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AGE AND GROWTH OF THE BLUEFIN TUNA, THUNNUS THYNNUS (L.) OF THE NORTHEAST ATLANTIC

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SUMMARY

This paper studies the growth and age of east Atlantic bluefin tuna based on the observation and analysis of hard parts (fin ray sections).

The different parts and types of rings observed on the fin ray section are defined. From this study it can be deduced that:

--the hyaline rings are winter rings which are formed between fall and winter (October-March);

--the opaque areas of active growth start forming in spring and conclude their formation in the fall (March-October);

--for younger aged bluefin (age-classes 1 to 3), summer growth is from 3 to 4 times more in size and from 4.5 to 6 times more in weight than winter growth;

--the winter hyaline rings can be single (thin or thick) or double.

From the growth equation obtained by combining data from the juvenile bluefin fishery of the Cantabrian Sea (north of Spain) with that from the adult bluefin fishery of the Strait of Gibraltar area, a value of $L\infty$ = 318.85 cm is obtained, which corresponds to a $W\infty$ of 615.90 kg.

RESUME

Le présent document étudie l'âge et la croissance du thon rouge est-atlantique en se fondant sur l'observation et l'analyse de structures osseuses (coupes de rayons épineux).

Les différents éléments et types d'anneaux observés sur la coupe de rayon épineux sont définis. Cette étude permet de déduire que:

- les anneaux hyalins constituent une formation hivernale qui se produit en automne-hiver (octobre-mars);
- la formation des zones opaques de croissance active commence au printemps et se termine en automne (mars-octobre);
- chez les thons rouges juvéniles (classes d'âge 1 à 3), la croissance estivale est 3 à 4 fois plus rapide que la croissance hivernale pour la taille, et 4,5 à 6 fois pour le poids;
- les anneaux hyalins hivernaux peuvent être uniques (larges ou étroits) ou doubles.

L'équation de croissance obtenue en combinant les données sur la pêche de thon rouge juvénile en mer Cantabrique (au nord de l'Espagne) avec celles de la pêche de thon rouge adulte de la région du détroit de Gibraltar permet de calculer une valeur de $L\infty$ = 318,85 cm, ce qui correspond à un $W\infty$ de 615,90 kg.

RESUMEN

El presente documento estudia el crecimiento y la edad del atún rojo del Atlántico este, basándose en la observación y análisis de partes duras (secciones de radios).

Se definen las diferentes partes y tipos de anillos observadas en las secciones de radios. De este se deduce lo siguiente: - Los anillos de hialina son anillos invernales que se forman en otoño e invierno (octubre-marzo).

- Las zonas opacas de crecimiento activo inician su formación en primavera, terminando en otoño (marzo-octubre).

- En el atún rojo juvenil (edades 1-3), el crecimiento en verano es de 3 a 4 veces superior en talla y de 4.5 a 6 veces superior en peso al de invierno.

- Los anillos de hialina en invierno pueden ser sencillos (anchos o estrechos) o dobles.

- De la ecuación de crecimiento que se obtiene combinando datos de la pesquería de atún rojo juvenil en el mar Cantábrico (norte de España) con la procedente de la pesquería de atún rojo adulto en la zona del Estrecho de Gibraltar, se obtiene un valor de Loo = 318.85 cm que corresponde a una Woo de 615.90 kg.

INTRODUCTION

The age and growth of the bluefin tuna is studied, paying special attention to the interpretation of the signs manifested in some hard parts of its body (in this case, the spinal sections).

MATERIALS AND METHODS

The taking of samples was done in northern and southern ports of Spain between the months of May and November.

The range of sizes convered is between 45 and 200 cm in the fisherie of the Cantabrian Sea (northern of Spain), and between 170 and 304 cm in the traps of the Gulf of Cádiz (southern of Spain). In both cases fork length as reference was taken.

The method of extraction, preparation and the cutting of the spine, is the one described by Compeán-Jiménez & Bard (1980a; 1980b).

Following their same method, some cross sectional cuts ranging from 0.5 to 0.7 mm in thickness on the first dorsal fin using a slow rotating diamond saw were made.

The cuts were prepared on slides covered with a highly transparent resin, and a slide cover.

The measuring and reading of the spinal sections was carried out with a profile projector using a zoom of about 10 to 50.

The back-calculated growth size of the fish and the diameter of its spine were calculated for a sample of 300 tunas, by Rey & Cort (1984). The range of sizes in this relation, is from 29 to 200 cm fork length (FL); those fish under 50 cm were from the Mediterranean Sea.

(Including these fish gave us a better fit to the back-calculated growth).

THE VON BERTALANFFY MODEL

It is expressed by the following relations :

$$LT = L_{\infty} \, [1 - e^{-K (t - t_0)}]$$

$$WT = W_{\infty} \, [1 - e^{-K (t - t_0)}]$$

Where :

LT, WT = Size (length or weight) of the fish at t moment.

L_{∞}, W_{∞} = Maximum average (asymptotic), size (length or weight)

K= Physiological mean constant (catabolism coefficient).

t= Theoretical instant where $L=0$ or $W=0$.

The average value by age, of bluefin tuna from the Cantabrican Sea, between 1 and 8 years of age, was estimated from the following equation:

$$Y = 12.780863 \, X^{0.576}$$

(For 12, 24, 36, 48, 60, 72, 84 y 96; X = month)

The equation is obtained by potential adjustment of the modal values of monthly size distributions (Cort, 1989).

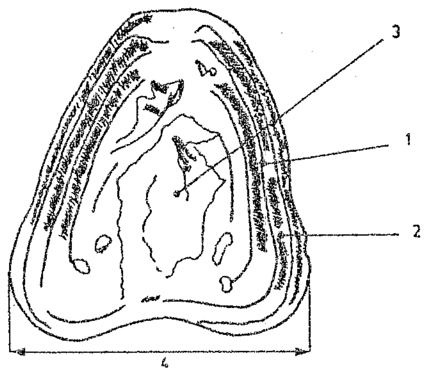
RESULTS.

GROWTH IN HARD PARTS (SPINE SECTIONS)

The cross sectional cuts of the spines show an alternation of wide areas (active growth) and translucent bands (slow growth). The correct interpretation of these marks, is fundamental in order to develop the study on grouth as well as to come to conclusions on the biological and ecological aspects of this species.

Parts of a dissected spine

In the cross sectional cuts on the spines, the following parts can be noticed :



1. - Translucent area of slow growth which can be formed by two rings or just one.

2. - Opaque area of fast growth,

3. - Vascularized nucleus, which in fish over 2 years old has a reabsorbed part in which the translucid bands disappear, and

4. - Diameter of the spine.

In young individuals (up to 3 years old) it is eassy to find all the hyaline rings of a spine. However, in fish over 3 years the central area of the spine is reabsorbed and consequently the bands are gone. Therefore for those fish a back calculation of the size of the fish at the moment of the formation of the first visible rings must be made.

WINTER GROWTH

For samples of the spinal sections of bluefin caught in the Cantabrian Sea during the 1985 fishing season, different observations and measurements have been carried out on the translucent rings to study the development of the sizes by age in 1 - 7 year old fish (50 to 175 cm).

The translucent rings found respond to different interpretations due to their shape and apparent composition (Figure 1).

1.- In some cases two thin translucent rings can be seen separated by an opaque band. This is called couplet and the interpretation of these is as follows :

The first ring indicates the beginning of the cold season (this translucent band shows a poor protein dosis which causes a visible acumulation of minerals in the bonny parts), which can coincide with the outward migration from the Cantabrian Sea to the wintering areas.

The opaque band which appears next (between the two rings that form the couplet) is the winter growth.

Finally there is the second ring which shows the end of winter. This one, which can coincide with the migration to the areas of active feeding, has the same composition as its twin.

2.- Fine,single rings.

These show that the fish scarcely grew during winter. Since the begining of the cold season until the fish return to the active feeding area (in Spring), the growth slowed down quite notably.

3.- Thick,translucent rings.

This indicate that the bluefin had a more active growth than in the previous case. Here the growth is the same as in the first case, but the diet had no proteins.

After having explained the different cases of spinal rings, the growth of bluefin tuna during the winter can be shown. To do so, measurements of the diameter of the translucent rings were taken, from the beginming of these (whether simple or double) till the end of them.

Using a sample of 363 bluefin tuna aged 1 to 7, the distribution of frecuencies of the diameter of the winter rings were obtained. The results and their corresponding parameters, are shown in tables 1 and 2.

Using this equation:

$$Y = -0.551 + 0.060 X \text{ (Rey \& Cort, 1984)}$$

which relates Y (diameter of the spine) with X (zoological length of the tuna), the results shown in Tables 3 and 4 were obtained. In these tables the size distributions back-calculated to the beginning of the winter ring are expressed as TC (1-7) and by TF (1 - 7) as the end of the winter ring. (The paremeters of these back-calculated size distributions are shown in Table 5).

The winter growth of bluefin from the Cantabrian Sea was obtained by calculating the difference between the average values by age at the end and at the beginning of the rings (data obtained from Table 5). The final results are expressed as follows:

AGE	WINTER GROWTH (cm)
1	2.90
2	3.11
3	3.83
4	6.39
5	7.00
6	6.21
7	6.03

SUMMER GROWTH

To estimate the summer growth of bluefin tuna, sampling of spines from fish of age groups 1, 2 and 3 was carried out. These fish are normally found in the Bay of Biscay from the beginning of the summer season (June), until the end of the season (October).

The idea is to follow from the beginning, the distance from the last visible ring in the cuts of the spines, to the end of the ring.

As the fishing season advances, the ring becomes farther and farther from the end of the cut. In the beginning of the season (June) this ring was at the edge of the spine.

The results are shown in Table 6 and in Figure 2, where the following growth can be observed for the three cases :

AGE	RING	SIZE OF THE FISH (◊)	INCREASE
1	0.22 - 0.67 (0.45 mm)	57.7 - 67.4	9.70 cm
2	0.16 - 0.75 (0.59 mm)	75.25- 88.40	13.15 cm
3	0.15 - 0.81 (0.66 mm)	93.88-109.28	15.40 cm

(◊) Fork length (FL) in cm

Therefore, the average increase in length and weight for the different age classes of bluefin tuna in the Cantabrian Sea which studied is as follows:

AGE	FALL-WINTER (◊) (cm)	(kg)	SUMMER-FALL (♀) (cm)	(kg)	
1	2.90	0.4	9.70	2.5	
2	3.11	1.3	13.15	5.8	
3	3.83	1.7	15.40	10.3	
4	6.39	4.0	13.00 *	10.5	(June-Sept.)
5	7.00	6.4	14.00 *	14.8	(June-Sept.)
6	6.21	7.4			
7	6.03	8.4			

* Average values taken from from Table 8a.

(◊) Between October and March.
(♀) Between June and October.

Summer growth in relation to winter growth, is as follows for the ages studied:

AGE	MULTIPLE OF (◊)	(♀)
1	3.34	6.2
2	4.23	4.5
3	4.02	6.1
4	2.03	-
5	2	-

(◊) Growth in size (cm).
(♀) Growth in weight (kg).

That is, for age classes 2 and 3, summer growth (in cm), is 4 times more than winter growth. For the other age classes, summer growth is at least twice as much, and in age class 1 fish it is over 3 times more. As regards weight for the first 3 age groups, summer growth is on the average, five to six times more than winter growht.

DISCUSSION ON THE STUDY OF THE GROWTH OF THE BLUEFIN TUNA FROM FIN RAY SPINES.

At this stage, a discussion can take place on the results obtained in this study and earlier studies by Compeán-Jiménez (1980) and Compeán-Jiménez & Bard (1983).

According to these authors, and referring to bluefin tuna from the Cantabrian Sea, it can be seen that::

" The rapid growth of the bluefin tuna during their early years of life enables the identification of the first age classes. It is therefore possible to correlate the observed bands (fish collected in the Bay of Biscay) with the ecological conditions to which the fish are subjected. Thus, the first growth band corresponds to the migration from the Mediterranean Sea to the Atlantic coast of Morocco (Sara 1973; Rey 1979). This is supported by the fact that the first band is not present in age class 0 fish caught while they are still in the Mediterranean Sea. In the following two couplets, the first band of each pair (bands 2 and 4, respectively) corresponds to the summer migration from southern Morocco to the Iberian Coast and the Bay of Biscay. The second band in these same couplets (bands 3 and 5, respectively) corresponds to the tuna's return to the wintering area in the Ibero-Moroccan Bay (Brêthes 1979; Lamboeuf 1975). The sixth band or first mark of the third couplet results from a summer migration from Moroccan waters to their point of capture in the Bay of Biscay (Bard 1977).

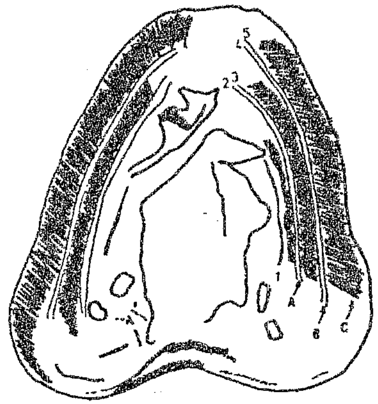
According to the back-calculated size frequency curves (Figs. 7, 8, and 9), it seems that the band that appears at the end of the fishing season (June to September) in juvenile bluefin tunas is formed just before their arrival in the Bay of Biscay, and it is only visible after their period of growth has started. It is known that juvenile bluefin tuna grow during their stay in the Bay of Biscay. Cort (1976) reported a growth of 15 cm FL in this period for tunas of estimated age 2. In this study, the same growth was found by comparing the mean length of samples at the beginning (Fig. 8) and end of the fishing season (Fig. 9)".

Conclusion from Compeán-Jiménez & Bard (1983):

" It is interesting to note that migratory movements may be the cause of band formation in bluefin tuna, at least in the eastern Atlantic area. This is particularly true for young, immature fish. For adults, the energetic problems involved in reproduction probably overlap the consequences of migration. Nevertheless, band formation in both young and adult bluefin tunas could be a function of bioenergetic stress associated with migration. This process clearly distinguishes bluefin tuna from other marine, temperate, sedentary fishes in which the reduction or lack of growth in winter reflects physical conditions of the environment. It should be pointed out that Sharp and Dotson (1977) indicated a high probability of lipid utilization as an energy source by migrating albacore, _T. alalunga_. Other temperate tunas that undergo long distance migrations probably register two growth bands each year (Bard & Compeán-Jiménez 1980)".

The information obtained on the interpretation of the bands on the fin ray spines helps us to understand some aspects of the relation between bluefin tuna and its evironement.

However, these interpretations can lead to erroneous conclusions. Therefore, the discrepancies found between this study wich those mentioned earlier are as follows:



Compeán-Jiménez (1980) Compeán-Jiménez & Bard (1983)		Present study
	<u>RING 1</u>	
Exit from Mediterranean to Atlantic.		First Winter (*)
	<u>RINGS 2 AND 4</u>	
Migration to Bay of Biscay		Beginning of cold season (beginning of fall).
	<u>RINGS 3 AND 5</u>	
Return to wintering areas		End of cold season (end of winter).
	<u>AREAS A AND B</u>	
Summer growth		Winter growth
	<u>AREA C</u>	
Winter growth		Summer growth

(*) 1 year old fish caught in the Mediterranean have this ring.

According to this, Compeán-Jiménez & Bard interpret that the phase of rapid growth corresponds to winter, and the couplet of the rings indicated migrations to and from the Bay of Biscay. In this way, the growth corresponding to the Bay of Biscay, would be between both rings.

These conclusions are completely opposite those reached, in this study, which are :

1.- Between the translucent bands of slow growth, there are at least 5 months (October-March), and

2.- The fast growth band (opaque band) corresponds to summer and early fall (June-October), though it starts to form in Spring. (This would be the case if double rings are visible).

According to Meunier et. al. (1979) the translucid areas are identified as slow growth areas due to their hypermineralization.

Therefore, the conclusions from the present study concerning the formation of translucid rings are as follows:

The first band is formed in the fall, and the second at the end of winter or early spring (March-April), before bluefin start their migration to the Bay of Bicay.

The beginning of the formation of the bands coincides with the important change in hydrological conditions in the temperate area of the ocean, such as the progressive decrease in the surface water temperature from fall until winter when minimum temperatures are reached, and when the formation of the translucent ring has concluded.

According to this, for fish entering in the Bay of Biscay, and which have formed two translucent rings, the location of this rings is unlike the conclusions reached in the study carried out by Copeán-Jiménez & Bard (op. cit.). That is, that the two rings formed the same year would correspond to the same couplet, but that between two rings of the same couplet, there are at least 5 months difference (October to March) and therefore, a change of a calendar year in between.

These conclussions are also valid for cases where the translucent rings are not doubled. In such circumstances, between the beginning and the end of the translucent ring (whether it's thin or thick) there exists a period of 5 months in which feeding is different from summer feeding.

VON BERTALANFFY GROWTH MODEL

One general model has been used for the whole species, using the age-class values (1-8) of the Bay of Biscay, and the 1984 bluefin trap fisheriy in the Gulf of Cádiz (age classes 9 to 19), from which fin ray spines are available (Table 7).

The values used are:

MONTH	AGE	FL (cm)	S	N	Observations
					According to equation $Y = 12.780863\ X^{0.576}$
12	1	53.48	-	-	"
24	2	79.72	-	-	" " "
36	3	100.69	-	-	" " "
48	4	118.84	-	-	" " "
60	5	135.14	-	-	" " "
72	6	150.10	-	-	" " "
84	7	164.04	-	-	" " "
96	8	177.15	-	-	" " "
	9	190.91	7.54	23	traps samples
	10	206.21	11.93	24	" "
	11	216.11	10.90	38	" "
	12	222.52	8.18	21	" "
	13	232.38	9.28	21	" "
	14	241.58	14.06	19	" "
	15	247.24	12.16	21	" "

The parameters of Von Bertalanffy equation, applying the fit of the model by Ford & Wadford (in Gulland, 1971), are:

L_∞ = 318.85 (cm)
t_0 = -0.97 (year)
k = 0.093 (annual)

The equation is as follows :

$$Lt = 318.85\ [1 - e^{-0.093\ (t + 0.97)}]$$

The estimate of W_∞ is difficult for bluefin due to the numerous size/weight equations calculated in areas where there are inmature and adult tunas.

Out of these, the equation by Rodríguez-Roda (1964) was selected since it has a wider range of sizes (25 - 279 cm, FL). This equation is as follows:

$$W = 0.000019\ L^3$$

Replacing in this equation:

$$W\infty = 0.000019\ L\infty^{3}$$

Where W∞ = 615.90 kg (for L∞ = 318.85 cm).

The Von Bertalanffy weighted equation would be :

$$Wt = 615.90\ [\ 1 - e^{-0.093\ (\ t\ +\ 0.97\ )}\ ]$$

The only information available on the integral growth of eastern bluefin tuna is from Rodríguez-Roda (1964), Compeán-Jiménez (1980) and Compeán-Jiménez & Bard (1983) although the last studies are very similar with slight variations.

Figure 3 shows the theoretic Von Bertalanffy curves for the three aforementioned studies. The results show a good fit of the present study to that by Compeán-Jiménez & Bard (1983), both of which were carried out by reading the fin ray spines.

In these two studies differences can be seen from the age 11 on, since the above mentioned authors, carried their study considering 19 different ages of bluefin tuna. While in the present study we only cover 15.

The Rodríguez-Roda (1964) curve deviates from previous ones after the third year (this study was done by age reading of caudal vertebrae).

APPLICATIONS OF THE DESCRIBED STUDY

Studies on bluefin growth, as noted in the preceding chapter, show a considerable metabolic activity of this species during the months they spend in the Cantabrian Sea (from the end of spring to mid-fall).

Due to the almost complete stop in growth in the months corresponding to the cold season (November to March), it is important to point that bluefin return to the Cantabrian Sea the following year and are the same size they were when they left 7 months before (see Tables 8a,8b).

Because of this, the application of the size/age keys have to be done seasonally. The use of only one key for al the catches would distort the size distribution of these catches.

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AGE / Ø Ring (mm)	1		2		3		4		5		6		7	
1.0	—	—	—	—										
2	—	—	—	—										
4	—	—	—	—										
6	1	—	—	—										
8	10	1	—	—										
2.0	21	15	—	—										
2	24	18	—	—										
4	9	21	—	—										
6	—	9	1	—										
8	—	1	1	—										
3.0	—	—	13	3										
2			15	14	—	—	—	—						
4			16	18	—	—	—	—						
6			3	10	—	—	—	—						
8			14	13	—	—	—	—						
4.0			3	6	1	—	—	—						
2			5	4	11	—	—	—						
4			2	2	11	9	—	—						
6			—	3	15	14	—	—						
8			—	—	4	13	—	—						
5.0			—	—	7	9	6	—						
2					8	6	3	4	—	—				
4					4	4	5	4	—	—				
6					5	8	7	2	—	—				
8					2	3	8	5	—	—				
6.0					0	2	9	9	—	—				
2							7	7	—	—				
4							6	3	4	—				
6							3	10	4	1				
8							1	7	7	3				
7.0							0	1	6	3				
2							0	2	1	7	—	—	—	—
4							1	0	6	4	—	—	—	—
6							—	2	4	5	3	—	—	—
8							—	0	2	2	5	—	—	—
8.0							—	0	0	8	6	4	1	—
2							—	—	1	1	3	3	1	—
4							—	—	2	0	4	5	1	2
6							—	—	—	1	5	6	1	0
8							—	—	—	2	2	4	2	0
9.0							—	—	—	—	3	4	6	1
2											3	4	4	4
4											1	3	4	2
6											2	0	4	10
8											—	3	0	1
10.0											—	1	0	2
2											—	—	0	2
4											—	—	2	1
6											—	—	1	1
8											—	—	—	0
11.0											—	—	—	1
N	65	65	73	73	68	68	56	56	37	37	37	37	27	27

Tabla 1. Distribución de frecuencias del diámetro de los anillos invernales. (Para cada edad, la columna de la izquierda es la distribución de los diámetros al comienzo del anillo; a la derecha, al final del mismo).

Table 1. Diameter frequency distribution of the winter rings. (For each age, the left column indicates the distribution of the diameters at the bigining of the formation of the ring; the right column indicates the distribution of the diameters at the end of their formation).

AGE

	1	1	2	2	3	3	4	4	5	5	6	6	7	7
N	65	65	73	73	68	68	56	56	37	37	37	37	27	27
$\bar{X}$ (mm)	2.14	2.33	3.48	3.66	4.79	5.02	5.90	6.29	7.19	7.62	8.47	8.84	9.28	9.65
σ	0.18	0.20	0.41	0.39	0.43	0.44	0.52	0.58	0.54	0.55	0.57	0.55	0.60	0.57
Sy	2.10	2.28	3.39	3.57	4.69	4.92	5.76	6.14	7.02	7.44	8.29	9.02	9.05	9.43
Sx (Int.Conf. 95%)	2.18	2.38	3.57	3.75	4.89	5.12	6.04	6.44	7.36	7.80	8.65	8.66	9.51	9.87

Tabla 2. Valores y parámetros obtenidos en la medición de los anillos invernales. (A la izquierda se expresa el diámetro al comienzo de la formación del anillo, a la derecha al final del mismo).

Table 2. Values and parameters obtained from measuring the winter rings. (The diameter at the beginning of the formation of the ring is shown on the left; the diameter at the end of the ring formation is given on the right

FL (cm)	TP 1	TP 2	TP 3	TP 4	TP 5	TP 6	TP 7
35 - 39	3	-	-	-	-	-	-
40 - 44	28	-	-	-	-	-	-
45 - 49	31	-	-	-	-	-	-
50 - 54	3	1	-	-	-	-	-
55 - 59	-	8	-	-	-	-	-
60 - 64	-	23	-	-	-	-	-
65 - 69	-	17	-	-	-	-	-
70 - 74	-	14	-	-	-	-	-
75 - 79	-	5	3	-	-	-	-
80 - 84	-	5	20	-	-	-	-
85 - 89	-	-	19	-	-	-	-
90 - 94	-	-	9	6	-	-	-
95 - 99	-	-	11	4	-	-	-
100 - 104	-	-	5	11	-	-	-
105 - 109	-	-	1	15	-	-	-
110 - 114	-	-	-	9	-	-	-
115 - 119	-	-	-	6	5	-	-
120 - 124	-	-	-	4	10	-	-
125 - 129	-	-	-	-	7	-	-
130 - 134	-	-	-	1	6	-	-
135 - 139	-	-	-	-	6	5	-
140 - 144	-	-	-	-	-	9	1
145 - 149	-	-	-	-	2	5	2
150 - 154	-	-	-	-	1	7	1
155 - 159	-	-	-	-	-	5	5
160 - 164	-	-	-	-	-	3	7
165 - 169	-	-	-	-	-	2	6
170 - 174	-	-	-	-	-	1	2
175 - 179	-	-	-	-	-	-	-
180 - 184	-	-	-	-	-	-	2
185 - 189	-	-	-	-	-	-	1
190 - 194	-	-	-	-	-	-	-
N	65	73	68	56	37	37	27

Tabla 3. Valores numéricos de las distribuciones de tallas retrocalculadas al comienzo del anillo invernal (edades 1-7).

Table 3. Numeric values of the size distributions back-calculated to the beginning of the winter ring. (Ages 1-7).

FL (cm)	TF 1	TP 2	TP 3	TP 4	TP 5	TF 6	TF 7
35 - 39	-	-	-	-	-	-	-
40 - 44	14	-	-	-	-	-	-
45 - 49	32	-	-	-	-	-	-
50 - 54	18	-	-	-	-	-	-
55 - 59	1	-	-	-	-	-	-
60 - 64	-	18	-	-	-	-	-
65 - 69	-	25	-	-	-	-	-
70 - 74	-	14	-	-	-	-	-
75 - 79	-	8	-	-	-	-	-
80 - 84	-	5	8	-	-	-	-
85 - 89	-	3	24	-	-	-	-
90 - 94	-	-	14	-	-	-	-
95 - 99	-	-	7	5	-	-	-
100 - 104	-	-	10	5	-	-	-
105 - 109	-	-	5	7	-	-	-
110 - 114	-	-	-	14	-	-	-
115 - 119	-	-	-	9	-	-	-
120 - 124	-	-	-	11	4	-	-
125 - 129	-	-	-	1	7	-	-
130 - 134	-	-	-	2	7	-	-
135 - 139	-	-	-	2	6	-	-
140 - 144	-	-	-	-	9	4	-
145 - 149	-	-	-	-	1	5	2
150 - 154	-	-	-	-	1	9	-
155 - 159	-	-	-	-	2	7	1
160 - 164	-	-	-	-	-	5	4
165 - 169	-	-	-	-	-	3	8
170 - 174	-	-	-	-	-	3	5
175 - 179	-	-	-	-	-	1	4
180 - 184	-	-	-	-	-	-	1
185 - 189	-	-	-	-	-	-	1
190 - 194	-	-	-	-	-	-	1
N	65	73	68	56	37	37	27

Tabla 4. Valores numéricos de las distribuciones de tallas retrocalculadas al final del anillo invernal. (Edades 1-7).

Table 4. Numeric values of the size distributions back-calculated to the end of the winter ring. (Ages 1-7).

AGE	1	1	2	2	3	3	4	4	5	5	6	6	7	7
N	65	65	73	73	68	68	56	56	37	37	37	37	27	27
$\bar{X}$ (FL cm)	45	47.90	67.18	70.29	89.10	92.93	107.79	114.18	129.30	136.30	150.49	156.70	164.04	170.07
σ	3.04	3.56	6.83	6.59	7.10	7.23	8.69	9.62	8.95	9.13	9.53	9.10	10.06	9.63
Sy Sx (Int. Conf. 95%)	44.26 45.74	47.03 48.77	65.60 68.76	68.77 71.81	87.41 90.79	91.21 94.65	105.51 110.07	111.66 116.70	126.42 132.18	133.36 139.24	147.42 153.56	153.77 159.63	160.25 167.83	166.44 173.70

Tabla 5. Tamaños retrocalculados al inicio y final de la formación del anillo invernal (la diferencia entre ambos es el crecimiento experimentado durante el invierno).

Table 5. Sizes back-calculated to the beginning and end of the formation of the winter ring. (The difference between both indicates the growth during the winter).

<----LAST RING---->					<----SAMPLE VALUES---->			
AGE 1	SPINES (N)	σ (mm)	X (mm)	SY/SX	N	σ (cm)	FL (cm)	SY/SX
JUNE	23	0,069	0,22	0,19 0,25	23	1,48	57,7	57,1 58,3
JULY	21	0,096	0,28	0,18 0,26	21	2,73	57,7	56,5 58,9
AUGUST	10	0,078	0,32	0,27 0,37	9	2,00	60	58,7 61,3
SEPT.	32	0,13	0,51	0,46 0,56	32	2,38	61,1	64,3 65,9
OCT.	35	0,20	0,67	0,60 0,74	34	3,47	67,4	66,3 68,5

<----LAST RING---->					<----SAMPLE---->			
AGE 2	SPINES (N)	σ (mm)	X (mm)	SY/SX	N	σ (cm)	FL (cm)	SY/SX
JUNE	40	0,062	0,16	0,14 0,18	40	2,95	75,3	74,3 76,1
JULY	35	0,12	0,27	0,23 0,31	35	5,16	80,0	78,3 81,7
AUGUST	33	0,12	0,38	0,34 0,42	33	4,88	80,3	78,7 82,0
SEPT.	39	0,17	0,66	0,61 0,71	39	4,34	88,4	87,1 89,8
OCT.	36	0,14	0,75	0,70 0,80	35	3,20	88,4	89,5 87,3

<----LAST RING---->					<----SAMPLE---->			
AGE 3	SPINES (N)	σ (mm)	X (mm)	SY/SX	N	σ (cm)	FL (cm)	SY/SX
JUNE	35	0,046	0,15	0,13 0,17	35	5,49	93,9	92,1 95,7
JULY	44	0,067	0,28	0,26 0,30	44	6,14	101,8	99,9 103,6
AUGUST	42	0,13	0,46	0,42 0,50	41	8,65	102,8	100,1 105,4
SEPT.	20	0,11	0,76	0,71 0,81	20	2,48	109,5	110,5 108,4
OCT.	35	0,15	0,81	0,76 0,86	35	3,58	109,3	108,1 110,5

Tabla 6. Valores numéricos pertenecientes a la evolución del último anillo visible en espinas y su correspondiente transformación en tamaños para el atún rojo del Mar Cantábrico. (Edades 1-3).

Table 6. Numeric values of the last visible ring on the spines and their corresponding conversion to sizes for bluefin tuna from the Cantabrian Sea. (Ages 1-3).

AGE (YEARS)

FL(cm)	6	7	8	9	10	11	12	13	14	15	16	17	18	19
170-174	2	2	1	1										
175-179		3	2											
180-184	1	2	1	4	1									
185-189				5	1									
190-194			1	5	2	1								
195-199			1	6	4	1								
200-204				1	4	4								
205-209			1	1	4	6								
210-214					1	4	3	1						
215-219					3	6	8							
220-224					3	6		3	3					
225-229						8	4	4	1	1				
230-234					1	2	4	6	4	2				
235-239							2	2	1	3				
240-244								4		5	2			
245-249									5	1				
250-254								1	1	2	1			
255-259									2	3				
260-264									1	2		1		
265-269									1	2				
270-274													1	
275-279														
280-284												1		
285-289													1	
290-294														
295-299														
300-304														1
N	3	7	7	23	24	38	21	21	19	21	3	2	2	1
FL (cm)	-	-	-	191	206	216	222	232	242	247	-	-	-	-

	9	10	11	12	13	14	15
Int. Conf. (95)%	187.8	201.4	212.6	219.0	228.4	235.3	242.0
	194.0	211.0	219.6	226.0	236.3	247.9	252.4

Tabla 7. Clave talla/edad del atún rojo capturado en las almadrabas del sur de España.

Table 7. Size/age key of bluefin tuna caught by traps off the south of Spain.

AGE	MAY	JUNE	JULY	AUGUST	SEPT.	OCT.	NOV.
	-	3,5	3,6	4,0	4,8	6,2	6,4
1	2,8	4,1	4,7	4,8	5,9	6,8	7,6
	-	7,7	8,8	9,0	10,5	13,4	15,2
2	7,9	9,3	10,6	12,5	12,8	16,0	16,3
	-	15,2	14,7	17,0	19,8	27,6	-
3	15,2	17,6	19,8	22,9	26,2	32,0	-
	-	27,9	28,8	32,4	36,3	-	-
4	-	30,4	37,0	41,5	42,4	-	-
	-	42,0	49,1	49,5	55,4	-	-
5	-	48,0	55,8	61,4	64,3	-	-
6			66,9 - 79,6				
7			86,4 - 101,3				
8			109,3 - 117,7				

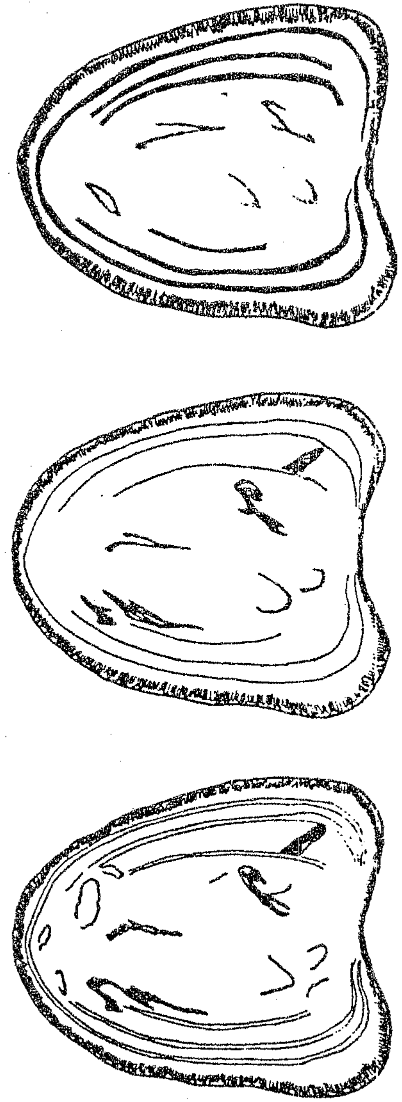
Tabla 8a. Límites de peso por edad y tiempo en el atún rojo del Mar Cantábrico.

Table 8a. Range of weights by age and by month for bluefin tuna from the Cantabrian Sea.

AGE	MAY	JUNE	JULY	AUGUST	SEPT.	OCT.	NOV.
	-	55.5	55.7	57.8	61.7	66.2	67
1	50.9	58.3	61.2	61.7	65.1	68.4	71.1
	-	72.1	76.5	77	81.4	88.8	92.9
2	73.6	77.1	81.7	86.6	87.4	94.6	95.2
	-	91.9	91.8	96.6	102	111.6	-
3	92.9	96.7	102	107.4	112.7	117.6	-
	-	115.2	116.5	121.5	126.5	-	-
4	-	118.8	127.4	132.7	133.7	-	-
	-	132.2	140.9	141.3	147	-	-
5	-	139.7	147.4	152.5	155	-	-
6			157.2 - 161.7				
7			166.4 - 175.9				
8			180.7 - 185.4				

Tabla 8b. Límites de talla por edad y tiempo en el atún rojo del Mar Cantábrico.

Table 8b. Range of sizes by age and by month for bluefin tuna from the Cantabrian Sea.



3

2

1

Figura 1. Cortes de espinas de atún rojo mostrando tres tipos de anillos y las zonas intercalares.
1. Anillo doble
2. Anillo sencillo fino
3. Anillo sencillo grueso

Figure 1. Spine sections of bluefin tuna showing three types of rings and the intercalary areas.
1. Double ring (couplet)
2. Single, thin ring
3. Single, thick ring

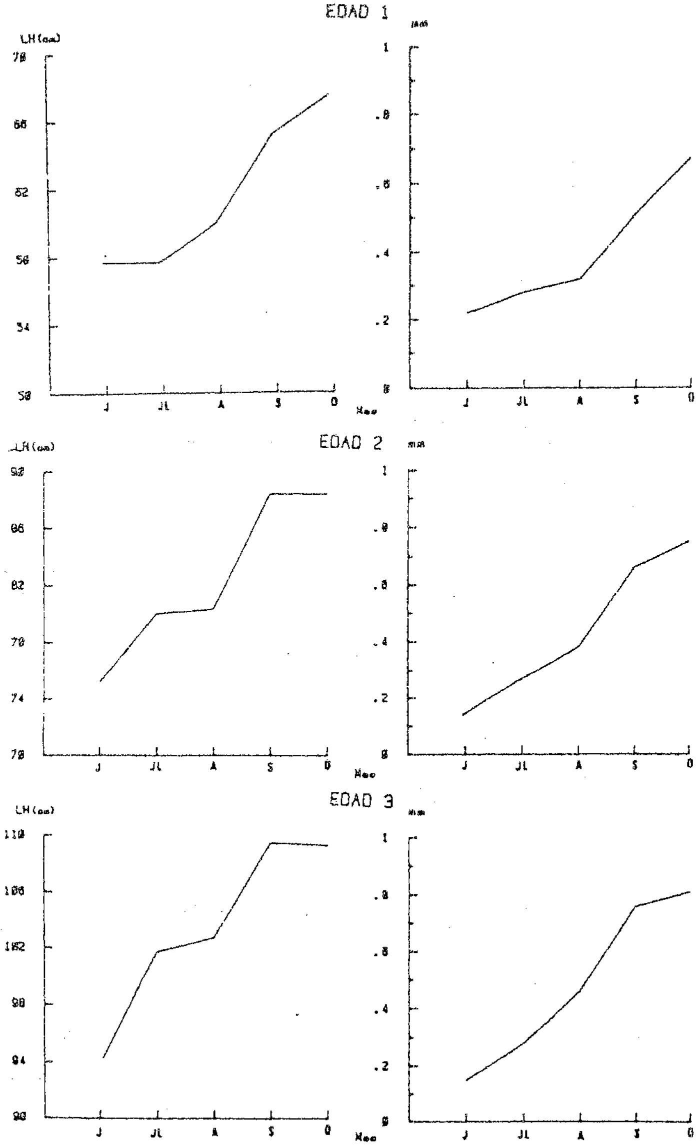


Figura 2. Evolución del último anillo visible en la espina del atún rojo del Mar Cantábrico (derecha) y su transformación en tamaño a la LH (izquierda).

Figure 2. Development of the last visible ring on the spine of bluefin tuna from the Cantabrian Sea (right panel) and conversion to size in fork length (FL) (left panel).

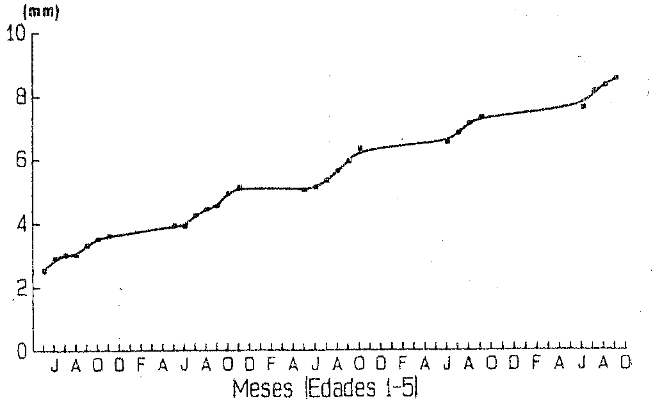


Figura 2b. Evolución estacional del diámetro de la espina de atún rojo, calculada a partir del último anillo visible (clases de edad 1-5). (Los puntos indican los meses en los cuales hay muestras).

Figure 2b. The seasonal development of the diameter of the spine of bluefin tuna, calculated from the last visible ring (age classes 1 to 5). (The dots indicate the months for which samples are available)

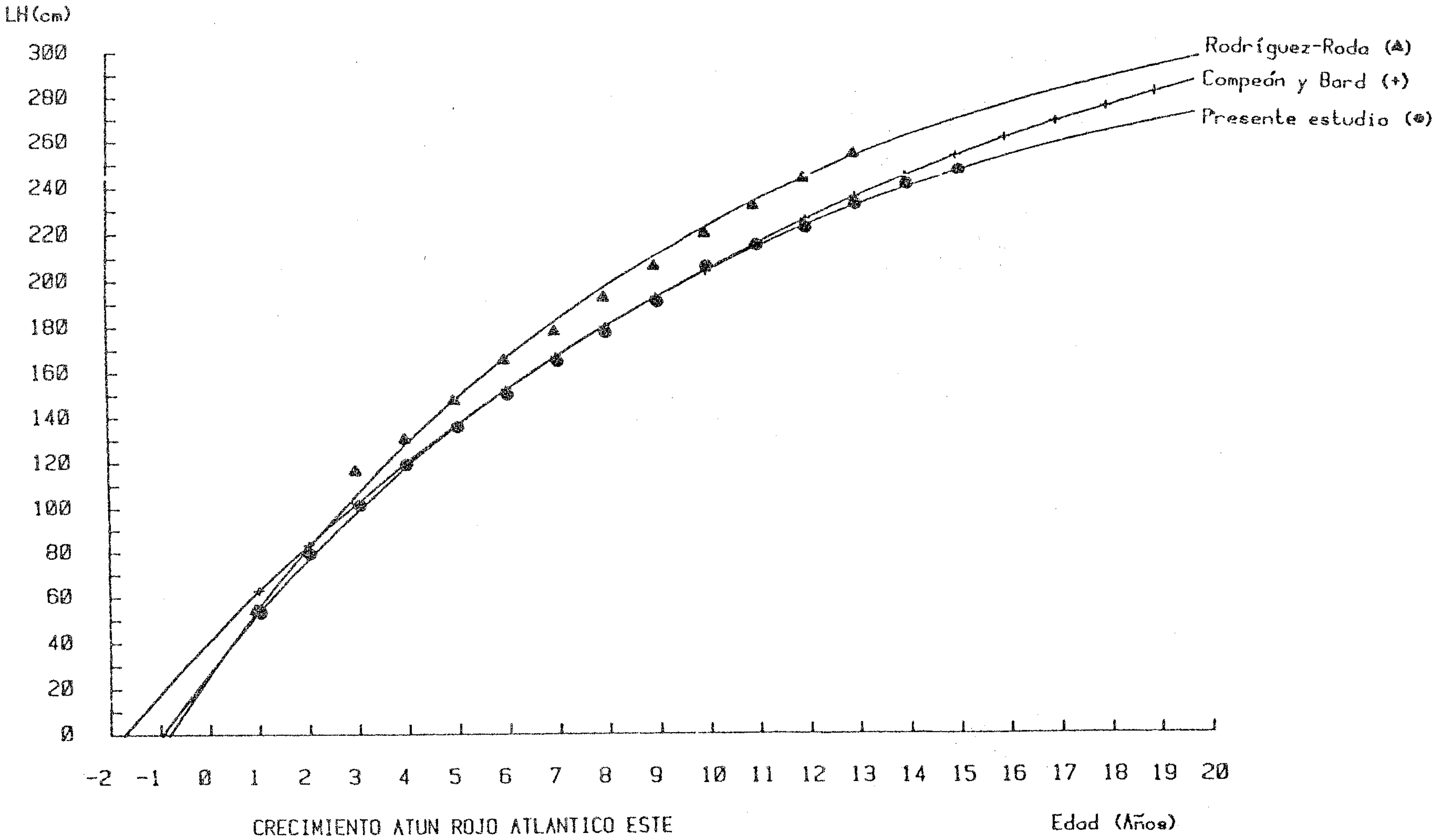


Figura 3. Crecimiento de atún rojo del Atlántico Este según distintos autores.

Figure 3. Growth of East Atlantic bluefin tuna according to different authors.

PHOTOGRAPH CAPTIONS

Photograph nº 1

Thunnus thynnus (East Atlantic)

FL = 84 cm

Tag number: K9760
Date of tagging: 08/29/1984
Date of recovery: 06/13/1985

Spine: 4.82 mm (diameter)

Photograph nº 2

Thunnus thynnus (Cantabrian Sea)

FL = 112 cm

Date caught: 10/21/1985

Spine: 6.92 mm (diameter)

Photograph nº 3

Thunnus thynnus (Mediterranean Sea)

Weight: 17.3 kg
FL = 96 cm
Date caught: 04/23/1986
Location: Gulf of Lion

Spine: 5.29 mm (diameter).

Photograhp nº 4

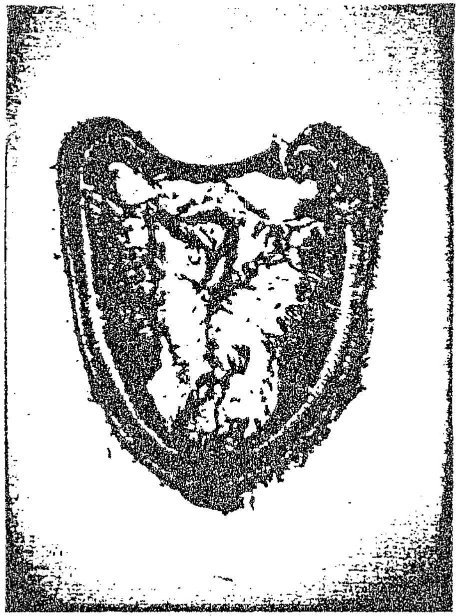
Thunnus thynnus (Mediterranean Sea)

FL : 51 cm

Date caught: 07/14/1983
Location: 37°N/05°E (Algerie)

Spine: 2.58 mm (diameter).

1



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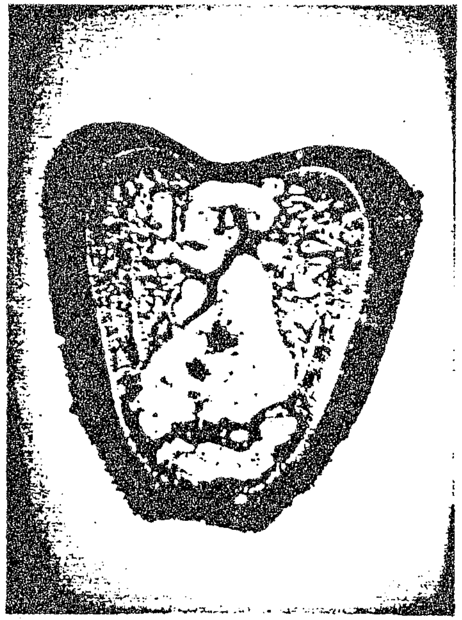

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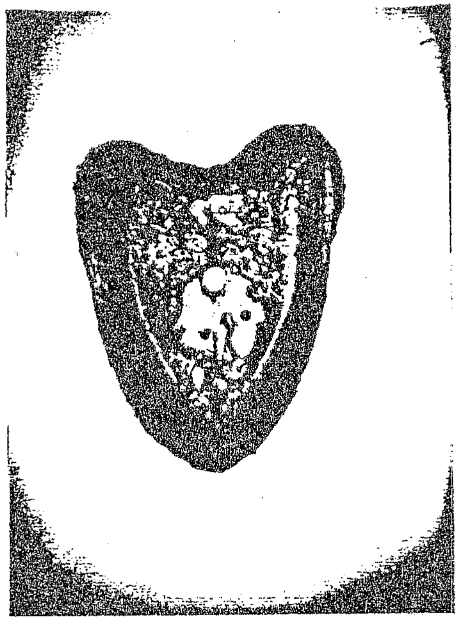

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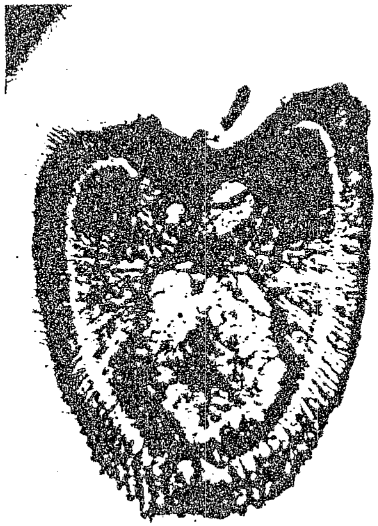

COMMENTS ON THE PHOTOGRAPHS

Nº 1. The section of this spine corresponds to a bluefin tuna that had just become 3 years old.

It has three winter rings. The first one, which is hard to distinguish from the reabsorbed area of the spine, has a diameter of 2.1 mm; the second is 3.9 mm, and the last ring, formed during winter which had recently ended, is 4.6 mm.

From the time of capture, in the spring, and the area (42ºN/12ºW), in migration towards the Bay of Biscay, it can be seen that the ring was not formed during migration.

The slight growth observed from the end of winter (last visible ring) and the end of the spine (time of recovery), is formed during the time of active growth. The ring, therefore, begins to form before fish migration towards the Bay of Biscay.

In this particular case, involving a bluefin which was tagged and recovered, and for which its measurements are known, the fish shows a lesser growth than that corresponding 3 year-old bluefin. Precisely in the summer when it was tagged, lesser growth is observed. This tagging experiment could have had some effect on the active growth of the fish.

Nº 2. This is a section of a spine of a 3 year-old bluefin tuna which is at the end of its active growth period.

Only two rings are visible (the first is reabsorbed in the central area of the spine). The second winter ring has a daimeter of 3.6 mm and the last one 5.2 mm.

It is verified that the active growth period corresponds to the opaque area of the spine. In this case there was considerable growth during summer (at least 15 cm) which ceased one month before the fish was caught.

The last winter ring is very far from the edge of the spine.

Nº 3. This shows a fin ray spine of a bluefin tuna caught in the Mediterranean Sea. This fish is not yet 3 years old, but it has lived 3 winters.

Part of the first ring is difficult to see in the reabsorbed area of the spine. The diameter of the ring is 2.0 mm. The second ring is 3.4 mm in diameter and the third is 5.1 mm.

This sample shows that as occurs in the Atlantic, Mediterranean bluefin tuna form the ring during winter, and therefore these are considered winter rings.

This fish, which was caught in early spring, has the last ring next to the edge of the spine, which shows that its formation ended recently. Since then it has experienced through slight growth (such as occurred with the sample in photograph nº 1) which will be completed at the end of fall (which is the end of the active growth period).

Nº 4. This shows a one-year old bluefin tuna, supposedly born in the Mediterranean Sea, caught off the coast of Algeria.

Only one ring measuring 2.0 mm diameter which formed during the past winter, can be seen. The back-calculated size of this bluefin when it formed the ring was 42 cm (FL), and it had since the grown 9 cm that form part of active growth in the outside opaque area of the spine.

Considering that the only known spawning area for the East Atlantic bluefin tuna is the Mediterranean Sea, the winterly aspect of the ring is obvious, as is the case of the other samples studied in these photographs.

Compeán-Jiménez (1980) attribute the formation of the first ring during the fall, for bluefin tuna (age class 0) which migrate across the Strait of Gibraltar. Sample nº 4 indicates that 1 year- old tuna which did not cross the Strait, have this ring in the fin ray spines.