EXAMINATION ON AGE DETERMINATION OF THE FIN WHALE

SEIJI OHSUMI

INTRODUCTION

As the age characters of the fin whale (*Balaenoptera physalus* L.), the following have been reported hitherto. They are body length, stage of growth, number of ovulation, white scars (Mackintosh & Wheeler, 1929), baleen plate (Ruud, 1940), christalline lens (Nishiwaki, 1950), and ear plug (Purves, 1955). Among them, laminations presented in core of the ear plug is considered as the best age character, because the lamination is considered to be formed periodically, is used for both sexes, and is recognized for all life span. Furthermore, ear plug is relatively easy to be collected and prepared to examine the number of laminations in the core.

Number of corpora albicantia accumulated in overies has some weak points as an age character. There is individual variation in the accumulation rate of corpora, and number of corpora is applicable as an age character for only sexually mature females. However, it is useful for age character next to ear-plug lamination, and the data of corpora count have been collected for long seasons. Furthermore the annual accumultion of corpora is also useful for the study of reproductive physiology of the whale.

Ridges presented on the baleen plates is considered to be the most excellent age character of the baleen whales in younger age groups, but unfortunately, it is not able to be used for older age groups.

Now, it is very important to determine age of whale from above age characters, and many hypotheses have been published on the age determination.

Concerning the ear-plug laminations, Purves (1955) first considers that the period of arrested growth corresponds to the migratory periods when physiological demands of active swimming coincide with complete absence of food, so that each lamination represents a growth period of 6 months. Laws & Purves (1956) estimate that the biannual formation of lamination is correct, compared the ear plug with baleen plate for small samples of fin whales. Nishiwaki (1957), Chittleborough (1959), Dawbin (1959) and Laws (1961) did not denied the hypothesis. The hypothesis of biannual formation of lamination now influences on the cetacean biology and population dynamics. However, recently long term marked whales have been recovered (Brown, 1962) and the investigation of ear plug of the recaptured fin whales give a question on the annual accumulation rate of ear-plug lamination (Ohsumi, 1962). Purves & Mountford (1959) state that it is very doughtful whether environmental conditions have any direct influence of the time of formation of the laminae of the ear plug in whales. Since there is strong evidence (not given by them) that lamina formation is in inherent moulting cycle, it is very probable that it takes place whether the whale migrates or not, and Ichihara (1959) discribed by the histological examination of ear plug that the effects of hormone and enzyme on the degenerations of epithelial cells of glove-finger were regarded initially, besides, the effect of the environmental factors were preseumed indirectly.

There are also many hypotheses on the accumulation rate of corpora albicantia in ovaries. Laws (1958, 1961) reviewed the previous works on the problem. On the fin whale, Mackintosh & Wheeler (1929) plotted the frequencies of corpora, found peakes occurred at 4–5, 12 and 19 corpora, and suggested that these represented the increase in number of corpora at intervals of 2 years. Wheeler (1930) developed this hypothesis by more material, and concluded that about 5 ovulations occur each breeding cycle, or in average 2.5 per year. Peters (1939) reported that he had been able to establish morphological and histological criteria for distinguishing the corpora albicantia representing pregnancy and ovulations, and be estimated that there is an average of 0.9 in a year by counting the pregnant corpora albicantia and assuming a 2-years reproductive cycle. Mackintosh (1942) showed by a marked fin whale recaptured that the annual increment of corpora albicantia had possibility to be less than one. Using the baleen plates as a new method for age determination, Ruud (1940, 1945) suggested that in the breeding season, up to 6–7 ovulations are possible before pregnancy inpervenes. Nishiwaki (1952) assumed that the annual increment of corpora albicantia after the first sexually mature age should be 1.5, combining baleen plates, crystalline lens, number of ovulation and sexual and physical maturity.

Since ear plug was discovered as a new method of age determination by Purves (1955), many authors have reported the relation between ear-plug lamination and number of corpora in the ovaries. Nishiwaki (1957) drew a figure on this relation for the Antarctic fin whales and got a result that in average corpora accumulation was 1.2, if ear-plug laminations are formed biannually. Nishiwaki, Ichihara and Ohsumi (1958) drew similar figure as above paper and got that there was individual and racial variation in annual accumulation rate of corpora and in average the annual corpora accumulation rate was 0.9 in the Antarctic fin whale and about 0.8 in the North Pacific fin whales, if ear-plug lamination was formed biannually. Laws studied the annual accumulation rate of corpora albicantia in his valuable paper (1961) from several aproaches, and got the annual accumulation of corpora albicantia is 1.43 in average.

And he compared the ages of the fin whales between the age from ear plug (biannual accumulation) and the age from ovary (annual accumulation rate is 1.4), and got the exact agreement between both ages. Fujino (1963) also calculate the corpora accumulation rate per 4 ear-plug laminations from the relation between ear plug and corpora for the Antarctic fin whales separating the areas, and got the result that the rate was 2.80 in Area-II (Laws's result), 2.31 in Area-III west, 1.91 in Area-III east, 1.84 in Areas-IV, and 1.60 in Areas-VI and I respectively. Then, the difference of the annual rate of corpora between Nishiwaki et al. (1958) and Laws (1961) will be caused by the difference of races.

On the age determination of baleen plates, Ruud (1940, 1945), Tomilin 1940, 1945), Nishiwaki (1950 a, 1950 b, 1951, 1952, 1957), Chittleborough (1954, 1959), Laws & Purves (1956) and Laws (1961) all recognize that one ridge grows in one year. Especially Nishiwaki (1952) tried to estimate the annual growth of baleen plates.

Although there are many hypotheses on the age determination of the baleen whales, I think the age determination has not been established. Recently the age characters have been obtained from the long term recaptured fin whales (Ohsumi, 1962). Direct age of recaptured whale is able to be checked by the time from marking till recovery. And examinning the recaptured fin whales, above hypotheses are not able to explain some of the actual data. We must re-examine the age determination to solve the actual results on the age characters.

MATERIAL AND METHOD

Several methods were shown to examine the age determination of the whales by Ohsumi, Kasuya & Nishiwaki (1963). Among them breeding experiment as used by Sergeant (1959) and the time marking in the age characters of living animals as used by Nishiwaki & Yagi (1953) are not able to use for the fin whale because of the difficulty of the breeding of the whale. And I have no material for study of the seasonal growth of the age characters as used by Ohsumi, Kasuya & Nishiwaki (1963) on tooth of the sperm whale (*Physeter catodon*).

I examined the age determination in this report by the following three methods. One is the examination of age characters from the recaptured fin whales. The second method is the comparison between each age characters. The third is a population dynamical examination on the age composition based on the ear-plug laminations. Combining the results obtained from above methods, I will examine whether the previous hypotheses are contradictory or not.

Biological material obtained by Japanese fleets from recovered fin whales are based on the data by my previous paper (Ohsumi, 1962).

Baleen plates were collected with ear plug from 74 fin whales in the Antarctic and northern part of the North Pacific, and the ridges appeared on the plates are counted by eye. Ear-plug laminations are counted after the same preparation as by Nishiwaki, Ichihara and Ohsumi (1959).

Ear-plug laminations are counted by the saffs of our Institute using dissecting-microscope. Standardization of the reading ear-plug lamination is need as trying by Ichihara (1963). If the standardization is established and the reading is different to the present reading, my following examinations are needed to be re-examined.

Number of corpora lutea and albicantia were counted with naked eye by slicing the left and right ovaries.

Sexual maturity is determined by the investigation of ovaries or testes. For females, those who have at least one corpus luteum or albicans in their ovaries are determined to be sexually mature. For males, those whose weights of larger side of testes are 2.5 kg or more than 2.5 kg are recognized as sexually mature.

Material for the comparison between ear-plug lamination and other age characters are all obtained from fin whales caught by Japanese fleets in the Antarctic Areas IV and V in 1958/59 and 1959/60 seasons and northern part of the Pacific during 1959 to 1961 seasons.

Ear-plug laminations are counted from 978 female fin whales caught in the north of east Aleutian Islands in seasons from 1959 to 1961, and the age compositions are drawn in the two cases of annual accumulation rate.

Estimated number of marked fin whales in the north of east Aleutian Islands and the number of recaptured whale from the marked whales are gathered from Japanese whale marking and recovery records during 1954 to 1962.

Number of female fin whales of sexually mature, immature and pregnant are cited from annual reports on the biological investigation of whales caught in the North Pacific from 1954 to 1961.

EXAMINATION OF AGE DETERMINATION BY MEANS OF WHALE MARKING

SOME POINTS TO BE CONSIDERED IN THE MARKING METHOD FOR EXAMINATION OF GROWTH AND AGE OF WHALES

On the whale marking investigations many reports have been published. However, most of them are on the migration and movements. And the reports on the examination on the age and growth by means of whale marking are relatively few, and all of them are fragmentary. Mackintosh (1942) discussed the rate of accumulation of corpora albicantia in the ovaries on a recaptured fin whale. Omura & Kawakami (1956) studied the growth of the marked sperm whales. Ohsumi, Nishiwaki & Hibiya (1958) discussed the growth and age of the fin whale in the northern Pacific from the data of whales recaptured by Japanese whalers. Chittleborough (1959) used results of marking for the study of age in the humpback whale (*Megaptera novaeangliae*). Dawbin (1959) also studies whale marking as the evidence on growth rate of the humpback whales. Laws (1961) examined the annual corpora accumulation rate from 10 recaptured fin whales.

In the whales, it is entirely difficult to use the similar marking method as is usually used in other animals liked as fishes or birds. That is to say, in the whales except some porpoises and dolphins, we cannot catch and examine biologically the individual on board of ship before the marking and discharge. Therefore, one of the weak points in the whale marking is the difficulty of the biological investigation at the time of marking. Although it is not so weak point for the purpose to examine the movement of whales, it is the biggest defect to the study of the growth and age of the whales.

We usually estimate the species and body length of the whale at marking. At that time, the estimation involves more or less errors, because we measure with eye the whales moving in the water. Sometimes we make mistakes in estimation of species. For example, a Japanese mark No. 4267 whales was recorded as a sei whale (*Balaenoptera borealis*) at the marking, but it proved to be a fin whale in the recovery. It is difficult to distinguish between a sei whale and a Bryde's whale

(*B. edeni*) at the time of marking, therefore, Bryde's whales were recorded as sei whales in the marking records of our country. The mistake of this sort affects to the calculation of population size by means of the marking method. It is also difficult to estimate the sexes of the whale at marking, except adult killer whale or some other species. Furthermore, we cannot estimate the age of a whale at marking. When a calf with its mother is marked, we can estimate its approximate age. But in other cases, we cannot estimate the age and collect the age characters of a whale at marking. Whale mark is only used as a correct artificial age character from marking till recovery.

The next point is the scantiness of the marked and recovered whales. For the purpose of the study of growth and age of whales by means of marking, the more recovered whales we get, the better results are obtained. But, at first, we cannot use many marks, for the marking investigation is very expensive. On the second, the rate of hit on whales is relatively low. On the third, the rate of recovered whales per marked whales is also relatively low.

The third point to be considered in the marking method for the study of growth and age of the whale is the influences to the whale body by the marking. Whale marking which we use is not what is called a marking but a sort of tagging, and a 25–28 cm long metal tube is inserted in the body of whales. The body parts of the insertion is mainly the muscle of back, but sometimes the mark destinates the vertebrae or internal organ. Therefore, sometimes abnormality must be considered in the growth and life of whales by marking. The example that 3 sperm whales which had been marked in the adjacent waters to Japan were found floating dead shortly later shows a fatal influence of marking to those whales (Omura & Kawakami, 1956). The marks were inserted in the body cavity of those whales. There are other some examples in which the marks influenced badly on the growth of whales.

The fourth point is the difficulty of investigation of recovered whales. The best condition to investigate the marked whale is to discover the mark before the flensing and for that purpose streamer mark was made to try (Ruud, Clarke & Jonsgard, 1953; Omura & Kawakami, 1956), and a modified mark was tested by Chittleborough & Godfrey (1957), because the earlier the mark is discovered in flensing, the better investigation is made on the recovered whales. When the mark is recovered in flensing, meat cutting or bone cutting, the mark is usually checked with the marked whale and we can investigate and collect the necessary data and material for the examination of the age and growth. But if a mark is recovered in cooker or reflegarator vessel, we cannot connect the mark with the marked whale. Fortunatley, in Japanese fleets, we flense the whales thoroughly, because we use the whale for food, and we can recover many marks in the place outside of the cooker.

Marking is considered to be an artificial age character, and although marking has a weak point that we cannot know the age of the whale before the time of marking, it has an advantage that we can confirm the elapsed time from marking until recapture.

If an age character increase in arithmetical progression, age at the time of marking is symbolized as x, elapsed time as t, and the annual accumulation rate is b, the size of age character at the time of recapture (y) is:

$$y = b(x+t)$$

Then,

$$\frac{y}{t} = b\left(\frac{x}{t}+1\right)$$

The smaller x is, and the larger t becomes, the smaller x/t becomes. Then, y/t becomes near b. Therefore, the useful material for estimation of the accumulation rate of age character by means of marking is desireble to be long elapsed time and younger age until the time of marking.

EAR-PLUG LAMINATIONS OF RECAPTURED WHALES

Tables 1 and 2 show the number of ear-plug laminations, elapsed years and number of laminations dividing by the elapsed years for 59 fin whales recaptured by Japanese fleet in the Antarctic and the northern part of the North Pacific, which are listed in the paper of Ohsumi (1962).

If a whale mark fit a new-born whale, we can get an actually annual accumulation rate of ear-plug laminations, but this case is practically impossible. All whales will be marked at some time after birth. And if we can record the time of marking in an ear plug, we shall get an accurate number of laminations per year by counting the number of lamination from the record, but such recording is now also impossible.

Then, as the laminations accumulated in the time from marking until recovery are added to the laminations which were accumulated by the time of marking, the mean values which are got dividing the total number of ear-plug laminations by the elapsed time come to be more than the actually annual number of laminations.

The longer the elapsed time is, the shorter relatively is the time from birth until marking. Therefore, the mean number of laminations per year approaches to the actually annual increment of laminations as the period from marking until recovery increases.

Fig. 1 shows the relation between the elapsed time and the mean number of ear-plug laminations, and in addition shows the typical curves of mean number of ear-plug laminations for the case of 4 whales which are, respectively, just born (D, D′), 10 laminations (C, C′), 25 laminations (B, B′) and 50 laminations (A, A′) at the time when they are marked. Broken lines (A′, B′, C′, D′) show the case in which the annual increment of ear plug is 2 laminations, and solid lines (A, B, C and C) show the case in which the annual increment is one lamination.

In the whales which were recovered within one year, the apparent mean numbers of laminations per year are relatively large. But in those which were recovered after more than 2 years, we get relatively smaller figures.

There is a North Pacific fin whale (No. J. 6817) of which mean number of

TABLE 1. DATA FOR EXAMINATION OF ACCUMULATION RATE OF EAR-PLUG LAMINATION BY RECAPTURED FIN WHALES IN THE ANTARCTIC (DISCOVERY MARKS)

Mark No.	Sex	Elapsed time (A) (Yr.–Mon.)	Estimated body length at marking (ft.)	Body length at recapture (ft.)	No. of ear-plug laminations (B)	B/A
17860	M	0–2	59	57	7	—
22236	M	0–1	66–67	60	8	—
22417	F	0–0	65	66	18	—
22517	F	0–1	70	73	22	—
22526'30'33	M	0–1	67	69	31	—
24038	M	0–1	60	63	10	—
24083	M	0–1	70	64	8	—
24202	M	0–0	70	65	10	—
24361	M	0–1/2	62	66	16	—
24501	F	0–0	66	68	24	—
22517	M	0–2	66–65	62	6	—
24064	F	0–2	70	70	16	—
24349	F	0–2	55	62	7	—
24547	M	0–3	70	70	53	—
17876	M	1–1	58	63	24	22.2
17476	M	1–2	63	67	16	13.7
17903	F	1–1	70	69	10	9.23
19813	M	1–1	74	69	15	13.8
20944	F	1–1	65	75	60	55.4
21077'90	F	1–1	67	74	22	20.3
21161'72	F	1–1	54	71	19	17.5
20927'8	F	1–2	65	64	6	5.15
13347	M	2–4	—	64	8	3.44
19811	M	2–2	65	63	9	4.15
21081'5	M	2–1	63	66	15	7.20
21190	M	2–1	68	62	9+(3)	5.76
17516	F	3–1	64	72	18	5.84
14610	M	3–1	64	66	21	6.81
17894	F	3–2	75	67	21	6.63
17945	M	3–1	70	67	14+(2)	5.17
18049	M	3–2	66	65	57	18.0
18330	M	3–1/2	67	67	12	3.96
18573	F	3–3	62	68	24	7.38
16309	F	4–0	66	73	42	10.5
14700	F	4–1	68	77	29	7.11
12761	M	4–2	62	67	14	3.36
14779	F	4–3	63	73	67+	15.8+
14621	F	5–2	65	69	15+(2)	3.29
12798	F	5–4	68	73	48	9.00
12677	F	6–4	70–75	72	31	4.90
3013	F	24–11	—	70	33	1.33
3184	F	24–11	—	69	36	1.45
2825	F	25–0	—	71	38	1.52
2932	M	25–0	—	66	38+(3)	1.64
3171	F	25–0	—	72	28	1.12
5763	M	24–11 1/2	—	69	34	1.37

TABLE 2. DATA FOR EXAMINATION OF ACCUMULATION RATE OF EAR-PLUG LAMINATION BY RECAPTURED FIN WHALES IN THE NORTHERN PART OF THE NORTH PACIFIC (JAPANESE MARKS)

Mark No.	Sex	Elapsed time (A) (Yr.-Mon.)	Estimated body length at marking (ft.)	Body length at recapture (ft.)	No. of ear-plug laminations (B)	B/A
7968	F	0-0	62	66	9	—
8416	F	0-0	62	57	4	—
8433	F	0-0	65	63	9	—
8434	M	0-0	53	61	6	—
8567	F	0-0	60	69	31	—
8618	M	0-0	63	61	19	—
8632	F	0-1/2	66	73	12	—
7988	M	0-0	64	59	6	—
6801'2	F	0-10	60	58	7	8.43
6799	M	0-10	60	59	13	15.7
7962	F	0-11	61	64	12	13.2
6834	M	0-9	69-70	61	28	37.3
6831'7	M	0-10	61-62	58	14	16.9
7975	M	1-0	64	61	50	50.0
7686	F	1-1	62	57	10	9.23
4552	F	1-10	60	62	11	6.01
6264	M	1-10	60	56	8	4.37
6807	F	1-10	56-57	57	5	2.73
6939	F	1-11	62	64	41	21.5
7708	F	1-11	55-57	62	8	4.19
6923	F	2-0	62	64	32	6.00
5979	M	2-0	60	58	9	4.50
8089	F	2-1	73	68	13	6.25
6808	F	2-9	65-66	64	15	5.45
4558	M	2-10	65	62	21	7.42
7026	M	2-10	60	62	14	4.95
7200	M	2-10	54	58	8	2.83
6274	F	2-10	60	62	8	2.83
6835	M	2-10	60-61	61	16	5.65
7170	M	2-11	55	59	9+	3.08+
6504	F	2-11	63	58	7	2.40
6782'5	F	2-11	60	61	8	2.74
3243	F	3-0	(70)	55	13	4.33
6471'7'8'80	F	3-0	54-55	57	12	4.00
6498	M	3-0	61	60	12	4.00
7705	F	3-0	66-68	60	13	4.33
7727	F	3-0	58	65	19	6.33
7737	M	3-1	60	64	10	3.25
7541	F	3-1	60	58	6	1.95
6817	M	3-10	57	59	6	1.57
6977	M	3-10	55	61	12	3.13
3391	M	3-11	63	64	27	6.89
6044	F	4-10	65	67	21	4.35
7025	M	4-10	55	63	13	2.69
4393	F	4-11	60	65	21	4.27
6052	F	4-11	62	67	9+	1.83+
6098	M	4-11	52	62	9	1.83
4615	M	4-10	—	61	12	2.48
4452	M	5-0	—	59	10	2.00
6172	F	5-1	56	62	11	2.16
4564	F	5-9	60	56	10	1.74
6097	M	5-9	62	65	23	4.00
5960	M	5-11 1/2	50	64	15	2.52
4146	F	6-0	60	68	16	2.67
3287'3343	M	6-11	65	64	16	2.31
4651	M	6-11	65	67	43	6.22

laminations per year is 1.6, although it was recovered only 3 years and 10 months later. According to the record at marking, the whale was estimated as 57 feet long, and it might be over one year old at marking. When the age at marking is added on the elapsed time, mean number of laminations per year becomes under 1.3.

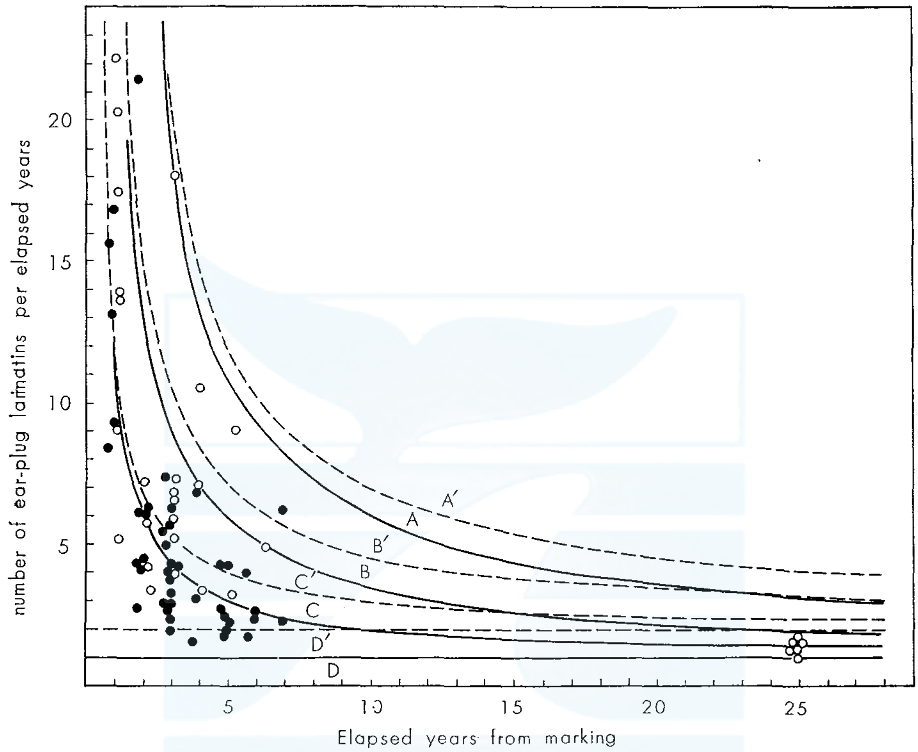

Fig. 1. Change of number of ear-plug laminations per elapsed years according to the elapsed years from marking until recapture.
A, A′: 50 laminations at marking, B, B′: 25 laminations at marking, C, C′: 10 laminations at marking, D, D′: 0 lamination at marking (birth at marking), A, B, C, D: One lamination accumulate a year, A′, B′, C′, D′: Two laminations accoumulate a year. Open circle: Antarctic fin whale, closed circle: North Pacific fin whale.

In the North Pacific, Nos. J. 7541, J. 6098 and J. 4564 whales are also calculated the mean number of laminations per elapsed years as under 2, notwithstanding their elapsed times are within 6 years. Further, in the Antarctic, 6 long term marked fin whales from which ear plug were collected had been recaptured by Japanese fleets by 1961/62 season. The mean numbers of laminations per elapsed year of the 6 whales are all under 2 (1.33 in No. E. 3013, 1.45 in No. E. 3184, 1.52 in No. E. 2825, 1.64 in No. E. 2932, 1.12 in No. E. 3171, and 1.37 in No. E. 5763). The tip of ear-plug core of No. E. 2932 whale is broken, but the broken laminae layers are estimated to be less than three, and the total lamination are estimated to be 41.

There is no whale of which mean number of ear-plug lamination is calculated as under 1.0 per year.

The mean number of ear-plug laminations per year calculated in this way, should be more than 2 for all recaptured whales, if they are actually laid down biannually. However, in view of these examples, the annual increment of ear-plug laminations is estimated to be under 2 for the marked fin whales, perhaps near one lamination per year. The solid lines in this examination also support the estimation that the accumulation rate of ear-plug lamination must be under two annually, and may be near one per year.

TABLE 3. ESTIMATION AND COMPARISON OF THE AGE COMPOSITION OF RECAPTURED FIN WHALES AT MARKING BETWEEN TWO CASES OF ANNUAL ACCUMULATION RATE OF EAR-PLUG LAMINATION

Annual accumulation rate of ear plug	Age at marking	Elapsed years (actual figures) 0	1–2	3–4	5–7	Total	Elapsed years (per cent) 0	1–2	3–4	5–7
One	51<	1	1	2	—	4	4.6	3.7	6.9	0.0
	26–50	2	4	2	3	11	9.1	14.8	6.9	18.8
	11–25	7	10	12	4	33	31.8	37.0	41.4	25.0
	6–10	11	10	7	6	34	50.0	37.0	24.2	37.5
	0–5	1	2	6	3	12	4.6	7.5	20.7	18.8
	0>	—	—	—	—	—	0.0	0.0	0.0	0.0
	Total	22	27	29	16	94				
Two	51<	1	1	2	—	4	4.6	3.7	6.9	0.0
	26–50	2	4	1	2	9	9.1	14.8	3.4	12.5
	11–25	7	8	8	4	27	31.8	29.6	27.6	25.0
	6–10	11	8	9	1	29	50.0	29.6	31.1	6.3
	0–5	1	6	7	7	21	4.6	22.2	24.2	43.8
	0>	—	—	2	2	4	0.0	0.0	6.9	12.5
	Total	22	27	29	16	94				

Table 3 and Fig. 2 show the estimated age composition at the time of marking by recaptured fin whales. Estimated age at marking is calculated from number of lamination at recapture, elapsed time and the annual accumulation rate of ear-plug laminations. I calculated the estimated age in two cases where annual accumulation is one and two. The comparison of age composition at marking is made in elapsed year classes 0, 1–2, 3–4 and 5–7. According to Fujino (1960), the estimated size distribution of marked whale at the time of marking is not so different from that which were caught, although young whales distribute little rather more than the whales caught and the markings of whales are considered to be made at randum from the stock in the whaling ground. If so, the estimated age distribution at the time of marking must be not so different in each season. Now, as shown in Fig. 2, the age composition at the time of marking is not so changed according to the elapsed years for the case of one-lamination age. Ratio of the age class of 0 to 5 at the time of marking increases according to the elapsed years. This can be explained that small whales are not caught soon after marking, but they grow to captuable size as the time goes by. On the contrary, in the case of two-laminations age, estimated age composition of marked whale at the time of marking changes by the increment of elapsed years. And in 5 to 7 elapsed years classes, the composition of under 5 years old class exceed the half of total whales. This is not able to be explained, because the age distribution of marked whales must not be so different from the whales caught at the time of marking. Besides, there exist the whales under 0-year old at the time of marking in the case of two-laminations age. They must be marked before birth. This is not practical.

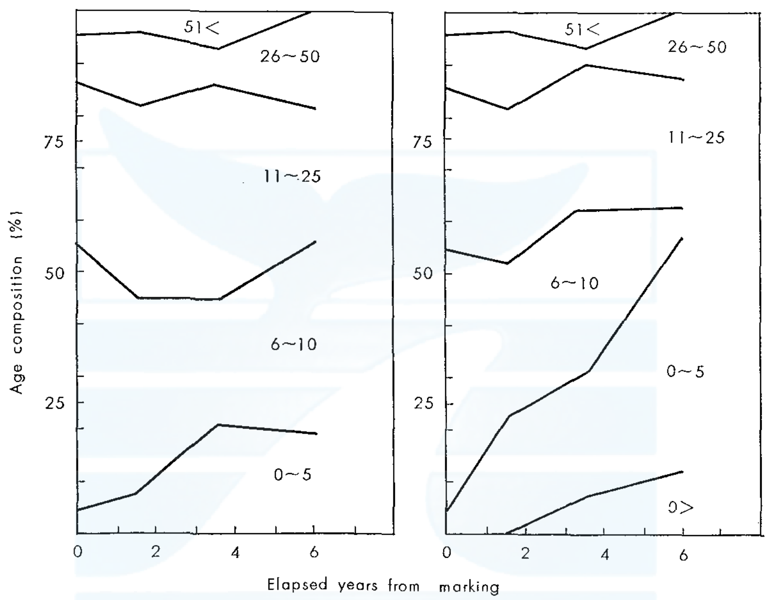

Fig. 2. Change of estimated age composition of recaptured fin whale at the time of marking according to the elapsed years from marking. Left figure: Annual rate of ear-plug accumulation is one lamina, Right figure: Annual rate is two laminae.

However, Chittleborough (1959) reported that a male humpback whale was marked when its body length was approximately 30 feet (he estimated to be an yearling) and it was recaptured 4 years and 10 2/3 months later. The ear plug contained as 12 laminations. From the above result, he agreeded with the biannual formation of ear-plug lamination. I am afraid that the whale was truly yearling. The estimate body length is sometimes different with the actual length. And there is individual variation in the body length. Dawbin (1959) also reports a marked humpback whales which had been at least one year old at marking and was recaptured 19 months later. Examining its baleen plate and ear plug, he states that the result are consistent with the view that ear plugs develope two laminations per year.

EXAMINATION OF THE AGE AT SEXUAL MATURITY BY THE MARKED WHALES

Sexual maturity is one of the remarkable stages in the life history of whales. Besides, it is used for classification of broad age groups. Therefore, it is considered to be a kind of age character. On the age at sexual maturity of the fin whale, Mackintosh & Wheeler (1929) state that an examination of sizes of young whales at different times of year suggests that sexual maturity is reached about 2 years after birth. Studying the baleen plates, Ruud (1945) describes that it is apparent that majority of the northern fin whales attain sexual maturity at an age of 3 years. From the similar method, Nishiwaki (1952) states that females reach to sexual maturity in the pairring season following the fourth birth day and the males at the age of about 3 years and a half in the case of the southern fin whales. In the modified method of surveying baleen plates, Van Utrecht (1956) obtained a result that the age at which the female becomes sexually mature lies between 5 and 6 years.

TABLE 4. SEXUALLY MATURE AND IMMATURE FIN WHALES IN EACH ELASPED YEARS FROM MARKING UNTIL RECAPTURE (INCLUDED DATA FROM TABLE BY LAWS, 1961)

		Elapsed years from marking																	
		0	1	2	3	4	5	6	7	11	12	17	19	20	21	23	24	25	Total
Males	I	8	4	2	1	1	3	—	—	—	—	—	—	—	—	—	—	—	19
	S	7	2	—	3	1	2	—	—	—	—	—	—	—	—	—	—	—	15
	M	8	8	3	5	2	1	2	2	—	—	—	—	—	—	—	—	1	32
Females	I	8	8	2	5	—	1	1	—	—	—	—	—	—	—	—	—	—	25
	S	5	4	1	4	—	1	1	—	—	—	—	—	—	—	—	—	—	16
	M	13	6	8	6	3	5	4	—	1	1	1	1	1	1	1	1	4	57
M+F	I	16	12	4	6	1	4	1	—	—	—	—	—	—	—	—	—	—	44
	S	12	6	1	7	1	3	1	—	—	—	—	—	—	—	—	—	—	31
	M	21	14	11	11	5	6	6	2	—	—	—	—	—	—	—	—	—	90
	Total	49	32	16	24	7	13	8	2	1	1	1	1	1	1	1	1	5	164

Remarks: I: Sexually immature (under 2.4 kg in larger testis for male, 0 ovulation for female).
S: Soon after sexual maturity (2.5–5.0 kg in testis for male, 1–2 ovulations for females).
M: Sexually mature (over 5.1 kg in testis for male, over 3 ovulations for females).

Since the discovery of laminations in ear plug, Laws & Purves (1956) reported that sexual maturity was reached at the age from 4 to 6 years in the male from the North Atlantic. Nishiwaki (1957) learned in the same method the age of sexual maturity of the southern fin whale was 4 or 5 years. Ohsumi, Nishiwaki & Hibiya (1958) state that if two laminations are formed every year, the fin whale in the northern Pacific will attain at sexual maturity in early term of seventh year after birth, and the precocious will be mature sexually by the fifth year, furthermore, by the eighth year all the fin whales will attain at sexual maturity. Purves & Mountford (1959) give a figure of 4 and a half years for males and 5–6 years for females. Laws (1961) also shows the percentage frequency of sexually mature females in different age-groups from ear plug (biannual rate), and get that the age corresponding to 50% of mature females is about 5 years.

Above results are not lead with the absolute age of whales. Table 4 shows the number of animals which are determined their sexual maturity among the recaptured fin whales. Data used for this purpose are from Ohsumi (1962) and Laws (1961). I divided sexually mature whales into two groups, that is, soon after maturity and fully mature groups.

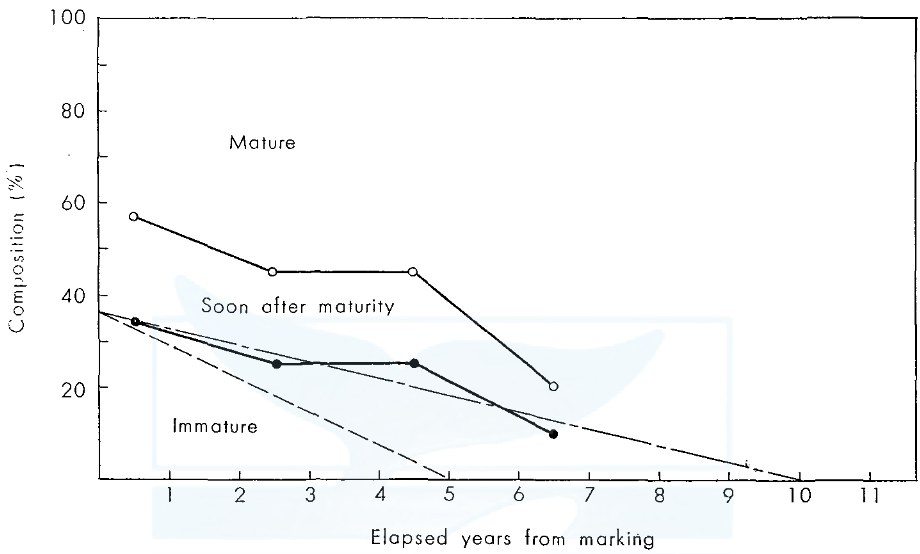

Fig. 3. Change of composition of sexually mature and immature fin whales recaptured according to elapsed years, and estimation of age at sexual maturity. Chain line: Regression line of immature rate, Broken line: Estimated decreasing line of immature rate assuming the age at sexual maturity as 5 years.

And Fig. 3 shows the change of the composition of sexually immature and mature animals according to the elapsed years calculated from Table 4. In 0-year group which were recovered within 3 months later, the rate of sexually immature whales is 32.7%. This is almost the same ratio as the usually caught whales in the factory ship whaling. But as the time elapses, the rate of immature whales gradually decreases. There is a sexually immature female whale (J. 4564) which was recovered 5 years and 9 months later. This whale certificates the existence of an individual which is sexually immature in the age of at least 5 years and 9 months. This whale had been estimated to be 60 foot long at the time of marking. Considering the error of the estimation, the whale is thought to be at least 1 or 2 years old at that time. If so, this whale must be still sexually immature in the age of 7 or 8 years.

There were several recovered whales which are estimated to be soon after sexual maturity more than 3 years later from marking. One of them is a female recovered 3 years later (J. 3243). It has only one corpus albicans in the ovaries. Considering from the existence of vaginal band and immature mammary gland, this whale is assumed to be soon after sexual maturity (puberty as defined by Chittleborough, 1954).

Regression line is calculated from the elapsed time and the composition equation of immature whales. It is:

$$Y = -3.68X + 36.49$$

Where, Y is a percentage of immature whales, and X is the elapsed years. From this equation, following values are calculated: The percentage of immature whales is 36.49 at the time of marking ($X=0$), and the elapsed time is 9.93 years when percentage of immature whale is 0.

Thus, we can estimate that the age at sexual maturity is about 10 years from the examination of age at sexual maturity by the recaptured fin whales. Broken line in Fig. 3 is a estimated declining line of sexually immature ratio, when the age at sexual maturity is considered to be 5 years as many authors reported. This broken line does not fit the actual change of composition of sexually immature animals. We must consider that there is individual variation in the age at sexual maturity, but usually whales are marked somewhile later from birth. And there are 5 immature animals (25%) among 20 animals which were recaptured after 4 and 5 years from marking. Even among 10 recaptured animals after 6 and 7 years' elaption from marking, there is one immature animal (10%). This phenomenon may mean that the age at sexual maturity is longer in fin whale than those which are recognized today by us, and I estimate from the change of composition of sexually immature animals according to elapsed years that the age at sexual maturity is about 10 years.

On the humpback whale, Chittleborough (1959 b) reported an sexually immature male which was recaptured 4 years and 1 month later.

ANNUAL ACCUMULATION RATE OF CORPORA ALBICANTIA IN THE RECAPTURED FIN WHALES

Chittleborough (1959 a) reportes " One female humpback whale marked when it was accompanied by a calf was killed 9 years later. The ovaries then obtained 10 corpora albicantia, so that if this female had been marked at the end of its first pregnancy, the average rate of ovulation would have been 1.0 ovulations per year." And calculating from the data by Chittleborough (1959 b), a mean number of ovulations per year for a marked humpback whale recovered 17 and a half years later is 0.9 ovulations.

By a result of a fin whale recovered 6 years and 2 months later, Mackintosh (1942) states that one cannot draw any final conclusion, but in this one, since it had only 8 corpora lutea, the rate of accumulation (mean number of ovulations is 1.3 per year) cannot have been much more than about one a year, and since there was no clue to the whales age at the marking, the rate of accumulation may have been even slower.

Laws (1961) checked the corpora accumulation rate by 10 recaptured fin whales. He calculated the mean elapsed period as 13.8 years (ranging from 2 to 24 years) and the mean corpora as 15.7 (ranging from 3 to 40). Then he gets the

TABLE 5. DATA FOR EXAMINATION OF ANNUAL ACCUMULATION RATE OF CORPORA ALBICANTIA IN THE MARKED FIN WHALES CAUGHT IN THE ANTARCTIC (DISCOVERY MARKS)

Mark No.	Elapsed time (Year-Month)	Estimated body length at marking (ft.)	Body length at recapture (ft.)	No. of corpora	No. of corpora per elapsed year
24350	0–0	61	63	0	—
18087	0–1	66	73	12	—
21196'98	0–1	70	64	4	—
14576	0–2	60	69	3	—
19843	0–2	66	64	0	—
20502'4	0–2	62	66	1	—
21187'21200	0–2	70	73	19	—
24064	0–2	70	70	18	—
24349	0–2	55	62	0	—
19837'9	0–3	66	64	0	—
20735	0–3	67	66	0	—
17903	1–1	70	69	1	0.92
19746	1–1	60	65	0	0.00
19835	1–1	63	69	2	1.85
19840	1–1	67	69	6	5.53
20927'8	1–2	65	64	0	0.00
15388	1–2	—	65	2	1.72
17839	1–2	62	66	0	0.00
17457	2–1	65	71	6	2.88
17516	3–1	64	72	3	0.97
18073	3–3	62	68	2	0.60
19921	3–2	60	63	0	0.00
13278	5–2	68	73	15	2.90
13481	6–2	60–65	73	13	2.11
6472	20–1	—	71	9	0.45
3507	20–11	—	70	23	1.10
3103	24–11	—	70	15	0.60
2627	24–1	—	69	32	1.33
5594	22–11	—	74	12	0.53
*10504	2.23	—	71	10	4.48
*12870	3.23	—	70	3	0.93
* 696	6.21	—	76	8	1.29
* 7972	11.13	—	69	5	0.45
* 4938	12.06	—	73	14	1.16
* 6818	17.05	—	75	40	2.33
* 1199'1203 * 1300	19.12	—	76	11	0.58

* Cited from Table 30 by Laws (1961)

TABLE 6. DATA FOR EXAMINATION OF ANNUAL ACCUMULATION RATE OF CORPORA ALBICANTIA IN THE MARKED FIN WHALES CAUGHT IN THE NORTHERN PART OF THE NORTH PACIFIC (JAPANESE MARKS)

Mark No.	Elapsed time (Year-Month)	Estimated body length at marking (ft.)	Body length at recapture (ft.)	No. of corpora	No. of corpora per elapsed year
4266	0-0	68	62	1	—
7968	0-0	62	66	1	—
8416	0-0	62	57	0	—
8433	0-0	65	63	0	—
8632	0-1/2	66	73	4	—
4684	0-1	65	61	2	—
4802	0-1	71	65	1	—
7720	0-1	64-66	66	7	—
8567	0-0	60	69	11	—
4270	0-2	68	63	0	—
4658	0-11	61	58	0	0.00
4543	0-11	62	66	9	9.81
6815	0-10	62	60	0	0.00
6843	0-10	62-63	56	0	0.00
6801'2	0-10	60	58	7	8.08
7962	0-11	61	64	2	2.18
4552	1-10	60	62	1	0.55
6042	1-8	55	64	9	5.40
5995	1-10	57	65	15	8.27
6939	1-11	62	64	14	7.30
7708	1-11	55-57	62	0	0.00
6807	1-10	56-57	57	0	0.00
7686	1-1	62	57	0	0.00
4267	2-0	45	63	3	1.50
6923	2-0	62	64	8	4.00
6274	2-10	60	62	1	0.35
6504	2-11	63	58	0	0.00
6782'5	2-11	60	61	0	0.00
6808	2-9	65-66	64	6	2.18
8089	2-1	73	68	3	1.44
3243	3-0	(70)	55	1	0.33
3213	3-2	60	63	16	5.06
6471'7'8'80	3-0	54-55	57	0	0.00
7705	3-0	66-68	60	3	1.00
7270	3-2	60	60	1	0.32
7727	3-0	58	65	4	1.33
7541	3-1	60	58	0	0.00
4393	4-11	60	65	5	1.02
6044	4-10	65	67	7	1.45
6052	4-11	62	67	2	0.41
6172	5-1	56	62	0	0.00
4564	5-9	60	56	0	0.00
4146	6-0	60	68	1	0.17

result that mean increment of corpora is likely to be 1.14 per year if fin whales are marked on average at about the time of puberty.

Table 5 and 6 show data for examination of corpora accumulation rate by recaptured fin whales. Most of data are obtained by Japanese fleets in the Antarctic and the northern part of the North Pacific which are listed in the paper of Ohsumi (1962). In addition to them, I cited the data from Table 30 of the paper by Laws (1961).

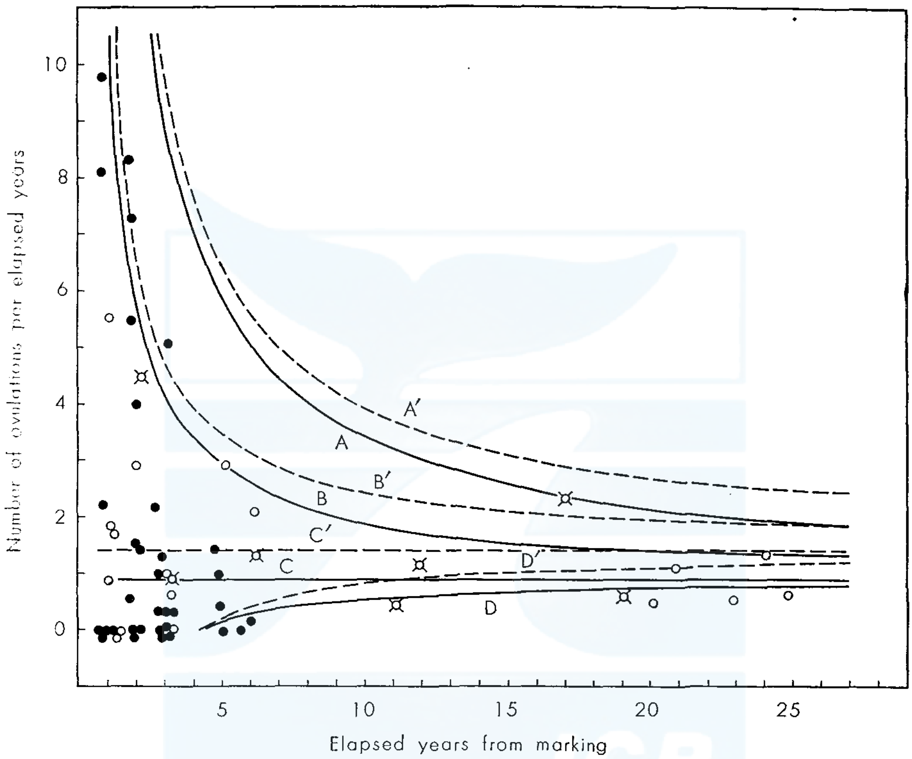

Fig. 4. Change of number of ovulations per elapsed year according to the elapsed years from marking until recapture. A, A′: 25 ovulations at marking, B, B′: 10 ovulations at marking, C, C′: Just sexually mature at marking, D, D′: Just birth at marking, A, B, C, D: Age at sexual maturity is 5 years, and 0.9 ovulations per year (Nishiwaki et al., 1958), A′, B′, C′, D′: Age at sexual maturity is 5 years, and 1.43 ovulations per year (Laws, 1961).

If the time of marking coincides with the attainment of sexual maturity of the marked whale, we can get the actual annual-increment of corpora albicantia, dividing the number of ovulations by the elapsed years. But it is a very rare case, and most whales will be marked after or before the time of sexual maturity. When a sexually mature whale is marked, the mean number of ovulations per year, given by dividing the number of ovulations at recovery by the elapsed years, is more than the actually annual number of ovulations. On the contrary, when a sexually immature whale is marked, the mean number of ovulations per year should be less than true annual number of ovulations. However, as the elapsed time from marking increases, the number of ovulations accumulated before marking becomes relatively small, and mean number of ovulations calculated must approach to the actually annual rate of ovulations.

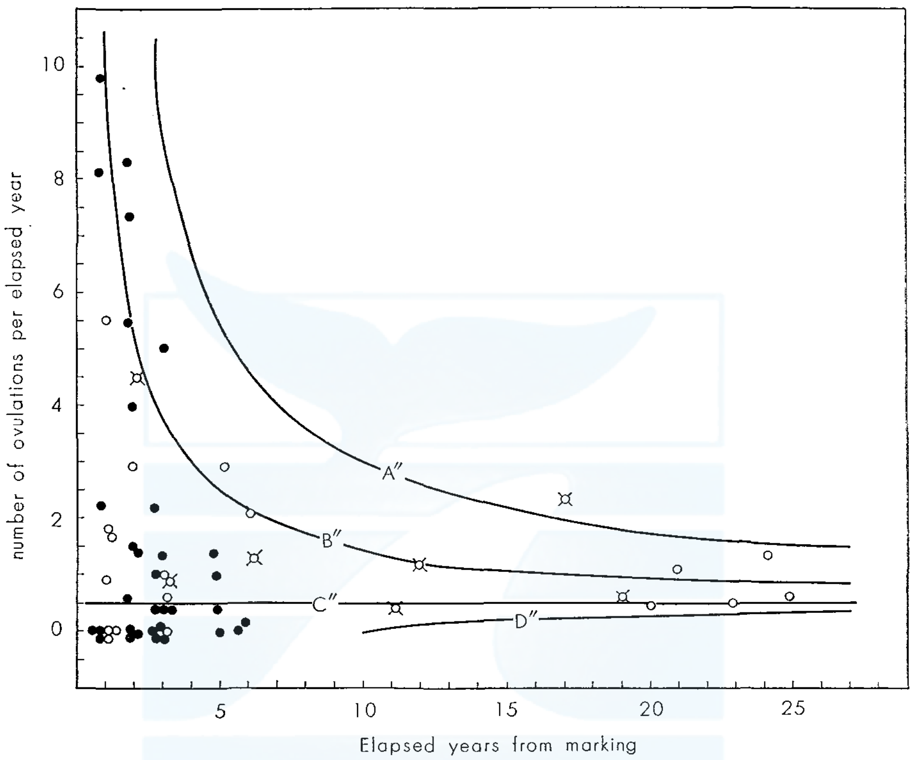

Fig. 5. Change of number of ovulations per elapsed year according to the elapsed years from marking until recapture. A″: 25 ovulations at marking, B″: 10 ovulations at marking, C″: Just sexual maturity at marking, D″: Just birth at marking. A″, B″, C″, D″: Age at sexual maturity is 10 years, and 0.5 ovulations per year.

Fig. 4 shows the relation between the elapsed years from marking till recapture and the mean number of ovulations per elapsed year. The range of the mean number of ovulations in marked whales which were recaptured shortly after, are largely distributed. The reason is that the number of ovulations before marking greatly influences the value obtained. However, with the lapse of time, the range becomes narrow, and more than 19 years later, mean annual number of ovulations in 6 Antarctic fin whales are within the limits of 0.45 and 1.33. The mean value of the 6 individuals is 0.77.

The broken line (A′, B′, C′, D′) in Fig. 4 is a case where the age at sexual maturity is 5 years and the annual accumulation rate of corpora is 1.43 as calculated by Laws (1961), and solid line (A, B, C, D) is another case where the age at sexual maturity is 5 years and the annual rate of corpora is 0.9 as calculated by Nishiwaki et al. (1958) from the relation between the number of lamination in ear plug and the number of ovulation when annual accumulation of ear-plug lamination is assumed as two. A, B′ ; B, B′ ; C, C′ and D, D′ is the cases of 25 ovulations, 10 ovulations just puberty and just birth at the time of marking. According to this figure, broken lines do not fit the actual values, and there are 8 individuals which are under D′ line. This means that the individuals had been marked before birth. This hypothesis is inconsistant with the actual data, for they must have been marked after birth. Solid lines are more suitable than the broken line, but they have the same inconsistance as broken line. Therefore, above two theories are not able to explain the actual figures obtained from recaptured fin whales.

TABLE 7. ESTIMATION AND COMPARISON OF OVULATION COMPOSITION OF RECAPTURED FIN WHALES AT MARKING BETWEEN TWO CASES OF ANNUAL RATE OF OVULATION

Annual rate of ovulation	Ovulation at marking	Elapsed years (actual figures)						Elapsed years (per cent)				
		0	1–2	3–4	5–7	10–25	Total	0	1–2	3–4	5–7	10–25
0.50	26<	—	—	—	—	1	1	19.0	8.3	6.3	11.1	30.0
	11–25	4	2	1	1	2	10					
	6–10	1	6	—	1	2	10	42.9	50.0	43.7	44.4	40.0
	1–5	8	6	7	3	2	26					
	0	8	10	8	4	2	32	38.1	41.7	50.0	44.4	30.0
	Total	21	24	16	9	9	79					
1.43	26<	—	—	—	—	—	—	19.0	8.3	6.3	—	10.0
	11–25	4	2	1	—	1	8					
	6–10	1	4	—	1	—	6	42.9	37.5	6.3	22.2	0.0
	1–5	8	5	1	1	—	15					
	0	8	13	14	5	3	43	38.1	54.2	87.4	55.6	30.0
	Not birth	—	—	—	2	5	7	0.0	0.0	0.0	22.2	60.0
	Total	21	24	16	9	9	79					

Fig. 5 shows the change of mean number of ovulations per elapsed year in the case where age at sexual maturity is 10 years as shown in previous section and the annual accumulation rate is 0.5 as discussed in the following chapter. According to this hypothesis, the curves (A″, B″, C″ and D″) fairly fit the actual values.

Age composition of marked whales is shortly less than the whales caught (Fujino, 1960). According to Laws (1961) and Mackintosh (1942), the average number of corpora of fin whale is calculated as 12.5 in adult female in 1939∼41 season and the ratio of immature whales is 15.1% in 1936–37 Antarctic pelagic whaling. Therefore, the mean number of corpora including immature whales in 1936∼40 season is calculated to be 10.6. If the mean number of corpora in ovaries of marked fin whales is 10 in the Antarctic pre-war seasons and the annual rate of corpora accumulation is assumed to be 0.5, mean corpora divided elapsed years after 20 to 25 years' elaption is calculated to be 1.0 to 0.9. This mean values agree relatively well with the mean number of corpora calculated from 6 recaptured fin whales after 19～25 years elaption (0.77). If annual accumulation rate is 1.43, the former values must be comes between 1.93 and 1.83. This is larger than the actual values.

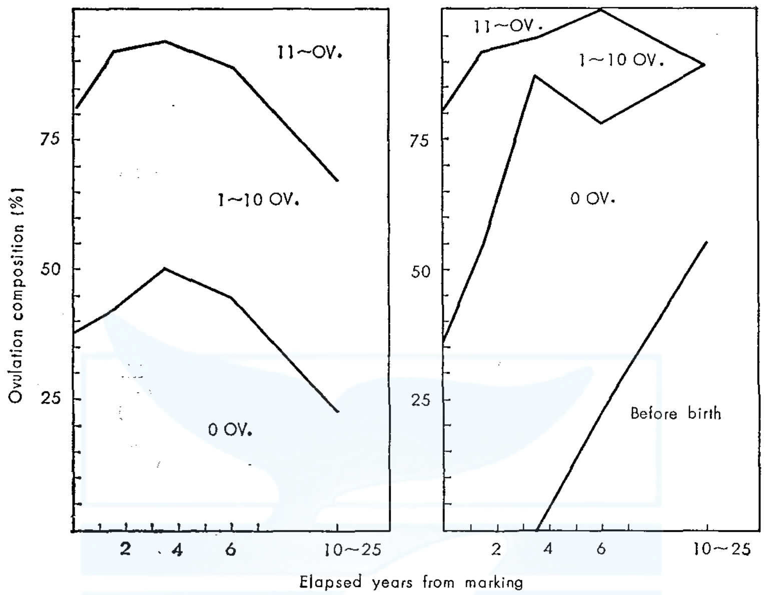

Fig. 6. Change of ovulations composition of recaptured fin whales at the time of marking according to the elapsed years from marking. Left: Annual rate of ovulation is 0.5 and the age at sexual maturity is 10 years, Right: Annual rate is 1.43 and age at sexual maturity is 5 years.

Now, Table 7 and Fig. 6 show the estimated corpora composition at the time of marking by recaptured fin whales. Estimated number of corpora at marking is calculated from number of corpora at recapture, elapsed time and the annual rate of corpora accumulation. And I calculated the estimated corpora number in two cases where annual accumulation rate is 0.5 and 1.43. The comparisons of corpora composition at marking is classified in elapsed year classes 0, 1–2, 3–4, 5–7 and 10–25. As repeatedly said, the estimated size distribution of marked whale is not so different from that which caught. If so, the estimated corpora distribution at the time of marking must be not so different in each season. According to Fig. 6, the estimated corpora composition is not so changed by 7 years of elaption from marking in the case of annual accumulation rate is 0.5. In the 10–25 elapsed years group, estimated immature whale is smaller than the former years classes. But this can be explained that they are pre-war marked whales, and in pre-war seasons the composition of larger whales must be larger than recent season. And the estimated composition of immature class of pre-war marked whale (22%) fairly agrees with the immature rate (15.1%) of pelagic catch in 1936–37 season obtained by Mackintosh (1942). On the contrary, in the case of which annual accumulation rate is 1.43, estimated corpora composition at the time of marking changes remarkably by the increment of elapsed years. And over 4 elapsed years classes, the percentage of immature whales attaines over 75%. This is not able to explain the actual age composition of the whales in the sea. Besides, there exist the whales before birth at the time of marking in the case of annual rate of 1.43, and the rate attains to 55% in 10–25 elapted years class. This is not practical. Thus, this examination also support the estimation that the annual rate of corpora accumulation must be under 1.43, and may be near 0.5 per year.

However, above examination of annual rate of ovulations is considered as mean value. And we must remember that there are indivdiual variations in the ovulation rate as shown by Nishiwaki et al. (1958), and racial variation as shown by Fujino (1963).

RELATION BETWEEN EAR-PLUG LAMINATION AND OTHER AGE CHARACTERS

RELATION BETWEEN EAR-PLUG LAMINATION AND NUMBER OF OVULATION

Fig. 7 shows the mean number of ovulations (corpora lutea and albicantia) in each class of ear-plug lamination for the fin whales caught in Antarctic Areas IV and V in 1958/59 and 1959/60 seasons.

As shown in this figure, there is linear relation between number of laminations and number of ovulations except the old age. An equation is given from this line. It is

$$Y = 0.49X - 4.28$$

Where, Y is the mean number of ovulations, and X is the number of ear-plug laminations. This equation is similar with that obatined by Nishiwaki, Ichihara & Ohsumi (1958).

Thus, coefficient of X is given as 0.49. If the accumulation rate of ear-plug lamination is one per year, the coefficient, that is, 0.49, shows the annual ovulation rate. Notwithstanding two ovulation rates are calculated independently by examination of ovulation of recaptured whales and by relation between number of ear-plug laminations and number of ovulations, the both agree closely with each other. This is, in other word, one of the certification that accumulation rate of ear-plug lamination is one per year.

SEXUAL MATURITY AND NUMBER OF EAR-PLUG LAMINATIONS

Fig. 8 shows the change of ratio of sexual maturity according to increment of ear-plug laminations for the Antarctic fin whales caught in Areas IV–V in 1958/59 and-1959/60 seasons. Individual stages of sexual maturity have been estimated from the standard described in previous chapter.

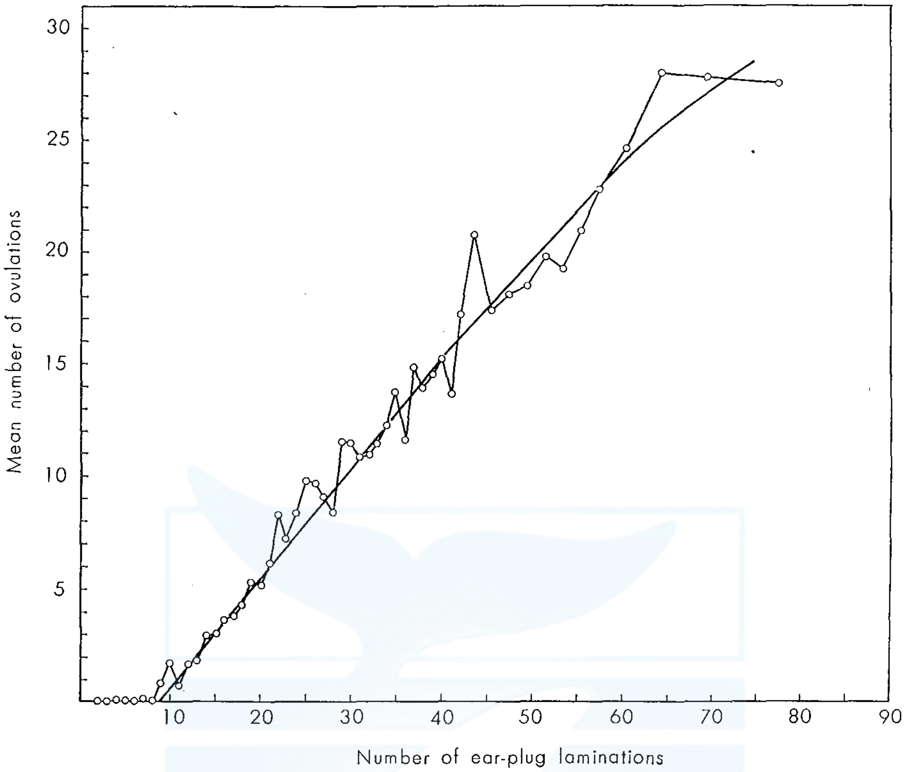

Fig. 7. Relation between number of ear-plug laminations and the numbr of ovulations in the Antarctic fin whale in Areas IV—V.

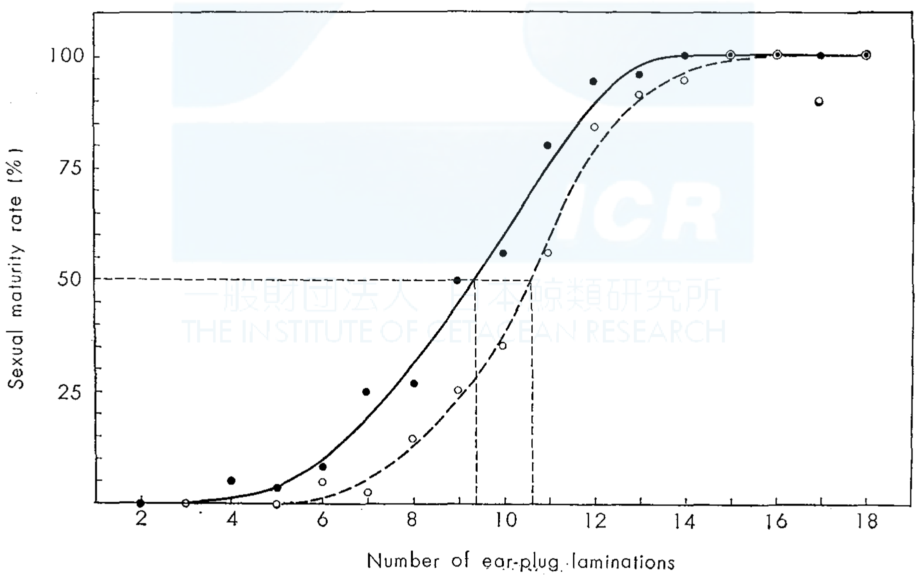

Fig. 8. Percentage of sexual maturity in successive ear-plug laminations, on the Antarctic fin whales in Areas IV—V. Open circles and broken line: Females, Closed circles and solid line: Males.

Males start to attainment of sexual maturity from 4 laminations, and by 14 laminations all individuals attain to maturity. Females attaines to maturity later than the males, they start from 6 laminations and end by 15 laminations. The number of ear-plug laminations corresponding to 50% of maturity is 9.4 in males and 10.7 in females. In Fig. 7, the number of laminations at the point where one corpus level accross the average line is 11 laminations.

On the relation between number of ear-plug laminations and sexual maturity of fin whales, Laws & Purves (1956) compared testes weights and ear-plug laminations, and they concluded that sexual maturity is attained at 8–12 laminations in the case of males in the North Atlantic fin whales. Nishiwaki (1957) compared the number of laminations with number of corpora in ovaries of 34 Antarctic fin whales and he found that 10 laminations corresponded to one corpus. Nishiwaki, Ichihara & Ohsumi (1958) tablated the frequency of sexually immature and mature fin whales caught in the Antarctic and North Pacific in different number of ear-plug laminations in Apendix. And they said that male and female fin whales matured at about 11 laminations. Purves & Mountford (1959) draw growth curves of males and females in the Antarctic areas I and II where ages are based on ear-plug laminations, and estimating body lengths at sexual maturity as 66 feet in females and 63 feet in males, they concluded that the age at sexual maturity is 10–12 laminations in the females and 9 laminations in the males. Laws (1961) shows the percentage of sexually mature females in successive age groups based on ear-plug laminations, and he obtaines that age corresponding to 50% of mature female is about 5 years (10 laminations).

Summarizing the above results, the number of ear-plug laminations at sexual maturity may be concluded to be 10–11 in the females and 9–10 in the males respectively in the case of fin whales.

Now, in the examination of age at sexual maturity by recaptured fin whales, it is estimated to be about 10 years. This result is based on absolute time as elapsed years from marking until recapture. On the other hand, the number of laminations at sexual maturity is obtained independently as 9–11 laminae. Connecting these two results, I can get a conclusion that the annual accumulation rate of ear-plug laminations must be near one. This conclusion also coincides with the results obtained by the examination of annual rate of ear-plug laminations from recaptured fin whales.

RELATION BETWEEN EAR-PLUG LAMINATIONS AND RIDGES ON BALEEN PLATE

On the relation between number of ear-plug laminations and the number of ridges on baleen plates of fin whales, Laws & Purves (1956), Nishiwaki (1957) and Laws (1961) examined, and Chittleborough (1959) also examined the relation between ear plug and baleen on the humpback whale. They all recognized that two laminations corresponded to one ridge. However, for example, in Fig. 55 (p. 467) on the report by Laws, there are individuals which are over the 45° line. If two laminations correspond to one ridge, all individuals must be plotted on or right side of the line. And in the Fig. 4 of the paper by Chittleborough (1959), also there are many individuals of which number of ridges more than half of the number of ear-plug laminations. And from these figures, we can consider that there is possibility of the existence of individual of which one ridge on baleen plate correspond to less than two laminations.

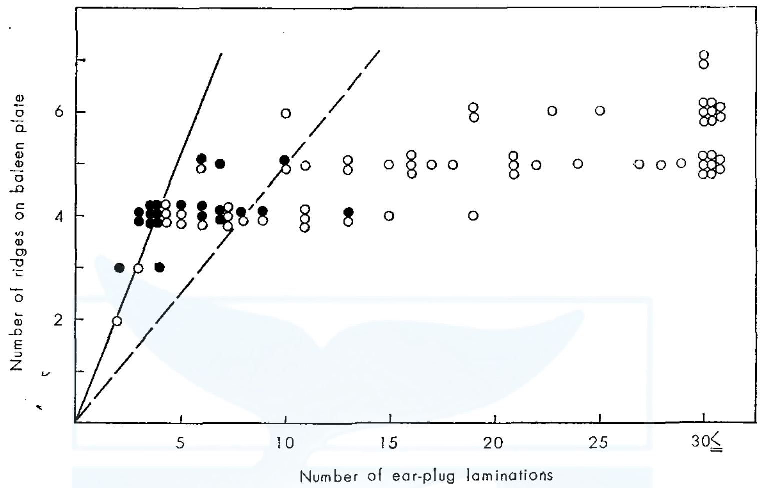

Fig. 9. Relation between number of ear-plug laminations and the number of ridges on baleen plate for fin whales. Open circle: Antarctic, Closed circle: North Pacific, Solid line: One lamina correspond to one ridge, Broken line: Two laminae correspond to one ridge.

Fig. 9 shows the relation between number of ear-plug laminations and baleen ridges on 53 Antarctic and 21 North Pacific fin whales. In this figure, broken line is base on hypothesis that two laminations correspond to one ridges, and solid line is based on another hypothesis that one lamination corresponds to one baleen ridge. As mentioned above, if former hypothesis is true, all individuals must be on the broken line or right side of the line, because baleen plate become to wear at the tip from relatively young ages (Ruud, 1950). However, there are many individuals which are on the left side of the broken line. Then, we must abandon the former hypothesis. On the contrary, almost of all points distribute on solid line or right side of the line. I have scanty of data on the material less than 3 laminations, but the latter hypothesis approaches to the truth more than the former hypothesis. That is to say, there is possibility that one ear-plug lamination corresponds to one baleen ridge in the first few ages. As reviewed in Introduction, nowaday, it seemes to be recognized that annual increment of baleen is equivalent to one ridge (Ruud, 1940, 1945; Nishiwaki, 1951; Chittleborough, 1959). If it is correct, one ear-plug lamination corresponds to one year. This conclusion agrees also with the results in former sections in the present paper. However, I must notice that there are 3 individuals which distribute on the left side of the solid line. Ichihara (1964) confirms the prenatal formation of ear plug. But there is no report on the formation of ear plug chiefly in calf stage. Furhter examinations are needed for this problem.

EXAMINATION OF AGE COMPOSITION BASED ON EAR-PLUG LAMINATIONS

AGE COMPOSITIONS OF FIN WHALES CAUGHT IN NORTH OF EAST ALEUTIAN ISLANDS

By immunologic and marking approaches, Fujino (1960) reported that almost of the fin whales caught in the north of east Aleutian Islands are composed with pure Population-II. And as Omura (1955) reported, the whaling in this area had not been operated on a large scale before the time when Japanese fleets began to operate in 1954.

TABLE 8. AGE COMPOSITION OF FEMALE FIN WHALES CAUGHT IN THE NORTH OF EAST ALEUTIAN ISLANDS DURING 1959 TO 1961

	Annual accumulation rate			Annual accumulation rate	
Age	One lamination	Two laminations	Age	One lamination	Two laminations
0	—	—	26	17	2
1	—	7	27	20	2
2	2	88	28	12	6
3	5	159	29	11	1
4	29	114	30	9	4
5	59	87	31	9	4
6	69	57	32	12	3
7	90	42	33	13	3
8	64	42	34	7	4
9	50	34	35	10	—
10	51	40	36	11	1
11	36	36	37	8	1
12	30	35	38	6	—
13	27	37	39	7	1
14	27	23	40	8	—
15	15	18	41	9	2
16	22	25	42	4	—
17	20	17	43	4	1
18	17	19	44	2	—
19	17	13	45	3	—
20	12	17	46	2	—
21	28	8	47	—	—
22	18	5	48	2	1
23	18	2	49	6	2
24	20	8	50	2	—
25	15	4	51<	43	3
			Total	978	978

Table 8 and Fig. 10 show the estimated age compositions of female fin whales caught in the north of east Aleutian Islands during 3 years from 1959 to 1961 based on ear-plug laminations. In this figure, the age distributions are converted on both assumptions of biannual (two-laminations age ; broken line) and annual (one-lamination age ; solid line) accumulation rate of ear-plug laminations. Frequencies are shown in logarithm.

Modes of frequencies exist in 7 years in the case of one lamination age and in 3 years in the two-laminations age. This is because size limit is prescribed as 55 feet for northern hemisphere fin whale in the factory ship whaling, and younger animals are protected from whaling.

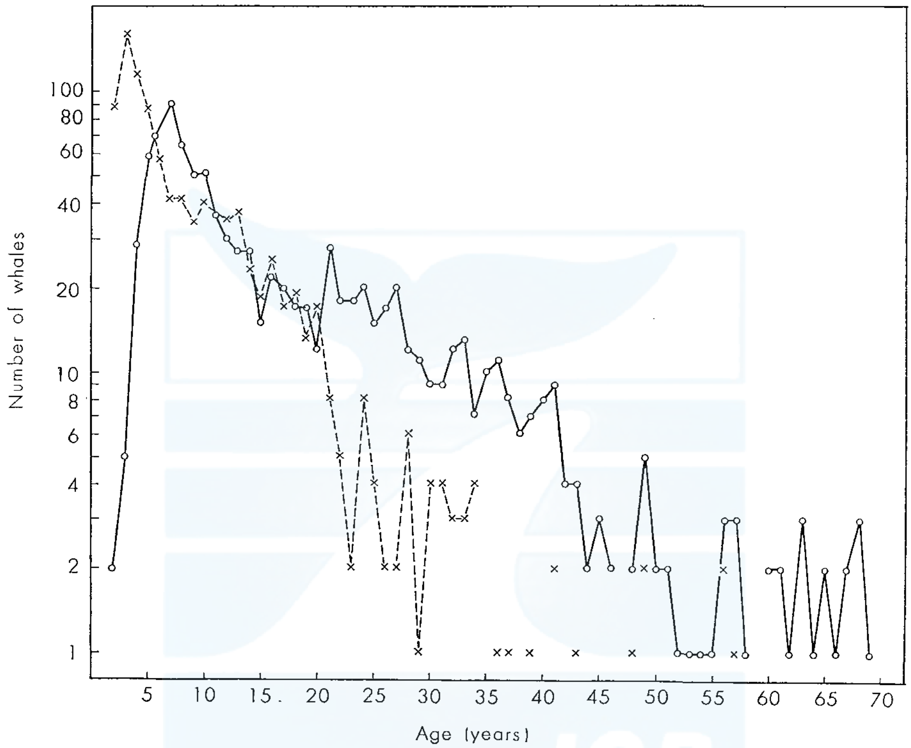

Fig. 10. Age compositions based on ear-plug laminations of the female fin whales caught in the north of east Aleutian Islands during the seasons from 1959 to 1961. Open circles and solid line: Annual accumulation rate is assumed as one, Cross and broken line: Annual accumulation rate is assumed as two.

Now, as shown in Fig. 10, catch curves are seemed to be separated to two straight lines excluding older age respectively in two accumulation rates. The cross point of two straight lines is estimated to be 15 years for the case of one-lamination age and 7 years for the case of two-laminations age.

If there is a population of which natural mortality coefficient (M) is constant and a constant fishing (coefficient is F) is operated to the population (more than A-age individuals are catchable), the logarithmic catch curves must be changed by years as shown in Fig. 11. Catch curves are separated to two straight lines. And right line has the same coefficient as M. On the other hand, left line has a coefficient which is $Z\ (=M+F)$. Cross point of these two lines moves according to the fishing years, and after t years, the cross point must become to $(A+t)$-age.

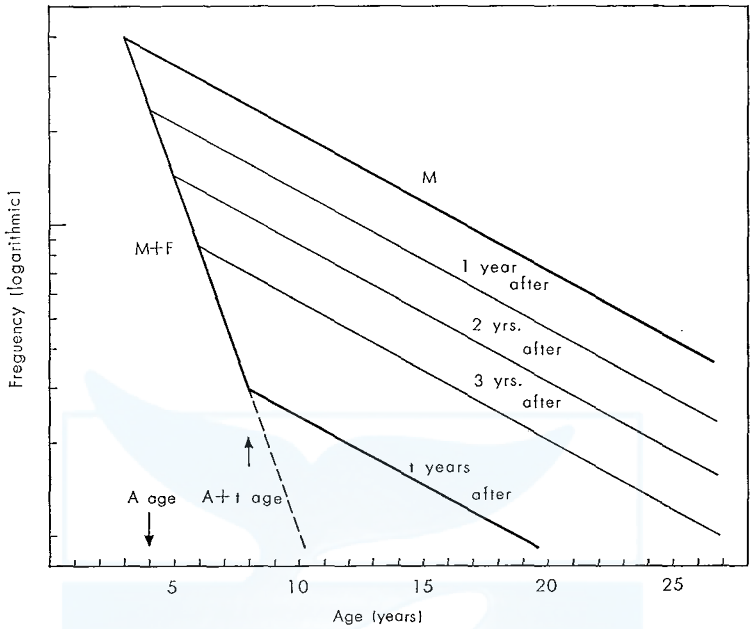

Fig. 11. Modelal catch curves according to the change of years, when a constant fishing effort (F) is given to a population of which natural mortarity (M) is constant and recruit is constant.

When this modelal catch curves are able to adapt the actual catch-curves, the following factors must be chequed:

1) Natural mortality rate is constant: We cannot cheque on this factor. But in the one-lamination age, mortality is seemed to be constant during the ages from 15 to 40.

2) Recruitment to the age catchable is constant: We cannot know on this factor.

3) Fishing effort is constant: Table 9 shows the C.D.W. (catchers days work) in the operation in the north of east Aleutian Islands from 1954 to 1961. During the 8 years, C.D.W. are not always constant, and they vary between 110 and 350. But there is no tendency in the variation. And average of C.D.W. is 286.8.

Although there are above weak points, the actual curve is seemed to be adapted the modelal catch-curve.

On the cross point of two straight line, following result is obtained:

	A	t	A+t	Actual cross point
One-lamination age	7	6	13	15
Two-laminations age	3	6	9	7

As actual catch-curve is given from sum of 3 seasons 1959–1961, this is considered to be a catch curve in 1960. Therefore, t is 6 years. From above result, I cannot determine which curve is more suitable to truth, but deviation between actual cross point is 13% in one lamination age, on the other hand, it is 29% in two laminations age. More accuarate result will be obtained in future on this subject by examining the tendency of change of age composition.

TABLE 9. CATCH EFFORTS FOR FIN WHALES IN THE NORTH OF EAST ALEUTIAN ISLANDS (Areas P 25 BS AND P 26 BS)

Year	Catchers*	Days work	C.D.W.	Average tonnage	No. of fin whales caught
1954	5	52	260	460.4	587
1955	9	50	450	504.0	1177
1956	10	33	330	572.7	773
1957	10	22	220	632.0	408
1958	10	11	110	657.2	299
1959	10	29	290	673.5	705
1960	10	37	370	688.8	948
1961	10	26	260	690.7	585

* Including scouting boats

NATURAL AND FISHING MORTALITY RATE OBTAINED FROM AGE COMPOSITION BASED ON EAR-PLUG LAMINATIONS

From Table 9, natural mortality coefficient (M) and total mortality coefficient (Z) are calculated on two cases of annual accumulation rate of ear-plug laminations as follows:

Annual accumulation rate of ear-plug lamination	Z	M
One (one-lamination age)	0.192	0.067
	(7–15)	(16–50)
Two (two-laminations age)	0.336	0.150
	(3–7)	(8–25)

( ): Range of age classes in the calculation

The values of Z and M in the latter case are about twice of the former. Fishing mortality coefficient (F) is calculated from Z and M values. That is,

$$F = Z - M$$

So, F values are given as 0.125 and 0.186 respectively for above two cases. Then total mortality rate $(1-S)$, unconditional natural mortality rate $\left(D = \frac{M}{Z}(1-S)\right)$ and exploitation rate $\left(E = \frac{F}{Z}(1-S)\right)$ are calculated as follows:

Annual accumulation rate	1−S	D	E
One lamina	0.174	0.061	0.113
Two laminae	0.285	0.127	0.158

RELATION BETWEEN NATURAL MORTALITY RATE AND RECRUIT RATE

In the virgin stock, if natural mortality rate and pregnant rate in mature stage are constant throughout life, recruit rate is calculated presumably by the mortality rate and pregnant rate.

In the north of east North Pacific, the pregnant rate are obtained from mature and pregnant female whales caught as shown in Table 10.

Pregnant rates vary between 43.9% and 68.1%, and average rate during 8 years is 55.5%.

TABLE 10. PREGNANT RATE OF FIN WHALE CAUGHT IN THE NORTH OF EAST ALEUTIAN ISLANDS DURING 1954 TO 1961

Year	Mature females	Pregnant whales	Pregnant rate (%)
1954	224	139	62.1
1955	395	219	55.4
1956	269	118	43.9
1957	140	85	60.7
1958	64	41	64.1
1959	204	139	68.1
1960	337	164	48.7
1961	160	88	55.0
Total	1793	996	55.5

We consider that above pregnant rates do not show the true value, and I guess the rate is higher than the true value, because lactating animals are protected from catch by International Whaling Regulation, and so, most of them are not included into the figures in Table 10.

Now, recruit rate (R) are calculated in Table 11, when the first recruit number (number of whales born) is 1, sex ratio of females is 0.5, natural survival rate is S, age at sexual maturity is m, and pregnant rate is P, as follows:

$$R = P/2\,(S^m + S^{m+1} + \ldots\ldots + S^\infty)$$
$$= \frac{P \cdot S^m}{2}\left(\frac{1-S^\infty}{1-S}\right)$$

Then S is smaller than 1,

$$R = \frac{P \cdot S^m}{2(1-S)}$$

Age at sexual maturity (m) is considered to be 5 years in the case of two-laminations age and 10 years in the case of one-lamination age. And true pregnant rate is not known, but I set the rate as 0.30, 0.40, 0.50, and 0.60. Then, the recruit rates are calculated as shown in Table 11.

If survival rate does not vary throughout life, in the range in which R is smaller than 1, the number of whales born become to be less than the previous number, and such a population cannot maintain the number of stock. Then, in general, the mortality rate in calves is conciderable to be more than the adults, so, the *R*-value calculated by above process must be fairly more than 1 in practice.

In one-lamination age, survival rate in which the stock continue the size are more than 0.93 and 0.90 respectively in the cases of which pregnant rates are 0.30 and 0.60. On the contrary, in two laminations age, they are more than 0.91 and 0.86 respectively.

TABLE 11. RECRUIT COEFFICIENT OF THE FIN WHALE CHANGING THE SURVIVAL RATES AND PREGNANT RATES

Age at sexual maturity	10 years old				5 years old			
s.r.\p.r.	0.60	0.50	0.40	0.30	0.60	0.50	0.40	0.30
0.97	7.38	6.15	4.92	3.69	8.60	7.17	5.73	4.30
0.96	5.00	4.16	3.33	2.50	6.13	5.11	4.09	3.06
0.95	3.60	3.00	2.40	1.80	4.65	3.88	3.10	2.33
0.94	2.69	2.25	1.80	1.35	3.67	3.06	2.44	1.83
0.93	2.08	1.73	1.39	*1.04*	2.98	2.48	1.99	1.49
0.92	1.63	1.36	*1.09*	0.82	2.51	2.09	1.67	1.25
0.91	1.30	*1.08*	0.86		2.08	1.73	1.39	*1.04*
0.90	*1.04*	0.87			1.77	1.48	1.18	0.89
0.89	0.85				1.52	1.27	*1.02*	
0.88	0.70				1.32	*1.10*	0.88	
0.87	0.53				1.15	0.96		
0.86	0.47				*1.01*			
0.85	0.39				0.88			

s.r.: Survival rate, p.r.: Pregnant rate

Now, the natural mortality rates were shown in previous section that 0.061 (survival rate is 0.939) in the case of one lamination age. This value satisfy the *R*-value even if pregnant rate is 0.30, and when pregnant rate is more than 0.30, the mortality rate is suitable for the continuance of the population size. On the other hand, the natural mortality rate in the case of two-laminations age is 0.127 (survival rate is 0.873). In this case *R*-value is lower than 1 when pregnant rate is lower than 0.50. Even if the pregnant rate is 0.60, *R*-value is 1.1. This value will be not safe for the continuance of population size, considering the higher mortality rate in the young stage.

Therefore, when the annual accumulation rate of ear plug is assumed to be two, the natural mortality rate calculated from age composition is too high for maintain the population size. On this point of view, the hypothesis of two-laminations age should be abandoned.

Purves & Mountford (1959) calculated the mortality rate from the age distribution based on ear-plug lamination on the fin whales in the Antarctic area I. And they got mortality coefficient. They are 0.133 in the female and 0.106 in the male. The figures are based on an assumed rate of formation of 2 laminations per year. Although Purves & Mountford did not consider the effect of whaling on the age distribution, they seem to recognize the figures show the natural mortality coefficient. The coefficient in the female is similar to my result in 2 laminations age.

Laws (1961) calculated the mortality rate from the age distribution based on number of corpora in the ovaries on the female fin whale in the Antarctic area II in pre-war period when, as he estimated, fishing mortality was relatively small. The mortality coefficient is 0.0973 corresponding to annual mortality rate of 9.2%. In the calculation, the annual accumulation rate of corpora is assumed to be 1.43. However, Doi (in press) calculates the natural mortality rate comparing the change of number of fin whales catch per unit effort between the Antarctic pre-war and post-war seasons independently to the age distribution. And he got the result that the natural mortality rate is 5–7%.

CALCULATION OF FISHING AND SURVIVAL RATE BY THE RECOVERY OF MARKED FIN WHALE

There are many undetermined factors for adaption of marking to population dynamics (Ricker, 1958). And I don't want to examine thoroughly the marking method for population dynamics. In this section, I examine the marking result only for check the fishing rate and total survival rate calculated by the age composition based on ear-plug laminations.

Table 12 shows the estimated number of fin whales marked in the north of east Aleutian Islands and number of whales recaptured among them during 1954 to 1962 seasons. Number of whales recaptured are variable according to the number of whales caught. Then, the number of whales recaptured are reviced assuming that 1000 whales are caught in every year. Number of whales marked (M) and recaptured (R) are so small that the average value is considered to be more suitable for the exmaination.

Survival rate S is estimated by following formula (Ricker, 1958):

$$S=\frac{R_1+R_2+\ldots\ldots R_n}{R_0+R_1+\ldots\ldots R_{n-1}}$$

The number of recaptured whales in the same year of marking have many discussable factors, so I consider the data of the recovery in the same season must be excluded for this calculation, so the formula is reviced as following:

$$S=\frac{R_2+R_3+\ldots\ldots R_n}{R_1+R_2+R_{n-1}}$$

The results are shown in Table 13. The calculated survival rate becomes more correct by the increment of elapsed years. In the last 4 cases in the table, survival rates are 79–86%.

The survial rate S calculated from age composition is 82.6% in the case of one lamination age, and 71.5% in the case of two laminations age. Then one lamination age corresponds to the result obtaned from marking experiments. And the survival rate attained from age composition of two laminations age is considered to be too high.

Fishing mortality rate is calculated briefly as follows:

$$f=\frac{R_0}{M}$$

They are 5.1% and 8.3% respectively in actual and reviced. But whaling and marking are operated almost parallelly in practice. So the twice of the calculated

TABLE 12. NUMBER OF FIN WHALES MARKED AND RECAPTURED IN THE NORTH OF EAST ALEUTIAN ISLANDS DURING 1954 TO 1962

Year	No. of whales marked	Elapsed years from marking till recapture										No. of whales caught
		0	1	2	3	4	5	6	7	8	Total	
A. Actual figure.												
1954	210	7									7	585
1955	33	2	7(1)								9(1)	1177
1956	57	—	1(1)	2							3(1)	773
1957	41	3(1)	—	6(3)	1						10(4)	601
1958	28	1	7(2)	1	1	1					11(2)	455
1959	15	4	1	3	3	—	5(2)				16(2)	705
1960	11	—	2	—	6	1(1)	1	1			11(1)	1066
1961	23	5	—	—	2(1)	1	1	1	2		12(1)	587
1962	6	—	2	1	1	1	—	—	—	—	5	284
Total	424	22(1)	20(4)	13(3)	14(1)	4(1)	7(2)	2	2	—	84(12)	6233
average	47.1	2.44	2.50	1.86	2.33	0.80	1.75	0.67	1.00	—		
B. Reviced figure when 1000 whales were caught in every year.												
1954	210	12.0									12.0	1000
1955	33	1.7	6.0								7.7	1000
1956	57	—	1.3	2.6							3.9	1000
1957	41	5.0	—	10.0	1.7						16.7	1000
1958	28	2.2	15.4	2.2	2.2	2.2					24.2	1000
1959	15	5.7	1.4	4.3	4.3	—	7.1				22.7	1000
1960	11	—	1.9	—	5.6	0.9	0.9	0.9			10.3	1000
1961	23	8.5	—	—	3.4	1.7	1.7	1.7	3.4		20.4	1000
1962	6	—	7.1	3.5	3.5	3.5	—	—	—	—	17.6	1000
Total	424	35.1	33.1	22.6	20.7	8.3	9.7	2.6	3.4	—	135.5	9000
average	47.1	3.91	4.14	3.23	3.45	1.66	2.42	0.87	1.70	—		

( ): Number of whales recaptured in other whaling areas or whales which were not known the position recaptured.

TABLE 13. TATOL SURVIVAL RATE OF MARKED FIN WHALES CALCULATED

Elapsed years (n)	1954–1957 Actual	1954–1957 Reviced	1954–1962 Actual	1954–1962 Reviced
2	0.800	0.841	0.744	0.780
3	0.852	0.794	0.961	0.906
4	0.684	0.678	0.757	0.771
5	*0.805*	*0.785*	0.912	0.862
6	—	—	0.811	0.781
7	—	—	*0.857*	*0.845*
Fishing mortality rate	0.062	0.102	0.111	0.194

f will become near the truth. Then, they are 10.2% and 16.6% respectively. As the data concerning recoveries in the same year of marking have many discussive factors, the following formula (Ricker, 1958) are suitable for this purpose:

$$f=\frac{R_1+R_2+\ldots\ldots+R_n}{SM(1+S+\ldots\ldots S^{n-2})}$$

The results calculated from above formula is:

	1954–1957		1954–1962	
	Actual	Reviced	Actual	Reviced
S	0.805	0.785	0.857	0.845
f	0.062	0.102	0.111	0.194
D	0.133	0.113	0.032	−0.029

Fishing mortality rates are situated between 0.062 and 0.194. The calculated fishing mortality rates from age compositions are 0.113 and 0.158 respectively in one lamination age and two laminations age. The former rate corresponds to reviced result of 1954–1957 and actual result of 1954–1962. And the latter is near the result of reviced data 1954–1962. However, in the latter case the natural mortality rate obtained from marking experiment is smaller than 0 (–0.029). This cannot explain the actual phenomena, because the natural mortality rate should be more than 0. Therefore the fishing mortality rate of 0.194 is higher than the actual states of the whaling. Then, the one-lamination age agrees more with examination of fishing mortality rate from marking than the two laminations age.

CHANGE OF MATURITY RATE ACCOMPANIED WITH WHALING

Sexual maturity rate changes accompaniing with the increasement of whaling years. Table 14 and Fig. 12 show the change of maturity rate of female fin whales caught in the north of east Aleutian Islands from the begining of whaling in 1954 to 1961. The rate decrease by the increasement of years.

Now, taking following two model-age-compositions, and the change of sexual maturity rate are calculated from the begining of whaling in Table 15.

	Model I (One lamination age)	Model II (Two laminations age)
Natural mortality rate	0.061	0.127
Fishing mortality rate	0.113	0.158
No. of whales in O year class	10,000	10,000
Age at sexual maturity	10	5
Age at recruitment for whaling	7	3
No. of whale caught before racruitment	No. of whales in age 7×2	No. of whales in age 3×1

In Model I, number of mature females at the begining of whaling is 87,363. If a quater of the mature females is the number of female whales which are born, the number is 21,841. Whereas the first assumption of females which are born is 10,000. From this calculation we can recognize that the natural mortality rate in young stage is fairly large. By the way, in Model I, whaling does not influence to the recruitment at least until 7th years after the beginin of whaling. In practice, there are whales caught before the age at recruitment for whaling, as shown Table 15, so, I assumed the whales as the twice of the number of whales at the age of recruitment (12,873). In Fig. 12, the change of maturity rate of Model I is similar to the actual change of the maturity rate.

TABLE 14. ACTUAL NUMBER OF SEXUALLY MATURE AND IMMATURE FEMALE FIN WHLES CAUGHT IN THE NOTH OF EAST ALEUTIAN ISLANDS DURING THE SEASONS FROM 1954 TO 1961.

Year	Immature	Mature	Mature rate (%)
1954	80	224	73.7
1955	166	395	70.4
1956	103	269	72.3
1957	70	140	66.7
1958	77	64	45.4
1959	153	204	57.1
1960	223	337	60.2
1961	135	160	54.2
Total	1007	1793	64.0

TABLE 15. CALCULATED NUMBER OF TOTAL AND MATURE FEMALES CAUGHT IN THE CASES OF MODELS-I AND -II.

Model-I: D=0.061, E=0.113 (One-lamination age).

Year	Total	Mature	Mature rate (%)
1st	118391.2	87362.6	73.8
2nd	106468.8	76849.9	72.2
3rd	96621.9	67601.8	70.0
4th	88483.7	59465.6	67.2
5th	81765.2	52747.1	64.5
6th	76287.7	47269.6	62.0
7th	71589.8	42611.7	59.5
8th	67842.9	38824.8	57.2

Model-II: D=0.127, E=0.158 (Two-laminations age).

Year	Total	Mature	Mature rate (%)
1st	59041.4	39926.6	67.6
2nd	50764.8	32701.1	64.4
3rd	44846.8	26782.7	59.7
4th	<40614.8	22551.0	>55.5
5th	<37589.3	19525.5	>51.9
6th	<35425.8	<17362.0	>49.0
7th	<33879.4	<15815.6	>46.7
8th	<32773.1	<14709.3	>44.9

However, in model II, even in the virgin stock, the number of whales born is lower than the firstly assumed number of whales born which can maintain the population size. Then the whaling will influence to the number of recruitment for whaling after 3 years.

Assuming the number of whales caught before the age of recruitment to be as the same as number of whales at the age of recruitment, the maturity rates are lower than the actual figures.

After 3 years from the start of whaling, the number of recruit becomes to be smaller than the virgin stock. Then, as the number of immature whales become relatively smaller, the maturity rate must be higher than the calculated rate. In Fig. 12, the estimated changes of maturity rate are shown. This estimated change in Model II does not correspond the feature of the actual data.

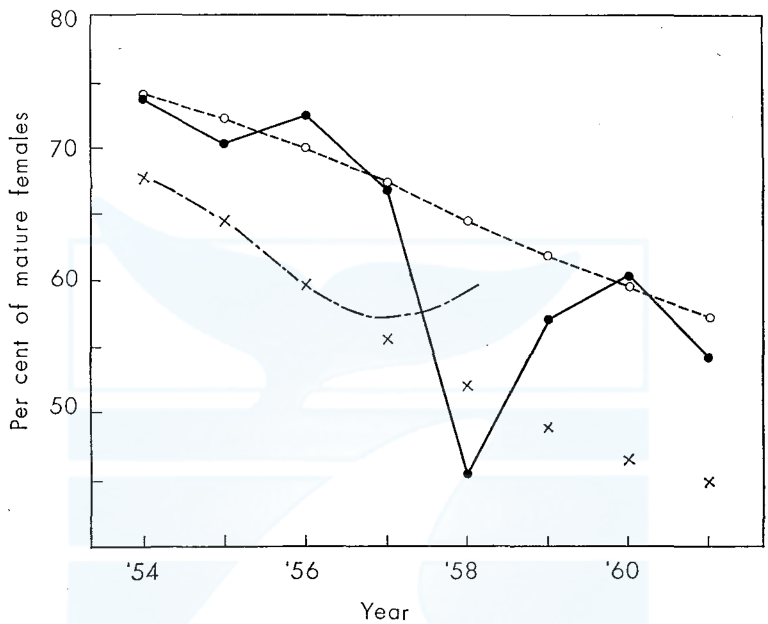

Fig. 12. Change of sexual maturity rate of the female fin whales for actual and two models. Open circle and straight line: Actual data from the female fin whales caught in the north of east Aleutian Islands, Closed circle and solid line: Model I, Cross and broken line: Model II.

In conclusion, the actual change of maturity rate correspond fairly with Model I (the accumulation rate is one annually), but those of which Model II is not consistent with the actual change.

DISCUSSION

By some examinations which were described above, I conclude that the annual ear-plug accumulation rate must be under two which is nowaday recognized by us, and I showed some examples for estimation that the annual accumulation rate may be near one.

Indeed, ear plug is the best of age characters in the fin whale, but there are many points which must be investigated further. One of them is a standardization of lamination count. As Ichihara (1963) reported, there is individual discrepancy in lamination count. And the photometric method which Ichihara (1963) manufactured for trial must be developed further for this purpose. When standardization of ear plug reading is estabished, and if the new reading becomes different to the present reading, the above examinations should be re-examineed. The second point to be investigated in future is the periodicity of laminae formation. Purves (1955) considered the migratory period as the relation of laminae formation. However, Clarke (1962) reported the feeding of fin whales off the coast of Chile in October and November. And according to Mackintosh (1942) and Nemoto (1962), food of whales are scanty in the lower latitude, and the baleen whales do not feed so much in winter season. If the mechanism of formation of ear-plug lamination is coincided to the nutrition, the formation of ear-plug lamination must have more relation with the winter (reproductive season) or summer (feeding season) than the migratory seasons. Ridges of baleen plates are also considered to have relation with nutrition (Ruud, 1940, 1945). If so, the periodicity of formation of ear-plug lamination and ridges of baleen plates should be the same each other. My result of correlation between baleen ridges and ear-plug lamination briefly support on the same mechnaism of formation between two characters. On the lamination formation, Purves & Mountford (1959) and Ichihara (1959) discribed on possiblity as shown in Introduction. Furthermore, Mr. Ichihara suggests me the possibility of the change of periodicity of ear-plug lamination by the age. We must investigate the formation mechanism of ear-plug lamination. Then the factors conserning the formation of laminae will be known, and it will be solved the annual rate and whether the periodicity of formation are variable or constant.

My second conclusion is on the annual ovulation rate of the fin whale. The rate must be less than 1.4 which as Laws (1961) studied throughly. I got a result that it may be near 0.5 although there are individual variations and the difference among the different stocks as shown by Nishiwaki, Ichihara & Ohsumi (1958) and Fujino (1963), and Kimura (1956) reported the tendency of multiple ovulations in the course of increase of age by ths study of twinning.

The annual ovulation rate is very important not only for the age determination but also for the reproductive physiology of the whales. According to my result, the fin whale ovulates in average one every two years. Then pregnancy rate may be under 50%, because there are evidence that some corpora albicantia are non-pregnant (Laws, 1961). Apparent pregnancy rate is 55% in my material, but I consider that they are higher than the true rate. Although Laws (1961) considered that over 80% of females wean their calves before they enter the pelagic whaling grounds, Chittleborough (1958) reported that the weaning period of humpback whales is 10 months. And there are other observations on the suckling of dolphins. According to Tavolga & Essapian (1957) and Nakajima et al. (1962), bottlenose dolphin (*Tursiops sp.*) suckles for over 1 year in aquarium. Although we have no data on direct observation of weaning period in the fin whale and above data are given by other species, I think the lactating stage of the fin whale will be longer than previous descriptions (Mackintosh & Wheeler, 1929; Laws, 1961). Mackintosh & Wheeler (1929) suggest that for the nursing period the lactating females are segregated from the main herds, so that all lactating females do not appear on the whaling grounds. And in the whaling grounds, the taking of calves or females accompanied with calves are prohibited by the International Whaling Convention. Therefore, the pregant rate calculated by actual data are considered to be higher than the true rate.

Concerning this subject, Laurie (a letter to Purves & Mountford, 1959) also discussed and he wrote, if so, annual increment of corpora in the blue whale must be lower than 1.13 and connected as 0.69. Further ecological knowledges are need on this problem. I think that the two-years breeding cycle will be common in the fin whale, but there will be some individuals whose breeding cycle is more than two years.

In the examination on the relation between ear-plug laminations and baleen plate ridges, there are some material which are not able to explain by the correspondence one to one. The number of ridges is more than the number of ear-plug lamination. As one of the caution, the discount of ear-plug lamination or baleen ridges is considerable, but more collection and comparison are needed on this subject especially on the calves.

SUMMARY

1. Age determination of the fin whale (*Balaenoptera physalus* L.) was examined by some methods.

2. Considering the elapsed time from marking, the annual accumulation rate of ear-plug lamination of marked whales recaptured should be less than two, and there is no whale of which number of ear-plug lamination devided by elapsed years is less than one.

3. Sexually immature rate of recaptured whales decrease with the increasement of elapsed years. And from the tendency of the decrease of immature rate, the age at sexual maturity is estimated to be about 10 years.

4. Numbers of corpora lutea and albicantia in the ovaries of recaptured fin whales devided by elapsed years are able to be explained more easily in the assumed case which the annual ovulation rate is 0.5, and age at sexual maturity is 10 years.

5. Relation between the ear-plug lamination and mean number of corpora shows that annual accumulation rate of corpora is 0.49 in the fin whales caught in the Antarctic areas IV and V, if one lamination accumulates in a year.

6. Percentage of sexual maturity in successive the number of ear-plug lamination shows that the number of ear-plug lamination corresponding to 50% of sexual maturity is 9.4 in males and 10.7 in females.

7. Before the tip of baleen plates begin to wear, number of ear-plug lamination coincide the number of ridges on baleen plates.

8. Age compositions of the female fin whales caught in the north of east Aleutian Islands based on ear-plug lamination are drawn in following two cases. And the natural mortality rate (D) fishing mortality rates (E) and total mortality rate (Z) are calculated as follows:

Annual rate	Z	D	E
One lamination	0.174	0.061	0.113
Two laminations	0.285	0.127	0.158

9. In the virgin stock, relation between natural mortality rate and recruit rate is discussed. And natural mortality rate in the case of two laminations age is considered to be too high for maintainance of the stock size.

10. Examining the number of fin whales marking and recovery in the north of east Aleutian Islands, survival rate is calculated to be 79~86%. And the fishing mortality rate is also calculated from the data. It is 10–12%.

11. Yearly change of sexual maturity among the actual, Models I and II populations are compared. And the change of Model I (annual rate is one lamination) is suitable to the actual change. On the contrary, Model II (annual rate is two laminations) is not able to explain the actual change.

12. Thinking collectively above examinations, it will be concluded that the annual accumulation rate of ear-plug lamination must be less than two, probably near one, and average annual ovulation rate will be under one, probably near 0.5, although there are individual and racial variations. In addition, the average age at sexual maturity will be older than 5 years, probably 9~11 years. Of course there are individual variation in the age of sexual maturity.

13. The standardization of the reading of ear-plug lamination should be established, and after then above examinations must be re-examined.

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REFERENCES

Brown, S. G. (1962 a). The movements of fin and blue whales within the Antarctic Zone. *Discovery Rpts.* 33: 1–54.

—— (1962 b). Whale marks recovered during Antarctic seasons 1960/61, 1961/62 and in South Africa 1962. *Norsk Hvalfangst-Tid.*, 51 (11): 429–34.

Chittleborough R. G. (1958). The breeding cycle of the female humpback whale, *Megaptera nodosa* (Bonnaterre). *Aust. J. Mar. Freshw. Res.*, 9 (1): 1–18.

—— (1959 a). Australian marking of humpback whales. *Norsk Hvalfangst-Tid.*, 48 (2): 47–55.

—— (1959 b). Determination of age in the humpback whale, *Megaptera nodosa* (Bonnaterre). *Aust. J. Mar. Freshw. Res.* 10 (2): 125–43.

—— (1960). Marked humpback whale of known age. *Nature* 187: 164.

Chittleborough, R. G. & Godfrey, K. (1957). Review of whale marking and some trials of a modified whale marks. *Norsk Hvalfangst-Tid.*, 46 (5): 485–508.

Clarke, R. (1962). Whale observation and whale marking off the coast of Chile in 1958 and from Ecuador towards and beyond the Garapagos Islands in 1959. *Norsk Hvalfangst-Tid.*, 51 (7): 265–87.

Clarke, R. & Brown, S. G. (1957). International co-operation in Antarctic whale marking from 1945 to 1957. *Norsk Hvalfangst-Tid.*, 46 (9): 513–7.

Dawbin, W. H. (1959a). Evidence on growth-rates obtained from two marked humpback whales. *Nature* 183: 1749–50.

—— (1959 b). New Zealand and South Pacific whale marking and recoveries to the end of 1958. *Norsk Hvalfangst-Tid.*, 48 (5): 213–38.

Doi, T. (1964). Estimation of coefficient of natural mortality rate of fin whale population in the Antarctic. *Bull. Tokai Reg. Fish. Res. Lab.*, 38 (In press)

Fujino, K. (1960). Immunogenetic and marking approaches to identifying subpopulations of the North Pacific whales. *Sci. Rep. Whales Res. Inst.*, no. 15: 85–142.

—— (1963). Population genetics of whales with reference to blood types. *Bull. Jap. Soc. Sci. Fish.* 29 (12): 1133–8

Hylen, A., Jonsgard, A., Pike, G. C. & Ruud, J. T. (1955). A preliminary report on the age composition of Antarctic fin whale catch 1945/46 to 1952153 and some reflections on total mortality rates of fin whales. *Norsk Hvalfangst-Tid.*, 44 (10): 577–89.

Ichihara, T. (1959). Formation mechanism of ear plug in baleen whales in relation to glove-finger. *Sci. Rep. Whales Res. Inst.*, no. 14: 107–135.

—— (1963). Photometric method for counting laminae in ear plug of baleen whale. *Sci. Rep. Whales Res. Inst.*, no 17: 37–48.

—— (1964). Prenatal developement in ear plug of baleen whale. *Sci. Rep. Whales Res. Inst.*, no. 18: 29–48

Kimura, S. (1957). The twinning in southern fin whales. *Sci. Rep. Whales Res. Inst.*, no. 12: 103–25.

Laurie, A. H. (1937). The age of female blue whales and the effect of whaling on the stock. *Discovery Repts.* 15: 223–84.

—— (1959). See Purves & Mountford (1959).

Laws, R. M. (1960). Problems of whale conservation. *Trans. N. Amer. Wildlife Conf.* 25: 304–19.

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

Laws, R. M. & Purves, P. E. (1956). The ear plug of the Mysticeti as an indication of age with special reference to the North Atlantic fin whale. *Norsk Hvalfangst-Tid.*, 45 (8): 413–25.

Mackintosh, N. A. (1942). The southern stocks of whalebone whales. *Discovery Repts.* 22: 197–300.
Mackintosh, N. A. & Wheeler, J. F. G. (1929). Southern blue and fin whales. *Discovery Repts.* 1: 257–540.
Nakajima, M., Takahashi, K., Ogura, M. & Sawaura, K. (1963). On the growth of infants of the small size toothed whales. *J. Jap. Zoo and Aquarium.* 5 (1): 16–22 (In Japanese)
Nemoto, T. (1962). (Food of baleen whales) *Geiken Soshyo* no. 4: 136 pp. (In Japanese)
Nishiwaki, M. (1950a). Determination of the age of Antarctic blue and fin whales by the colour changes in crystalline lens. *Sci. Rep. Whales Res. Inst.*, no. 4: 115–61.
—— (1950 b). Age characteristics in baleen plates. *Sci. Rep. Whales Res. Inst.* no. 4: 162–83.
—— (1951). On the periodic mark on the baleen plates as the sign of annual growth. *Sci. Rep. Whales Res. Inst.*, no. 6: 133–52.
—— (1952). On the age-determination of Mystacoceti, chiefly blue and fin whales. *Sci. Rep. Whales Res. Inst.*, no. 7: 87–119.
—— (1957). Age characteristics of ear plugs of whales. *Sci. Rep. Whales Res. Inst.*, no. 12: 23–32.
Nishiwaki, M. & Yagi, T. (1953). On the age and the growth of teeth in a dolphin (*Prodelphinus caeruleo-albus*) (1). *Sci. Rep. Whales Res. Inst.*, no. 8: 133–46.
Nishiwaki, M., Ichihara, T. & Ohsumi, S. (1958). Age studies of fin whales based on ear plug. *Sci. Rep. Whales Res. Inst.*, no. 13: 155–69.
Ohsumi, S. (1962). Biological material obtained by Japanese expedition from marked fin whales. *Norsk Hvalfangst-Tid.*, 51 (5): 192–8.
Ohsumi, S., Nishiwaki, M. & Hibiya, T. (1958). Growth of fin whales in the northern Pacific. *Sci. Rep. Whales Res. Inst.*, no. 13: 97–133.
Ohsumi, S., Kasuya, T. & Nishiwaki, M. (1963). The accumulation rate of dentinal growth layers in the maxillary tooth of the sperm whale. *Sci. Rep. Whales Res. Inst.*, no. 17: 15–35.
Omura, H. (1955). Whales in the northern part of the North Pacific. *Norsk Hvalfantst-Tid.*, 44 (6): 323–45, 44 (7): 395–405.
Omura, H. & Kawakami, T. (1956). Japanese whale marking in the North Pacific. *Norsk Hvalfangst-Tid.*, 45 (10): 555-63.
Peters, N. (1939). Über Grösse, Wachstum und Alter des Blauwales (*Balaenoptera musculus* (L)) und Finnwales (*Balaenoptera physalus* (L)). *Zool. Anz.* 127: 193–204.
Purves, P. E. (1955). The wax plug in the external auditory meatus of the Mysticeti. *Discovery Repts.* 27: 293–302.
Purves, P. E. & Mountford, M D. (1959). Ear plug laminations in relation to the age composition of a population of fin whales (*Balaenoptera physalus*). *Bull. British Mus. (H.N.). Zool.* 5 (6): 6–161.
Rayner, G. W. (1940). Whale marking. Progress and results to December 1939. *Discovery Repts.* 19: 245–84.
Ricker, W. E. (1958). Handbook of computations for biological statistics of fish populations. *Bull. Fish. Res. Board Canada* no. 119: 300 pp.
Ruud, J. T. (1940). The surface structure of the baleen plates as a possible clue to age in whales. *Hvalradets Skrifter* nr. 23: 24 pp.
—— (1945). Further studies on the structure of baleen plates and their application to age determination. *Hvalradets Skrifter* nr. 29: 69 pp.
Ruud, J. T., Clarke, R. & Jonsgard, A. (1953). Whale marking trials at Steishamn, Norway. *Norsk Hvalfangst-Tid.*, 42 (8): 429–41.
Sergeant, D. E. (1959). Age determination in Odontocete whales from dentinal growth layers. *Norsk Hvalfangst-Tid.*, 48 (6): 273–88.
—— (1962). The biology of the pilot or pothead whale, *Globicephala melaena* (Traill) in Newfoundland waters. *Bull. Fish. Res. Board Canada* no. 132: 84 pp.
Tavolga, M. C. & Essapian F. S. (1957). The behavior of the bottle-nosed dolphin (*Tursiops truncatus*): Mating, pregnancy, parturition and mother infant behavior. *Zoologica* 42 (1): 11–31.
Tomilin, A. G. (1945). (The age of whales as determined from their baleen apparatus). *C. R. Acad. Sci. Dokl. Acad. Nauk.. SSSR.* 49 (6): 460–3.
Wheeler, J. F. G. (1930). The age of fin whales at physical maturity. *Discovery Repts.* 2: 403–34.