (BIWS, 1930–73).

Due to the fact that fin whales were the main object of pelagic whaling, its operation was conducted largely in the regions north of 50°N before the 1963 season. Since the 1964 season, the number of sei whales taken dramatically increased, and the yearly mean number taken from the 1964 season to the 1972 season was 4, 234 animals and the sei whale occupied 83.6% of the baleen whales in pelagic whaling operations in the North Pacific.

During the season of 1952 through 1966, sei whales were taken in the western part of the North Pacific north of 50°N and in the Gulf of Alaska, and since the 1967 season, the waters of operation extended over the eastern portion of the North Pacific between 40°N and 50°N and also beyond the waters south of 40°N.

The main objective species of Japanese pelagic whaling has changed to the relatively smaller sized species, the sei whale, from the larger sized one, fin whale, since the 1967 season when the business of capturing sei whales became more efficient than capturing of fin whales in the North Pacific, and sei whale meat comprised about 80% of total whale meat products (Whaling Section, Marine Production Division, Fisheries Agency, Japan, 1973).

The study of the stock assessment of the North Pacific sei whale was taken up for the first time at the meeting of the IWC *Ad Hoc* Scientific Committee held in London in 1962. Until 1964, the Working Group on North Pacific Whale Stocks had discussed research programmes for its study, but in 1965, Japanese scientists made preliminary estimates of the population size of sei whales. However, the data for this species both in determining reliable age length key and in evaluating the effort have not been analyzed.

Doi *et al.* (1966b) presented population estimates based on De Lury's method and on age distribution at the sixth meeting of the Working Group on North Pacific Whale Stocks in Honolulu, Hawaii, 1966. At the same time, Doi *et al.* (1966a) presented natural mortality coefficient based on age length key, and presented some ecological facts, that is, a marked segregation of sex, age and maturity classes of sei whales in different areas, especially among females.

Doi and Ohsumi (1969) presented overall estimates of population size of sei whales based on the following methods; (1) catchability coefficient method, (2) whale sighting method, (3) whale marking method, (4) the De Lury's method and modified method, (5) method of taking reproduction into account. In addition, they presented the biological parameters for stock assessment of the North Pacific sei whale, that is, age and body length at sexual maturity, age at recruitment, pregnancy rate and natural mortality coefficient which are mainly based on the data from the seasons of 1957 to 1968.

The Working Group has discussed the importance of the study of identifying different stocks and has recognized necessity of special studies for age determinations at every time of the annual meeting up to the present.

The biological parameters necessary to the stock assessment of the North Pacific sei whales have not been thoroughly examined to date. Although it is desirable to manage the whale stock by units, the study of stock identification of the sei whale in the North Pacific was first dealt with by FUJINO (1964a), and further analysis has not progressed since. This study at hand was undertaken with the intention of managing sei whale stock in the North Pactfic rationally by means of the clarification of their life history and the identification of stock units.

Chapter I presents an outline of the materials and methods used in this paper. Growth and reproduction of the sei whale are discussed in Chapters II and III, respectively. Chapters IV and V examine the biological parameters for stock assessment, and deal with the problems of migrations and movements. In Chapter VI, separation of stock units is analyzed. Chapter VII states the results of the study and arguments concerning them.

I. Materials and methods

As mentioned in introduction, modern whaling in the North Pacific forms two types ot operation, coastal and pelagic. In the hight of operation, four countries namely Japan, USSR, Canada and USA engaged in coastal whaling and Japan and USSR engaged in pelagic whaling.

However, the statistical data used in this study are limited to the Japanese data by reasons of high reliability and, moreover, convenience of access.

Biological investigations at Japanese coastal whaling stations had not been carried out systematically until the 1973 season, and consequently, biological/statistical data used in this study are mainly obtained from the Japanese pelagic expeditions in the North Pacific. The ear plugs and testis tissue samples were collected in the whaling seasons of 1968 to 1972 by the Japanese expeditions.

An outline of the main data sources and specimen materials are shown below, and the particulars are explained in each related passage.

"Geirui-hokaku-daicho, 1952–1972", (The ledger of whales caught): This ledger provides for each whaling season by each participating expedition, and includes the following data for each whale taken; serial number, sex, body length, species, stomach contents (species, amount and size), foetus (sex and body length), thickness of blubber, testis weight, number of corpora lutea and albicantia in ovaries, age, condition of lactations, catch date and catch position.

In the case when a biologist was on board, the number of ovarian corpora was counted on deck, in other cases the ovaries, ear plugs and teeth (for sperm whales) were preserved and carried back to the laboratory for the sake of finer examination. In principle, specimen materials have been collected from almost all whales caught.

"Densanki ni yoru geirui-seibutsu-tokei-hyo, 1966–1972" (Tables of the bio-statistics of whales caught, which have been calculated by computer): These tables have been made from the original data being "The ledger of whales caught" mentioned above, and rearranged by several maps and tables corresponding with subjects such as "The map of catch distribution", "The tables of age composition using an age-length relationship", "The tables of the age-ovulation relationship" and "The tables of the growth of the foetus".

"Kita-taiheiyo-san geirui no shigen-seibutsugakuteki chosa-hokoku-sho, 1955–1966" (The research report of biological study of whales in the North Pacific): These reports were published by the Whales Research Institute, Tokyo, Japan.

"Gyojyo-chosa-sen ni yoru geirui-hakken-gei-hokoku, 1965–1972" (The whale sighting report by scouting boats): Whale sighting have been carried out by scouting boats accompanying with Japanese whaling expeditions. Items of datum surveyed are noon position, visibility, wind force and direction, air and sea temperatures, water color, weather conditions, scouting distance run, number of whales and herd size sighted by species, and the number of cows with calf.

"Kita-taiheiyo ni okeru geirui-hyoshiki kiroku-bo, 1953–1973" (The ledger of whale marking in the North Pacific): This publication is an array of the data of the whale marking program carried out by Japan in the North Pacific since the 1949 season. The data items are as follows; date marked, position found, position marked, number of whales in the herd, body length composition of the herd estimated by eye, swimming and escape directions, temperment of the whales found, visibility, wind force and direction, air and sea temperatures, water color, weather conditions, whale species, mark number, results of marking effort, hit area of mark on whale body, and estimated body length.

"Kita-taiheiyo ni okeru hyoshiki-gei saiho-ichiran, 1950–1973" (The table of recaptured whales in the North Pacific): This table is the records of the recaptured whales, and contents followings; mark number, date caught, position caught, serial number of the whale treated, whale species, sex, body length, area of body in which mark was found and the state of healing of the wound caused by the mark.

"Baleen plates": A total of 252 sei whale baleen plates used in this study were collected by Japanese expeditions during the 1973 season.

"Testis tissue, vertebral tissue, ear plugs, mammary gland thickness and color of the tissue, state of lactations, penis length, index of testis volume, testis weight, and the diameters of the ovarian corpora": These were collected and examined on aboard of Tonan maru and Kyokuyo maru No. 2 during 1968 and 1970 whaling seasons, respectively. Part of the samples of testicular and vertebral tissue were collected in the 1969 and 1971 seasons by Kyokuyo maru No. 2 and Kyokuyo maru No. 3, respectively. Results obtained by the Whales Research Institute, Tokyo, Japan on a sei whale cow and calf which were caught by Tonan maru under a special scientific permit in the 1968 season, are used in this paper.

Additional materials utilized are; "Nihon engan-hogei ni okeru geirui seibutsu-chosa daicho, 1950–1972" (The ledger of the results of biological research of Japanese coastal whaling); "Nihon engan-hogei-tokei, 1950–1972" (Japanese coastal whaling statistics) and "International Whaling Statistics, 1930–1973".

Geographical breakdown used in the study is shown in Fig. 1 in order to facilitate understanding of the discussion.

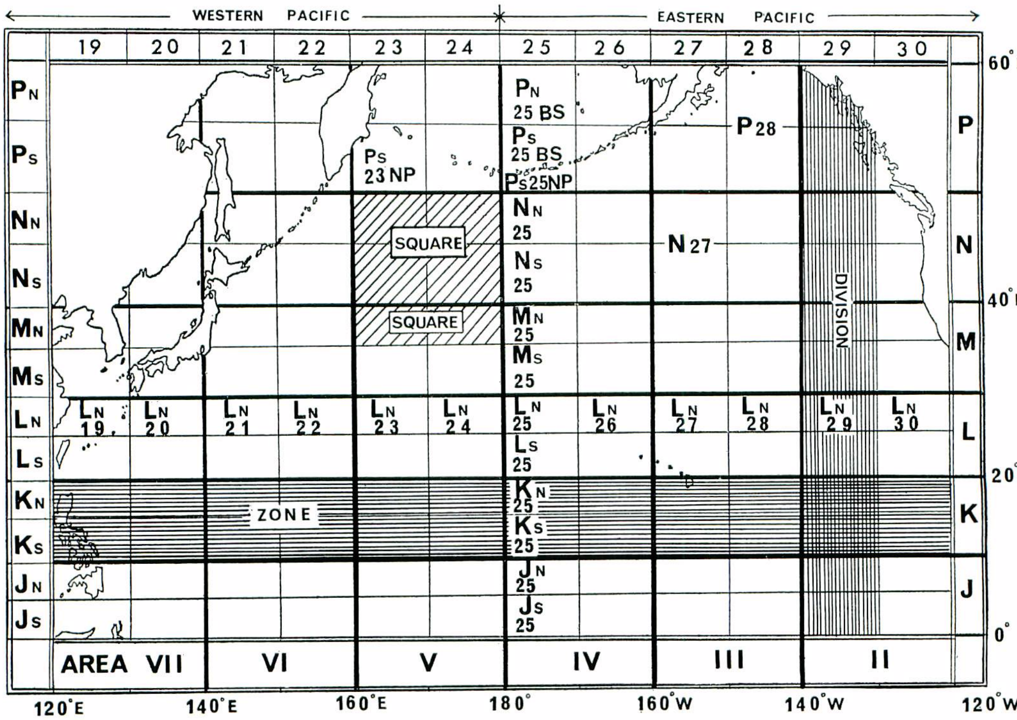


Fig. 1. Breakdown of areas, squares, divisions and zones for whaling in the North Pacific.

II. Growth

In Section 1 of this Chapter, foetal growth is examined. Criterion for sexual maturity is established in the Section 2. Using the criterion, analyses of both age and body length are handled in the Sections 3 and 4. In the final Section of this Chapter, a growth curve of the North Pacific sei whale is estimated from the results obtained from the previous Sections.

II–1 Foetal growth

The analysis of foetal growth should not be limited just to its contribution to the total process of growth, since it offers particular information on the time of mating, gestation, parturition and reproductive seasonality in general. However, other subjects than growth of the foetus will be discussed in Section 3.

The data used in this Section are comprised of two items, the foetal body length and date of capture, of 4,573 pregnant sei whales taken by Japanese expeditions during the seasons of 1952 through 1972 and from the Japanese coastal whaling seasons of 1960 through 1965. These items are mesured and recorded by fisheries inspectors of the Japanese Government or biologist of Whales Research Institute, Tokyo.

The date of capture of pregnant sei whales extends from April to October and is grouped every six-day period (Fig. 2). The mean foetal growth curve derived from this data leaves much to be desired for lack of information on the very early pregnancies and the later ones. While comparing the mean foetal body length for each six-day of the North Pacific sei whale with the mode of that for each month of the Antarctic one (GAMBELL, 1968, Figs. 23 and 24), they exactly coincide each other when the latter is shifted to 6.2 months, as shown in Fig. 3. Putting above two data together, a deficiency of information on the early pregnancies of the North Pacific sei whales may be made up by GAMBELL's data.

Figure 4 shows the body length composition of the North Pacific sei whale foetuses within each month of the sample. It is noted that the shape of the curve for the months April through August are nearly symmetrical, but those for September and October show an irregular decline. This phenomenon, as LAWS (1959) pointed out, is due to the fact that pregnant whales with large or near-term foetuses depart the whaling ground (sampling site) sooner than those with smaller foetuses. Accordingly, the compositions of foetal lengths for September and October show distorted curve compared with those before August.

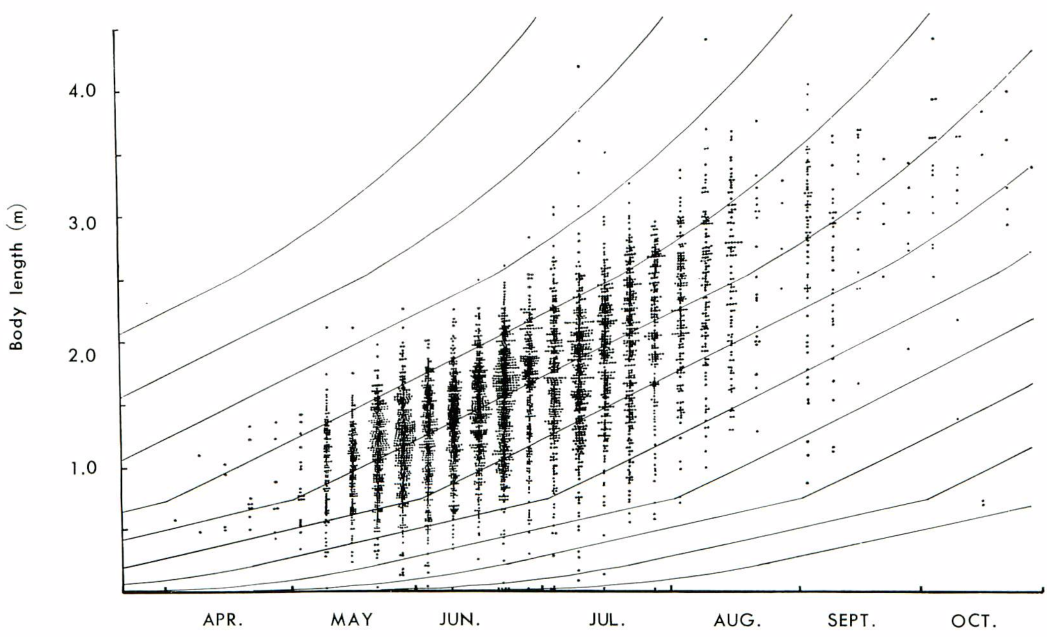


Fig. 2. Distribution of the foetal body length by every six-day of the North Pacific sei whale.

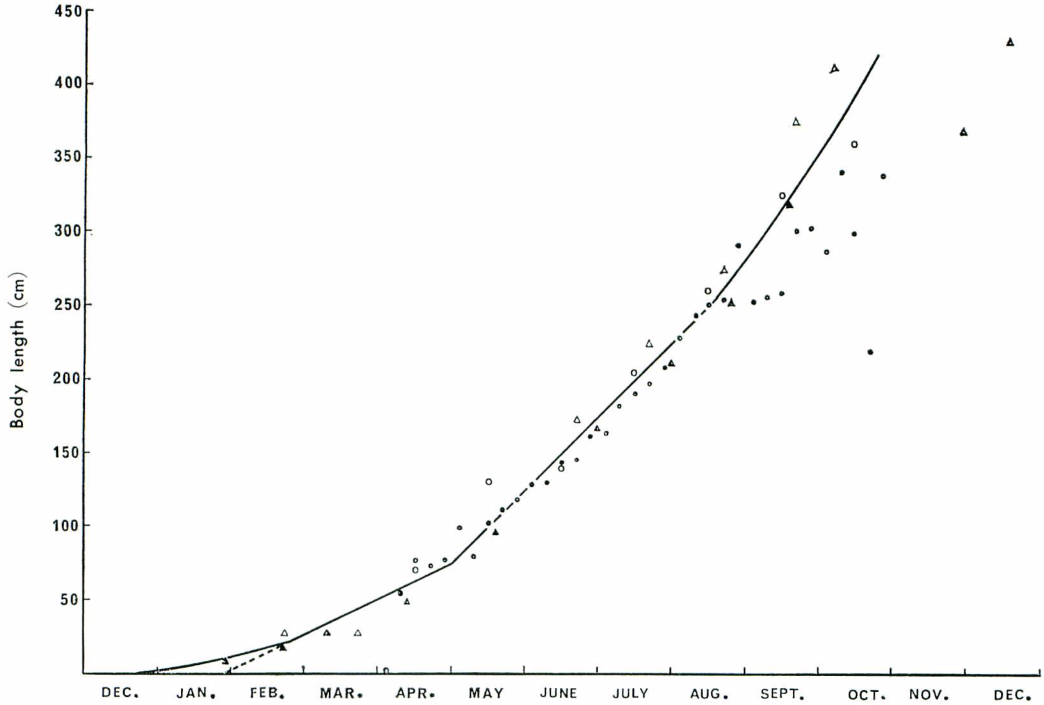


Fig. 3. Foetal growth curve of the North Pacific sei whale. Closed circle; mean foetal body length by every six-day. Open circle; the figure of the monthly mode of foetal body length composition. Open triangle; the figure of the monthly mode of foetal body length composition from GAMBELL (1968). Closed triangle; mean foetal body length by week from GAMBELL (1968).

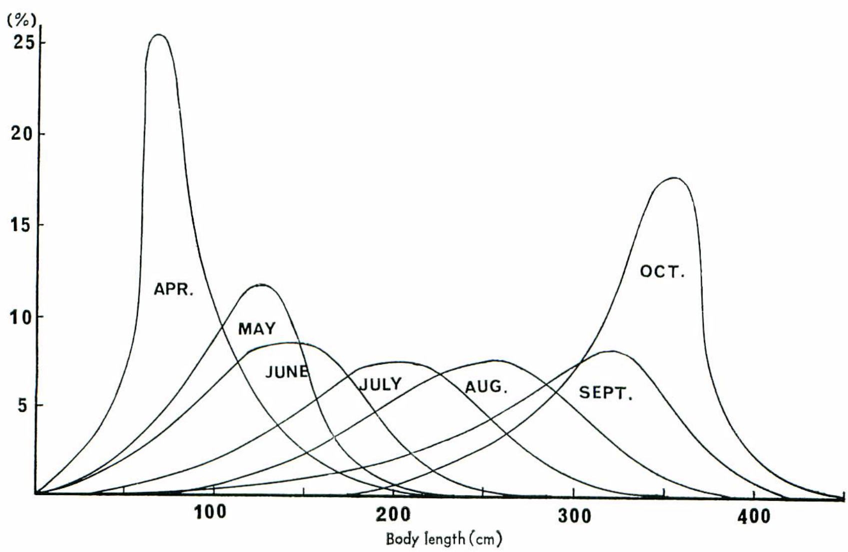


Fig. 4. Monthly frequency distribution of foetal body length of the North Pacific sei whale.

Furthermore, small foetuses which were estimated to be fertilized in the spring and early summer, appear in the beginning of September. They biase the six-day units of mean body length towards smaller than the actual figures. In view of the above discussion, the foetal growth curve can be drawn using mean foetal body length per six-day units only until September of the sampling period.

In light of this fact, it assumes that the figures of the mode of mean foetal body length in September and October are more exact than those in each of the six-day units. Accordingly, the foetus of the North Pacific sei whale grows linearly until September as shown by LAWS (1959), GAMBELL (1968) and FRAZER and HUGGETT (1973). However, it is expressed by the two straight lines. The first of these lines runs through from February to April and the second connects the figures for the months from May to August. MATTHEWS (1938), GAMBELL (1968) for the Antarctic sei whale and FRAZER and HUGGETT (1973) for blue, fin, humpback, sei, gray, minke, sperm, pilot, white, etc. have reported that the foetal growth rates in these species are nearly a straight line except for the early stages of gestation.

On the other hand, LAWS (1959) reported that the first half of foetal growth of the northern hemisphere sei whale was linear, while the second part agreed quite well with an exponential growth rate. MATTHEWS (1938) drew a shallow curve through the early months of gestation to connect with the straight line joining the means of the later months for the Antarctic sei whales.

It is estimated that the growth curve of the North Pacific sei whales is not linear as reported by GAMBELL (1968) and FRAZER and HUGGETT (1973), but it is slightly sigmoidal as shown by LAWS (1959). Data on foetal growth prior to April for the North Pacific sei whale are not yet to be obtained in this writing except those converted from GAMBELL's data.

LAWS (1959) estimated the gestation period of the North Pacific sei whales on the basis of the time of conception and the point of intersection at which the linear growth phase crosses the X axis as shown in Fig. 3. This intersection has been termed " t_0 " by HUGGETT and WIDDAS (1951). The calculation deriving the first rapid linear growth phase in Fig. 2 is expressed as follows;

$$Y=0.79X-21.4$$

where, X=Nunmber of days (First January=0), Y=Foetal body length (cm).

The regression of foetal body length against number of days, when extrapolated backwards, intercepts the abcissa late in January. If the 36 days of LAWS' (1959) " t_0 " is applied to the length of gestation before the beginning of the linear growth phase, the mean date of conception for the North Pacific sei whales is estimated to be the late in December.

Furthermore, in estimating the time of mating, the author used the method of MACKINTOSH and WHEELER (1929) which is to calculate the number of foetuses between the two growth curves and then shift the mean foetal growth curve back and forth by a month (Fig. 4). With this calculation it is estimated that the major mating time coincides with the estimate made by foetal growth curve (Fig. 5). The mating season appears to extend over five months, from November to March. It can be seen from Figs. 4 and 5, however, that the frequencies of the numbers of pregnant whales before November (e. g., September and October) and af-

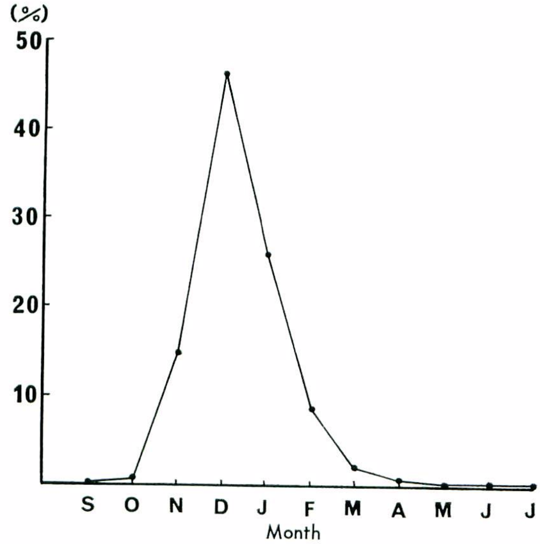


Fig. 5. Monthly frequency distribution of time of conception.

ter March (e. g., April, May, June and July) are lower than those of the other months.

MIZUE and JINBO (1950), and LAWS (1959) reported the average date of conception to be January and the third week in November, respectively, for the North Pacific sei whale. On the other hand, for the Antarctic sei whales, MATTHEWS (1938) and GAMBELL (1968) concluded that pregnancy starts in July and in the first week in June, respectively.

There is no reliable data on the length of birth for the North Pacific sei whale. MIZUE and JINBO (1950) estimated that the length at birth is 4.4 m based on the length of a stranded calf. TOMILIN (1957) also reported that sei whale of 427 cm in length, which had been caught in the China Sea appeared to be new born. The maximum foetal length recorded in this paper was 443 cm. MATTHEWS (1938) reported the length at birth to be 4.5 m for the Antarctic sei whale. This length is accepted by GAMBELL (1968). TOMILIN (1957) reported that possible new born calves are smaller in the northen hemisphere than in the southern hemisphere.

Refering the above estimates, it is quite reasonable to adopt 440 cm, in this study, as the length at birth for the North Pacific sei whale. Using this length and the foetal growth curve in Fig. 2, the mating time can be calculated to be the beginning of November.

The average date of birth of sei whales has been reported by many authors that it is the end of November (MIZUE and JINBO, 1950) and mid-November (LAWS, 1959) in the North Pacific, July (MATTHEWS, 1938) and the second week of June (GAMBELL, 1968) in the Antarctic.

Due to the lack of materials of late pregnancies of the North Pacific sei whales, further detailed examination of foetal growth is impossible at this time.

II-2 Sexual maturity

In understanding the life history of an animal, age at sexual maturity is one of the important parameters. In this Section, criteria for evaluating the sexual maturation of each sex are examined, then, discusses the characteristics of maturation for a large number of whales examined. Body length and age at sexual maturity were examined. Age was also estimated on the basis of the transition phase found in the growth layers of the ear plugs.

Specimen materials used in this Section were collected during the period of the 1952 to 1972 season including special materials taken by the author while aboard the Tonan maru in the 1968 season and the Kyokuyo maru No. 2 in the 1970 season.

II-2-i Sexual maturity of the female

(1) Criteria for evaluating sexual maturity

CHITTLEBOROUGH (1955b) reported that there is a pubertal stage for female humpback whale. That is, pubertal individuals can be recognized by the following state; young females whose ovaries contained at least one corpora albicantia while the mammary glands had not yet been functional, closely resembling the glands of immature females both in size and structure. Since few data for the condition of mammary glands of the North Pacific sei whales are available, puberty of them can not be established.

However, it is supposed that the greater part of female sei whales become pregnant at the first ovulation, so that sexual maturity of these females may roughly coincide with puberty. Therefore, sexual maturation of an individual is indicated by the presence of at least a corpus luteum or a corpus albicans in ovaries.

(2) Body length at sexual maturity

By use of 5, 830 whales as materials, the correlation of sexual maturity rate with body length for the entire North Pacific is shown in Fig. 6 which was drawn by freehand. The North Pacific sei whale attains sexual maturity at the body length from 12. 5 m to 14. 2 m, and it can be seen that 50% of the females achieved sexual maturity at a length of about 13. 4 m.

Many authors have reported on the body length at sexual maturity of sei whale; RICE (1963) reports 45 ft. (13. 7 m) off California, MATSUURA (1935a) reports 40 ft. (12. 2 m), OMURA (1950) and KASAHARA (1950) list 13. 7 m off the Japanese coast, and TOMILIN (1957) reports 12. 8 m to 13. 5 m in the northern hemisphere. RUUD (1937) reports one sei whale off Norway that was mature at 13. 1 m.

For the southern hemisphere sei whale, the mean length at sexual maturity has been also reported by various authors as follows; 45. 69 ft. (13. 9 m) (GAMBELL, 1968, off South Africa), 46. 33 ft. (14. 1 m) (GAMBELL, 1968, in the Antarctic), 47. 6 ft. (14. 5 m) (MATTHEWS, 1938, in the Antarctic), 47 ft. (14. 3 m) (MACKINTOSH, 1965, in the southern hemisphere). NASU and MASAKI (1970) reported the mean length at sexual maturity of the Antarctic sei whale for each Area from III to VI as follows; 45. 6 ft. (13. 9 m) in Area III, 45. 4 ft. (13. 8 m) in Area IV, 46. 8 ft. (14. 3 m) in Area V, 47. 4 ft. (14. 4 m) in Area VI and 46. 0 ft. (14. 0 m) for whole area. They also pointed out that there was a possibility of the difference of sexual maturity among stock units.

Moreover, MACKINTOSH (1965) said that it is clear that, in at least fin and sei whales, sexual maturity is reached at a significant smaller size in the northern hemisphere than in the southern one.

From above figures, the mean length of 13.4 m at sexual maturity of the North Pacific sei whale seems to be a reasonable estimate.

(3) Age at sexual maturity

Of sei whales caught by Japanese expeditions in the North Pacific during the period of

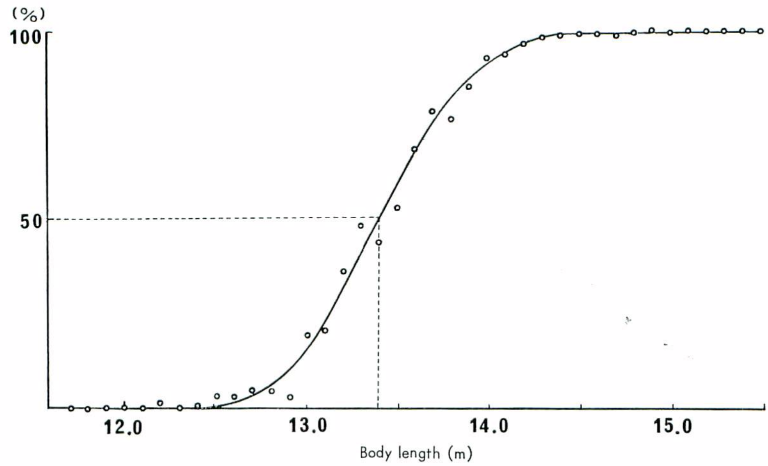


Fig. 6. Percentage of number of individuals of sexually mature female for each body length on sei whale in the North Pacific.

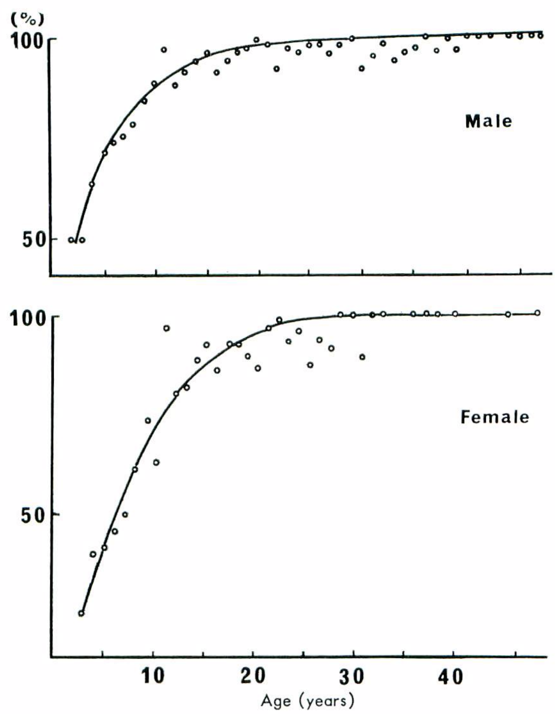


Fig. 7. Relation between age and rate of sexual maturity of the North Pacific sei whale.

1967 through 1972, 1,060 specimens of known age were evaluated for sexual maturity. The mean sexual maturity rate for females of each age group is shown in Fig. 7. The rate in each age group was fitted to a freehand curve and the mean age of sexually mature females (50%) was calculated to be 6. 5 years.

The ratio of the collection of ear plugs from immature whales is lower than that of mature animals (MASAKI, 1973). The ear plug sometimes lacks the neonatal and germinal layers, also the ear plugs of younger individuals are softer and smaller, and in many cases these layers may be difficult to recognize even microscopic examination (MASAKI, 1968; ROE, 1968). Taking the above factors into account, it is thought that the age of younger animals is often estimated less than that of the actual age.

For each Area in the North Pacific, the age at sexual maturity has been calculated from the correlation between age and number of ovulations as the age immediately after at which the number of ovulations is zero. Using this correlation, the age at sexual maturity for the entire North Pacific is calculated at 5. 2 years, for Areas III, IV and V, at 5. 3, 5. 4 and 5. 5 years, respectively. These ages may be more or less underestimated, because of the above mentioned difficulty of age determination.

II-2-ii Sexual maturity of the male

In analyzing the sexual maturity of individuals in this Section, the standards and criteria for evaluating sexual maturity of testicular tissue are examined from the histological point of view. Some useful characters in evaluating the sexual maturity to a large number of individuals were selected, and then a standard value was established for each character. The characters utilized in evaluating male sexual maturity are; penis length, an index of testis volume and the weight of the testis.

Most specimen materials used in this study were collected aboard the Kyokuyo maru No. 2 in the 1970 season.

(1) Maturity of testicular tissue

The simple presence or absence of spermatozoa in a seminiferous tubule was not utilized as a character of maturity due to the fact that the sampling was done during a summer season which was thought to be a sexually quiescent period. Because of this, sexual maturity was evaluated by examining the stages of development of spermatogenic cells as seen in the seminiferous tubules. The degrees of maturity are classified into three categories based on the diameter of the seminiferous tubules and the developmental aspects of the spermatogenic cells within them, as has been done in the studies of sperm whales (AGAUYO, 1963; BEST, 1969), humpback whales (CHITTLEBOROUGH, 1955a), and sei whales (GAMBELL, 1968). The categories are: (A) Mature condition; the interstitial cells of Leydig in a Lobuli testis are few. The diameter of the seminiferous tubules is large and they possess an open lumen. Spermatogonia, sustentacular cells of Sertoli and spermatogenic cells are in some stages of spermiogenesis in the seminiferous tubules (Plate I-A). (B) Immature condition; many interstitial cells of Leydig are in the Lobuli testis. The diameter of the seminiferous tubules is small and the lumen closed. The tubules consist of Sertoli cells and spermatogonia (Plate I-B). (C) Intermediate stage; both seminiferous tubules of maturity and immaturity are found in the Lobuli testis

(Plate I-C).

According to these criteria, the degrees of maturation of the North Pacific sei whale testicular tissue were evaluated. In order to simplify the judgement of the degrees of maturation of the testis, the relative diameter of the seminiferous tubules was used as an index, as in GAMBELL (1968).

Many discrepancies will be anticipated if sexual maturity is judged solely from histological aspect of the spermatid within the tubules. Sometimes a spermatid in the tubule is lost, particularly if the specimen was not fresh at the time of sampling, and the histological preparation was done poorly. Because of these facts, the evaluation of sexual maturity based on the measurement of the diameter of the tubules is useful to solve the problems of specimen preparation and to increase accuracy of evaluation.

According to the criterion of the degrees of sexual maturity described above, tissue samples taken from the dead center of the testis were classified into three categories. The specimens used for this purpose were 232 whales of the material shown in II-2.

The diameters of 20 seminiferous tubules which were nearly cylindrical, were measured with a micrometer in 1 μ and the mean diameters of the tubules was calculated for each testis examined.

Figure 8 shows the frequency distribution of the mean diameters of the tubules for each sexual state. In this Figure, it can be seen that the frequency distribution of the diameters of the immature whales are separated from those of the mature stage. The frequency distribution of the mean diameters of the intermediate stage can be seen to lie between the other two distributions. In view of these distributions the mean diameter of all the seminiferous

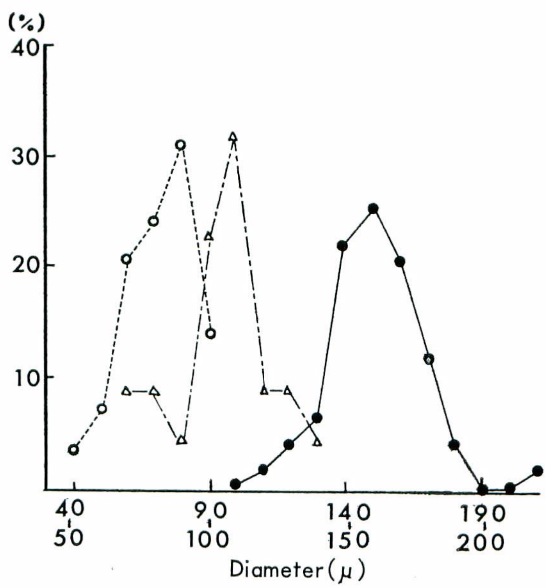


Fig. 8. Frequency distribution of the average seminiferous tubule diameters for each sexual state. Open circle and dotted line; Immature. Open triangle and chain line; Intermediate. Closed circle and solid line; Mature.

tubules will be over 110 μ. Table 1 shows the maximum, minimum and mean tubule diameter for each state of sexual development. It is estimated that the mean diameter of the tubules is less than 90 μ in animal of the immature state. This result is almost the same as that obtained from the southern hemisphere sei whale (GAMBELL, 1968).

Table 1. Minimum, maximum and mean seminiferous tubule diameter in μ for each sexual state of the North Pacific sei whale.

	Minimum	Maximum	Mean	Sample size
Immature	47.0	117.0	76.8	32
Intermediate	67.0	137.0	98.8	21
Mature	109.0	213.0	154.8	179

(2) Evaluation of the degree of maturity from the analysis of testicular tissue

BEST (1969) has pointed out that the state of sexual maturation of the testis tissue differs in various parts of the organ in his study of sperm whales. He has also reported that the mature tissue expands radially from the dead center to the periphery of the testicle. Individuals in which only the tissue of the dead center is mature, demonstrates a pubertal state which is shifting from immaturity to maturation. He also reported that testicular matuartion was complete when mature tissue is found all over the testicle.

In this study, the differences in the various portions of testes in all states of maturation were investigated, and then examined several sites of the testes to evaluate the sexual maturity of the sei whale.

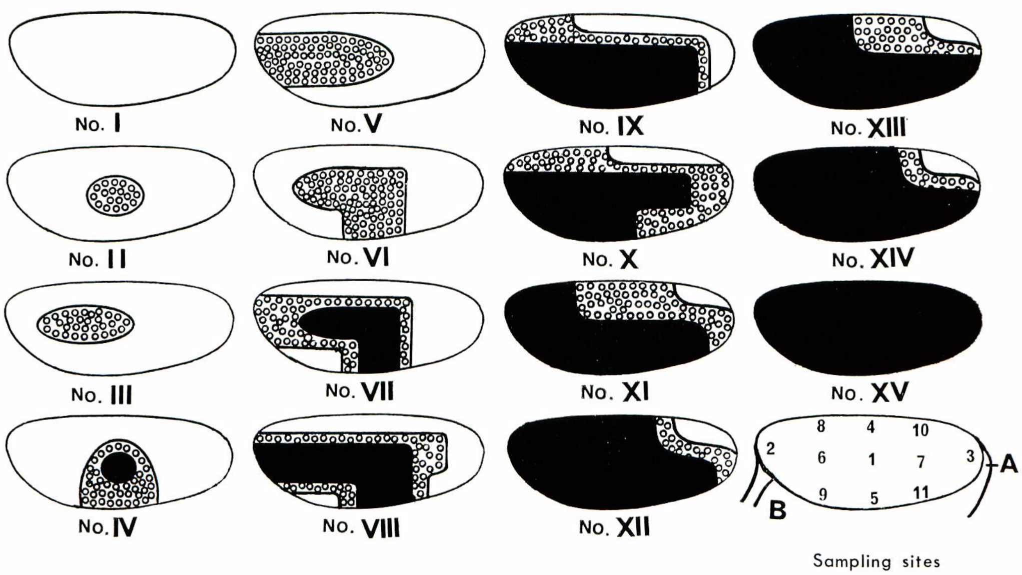


Fig. 9. Schematic presentation of the process of testicular maturation and sampling sites of the North Pacific sei whale. White; Immature. Small circle; Intermediate. Black; Mature. A; Caput epididymis. B; Cauda epididymis.

Twenty-nine specimens of the materials shown in II-2 were utilized in this Section, and as shown in Fig. 9, a maximum of 11 portions of testicular tissue were examined. The result of this study, that the tissue matures from the dead center to the periphery, is presented diagramatically in Fig. 9. However, the process of tissue maturation in sei whale testes differs from that of sperm whales. In the sei whale, the tissue does not mature radially, but rather from dead center to the posterior, then to the dorsal periphery, and finally the process of testicular maturation is completed with expansion of the mature tissue to the anterior ventrum of the organ. This last part to reach maturity is sampling site 10 shown in Fig. 9.

It is usually considered that a male sperm whale has achieved sexual maturity when the tissue of the periphery of the testis has matured (The International Whaling Commission, 1971). However, in view of the above studies, this criterion is not applicable to the case of sei whales. This is due to the fact that the different process of maturation of the testis, such as from the posterior to the anterior as well as from the dorsum to the ventrum of the organ is observed in sei whale.

Figure 10 diagramatically shows the course of the maturation process, which are expressed percentage distributions of mature, intermediate and immature against the index of maturation stages I through XV. The percentage distributions for the stages I to XV are determined by examination of the tissue from 11 sampling sites shown in Fig. 9.

The distribution of testicular tissue of the three sexual states of maturation confirmed by their occurrence at the 11 sampling sites is presented in Fig. 9. In the attainment of maturation, the matured portion of the tissue has to occupy about 75% of the whole testis as re-

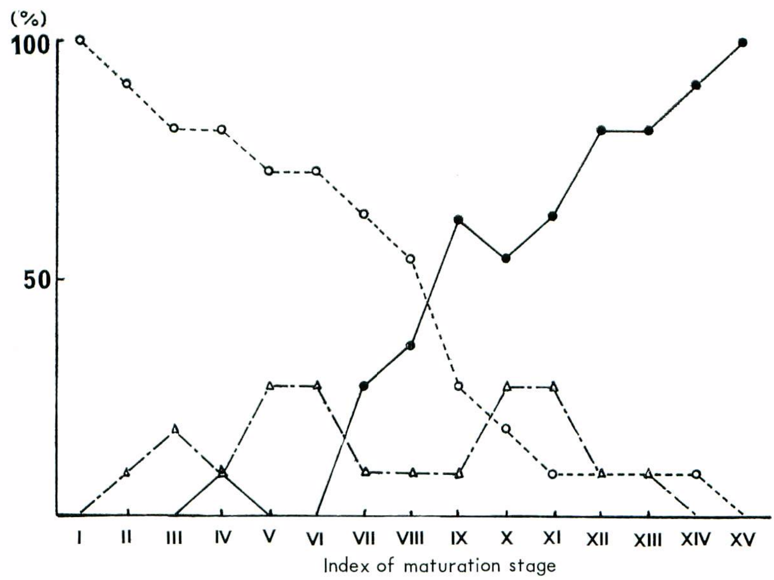


Fig. 10. Percentage distribution of testicular maturation by stage of development. Open circle and dotted line; Immature, Open triangle and chain line; Intermediate, Closed circle and solid line; Mature.

presented by stages XI and XII. A male animal being in this level of development is considered to have attained sexual maturity and to participate in breeding behaviour, although the tissue at sampling site "10" is immature. However, the tissue of sampling site "4" develops either into mature or into intermediate state.

In view of this fact it is concluded that the tissue at sampling site "4" being either the mature state or the intermediate state can be used as the criterion for maturity of the male North Pacific sei whale.

The sexually developmental stage of the testes of pubertal individuals is defind as; tissue at sampling site "1" being either the mature or the intermediate state and simultaneously tissue at sampling site "4" is the immature state. Finally, the developmental stage of the testes of immature individuals is defined as; tissue at sampling site "1" is the immature state.

Therefore, evaluation of the various states of maturation can be done by examining the tissue at sampling sites "1" and "4".

(3) Characters and criteria in the evaluation of sexual maturity

Examination of testicular tissue causes inconvenience to the determination of the sexual development for a large number of individual. In this study, the characters of penis length, an index of testis volume and the testis weight were utilized in judging whether or not an animal was sexually mature. In order to simplify the evaluation of sexual maturity, it is important to establish external characters which are easily recognizable and measurable. In view of the fact that the penis of most male sei whales is exposed at the time of capture, its measurement has proven to be a useful character.

The penis length of 162 male sei whales was measured from base to tip when the animals were drawn up on the deck of the whaling factory ship. The relationship of penis length to body length is shown in Fig. 11. The penis length of the North Pacific sei whale

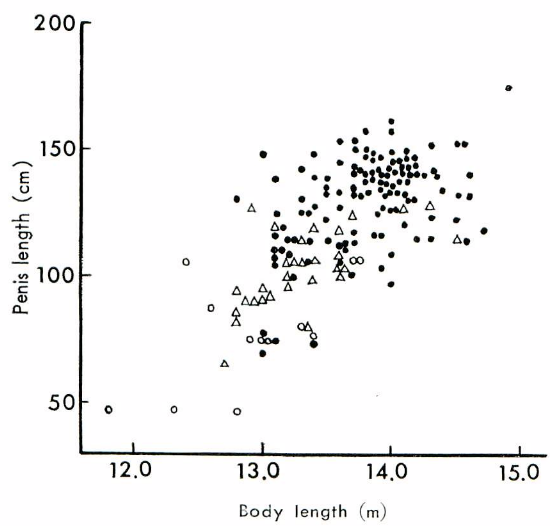


Fig. 11. Relationship between body length and penis length. Open circle; Immature. Open triangle; Intermediate. Closed circle; Mature.

Table 2. Minimum, maximum and mean penis length in cm for each sexual state of the North Pacific sei whale.

	Minimum	Maximum	Mean	Sample size
Immature	46.0	106.0	77.6	12
Intermediate	65.0	128.0	102.9	30
Mature	70.0	174.0	130.0	120

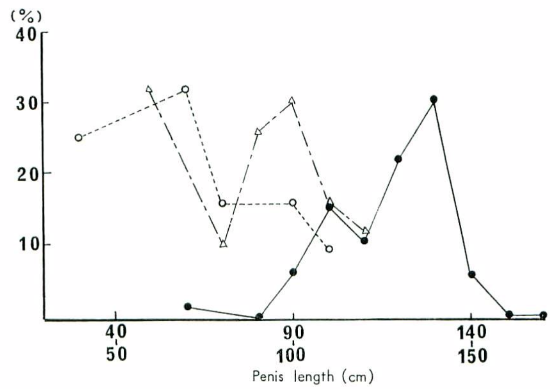


Fig. 12. Frequency distribution of penis length for each sexual state of the North Pacific sei whale. Open circle and dotted line; Immature. Open triangle and chain line; Intermediate. Closed circle and solid line; Mature.

increases with increasing body length, as in the case of the Antarctic sei whales (MATTHEWS, 1938; GAMBELL, 1968). The relationship does not show a definite trend because of the lack of data for small sized individuals. However, it shows a sudden increase in size, at about 13.0 m of body length when it is some 100 cm in length. Penis length ceases to grow at 14.0 m of body length and is fixed at an average of 130 cm in length.

The range of penis length tabulated for each sexual state is shown in Table 2 and its frequency distribution is shown in Fig. 12.

From Table 2 and Fig. 12, it can be seen that the ranges of penis length of immature and mature whales overlap each other. It should be noted that the ratio of mature whales to immature ones is 1 : 1 at 100 cm of penis length. In view of this, the evaluation of sexual maturity of the North Pacific sei whale can be made by a penis length of 100 cm. This result is almost the same as that obtained from the Antarctic sei whale. GAMBELL (1968) reported that a penis length of one meter or greater was a rough indication of sexual maturity. As the measuring error of penis length is unavoidable its standard value covers a wide range of testicular development, and should be regarded as having a low accuracy in determining sexual maturation.

MACKINTOSH and WHEELER (1929) for the Antarctic blue and fin whales, OMURA (1950) for the North Pacific sei whale, CHITTLEBOROUGH (1955a) for the Antarctic humpback whale and MATTHEWS (1938) and GAMBELL (1968) for the Antarctic sei whale have reported a sud-

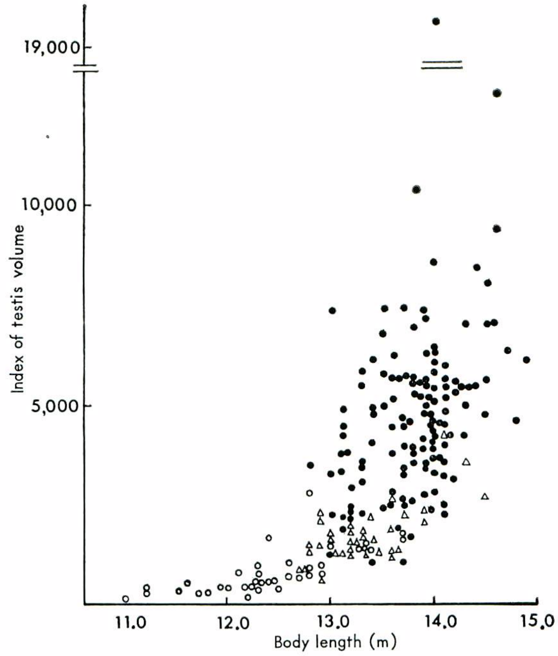


Fig. 13. Relationship between body length and index of testis volume. Open circle; Immature. Open triangle; Intermediate. Closed circle; Mature.

Table 3. Minimum, maximum and mean index of testis volume for each sexual state of the North Pacific sei whale.

	Minimum	Maximum	Mean	Sample size
Immature	78.0	1,705.0	702.0	38
Intermediate	677.0	4,208.0	1,922.0	35
Mature	990.0	19,602.0	5,122.1	131

Index of testis volume: the product of length, breadth and depth of the testis.

den increase in testis volume on attaining sexual maturity. It was presumed that these phenomena would appear in the North Pacific sei whale. An index of testis volume was calculated for 204 North Pacific sei whales, by multiplying length, breadth and depth of the organ as was done by MACKINTOSH and WHEELER (1929).

Figure 13 shows the relationship between body length and the index of testis volume for each sexual state. It can be seen that the index of testis volume increases suddenly at a body length of 13.0 m. The index of testis volume increases slowly with increasing body length in both the immature and the pubertal states. In contrast, on attaining sexual maturity, the testis volume increases suddenly and also individual differences become conspicuous and large (Table 3).

Figure 14 shows the relationship between the index of testis volume and its frequency for each sexual state of testicular development. The mode of the frequency distribution of the

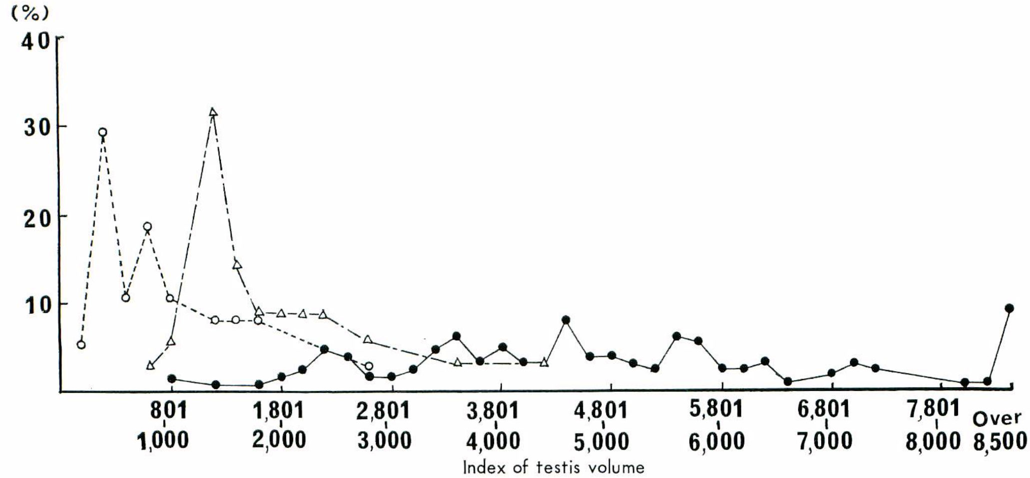


Fig. 14. Frequency distribution of the index of testis volume for each sexual state. Open circle; Immature. Open triangle; Intermediate. Closed circle; Mature.

index of the immature testis volume is located between 201 and 400. The mode for pubertal whales is seen between 1, 201 and 1, 400. However, the mode of the frequency distribution of the index for the mature whales is not a single but rather multiple. The first of these modes is located between 2, 201 and 2, 400. The index of the testis volume increases when the animal attains the pubertal state, however, the point at 50% sexual maturity does not coincide with the mode of the frequency distribution of the pubertal animal and this figure is a little larger than that of the mode.

In view of this discussion, the index of testis volume at sexual maturity of the North Pacific sei whale is considered as being more than 2, 000. This result is as same as GAMBELL's (1968) one. That is, GAMBELL (1968) reported that over a size of 2 liters nearly all the testes are mature or pubertal for the Antarctic sei whale. On the other hand, OMURA (1950) noted a sudden increase at testis volume of 1, 500 cc of sei whales taken in Japanese coastal waters and considered individuals which have a volume greater than 1, 500 cc as matured. However, these results were not based on a histological examination of the testicular tissue, in addition, materials of Bryde's whale were included in the study, consequently they can not be compared with present one.

As shown in Fig. 15, the weight of larger testis of a pair of testes of individuals of the North Pacific sei whele increases with increasing body length. Materials used in this Section are from a total of 7, 067 whales which were caught by Japanese expeditions from the 1968 to 1971 season, and from a total of 571 whales caught by Japanese coastal whaling stations from the 1959 to 1965 whaling season.

The relationship between body length and the weight of the testis of all the materials is shown in Fig. 15 and the relationship between body length and the mean weight of the testis is presented in Fig. 16. As shown in Fig. 16, the weight of the testis of individuals of 12. 3 m to 13. 2 m of body length increases suddenly. If such a sudden increase in the

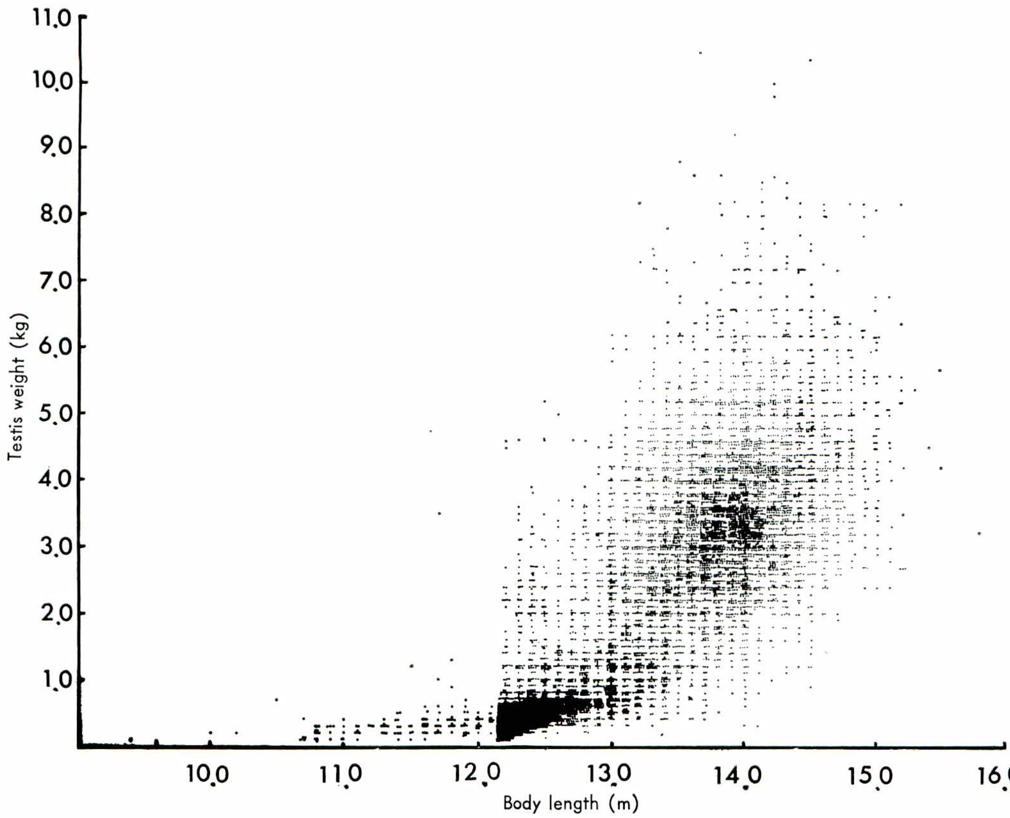


Fig. 15. Relationship between body length and the weight of larger testis of a pair of testes of the North Pacific sei whale.

mean testis weight indicates the attainment of sexual maturity, the body length at sexual maturity will be included in the range mentioned above. Similar facts have been reported by various authors for various species of whale; OMURA (1950), the North Pacific sei whale; JONSGÅRD (1951), minke whale; NISHIWAKI, *et al.* (1954), Bryde's whale; CHITTLEBOROUGH (1955a), humpback whale; GAMBELL (1968), the Antarctic sei whale; RICE and WOLMAN (1971), gray whale.

However, the testis weight at sexual maturity can not be simply derived from the relationship of body length to testis weight due to the fact that the range of the testis weight is wide.

Table 4. Minimum, maximum and mean testis weight in Kg for each sexual state of the North Pacific sei whale.

	Minimum	Maximum	Mean	Sample size
Immature	0.1	1.7	0.48	36
Intermediate	0.4	2.1	1.40	38
Mature	0.6	14.0	2.81	134

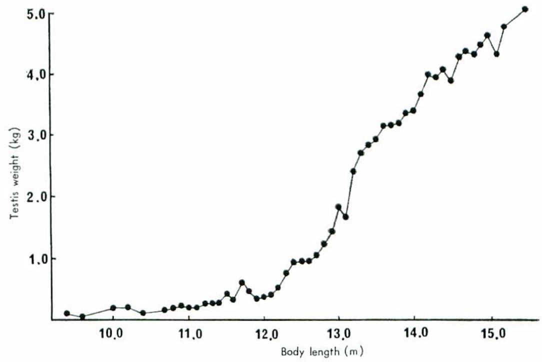


Fig. 16. Relationship between body length and mean testis weight of the North Pacific sei whale.

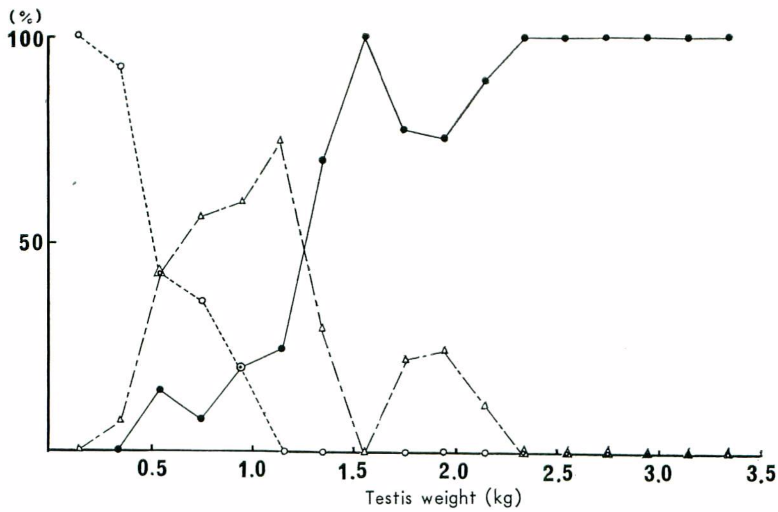


Fig. 17. Ratio to the testis weight by maturity state. Open circle; Immature. Open triangle; Intermediate. Closed circle; Mature.

Figure 17 shows the ratio of each maturation state, histologically examined, to the respective testis weight of the materials studied in II-2. Table 4 presents the maximum, minimum and mean testis weight of each maturation state. The testis weight at 100% immaturity and 100% maturity is less than 0.2 kg and more than 2.4 kg, respectively. Testis weight at 50% of puberty corresponds to that of the same ratio of immature individuals as well as the other maturation states. That is to say, it is equivalent to 0.55 kg (Fig. 18). Testis weight at 50% maturity corresponds to the value at which the ratio of mature individuals is equal to that of the intermediate sexual state, and is equivalent to 1.3 kg (Fig. 17). It should be remembered that the testes of pubertal individuals include a combination of immature and mature testicular tissue. The mean testis weight of the pubertal animals is represented by the point at which each ratio of the left and right hand side of the mode of the frequency distribution (Fig. 17) of the pubertal testis weight is equal and it is equivalent to 0.88 kg. Furthermore, the point at which the ratios of immature and mature whales are equal in testis weight is 0.88 kg. On the basis of these results, the testis weight heavier than 0.9 kg can be applied as a standard for evaluating sexual maturity.

According to OMURA (1950), sexual maturity of the North Pacific sei whale was recognized by the testis weight of 1.0 kg from which a sudden increase in testis weight in relation to body length was observed. The testis weight of sexually mature sei whales reported by OMURA (1950) is almost the same that obtained from the present study.

The testis weight of the sei whale at maturity is heavier in the Antarctic than in the North Pacific according to the fact that the weight more than 1.5 kg was obtained from mature or pubertal male in the Antarctic (GAMBELL, 1968).

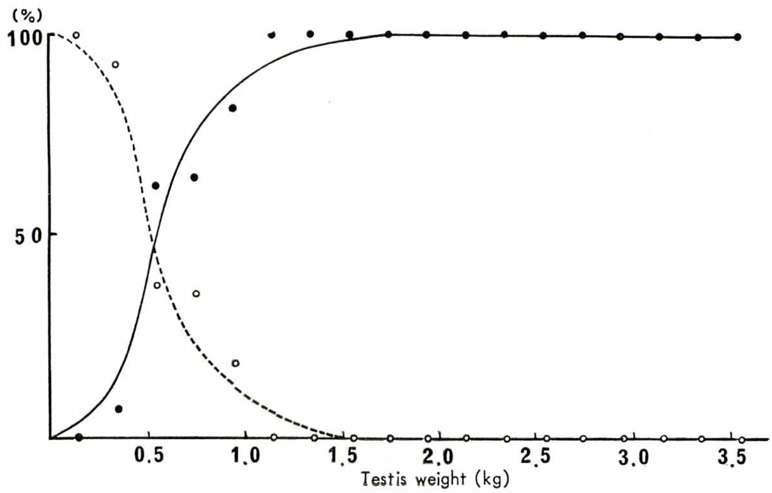


Fig. 18. Ratio of individuals of immature and others to testis weight. Open circle; Immature. Closed circle; Intermediate and mature.

(4) Body length at sexual maturity

Figure 19 shows the percentage distribution of each maturation state to body length. The body length at 50% of puberty is located at the point where the ratio of immature whales and that combined other two maturation states are equal to each other, that is to say, 12.7 m of body length. The body length at which 50% of mature male whales were observed is 13.2 m, and the mean body length at sexual maturity is estimated at 12.9 m (Figs. 19 and 20).

Body length at sexual maturity for male sei whales in the North Pacific has been reported by various authors as follows; 42 ft. (12.8 m, RICE, 1963, off California), 13.1 m (OMURA, 1950 and KASAHARA, 1950, off Japan) and 12.0 m (TOMILIN, 1957, for the northern hemisphere).

On the other hand, many authors also reported the mean length at sexual maturity for the Antarctic sei whales as follows; 44 ft. (13.5 m) (MATTHEWS, 1938), 45 ft. (13.7 m) (MACKINTOSH, 1965), 44.45 ft. (13.5 m) (for South Africa sei whale), 43.69 ft. (13.3 m) (GAMBELL, 1968), 43.4 ft. (13.2 m) in Area III, 42.3 ft. (12.9 m) in Area IV, 43.5 ft. (13.3 m) in Area V, 43.5 ft. (13.3 m) in Area VI and 43.5 ft. (13.3 m) in whole area in the Antarctic sei whale (NASU and MASAKI, 1970).

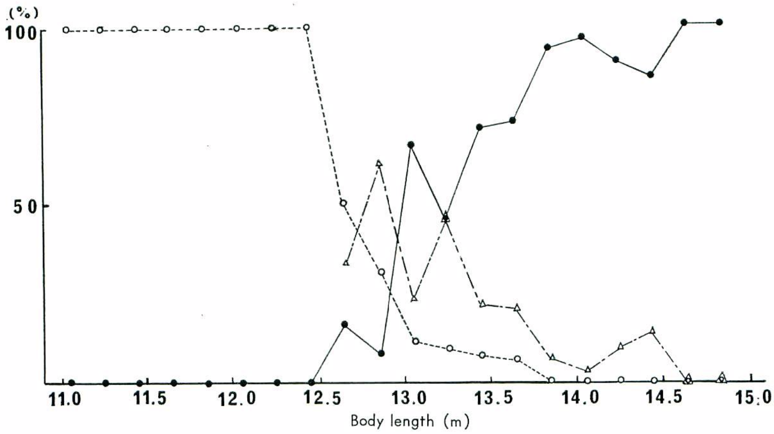


Fig. 19. Ratio of individuals of each maturation state to body length. Open circle; Immature. Open triangle; Intermediate. Closed circle; Mature.

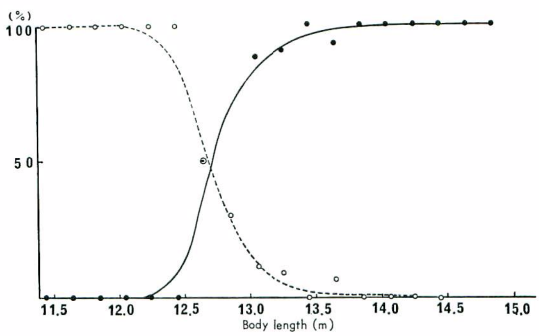


Fig. 20. Ratio of individuals of immature and others to body length. Open circle; Immature. Closed circle; Intermediate and mature.

(5) Age at sexual maturity

The standard value of 0.9 kg as a sexually mature testis weight has been determined by the histological examination of the states of maturation. Figure 7 shows the rate of sexual maturity to the age for a total of 1,924 sei whales. Although the age at 50% of sexual maturity was estimated to be 2.5 years from Fig. 7, this age might not be correct as discussed the case of the females previously.

II-3 Physical maturity

The examination for fusion of vertebral epiphyses to the centra of the thoracic vertebra is used as the criterion in evaluating the physical maturity of whales. OHSUMI *et al.* (1958), in investigating physical maturity of the North Pacific fin whale, found gradients from the anterior end of the column to the thoracic segment, and simultaneously from posterior to anterior of the vertebral column. The result suggests that epiphyseal fusion to the centrum takes place lastly in the thoracic segment. The author examined the middle thoracic vertebrae in studying epiphyseal fusion on the assumption that the similar gradient of anterior-posterior occurs in sei whales.

Specimens used were thoracic vertebrae of 97 male and 92 female sei whales, collected by Japanese expeditions in the 1969, 1970 and 1973 seasons.

II-3-i Body length at physical maturity

The distribution of physically mature whales for each body length is presented in Fig. 21. It can be seen from the Figure that the body length, at which 50% of the individuals of each sex reaches physical maturity, is 15.2 m in females and 14.3 m in males.

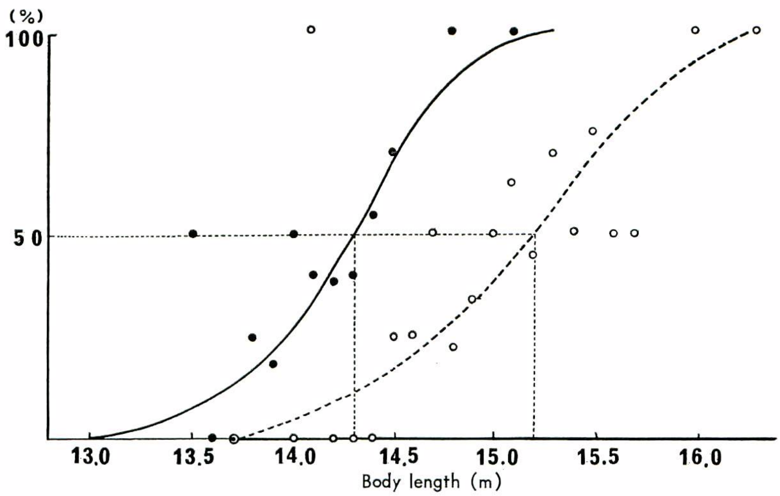


Fig. 21. Body length at physical maturity for each sex. Open circle; Female. Closed circle; Male.

II-3-ii Age at physical maturity

The number of specimens available for age determination by the examination of physical maturity is not many (46 out of 97 for male whales and 37 out of 92 for female whales), furthermore, the rate of physical maturity for both sexes by each age varies considerably. In addition, the difficulties of age determination based on ear plug studies were also experienced (MASAKI, 1968, 73; ROE, 1968), therefore, age at physical maturity of both sexes of the North Pacific sei whale could not be determined directly.

Figure 22 shows the relationship between the number of ovulations and the percentage of physically mature female animals. Fifty percent of physically mature animals possesses 12 ovarian corpora and this figure corresponds to about 25 growth layers in the ear plug as calculated by the relationship between age and the number of ovulations discussed in Chapter III.

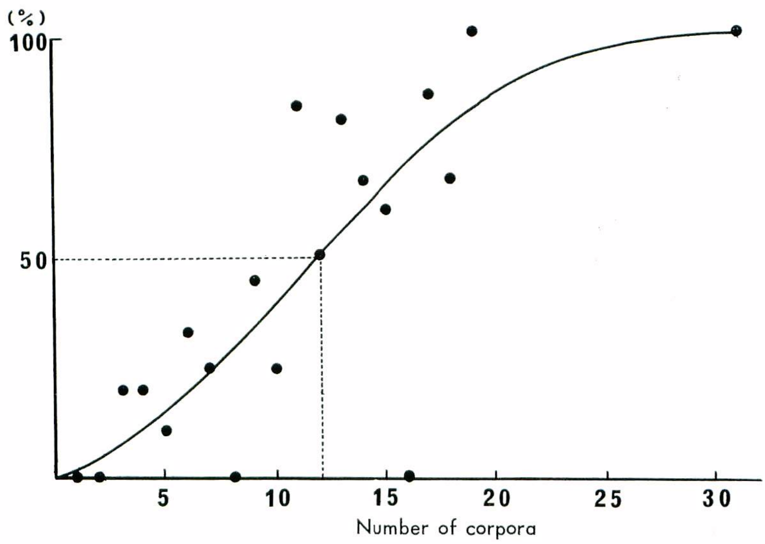


Fig. 22. Number of ovulation at physical maturity.

II-4 Age at sexual maturity based on ear plug studies

Studies of the ear plug of the fin whales demonstrated that the number of laminae from the neonatal layer to the marked constriction in breadth of an ear plug lamina indicates the age of sexual maturity (ICHIHARA, 1966). This constricted lamina has been termed the "transition phase" by LOCKYER (1972). A similar sudden constriction in breadth of growth annuli has been reported in the studies of teeth and bone of seals (KLEVEZAL and KLEINENBERG, 1967). As the transition phase in the ear plug laminae of the North Pacific sei whale was recognizable, a estimate of age at sexual maturity utilizing the transition phase criterion was made for 188 male and 151 female sei whales taken by Japanese expeditions in the 1968 to 1973 seasons in the North Pacific. Figure 23 shows the presumptive age at sexual maturity of these whales by the year classes of birth. It can be readily seen in this Figure that the age at sexual maturity for both sexes to each year class varies considerably. The mean age at sexual maturity born prior to 1930's is approximately ten years, while it has been decreasing slowly year to year, and it becomes 6-7 years since 1960's in both sexes.

As can be seen in Fig. 23 the age at sexual maturity has been changing since 1920's. Similar trend is also observed in southern sei whale (GAMBELL, 1968) and in southern fin whale (LOCKYER, 1972). Since the regular catch of sei whale started in 1960's in the North Pacific, this change in mature age cannot be explained as the reaction upon the change in population level of the sei whale itself, but may associate with the decline of population of right whales during last century (MITCHELL, 1974) and blue whales in the beginning of this century.

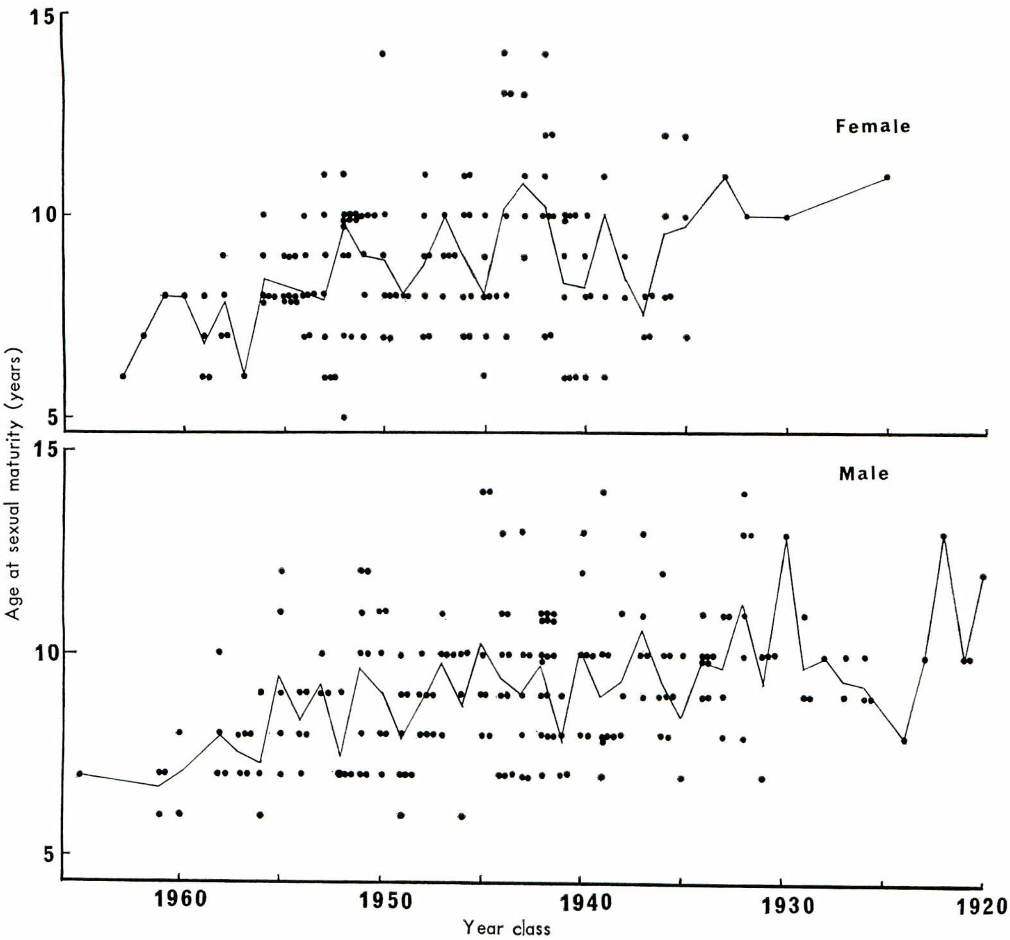


Fig. 23. Age at sexual maturity for each year class by sexes as determined by the transition phase.

II-5 Growth curve

A reliable method of age determination for the North Pacific sei whale has not been firmly established yet (The International Whaling Commission, 1969; ROE, 1968; MASAKI, 1968, 73). Furthermore, the lack of data on late gestation periods and immature animals makes it difficult to determine a complete growth curve. The materials used in this Section are almost the same as those treated in II-2. The mean body length shown in Fig. 24 represents the figure of the mode of body length composition to each age class. In attempting to fit representative values for a growth curve, the mean body lengths of age classes less than 10 years old in males and less than 5 years in females were omitted from the estimated sigmoidal growth curve. Nevertheless, considering the fact that the age of younger individuals is apt to estimate under as stated in II-2-i, two growth curves were presented in order to compensate biased and insufficient data.

Useful information relate to the early growth of sei whale was obtained from the pair of cow and calf caught at 44°14′–17′N, 174°50′–55′E on 2 June 1968 under a special permit for whaling issued by the government to the Whale Research Institute, Tokyo, Japan. The cow was 14. 1 m long, possessed five corpora albicantia in the ovaries, and the thickness of the mammary glands and blubber was 15. 0 cm and 4. 0 cm, respectively. The mammary glands contained milk tinged with yellow. While, the fact that not a large quantity of milk or curd

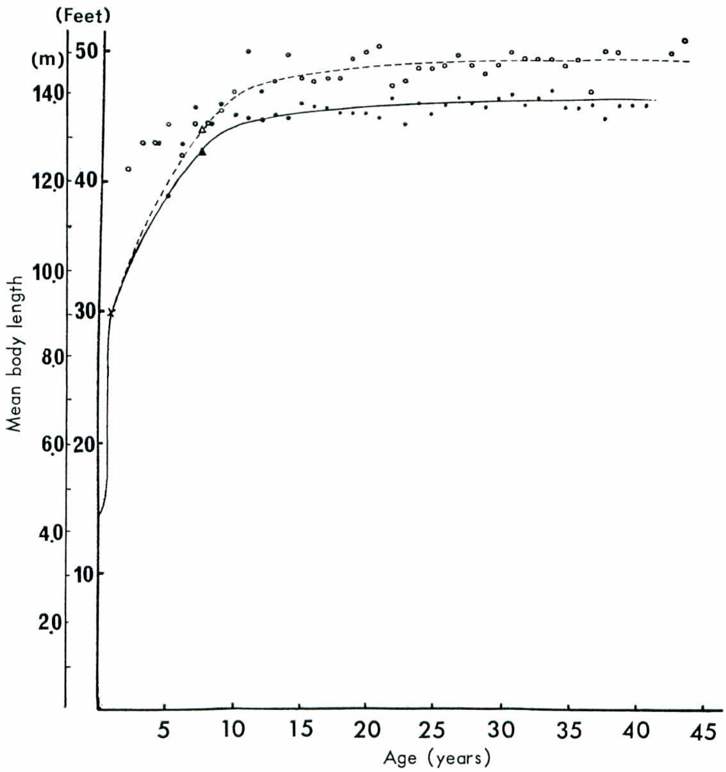


Fig. 24. Growth curve of the North Pacific sei whale. Open circle and dotted line; Female. Closed circle and solid line; Male. Open and closed triangles; Age and body length at sexual maturity of female and male, respectively. ×; Age and body length at weaning.

but a few *Calanus cristatus* was found in the stomach indicates the commencement of feeding of the calf. Considering the lactating condition of the cow and the weaning mark which remained on the baleen plates of the calf, it was presumed that nursing would stop when the calf grew to 9. 0 m in body length. In view of these findings, the period of lactation is estimated about 7 months as will be discussed in Chapter III.

Although the data of growth from birth to 5 years old in the female and 10 years in the male are insufficient, in addition, the age of younger individuals is apt to estimate under, the early growth curve for both sexes can be determined from the body lengths at birth, weaning and sexual maturity as shown in Fig. 24. The growth becomes very slow for the individuals older than 15 years in both sexes. While the body lengths at physical maturity of males and females were estimated as 14.3 m and 15.2 m, respectively, but the age at physical maturity was not definite in the male. Then, combining the growth curve and body length of physically mature whales, the age that physical maturity is attained is conjectured between 25 and 30 years of age. An intensive collection of the ear plugs and improvement of methods for age determination, particularly of animals less than 15 years of age are necessary for understanding the life history of the North Pacific sei whale.

III. Reproduction

The factors relating to the reproduction of the North Pacific sei whale such as the periods of gestation, lactation and resting are discussed in this Chapter.

The materials used in these studies were collected largely aboard the Kyokuyo maru No. 2 during the 1970 whaling season. The items of data collected are; status of lactation, thickness of the mammary glands, diameters and number of the corpora albicantia, breadth of the uterine horns, thickness of the blubber and body length of the foetus.

III-1 Gestation period

Gestation period is defined as the time from conception to birth. It was estimated in Section II-2 that the mean dates of mating and parturition are the late in December and early in November, respectively. So that, the mean period of the gestation is estimated to be 10.5 months for the North Pacific sei whale.

MIZUE and JINBO (1950) reported that the gestation period for the North Pacific sei whale was less than 11 months. LAWS (1959) reexamined the gestation period using the data of MIZUE and JINBO (1950) and estimated the gestation period at almost 12 months. TOMILIN (1957) reported that the gestation period of the northern hemisphere sei whale was almost one year.

On the other hand, MATTHEWS (1938) and GAMBELL (1968) reported that the total gestation period was almost exactly 12 months for the Antarctic sei whale.

One of the reasons for such difference in the gestation period of sei whales, as mentioned above, depends on the difference in the shape of foetal growth curve adopted.

III-2 Lactation period

The greater part of the materials were obtained in the main pelagic whaling season, between the late in May and August. Therefore, materials in winter are lacking in this study, and there are not so many materials representing the lactation period in spring. The most direct method to understand the lactation period would be to examine the suckling calf. However, the capture of a cow with calf is prohibited by the International Whaling Convention, therefore, actively lactating whales are not canght by the whaling industry in principle. Occasionally, a small number of lactating whales are taken during the pelagic whaling season, but information whether or not these animals are accompanied by a calf is currently not available. Only one cow with calf has been examined by the operation under special permit as described in II-5.

The judgement whether or not a female is nursing is decided by the quantity and color of milk in the mammary glands. However, on some occasions, it has been found that the greater part of the milk had been expressed before had pulled the whales up the deck. The causes of squeezing milk from the mammary glands are to be sought in inflating the captive whales by compressed air coupled with fastening them on the catching vessel, and in bumping them against the side while towing them to the factory ship. For these reasons, it is difficult in many cases to evaluate the state of lactation by the examination of color and viscosity of milk.

In this Section, the thickness of mammary glands, breadth of the uterine horns, the diameter of the largest corpora albicantia and the thickness of the blubber were examined in order to find out the indices in evaluating the state of lactation. In addition, the time of termination of suckling was estimated using the indices obtained from the above studies and the monthly change in the number of cow with calf sighting by Japanese catcher boats.

III-2-i Criteria in the evaluation of lactation

Determining the nursing status of female whales is difficult as mentioned above using only specimen materials of the cows, but in this paragraph, the lactating whale is regarded as a nursing cow. There are two distinct states in a lactation period, that is, one is active lactation state and the other is late lactation state, and in both there is milk in the mammary glands. The states are determined on the basis of the volume and color of the milk and its viscosity. Generally, the milk in late lactation state has following properties, that is to say, the quantitiy is a small, the color is tinged with yellow and it is relatively sticky. The thickness of the mammary glands was measured in the central part in units of 0.5 cm. Figure 25 shows the frequency distribution of mammary glands thickness in four reproductive states; lactating, resting, pregnant and sexually immature. Further, the mean thickness of the mammary glands for each of the states is presented in Table 5. It can be seen in Fig. 25 that the thickness of the gland of actively nursing whales is more than 8 cm, and in late lactation period the gland is less than 8 cm in thickness, as same as other states mentioned above. The frequency distribution of the thickness of mammary glands of actively nursing

Table 5. The range, mode, and mean on the thickness of mammary glands for each physiological state of the North Pacific female sei whale.

Physiological state	Active lacation	Late lactation	Pregnant	Resting	Immature
Range (cm)	9-2	1-8	3-5	2-4	1-3
Mode (cm)	11.0	5.0	3.0	3.0	1.0
Mean (cm)	12.0	4.6	3.0	2.6	1.3
Sample size	73	11	95	11	63

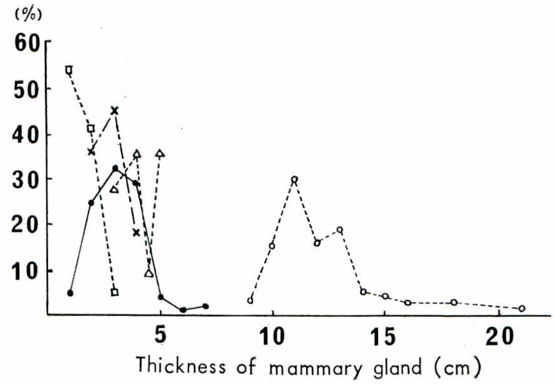


Fig. 25. Frequency distribution of the mammary gland thickness in four physiological states. Open circle and dotted line; Active lactation. Open triangle and dotted line; Late lactation. Closed circle and solid line; Pregnant. Open square and dotted line; Immature. Cross and chain line; Resting.

whales during May to September ranges between 9.0 cm and 21.0 cm with its mode at 11.0 cm. These figures are somewhat larger than those of the Antarctic sei whale (the thickness ranging from 6 to 13 cm with a mode at 10 cm) (GAMBELL, 1968). Further, the present estimate of the thickness of actively lactating mammary glands of 11.0 cm is about a half of that of the Antarctic fin whale (LAWS, 1961).

Figure 26 presents a relationship between the thickness of mammary gland and that of blubber. The regression can be expressed as follows;

$$Y=-0.11X+6.98$$

where, Y=Thickness of blubber (cm), X=Thickness of mammary gland (cm).
This equation shows that the thickness of blubber decreases with an increasing thickness of mammary glands in actively nursing females.

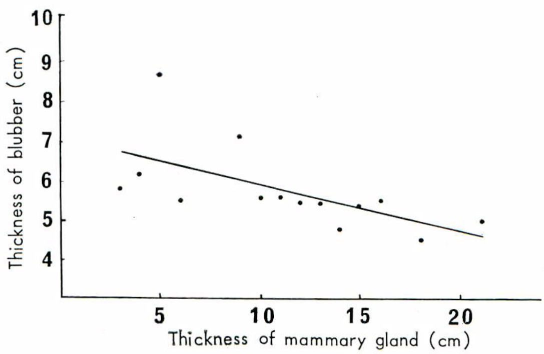


Fig. 26. Regression relationship between the thickness of mammary gland and the thickness of blubber.

Figure 27 shows the frequency distribution of the blubber thickness of lactating and of pregnant whales by month. The thickness of blubber of pregnant whales shows a continuous increase from May to August, but that of lactating whales does not show any remarkable change in May and June, however, slight increase is observed during July to August. In light of this, it is probable that the lactating whales arrive on the feeding grounds from May to June, though they begin to wean from July.

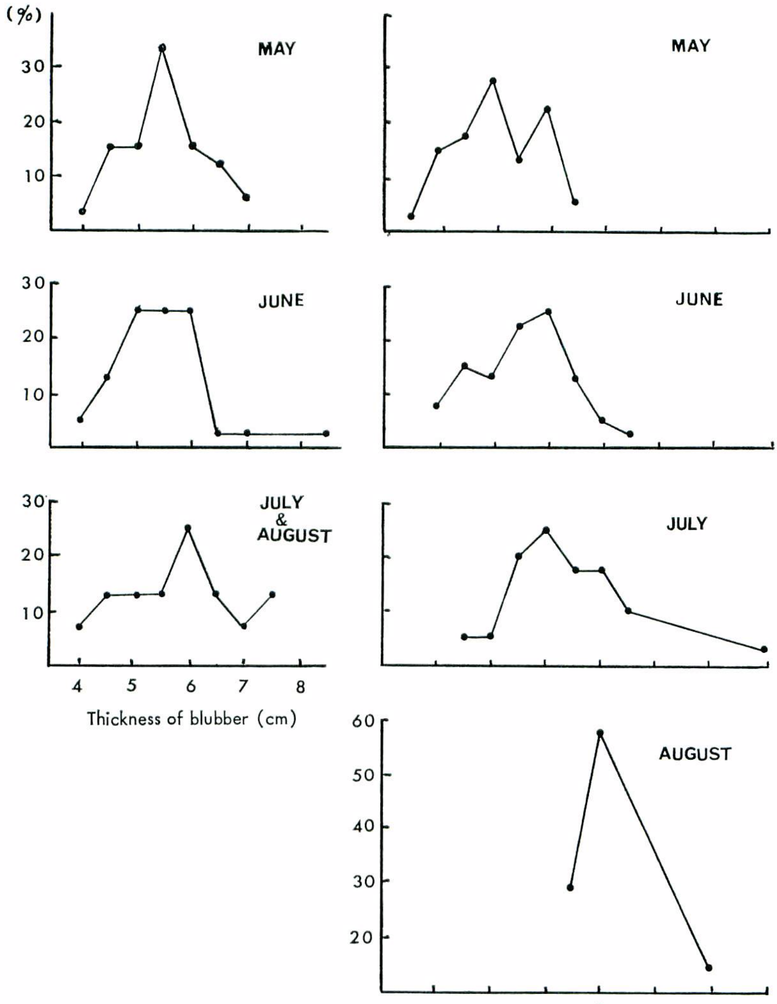


Fig. 27. Frequency distribution of the blubber thickness of lactating and pregnant whales by month. Right; Pregnant whale, Left; Lactating whale.

The corpus luteum constricts into a corpus albicans after parturition, and its diameter becomes smaller with the lapse of time. It should be remembered that the corpus albicans is retained throughout the life of the female (Fig. 28). It has been mentioned that any small or old corpora albicantia persist through life in the ovaries of various species of whale

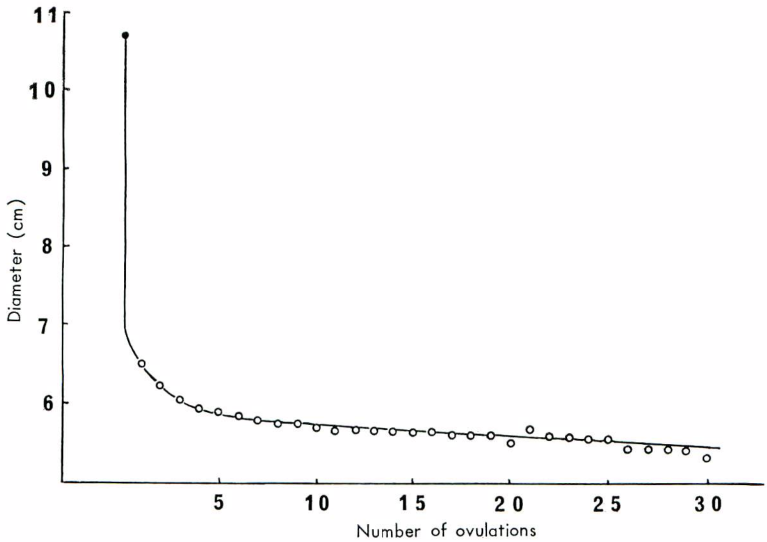


Fig. 28. Relation between mean diameter of corpora lutea and albicantia in ovaries and the number of ovulations of the North Pacific sei whale. Closed circle; Corpus luteum. Open circle; Corpus albicans.

(LAWS, 1961, for the Antarctic fin whale; BEST, 1967, for sperm whale; GAMBELL, 1968, for the Antarctic sei whale; RICE and WOLMAN, 1971, for gray whale).

Figure 29 shows a relationship between the thickness of mammary glands of lactating whales and the diameter of the largest corpus albicans.

The correlation is expressed by the following equation;

$$Y=0.1X+2.0$$

where, Y=The diameter of the largest corpus albicans (in cm), X=The thickness of mammary glands (in cm).

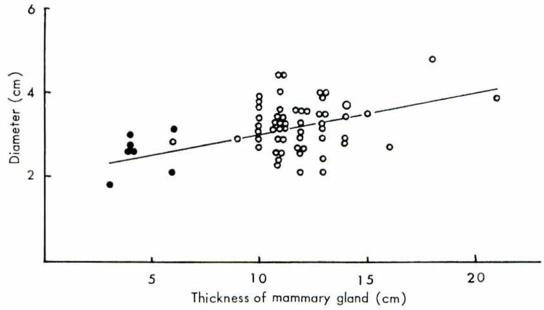


Fig. 29. Regression relationship between the thickness of mammary gland of lactating whales and the diameter of the largest corpora albicans. Open circle; Active lactating whale. Closed circle; Late lactating whale.

The diameter of the largest corpora albicantia in lactating whales ranges from 2.1 cm to 4.8 cm with the mean value of 3.9 cm. The process of shrinkage of the post-partum corpus albicans is slow and shows a largely individual variation. Accordingly, it is very difficult to judge whether a cow is lactating or not by the diameter of the largest corpora albicantia.

The uterus of whales comprises two uterine horns. The incidence of twinning or multiplet pregnancies is very rare (Chapter IV). Sometimes a foetus exists in each of the uterine horns on the occasion of multiplet. In case of single birth, the widths of the right and left uterine horns are different even in lactation period, though the uterus shrinks after birth. The relationship between the thickness of the mammary gland and the difference in width of the left and right uterine horns is shown in Fig. 30. The difference of 5.0 cm in width between the two uterine horns divides the lactating whales into two groups. Although the difference in width between the two uterine horns varies according to the elapsed time after parturition, it demonstrates that the contraction of the uterus takes place much more qnickly than the degree of decreasing the thickness of mammary glands or the shrinkage of the diameter of the largest corpus albicans. Difficulties are encountered in estimating the end of lactation by the difference in width between the both horns of uterus, however, the whales possessing more than 5.0 cm of the difference are seemed to be lactating.

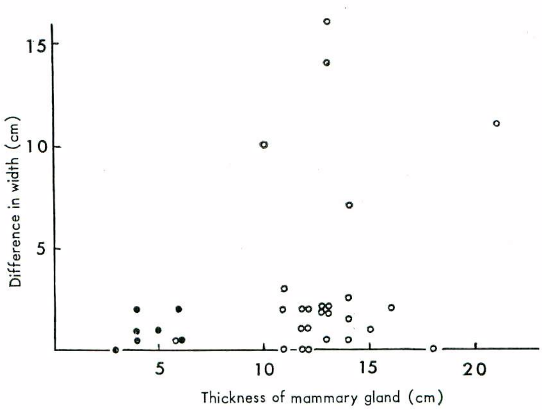


Fig. 30. Relationship between the thickness of mammary glands and the difference in width between the left and right uterine horns. Open circle; Active lactation. Closed circle; Late lactation.

From the above discussions, it is suggested that the thickness of mammary glands is the best character in evaluating the state of lactation, namely, when the whales are in late lactating state the thickness is less than 8.0 cm and those in active lactation state it is more than 8.0 cm. Considerably individual variations are observed in the thickness of blubber and the diameter of the largest corpora albicantia, however, the whales possessing less than 6.1 cm of blubber thickness and more than 2.8 cm of corpora albicantia are considered in active lactation state. It is considered that the difference in the widths between the two uterine horns is inferior to other characters in judging the state of lactation.

III-2-ii The end of active lactation period

Table 6 shows the number of sexually mature females taken and the percentage of each reproductive state to the total females by month. The percentage of lactating whales to the total females of sexually mature drops to about a half from the previous months in July.

Table 6. Number and percentage of sexually mature females by reproductive states caught by Kyokuyo maru No. 2 in the North Pacific in 1970.

	May	June	July	August	Total
In number					
Sexually mature female	138	133	114	15	400
Lactating whale	33(4)	40(9)	14(1)	2	89(14)
Pregnant whale	89(4)	92(9)	82(1)	11	274(14)
Resting whale	16	1	18	2	37
In percentage					
Lactating whale	23.9	30.1	12.3	13.3	22.3
Pregnant whale	64.5	69.2	71.9	73.3	68.5
Resting whale	11.6	0.8	15.8	13.3	9.3

( ): Number of pregnant and lactating whales.

Frequency distribution of mammary gland thickness of lactating whales by month is presented in Fig. 31. The mode of the frequencies for May and June locates at 11.5 cm and that for July at 11.0 cm. The shape of the distribution to the left of the mode for May and June is steeper than that to the right of it, however, the reverse is the case in July. In other

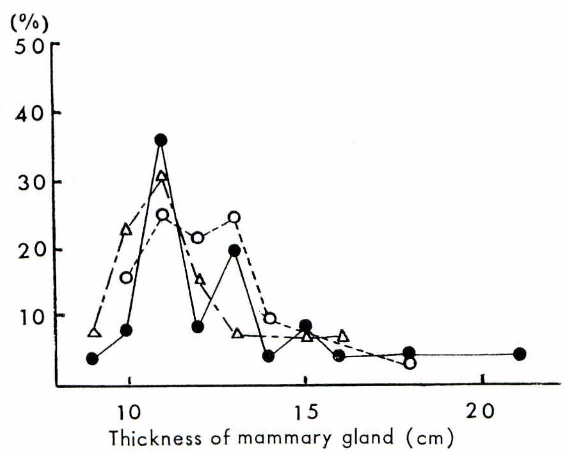


Fig. 31. Monthly frequency distribution of the thickness of mammary glands of lactating whale. Closed circle and solid line; May. Open circle and dotted line; June. Open triangle and chain line; July.

words, the number of lactating females possessing relatively thin mammary glands increases in July, and this indicates that the lactating whales are beginning to wean in July.

The monthly ratio of the number of cows with calf to the total number of sei whales observed by Japanese survey vessels during 1966 to 1973 whaling seasons is shown in Fig. 32. As is seen in this Figure, a sudden decrease of the ratio is observed from March to May. This change is one of the evidences of weaning period. The latitudinal distribution of the cows with calf is interpreted according to the rearrangement of above mentioned ratio for 5 degrees latitudinal zones to the regions, east and west longitudes, as presented in Fig. 33. The high ratio of sightings in February to April, mainly in the waters south of 30°N, suggested the period of active nursing.

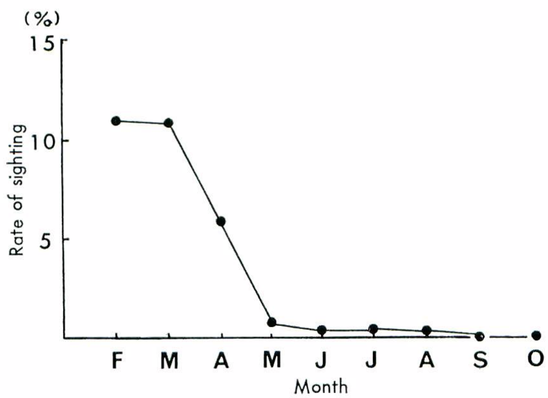


Fig. 32. Ratio of the number of cows with calf to the total number of sei whale sighted.

During May, the cows with calf are found widely in the east and west regions between 30°N and 45°N. Such a distribution seems to be a result that the cows start northward migration to the feeding grounds as active nursing is nearly over. On the other hand, during June and July, cows with calf sighted concentrate in the waters around 40°N, and almost all of them are not in nursing state but in feeding state in these waters at this time.

Since the weaning season is estimated to be June, as mentioned above, active nursing period of the North Pacific sei whale is calculated to be about seven months.

GAMBELL (1968) estimated the lactation period to be six months for the Antarctic sei whale based on the analysis of the data of mammary gland. Although the weaning period was reported during the summer feeding season, the end of lactation period was not clear in his paper.

III-3 Resting period

The resting period is defined at the time to stop reproductive functions, and it is the period between the weaning and the next pregnancy. However, it is difficult to obtain reliable evidence in understanding of the resting period.

The periods of gestation and lactation have been estimated in Sections III-1 and III-2,

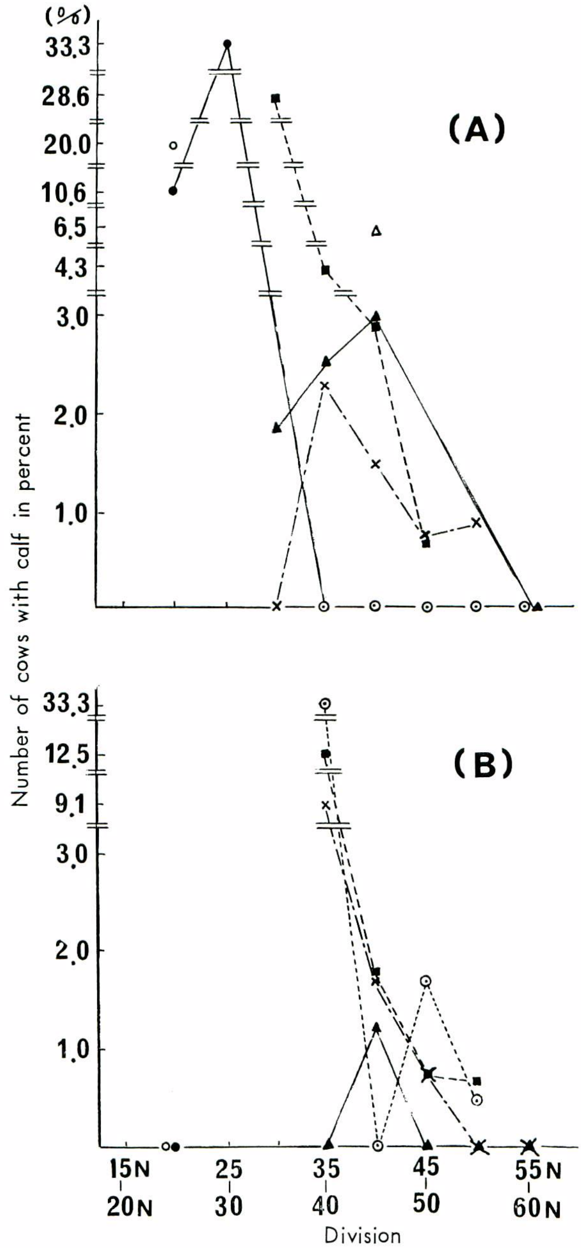


Fig. 33. Rate of the number of cows with calf to the total number of sei whales observed by five degrees latitudinal division and by month. (A); Waters west of 180°. (B); Waters east of 180°. Closed circle and solid line; February. Open circle and solid line; March. Open triangle and solid line; April. Closed triangle and solid line; May. Cross and chain line; June. Closed square and dotted line; July. Open circle with dot and dotted line; August.

respectively, thus, the remaining period of a reproductive cycle is the resting period. As mentioned earlier, the total number of ovulations can be determined by counting the number of corpora lutea and corpora albicantia in both ovaries. However, even though the recognizable corpora persist in the ovaries through the life of the animal (corpora albicantia), it is impossible to discriminate the corpora of pregnancy from the corpora of ovulation. Accordingly, the number of ovulations does not necessarily represent the number of pregnancies, but indicates the upper limit of the number of pregnancies. The calculation of the mean ovulation rate to year is based on three different methods which will be discussed in Chapter IV, Sections 5-1, ii and iii. The ovulation rate differs with age and different regions, and its range and mean values are from 0.567 to 0.630 and 0.604, respectively, for animals under 23 years of age. Over 24 years of age, the range is 0.388 to 0.414 and the mean is 0.438. The mean ovulation rate to year, as calculated by the transition phase in the ear plug (see Chapter IV, Section 5-ii), changes from 1.00 at age 10 to about 0.30 at age 40.

The maximum and minimum durations of a complete reproductive cycle, as calculated from the values mentioned above, are 12 months and 40 months, respectively. This big difference of the duration of reproductive cycle seemed to be caused by the following factors; (1) Some younger females may ovulate twice a cycle, (2) An animal may ovulate out of oestrus, (3) Ovulation may become increasingly irregular in older animals, and (4) Older females may cease ovulation completely.

As the individual variation of the gestation and lactation periods is narrow and has no relation to the age, the length of the reproductive cycle depends largely on the duration of the resting period. If a female sei whale copulated in the next nearest mating season after the weaning (III-1 and III-2), the resting period would be about 6.5 months.

Considering all of the above facts and discussions, the duration of a reproductive cycle for the female of the North Pacific sei whales is estimated to be two years on the average, and it is comprised of the following periods; 10.5 months' gestation, 7 months' lactation and 6.5 months' resting.

IV. Biological parameters for stock assessment

On the basis of the life historical and reproductive studies presented in Chapters II and III, here, the sex ratio, multiple pregnancy, the rate of sexual maturity, pregnancy rate, the rate of ovulation, body length at sexual maturity, the mean age of recruitment and the natural mortality coefficient are discussed. In addition, the differences of these parameters in various areas are examined.

IV-1 Sex ratio

If there were no limitations of capture and no differences in the distribution between male and female whales in all the areas, specimens of both sexes could be sampled proportionally with natural conditions. However, some differences in the ratio of male and female whales are observed from several reasons in the North Pacific.

In this Section, a trend of the sex ratio with the change of the stock size and the problems of sexual segregation are analysed by the changes of the sex ratio by year and by area.

The materials used in this Section were obtained by Japanese expeditions in the North Pacific during the whaling seasons of 1952 to 1972. The term of sex ratio in this paper is defined as the ratio of male whale to the total number of whales taken. The yearly change of the sex ratio of whales caught is shown in Fig. 34. The sex ratio prior to the 1962 season showed large yearly fluctuations, because of the small number of sei whales were taken. The sex ratio of the 1963 to 1966 seasons was about 60%, and gradually decreased from 1967 to 49% in the 1972 season. The cause of this decline can be explained by the selective hunting for the female in recent years as the body length of the female is larger than the male at the same age. Segregated distribution of sei whales by sex has been reported by Doi *et al.* (1969) for the North Pacific and by Nasu and Masaki (1970) for the Antarctic, recently, the catch has increased in Zone N where the males are relatively few. It is thought that the decline in sei whale population is not the direct cause of the yearly change in sex ratio of the whales taken.

Figure 35 shows the sex ratio by 10 degrees square. The mean sex ratio of Zone P (between 50°N and 60°N) is 60.4%, while in Zone N (between 40°N and 50°N) it is 54.4%. In the waters of Zone M (between 30°N and 40°N), it becomes 41.3%. These facts indicate

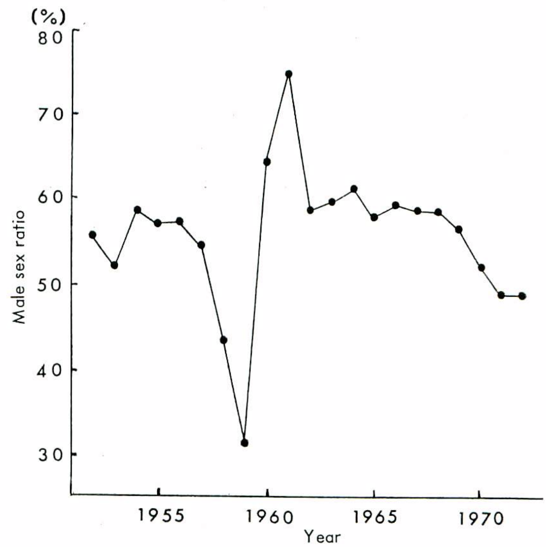


Fig. 34. Yearly change of the male sex ratio of the North Pacific sei whale.

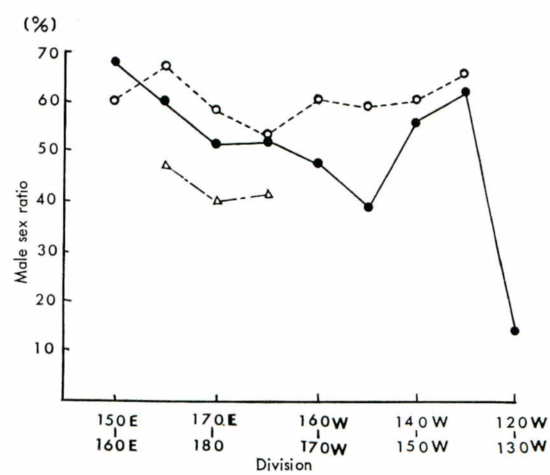


Fig. 35. Sex ratio by 10 degrees square of the North Pacific sei whale. Open triangle and chain line; Zone M (30°N-40°N). Closed circle and solid line; Zone N (40°-50°N). Open circle and dotted line; Zone P (50°N-60°N).

that the more males are taken in higher latitudinal waters. Latitudinal sexual segregation was also observed in the southern hemisphere sei whale (DOI *et al.*, 1967).

As shown in Fig. 35, the sex ratio of the central North Pacific is lower than that of east and west regions. These central whaling grounds are narrow latitudinally between the Aleutian Islands and the sub-Arctic convergence where is the male feeding grounds of the North Pacific sei whale (NASU, 1963, 66, 72; NEMOTO, 1957, 59, 62; NEMOTO and KASUYA, 1965). It should be noted that the inclination of the sea water temperature between the northern and southern parts of the feeding grounds of the central Pacific is larger than that of the waters of the east and west. As a consequence of such oceanographic differences, the sexual segregation is much more marked in the waters of the east and west than in the central Pacific.

Another aspect, which provides important information, is the examination of the sex ratio of the foetus. Table 7 shows the number of sei whale foetuses which were collected by Japanese whaling expeditions from the 1967 to 1972 seasons. Although there is some annual fluctuations, the sex ratio is 50.56% in average. This ratio is a little larger than the figure of the Antarctic sei whale of 49.7% (GAMBELL, 1968), and it is somewhat smaller than that of MATTHEWS (1938) of 65.3%. However, MATTHEWS' large figures must be attributed to the small number of records (69 foetuses). Further, LAURIE (1937) for blue whale, MACKINTOSH (1942) for fin whale and KIMURA (1957) for fin whale reported the foetal sex ratio of 53.6–54.4%, 52.0±0.19% and 50.6%, respectively.

Although MACKINTOSH (1942) reported that slightly more males were expected for the foetuses of blue and fin whales, the sex of the foetuses of the North Pacific sei whale seemed to be equal in male and female.

Table 7. Notes on the foetuses of the North Pacific sei whale.

Season	Male	Female	Total	Male sex ratio	Number of twin	Twining ratio
1967	349	324	673	51.86	5	0.737
1968	385	406	791	48.67	2	0.252
1969	380	338	718	52.93	4	0.554
1970	307	306	613	50.08	4	0.648
1971	259	257	516	50.19	0	0.000
1972	174	182	356	48.88	4	1.111
Total	1,854	1,813	3,667	50.56	19	0.515

IV-2 Frequency of multiplets in foetal stage

One of the factors which prescribes the procreative rate is litter size. In the course of examining 3,686 pregnant sei whales, 3,667 had a single foetus, and 19 had twins. Multiplets more than twins were not found. However, RISTING (1925) reported multiplets of sei whales in the North Pacific, that the rate of multiplets in sei whales more than twins may be comparatively lower than the rates of multiplets in blue (0.02–0.05%) and fin (0.01–0.03

%) whales (MATSUURA, 1940; KIMURA, 1957; SLIJPER, 1958).

The rate of twining in the North Pacific sei whale pregnancies was 0.52%. This is lower than that in the southern hemisphere sei whale (1.3%, GAMBELL, 1968). MATSUURA (1940) reported that the rate of twining differs in different stock units of the same species. Table 8 shows the twining rate in the North Pacific by division.

Table 8. Rate of twining of the North Pacific sei whale for each division.

Division	22, 23 and 24	25, 26 and 27	28, 29 and 30
Number of pregnant whales	2,504	866	316
Number of twins	14	4	1
Rate of twining	0.56%	0.46%	0.32%

IV-3 Rate of sexual maturity in whales caught

The rate of sexual maturity of whales captured is important not only in understanding the trends and conditions of the various whale stocks in certain waters at a given time but also as basic parameter in ecological considerations, e.g., migration and segegration, etc.

In this Section, the changes in the rate of sexual maturity by year and by area are discussed for each sex, and the sexual segregation of sei whales in the North Pacific is clarified. The data used in this Section are obtained from the materials described in Section IV-1.

The rate of sexual maturity from the 1952 to 1972 whaling seasons is presented in Fig. 36 by year, by sex, and by latitudinal zone. The rates in both Zones P and N for both sexes show a continuous decrease since 1952 season, excepting a marked increase in Zone P for both sexes since 1970 season.

It is thought that the continuous decrease of the rate is a function of the sei whale stocks which have been gradually decreasing (DOI and OHSUMI, 1968, 69; OHSUMI *et al.*, 1970; OHSUMI, 1970; OHSUMI and MASAKI, 1971), and in the North Pacific fin whale, the same phenomenon was reported by OHSUMI (1964). While the trend of increase seen in Zone P is considered as the results of selective catching for the larger sei whales in recent years.

Throughout the whole North Pacific during 1965 to 1967, the mean rate of sexual maturity of males and females was 86.9% and 73.8%, respectively, however, in the 1972 season, the rate for males and females decreased to 49.1% and 62.4%, respectively. Figure 36 shows higher rate of sexual maturity for males than females in both Zones P and N. This difference was also mentioned for the Antarctic sei whale (NASU and MASAKI, 1970). This difference of sexual maturity seems to be owing to the facts that the body length at sexual maturity is larger in the females than males and the capture of cows with calf is exempted.

Figure 37 shows the monthly change in the rate of sexual maturity, and it can be seen that each rate in Zones N and P shows a similar change. The rate decreases gradually month by month from May, however, in September the rate is slightly higher than in August. Although the sexually mature rate is higher in Zone P than that in Zone N in general, the contrary phenomenon was observed in the females in August. However, in September, the mean

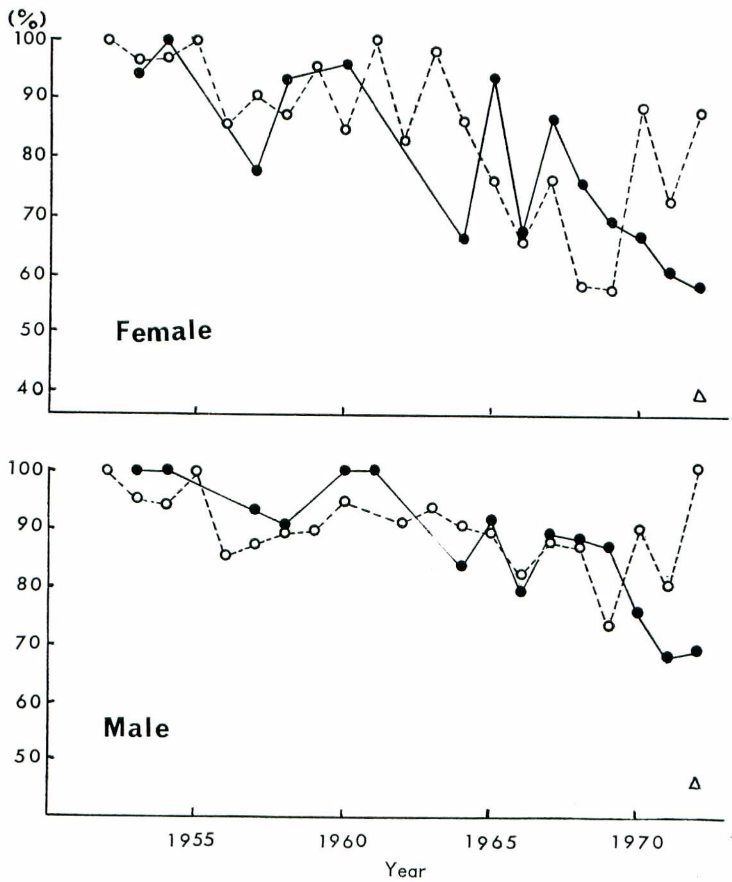


Fig. 36. Annual change of the rate of sexual maturity by sex and by latitudinal zone. Open triangle; Zone M (30°N–40°N), Closed circle and solid line; Zone N (40°N–50°N), Open circle and dotted line; Zone P (50°N–60°N).

rate of sexual maturity in Zone P becomes again higher than Zone N. The cause of these monthly changes in the rate of sexual maturity is attributed to the fact that migration seasons differ with animals in different reproductive states, as will be discussed in Chapter V.

Figure 38 shows the change of the sexual maturity rate by area. In Zone N, the rate in Area VI (140°E–160°E) for both sexes is the highest i. e., 95.5% in females and 96.1% in males, and it then becomes lower as it shifts to waters of the eastern side of the North Pacific. In Area II (120°W–140°W), it is 60.1% and 82.6% in females and males, respectively. The trend of decrease in the rate for females in Zone N is more marked than that for the males.

The trend of the rate in Zone P shows the reverse of that in Zone N for both sexes. The rate in Area II of Zone P for both sexes is the highest (95.3% in males and 84.9% in females), while the rate in Area VI is the lowest (77.8% in males and 66.7% in females).

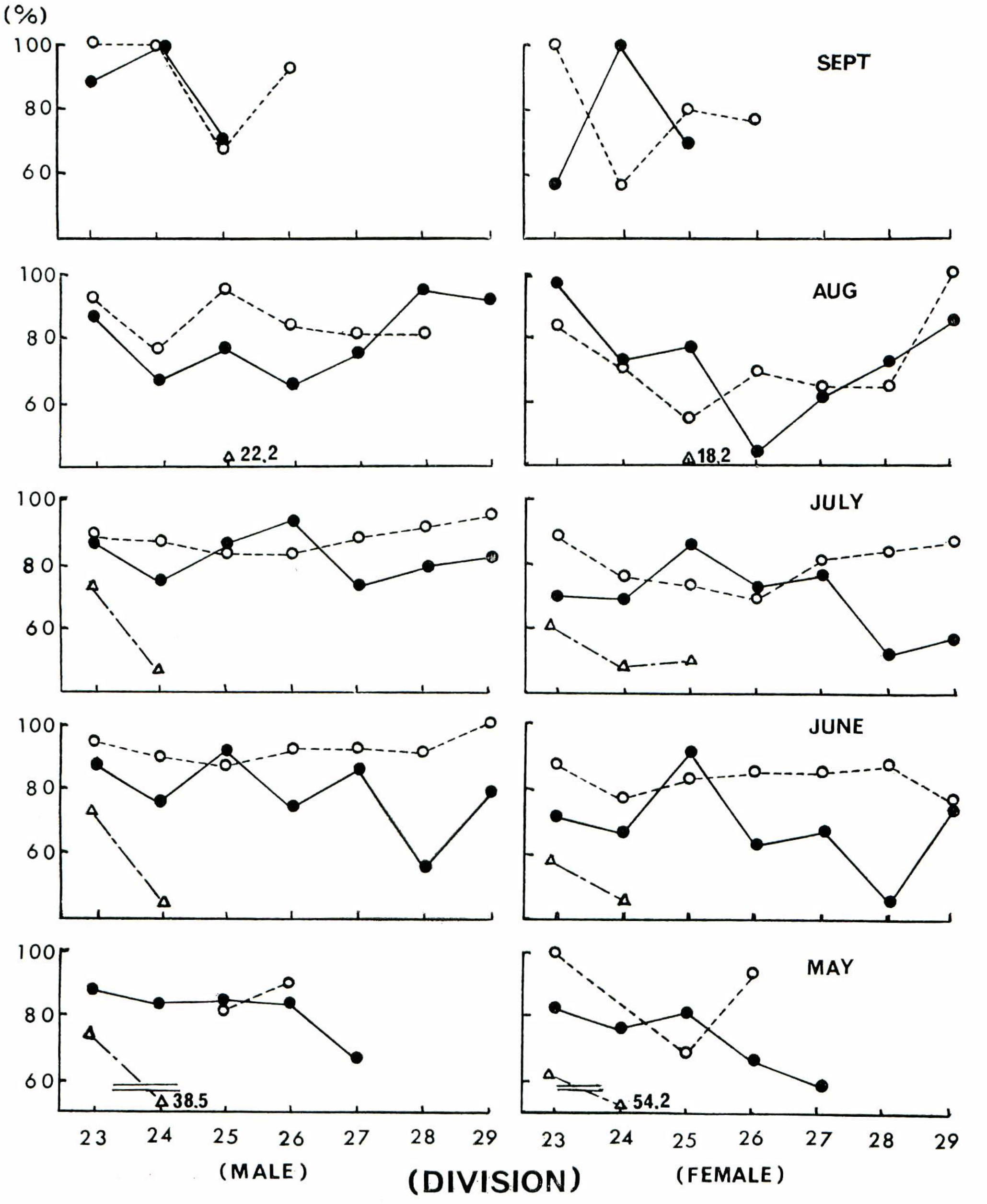


Fig. 37. Monthly change of the rate of sexual maturity of sei whales in the North Pacific. Open triangle and chain line; Zone M (30°N–40°N). Closed circle and solid line; Zone N (40°N–50°N). Open circle and dotted line; Zone P (50°N–60°N).

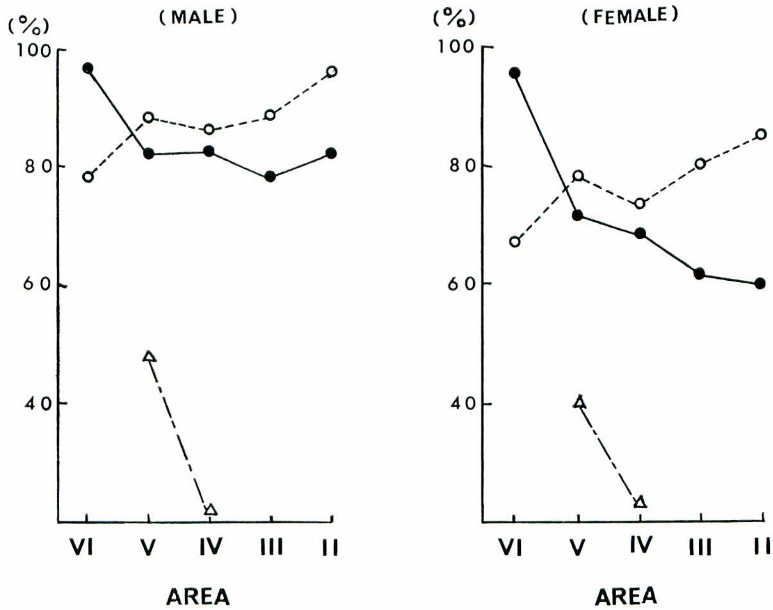


Fig. 38. Changes of the rate of sexual maturity by sex, by zone and by area. Open triangle and chain line; Zone M (30°N-40°N). Closed circle and solid line; Zone N (40°-50°N). Open circle and dotted line; Zone P (50°N-60°N).

The data available for Zone M are only from Areas IV and V, and the range of the rate is from 22.2% to 47.8% in males and 23.1% to 40.0% in females. Both of these values are considerably lower than those found for Zones N and P.

In summary, it is found that in Areas except Area VI, the number of sexually mature whales is much larger than that of the immature animals in higher latitude, especially, in Areas II and III of the North Pacific where latitudinal segregation of maturity is remarkable.

IV-4 Pregnancy rate

The pregnancy rate is usually expressed as a ratio of pregnant animals to the total of sexually mature females captured. However, in view of the fact that the International Whaling Convention places a ban on the taking of cows with calf, the pregnancy rates which are calculated from the whales caught may show apparently a higher value than that which exists naturally. Therefore, this "apparent" pregnancy rate is dealt in this paper, because it is impossible to estimate the true pregnancy rate.

The changes of the pregnancy rate by month, by area, and by year were examined in light of segregation of stocks. Figure 39 shows the pregnancy rate by 10 degrees square in the North Pacific. The pregnancy rate in the waters of the western side of the North Pacific is higher than in the central and eastern side. Further, similar phenomemon was seen in the North Pacific sperm whale (MASAKI, 1970b). This trend is remarkable in Zone N. For example, the rate in Square N23 is 74.2% while that in Square N29 is 45.9%. On the other hand, in Zone P the rates in west (P25) and east (P27) regions are higher than these in the region between Squares P25 and P27.

Figure 40 shows the monthly change in the pregnancy rate of the North Pacific sei whale. The rate decreases month by month after May with a rapid decrease in July and August. The rate is higher in Zone P than in Zone N until August except May. In September, the pregnancy rate in Zone P is similar to that of August, while in Zone N it becomes higher. These monthly changes in the pregnancy rate in both Zones N and P may substantiate the pattern of migration which differs according to the reproductive conditions as was discussed in Section IV-3. These changes may concern with the recruitment of weaned females into the catchable stock as it reduced an apparent rate of pregnancy.

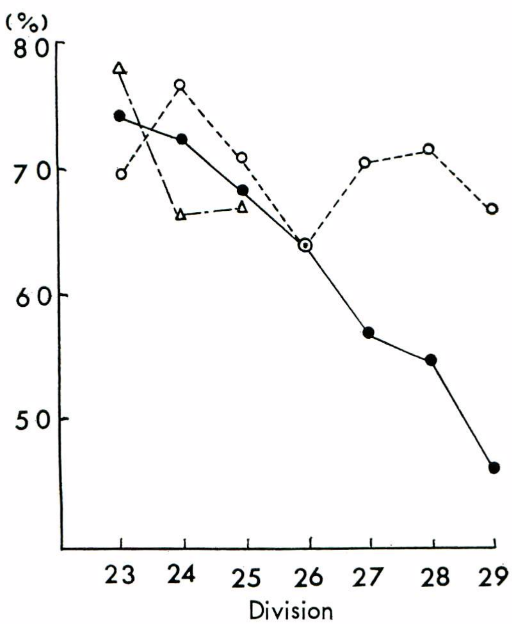


Fig. 39. Areal change of the pregnancy rate of the North Pacific sei whale. Open triangle and chain line; Zone M (30°N–40°N). Closed circle and solid line; Zone N (40°N–50°N). Open circle and dotted line; Zone P (50°N–60°N).

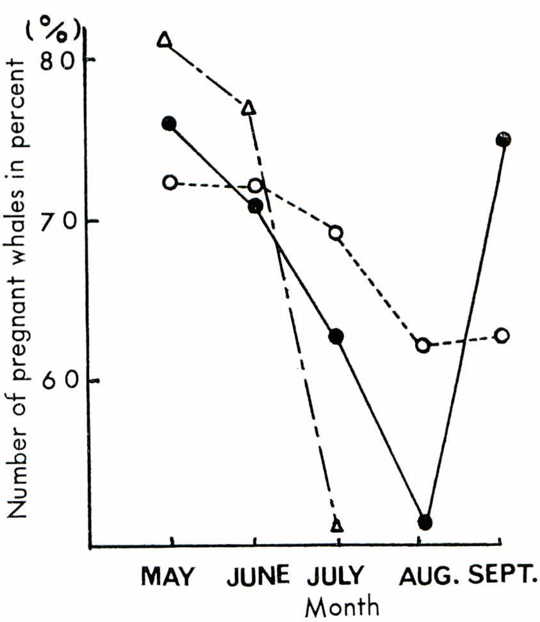


Fig. 40. Monthly change of the pregnancy rate for each zone. Open triangle and chain line; Zone M (30°N–40°N). Closed circle and solid line; Zone N (40°N–50°N). Open circle and dotted line; Zone P (50°N–60°N).

Figure 41 shows the total pregnancy rate of the North Pacific sei whale from the 1952 to 1972 seasons. The annual fluctuation of the rate is shown after the 1964 season. The average pregnancy rates in Zones P and N were 70.8% and 69.3%, respectively, prior to the 1969 season. After the 1970 season, pregnancy rates in both Zones P and N became 67.3% and 63.3 % respectively. Particular note is the marked decrease of the rate in Zone P in 1972.

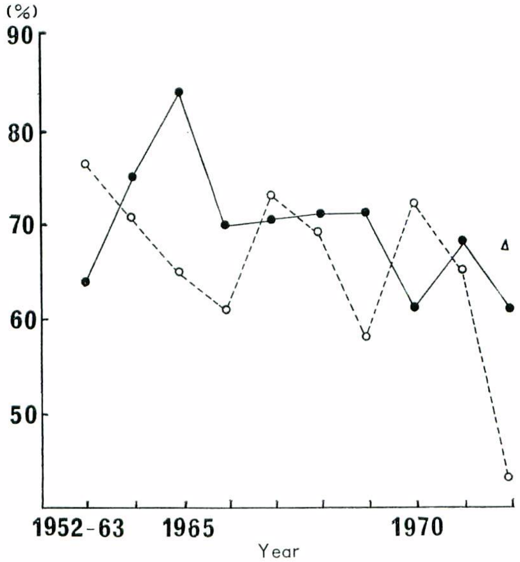


Fig. 41. Annual change of the pregnancy rate of the North Pacific sei whale. Open triangle; Zone M (30°N–40°N). Closed circle and solid line; Zone N (40°N–40°N). Open circle and dotted line; Zone P (50°N–60°N).

An explanation of these phenomena can be obtained from the following three factors: the whaling grounds have come to include waters of lower latitude in recent years, the grounds have also shifted to the waters of the eastern North Pacific since about the 1970 season, and the whaling season has shifted later in recent years.

In the studies of the southern hemisphere sei whales, it has been reported that the pregnancy rate increased from 1946 to 1972 (GAMBELL, 1973). According to OMURA (1950), the apparent pregnancy rate of sei whale from Hokkaido was 30.7% in 1948 and 1949 seasons. Then, similar phenomenon is seen in the North Pacific sei whale, but the recent trend of apparent pregnancy rate does not coincide with the trend of population size as reported by LAWS (1961) for the southern fin whale. The hasty change of the population size in the North Pacific sei whale has not elapsed time enough to influence an increase in the pregnancy rate.

Figures 42 and 43 show the pregnancy rates by age and the number of ovulation in the sei whales taken by Japanese expeditions during the years 1963 to 1973. The pregnancy rate is almost constant up to 40 years of age, but then it shows decreasing trend. On the other hand, the pregnancy rate is somewhat low up to about four ovulations being around 65%, and then the rate rises to about 70% until 20 ovulations. However, after about 20 ovulations, it gradually decreases with the increasing number of ovulations (Fig. 43).

As was described in Chapter II, because of the fact that materials of sei whales over 40 years of age are very few, the tendency of sudden decrease of the pregnancy rate in older animals shown in Fig. 43 is considered unreliable. The low pregnancy rate in older female sei whales indicates that they no longer conceive as frequent as younger generations.

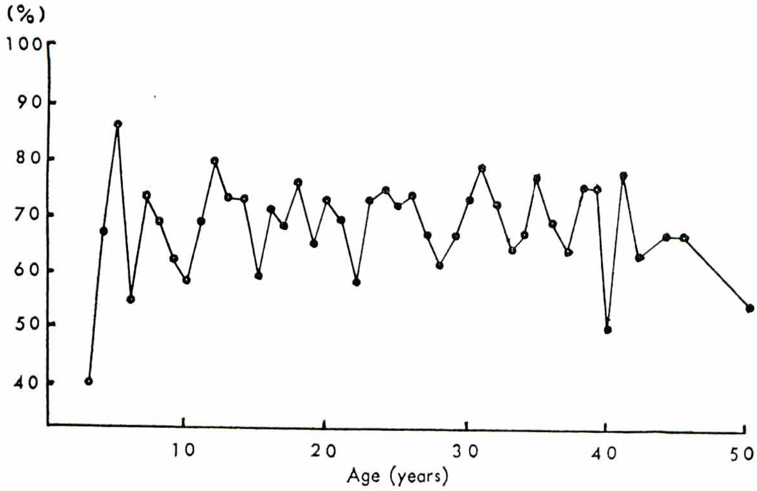


Fig. 42. Changes of the pregnancy rate by age of the North Pacific sei whale.

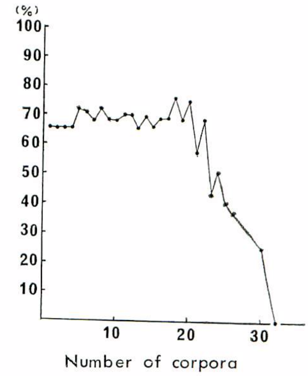


Fig. 43. Changes of the pregnancy rate by number of ovulations of the North Pacific sei whale.

IV-5 Ovulation rate

Ovulation rate is one of the most important parameters available in understanding the procreative potentials and in prescribing the shortest limit of the reproductive cycles for the animals. It should be remembered that in the Cetacea each ovulation is recorded as a corpora albicans in the ovaries for the life of the animal. The rate of ovulation has been calculated for the North Pacific sei whale by the three approaches mentioned below, then, differences of calculated ovulation rates will be examined by age and area.

(1) The relationship between age and number of ovulations,

(2) The relationship between number of laminations from the transition phase to the germinal layer of the ear plug and number of ovulations at the time of capture, and

(3) Ovulation rate calculated by the method of GAMBELL (1968).

IV-5-i The average annual ovulation rate based on the relationship between age and number of ovulations

The age and the total number of corpora albicantia and lutea in ovaries examined for 1,040 female sei whales captured by Japanese expeditions in the North Pacific in the seasons from 1967 to 1972, were used for the study in this Section.

The relationship between age and number of ovulations for Areas III, IV and V (see Fig. 1) and the total area is presented in Fig. 44. In calculating formula of the regression lines of the relationship, it was found that there is a refraction point of the regression lines at age 23 through all areas. It was felt that the regression formulas should be calculated in two separate analyses, e.g., over age 24 and under age 23, and the results obtained are shown in Table 9. The Table shows that the yearly average ovulation rate of the whales over 24 years old is slightly less than that of younger than 23 years. As mentioned in Section III-2, the North Pacific sei whale continue to ovulate throughout their life, in other words, no menopause is recognized.

Table 9. Age at sexual maturity and reproductive cycle of the North Pacific sei whale by area based on the relationship between age and number of ovulations.

Area	Reproductive cycle (months)		Age at sexual maturity (years)	Regression estimate	
	Under age 23	Over age 24		Under age 23	Over age 24
V	30.2	19.0	5.5	Y=0.397X+1.311	Y=0.630X−2.451
IV	30.9	20.5	5.4	Y=0.388X+2.379	Y=0.584X−1.940
III	29.0	21.2	5.3	Y=0.414X−1.224	Y=0.567X−2.028
Whole	27.4	19.9	5.2	Y=0.438X+0.062	Y=0.604X−2.147

X: age in years, Y: number of ovulations.

Yearly average rate of ovulation of the whales under age 23 for the entire North Pacific is 0.604 and the ovulation rates of the Areas studied, e.g., III, IV and V are 0.567, 0.584 and 0.630, respectively (Table 9).

The average annual ovulation rate for various species of whale has been reported by GAMBELL (1968) as 0.69 for the Antarctic sei whale, MASAKI (1973) as 0.588–0.599 for the North Pacific sei whale, NISHIWAKI *et al.* (1958) and MASAKI (1973) as 0.38–0.42 and 0.512–0.580, respectively for the North Pacific fin whale, PURVES and MOUNTFORD (1959), LAWS (1961), OHSUMI (1964), ROE (1967) and LOCKYER (1972) as 1.4, 1.43, 0.490, 0.72 and 0.671, respectively for the Antarctic fin whale. The annual rate of ovulation for the North Pacific minke whale has been estimated by OMURA and SAKIURA (1956) as once a year or half a year. OHSUMI *et al.* (1970) and MASAKI (1973), on the other hand, reported 0.77 and 0.853–0.970 on the annual ovulation rate for the Antarctic minke whale, respectively. RICE and WOLMAN (1971) estimated the mean annual ovulation rate for gray whale as 0.52. Also, for the humpback whale, CHITTLEBOROUGH (1954) indicated that the mean number of ovulation during its ovulatory period is slightly over one, probably less than 1.5.

From these results, the average annual rate of ovulation for sei whale is smaller than that of minke whale, and is larger than that of fin, gray and humpback whales. Furthermore, it may be considered that the mean annual ovulation rate for the North Pacific sei whale is almost similar to that of the Antarctic sei whale.

Yearly average ovulation rate is the highest in the western waters of the North Pacific, and it falls as the waters shift to the east. Remarkable difference is not observed between Areas III and IV. However, it should be noted that the ovulation rate in Area V increases possibly as stock level decreases. The changes of the stock sizes for the different areas can be analyzed by refering to the papers by DOI and OHSUMI (1969); OHSUMI *et al.* (1970); OHSUMI (1970); OHSUMI and MASAKI (1971); OHSUMI and WADA (1973); OHSUMI and FUKUDA (1974); WADA (1972, 75, 76) and TILLMAN (1976).

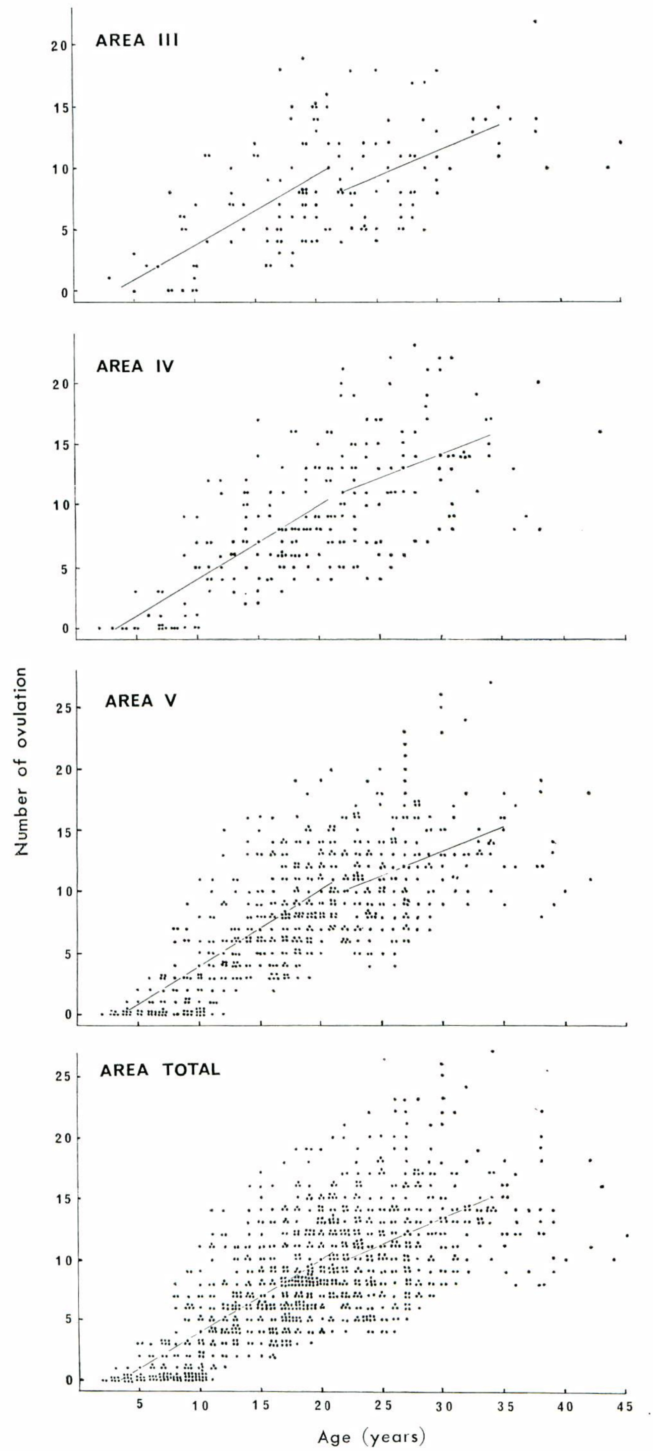


Fig. 44. Regression relationship between age and number of ovulations, totaled corpora lutea and corpora albicantia, of the North Pacific sei whale.

IV-5-ii The relationship between number of laminations from the transition phase to the germinal layer of the ear plug and number of ovulations at the time of capture

The method of calculating the rate of ovulation to the age determined by the ear plug (Chapter II-4) is expressed as follows;

$$Y = B/(A - TP)$$

where, Y = Yearly average number of ovulations, B = Total number of ovulations in the ovaries, A = Age (e.g., Total number of growth layers in the ear plug), TP = Age at sexual maturity based on number of growth layers up to the transition phase of the ear plug.

Specimens of 143 female sei whales were used here. They were examined on age at sexual maturity (TP), age (A) and the total number of corpora (B). These whales were collected by the Japanese expeditions in the North Pacific during the years 1968 to 1973, except the 1970 season.

Figure 45 shows the yearly average ovulation rate by age. The annual rates of ovulation are 1.00 at age ten and 0.30 at age forty, that is to say, sexually mature females ovulate once a year at age ten, and the ovulation in older age (forty years old) decreases once in 3.3 years. Therefore, there is a large difference in the ovulation rate at a given age.

The incidence of ovulation rate at different age was examined by LAWS (1961) for fin whale and MACKINTOSH (1965) for fin and blue whales. LAWS (1961) also reported that both the rate of ovulation and the percentage of successful ovulations do not change much with age, though there are signs of slightly lower fertility in the youngest mature female and be-

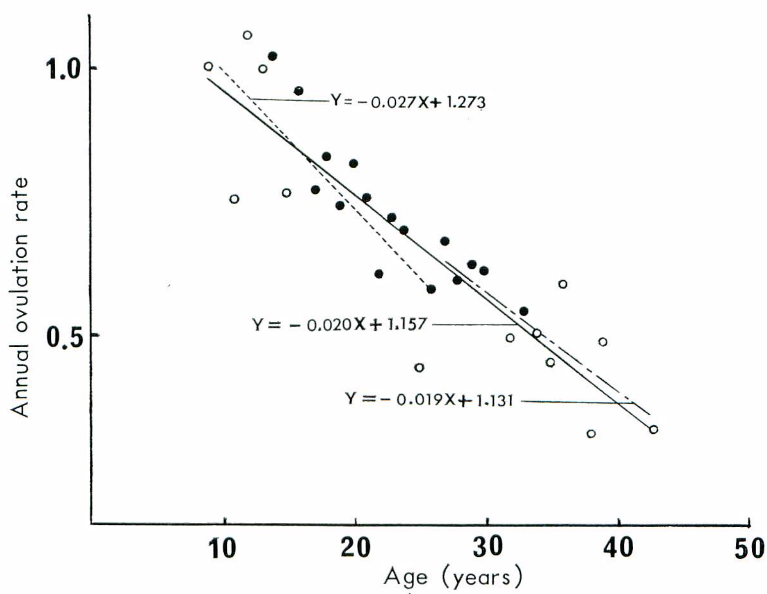


Fig. 45. Regression analysis of the yearly average ovulation rate by age. Open circle; Number of specimens less than four, Closed circle; Number of specimens more than five.

yond the age possessing about 35 corpora. Although the present results indicate the opposite tendency in the youngest mature female, the case of such high ovulation rate has not been ascertained yet.

The relationship between age (X) and the annual ovulation rate (Y) is shown by the following correlation formulas;

Between ages 9 and 43	$Y=-0.02X+1.16$
Between ages 9 and 23	$Y=-0.03X+1.27$
Between ages 24 and 43	$Y=-0.02X+1.13.$

IV-5-iii The ovulation rate calculated by GAMBELL'S method

CHITTLEBOROUGH (1955b), GAMBELL (1968) and RICE & WOLMAN (1971) reported that for humpback, sei and gray whales respectively, though they usually conceive immediately after ovulation, may undergo two or three oestrus cycles if pregnancy does not intervene. Then, the average annual ovulation rates estimated by means of the previous two methods may be slightly low.

GAMBELL (1968), in his study of the Antarctic sei whales, reported that the best estimation of the average number of ovulations per reproductive cycle is done by considering the severa relevant biological factors bearing on the number of ovulations which can occur during each ovulatory period such as winter, summer and post-partum within the reproductive cycle.

Materials used in this Section are obtained from 400 sei whales examined on board the Kyokuyo maru No. 2 in the 1970 season.

In most whales, the winter ovulation is followed by pregnancy. It is assumed, following GAMBELL (1968), that, as in the Antarctic sei whales, any female in the resting phase in the North Pacific with the largest corpus albicans exceeding 50 mm in diameter ovulated during the summer of the preceeding reproductive cycle. A size frequency distribution of the largest corpora albicantia in resting sei whales is shown in Fig. 46. The number of individuals possessing the corpora albicantia larger than 50 mm in diameter is five out of 55 resting animals. These whales are considered to have ovulated during the summer of the preceeding reproductive cycle, and they constitute 9.1% of the total of non-pregnant and non-lactating mature females sampled.

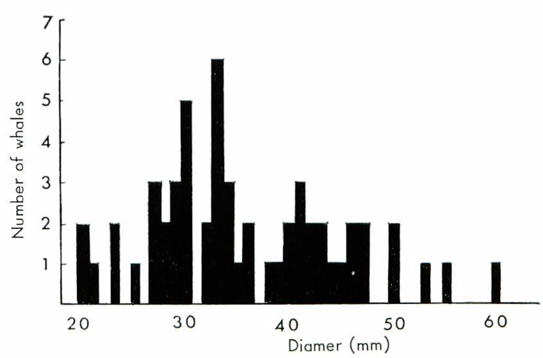


Fig. 46. Frequency distribution of the diameter of the largest corpora albicans of resting female sei whale.

Unfortunately, the frequency of post-partum ovulation could not be determined due to the insufficiency of data on the number of follicles and their diameters for females in this state. Under such circumstances, GAMBELL'S (1968) post-partum ovulation rate of 0.111 is adopted in this analysis of the North Pacific sei whale. The results of calculation of ovulation rate from this method are so similar

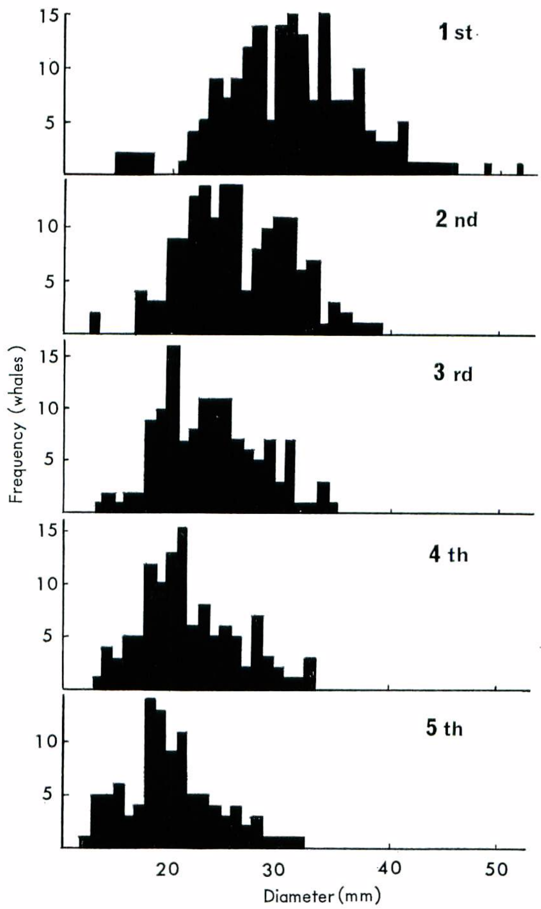


Fig. 47. The size frequency distribution of the first to fifth largest corpora albicans of pregnant sei whales in the North Pacific.

to the rates established by other criteria in Section IV-5-i and ii, that GAMBELL's (1968) post-partum ovulation rate of 0.111 for the Antarctic sei whale can be used as a reasonable value in case of the analysis of the average number of ovulations per reproductive cycle for the North Pacific sei whale.

Figure 47 presents the size frequency distribution of the first through fifth largest corpora albicantia of both ovaries of the pregnant whales. The number for each of the five classes suggests that they are ovulated more recent than the others which are unfertilized ovulations at various points in preceeding oestrus cycle.

On this premise, the average number of ovulations in the winter breeding period is estimated. In each pregnant whale,

the corpus luteum represents one ovulation $=1.000$

of the first largest corpora albicantia, 6 out of 184

represent a second ovulation =0.033
of the second largest corpora albicantia, 2 out of 156
represent a third ovulation =0.012
of the third largest corpora albicantia, 0 out of 133
represent a fourth ovulation =0.000
of the fourth largest corpora albicantia, 4 out of 117
represent a fifth ovulation =0.034
of the fifth largest corpora albicantia, 3 out of 102
represent a sixth ovulation =0.029
therefore, the average number of ovulations per pregnant whale =1.108.

The ovulation rate may be calculated in the following way; Winter ovulation=1.000, Post-partum ovulation=0.111, Summer ovulation=0.091, Total number of oestrus cycles=1.202. Total number of ovulation=1.202×1.108 ovulation per oestrus=1.332 per breeding cycle=0.666 per year.

This result is almost the same as that obtained from the southern hemisphere sei whale (GAMBELL, 1968).

FUJINO (1964 a, b) suggested the slightly different ovulation rates associated with stocks distinguished by blood groups, however, in the present study, areal difference in ovulation rates for the North Pacific sei whale could not be detected due to the lack of materials.

IV-6 Differences in body length at sexual maturity by area

The testis weight at sexual maturity was estimated as 0.9 kg in Chapter II-2. There seems little doubt whether 0.9 kg of testis weight can be applied or not as a standard value of sexual maturity for male whales of the North Pacific waters, because the value was obtained from the whales caught mostly west of 180° longitude. Therefore, the differences in body length at sexual maturity discussed in this Section are based on the assumption that there is no difference in the testis weight at sexual maturity of males among the various stocks.

The data on the gonads of 7,178 males and 5,830 females were used in this Section. These whales were taken by Japanese expeditions in the seasons of 1968 to 1971. Additional data on 272 males and 207 females taken from Japanese coastal whaling grounds during the seasons of 1963 to 1965 were also available.

LAWS (1962) pointed out the possibility that reduction of the stock size has led to faster growth and lowering of the age at maturity of the members. OHSUMI and SHIMADZU (unpublished) reported that the body length at sexual maturity differs according to the stock units in the Antarctic fin whale. For the Antarctic sei whale, NASU and MASAKI (1970) also showed that the body length at sexual maturity varies with area or the stock unit.

Figure 48 shows the rate of sexual maturity by body length and by sex for the Areas II through VI. The body lengths at which 50% of individuals attain sexual maturity are calculated from Fig. 48 and are presented in Table 10. The body length at sexual maturity is the largest in Area VI in both sexes. It is 13.5 m in females and 13.0 m in males, respectively.

Body length at sexual maturity is larger in the western North Pacific than in the eastern waters. Since the longitudinal trend in the difference of body length at sexual maturity is continuous from Area to Area in the North Pacific, such a difference cannot be used as an index in dividing the sei whales into stock units.

Table 10. Body length (m) at which 50% of individuals attain sexual maturity for each sex by area of the North Pacific sei whale.

	Area VI	Area V	Area IV	Area III	Area II	Whole
Male	13.0	12.9	12.9	12.7	12.8	12.9
Female	13.5	13.4	13.4	13.3	13.3	13.4

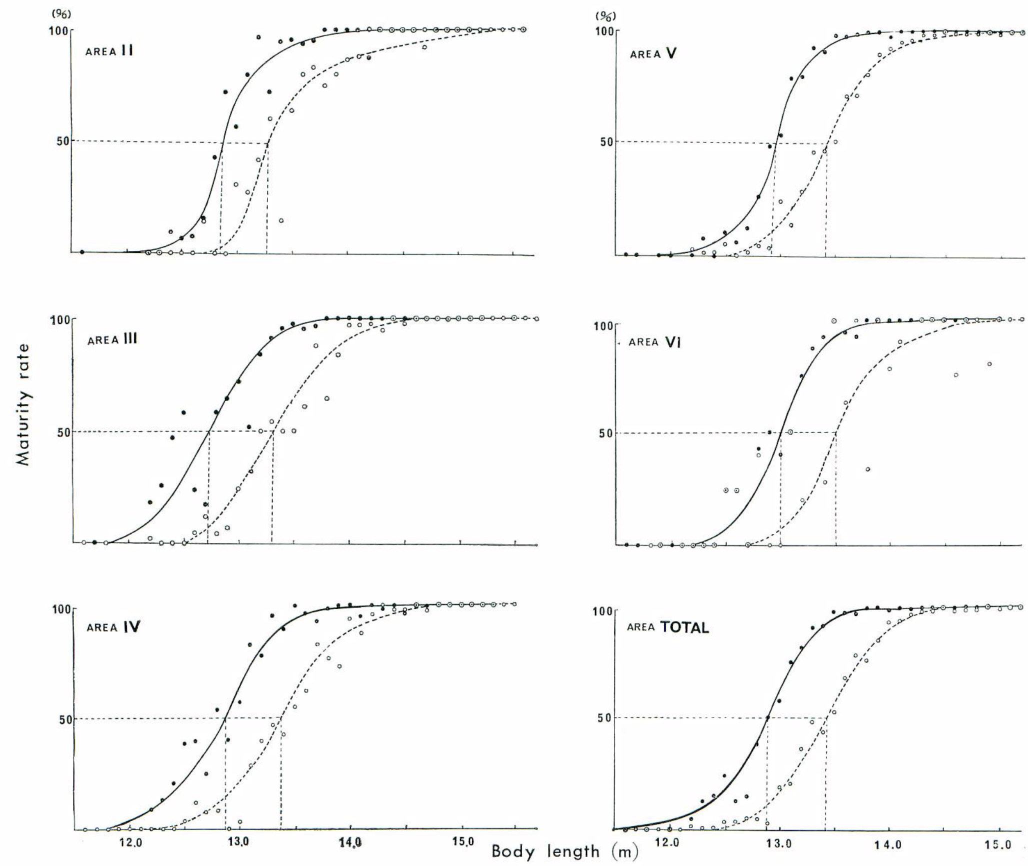


Fig. 48. Maturity rate of the whales at each body length by sex for the Areas II to VI. Open circle and dotted line; Female, Closed circle and solid line; Male.

IV-7 Average recruitment age

The frequency distribution of the age of the whales caught has quadratic slope on its left, because of the size limit regulations of the catch. In general, all the whales attaining to a certain age do not enter the exploitable stock together, due to the individual variation of growth.

The average recruitment age is calculated by means of ALLEN's (1966) method. The age composition data used in this Section are obtained from the convertion of size distribution by an age length key. The data of size distribution were taken by Japanese expeditions in the seasons of 1965 to 1972.

Table 11 shows the average recruitment age by year, by area and by sex. The average recruitment ages in Areas IV and V were about 6 or 7 years in 1965, but they had decreased to about 5 or 6 years by 1972. The cause of this decrease may be a result of the catch of whales in these Areas during those years. In contrast, the average recruitment ages in Areas II and III were increasing in recent years. This is probably due to the selective catch of larger sized whales. For the Antarctic fin whale (DOI *et al.*, 1970) and the Antarctic sei whale (GAMBELL, 1973, 74) it was reported that there was a slight change in the age at recruitment to lower as the stock declines.

Table 11. Average age at recruitment of the North Pacific sei whale.

Season	Area V		Area IV		Area III		Area II	
	Male	Female	Male	Female	Male	Female	Male	Female
1965	5.8	5.7	6.9	7.1	6.4	6.7	5.7	7.2
1966	7.0	7.7	6.5	7.2	6.6	6.8	7.8	7.7
1967	7.1	7.4	7.3	7.4	—	—	—	—
1968	6.4	7.3	6.1	6.7	6.4	7.0	—	—
1969	6.4	7.2	6.2	6.8	5.8	6.9	—	—
1970	6.1	6.7	6.0	6.8	6.2	6.4	6.8	7.4
1971	6.0	5.8	6.1	6.9	9.2	9.4	9.2	8.4
1972	6.4	5.2	6.7	5.4	9.4	7.8	—	—
Average	6.4	6.9	6.5	6.8	7.1	7.3	7.4	7.7

There are some differences in average recruitment age for the years 1965 to 1972 among the different areas (Table 11). The age in Areas IV and V is about 7 years for females and about 6.5 years for males, while in Areas III and II it is about 7.5 years and 8.0 years for the females respectively, and about 7.0 and 7.5 years for the males, respectively. DOI and OHSUMI (1969) calculated the age at 50% recruitment as 10 to 11 years for the North Pacific sei whale based on the age composition data from 1957 to 1968 seasons. Present results are smaller than that of DOI and OHSUMI (1969), because the method used in their study is different from ALLEN's (1966) method.

However, the difference of the age at recruitment among the different areas in the North Pacific as shown in Table 11 is not much, and this may be partly due to the application of the same age-length key to all areas in the present study. As the recruitment age decreases with decrease of the population as mentioned above in Areas IV and V, the difference of the age among the areas is a reflection of difference catch efforts put into each area. In other words, the effects of catching pressure on one stock may not affect other stocks.

IV-8 Natural mortality coefficient

ALLEN (1970) reported that the natural mortality rate of the Antarctic fin whale changed with age. He estimated the average natural mortality rate for the new recruit was about 0. 14, and also reported that the natural mortality rate seems unlikely to fall abruptly from 0. 14 to 0. 04 immediately after recruitment is complete. The average natural mortality coefficient for pre-recruitment ages is not estimated as the pregnancy rate and natural mortality coefficient after recruitment have not been established yet. Then, the natural mortality coefficient after recruitment is estimated merely in this paper.

Examples of the age composition of the North Pacific sei whales for the years of 1968 and 1971 are shown in Fig. 49. The total mortality coefficient is estimated by the inclina-

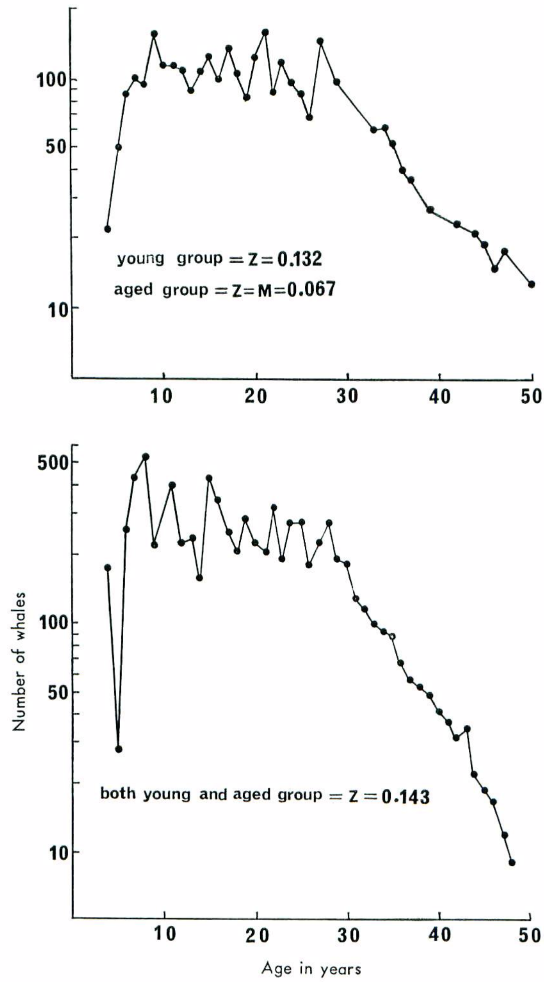


Fig. 49. Some examples of the age composition of the North Pacific sei whale. Top; Male, Area V, 1971 season, Bottom; Male, Area III, 1968 season.

tion of the right hand side of the age composition graph (Fig. 49). The inclination of older part of the graph for 1968 represents the natural mortality coefficient, because they have not been affected by catching (Doi, 1964). After the 1971 whaling season, however, the older whales had been affected by catching, therefore, the natural mortality coefficient could not be calculated from this age composition.

Table 12. Total mortality coefficient and natural mortality coefficient for each year, by area and by sex, based on age composition of the North Pacific sei whale.

	Area V				Area IV			
	Male		Female		Male		Female	
	Z	R	Z	R	Z	R	Z	R
1965	0.100	10–39	0.102	20–47	0.094	17–30	0.111	20–45
	0.020	33–50	—	—	0.023	33–47	—	—
1966	0.143	30–39	0.104	21–48	0.135	29–39	0.082	21–31
	0.057	41–50	—	—	0.046	42–50	0.040	33–49
1967	0.133	27–37	0.139	21–36	0.128	27–37	0.112	21–47
	0.058	39–50	0.096	37–48	0.058	39–50	—	—
1968	0.082	21–37	0.153	21–34	0.142	27–37	0.153	20–33
	0.043	39–50	0.048	37–50	0.079	39–50	0.090	35–50
1969	0.126	27–35	0.145	21–34	0.135	27–38	0.140	21–34
	0.072	36–50	0.064	37–50	0.059	39–50	0.094	37–50
1970	0.130	27–30	0.120	21–36	0.125	27–37	0.120	21–36
	0.070	39–50	0.024	37–47	0.061	39–50	0.023	37–47
1971	0.143	28–46	0.197	24–40	0.130	28–47	0.216	27–42
	—	—	—	—	—	—	—	—
1972	0.132	31–46	0.237	24–45	0.153	30–47	0.220	22–38
	—	—	—	—	—	—	—	—

	Area III				Area II			
	Male		Female		Male		Female	
	Z	R	Z	R	Z	R	Z	R
1965	0.101	10–30	0.100	20–47	0.113	10–30	0.127	20–39
	0.019	33–47	—	—	0.028	33–49	0.042	40–47
1966	0.108	29–46	0.113	21–39	0.072	23–46	0.128	20–29
	—	—	—	—	—	—	0.061	32–48
1967	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
1968	0.132	27–37	0.101	21–30	—	—	—	—
	0.067	39–50	0.065	31–47	—	—	—	—
1969	0.129	8–17	0.115	21–47	—	—	—	—
	0.078	19–50	—	—	—	—	—	—
1970	0.105	21–37	0.129	18–48	0.093	21–47	0.124	20–48
	0.062	39–50	—	—	—	—	—	—
1971	0.104	18–42	0.090	20–41	0.142	18–43	0.200	19–29
	—	—	—	—	—	—	0.053	30–41
1972	—	—	0.233	22–36	—	—	—	—
	—	—	—	—	—	—	—	—

The upper row of Z; Total mortality coefficient. The lower row of Z; Natural mortality coefficient. R; Range of age adopted for the estimation of Z.

The natural mortality coefficient does not show a yearly change within an area for a given sex (Table 12). The average natural mortality coefficient for the entire area of the North Pacific is larger in females (0.060) than in males (0.054).

For the North Pacific sei whale, DOI *et al.* (1966 a, b) reported that the natural mortality coefficient was 0.060 to 0.080 in males and 0.10 to 0.12 in females on the Asian side, and 0.084 in males and 0.137 in females on the north American side. For the sei whales in the pelagic whaling grounds, DOI and OHSUMI (1969) reported the coefficient of 0.06–0.08 and 0.10–0.12 for males and females, respectively, on the data of whales caught by 1965. ALLEN (1968) reported it as 0.05 for both sexes of the North Pacific sei whales, further, for the Antarctic sei whale, DOI *et al.* (1967) reported 0.059 to 0.079 and 0.065 as average for both sexes.

According to above results, the present estimate of average mortality coefficients of the North Pacific sei whale for both sexes are slightly smaller than those of DOI *et al.* (1966a, b) and DOI and OHSUMI (1969), and at the same time, they are smaller than those of the Antarctic sei whale (DOI *et al.*, 1967). One of the causes leading to the difference of natural mortality coefficient is possibly originated from the application of different Age-Length Keys to each cases.

As seen in Table 12, the average natural mortality coefficients in Areas II and V are lower than those of Areas III and IV. This difference is indicative of the different stock condition.

V. Migrations and movements

It has been presumed that the North Pacific sei whale migrates northward and southward every year between feeding and breeding grounds, and a pattern of movements in the feeding ground is complex. The various aspects of migrations and movements are discussed in this Chapter.

V-1 Northward and southward migration

Available information for the seasonal movements of baleen whales (for example, humpback, fin, blue, sei, and gray whales) has been obtained from sighting on migration, recovered marks, and seasonal changes of whaling grounds (see, MATTHEWS, 1937; MACKINTOSH, 1942, 65; OMURA, 1950; KASAHARA, 1950; MACKINTOSH and BROWN, 1956; DAWBIN, 1956 a, b, 66; PIKE 1962; BANNISTER and GAMBELL, 1965; GAMBELL, 1968; RICE and WOLMAN, 1971). However, for the North Pacific sei whale, much information is not available on northward and southward migration at present.

The north-south migrations of the North Pacific sei whale are proved by the results of an extensive program of whale marking and recovery. Data used in this Chapter are the results of the whale marking which have been conducted by the Japanese government from 1949 to 1973 in cooperation with the Japanese whaling companies.

Data of recovery of marked whales have also been provided by the governments of Canada, U. S. S. R. and U. S. A. The relationship between the date (month) and position (latitude) in mark release and recovery is presented in Figs. 50A, B. Figure 50A shows the result of recovery of marks which were recovered after the elapse of one winter season from marking, while Fig. 50B shows that obtained in the same season. The migration patterns expressed in those two Figures are quite similar to each other. In other words, there are not so much differences in the timing of the migrations, and in the time spent in the waters of the different latitudes each year. Similar facts for the Antarctic blue and fin whales were reported by BROWN (1954). The instances of marking and recovery are concentrated in the two parts of waters, 40°N and 50°N (Figs. 50A, B). The phenomena of a latitudinal segregation of whale groups will be discussed elsewhere in this Chapter. It should be kept in mind that Figs. 50A, B show longitudinal differences by a dotted line (west of 180°) and a solid line (east of 180°).

The North Pacific sei whales are distributed in the waters of 20°N to 23°N from late in January to early in February until they start to migrate northward to the waters of 35°N to 40°N, arriving there late in May or early in June, some animals moving to 50°N. In the waters

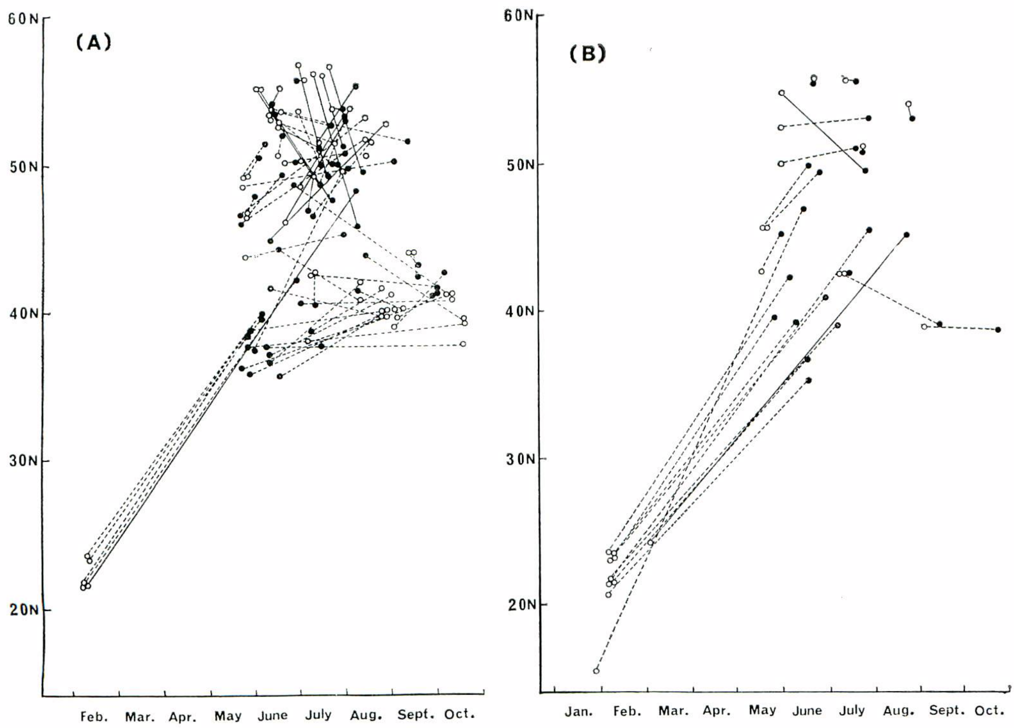


Fig. 50. Seasonal and latitudinal movements of the North Pacific sei whale estimated from marking experiments. (A); Long-period, recapture longer than one year, (B); Short-period, recapture within one year, Open circle; Month and latitude released, Closed circle; Month and latitude recaptured, Solid line; Waters in west of 180°, Dotted line; Waters in east of 180°.

east of 160°W and north of 50°N, the whales begin their southward migration during the month of July, on the other hand, in the waters west of 160°W and south of 50°N (including the cluster of 40°N shown in Figs. 50A, B), the southward migration begins from early in August to early in September.

The meridian of 160°W is seemed to form the boundary dividing the time of beginning of the southward migration. The time difference between the western and eastern waters is one to two months.

V-2 Movements in the whaling grounds

BANNISTER and GAMBELL (1965) and GAMBELL (1968) discussed the direction of movement of large whales off Durban as observed from the spotter aircraft. On the coast of Japan, KASUYA (1971) reported the seasonal and annual density fluctuations of several toothed whales based on the sighting records from airplane. Furthermore, RICE and WOLMAN (1971) discussed the migration of gray whale based on sighting and the records of stranding.

However, in analyzing the movements of sei whale within the whaling grounds in the North Pacific, the author used two sources of data. The first source is the direction of swimming as observed by the marking vessel navigators when conducting marking studies, and the second is monthly and areal changes in the numbers of whales sighted per 100 miles of scouting distance.

Whale sighting has been systematically carried out by the scouting boats which belonged to the Japanese whaling expeditions in the North Pacific from 1965 to 1973. Concurrently the whale marking program of Japan has recorded the swimming direction of whales sighted from 1949 to 1973. A density distribution is represented as the number of whales sighted per 100 miles of scouting distance.

Figure 51 shows the density of the sei whales for the whole North Pacific area by month. The density for April, May, August and September is low, and it is high for June and July. These changes imply the factors that the main groups of the North Pacific sei whale migrate

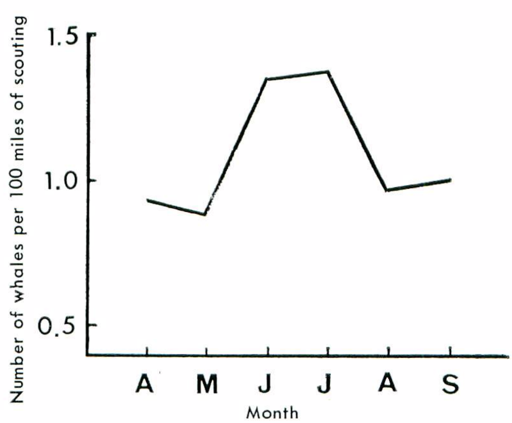


Fig. 51. Index of abundance of the sei whale by month for the entire North Pacific.

to the feeding grounds north of 40°N from waters of low latitudes from April to May. During June and July they stay in the feeding grounds, and then begin southward migration during August and September. This change in the density is one of the major factors in considering the northward and southward migrations.

NEMOTO (1959) reported that most schools of sei whale in June are consisted of a pair of individuals, and he suggested that they probably return to the south for mating. Although, it is considered that the time of beginning of southward migration may differ with latitude, the time reported by NEMOTO is about one or more months earliner than that of present result. The discordance between the two time may depend on that the results of NEMOTO are based on the data from the northern part of the North Pacific.

Figure 52 shows the density distribution of the North Pacific sei whale from April to

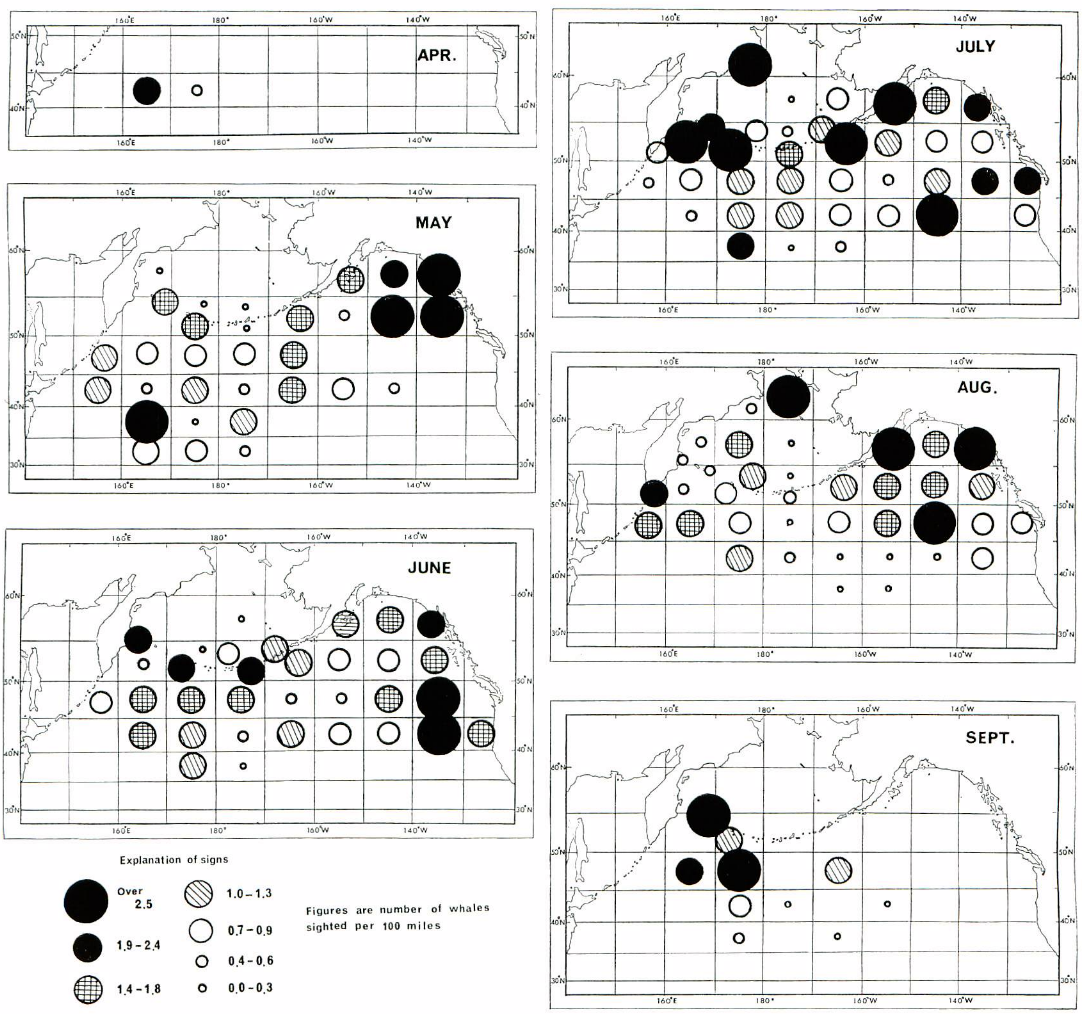


Fig. 52. Geographical distribution of density index by month based on sightings of the North Pacific sei whale from April to September during the seasons 1969 to 1972.

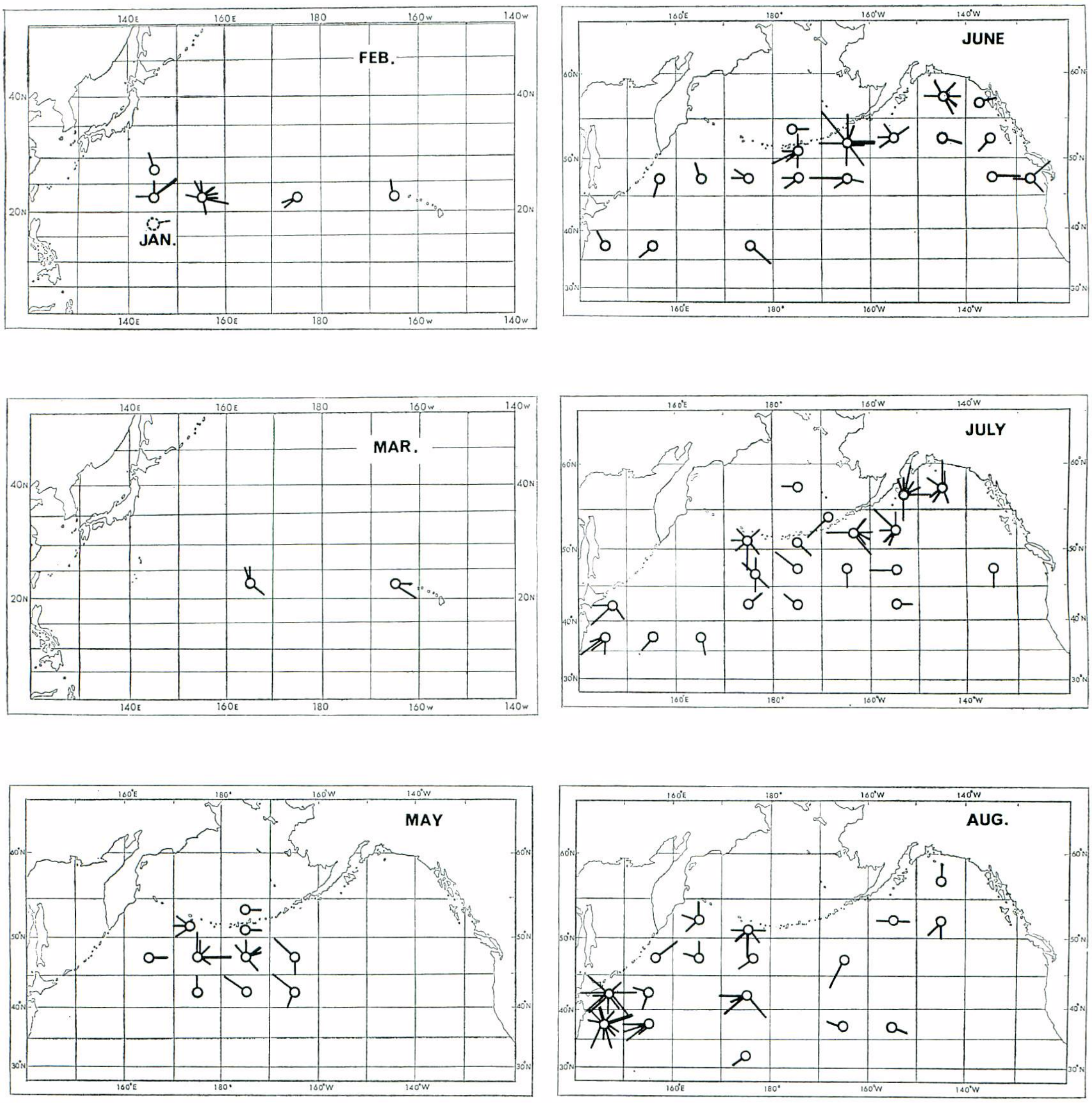
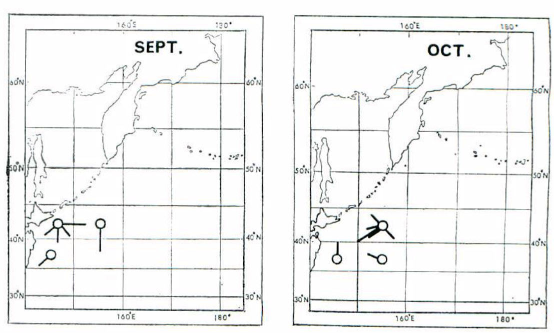


Fig. 53. Direction of swimming, based on sightings from February through October, except April, by month of the North Pacific sei whale.



September by month. Figure 53 shows the direction of swimming from February though October by month (except April, due to a lack of data).

GAMBELL (1968) reported that though the movement of whales to a specific direction may reflect behaviour related to local feeding or environmental conditions, the result of sightings should reveal any overall trends.

The pattern of movements of the whales from February to October is analyzed using the Figures mentioned above. Abbreviations of area, square, division, sector and zone as shown in Fig. 1 are useful to facilitate understanding further discussion of movements. The term of swimming direction is used interchangeably with the terms "heading" and "bearing".

The predominant direction of swimming in Squares Ls 21 and Ls 22 from February to March is north or northeast, and from the waters of the Bonin Islands and the Hawaiian Islands they begin northward migration. Judging from the map of density distribution for April, a considerable number of sei whales have already migrated into Square Mn 23.

Three squares of high density distribution are recognized in May; namely, Square Mn 23, Squares N 26 and Ps 26, and the inner part of the Gulf of Alaska.

The patterns of these distributions in May are discussed below. In the waters south of 50°N in Area V, the general heading of the whales is to the north and the east, and in the waters around the Aleutian Islands in the same Area, they are advancing to the west. It is considered that a part of the group which is observed in Square Mn 23 in April moves to the high latitudinal waters around Commander Islands and to the waters off the eastern side of the Kuril Islands.

MATSUURA (1935 b) and KASAHARA (1950) reported that the sei whales migrated to the waters off the Sanriku coast in May, and that the main whaling season in these waters was from June to August.

Further, SLEPTSOV (1955) reported that the number of sei whales migrated toward the Kuril Islands and eastern coast of the Kamchatka Peninsula from the south, southeast and the east, increased gradually from late in May to early in June. These movements are confirmed by the results of the whale marking research as shown in Fig. 63.

During May, in Area IV, the swimming direction to the northeast is prominent in Zone N, at the same time, a group of whales moves to the east in the waters of the Aleutian Islands in this Area. It is supposed that the sei whales in the general area of the Gulf of Alaska migrate to the Area IV through the waters south of 50°N before May.

The waters with high density distribution in June are almost the same as those of May. These waters with high density distribution lean to the north as a whole, and there are no much latitudinal differences in the index of distribution density among the waters. The direction of swimming is different in each area of the feeding grounds, because the whales began a regular feeding activity. A characteristic of the movements in June, as reported by SLEPTSOV (1955), is that the directions of heading are becoming more remarkable toward the waters around the Aleutian and Kuril Islands than in May.

A high density distribution in July is found in the following waters; (1) Squares Ps 23, Pn 23 and Ps 24, (2) Squares Ps 26 NP and Pn 27 NP, and (3) the waters east of 150°W in Zone N. The movements of sei whales to the east or toward the coast in Area III and Zone P (=Sector III P), and to the waters around 160°W, are taken place in two directions, i. e., southwest and southeast. A group which comes from the northwest to the waters off Sanriku and Hokkaido also passes through the coastal waters, then changes the course to west or southwest.

During August, three waters with high density distribution are recognized as follows: (1) Squares Ps 22NP, Nn 22NP and Nn 23, (2) Squares Ps 26 NP, Ps 27, Nn 26 and Nn 27, and (3) the waters of the Gulf of Alaska. This density distribution is similar to that observed in May on the whole.

Data on heading direction are only available for the area of the western part of the North Pacific. The general direction of heading in Division 24 is the south-southwest, and in the waters off Sanriku and Hokkaido, the sei whales migrate continuously to the coastal waters from the northeast during July. The heading of the whales in Squares Mn 21 and Ns 21 shows various directions, but one of these is the southeast and south, and in general it can be considered that the southward migration has just begun. On the other hand, one of the groups which passed through the Aleutian Islands into the Bering Sea in July, moves further to the northern waters during August (Fig. 52).

In September on the western side of the North Pacific, the waters, though the data are restricted, with high density distribution are seen in Squares Pn 23, Ps 24, Nn 23 and Nn 24. In September and October, the direction of swimming in the waters off Sanriku and Hokkaido is almost the south, however, there are two types of whales, one moves southward from there and the other arrives there from the northern waters off the Olyutorskyi coast and the waters of southeastern Kamchatka Peninsula.

The above discussion is summarized as follows;

(1) The waters of the western side of the North Pacific (west of 180°):

The sei whales begin to migrate from the waters of 20°N–30°N to the north or northeast during February and March. In May and June, they move to the north or east from Squares P 23 and N 23, and on reaching the Aleutian Islands, they swim westward along the Aleutian's southern coast. At the same time, one group of sei whales which migrates through Squares P 23 and N 23, turns westerly to the northern waters of Japan, the Kuril Islands and the eastern coast of the Kamchatka Peninsula.

In July and August, the sei whales in Sector V N begin southwestward migration. In Squares Ns 21 and Nn 21, they move to the west or southwest, and migrate into the waters off northern Japan (Sanriku and Hokkaido). From these waters they migrate to the south in September and October.

(2) The central waters of the North Pacific between 180° and 160°W:

From February and March, the whales migrate to the northwest, and on reaching the Aleutian Islands they change course to the east. In July, the sei whales in Squares P 25 and P 26 move in southerly directions, either to the southeast or to the southwest.

(3) The waters east of 160°W:

The sei whales migrate to the north through the waters off Vancouver Island during June,

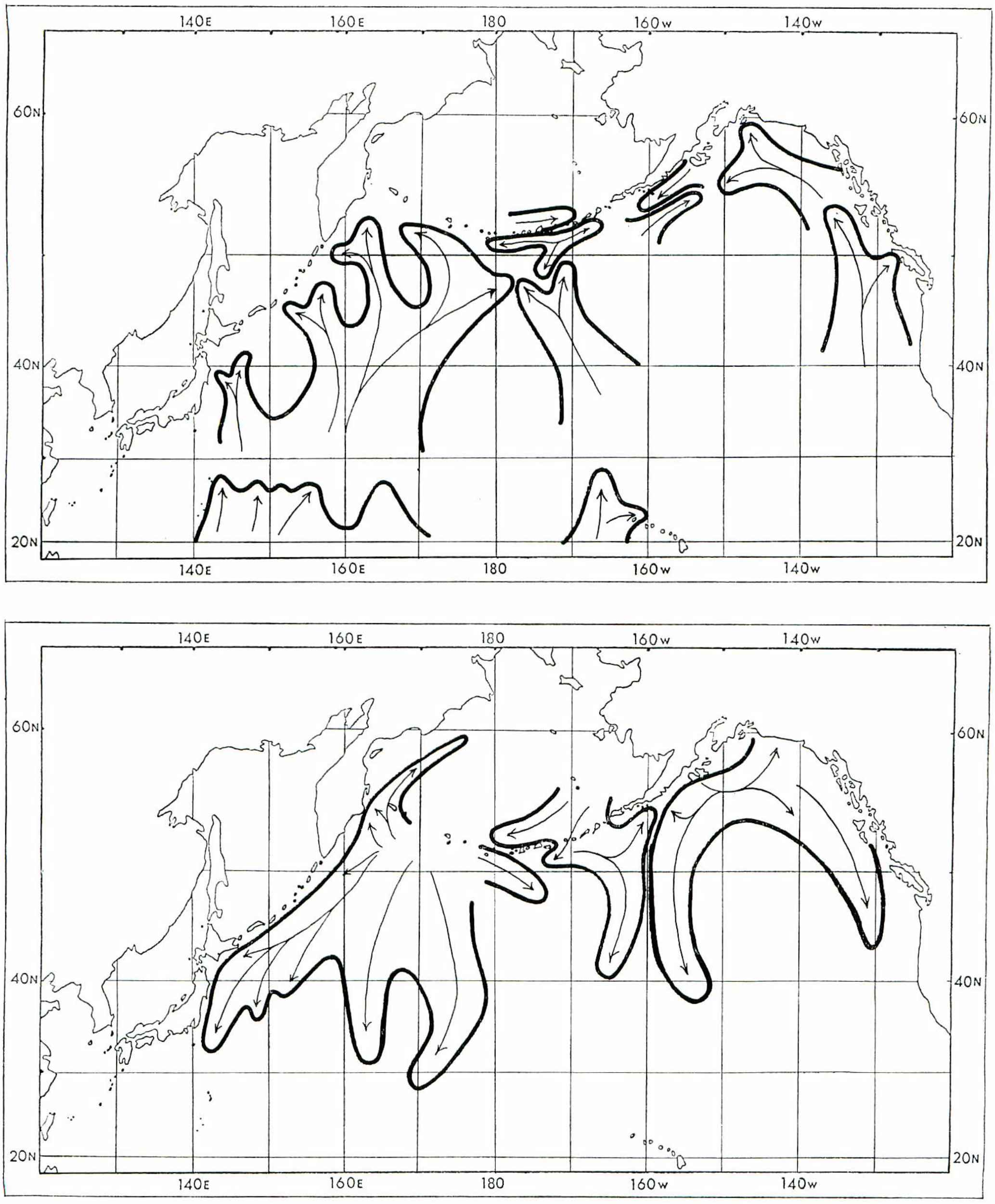


Fig. 54. Schematic map of migratory movements of the North Pacific sei whale. Top; During the months of January to June. Bottom; During the months of July to October.

and on reaching the upper part of the Gulf of Alaska they change direction to the west.

In July, two southerly migration routes are observed, one route heads south repeating the track of the northward migration, though the route is rather close to the coast, the other route is a movement heading to the southeast, passing through Square P 27 NP.

Summarized maps of the above described migratory movements are presented diagramatically in Fig. 54.

V-3 Migration of the cow and calf

The patterns of the northward and southward migrations and the spatial movements of the sei whales are presented in the previous Sections. In this Section, the migration and movements of cows with calf are specially handled.

The same data source as in the previous Section of this Chapter are used. The ratio of cows with calf to the total number of sei whales sighted, is presented in Fig. 55 by month in latitudinal zones of five degrees for the entire North Pacific. Figure 33 presents the ratio for the east and west longitude in order to show latitudinal differences of the ratio in the respective waters.

In the waters of east longitude (that is "Western Pacific"), the highest sighting ratio from February to March is observed in Zone N. This group of whales seems to begin northward migration at this time. During April to May, this group moves further to the north, and distributed in the waters between 35°N and 45°N. By June, the main group of cows with calf are widely distributed in the area between 35°N and 55°N.

In July, a large group of cows with calf moves southward to the waters around 30°N, and the remainder is found around 45°N. By August, cows with calf are not observed in the waters north of 35°N, this indicates that all cows with calf have migrated southward to the waters beyond 35°N.

In the waters of west longitude (that is "Eastern Pacific"), the main distribution of cows with calf is observed between 40°N and 45°N. With coming of August, those cows with calf occur north of 50°N and begin to move southward. During July and August, however, the main group of cows with calf is found in the waters south of 40°N. These two types of distribution which are also found in the Western Pacific lead an interpretation that the weaning has occurred in the cow-calf pair found in the waters north of 40°N. Interestingly, the cows with calf in the Eastern Pacific arrive in the waters north of 40°N earlier than those in the Western Pacific, however, the beginning of the southward migration in the Eastern Pacific is later than that of the Western Pacific. Possible explanation of these phenomena is that the cows with calf which migrate north of 40°N from the Eastern Pacific remain there longer than those from the Western Pacific by almost one month.

V-4 The differences of the migratory patterns of the sei whales analyzed by the stages of sexual maturation and pregnancy

DAWBIN (1960, 66) showed a clear demonstration of "temporal segregation" through the seasonal cycle in the southern hemisphere humpback whale. BANNISTER and GAMBELL (1965) and RICE and WOLMAN (1971) also showed some evidence of seasonal segregation by sex and sexual maturity for the Antarctic fin and sei whales, and Californian gray whale, respectively.

The author attempted to clarify the migratory patterns of the North Pacific sei whale by analyzing two biological parameters in relation to the whale's movements. They are the rate

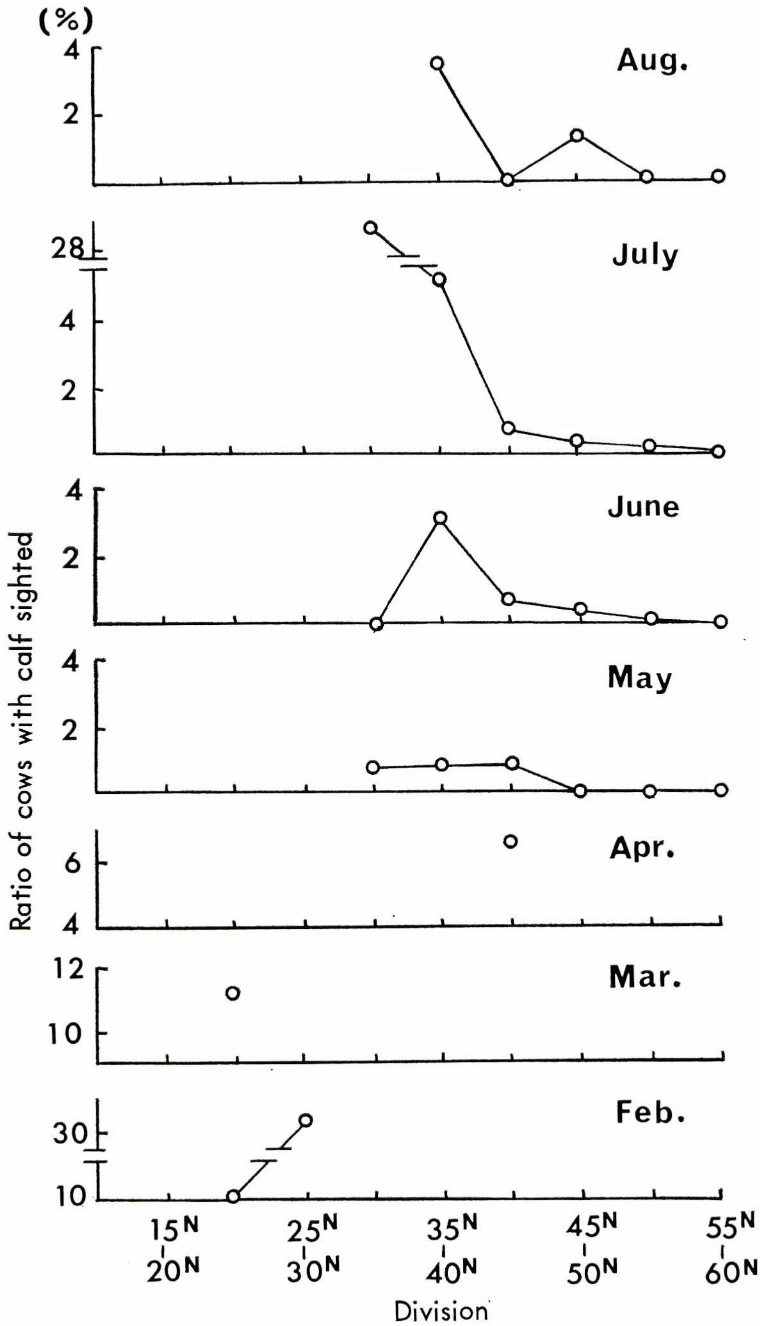


Fig. 55. Ratio of cows with calf to the total number of sei whales sighted by month in latitudinal division of five degrees for the entire North Pacific.

of sexual maturity and pregnant whales by month and by area. The data used in this discussion are the same as those in Sections IV-3 and IV-4.

V-4-i Differences of the migratory pattern with sexual maturity

Figure 37 shows the change in the rate of sexual maturity for each month by area and by sex. The rate of sexual maturity in Zone N (40°N to 50°N) during May is the highest in Square N 23, and it is low in Square N 27 which is situated in the waters of the central North Pacific. The rate in Zone P (50°N to 60°N) decreases sharply in Square P 25, especially for the females. The mature sei whales in the western part of the North Pacific move to the north earlier than those in the central region, and again, this tendency is more notable in the females. The first group arriving in the feeding grounds (whaling grounds) is the mature whale group which always precedes the immatures in moving to high latitudinal waters. This phenomenon coincide with the results of BANNISTER and GAMBELL (1965), DOI *et al.* (1967) for the Antarctic sei whale, WHEELER (1934), MACKINTOSH (1942), LAWS (1961) for the Antarctic fin whale and RICE and WOLMAN (1971) for gray whale.

During June, the change in the percentage of sexually mature animals by square shows almost the same pattern as that of May. At this time, the percentage of sexually mature whales in Zone N decreases because the mature animals move to Zone P, and they are replaced by immature whales coming into Zone N from the south. A comparison of the percentage of sexually mature animals found in the waters east of Division 28 to that found in Divisions 25, 26 and 27 suggests that the mature sei whales in the waters east of Division 28 arrive in Zone P earlier. It is notable that there is a segregation of mature animals from immatures by latitude in Division 28.

The divisional difference in the percentage of sexually mature whales during August through Divisions 23 to 29 is larger than that of May and June. That is to say, the rate of sexually mature whales in the central North Pacific (Squares N 25, N 26 and N 27) is lower than that of the eastern Squares N 28 and N 29, and the western Squares N 23 and N 24. Such differences by area were also observed in the Antarctic sei whale (NASU and MASAKI, 1970). These facts are seemed to originate in the different history of exploitation of the North Pacific sei whale stocks and in the difference of the oceanographic structures.

V-4-ii Migration of pregnant whales

The changes of the pregnancy rate by month, by area and by year are shown in Figs. 39, 40 and 41, and discussed in Chapter IV. In this Section, those monthly and areal differences are discussed in the light of migratory patterns. Figure 56 shows the pregnancy rate for each month by 10 degrees division of longitude by zone. The pregnancy rate, latitudinally from Square N 23 to Square N 29, shows a high percentage in the western side of the North Pacific and gradually decreases toward the eastern side. This trend of a progressive decrease in the pregnancy rate is common from May to September. However, the pregnancy rate is high in May, July and September, and on the contrary, it is low in June and August in Zone N.

As reported by WHEELER (1934), MACKINTOSH (1942), LAWS (1961) for the Antarctic fin whale, BANNISTER and GAMBELL (1965), DOI *et al.* (1967), NASU and MASAKI (1970) for the

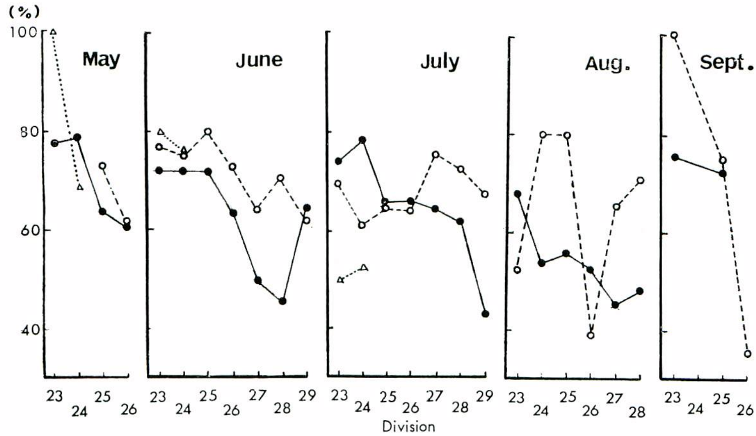


Fig. 56. Changes of the pregnancy rate for each month by division of longitude of the North Pacific sei whale. Open triangle and dotted lind; Zone M (30°N–40°N). Closed circle and solid line; Zone N (40°N–50°N). Open circle and dotted line; Zone P (50°N–60°N).

Antarctic sei whale and Rice and Wolman (1971) for gray whale, it was indicated that pregnant sei whales arrive in the feeding grounds early and leave there early. However, in contrast with these, Dawbin (1960, 66) reported that pregnant humpback whales make a long stay in the feeding grounds.

In view of the latitudinal and longitudinal differences of appearance, the migratory patterns of pregnant sei whales are estimated that they arrive in Zones N and P as a group in May earlier than the whales of other reproductive conditions. In June, some animals of this pregnant group move northward to Zone P, resulting in a temporary decrease of the pregnancy rate in Zone N. However, the rate increases again in July for the reasons that the group of pregnant whales which travelled further north to Zone P in May return to Zone N at this time, and the pregnant whales which have conceived in the close of mating season arrive in this waters. The movements of pregnant whales in Sepember can not be explained due to the lack of data.

These latitudinal movements show some differences in different areas. No marked differences are noted in May and June. However, in July, pregnant whales in the central North Pacific waters of Divisions 25 and 26 begin to move southward from Zone P to Zone N. These movements are relatively insignificant.

The most substantial difference in the movements is the segregation of pregnant whales from non-pregnant mature females in Zones P and N in the east of Division 27.

There is a marked trend that pregnant whales in the central North Pacific begin to migrate southward earlier than those in other areas of the Pacific.

V-5 Movements of the North Pacific sei whales analyzed by body length

Analysis of body length composition offers useful information for migrations, movements, the changing trends of the stock's condition, etc.

The movements according to the sex and body length, and differences in the migration routes in the various waters are examined by observing the monthly change of body length, in addition, the condition of stock is judged from the annual change in body length of whales captured. Similar method was applied by OMURA (1950) and KASAHARA (1950) for large whales in the adjacent waters to Japan.

The body length data used in this Section are collected by Japanese expeditions during the whaling seasons of 1952 through 1972 in the North Pacific. The time series is divided into four periods according to historical change of catching effort imposed on this whaling (see Introduction). These four periods are as follows: Period I, 1952–1963; Period II, 1964–1966; Period III, 1967–1969; and Period IV, 1970–1972. The changes in the mean body length and the pattern of body length compositions are analyzed by sex, by period and by 10 degrees square of distribution.

V–5–i Changes in mean body length

Figure 57 shows the changes in mean body length by sex and by year from 1952 to 1972. The mean body length between 1952 and 1961 has been lumped together owing to the small catch of sei whales through this period. The mean body length of the whales caught in the period from 1952 to 1961 was 14.6 m (47.9 feet) for the females and 14.0 m (46.0 feet) for the males. These values decreased steadily for both sexes in recent years, and in the 1972 season, the mean body length was 13.4 m (43.8 feet) and 13.8 m (45.2 feet) for males and females, respectively. The decrease of mean body length in recent years can be expressed 5.7% for male and 4.8% for female by comparison the values in 1972 with those prior to 1961. A decreasing of mean body length in recent years may be consequent on a decreasing stock size caused by catching.

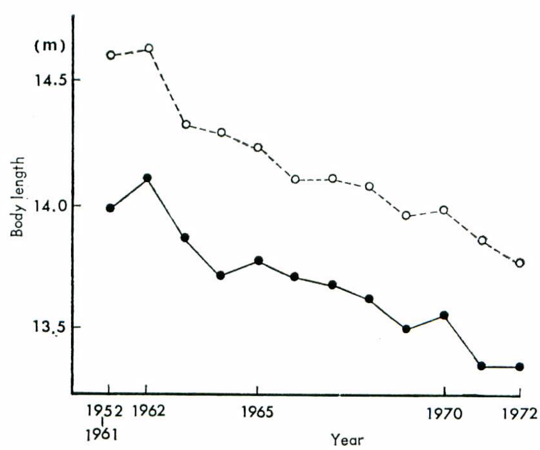


Fig. 57. Annual change of mean body length of sei whale for each sex from the 1952 to 1972 seasons caught by Japanese expeditions in the North Pacific. Open circle and dotted line; Female. Closed circle and solid line; Male.

The changes of mean body length by month in various waters are analyzed. It is realized that even if mean body length of the whales captured decreases as a result of catching, this changes is considered to represent the status of the stock as a whole. Therefore, the patterns of the changes in mean body length by month and by area may not be influenced solely by catching within the same period mentioned above.

Figure 58 shows mean body length in Zone N by sex, by month and by 10 degrees longitude for Periods III and IV. Figure 59 shows the same data for Periods I, II and III in Zone P with additional data of September.

There is a lack of data in these two Figures since Japanese expeditions did not operate in both Zones N and P for all four periods. Therefore, the changes in mean body length of the third (1967-1969) and fourth Periods (1970-1972) in Zone N (Fig. 58), and mainly the first (1952-1963) and second Periods (1964-1966) in Zone P (Fig. 59) are examined.

For the sake of convenience, the patterns of change in the mean body length are grouped into three types as follows:

A: mean body length decreases with month,

B: mean body length decreases with month, then increases again, and

C: mean body length increases with month.

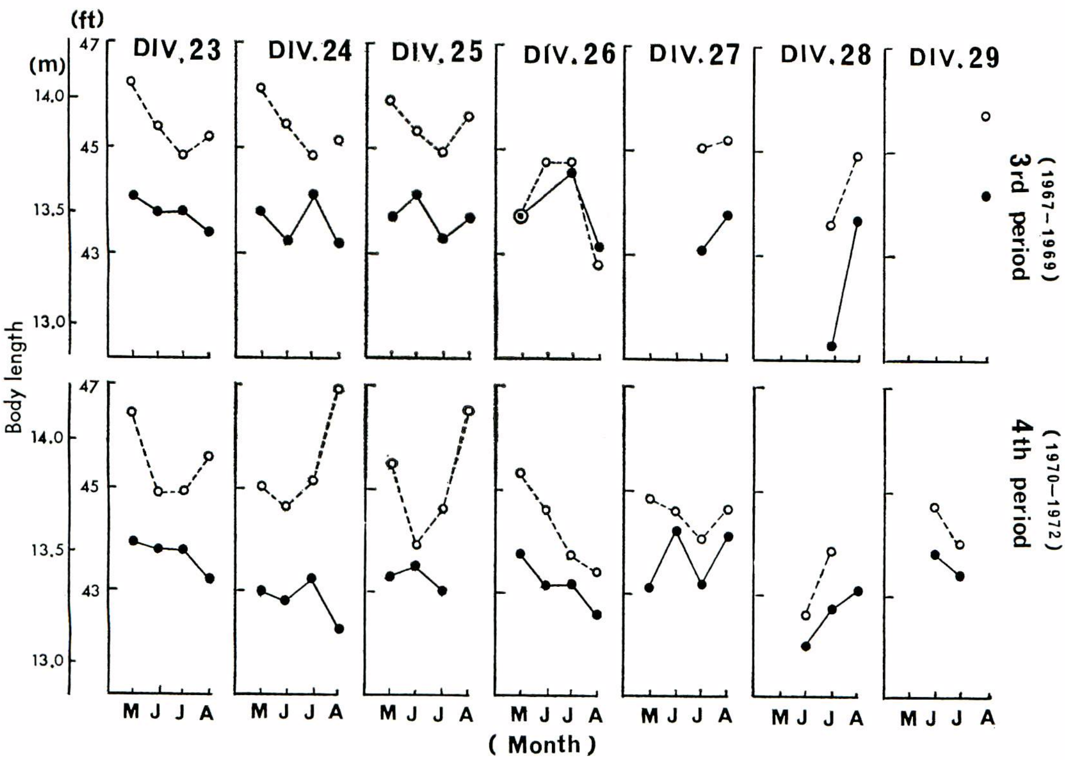


Fig. 58. Monthly change of mean body length of the North Pacific sei whale in Zone N (40°N-50°N) for each sex by division for Periods III (1967-1969) and IV (1970-1972). Open circle and dotted line; Female. Closed circle and solid line; Male.

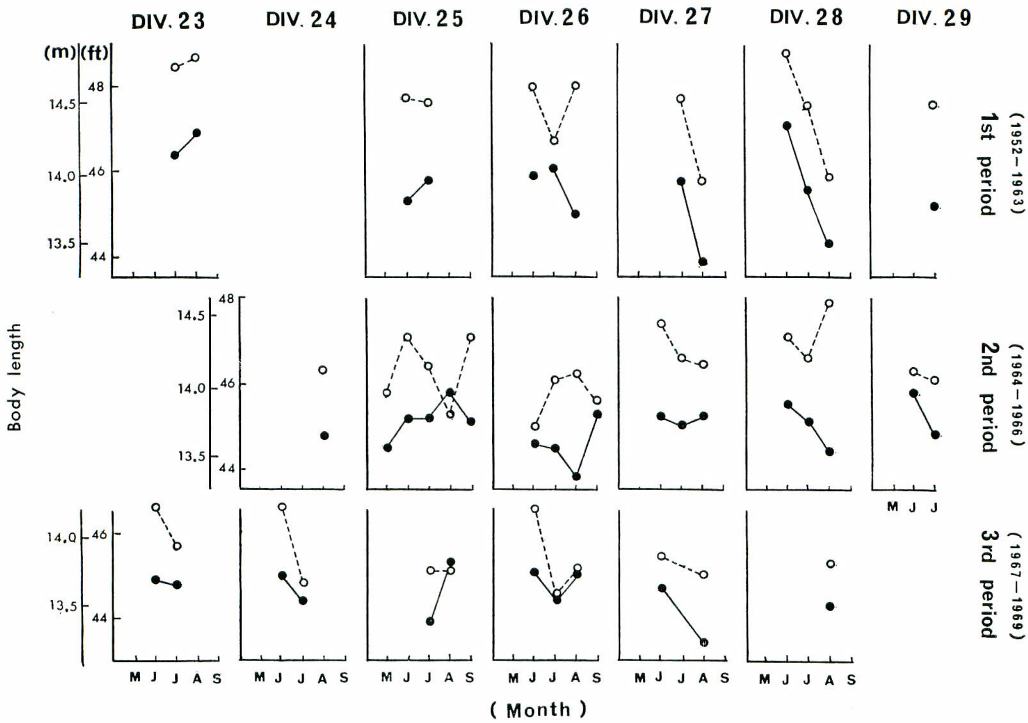


Fig. 59. Monthly change of mean body length of the North Pacific sei whale in Zone P (50°N–60°N) for each sex by division for Periods I (1952–1963), II (1964–1966) and III (1967–1969). Open circle and dotted line; Female. Closed circle and solid line; Male.

The changes in mean body length among divisions are analyzed according to the above mentioned types. For the third and fourth Periods Squares N 23, N 24 and N 25 are all type B, Squares N 26 and N 27 are type A and Squares N 28 and N 29 are type C. On the other hand, the change of Period I is type A in Squares P 27 and P 28, and that of the second Period is also type A in Squares P 25 and P 26.

Much differences of mean body length between males and females are observed in both west of Square N 24 and east of Square P 27. This suggests a longitudinal segregation by body length. The same phenomenon was reported by MATTHEWS (1938), BANNISTER and GAMBELL (1965), DOI *et al.* (1967) and NASU and MASAKI (1970) for the Antarctic sei whale and MACKINTOSH (1965) for the Antarctic blue and fin whales.

The pattern of monthly change in the mean body length is different among the whales taken from different squares. These differences are indicative of the fact that the North Pacific sei whales migrate separately according to the classes of body length as well as to the localities in the same latitude. Furthermore, in August, the fact that marked differences in trend of change in mean body length between males and females are observed in Divisions 23, 24 and 25, indicates the migratory pattern may differ with the sexes.

V–5–ii Patterns of the body length composition

The sei whales have been realized as the main species of Japanese pelagic whaling since

1967, and the sei whale operations expanded almost all over the North Pacific whaling grounds as mentioned in the introduction.

Therefore, in order to clarify the trend of the changes in stock size and to elucidate the differences of migration times with regard to sex and body length, the data on body length composition after the 1967 season are of more value than the preceeding ones. The body length composition of the North Pacific sei whale taken during the seasons of 1952 through 1972 is presented in Fig. 60 by sex and by year. Two modes are observed on size frequency distribution during the years 1965 to 1972, the value at the mode of larger size does not show much differences for both sexes through the entire period, and it corresponds to 13.7 m–14.0 m (45–46 feet) for males and 14.3 m–14.6 m (47–48 feet) for females.

The distribution of the body length composition before the 1964 season possesses a single mode of a large value in both the male and female. However, after the 1965 season, the ratio of individuals less than 12.8 m (42 feet) to the total whales taken increased year by year, and after the 1967 season, the bimodal distribution of body length composition became prominent with a small peak at about 12.5 m (41 feet).

The larger whales were caught more than the smallers until the 1970 season, however,

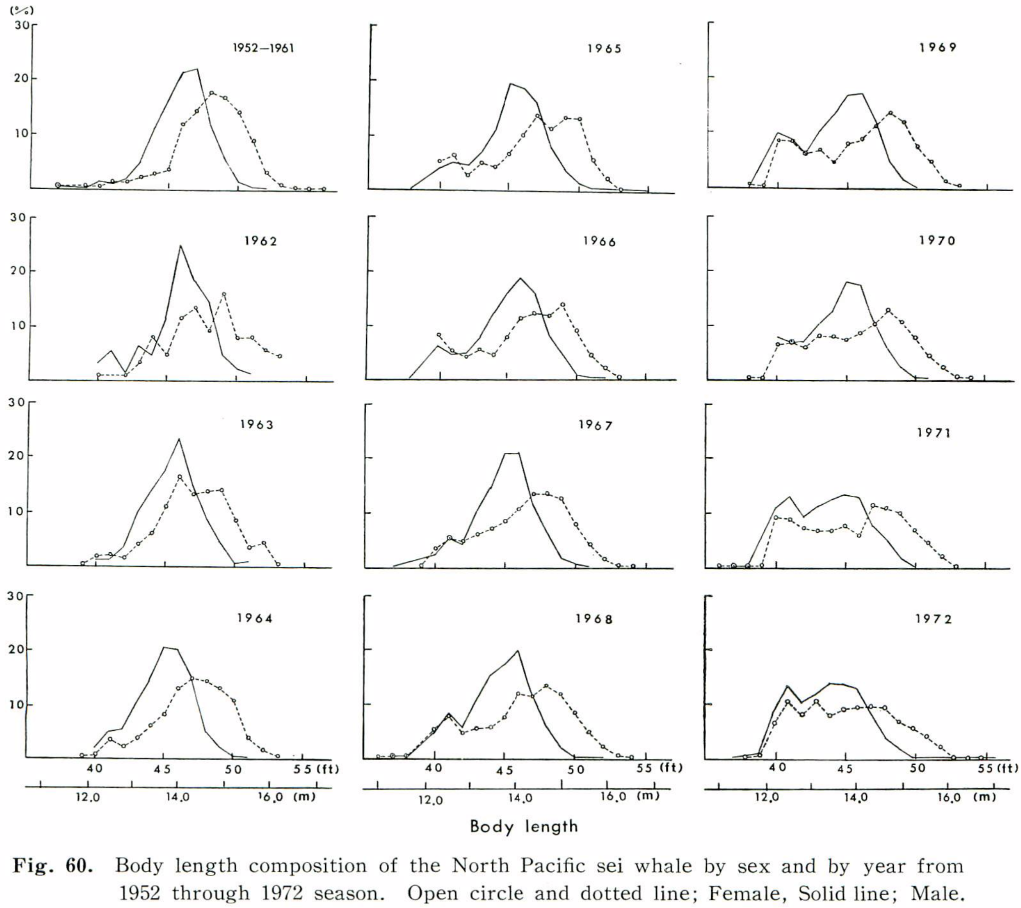


Fig. 60. Body length composition of the North Pacific sei whale by sex and by year from 1952 through 1972 season. Open circle and dotted line; Female, Solid line; Male.

they were caught almost equally since 1971.

Prior to the 1964 season, the ratio of larger whales of both the male and female averaged about 15% and 20%, respectively, to the total number of whales taken, but in the 1972 season, these ratios reduced to about 9% and 13%, respectively.

The whales regarded as a small size refer to individuals which occupy the valleys of the figures of the body length composition shown in Fig. 60. The body length of them (13.4 m in females, 12.9 m in males) are the same as those at sexual maturity (13.4 m in females, 12.9 m in males) discussed in Chapter II.

Figure 61 shows the yearly change in the ratio of these small sized whales to the total whales caught. The Figure shows that the ratio increases nearly in a straight line and this trend is more remarkable in the females. Prior to the 1964 season, this ratio was about 10% for each sex to the total whales caught, but from this season the ratio increased continuously to about 25% in males and about 40% in females in the 1972 season.

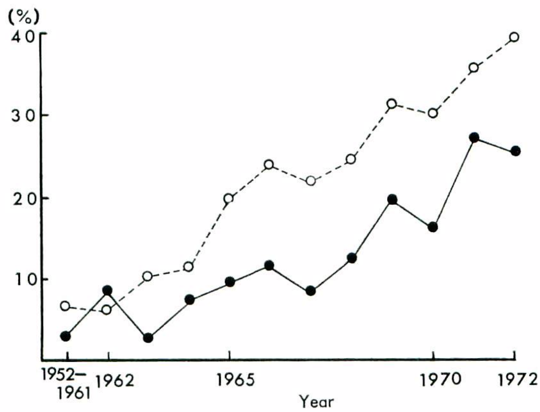


Fig. 61. Annual change in the percentage of small sized whale less than 40 feet to the total number of whales caught by Japanese expeditions from the 1952 to 1972 seasons in the North Pacific. Open circle and dotted line; Female. Closed circle and solid line; Male.

For the purposes to further discussion, with particular reference to Fig. 60 and Figs. 62A–E, the smaller sized whales comprising the left hand peak and valley of these Figures will be termed "Unit A", and the remaining larger sized whales will be termed "Unit B".

As mentioned above, the pattern of body length composition of the total catch (1952–1972) shows some characteristic changes in certain periods.

The changes of the patterns of "Unit A" and "Unit B", and the relative parameters of "Uuit A and B" by month and by Area per Zone (=Sector) are discussed according to the four Periods described in V-5-i. The results are presented in Figs. 62A-E. Th ecauses of the changes in the pattern of the body length composition with regard to segregation and migration are also analyzed.

Area V: The mode of "Unit A" from June to August for both sexes in Zone N is shown in Figs. 62A, B. The ratio of "Unit A" increases with lapse of time for both sexes, but in

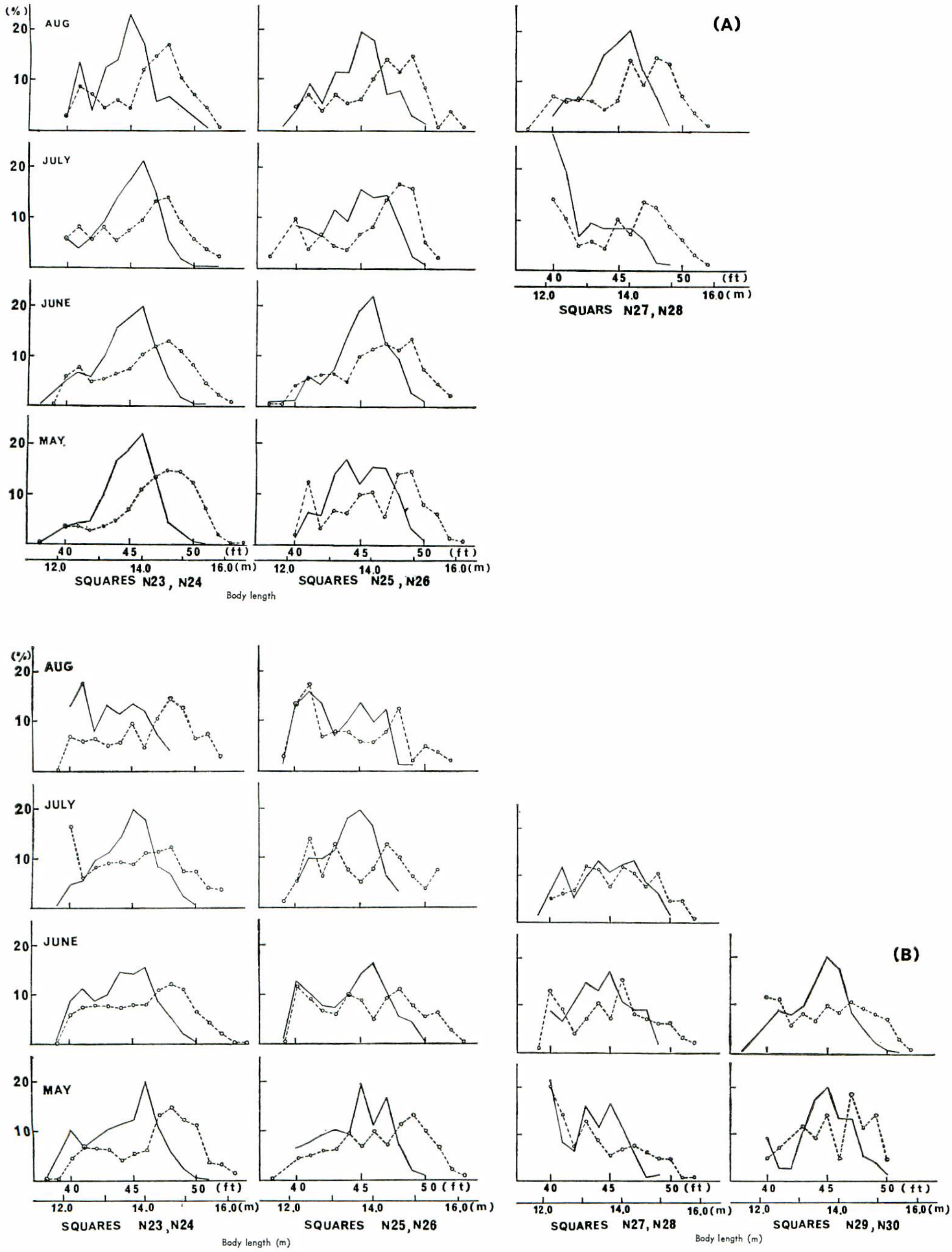
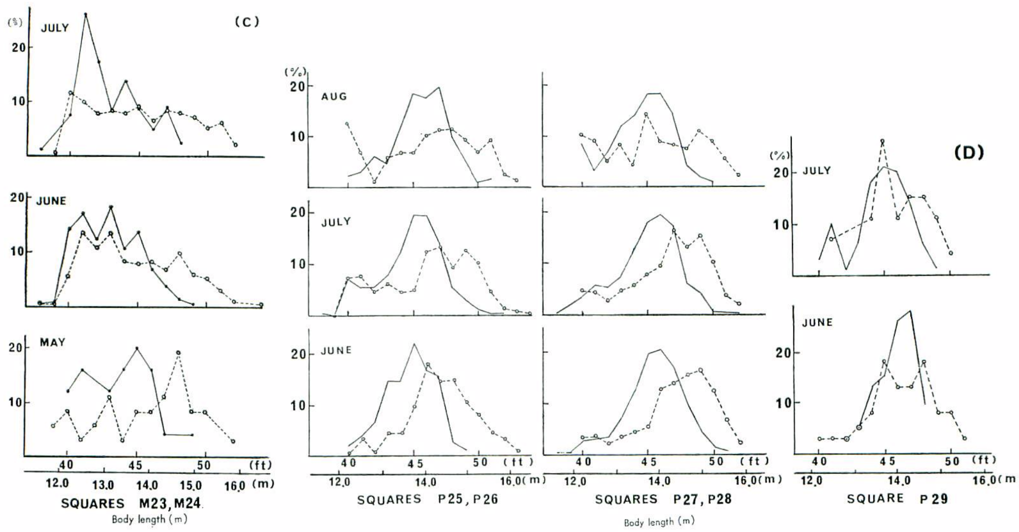
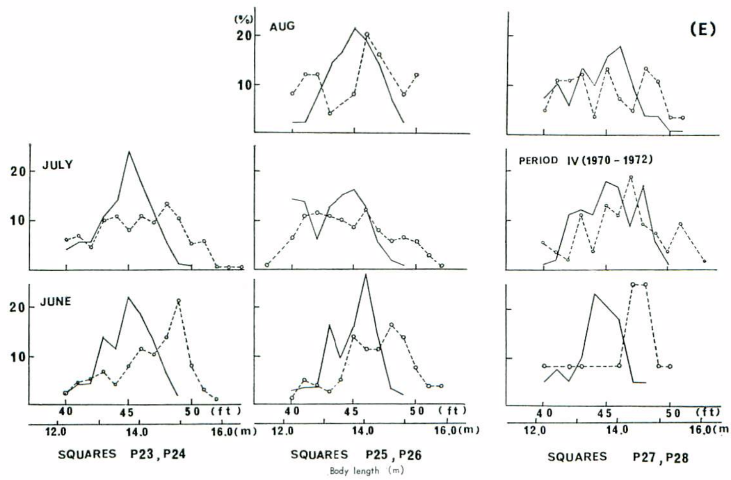


Fig. 62. A–E. Body length composition by month and by Area-Zone (Sector) for each sex and by Period of the North Pacific sei whale. Open circle and dotted line; Female. Solid line; Male. (A); Period III (1967–1969), Zone N.





(B); Period IV (1970–1972), Zone N. (C); Period IV (1970–1972), Zone M. (D); Period II (1964–1966), Zone P. (E); Period III (1967–1969), Zone P.

August it decreases. Further, the ratio of "Unit B" in Zone N is high in May and August, and it is low in June and July. In Zone M, the ratio of "Unit A" is also high. Furthermore, the ratio of "Unit A" in both June and July is higher than that of "Unit B". However, the monthly change in the ratio, the same as in the case of Zone N, shows almost the same trend for both sexes (Fig. 62C).

Area IV: The mode of "Unit A" from June to August in males and from May to August in females is shown in Figs. 62A, B for Zone N. The ratio of "Unit A" becomes higher with the lapse of time for both sexes, but agrees with the trend of a decreasing ratio in August, which is even smaller than that found in Area V. The percentage at the mode of "Unit A" is high in June and July, and low in May and August. Although the total number of whales taken in Zone P is not particularly large, the ratio of "Unit A" in June is low, but the value at the mode of "Unit B" is high compared to the ratios of July and August. In July, the ratio of "Unit A" becomes higher, and it reaches at about 40% in females and about 30% in males. In Zone P in July, the percentage of "Unit A" males becomes remarkably low, while at the same time, the ratio of "Unit A" females shows notably higher values than those of June (Figs. 62D, E).

Area III: Owing to the data for Zone N are not extensive, data mostly for the Periods III and IV are available. The ratio of "Unit A" is high in June and July, but it becomes low in August (Figs. 62A, B).

In Zone P for the Period II, the percentage of "Unit A" increases from June to August. The percentage of "Unit A" male does not show any particular trend by month, but a trend of decreasing is seen in the females (Fig. 62D). The patterns of the body length composition of male sei whales in June and July for the Period II and in June for the Period III in Zone P are very similar to the pattern of Sector V N in May (Fig. 62E). In addition, the patterns of Sector III N for the Period III in July (Fig. 62A) and the Period IV in June (Fig. 62B), resemble those of Sector V M in June and July for the Period IV (Fig. 62C).

For the Area II, available data on body length composition are for the Period II in June and July for Zone P, and for the Period IV in June and July for Zone N (Figs. 62B, D). A comparison between Zones N and P shows that the females of "Unit A" and "Unit B" are dominant in Zones N, and P, respectively.

In considering the patterns of the body length composition, the following matters are discussed. "Unit B" has arrived in Sector V N from lower latitudinal waters during May. Continuous increase in the ratio of "Unit A" from May to July indicates northward movements from Zone M to Zone N (Figs. 62A, B and C). Such movements are also supported by the following facts; the percentage of the mode of "Unit A" during June and July in Zone M becomes larger than that of "Unit B", and the ratio of "Unit B" in Zone P is higher than that of Zone N (Figs. 62A, B, D and E). An increase in the percentage of "Unit B" in Zone N in August demonstrates that the large whales move to the south from Zone P prior to the smaller animals.

In Area IV, the ratios of "Unit B" in Zone P and those of "Unit A" in Zone N become higher from May through June for both the males and females. This clearly demonstrates that larger sized whales migrate into Sector IV N earlier than the time when they move from Sector VN to Sector V P. However, in July, the percentage of "Unit A" in Zone N decreases owing to the influx of "Unit B" into Zone N from Zone P.

The differences of the ratio in the "Unit A" between male and female in Zone P seemed to be caused by the fact that "Unit A" males move south to Zone N prior to "Unit A" females.

In Area III, the ratio of "Unit A" decrerses with month in Zone N, and it is opposite to Zone P. This reversal of the ratio demonstrates the fact that the "Unit B" arrives in Zone N before May, and it moves from Zone N to the south during August. Furthermore, a comparison of the patterns of the body length composition between Areas V and III indicates that the whales of Area III begin northward migration about one month earlier than those of Area V in the same latitude.

In Area II, in regard to the female, the percentage of "Unit B" is the largest in Zone P, on the other hand, it is opposite to Zone N, that is, the percentage of "Unit A" is large. In this Area, latitudinal segregation of the female animals by body length is observed remarkably.

The movements and migrations of the North Pacific sei whales discussed above are summarized as below. For the convenience of explanation, the North Pacific whaling grounds are divided into three Regions, I; the waters west of 180°, II; between 180° and 160°W, and III; east of 160°W.

The sei whales migrate northward in spring and southward in autumn through the Regions. The larger sized mature whales migrate first, and they are followed by the smaller sized immature ones as same as the cases of the Antarctic sei, fin and Californian gray whales (DOI *et al.*, 1967; LAWS, 1961; and RICE and WOLMAN, 1971). There are three successive modes of the migration in the mature female whales, that is, pregnant, resting and lactating, in order. This migratory order was also mentioned by DAWBIN (1966) for humpback whale and RICE and WOLMAN (1971) for gray whale. The successive order of migration according to the reproductive phases of sei, fin, humpback and gray whales may be almost the same as mentioned by GAMBELL (1968), however, a little disorder is occurred in some cases.

The differences in direction of heading on the migration are observed among the three Regions. In Region I, in both migrations towards the north and south, there is a westerly movement. In Region II, the northward migration tends to the west toward the Aleutian Islands, while on the southern movement, the whales aggregate in the waters around 160°W, and then migrate to the south. The direction of movement in Region III is the same as in other Regions on the northern migration, but on the southern movement, the direction is split into the east and west around the waters of the Alaskan gyre.

The beginning of the northern migration of cows with calf in Regions II and III is earlier than that in Region I, but in the former Regions the southward migration begins later by about one month.

In a general consideration of migration of the North Pacific sei whale, the various modes of movement are viewed best from their passing in the waters of Zone N (40°N-50°N). The northward migration has its earliest arrival in Region III in April. The next arrival on the trip to the north is during April through May in Region II, and the latest arrival into Zone N is in May in Region I.

Regarding the southern migration, if the beginning of the migration from Zone P (50°N–60°N) is adopted as the standard of comparison, it occurs in August in Regions I and III, while it is July in the central waters of Region II.

In conclusion, the very complicated movements and staggered migrations of the North Pacific sei whales are understood best in terms of the time, direction of heading and the beginning of the migrations which are particular to each of the three defined Regions in the North Pacific. However, more materials outside the whaling grounds and off seasons are needed for further detailed examination of movements and migrations of the North Pacific sei whale.

VI. Stock units

The whale resources should be managed rationally by each stock unit, therefore, stock identification is the basic problem in the population study. The greater part of large sized whales except some one, e. g., gray and humpback whales (RICE and WOLMAN, 1971; MACKINTOSH, 1942; DAWBIN, 1956a, b, 64, 66; CHITTLEBOROUGH, 1959a, b), the stock units have been separated distinctly up to now. The separation of whales into the stock units has been tried by many methods, such as catch distribution (HJORT *et al.*, 1932), whale marking (RAYNER, 1940; BROWN, 1954; CHITTLEBOROUGH, 1959 a, b; DAWBIN, 1964), whale sighting (GILMORE, 1960; BROWN, 1957, 58), iodine values (LUND, 1951), blood typing (FUJINO, 1960, 64 a, b), body proportion (IVANOVA, 1955; ICHIHARA, 1957), shape of the baleen plate (MIZUE and FUJINO, 1957), etc. Furthermore, the separation of the North Pacific sperm whales into stock units has been tried by following methods, i. e., analysis of whale marking data, blood typing, catch distribution, whale sighting and size composition (MASAKI, 1970a).

The separation of the stock units of the North Pacific sei whales has been tried by means of following methods; body length composition (KASAHARA, 1950), blood typing (FUJINO, 1964 a), catch distribution (NISHIWAKI, 1966), and whale marking (IVASHIN and ROVNIN, 1967).

However, these studies were carried out on the insufficient data before 1967 when the pelagic whaling began to take sei whale regularly. In this Chapter, the separation of the stock units of the sei whale in the North Pacific is attempted by use of recent biological data which were provided with whale marking, catch distribution, whale sighting and the shape of the baleen plates.

VI-1 Whale marking

The results of whale marking have been used for many species of whales as one of the direct methods for separation of the stock into units. The data used in this Section were the results of whale marking conducted by Japan from 1949 to 1973. Japanese whale marking research began in 1949 and has been conducted systematically by Japanese Government in the North Pacific (NISHIMOTO, 1951). The marking for large sized whales has been executed mainly in the whaling grounds by the scouting boats accompanied with whaling expeditions. In addition, whale marking cruise by the catcher boats which are chartered by the Japanese Government has been conducted with interruption from 1956 to 1967. Chartered vessels are albe to mark whales outside the whaling ground and off season. This project has been expanded to the lower latitudinal waters in winter season since 1972 (MASAKI, 1972; OHSUMI and MASAKI, 1975). The number of whales marked and recaptured, and movements of recaptured whales are shown by area in Fig. 63. As the examples of long distant movement of marked whales, one moved from the Area H to Area F, and the other moved from the Area E to Area C. Most of the remains moved to adjacent areas, or stayed in the same area of the marking (OMURA and OHSUMI, 1964; OHSUMI and MASAKI, 1975). From these results, it may be thought that the North Pacific sei whales in the feeding ground did not make a long distant movement as seen in the male sperm whales and humpback whales.

Among all directions of the movement of the recaptured whales, the vectors of the north and the south are common in all stock units. The vectors of the east and the west direction

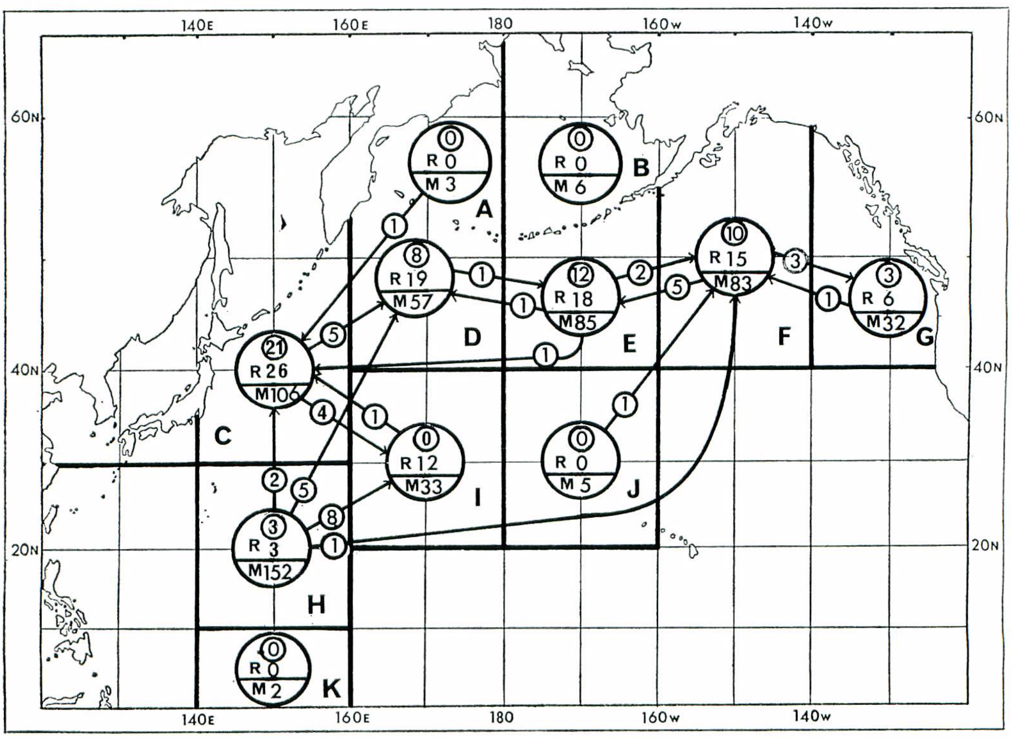


Fig. 63. Map showing the inter- and intra areal movement of the North Pacific sei whale estimated from Japanese release-recovery experiments from 1949 to 1973. M; Total number of whales released, R; Total number of whales recaptured, Numerals in small circle; Number of whales recaptured in same area, Numerals in small circle with arrow; Number of whales released at terminal area and recaptured at end area.

of the movement (dispersal) in the marked North Pacific sei whales are shown in Fig. 64. They were classified into two cases; in one case both marking and recapture were carried out within the same whaling season, and in the other case marked whales were recaptured subsequent to the next season after marking.

Figure 64 shows the frequency of the east- and westward vectors ot the movement of the recaptured whales by one degree longitude. The frequency of the vector is low (correspond to the parts of valley in Fig. 64) at 174°W and 155°W. In other words, the sei whales distributed in the areas of west of 174°W, between 174°W and 155°W and east of 155°W are well separated them from each other, however, they are remarkably mixed within the area. OMURA and OHSUMI (1964) and OHSUMI and MASAKI (1975) have not mentioned the separation

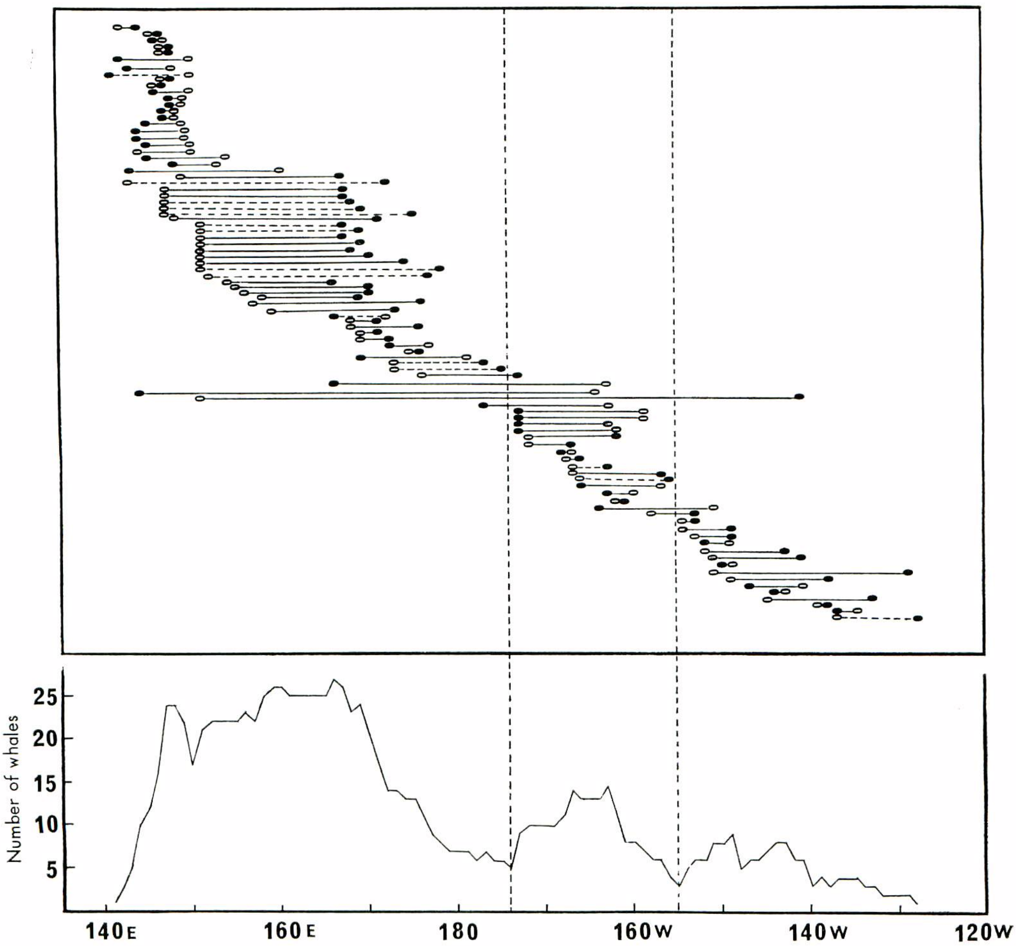


Fig. 64. East-west movement of sei whales estimated from Japanese release-recapture experiments in the North Pacific and number of individuals acrossed the each one longitudinal degree derived from upper Figure. Dotted line; Recaptured in the same season, Solid line; Recaptured after at least one winter season, Open circle; Position of release, Closed circle; Position of recapture.

of the stock units of whales, but referred the feature of movement and mixing among areas.

On the other hand, IVASHIN and ROVNIN (1967) recognized three local stocks, Asian, Central (Hawaiian) and American, of sperm whales in the tropical zone of the North Pacific. From this fact, they also analogized three local stocks in the tropical zone which occupy western, central and eastern parts of the North Pacific for the baleen whales (blue, fin and sei whales). Although the same number of the stock units was proposed for the sei whale in the North Pacific, their geographical classification was more obscure than the present one.

VI-2 Catch distribution

The separation of stock into units for the Antarctic blue and humpback whales was mainly carried out by analyzing the geographical distribution of catches. However, fine results have not been obtained from the whales other than blue and humpback whales in applying this method.

The number of sei whales caught by Japanese whaling in the North Pacific during the years of 1952 to 1972, is shown diagramatically in Fig. 65. At the same time, accumulated number of whales caught from each one degree longitude is also shown in Fig. 66. Four waters seem to be separated from the concentration of catch in Fig. 65. If each valley which is shown in Fig. 66 corresponded to a border of these waters, these four waters can be ex-

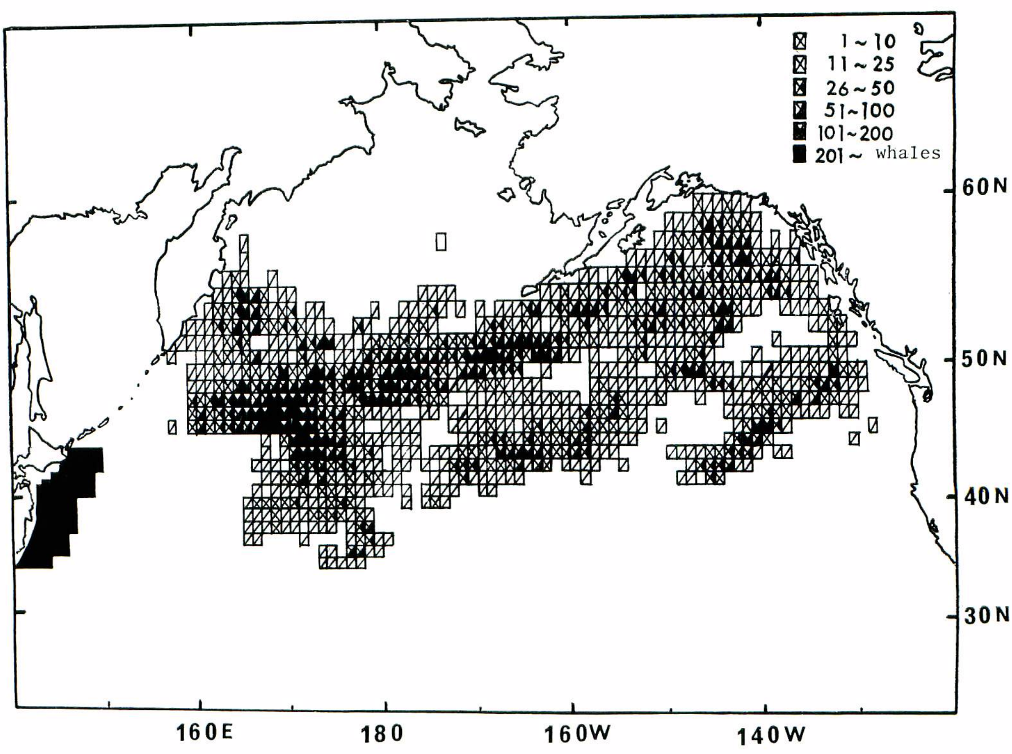


Fig. 65. Geographical distribution of accumulated number of sei whales caught by Japan from 1952 through 1972 seasons in the North Pacific.

pressed as follows; (1) west of 155°E, (2) between 155°E and 175°W, (3) between 175°W and 155°W, and (4) east of 155°W.

The area between 150°E and 159°E is not operated by the Japanese whaling because of the domestic regulatory measures, i. e., Japanese coastal whaling is limited to west of 150°E and the pelagic whaling is opened to east of 159°E. For these reasons, it is not reasonable to divide the area west of 175°W into two wasters by the blank waters around 155°E. If an independent stock unit was recognized in each of above mentioned three waters where relatively many whales were caught (Fig. 65), the North Pacific sei whales may be separated into three stock units.

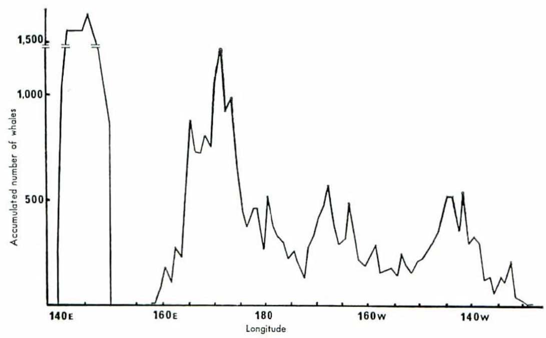


Fig. 66. Accumulated number of sei whales caught by Japan for each one degree longitude during the years 1952 to 1972 in the North Pacific.

VI-3 Whale sighting

Whale sighting has been done by ship, airplane and on the shore. The stock units of gray whale were recognized from the results of the whale sighting from the shore or ship (Mizue, 1951; Pike, 1962; Gilmore, 1960, etc.). On the other hand, Brown (1957, 58) reported that according to the analysis of the whale sighting data from marchant ship and others, large rorquals tend to distribute rather evenly and thinly in an east-west direction as if the whales were widely dispersed or migrated throughout a broad front rather than along narrow routes to localized breeding grounds. If he treated the data with other methods as used in this study, the different conclusions might be led.

As whale sighting by airplane is restricted within narrow limits, it may be difficult to apply the results to separate the stock into units.

The catch of whales is affected by economic factors and many regulation measures by the domestic or international laws. The map of catch distribution does not always show the real figure of the natural condition. The natural distribution of the sei whale will be shown by the map of the density index which is based on the whale sighting rather than by the catch distribution.

The whale sighting data obtained by the scouting boats belonging to Japanese whaling expeditions in the North Pacific during the years of 1965 to 1972 are used in the present study. The number of whales sighted per 100 miles scouting distances is used as the density index, and the index of abundance is calculated using the density index and the dimension of its area.

Density indices of sei whales sighted during the years of 1965 to 1972 are shown diagramatically in Fig. 67. Four highly dense areas are recognized, namely, (1) the west of the

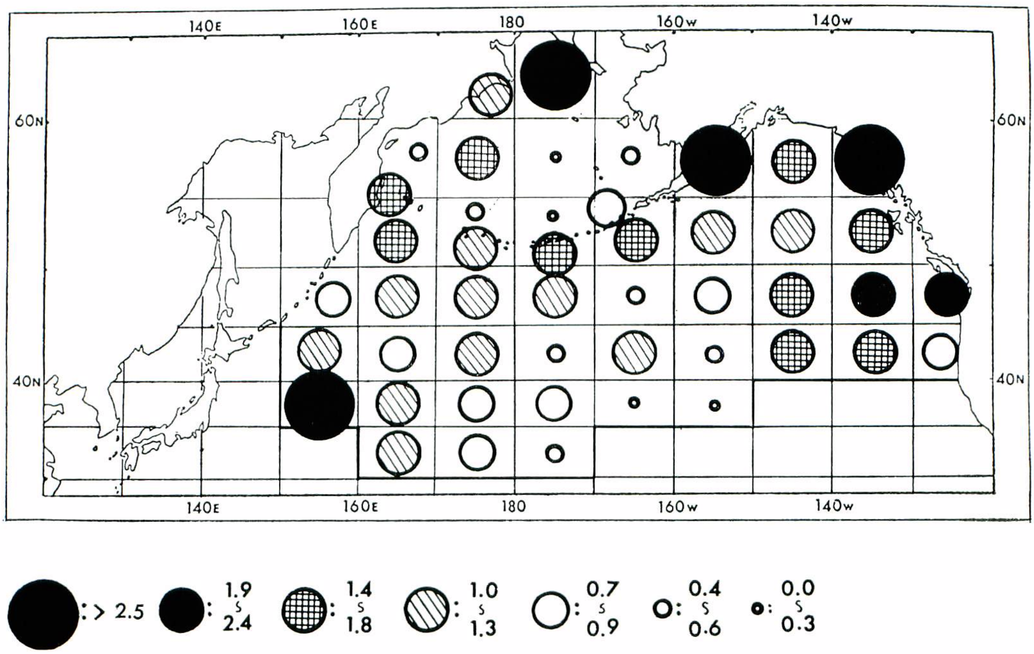


Fig. 67. Distribution of density index of sei whale based on the data of sighting in the North Pacific. The index is combined the whaling season from April to September, throughout 1965 and 1972.
Figures are number of whales sighted per 100 miles.

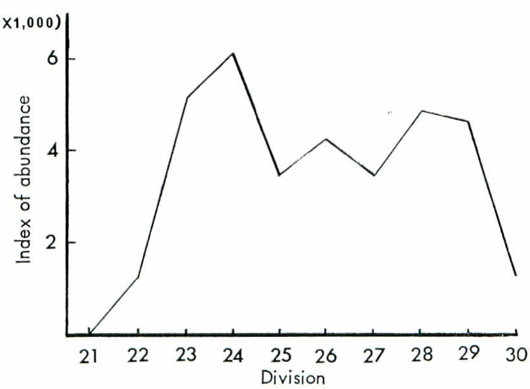


Fig. 68. Index of abundance of sei whale for all periods by division in the North Pacific.

Bering Sea, (2) the waters of the east longitude in the south of Aleutian Islands, (3) the waters between 180° and 150°W in the south of Aleutian Islands, and (4) the waters east of 150°W.

Figure 68 shows the accumulative indices of abundance by 10 degrees longitude. Judging from the valley as same as the case of the catch distribution, highly dense area can be divided into the following three waters; (1) west of 180°, (2) between 150°W and 180°, and (3) east of 150°W.

The density distribution may change month by month according to the migration of the sei whale in the North Pacific. The densely distributed sei whales in the western Bering Sea mainly in July and August are seemed to immigrate from the waters of the east longitude in the south of Aleutian Islands where they were abundant in May and June. If it was true, it is reasonable to regard the sei whales in both areas as a common stock unit.

VI-4 The shape of the baleen plate

Using the biggest baleen plate which were collected from 232 sei whales caught in 1973 and the data of length and breadth of baleen plates from 272 sei whales in the coastal waters off Sanriku by OMURA and FUJINO (1954), a difference of the shape of baleen plates in each area was examined. The length (L), and breadth (B) of each baleen plate were measured. As shown in Fig. 69, the length was measured along the outer edge of the baleen plate from the gum line to the tip of the plate. The breadth was measured along the straight line between the outer and inner edges of gum line.

There are no significant relationship between body length and ratio of L/B or the angle α, however the difference of mean values of L/B and α is recognized between both sexes by the t-test at 5% significant level. The sexual difference of the average value of each character was examined from four waters in the North Pacific, i.e., (A): between 160°E and 170°E, (B): between 170°E and 170°W, (C): between 170°W and 150°W, and (D): between 150°W and 130°W.

Figure 70 shows the results of the examination on the difference of the mean value of L/B among these waters. In males, there was no difference in the mean value of L/B in every combinations of the adjacent two waters. However, the difference was recognized between the combinations of Divisions 23 and 24–25, and Divisions 24–25 and

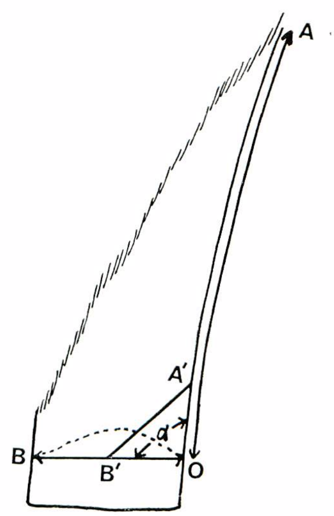


Fig. 69. Explanation of measurment of the baleen plate. OA'A; Length of baleen plate. OB'B; Breadth of baleen plate. Angle A'OB'; Angle α.

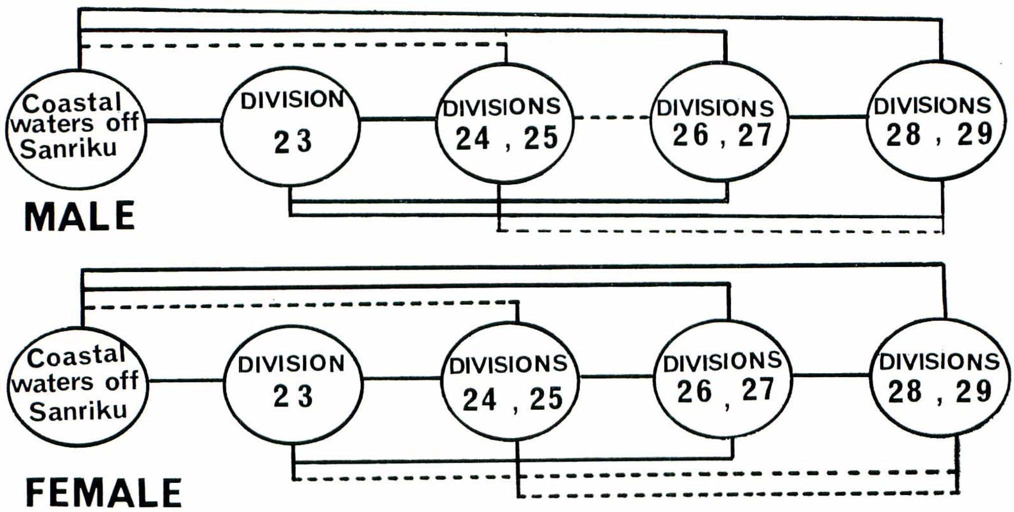


Fig. 70. Results of the test of interdivisional differences in the ratio of length/breadth of sei whale baleen plates for each sex in the North Pacific. Solid line; The difference is significant at 5% level of significance. Dotted line; The difference is not significant at 5% level of significance.

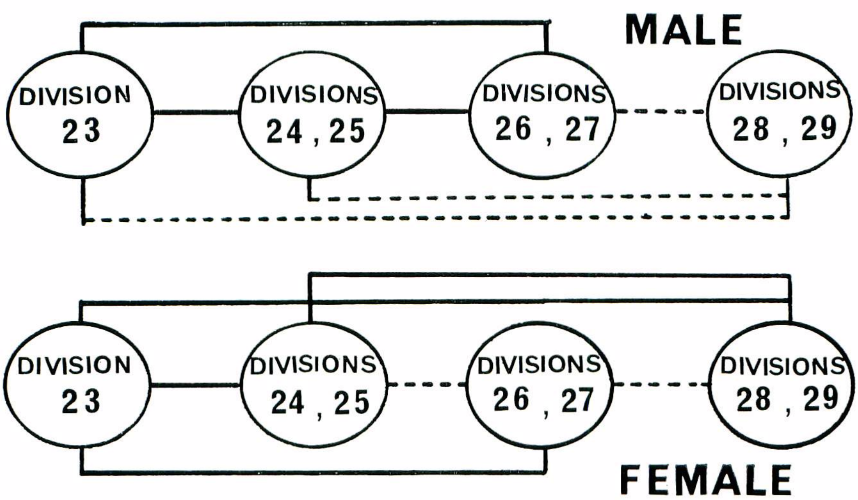


Fig. 71. Results of the test of interdivisional differences in the angle α of sei whale baleen plates for each sex in the North Pacific. Solid line; The difference is significant at 5% level of significance. Dotted line; The difference is not significant at 5% leval of significance.

28–29. In females, significant difference of the mean values of L/B was recognized in the combinations of the Divisions 24–25 and 28–29, and the Divisions 24–25 and 26–27. Judging from these results, the 170°W line may divide the sei whales into at least two stock units.

MIZUE and FUJINO (1957) showed that the fin whales in the East China Sea and in the northern part of the North Pacific belong to different races based on the comparison of the shape of baleen plates.

The angle α indicates a degree of outward bend of the baleen plate. When the points A′ and B′ are fixed 10 cm from the point O on the lines of OA and OB, respectively, as shown in Fig. 69, the value of angle α can be calculated by the following equation:

$$\mathrm{Sin}\ \alpha/2 = A'B'/20.$$

A careful examination was made for the relation between the angle α and the body length, however, no significant relationship between these two characters was recognized. Figure 71 shows the results of the examination in the difference of the mean value of angle α among several combinations of the area. In males there are differences between the Divisions 24–25 and 26–27, and the Divisions 26–27 and 28–29. On the other hand, in females there are also differences between the Divisions 26–27 and 28–29, the Divisions 23 and 28–29, and the Divisions 24–25 and 28–29. From these results, it is concluded that there are three stock units in each waters demarcated by the lines of 170°W and 150°W. The examination in the difference of the mean values of the L/B and the Angle α among the areas suggests that the North Pacific sei whale is separated into three stock units which are distributed in the waters of the west of 170°W, between 170°W and 150°W and the east of 150°W.

As stated above, the separation of the stock units of the North Pacific sei whales was tried by means of four methods, however, each of these methods showed both of merits and demerits. The whale marking method is at a disadvantage in being difficult to recapture many whales in a short time. Moreover, the scanty of marked whales in the breeding ground makes the separation of the stock into units indistinct. Nevertheless, the whale marking is one of the most direct methods of separating the stock into units by confirming the distribution and the movements of the whales. Therefore, the longitudes of 174°W and 155°W which were conjectured by this method as border lines of each of three stock units in the feeding ground though to be reliable.

Although the methods based on the distribution of the catch and the density index from whale sighting are fairly easy to separate the stock into units, these methods do not fit for a clear separation of the stock. However, the range of the distribution of the stock units estimated by these two methods provide with the results similar to those obtained with the whale marking.

The stock identification based on the shape of the baleen plate is a reliable method in view of its inheritable character. However, as this method must treat the data as a mass, the demarcation of the comparable areas becomes complicated. Concerning the North Pacific sei whale, the difference of shape of the baleen plates among areas was very small and, consequently, it did not give a definite result.

FUJINO (1964 a) showed a possibility of the identification of stock units of the sei whale by means of the blood typing method. He reported that the stock unit in the waters of the inner part of the Gulf of Alaska was different from that off Vancouver. However, it is considered that the sei whales which distributed in the Sector IV N move to inner part of the Gulf of Alaska within a short period. Then, if FUJINO's materials were composed of the trespasser from the Sector IV N, the possibility stated above will be brought naturally in the result of examination by the blood typing.

Taking all results mentioned above into account, it is concluded that the North Pacific sei whales can be separated into three stock units and, each of the stock units distributes in waters divided by the border lines of 175°W and 155°W (Fig. 72).

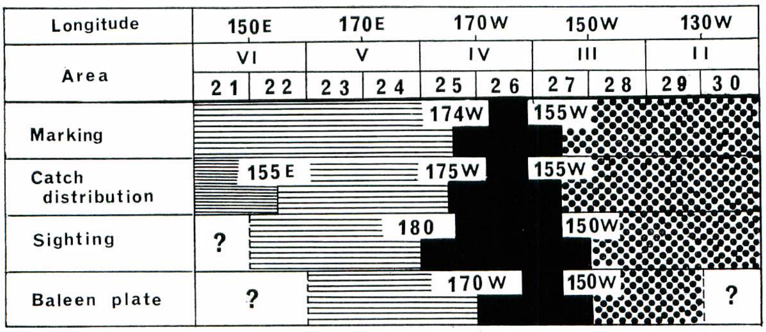


Fig. 72. Summary map for the stock identification examined with various methods of the North Pacific sei whale. ?; Uninvestigated division.

VII. Results and discussion

In the previous Chapters, life history, reproductive cycle, biological parameters by area, patterns of migration and movement and the separation of the North Pacific sei whale into stock units have been presented and analyzed. In this Chapter, the various results are summarized with reference to the relationship between these results and stock units.

(1) The growth curve of the foetus in the North Pacific sei whale increases gradually until the second month of gestation, at that time the foetus is about 20 cm in length, then the curve changes by the month to represent two straight lines. After this period, the rectilineal rate of growth increases somewhat until eight months when the foetus attains about 250 cm, after that the growth curve becomes exponential until birth. The gestation period is almost ten and a half months and the length at birth is estimated to be 4.4 m.

(2) Sexual maturity of female is determined by the presence of either at least one corpus luteum or one corpus albicans in either ovary.

The most usefull character to evaluate sexual maturity of male is the testis. Maturation of the testis is categorized into three stages, i. e., immature, intermediate (puberty) and mature.

Maturation of testicular tissue takes place gradually from the dead center of the organ to the caudal portion, and is completed when mature tissue extends to the periphery of the dorsal side and also to the abdominal periphery of the cephalic portion.

The judgement of the maturation of the testicular tissue can be made by the histological examination of measuring the diameter of the seminiferous tubules. The male whales possessing the tubules with a diameter more than 110 μ are considered mature, and those with a diameter less than 90 μ are regarded as immature. The individuals with diameters between 90 μ and 110 μ are considered as being at the intermediate stage.

The immature whales possess testicular tissue of the immature in the dead center of the testis, while the pubertal whales possess either mature or intermediate tubules in the ventral cephalic periphery of the organ. The mature whales are recognized by the presence of mature or intermediate tubules in the ventral cephalic periphery of the testicle (sampling site 4 in Fig. 9).

This method affords the most accurate results in evaluating the relative sexual maturity, however, the method is rather difficult to be examined. The following values can be applied to expedient judgement of sexual maturity for a large number of male whales: (i) Penis length: more than 100 cm long, (ii) Index of testis volume: more than 2, 000 and (iii) Testis weight: heavier than 0. 9 kg.

The testis weight is regarded as the best character for evaluation of sexual maturity by reason of small error and easiness of measurement, in addition, its result is in agreement with that obtained from histological examination.

(3) Age at sexual maturity can not be estimated exactly by the sexual maturity rate by age because of the difficulty in obtaining samples of ear plugs from younger whales.

Age at sexual maturity as revealed by the examination of transition phase of the ear plug was at ten years old in whales born between 1910–1920, but has gradually decreased year by year to the age of seven in the 1960's. This shift of age at sexual maturity is accompanied with the decline of population size in appearance.

(4) Body length at sexual maturity is 13. 4 m in females and 12. 9 m in males, respectively. As seen in Table 10, the body length at sexual maturity for each sex and by area becomes smaller from the western to the eastern waters of the North Pacific.

(5) Age at physical maturity could not be exactly calculated by a rate of physical maturity by age, because very few whales were examined for physical maturity and further, age was not determined for many. The number of ovulations at 50% of physical maturity was estimated at 12. This figure derived from correlation equation between age and the number of ovulations gave an estimate of age at physical maturity of about 25 years old. Body length at physical maturity was 15. 2 m in females and 14. 3 m in males.

(6) The peak of the mating period is the late in December, however, the mating period extends over five months, from November to March. The gestation period was estimated at ten and a half months with a peak of parturition at the beginning of November. The range of the calving period is from September to February. The active nursing period is estimated to be about seven months.

(7) The thickness of mammary glands, blubber, the diameter of the largest corpora albicantia, and the real difference in width between two uterine horns are more than; depth 8 cm, depth 6. 1 cm, diameter 2. 8 cm and 5. 0 cm, respectively during active nursing.

(8) A sexual segregation is recognized, the male sei whales being distributed in waters of higher latitude than the females during the period of feeding.

(9) The ratio of the male foetus to the total is 50. 56% and it is highly probable that the new born sex ratio is 1 : 1. The ratio of twinning through the entire North Pacific is 0. 52% and there is no significant difference in the twinning rate among the Division as shown in the Table 8.

(10) In the feeding grounds the sexually mature whales are distributed in higher latitudial waters than the sexually immature animals, and there is a more marked segregation by sexual state of the females in higher latitudes than the males. This segregation shown for each area is more notable in Areas II and III than in the areas west of Area IV.

(11) The pregnancy rate in the waters between 40°N and 50°N has a tendency to be higher on the western side of the North Pacific and to be lower on the eastern side. In the waters between 50°N and 60°N, the pregnancy rate is higher in the western and eastern than in the central waters. The pregnant females migrate to further northern waters, and segregate from whales of other reproductive conditions. This tendency is seen in both the eastern and western sides of the North Pacific, and it is especially remarkable in the eastern waters. Pregnant whales arrive in Zone N (40°N–50°N) earliest about May, and begin the southward migration from Zone P (50°N–60°N) in about August.

(12) The mean ovulation rate per annum for the entire area of the North Pacific is calculated by the relationship between age and number of ovulations as 0.604. The mean ovulation rate per annum by area shows a tendency of slight decrease from the western to the eastern side of the North Pacific.

The mean ovulation rate per annum differs by age, e.g., at 10 years of age it is about 1.00 and at 40 years it is about 0.30. The relationship between age and the annual mean ovulation rate was calculated using the following equations;

between 9 and 23 years of age, $Y=-0.03X+1.27$

between 24 and 43 years of age, $Y=-0.02X+1.13$

between 9 and 43 years of age, $Y=-0.02X+1.16$

where, Y=mean ovulation rate per annum, X=age.

The mean ovulation rate as estimated by GAMBELL's (1968) method is 0.666, however, this value is not accurate, because the ovulation rate after parturition could not be calculated for the North Pacific sei whale. Therefore, it is reasonable that the mean ovulation rate per annum be taken as 0.604, as mentioned above.

(13) The mean age at recruitment in Areas IV and V was 7 or 8 years of age in the 1965 whaling season, and it gradually decreased to 5 or 6 years of age by the 1972 season. On the other hand, it is not possible to compare the mean age at recruitment in Areas II and III during the years of 1965 to 1972, because of the sharp decline of the catch in these Areas in recent years.

The mean age at recruitment for the period 1965 through 1972 shows a tendency to be higher on eastern side and to be lower on the western side of the North Pacific, as seen in Table 11.

(14) From the 1965 to 1972 seasons, the mean total mortality coefficient of Areas IV and V was 0.148 in females and 0.127 in males, while in Areas II and III, it was 0.128 in females and 0.109 in males.

The total mortality coefficients in the Areas II and III were not affected by the heavy catch of whales in the Areas IV and V. An important point in regard to this is that the sei whales distributed in Areas IV and V may not intermingle with those in Areas II and III.

(15) The mean natural mortality coefficient estimated from the regression line which is not affected by the catch effort at the older age of the total composition is 0.054 in males and 0.060 in females.

The mean natural mortality coefficient from the 1965 to 1972 seasons is as follows; in Areas II, III, IV and V, it is 0.028, 0.057, 0.054 and 0.053 in males and 0.052, 0.065, 0.062, and 0.058 in females, respectively. The values of the natural mortality coefficient in Areas II and V seem to be lower than those of Areas III and IV, although the available data in Areas II and III are few.

(16) The North Pacific sei whale demonstrate marked northward and southward migrations. The duration of migration and the waters involved are as follows: At the beginning of the northward migration the whales pass through 20°N from January to February and reach 40°N in May and June, they continue to move northward to the waters between 40°N and 50°N and some reach as far as 50°N to 60°N.

The southward migration begins in the waters north of 50°N and east of 160°N about July, and in the waters north of 50°N and west of 160°W about August to September.

Three routes of movement are found in the whaling grounds and they are located west of 180°, between 180° and 160°W and east of 160°W.

Pregnant whales arrive in Zone N (40°N to 50°N) earliest in the waters east of 160°W, and latest in the central region. On the other hand, the southward migration of pregnant whales in Zone P (50°N to 60°N) begins in July in the central waters, while in the other regions it begins in August.

(17) The migration patterns of the North Pacific sei whale estimated by monthly and areal change of mean body length, and body length composition of the catch are as follows;

Area V: The first whales arriving in Zone N from the south during May are large sized animals which move north to Zone P. Subsequently, smaller sized animals arrive in Zone N and move northward to Zone P. The larger animals begin the southward migration from Zone P during August to Zone N prior to the smaller whales.

Area IV: The arrival of the larger whales into Zone N from April to May is earlier than in Area V, and the beginning of southward migration from Zone P in July is also earlier.

Area III: The larger whales enter Zone N in April which is about one month earlier than in Area V.

(18) The migration of the North Pacific sei whale takes place pregnant, mature and immature whales in order.

(19) The results of the identification of stock units in the North Pacific sei whale as studied by four methods are as follows:

(i) Whale marking; separated the population into three stock units distributed in each of the waters west of 174°W, the central waters between 174°W and 155°W, and east of 155°W.

(ii) Catch distribution; four stock units were identified, i.e., west of 155°E between 155°E and 175°W, between 175°W and 155°W, and east of 155°W.

(iii) Whale sighting; three stock units were identified. Their waters of distribution are;

the waters west of 180°; waters between 180° and 150°W, and the waters east of 150°W.

(iv) Shape of the baleen plates; three stock units were found. One is in the waters west of 170°W, another is between 170°W and 150°W and the third is east of 150°W.

(20) The two stock units distributed in west of 155°E and between 175°W and 155°E which were identified by catch distribution were seemed to be the same, although no Japanese catch data for the waters between 150°E and 159°E were available. This assumption is supported by the analysis of the whale marking which indicates that the whales found between 160°E and 174°W belong to the same stock unit.

(21) The distribution map of the whales based on the results of whale sighting seems to approximate the natural distribution most. However, whale sighting, as a technique, must cover the entire area and be conducted over a long period of time, and it should be enforced by the biological factors directly observed on the target species.

(22) Since the shape of the baleen plates is a hereditary character, the stock identification based on it is regarded as an effectual method. However, owing to the facts that the difference in the shape is indistinct in the North Pacific sei whale and the measuring error is unavoidable, this method is unsuited for stock identification of the North Pacific sei whale.

(23) As the results of whale marking analysis indicate the movements of individual in the breeding and feeding grounds as well as between the two grounds, whale marking is thought to be a very useful technique in identifying stock units.

(24) On the basis of these four methods, it is recognized that the North Pacific sei whale is divided into the following three stock units: Stock I-waters west of 175°W, Stock II-waters between 175°W and 155°W, and Stock III-waters east of 155°W.

(25) The extent of mixing among the stock units is supposedly small and, when mixed, the immigrants do not participate in the procreative activity of the stock. The independency of the stock unit is supported by the fact that the biological parameters affected by the stock size are fluctuated independently. It means that any change in stock size occurred in one of the three stock units in the North Pacific sei whale does not affect the biological parameters of the other two stock units. It is also assumed that each stock has its own route and timing of migrations and movements.

(26) The natural mortality coefficient is low in Areas II and V and high in Areas III and IV. This fact demonstrates that the whales distributed in the central waters have not mixed with those in the western or eastern sides of the North Pacific.

(27) The ovulation rate, body length at sexual maturity and the total mortality coefficient are all high values for the whales found east of 160°W. The mean age for recruitment is high in the waters east of 160°W and low in west of 160°W.

(28) Decrease in the population size is accompanied by a rise of the ovulation rate, as if in response to recover the population size. In such reduced populations, the rate of growth quickens and consequently the body length at sexual maturity becomes larger, additionally, the age at sexual maturity is lowered. As the number of older individuals dwindles with the decreasing population, the mean recruitment age is gradually lowered.

(29) Keeping above factors in mind, it can be thought that Stocks I and III are very inde-

pendent of each other. However, as the feeding grounds of Stock II are latitudinally narrow and longitudinally restricted, whales of this stock mix temporarily with those of the two other feeding grounds. Therefore, it is very difficult to define boundaries of distribution among these stock units by the changing parameters described above.

(30) The pregnancy rate presents a similar picture. It shows high values in Squares P 24 and P 25, and Squares P 27 and P 28, but low in Square P 26. It is easily realized that Stocks I and III are independent of each other on the basis of the different time of arrival in Zone P, however, pregnant whales of Stock II show, in part, movements from the waters between 155°W and 175°W in Zone N to Squares P 25 or P 27. These results make identification of Stock II unable on the basis of pregnancy rate.

(31) The rate of twinning shows values corresponding to the stock units as defined. These are 0.56% for Divisions 22, 23 and 24, 0.46% for Divisions 25, 26 and 27 and 0.32% for Divisions 28, 29 and 30. However, the differences of this rate among the above three Regions are not recognized as significant.

(32) The route and timing of migrations and movements of the North Pacific sei whale were examined for each of the stock units. The results are summarized as follows;

Stock I: About May, the northern migration is headed by the pregnant females, followed by the females of other physiological states, the mature males and the immature animals. During August, the pregnant whales move to the south first from Zone P and the order of northward migration is repeated. The northward migration is comprised of two major movements. One herd of sei whales from the south moves to the north or northeast through the waters around 160°E into Division 24 and then moves to the northwest along the chain of the Aleutian Islands. The other herd moving to the north along the waters between 140°E and 160°E splits off into two, one heads for the coast of northern Japan and the other for the Kuril Islands and Kamchtka Peninsula. In August some whales of both herds are found in the southern Bering Sea.

Stock II: The same succession of migration according to the sexes and ages seen in Stock I occurs in Stock II, however, the northern migration begins earlier than Stock I, and the southern migration from Zone P begins in July.

The route of movement is realized by the fact that the whales enter the waters around Square N 26 from their wintering grounds near the Hawaiian Islands. They continue to move northward or northwesterly until reaching the Aleutian Islands, then they move to either easterly or westerly on the southern and northern island coasts, repectively. The southward migration retraces the northward track.

Stock III: As in both other Stocks, the successive pattern of moving whales is the same. The pregnant animals are seen in Zone N before May, and it is about one month earlier than Stock I.

The southern migration from Zone P begins in August, as in the case of Stock I, however, the southward migration in Stock I is slower than the other two units due to a long stay in the feeding grounds.

The main herd of Stock III passes through Division 29 and heads along the coast of the

North America in the northward migration. The herd continues to follow this track to the west of the inner part of the Gulf of Alaska, and some individuals move further to the Bering Sea. The northward movement of the remainder of this stock is not definitely known, but it will probably be a reverse of the southern migration.

The southern migration is composed of two major tracks, one through the waters off western North America and the other passes through Division 27 heading southeast to the wintering grounds.

(33) Concerning the biological parameters available for the stock assessment of the North Pacific sei whale, it should be emphasized that decreases in the age at sexual maturity, mean body length of whales captured, the rate of sexual maturity and mean age at recruitment and increase in the rate of ovulation in recent years indicate a decreasing condition of a given stock.

Therefore, careful examinations on these values are needed for the rational management of the sei whales of the North Pacific.

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Explanation of Plate I

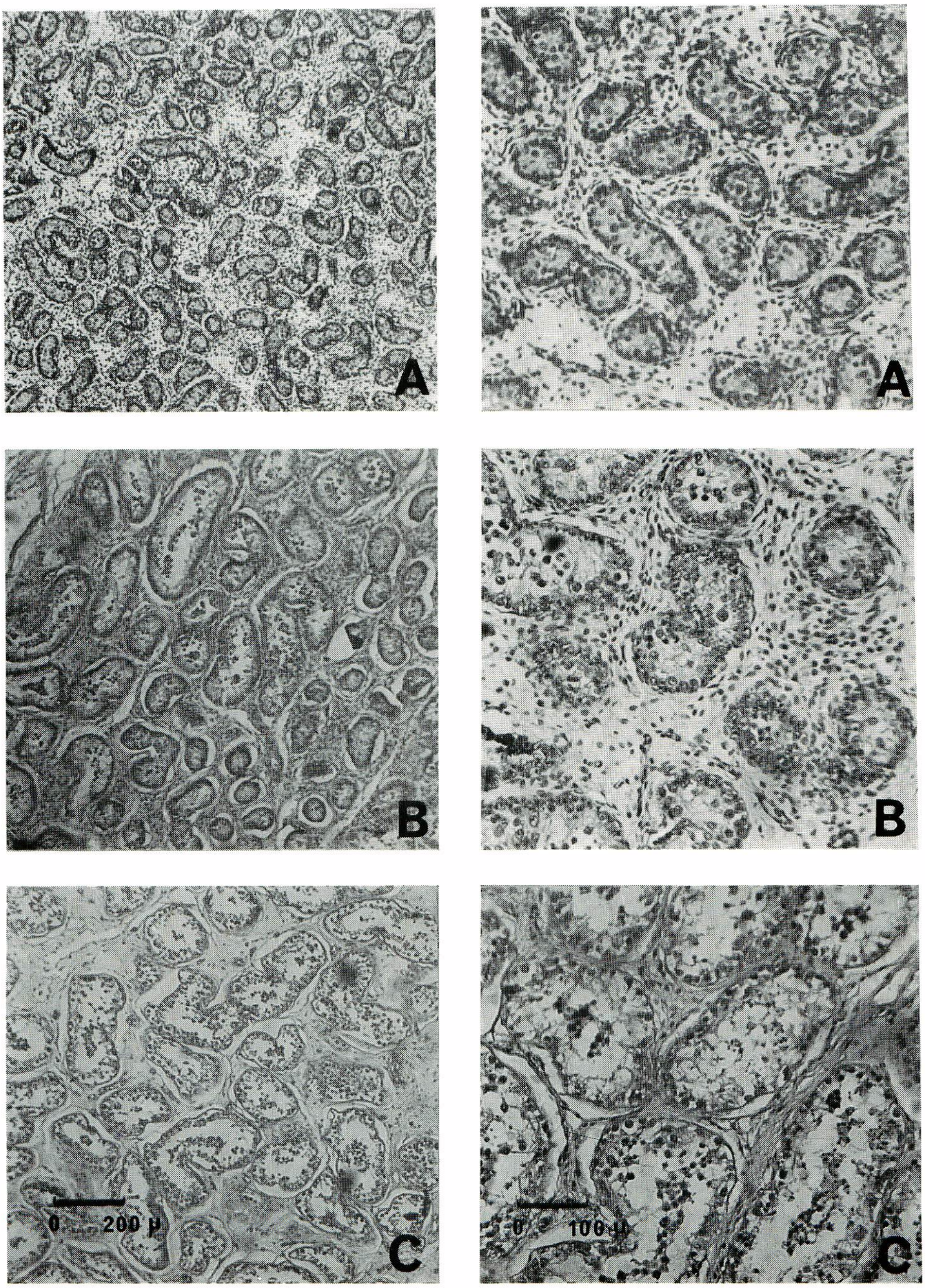
Photomicrographs of sections of testes of the North Pacific sei whale in different stages of the maturation.

A Immature.

B Intermediate.

C Mature.

Plate I



北太平洋産イワシクジラの資源生物学的研究

正　木　康　昭

要　約

捕鯨漁業は，捕獲し易く経済的価値の高い大型鯨種の資源の減少に伴ない，経済的要求と漁撈技術の進歩によって，従来捕獲し難かった小型鯨種の捕獲へと遷移してきた。北太平洋産イワシクジラは北太平洋捕鯨における大型ヒゲクジラ類資源の一つとして長い捕獲の歴史をもつが，1964 年以後とくに母船式捕鯨業の主対象として重要性が増してきた。

南半球産イワシクジラに関しては MATTHEWS (1938) を始め多くの漁業生物学的研究がなされ，最近では GAMBELL (1968) のすぐれた研究が報告されている。しかし，北太平洋産イワシクジラの資源状態を解明するために必要な生物学的特性値はまだ十分明らかにされていない。

本研究は，北太平洋産イワシクジラの生活史を解明することによって系統群の分離を行い，イワシクジラ資源の合理的な管理に資することを目的として行われた。

統計並びに生物測定資料は主として日本船団の1952年から1972年の間の操業結果を用い，また研究資料の多くは筆者が1968年に図南丸，1970年に第二極洋丸に乗船し調査した際に得たものである。

イワシクジラ胎児は，他のヒゲクジラ類と同様に，指数曲線的な成長をすると考えられる。胎児の成長曲線より妊娠期間は10.5か月，交尾の盛期は12月下旬，出産の盛期は11月初旬と算定された。

卵巣中の黄白体の有無を基礎として算出した雌の性的成熟体長は 13.4 m であった。

睾丸の組織学的検査より未成熟，中間段階および成熟の3つの組織像が認められた。睾丸の成熟過程は部位によって異なり，睾丸中央部より成熟し始め頭部腹側部で終わる。組織学的検査に基づく 50% 成熟睾丸重量は 0.9 kg と求められた。睾丸の組織学的検査に基づく雄の性的成熟体長は 12.9 m と算定された。また，性的成熟睾丸容積指数は 2,000 以上である。

精細管直径は春機発動期に急激に太くなる。性的成熟個体の平均精細管直径は 110 μ 以上，未成熟のものは 90 μ 以下であった。

陰茎長 100 cm を境として，未成熟と春機発動期の個体とを区別しうる。

胸椎骨の椎体と骨端板との間に存在する軟骨層の有無による判定結果から，肉体的成熟体長は雄 14.3 m，雌 15.2 m と算出された。

年令別性的成熟率からは性的成熟年令は求められなかったが，耳垢栓の成長層にみられる変移相から成熟年令を推定した結果，雌雄とも，1960 年代以後に生まれた個体は7才と算出された。

北太平洋産イワシクジラは母船式捕鯨による本格的操業が開始される以前から性的成熟年令は若くなる傾向がみられ，耳垢栓に示される個体の年令と変移相から推定すると，1925 年頃には雌雄とも10才位であったものが，1960 年には7才へ低下したと考えられる。

年令一体長相関表と上記の結果から北太平洋産イワシクジラの成長曲線を求めた。

乳腺の厚さと乳分泌状態の調査から，授乳期間を7か月と推定した。従って，性的機能が停止している休止期間は 6.5 か月と推定される。乳分泌中の鯨の乳腺の厚さは 8.0 cm 以上，脂皮の厚さは 6.1 cm 以下，そして最大白体直径は 2.8 cm 以上である。

捕獲鯨の雄の割合は1963年から1966年の間は平均約60% であったが，1967年以後徐々に低下し，1972年には 49.0% になった。海域による性別の棲み分けがあり，雄の割合は高緯度海域と北太平洋の東西両端海域で高い。なお，胎児の雄の割合は 50.56% であった。

北太平洋産イワシクジラの双胎出現率は北太平洋全域では 0.516% である。海区によって 0.320% から 0.560% と差が認められた。

1952 年から 1972 年の間に日本船団によって捕獲されたイワシクジラの性的成熟率は 50°N 以南においては，北太平洋西側海域の方が東側海域よりも高く，一方，50°N 以北では逆に西側海域の方が低い。資源の減少に伴なって性的成熟率は低くなり，50°N 以南の海域における 1954 年には雌雄とも 100.0% であったものが 1972 年には雌 58.2%，雄 69.3% に低下した。

月別緯度別性的成熟率の変化から，性的成熟鯨が未成熟鯨よりも早期に北上回遊を行うものと考えられる。

仔連れ雌鯨は保護されているため，捕獲鯨からは真の妊娠率は求められない。40°N から 50°N の間の北太平洋海域における見掛け上の妊娠率は，捕獲強度が強まった 1970 年以後はそれ以前の 70.8% に対して 63.6% に低下している。海域的には西高東低の傾向を示し，妊娠個体は休止個体よりも高緯度海域に分布する。妊娠率は年令 40 才以上，黄白体数 20 以上では低下するが，終生妊娠し続けるものと考えられる。

年令と排卵数の関係から求めた北太平洋産イワシクジラの全域における年間平均排卵率は 0.604 である。海域的には西高東低の傾向を示す。耳垢栓にみられる変移相から求めた性熟年令と捕獲時の年令および黄白体数から求めた年間平均排卵率は 10 才では 1.00 であり 40 才では 0.30 である。白体とグラーフ氏胞の大きさ等に基づいて求めた年間平均排卵率は 0.666 である。

性的成熟体長には海区による差が認められ，北太平洋西側から東側へ次第に小さくなる傾向がみられる。

捕獲加入年令は海区 IV，V では，1965 年には雌雄とも 7～8 才であったが 1972 年には 5～6 才に低下した。

自然死亡係数は雄 0.054，雌 0.060 である。雌雄とも海区 II，V が海区 III，IV よりも自然死亡係数は低い。

目視に基づく分布密度の季節的変化と遊泳方向から，北太平洋産イワシクジラは (1) 180° 以西，(2) 180°～160°W，(3) 160°W 以東の各海域において独自の回遊時期と移動方向をもっていると推定される。

1952 年から 1972 年の間に日本船団によって捕獲されたイワシクジラの平均体長は雌雄とも 1962 年以後低下し，1962 年には雌 14.6 m，雄 14.2 m であったのに対し，1972 年には雌 13.8 m，雄 13.4 m になった。月別海区別の平均体長の変化の比較から，海区によって回遊時期に差があり，性別，体長による棲み分けがあると考えられる。同様に，体長組成の型の変化の比較から，北太平洋西側海域においては，東側海域よりも同一緯度では回遊時期が約 1 か月遅いと考えられる。

160°W 以東の海域においてイワシクジラ群は最も早期に北上し，180° 以西の海域が最も遅い。南下回遊を始めるのは 150°W～180° の中央部海域が最も早い。

1965 年より 1972 年までの目視調査による分布密度と，1952 年から 1972 年の間の日本船団によって捕獲された捕獲分布図からは，北太平洋産イワシクジラは 4 系統群に分離されると考えられる。しかし，1949 年より 1973 年までに日本政府によって実施された標識調査とその再捕結果からは 3 系統群に分けられた。また，くじらひげ板の形態からも 3 系統群に分けられた。

上述した性的成熟率，妊娠率，体長組成の型および移動方向等の海区別変化からも，上記の 3 系統群に分離した妥当性が裏づけられた。上記の結果を総合すると，北太平洋産イワシクジラの系統群は 175°W 以西の海域（第 I 系統群），175°W から 155°W の海域（第 II 系統群）および 155°W 以東の海域（第 III 系統群）に分布する 3 つの系統群に分離することが妥当であると考える。

生物学的特性値のうち，特に，性的成熟年令，捕獲鯨の平均体長，性的成熟率および平均捕獲加入年令等の低下，並びに排卵率の上昇は資源の減少状態を示す指標と考えられる。これらの値が変化しはじめた場合には資源の状態に注意を払わなければならない。