

Length and Growth of the Porbeagle (*Lamna nasus*, Bonnaterre) in the North West Atlantic

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I. INTRODUCTION

The data considered in this paper were collected by the present author aboard a commercial fishing vessel operating with pelagic long lines for porbeagle in the North West Atlantic. The long lines were shot in altogether 52 localities scattered over the area with an average number of 500 hooks in a shot. The effective fishing depth was generally 10—30 m. In all, 2488 porbeagle were caught. Of these 2066 fish were sampled. Fig. 1 shows the area of operation with some of the principal fishing grounds.

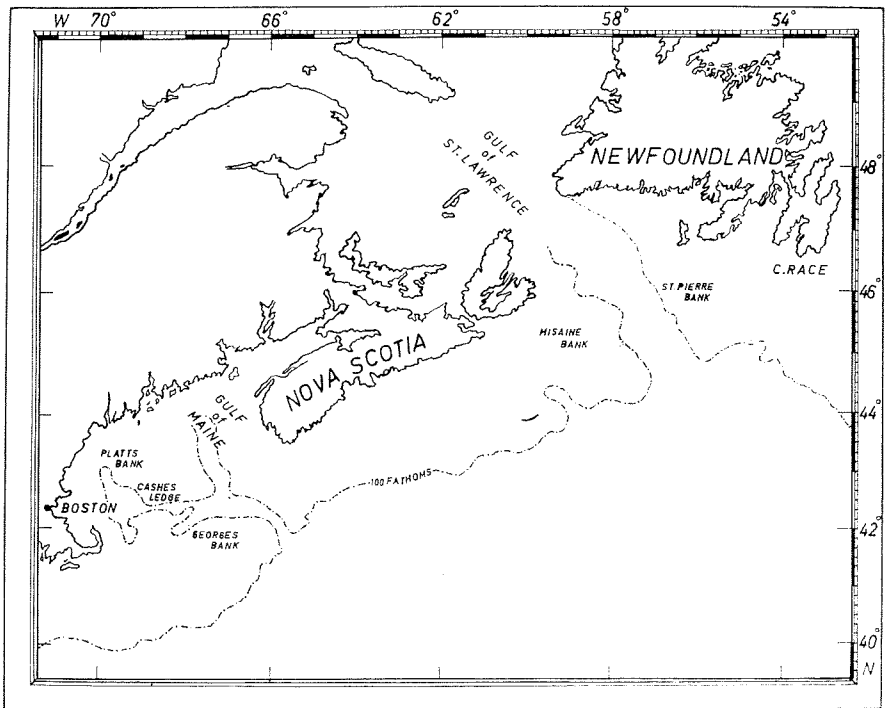


Fig. 1. The fishing area.

II. THE LENGTH

1. *Dorsal length*

It proved impractical, if not impossible, to measure the total length of any great number of fish during the fishing operations. To circumvent this difficulty, only the "dorsal length" was recorded in the majority of the measurements. This "dorsal length" was chosen because one single observer could operate both quickly and precisely without hampering the fishermen's work during the hauling of the line. A further advantage is that the measurement can be performed also after the fish is gutted, beheaded, and the fins cut off. The "dorsal length" (l) is, by definition, the length from the anterior edge of the first dorsal fin at the base to the anterior edge of the pre-caudal pit (Fig. 2).

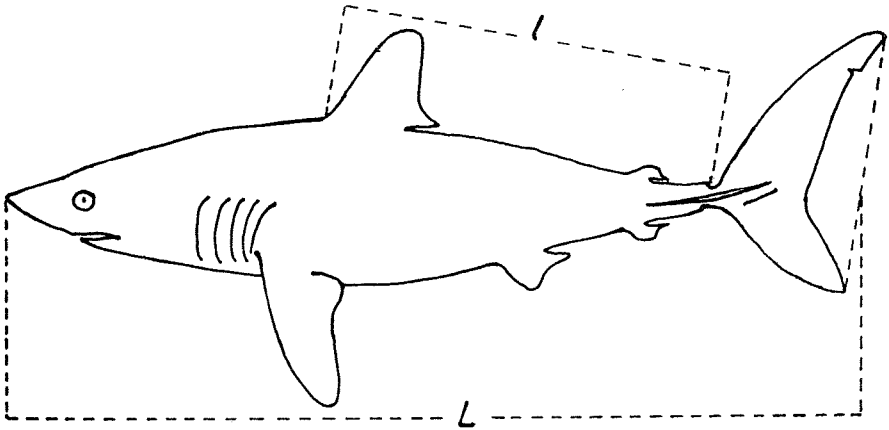


Fig. 2. Total length (L) and dorsal length (l). For further explanation see text.

Several days with good fishing elapsed before a workable routine could be established, and these catches were but poorly sampled. For the rest, however, the dorsal length was recorded for every fish going into the freezer. When arranging the material, neighbouring localities are considered as sub-areas (named after the nearest principal fishing ground) and tabulated separately. Table 1 shows the frequency distributions of l in 3 cm groups, separately for males and females. In addition to the 1810 measurements entered in Table 1, the dorsal lengths of 55 fish for which the sex was not determined, were recorded.

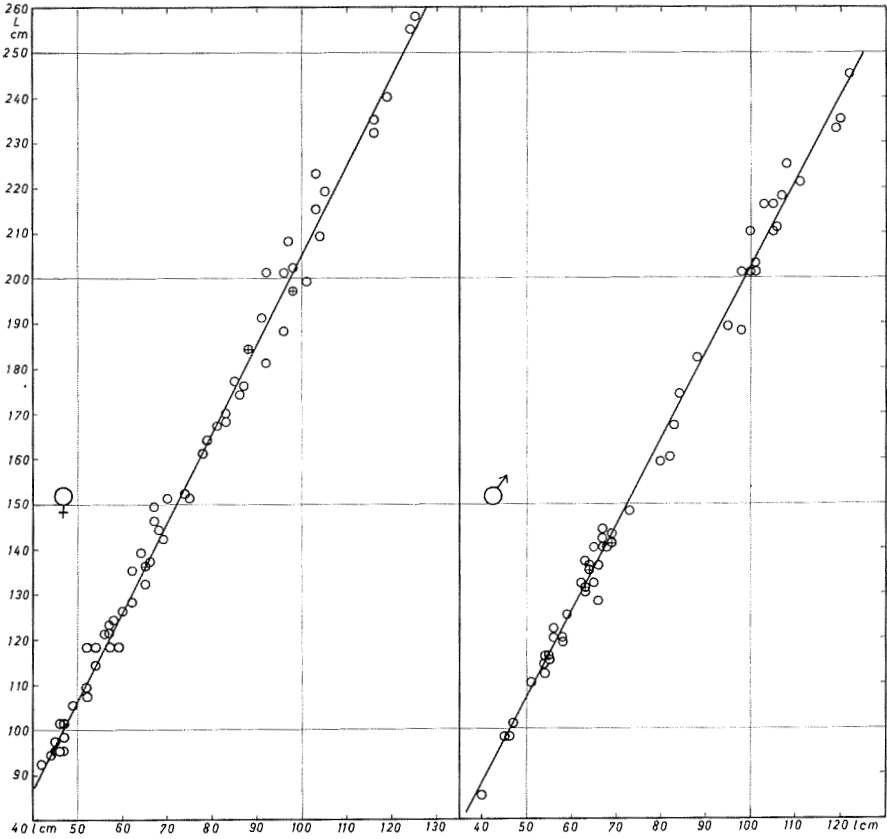


Fig. 3. The correlation of total length (L) and dorsal length (l). Circles: observation points. Circles with cross denote 2 observations in the same point.

2. Correlation between dorsal length and total length

In order to obtain data for calculation of the total length (L) from the dorsal length, both L and l were recorded in 122 fish (Table 2). L was measured as the length of the axis from the tip of the snout to a line drawn between the tips of the upper and lower lobe of the caudal fin (Fig. 2). Both measurements were read to the nearest cm using a steel measuring tape.

The close correlation between L and l is demonstrated in Fig. 3. Obviously, the relationship is linear. The regression is calculated from the data set forth in Table 2 where also the sums of L and l and their squares and cross products are entered separately for males and females.

Writing the regression in the form (Fisher, 1948):

$$L = a + b(l - \bar{l}) \quad (1)$$

Table 2. Corresponding measurements of total length (*L*) and dorsal length (*l*). North West Atlantic, July—August 1961. (*Lamna nasus*).

Date	Sex	<i>L</i> cm	<i>l</i> cm	Date	Sex	<i>L</i> cm	<i>l</i> cm	Date	Sex	<i>L</i> cm	<i>l</i> cm
14 July	♀	184	88	21	♀	118	59	3	♂	148	73
14	♀	107	52	21	♂	131	63	3	♂	144	67
14	♂	159	80	21	♂	120	58	3	♂	135	64
14	♀	223	103	22	♀	139	64	3	♀	167	81
14	♀	197	98	22	♂	114	54	3	♂	132	65
15	♀	184	88	22	♂	125	59	3	♀	114	54
15	♀	201	92	22	♂	142	67	5	♀	123	57
15	♂	141	69	22	♀	126	60	5	♂	116	55
15	♂	160	82	24	♀	168	83	6	♀	132	65
15	♀	177	85	24	♂	167	83	6	♀	101	46
16	♀	95	45	24	♂	188	98	6	♀	136	65
17	♀	235	116	24	♂	210	100	6	♀	105	49
17	♂	112	54	24	♀	181	92	6	♀	124	58
17	♀	199	101	24	♂	201	98	7	♂	182	88
17	♂	189	95	24	♀	144	68	7	♀	95	46
17	♀	128	62	24	♀	170	83	7	♂	140	65
17	♀	109	52	24	♂	174	84	8	♂	116	54
18	♀	215	103	24	♀	146	67	13	♀	98	47
18	♀	208	97	24	♂	225	108	16	♀	255	124
18	♀	202	98	25	♂	216	105	16	♂	98	45
18	♀	209	104	26	♂	141	69	17	♀	191	91
18	♂	201	101	26	♂	130	63	18	♀	219	105
18	♂	115	55	26	♂	135	64	19	♀	240	119
20	♀	136	65	26	♀	188	96	19	♀	258*	125
20	♂	201	100	27	♀	151	75	19	♀	101	47
20	♀	232	116	27	♀	149	67	20	♀	197	98
20	♀	164	79	27	♀	121	57	20	♀	161	78
20	♂	216	103	27	♀	121	56	21	♀	201	96
20	♀	118	52	27	♀	118	54	21	♀	174	86
20	♀	95	47	27	♂	137	63	22	♂	203	101
21	♂	245	122	27	♂	143	69	22	♂	235	120
21	♂	210	105	27	♂	120	56	23	♀	176	87
21	♂	221	111	27	♂	136	64	25	♂	101	47
21	♂	233	119	27	♂	140	68	25	♀	92	42
21	♂	211	106	27	♂	140	67	26	♀	137	66
21	♂	218	107	30	♂	131	63	26	♀	135	62
21	♂	110	51	3 Aug.	♀	151	70	30	♂	98	46
21	♀	118	57	3	♀	152	74	30	♀	97	45
21	♀	142	69	3	♂	136	66	30	♀	94	44
21	♂	119	58	3	♂	122	56	30	♂	85	40
21	♂	128	66	3	♂	132	62	Number		122	122

Σ	Sex	<i>L</i> cm	<i>l</i> cm	<i>L</i> ²	<i>l</i> ²	<i>Ll</i>	<i>n</i>	Mean	
		<i>L</i> cm	<i>l</i> cm					<i>L</i> cm	<i>l</i> cm
	♀	10 144	4 877	1 713 370	398 999	826 440	65	156.062	75.031
	♂	8 878	4 321	1 482 570	354 925	725 059	57	155.754	75.807

* See footnote p. 33 and Plates I and II.

the value of a will be equal to the average length of L : $a = \frac{S(L)}{n}$ or $a_m = 155.754$ cm and $a_f = 156.062$ cm where the indices m and f refer to males and females respectively. The estimate of b is the ratio of the covariance to the variance of the l distribution ($n-1$ falls out): $b = \frac{S(Ll) - n\bar{L}\bar{l}}{S(l^2) - n\bar{l}^2}$ or $b_m = 1.9020$ and $b_f = 1.9752$. The sampling variances of a and b are $V(a) = \frac{\sigma^2}{n}$ and $V(b) = \frac{\sigma^2}{S(l - \bar{l})^2}$. The value of σ^2 is estimated by summing the squares of the differences between the observed L and the calculated L_c and dividing by the degrees of freedom: $s^2 = \frac{1}{n-2} S(L - L_c)^2$. The sum of the squared deviations may also be found from the equation:

$$S(L - L_c)^2 = S(L - \bar{L})^2 - b^2 S(l - \bar{l})^2 \quad (2)$$

The values of s^2 are found to be: $s_f^2 = 19.79$, $s_m^2 = 14.43$, and the total: $s^2 = 17.29$. From this is calculated the t of the difference between the means and of the difference between b_f and b_m : $t = \frac{a_f - a_m}{s} \sqrt{\frac{n_f \cdot n_m}{n_f + n_m}} = 0.408$, and $t = \frac{b_f - b_m}{s} \sqrt{\frac{S_f(l - \bar{l})^2 \cdot S_m(l - \bar{l})^2}{S_f(l - \bar{l})^2 + S_m(l - \bar{l})^2}} = 2.16$.

In the first instance is found: $0.6 < P < 0.7$ and the difference between the mean total lengths is not significant. On the other hand, the difference ($b_f - b_m$) must be judged significant since $0.02 < P < 0.05$. From this analysis two important biological facts emerge: Firstly, the average growth rate is the same for males and females, and secondly, the relative position of the first dorsal fin is different in males and females, the males having the longer average dorsal measurement. It is also seen that the variability in position of the first dorsal fin is greater for the females. This does not by any means invalidate the technique of estimating the total length by measurement of the dorsal length. The sampling variance of (1) is: $V(L) = \sigma^2 \left[\frac{1}{n} + \frac{(l - \bar{l})^2}{S(l - \bar{l})^2} \right]$. From this it is seen, that in a sample of say 100 fish with a standard deviation of 15 cm, the errors introduced by measuring the dorsal lengths and using the regression to estimate the total lengths, are for the mean L : $\sigma \pm 0.38$ cm and $\sigma \pm 0.44$ cm, while the standard errors of the mean, inherent in the sample $\left(b \frac{15}{\sqrt{n}} \right)$, are: $\sigma \pm 2.35$ cm and $\sigma \pm 2.96$ cm. The precision of the estimates for L is lessened proportionally to the square of the distance

of l from \bar{l} . At the point $l - \bar{l} =$ twice the standard deviation (i.e. 30 cm) the errors would be: $\sigma \pm 0.85$ cm and $\varphi \pm 1.00$ cm.

These figures serve to demonstrate the practicability of the method of measuring the dorsal length and calculating the total length by means of a regression formula which is also manifest from the high value of the correlation coefficient: $r = \frac{S(Ll)}{\sqrt{S(L^2) S(l^2)}}$ which is found to be: $r = 0.9995$. for both males and females. The two regressions are:

$$\begin{aligned} \sigma L &= 155.754 + 1.9020(l - 75.807) \\ \varphi L &= 156.062 + 1.9752(l - 75.031) \end{aligned} \quad (3)$$

or for practical purposes:

$$\sigma L = 1.90 l + 12 \quad \text{and} \quad \varphi L = 1.98 l + 7$$

3. Total length

Owing to the fact that the smaller fish (below 150 cm, $l < 72$ cm)¹ obtain a lower price in the market, the fishermen tend to avoid grounds where small fish are caught. The smallest fish (less than 115 cm, $l < 54$ cm)¹ are not marketable and are generally thrown back into the sea. An unfortunate consequence of these circumstances is that a sample of the commercial catch will not, as a rule, give wholly reliable information about the composition of the stock. In the present case, however, it is possible to correct this bias to some extent, since all the fish not going into the freezer were given over to the fisheries biologist for dissecting and closer examination. In addition, 92 fish were tagged and liberated on various localities. For the tagged and the examined fish all total lengths were recorded (Table 3).

Returning to the measurements of the dorsal lengths, these may now be transformed into total lengths by means of (3) and the frequency distributions corrected according to Table 3. The relevant data are presented in Table 4. The calculations of n , range, and mean are straight-forward and need no explanation. The procedure of pooling two samples, with known variances and means, is given by the formula:

$$(n_1 + n_2 - 1)\sigma^2 = (n_1 - 1)\sigma_1^2 + (n_2 - 1)\sigma_2^2 + \bar{L}_1^2 n_2 + \bar{L}_2^2 n_1 - \bar{L}(\bar{L}_1 n_1 + \bar{L}_2 n_2) \quad (4)$$

where the indices 1 and 2 denote the original distributions and \bar{L} the mean in the grand sample with variance σ^2 . This is, in fact, equivalent to the method used in building the corresponding Analysis of Variance (Fisher, 1948). If the index 1 denotes the directly sampled fish, \bar{L}_1 and

¹ These limits are actually set by the gutted weight: < 25 kg and < 10 kg.

σ_1^2 are obtained from Table 3. \bar{L}_2 is calculated from the mean dorsal length (Table 1) by means of (3) and σ_2^2 according to (2). Since σ_2^2 is calculated from a transformed distribution, $(n_2 - 1)$ in (4) must be entered with $(n_2 - 2)$ and $(n_1 + n_2 - 1)$ with $(n_1 + n_2 - 2)$. \bar{L} is calculated as the weighted mean of \bar{L}_1 and \bar{L}_2 . Each item in (4) is now easily calculable and from the estimated value of σ^2 the standard deviation and the standard error of the mean in the new distribution are found.

From the beginning of July to the beginning of August, the catches were taken in the Gulf of Maine region. On the Nova Scotian Shelf proper no porbeagle was caught, but on either side of what may be termed the "entrance" to the Gulf of St. Lawrence (Misaine Bank, St. Pierre Bank), the species was again met with in some abundance although the catches were on an average smaller than in the Gulf of Maine. The fishery in the eastern region took place from the middle of August to the beginning of September. Table 4 shows that the average length of the porbeagle increases from the West to the East within the area which is also borne out from the statistics of the commercial part of the catch (Table 1). An analysis of the variances (σ^2) in Table 4 shows significant aberrations between the means ($F=8.10$, $P < 0.01$).

That the fish were concentrated in two main regions about 400 nautical miles apart does not necessarily mean that there are two separate populations, in spite of the differences between the means. In fact, a tagged fish, liberated at Platts Bank in July 1961 and recaptured near Cape Race in September of the same year (Aasen, 1962) indicates a common stock with migratory habits. Later recaptures on the Nova Scotian Shelf (Halifax) and in the Gulf of St. Lawrence from the same tagging region point to the same conclusion. If this is so, the differences in the length distributions must be caused by segregation or in other words: the migration pattern for the smaller fish is different from that of the larger ones. Judged from the success of the fishery, the migration from the Gulf of Maine began in early August when the catches decreased conspicuously in that region.

The importance of these observations on the porbeagle in the North West Atlantic is augmented by the fact that this stock has virtually been a virgin one, from a fisheries point of view, until the summer of 1961. It would appear that here a unique opportunity is offered to study the effects of the fishery on a population from the beginning of its exploitation. Provided that the composition of the catch presents a reasonably accurate picture of the stock composition, the grand total in Table 4 will be an overall estimate of the length frequency distribution of the porbeagle in the North West Atlantic in the unexploited phase. The 55 fish for which the sex was not determined, are excluded from this total.

Table 3. Frequency distributions of total length (*L*) for the tagged and the examined fish. North West Atlantic, July—September 1961. (*Lamna nasus*).

<i>L</i> cm	1 Platts Bank			2 Cashes Ledge			3 Georges Bank			4 Misaine Bank			5 St. Pierre Bank			6 Grand Total		
	♀	♂	<i>T</i>	♀	♂	<i>T</i>	♀	♂	<i>T</i>	♀	♂	<i>T</i>	♀	♂	<i>T</i>	♀	♂	<i>T</i>
85—87											1	1	1		1	1		2
88—90																		
91—93										1		1				1		1
94—96				2		2		1	1	2		2	1		1	5	1	6
97—99										2	3	5	1		1	3	3	6
100—102				1		1				1	1	2	1	1	2	3	2	5
103—105				1		1										1		1
106—108		1	1														1	1
109—111	1		1	2	1	3					1	1				3	2	5
112—114	1		1		1	1	2		2							3	1	4
115—117	1	1	2				1	2	3		1	1				2	4	6
118—120				3	3	6	1	1	2		1	1				4	5	9
121—123	1		1				4	1	5							5	1	6
124—126				3	2	5	1		1				1		1	5	2	7
127—129		1	1		2	2			2								3	3
130—132				2	1	3		4	4					1	1	2	6	8
133—135		2	2				1	2	3	1		1				2	4	6
136—138	3	1	4	1		1		3	3							4	4	8
139—141	1		1	1	2	3		3	3							2	5	7
142—144	1	1	2	2	1	3		2	2							3	4	7
145—147	1		1	1		1										2		2
148—150	2	1	3				1	1	2							3	2	5
151—153	2	1	3	3	1	4	3		3							8	2	10

154-156	2		2													2		2
157-159		1	1		1	1											2	2
160-162	2		2		2	2										2	2	4
163-165	1	1	2	1		1	1		1							3	1	4
166-168	2	1	3				1		1							3	1	4
169-171				1		1										1		1
172-174	2		2	1	1	2	1		1							4	1	5
175-177	1		1	1		1										2		2
178-180	1	1	2													1	1	2
181-183	3		3		1	1										3	1	4
184-186	1		1				1	1								1	1	2
187-189	2		2		1	1										2	1	3
190-192	1	1	2	1		1										2	1	3
193-195		1	1														1	1
196-198				1		1										1		1
199-201																		
202-204																		
205-207				1	1	2										1	1	2
208-210																		
211-213					1	1											1	1
214-216	1		1													1		1
217-219																		
220-222																		
223-225	1		1		1	1										1	1	2
Number	34	15	49	29	23	52	17	21	38	7	8	15	5	2	7	92	69	161
Mean ...	160.91	150.20	157.63	139.69	150.30	144.38	146.29	133.86	134.95	101.86	103.25	102.60	101.00	116.00	105.29	141.92	138.83	139.40
σ^2	719.76	659.31	712.04	906.65	1111.00	1005.36	419.08	284.85	336.71	209.27	120.21	150.26	211.50	450.00	269.75	994.47	842.89	926.19

Table 4. Characteristics of the various length distributions. For further explanation see text. North West Atlantic, July—September 1961. (*Lamna nasus*).

Sub-area	Sex	cm			number			cm ²			cm		
		Range	\bar{L}	\bar{L}_1	\bar{L}_2	n_1	n_2	n_1+n_2	σ_1^2	σ_2^2	σ^2	σ	$\pm \frac{\sigma}{\sqrt{n_1+n_2}}$
Platts Bank 1	♀	109—227	165.37	160.91	167.24	34	81	115	719.76	834.91	802.39	28.33	2.64
	♂	106—216	154.82	150.20	156.21	15	50	65	659.31	763.22	658.44	25.66	3.18
	T	106—227	161.56	157.63	163.03	49	131	180	712.04	787.24	768.39	27.72	2.07
Cashes Ledge 2	♀	94—245	176.33	139.69	184.03	29	138	167	906.65	782.31	1083.38	32.91	2.55
	♂	109—251	188.94	150.30	192.84	23	228	251	1111.00	763.47	942.95	30.71	1.94
	T	94—251	183.90	144.38	189.52	52	366	418	1005.36	784.27	1032.20	32.13	1.57
Georges Bank 3	♀	112—251	184.42	146.29	186.55	17	304	321	419.08	716.28	780.94	27.95	1.56
	♂	94—251	183.39	133.86	187.12	21	279	300	284.85	618.45	781.97	27.96	1.61
	T	94—251	183.92	134.95	186.82	38	583	621	336.71	668.32	802.97	28.34	1.14
Misaine Bank 4	♀	91—256	200.25	101.86	202.51	7	305	312	209.27	1232.36	1432.20	37.84	2.14
	♂	85—251	193.77	103.25	198.05	8	169	177	120.21	1180.11	1523.23	39.03	2.93
	T	85—256	197.90	102.60	200.92	15	474	489	150.26	1213.23	1468.76	38.32	1.73
St. Pierre Bank 5	♀	85—251	201.37	101.00	207.34	5	84	89	211.50	804.58	1381.45	37.17	3.94
	♂	100—262	212.53	116.00	213.65	2	172	174	450.00	359.65	467.69	21.63	1.64
	T	85—262	208.75	105.29	211.58	7	256	263	269.75	509.30	796.68	28.23	1.74
Grand Total 6	♀	85—256	187.13	141.92	191.69	92	912	1004	994.47	1041.96	1243.20	35.26	1.11
	♂	85—262	190.06	138.83	194.00	69	898	967	842.89	880.66	1079.19	32.85	1.06
	T	85—262	188.57	139.40	192.83	161	1810	1971	926.19	962.21	1174.22	34.27	0.77

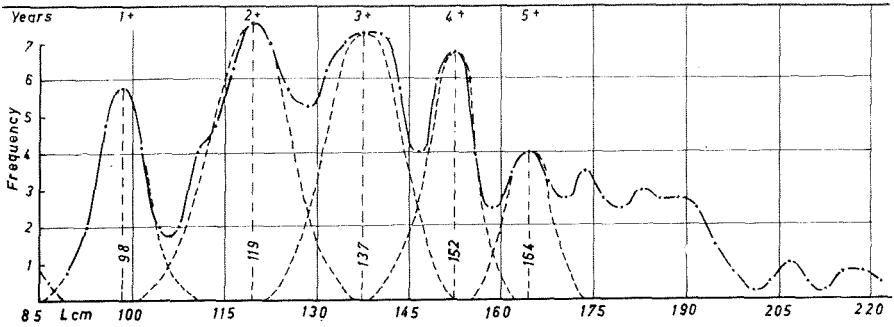


Fig. 4. Diagrammatic representation of the total length distribution for the tagged and examined fish demonstrating modes in the frequencies. For further explanation see text.

accordingly, seem to be in the Spring rather than in the Summer as stated by Bigelow and Schroeder (*loc. cit.*). The largest reported embryo was 66 cm and the smallest recorded fish 75 cm according to the same authors. It seems, therefore, very likely that the length at birth is somewhere around or between these figures. Working from this hypothesis it follows that the smallest measured fish (Table 3) probably belongs to the 0-group. The 1+ year old fish will consequently have an average length of 98 cm (the first mode in Fig. 4) and the mean length for the next year-group (2+) will be 119 cm. For the 3+, 4+, and 5+ year-groups the modal lengths are 137 cm, 152 cm, and 164 cm respectively.

Presuming a correct interpretation of the facts, these figures may be used to construct the growth curve for the porbeagle. Employing the von Bertalanffy's growth formula (Beverton and Holt, 1957), the length at any time (L_t) is determined by:

$$L_t = L_\infty - (L_\infty - L_0)e^{-kt} \quad (5)$$

where L_∞ and k are constants. The parameter L_∞ , or the asymptotic length, is found by a Walford graph (Walford, 1946) to be 280 cm. From (5) is obtained: $\ln(L_\infty - L_t) = -kt + \ln(L_\infty - L_0)$. If the average time interval from production until time of observation is denoted by Δt , one gets: $\ln(L_\infty - L_{t+\Delta t}) = -k(t + \Delta t) + \ln(L_\infty - L_0)$ or:

$$\ln(L_\infty - L_{t+\Delta t}) = -kt + \ln(L_\infty - L_{\Delta t}) \quad (6)$$

Putting the observed data for $L_{t+\Delta t}$ into (6), a series of values is found from which k can be calculated (Table 5). Denoting the age by t and the natural logarithms of $L_\infty - L_{t+\Delta t}$ by β , the following regression is obtained:

$$\beta = \bar{\beta} - k(t - \bar{t}) = 5.299 - 0.1107t \quad (7)$$

III. THE GROWTH

1. *Evidence from the length distributions*

An inspection of the entries in Table 1 will show that, as a rule, one or the other sex is dominating. This feature was, in fact, very striking in the individual catches. That implies that the sexes normally move in separate concentrations (no actual school was ever observed). However, Table 4 shows that in the final summation, the sexes occur in nearly equal numbers (♀ 49%; ♂ 51%), and the average lengths are also very much the same. A test of the difference between the means shows no statistical significance ($t=1.90$; $P>0.05$). From this fact it is inferred that males and females have the same average growth rate (see also page 25). That the mean lengths vary quite considerably from catch to catch for both ♂ and ♀ , but without any indication of the mean for either sex being consistently the greater, is taken as supporting evidence. In this connexion it is worth noting that a test of the difference between the means in the grand total of Table 1 gives $t=3.48$ and $P<0.001$, and this is highly significant. Judging from the dorsal length only, one would be led to the conclusion that the males grow faster than the females.

The distributions entered in Table 3 are all multimodal, and the modal lengths may be interpreted as the average lengths of different year-groups. Unfortunately, only in the grand total are the entries numerous enough to present a coherent picture. The modes for males and females are seen to be roughly corresponding, but the fine grouping and relatively scanty observations obscure the issue. It will not improve matters to use a coarser grouping since in that case relevant details are lost in the process. However, when ♂ and ♀ are considered together (Table 3.6.T) the first five modes in the distribution are clearly discernible. In Fig. 4 this feature is shown graphically with the frequencies smoothed according to the formula $d = \frac{a+2b+c}{4}$ (solid line). In the Figure the actual length distributions of the various distinguishable year-groups are also tentatively sketched in (broken lines).

No embryo was present in any of the several hundreds of mature females examined during the months July—September of 1961. Large embryos have been found at the Flemish Cap grounds in late May according to information supplied by fishermen, and embryos have been reported from the Gulf of Maine in November and January (Bigelow and Schroeder, 1948) The record of embryos in August by Bigelow and Schroeder (loc. cit.) is in sharp contrast to the present author's observations and must be considered rather unusual. The time for propagation would,

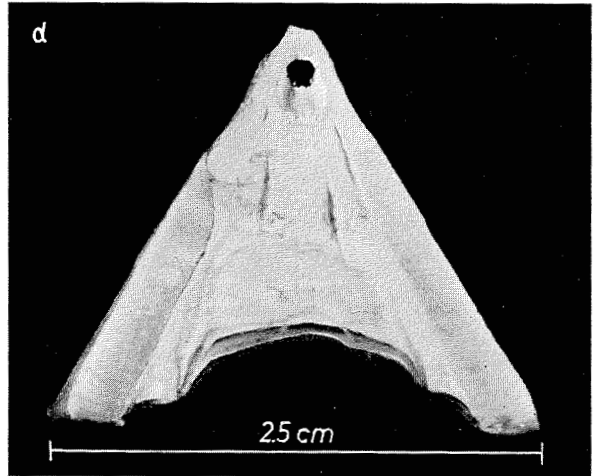
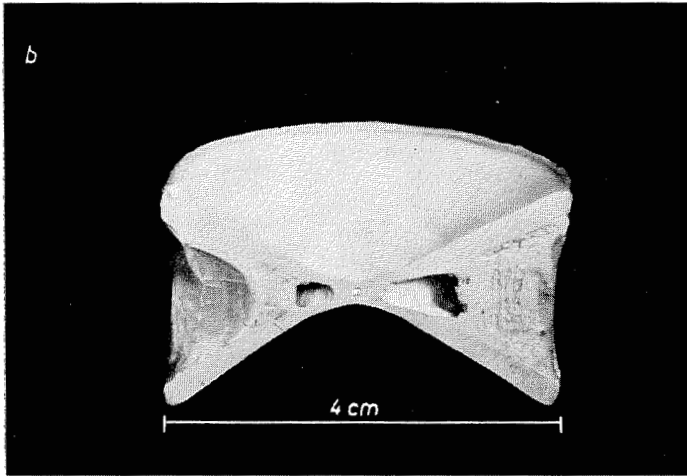
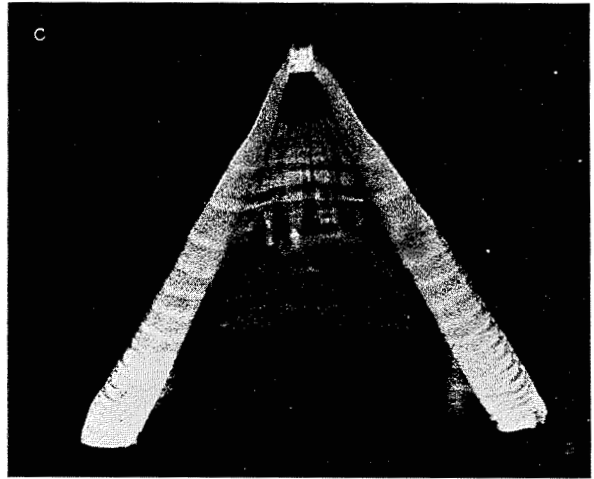
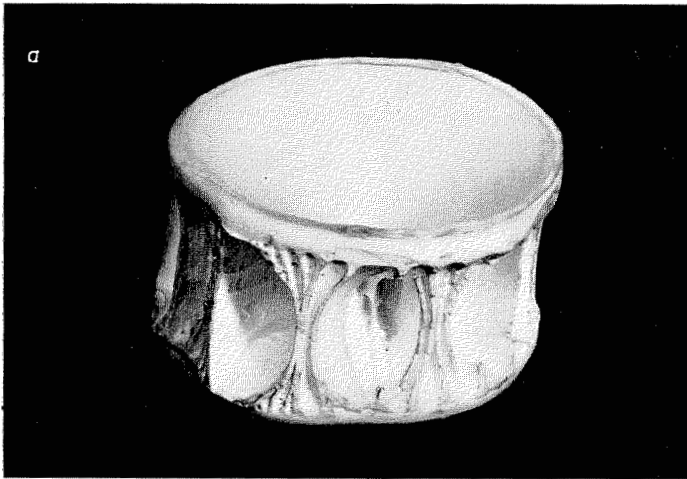


Plate I. a) Photograph of a vertebra from a porbeagle. b) Photograph of half a vertebra. c) x-ray photograph of a 1 mm thick section. d) Ordinary photograph of the same section as c). See footnote p. 33 and Table 2.

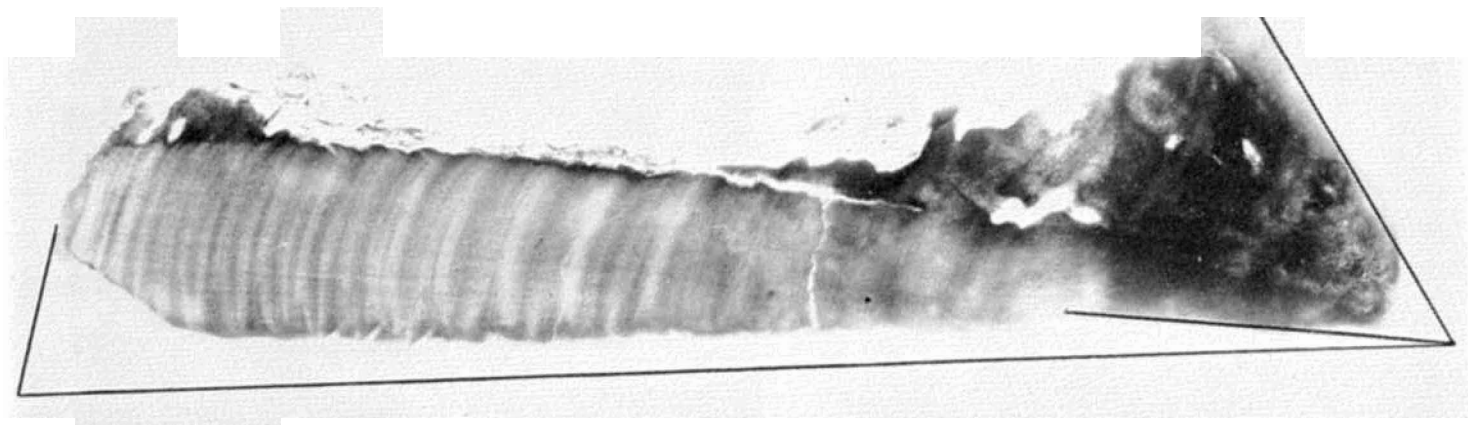


Plate II. Demonstration of growth zones in a vertebra. A 0.3 mm thick section is used as a negative for reproduction on photographic paper. On the transparent paper the growth zones are shown in diagrammatic form. See footnote p. 33 and Table 2.

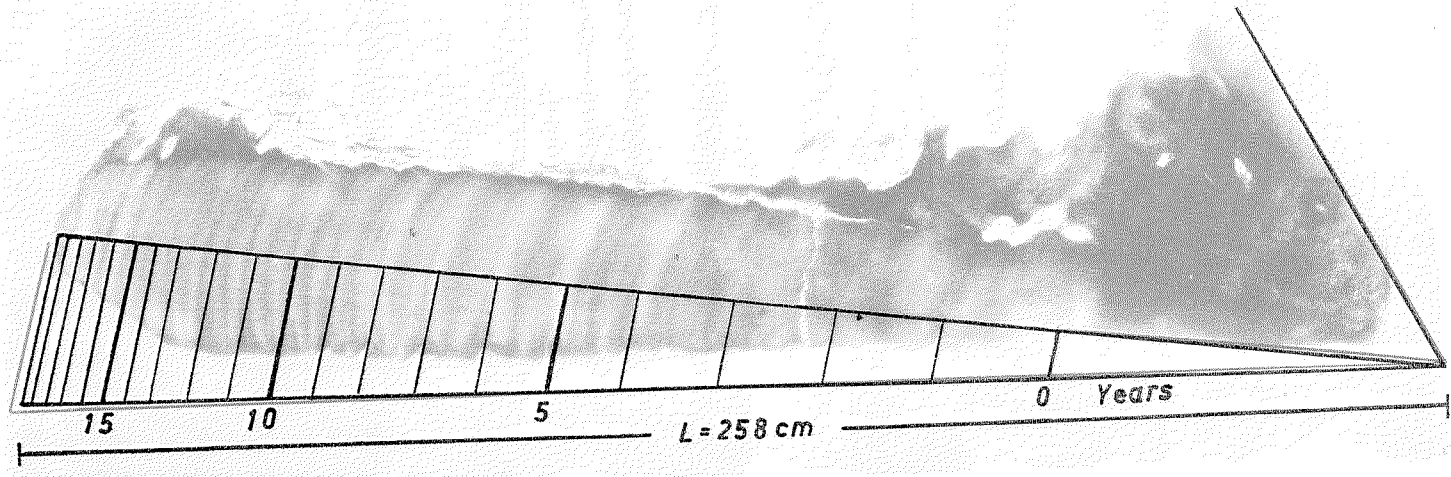


Plate II. Demonstration of growth zones in a vertebra. A 0.3 mm thick section is used as a negative for reproduction on photographic paper. On the transparent paper the growth zones are shown in diagrammatic form. See footnote p. 33 and Table 2.

Table 5. Basic data for calculation of k from frequency modes.

t Age	$L_{t+\Delta t}$ cm	$L_{\infty} - L_{t+\Delta t}$ cm	β $\ln(L_{\infty} - L_{t+\Delta t})$	Averages and sums of squares and cross-products
1+	98	182	5.205	$\bar{t} = 3$
2+	119	161	5.080	$\bar{\beta} = 4.967$
3+	137	143	4.961	$S(t^2) = 55$
4+	152	128	4.850	$S(\beta^2) = 123.596$
5+	164	116	4.750	$S(t\beta) = 73.398$

The intercept on the β -axis is equivalent to $\ln(L_{\infty} - L_{\Delta t})$ and consequently the mode of the 0-group at this time of the year ($L_{\Delta t}$) is 80 cm. The growth formula for the porbeagle, calculated on the basis of modes in the length frequencies is accordingly:

$$L_{t+\Delta t} = 280 - 200e^{-0.1107 t} \quad (8)$$

where the length is expressed in cm and t the age in full years. Δt is a constant so far unknown, but if the time between the middle of Spring to the middle of Summer is set to about 3 months, it will roughly amount to 0.3. (Fig. 5).

2. Evidence from the vertebrae

During the field work an attempt was made to analyse the vertebrae for growth zones and determine the age. Unfortunately, the facilities for such work aboard the commercial fishing vessel were exceedingly poor, and it is, therefore, not surprising that the results obtained were not very accurate (Aasen, 1961). It was, however, established that growth zones did in fact exist, and further work with more refined methods has furnished conclusive evidence of this finding. In Plate I are shown photographs of a vertebra from a porbeagle (*a*) and of half a vertebra (*b*) cut in a plane lengthwise through the axis. Plate I (*c*) shows an enlarged *x*-ray photograph of a 1 mm thick section of a vertebra, and (*d*) is an ordinary photograph of the same section. In Plate II the growth zones of a vertebra are demonstrated, using a 0.3 mm thick section as a negative for reproduction on photographic paper.¹ Superimposed (on transparent paper) is shown in diagrammatic form the growth zones which are interpreted as the yearly growths. There is no definite birth-mark on the vertebra;

¹ In Plate I (*b*), (*c*), and (*d*) and Plate II the same vertebra was used, taken from a 258 cm long female fished at Artimon Bank (45° 24' N, 58° 29' W) 19th August 1961. (See Table 2).

Table 6. Basic data for calculation of k from growth zones in a vertebra.

t Age	V_n mm	L_t cm	$L_\infty - L_t$ cm	β $\ln(L_\infty - L_t)$	Averages and sums of squares and cross- products
1	77.7	93.0	187.0	5.230	
2	95.0	113.8	166.2	5.115	
3	110.0	131.8	148.2	4.997	
4	125.1	149.8	130.2	4.872	
5	136.0	162.9	117.1	4.761	
6	147.3	176.4	103.6	4.641	$\bar{t} = 10$
7	156.4	187.3	92.7	4.530	$\bar{\beta} = 4.186$
8	164.5	197.2	82.8	4.415	
9	171.8	205.9	74.1	4.305	$S(t^2) = 2468$
10	178.2	213.5	66.5	4.197	
11	185.0	221.6	58.4	4.069	$S(\beta^2) = 340.498$
12	190.5	228.2	51.8	3.945	
13	196.1	234.8	45.2	3.813	$S(t\beta) = 729.740$
14	199.9	239.3	40.7	3.706	
15	202.6	242.7	37.3	3.619	
16	206.5	247.2	32.8	3.491	
17	208.8	250.0	30.0	3.402	
18	212.0	253.9	26.1	3.262	
19	214.0	256.3	23.7	3.165	
19+	215.3	258.0	22.0	3.092	

The value of V_n at 19+ = V .

but it is, perhaps, significant that the extrapolated value for zero age coincides with the point where the edge of the section changes its angle. It is a straight-forward matter to measure these zones with sufficient exactitude and a series of data is obtained from which the lengths at the various ages can be calculated. Here is used the simple proportion formula: $L_n = \frac{V_n}{V} L$ where V and V_n are the distances from the centre to the edge of the vertebra and to the completion of the n^{th} growth zone respectively. (Table 6). A Walford graph gives $L_\infty = 280$ cm as in the former case (page 32). Using the same symbols as in (7), the regression will be:

$$\beta = 5.341 - 0.1155t \quad (9)$$

The intercept on the β -axis, gives a value of $L_0 = 72$ cm which in this case is the length at birth. By substituting the values of L_∞ and L_0 in (5) the growth formula is obtained:

$$L_t = 280 - 208e^{-0.1155t} \quad (10)$$

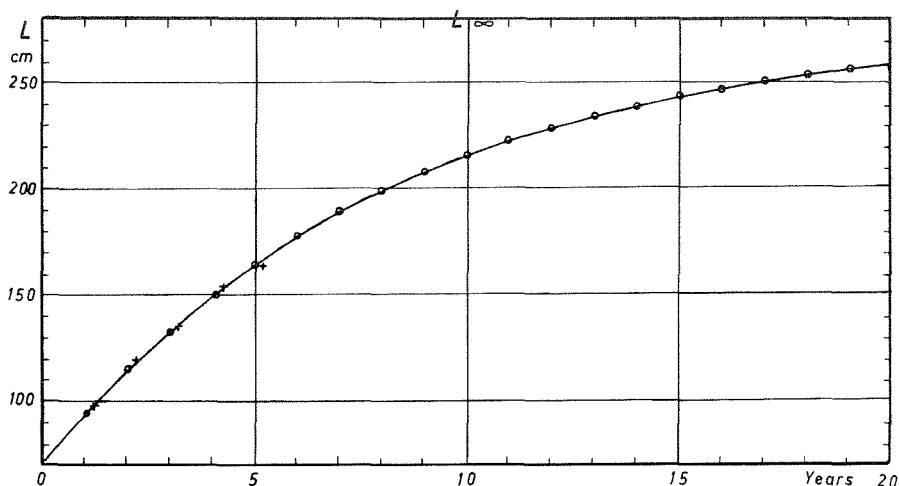


Fig. 5. The growth curve of the porbeagle based on growth zones in a vertebra. Circles: Observation points. Crosses: Modes in frequencies from Fig. 4. For further explanation see text.

The two equations (8) and (10) agree very well. A test of the difference between the two calculated values of k gives: $t=0.23$ and $P>0.8$ and this is definitely not significant. From the fact that identical results are obtained through two independent approaches, it is fair to conclude that for the first, the modes apparent in Table 3 do in reality express the average lengths of successive year-groups, and secondly, that the growth zones in the vertebrae, as interpreted, represent the yearly growths. The growth curve is shown in Fig. 5. From (7) and (9) is derived: $-k\Delta t = \ln(L_\infty - L_{\Delta t}) - \ln(L_\infty - L_0) = -0.042$; $\Delta t = 0.36$. This implies that the usual time for production is about 4 months prior to the average time of observations (early August) provided that the growth is uniform throughout the year. This is certainly not the case. Most probably the growth curve within the year is sigmoidal in appearance. If the values obtained from the modes in Fig. 4 are fitted in at 0.2 of the unit ($\Delta t' = 0.2$), they agree very well with the growth curve constructed from the vertebra (Fig. 5). This corresponds to a growth period of 9 months with uniform growth, and a rest period of 3 months within the year. The average propagation time would accordingly be in early June and possibly late May. This coincides approximately with the time of the year when the porbeagle ascend from deeper water into the surface layers and begin feeding intensively.

If the gestation period were longer than 12 months, embryos should be present all the year round in some of the females. Since this is evidently not the case, the porbeagle will in general reproduce every year. Judged

from the available information, the gestation period is about 8 months. The filling sperm-sacs, towards the end of August, point to the Autumn as mating time. However, the ripeness of the sperms was not investigated, and the evidence is rather vague.

The total length frequency distribution combined with the information on the growth may be used to estimate the total mortality in the stock: The calculated length at the age n corresponds to a certain frequency in the distribution. Plotting the logarithms of these frequencies against age, a series of points is obtained which from a certain age should theoretically lie on a straight line if the lengths are normally distributed. The slope of this line is equal to the total instantaneous mortality coefficient (M). In the present case where the distribution of the total lengths is represented by range, mean, and standard deviation, this method is of no immediate use. However, remembering that in calculating these data, the procedure followed is that of fitting a normal distribution, this fact may be utilized for calculation of any desired frequency. Writing the normal distribution in the form:

$$\ln f = \ln C - \frac{1}{2} \left(\frac{L - \bar{L}}{\sigma} \right)^2 \quad (11)$$

the relevant data are obtained directly by substituting the lengths calculated from the growth formula (10) for L in (11). Since, as mentioned before (page 27), the stock is practically a virgin one with respect to fisheries and only about 10 000 specimens were caught by the Norwegian long liners from March to September in 1961, the fishing mortality at the time of observation must be regarded as insignificant. M will therefore be the same as the natural mortality coefficient (N) and also expressive of the recruitment rate. When the method is applied to the total distribution in Table 4, the estimate of the coefficient is $M = N = 0.18$, which seems reasonable in an unexploited stock where the individuals have a long life span.

IV. SUMMARY

The measurements of the length of the porbeagle in the North West Atlantic, collected aboard a commercial long liner in the summer of 1961, are examined.

The analysis is in the main based upon measurements of the "dorsal lengths", and the total lengths are derived from these by means of regression formulas, which are slightly different, although significantly so, for males and females.

In the individual catches one or the other sex is, as a rule, dominant numerically, but the final summation shows that there is but little difference (49:51) in the stock as a whole.

The mean total length increases from the West towards the East within the area of investigation. This is explained as due to segregation caused by different migration patterns for smaller and larger fish. The overall estimate of the length distribution is characterized by: Range = 85–262 cm, mean = 188.57 ± 0.77 cm, and $\sigma = \pm 34.2$ cm.

There is no significant difference between the mean total lengths of ♂ and ♀. From this fact it is inferred that males and females have the same average growth rate.

The growth has been analysed in two ways: from the modes in the frequency distribution and from the growth zones in a vertebra. The results are in good agreement. L_0 is found to be 72 cm and $L_\infty = 280$ cm. The growth is described by the formula $L_t = 280 - 208e^{-0.1155t}$.

So far only a few vertebrae have been analysed, but it is evident that the porbeagle may reach a considerable age, at least up to 20 years and very likely some 10 years more.

Probably the porbeagle reproduce every year. The usual time for production is apparently in late spring (May/June). The mating presumably takes place in autumn (September/October), and the gestation period runs roughly to 8 months.

From the growth formula, the mean length and variance of the length distribution an estimate of the total mortality coefficient, $M = 0.18$, is obtained.

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