STUDIES ON EASTERN ATLANTIC BLUEFIN TUNA (*THUNNUS THYNNUS*) MATURITY – REVIEW OF OLD LITERATURE

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SUMMARY

A brief review of the some of the most significant ancient studies on sexual maturity and reproductive biology of eastern Atlantic bluefin tuna was carried out. A special attention was put on the works of Rodriguez-Roda and Frade, and in particular on the study of the fish size at first maturity. All these studies are well-known, but they are quite often forgotten in recent papers on bluefin tuna biology. Due to the recurrent discussions about the sexual maturity of eastern bluefin tuna, a summary of their findings can be useful.

RÉSUMÉ

Un bref examen a été réalisé de quelques-unes des études anciennes les plus importantes consacrées à la maturité sexuelle et la biologie reproductive du thon rouge de l'Atlantique Est. Une attention particulière a été accordée aux travaux de Rodriguez-Roda et de Frade et en particulier à l'étude sur la taille des poissons à la première maturité. Toutes ces études sont bien connues, mais elles sont assez souvent oubliées dans les récents documents sur la biologie du thon rouge. En raison des discussions récurrentes sur la maturité sexuelle du thon rouge de l'Est, un résumé de leurs conclusions pourrait s'avérer utile.

RESUMEN

Se llevó a cabo una breve revisión de algunos de los estudios antiguos más importantes sobre madurez sexual y biología reproductiva del atún rojo del Atlántico oriental. Se prestó especial atención a los trabajos de Rodríguez-Roda y Frade, y en particular al estudio sobre la talla de primera madurez de los peces. Todos estos estudios son muy conocidos, pero a menudo son olvidados en los documentos recientes sobre biología del atún rojo. Debido a discusiones recurrentes sobre la madurez sexual del atún rojo del este, un resumen de sus hallazgos podría ser útil.

KEYWORDS

Bluefin tuna, Maturity, Review

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1. Introduction

In spite of the centuries of studies of the Atlantic bluefin tuna (*Thunnus thynnus*), some of the most basic aspects of its biology are still uncertain. There is still a lot of controversy regarding the reproduction of this species, in particular its sexual maturity and spawning habits. Considering the amount of research which have been devoted to these issues, positive information on its spawning habits is surprisingly still incomplete (Matters *et al*., 1995), even if many important details have been made clear since years. An additional problem seems created by the fact that many old studies were published in various national languages. Even if the scientific literature on the last two centuries about the eastern bluefin tuna biology has been recently summarised and reviewed (Piccinetti *et al*., 2014), there is a great and ongoing demand for additional scientific research that would provide further insights on this subject. As a modest attempt to contribute to the current research, and as asked for by the SCRS Bluefin Tuna Species Group in its last meeting, we undertake a brief review of some of the existing literature on maturity studies, focusing almost exclusively on the studies carried out in the Iberian peninsula until the '60s) that we thought have been unjustifiable forgotten or overlooked.

Many of the assumptions made by Rodiguez-Roda in the '60s are still very valid (particularly those on the bluefin tuna reproductive biology), while others should be regarded according to the knowledge about the migratory patterns that were available at that time (almost all coming from the observation of tuna trap fisheries) and that were "biased" by the general lack of data coming from offshore fisheries, but also by the lack of the most recent data obtained by the electronic tags. Only in the late '70s, mostly thanks to the many studies by Arena (the list is provided by Piccinetti *et al*., 2014, along with the list of papers wrote by Rodriguez Roda), it was possible to have a broader overview of the offshore migrations of bluefin tunas in the Mediterranean Sea, further improved with most recent technologies and several studies by various scientists in the late '90s and in the following years.

As a matter of fact, this paper just reviews the original data provided by the two authors (Rodriguez Roda,, 1964, 1967; Frade, 1950; Frade and Vilella, 1962) about the maturity of eastern bluefin tuna.

2. Atlantic-Mediterranean migration and trap fishery terminology

Rodriguez-Roda (1964, 1967) conducted his studies in the tuna traps located in the Gulf of Cadiz (east Atlantic, Spain) that were fishing bluefin tuna during its seasonal migrations i.e. entering the Mediterranean Sea before the spawning season and exiting the Mediterranean at the end of the spawning season. Depending on the direction of its movement, Rodriguez-Roda distinguished between two groups of bluefin tuna, one that was entering the Mediterranean, the incoming schools, that he called "de derecho" ("arrival" tuna in Mather *et al*., 1995), tunas moving from west to east, and one that was exiting the Mediterranean and was moving conversely (from east to west) and that he called "de reverso" ("return" tuna in Mather *et al*., 1995). The "arrival" tuna could usually be found in the traps from May to the early beginning of July, depending on the trap location, while the "return" tuna are normally found in the same traps from the beginning of July till mid-August.

The "arrival" tunas have a high percentage of body fat and have the gonads in the pre-maturity or maturity stage, while "return" tuna are skinnier and the gonads are in the stage of post-spawning. It is important to mention that the determination of tuna as "arrival" or "return" was mostly based on the state of maturity and the direction of the fish rather than on the date on which they arrive at the trap. Additionally, captures of some "arrival" tuna in the plain "return" tuna fishing season were not unusual at all at that times[2].

3. Spawning season

Rodriguez-Roda (1964) noted that the mean bluefin length in the Atlantic Spanish traps tends to be higher at the beginning of the trap fishing season, than at its end. He attributed that situation to the fact that, in case most animals migrate, the old and more experienced ones are the first initiating the migration, only later to followed by the younger ones. Moreover, he hypothesized that the gonads of older migrant tuna maturate earlier in the spawning season than those of the younger migrant ones[3].

[2] Recent anecdotic information from Spanish tuna trap fishery masters ("Rais" or "Arráez") reports that this situation is not unusual even in recent years.

[3] The undefined fraction of the stock which remains in the Mediterranean Sea, overwintering there, was not considered by the Rodriguez-Roda, because these tunas were not among the catches of migrant tunas in the Atlantic Spanish traps.

This theory was corroborated by Mather *et al*. (1995), who affirmed that, while larger migrant individuals spawn mainly in the last half of June[4] and the first half of July, the smaller ones (which have reached the maturity) spawn later, throughout July and into August, and occasionally even into September. It has to be noted, though, that this is the case for south-central Mediterranean only, while in other parts of the Mediterranean the bluefin follows other spawning schedule.

4. Length-weight relationship

A study of the bluefin tuna length-weight relationship conducted by Rodriguez-Roda (1964) at the tuna traps fishing for both "arrival" and "return" tuna showed clear distinction of these two groups of bluefin tuna (**Figure 1** and **Figure 2**). These results were expected, having in mind that "arrival" tuna is fatter and has full gonads, while the "return" one is thinner and has empty gonads. Weight/length relationship is the same for both types of tuna while they are juveniles and it starts to differ when the first individuals reaching sexual maturity, which is around FL=115 cm.

5. Maturity stages and gonadal development

Frade (1950) established a scale of sexual maturity by means of histological study of the gonads and determination of a ponderal index (the weight of the gonads in relation to the weight of the body or the head), for the bluefin tuna fished by traps in Algarve (Portugal). While the correlation of the head weight with the size of the fish is more regular, the correlation of the entire body weight with the size varies more, depending to the level of the nutrition and the stage of the gonads (both are condition factors). Therefore, Frade established an index by simply calculating the weight of the gonads in correlation to the body length. According to this index (different for female and male), he distinguished between 7 different stages of maturity: A and B – tuna with full mature gonads; C and D – intermediate stage; and E, F and G – tuna with empty gonads at various stages. The scale was further tuned by histological examination of gonads (**Table 1**). Frade found that, during June, the frequency of stages A and B successively decreased for both sexes, in July prevailed females in stage C and males in stage B, while there were also some females in stage E and males in stages E-F; in August prevailed females in stages D-E while the stage A was missing, and males in stages B-C. Also, in August there were some fish in stage G, of both sexes.

In order to determine the state of maturity of bluefin tuna, Rodriguez-Roda (1964) established an empirical scale based on the observations of gonadal development during the different stages of maturity:

- I Immature. Gonads of rosy colour.
- II Pre-mature. Male gonads violaceous and female rose coloured.
- III Mature. Male gonads rose or white-pinkish coloured and female pinkish yellow or yellowish coloured.
- IV Pre-spawning. Male gonads milky violetish coloured.
- V Spawning.
- VI Post-spawning. Male and female gonads violetish coloured.

Given that Rodriguez-Roda only observed tunas captured by the Atlantic traps, it means that he could observe "arrival" tuna only prior to the spawning (in stages I, II and III) and "return" tuna after spawning season (stage VI). During the months of May and June, the majority of sampled tunas in these traps was in pre-spawning phase, while in July and August the majority was in the post-spawning phase (**Table 2**).

6. Gonadosomatic relationship

As another measure for sexual maturity, Rodriguez-Roda (1964) studied the gonadosomatic index (relative fecundity in correlation to ovary development and testes development), according to the formula: GSI = [Gonad Weight / Total Tissue Weight] x 100. He calculated the index for each sampled fish and then grouped it according to size, sex, phase and monthly 10-days period, in order to get the correlation between the fish fork length and the gonadosomatic index (**Table 3** and **Table 4**). It can be observed that the index increases with the length of the fish. Additionally, observing the mean index by a 10-days period it can be noted that it is the highest in June for both females and males ("arrival" tunas), while it decreases significantly in the months of July and August ("return" tuna). Rodriguez-Roda (1964) believed that these results were indicating that the period of spawning was at the beginning of July. Finally, the gonadosomatic index is generally higher for females than for males.

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[4] Matter *et al*. (1995) were missing the detailed information about the spawning area in the Balearic Sea, which may have bluefin tuna spawning activities also from May.

Rodriguez-Roda (1964) also studied the correlation between the fish length and the gonad weight and he represented it graphically (**Figure 3** and **Figure 4**). This relationship is showed separately for females and males, and by separating "arrival" and "return" tuna. Rodriguez-Roda found a positive correlation between these two factors. However, it should be noted that the biggest part of the "arrival" tuna gonads were in the III stage of maturity, while only few were in the II and the IV stage. Similarly, all "return" tunas were in the VI stage of maturity. The equations for calculating the gonad weight from known fish length, depending on the sex and state of maturity are shown in the **Table 5**.

Rodriguez-Roda (1967) studied as well the length of the gonads in correlation to the length of the fish. As two gonads of the same bluefin individual are usually of different size, being the right gonad normally the longer one, he used only the length of the right gonad for the calculation of this relationship. The results were represented in a scatterplot, separately for females and males and maturity stage, according to the type of migration (**Figure 5**). A relationship between the length of the gonads and body is not clearly visible, because the CVs are very big. The author explains the lack of clear relationship by the small number of samples or imprecise measurement of gonads. Nevertheless, a relationship does exist and Rodriguez-Roda provided several equations for relating the length of the fish and its gonads, depending on the sex and the maturity stage (**Table 6**). In the same study, he also published the equations for the correlation between gonads length and weight (**Table 7**) and showed their relationship on the scatterplot (**Figure 6**).

7. Size at first maturity

In the Mediterranean, according to Sella (1929), bluefin tuna becomes able to spawn from age 3, which correspond to the size of 97.5cm and the weight of 15 kg. In some cases of rapid growth, the maturity can already occur at the age of 2, while, likely, in other cases of slow growth, it doesn't occur until the age 4. According to Le Gall (1954), bluefin reaches maturity at the size of 95-105 and at the weight of 12-17 kg.

Frade and Vilela (1962) made a study of the bluefin caught off Portugal (Atlantic coast) and found that specimens of fork length of 65-70 cm have already initiated gametogenesis, while the ones having 1 meter FL are in much more advanced stage, showing signs that have already spawned. Therefore, they assumed that the bluefin reaches its first maturity at the size of 80-90 cm, which corresponded, according to the authors, to the age of 2 years.

Rodriguez Roda (1964) studied stages of maturity of bluefin tuna of different sizes and came to conclusion that the size at first maturity is FL=115 cm, which, according to his calculation, corresponds to bluefin tunas of age 3. He also stressed that this result is corroborated by his studies on bluefin tuna growth, because he found that the growth is rapid precisely up to the length of 115 cm, and after this FL it slows down.

In his later studies on size at first maturity, Rodriguez-Roda (1967) gathered the data from various years of bluefin tuna study (1956-1963). He grouped the fish according to the length classes and studied the percentage of mature fish (in stage II to VI) among total fish, separately for males and females (**Table 8**). He represented the same results on the maturity ogive (**Figure 7**), from which is visible that the first maturity (50% of fish) occurs at the length of FL=97.5 cm for female and FL=105 cm for male bluefin tuna, i.e. both of age 3, according to his calculation.

Taking into account the results of various studies conducted on bluefin tuna, Matter *et al*. (1995) concluded that the first spawning of eastern bluefin occurs at the age 4 (in exceptional cases at age 3 and by the age 6 all or almost all individuals are mature)[5]. Regarding the first spawning of the western Atlantic bluefin tuna, the hypothesized it to be at age 5, although he stressed that more research was needed to prove it.

8. Oocytes size frequency distribution

Rodriguez-Roda (1967) was also interested in bluefin tuna gamogenic development. For this purpose, he studied the oocytes (egg cells) size frequency distribution from 10 female specimens in the maturity stage III (mature fish). Oocytes in the ovarium are clearly of different sizes, depending on their respective maturity stage, but Rodriguez-Roda discovered that their size distribution is plurimodal. In other words, there were several groups of oocytes

[5] The recent review of the large available literature on the biology of eastern bluefin tuna carried out by Piccinetti *et al*. (2014), stated that fish sampled in many areas of the Mediterranean Sea at age 3 are usually 50% mature and 100% mature at age 4. These data mirror the situation of the SSB in the main spawning ground for the eastern bluefin tuna stock and, looking at all papers published in the last 50 years from scientist working in the Mediterranean Sea or in adjacent seas, they reached the same conclusion.

that will be spawned either in various successive phases during the same spawning season, or in various successive seasons, depending on their growth rate. Roda opted for fractioned spawning, but he stressed that the spawning season is probably very short, corroborating his hypothesis by the fact that bluefin tuna suddenly disappears at the end of June in Spanish traps, while still in phase III (mature fish), and re-appears again in July, when it is already in phase VI (post-spawning).[6]

Fractioned spawning was also supported by Frade (1950). He made a histological study of the gonads and demonstrated that the oocytes do not mature at once, but are rather developed and spawned fractionally.

9. Absolute fecundity

Absolute fecundity, i.e. the quantity of mature eggs that a bluefin is able to spawn during the spawning season was studied by Rodriguez-Roda (1967). He presumed that only oocytes whose radius is at least 0.333 mm (for bluefin in III stage of maturity) could be considered mature, as the smaller ones probably cannot achieve maturity during the current spawning season. Rodriguez-Roda counted the number of mature eggs, trying to put it in correlation with bluefin tuna size, weight and gonad weight and came with appropriate equations (**Figure 8**, **Figure 9** and **Figure 10,** respectively). The results show a high fecundity of bluefin tuna, which increases proportionally with size and weight of the fish. As an example, bluefin tuna of 120 cm FL can produce 5,500,000 eggs and one of 230 cm, nearly 30,000,000 of eggs[7].

[6] This assumption was clearly affected by his personal knowledge at that time and was not taking into account several papers published in other Mediterranean countries. As a matter of fact, spawning in the Mediterranean Sea usually occurs from mid-May to the first part of July, but some variability might happen from year to year, depending on climate and oceanography. Migrations from and to the Atlantic are also correlated in time.

[7] Recently, Aranda *et al*. (2013) assessed that a mature bluefin tuna is able to produce 48 eggs g^{-1} in average.

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Table 1. Maturity stages of bluefin tuna according to Frade (1950) – histological findings and the maturity index (relation between the length of the body and the weight of the gonads).

Maturity stage		FEMALE	MALE
A	**Full gonads**	Ovigerous lamellae with some mature eggs. Index=14.3%	Seminal vesicles: thick wall; some spermatozoids in the cavity. Active spermatogenesis. Index=9.5%
B		Mature eggs dominate; some follicles empty. Index=8.3%	Vesicles: thin wall; cavity filled with spermatozoids. Spermatogenesis in course. Index=5.5%
C	**Intermediate stages**	Mature eggs dominate; some follicles in the process of disintegration, some eggs in process of degeneration. Index=5.8%	Vesicles: some full, other already empty. Some still in spermatogenesis. Index=3.9%
D		Some mature eggs; lots of eggs in degeneration. Index =4.5%	Vesicles with some spermatogonial stem cells (beginning of regeneration). Some residual spermatozoids. Index=3.0%
E	**Empty gonads**	Without mature eggs; reabsorption of eggs and advanced disintegration of follicles. Index=3.7%	Vesicles completely coated with spermatogonia. Some residual spermatozoids. Index=2.4%
E-F		Without mature eggs; reabsorption of eggs and advanced disintegration of follicles. Index =3.1-2.7%	Vesicles without residual spermatozoids. Index=2.1-1.8%

Table 2. Percentage of bluefin tuna in different maturity phases by month in Atlantic Spanish traps (Rodriguez-Roda, 1964).

MONTHS	**MALES (N=284)**						**FEMALES (N=495)**					
	I	**II**	**III**	**IV**	**V**	**VI**	**I**	**II**	**III**	**IV**	**V**	**VI**
May			100						100			
June	0.62	3.09	95.06			1.23	0.41	3.26	96.33			
July		1.85	5.55	1.85		90.74			9.46			90.54
August			3.17			96.82			1.06			98.54

Table 3. Correlation between a fork length and a gonadosomatic index, for bluefin tuna captured in the trap of Barbate in 1956, grouped by sex and time of capture (10 days category). N represents the number of samples and M is mean gonadosomatic index (Rodriguez-Roda, 1964).

	FL (cm)	**95-99,5**	**100-104,5**	**105-109,5**	**110-114,5**	**115-119,5**	**120-124,5**	**125-129,5**	**130-134,5**	**135-139,5**	**140-144,5**	**145-149,5**	**150-154,5**	**155-159,5**	**160-164,5**	**165-169,5**	**170-174,5**	**175-179,5**	**180-184,5**	**185-189,5**	**190-194,5**	**195-199,5**	**200-204,5**	**205-209,5**	**210-214,5**	**215-219,5**	**220-224,5**	**N**	**M**
male "arrival"	**1st decade of June**	0,11					0,55				1,3			1,35	1,89		1,21				1,37	1,62	1,13	1,45	1,91			**20**	**1,31**
	2nd decade of June								1,44		1,28				1,66	0,8	1,19	1,18	2,28		1,43	2,48	1,71	2,28		1,22		**22**	**1,48**
	3rd decade of June									1,37	0,96					2	0,97				1,22	2,57	1,96			1,31		**10**	**1,63**
male "return"	**2nd decade of July**																0,69	0,71			1,17	0,69						**5**	**0,89**
	3d decade of July									0,33					1	0,54	0,84		0,51	0,63	0,44	0,57	0,66					**16**	**0,63**
female "arrival"	**1st decade of June**								1,44	0,93	1,36	0,8	1,39		1,46	1,18	0,96			1,8	1,53	1,25	2,06	1,14	1,71	1,83		**37**	**1,53**
	2nd decade of June					1,14			1,55	1,19	1,38	1,71	1,33	2,03	1,09	1,38	1,33	2,5	1,41		1,85	1,01	2,34	1,69		1,55		**36**	**1,51**
	3rd decade of June									1,16				1,9		1,71				1,54	2,02	2,07			1,24			**24**	**1,73**
female "return"	**2nd decade of July**													0,98		1,07	0,84			1,03	1,06	0,94	0,93	0,79	0,82			**26**	**0,92**
	3d decade of July									0,51	0,73	0,8		0,74	0,69	0,78	0,75	0,79	0,82	0,75	0,82	0,75	0,79	0,85				**64**	**0,77**

Table 4. Correlation between a fork length and a gonadosomatic index, for bluefin tuna captured in the trap of Barbate in 1958, grouped by sex and time of capture (10 days category). N represents the number of samples and M is mean gonadosomatic index (Rodriguez-Roda, 1964).

	FL (cm)	120-124,5	125-129,5	130-134,5	135-139,5	140-144,5	145-149,5	150-154,5	155-159,5	160-164,5	165-169,5	170-174,5	175-179,5	180-184,5	185-189,5	190-194,5	195-199,5	200-204,5	205-209,5	210-214,5	215-219,5	220-224,5	225-229,5	230-234,5	235-239,5	240-244,5	245-249,5	250-254,5	255-259,5	N	M
male "arrival"	1st decade of June		2,67		1,9	1,48	1,54	1,29	1,63			1,32	1,3	2,41	1,69		1,38	1,22		2,51	2,13	1,3		1,99						**31**	**1,73**
	2nd decade of June				2,58	1,92				1,39		2,02				1,73	2,06	1,87	1,86	1,07	2,25	1,73								**15**	**1,94**
	3rd decade of June																				2,64	2,76						3,06		**6**	**2,87**
male "return"	2nd decade of July								0,87		1,1				0,8	0,63						0,64	0,9	0,72		0,47	0,61			**12**	**0,72**
	3d decade of July						0,6	0,52			0,66	1	0,68	0,55		0,81		0,44	0,6	0,42						0,48	0,47			**13**	**0,59**
female "arrival"	1st decade of June	0,95		1,54	1,04	2,47	1,25	0,72	2,13	2,02	2,14	1,95		1,5	2,13	1,46	1,33	1,6	1	1,98	1,89	2,11								**41**	**1,65**
	2nd decade of June				1,1	1,78	1,7	1,26	1,4	1,62	1,37	1,64	1,34	1,75	2,05	1,75	1,53		3,14	2,49	2,47		2,17							**38**	**1,68**
	3rd decade of June																							1,94						**1**	**1,94**
female "return"	2nd decade of July						0,77			1,04		1,18	0,9	1,19	1	1,16					0,72	0,74	0,89	0,94						**17**	**0,96**
	3d decade of July			0,77				0,81	0,69	0,8	0,67	0,8	0,92		0,84	0,69	0,88													**24**	**0,8**

Table 5. The equations for calculating of the gonad weight from known length, depending on the sex and state of maturity. W_g is gonad weight in kilograms and L fork length in centimetres, while N is number of samples.

	Males	**Females**
"Arrival"	W_g=0.000000000032*$L^{4.77}$	W_g=0.0000000076*$L^{3.73}$
	(N=110)	(N=181)
"Return	W_g=0.00000041*$L^{2.74}$	W_g=0.00000012*$L^{3.02}$
	(N=45)	(N=132)

Table 6. Correlation between the size of the bluefin tuna and the length of its gonads. L is the fork length (cm) and l the length of the right gonad (cm) (Rodriguez-Roda, 1964).

	FEMALE	**MALE**
"Arrival"-stage III (pre-spawning bluefin)	L=-3.41+4.340812*l l=7.566+0.196126*L	L=27.2+3.426386*l l=5.23+0.229524
"Return"-stage IV (post-spawning bluefin)	L=4.75+3.558865*l l=1.95+0.213720*L	L=158.82+1.306082*l l=-3.2+0.23111L

Table 7. Correlation between the length and weight of bluefin tuna gonads. W is the weight of both gonads (g) and L is length of the right gonad (cm) (Rodriguez-Roda, 1964).

	FEMALE	**MALE**
"Arrival"-stage III (pre-spawning bluefin)	W=0.055434*$L^{2.8}$	W=0.0717*$L^{2.7}$
"Return"-stage IV (post-spawning bluefin)	W=28.337*$L^{0.98}$	W=0.3941184*$L^{2.1}$

Table 8. Number and percentage of mature fish (in phases II to VI) in total fish, for different length classes and in separate for female and male bluefin tuna in Atlantic Spanish traps. The table ends at FL 140 cm because all fish of that length or higher are found to be 100% mature (Rodriguez Roda, 1967).

Fork length classes (cm)	**FEMALE**			**MALE**		
	N total	**N mature**	**% mature**	**N total**	**N mature**	**% mature**
79-79,5	1	0	0	-	-	-
95-99,5	0	-	-	1	0	0
110-114,5	0	-	-	2	2	100
115-119,5	2	2	100	2	2	100
120-124,5	3	3	100	2	2	100
125-129,5	2	2	100	3	3	100
130-134,5	6	6	100	4	4	100
135-139.5	14	14	100	8	8	100

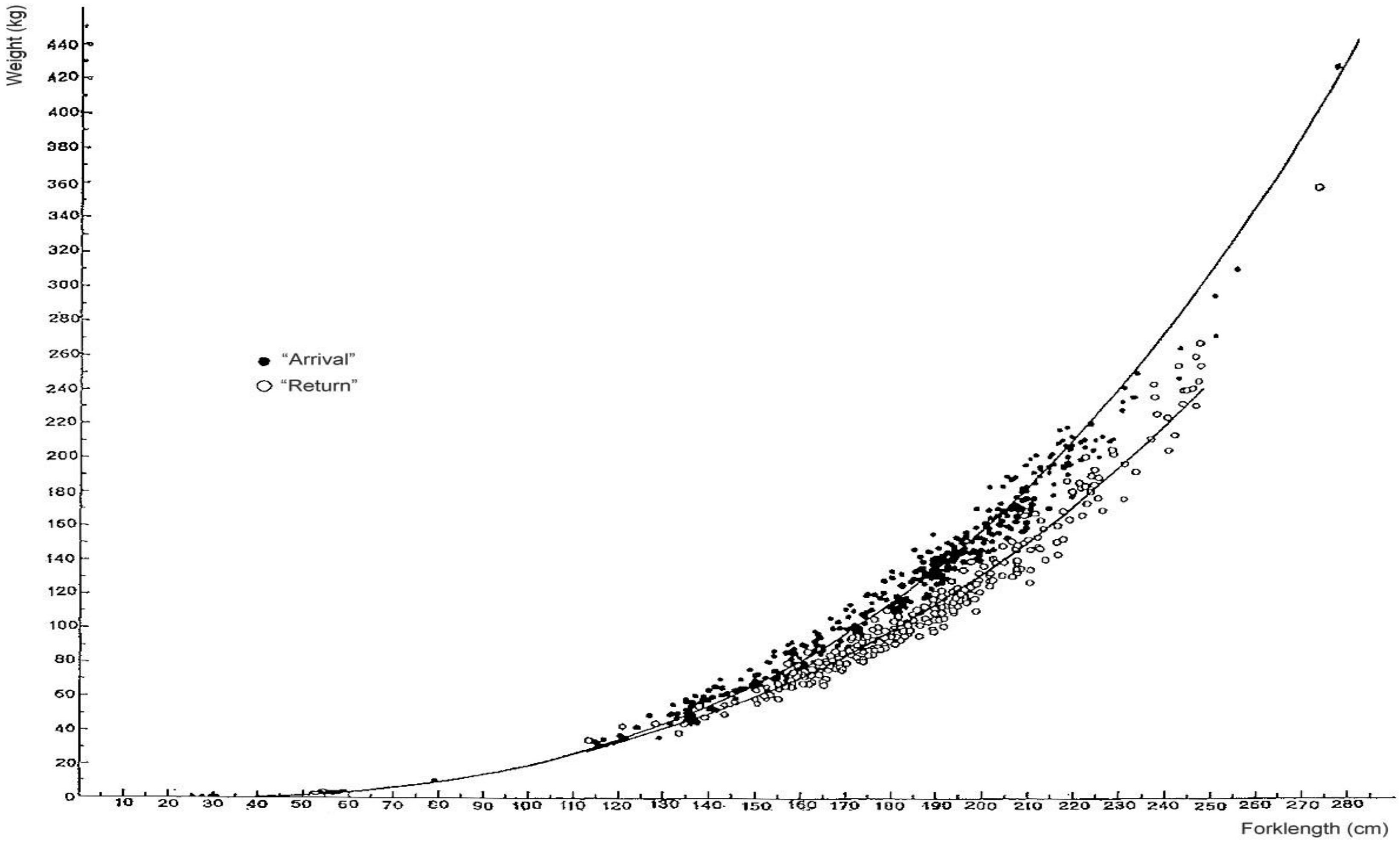

Figure 1. Weight/length correlation of bluefin tuna captured in Barbate trap (1956-1959). "Arrival" refers to the bluefin tunas entering the Mediterranean before the spawning season, while "return" refers to the bluefin tunas exiting the Mediterranean after spawning (Rodriguez-Roda, 1964).

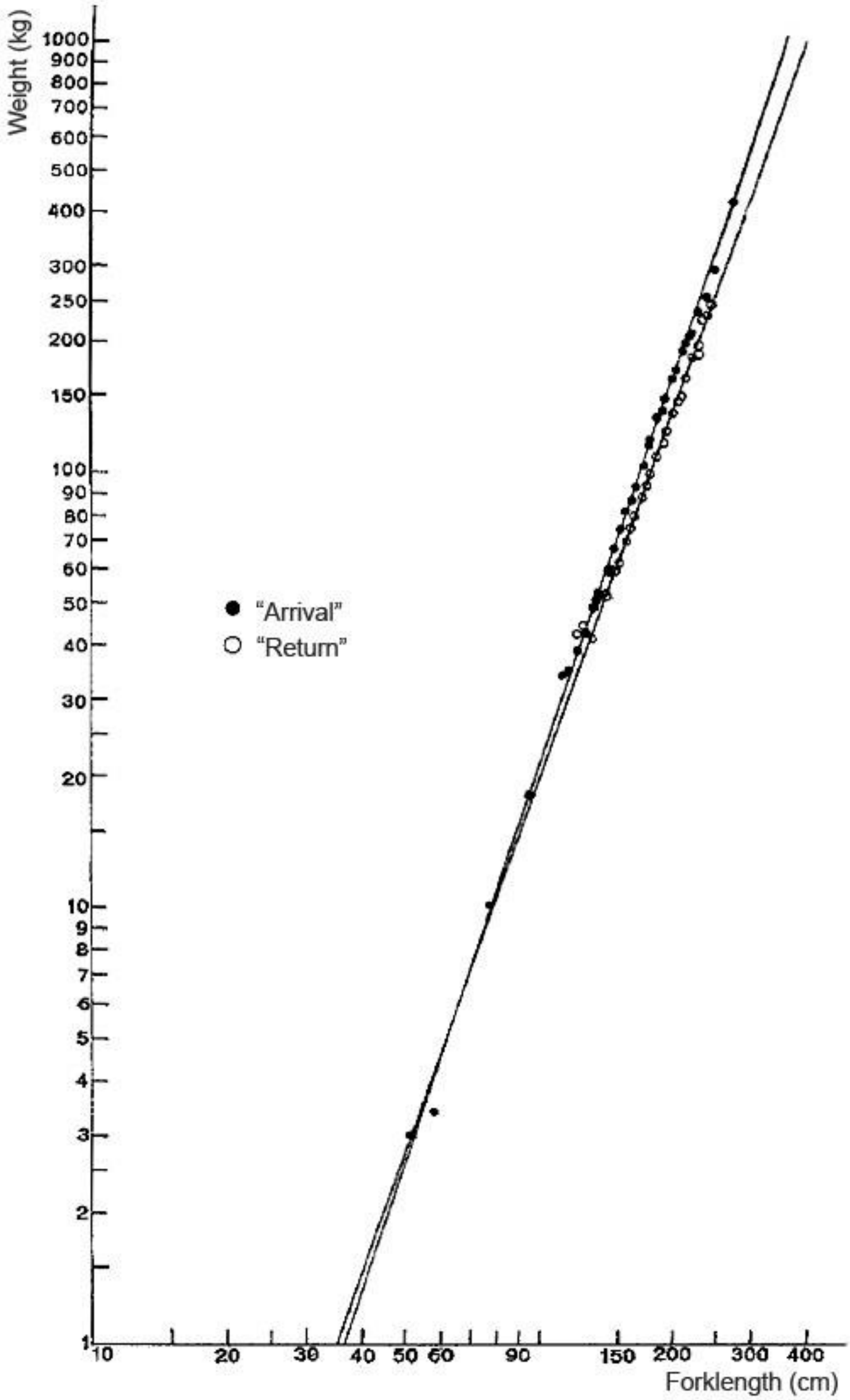

Figure 2. Weight/length correlation of bluefin tuna captured in Barbate trap (1956-1959) on logarithmic scale (Rodriguez-Roda, 1964). "Arrival" refers to bluefin tunas entering the Mediterranean before the spawning season, while "return" refers to bluefin tunas exiting the Mediterranean after spawning.

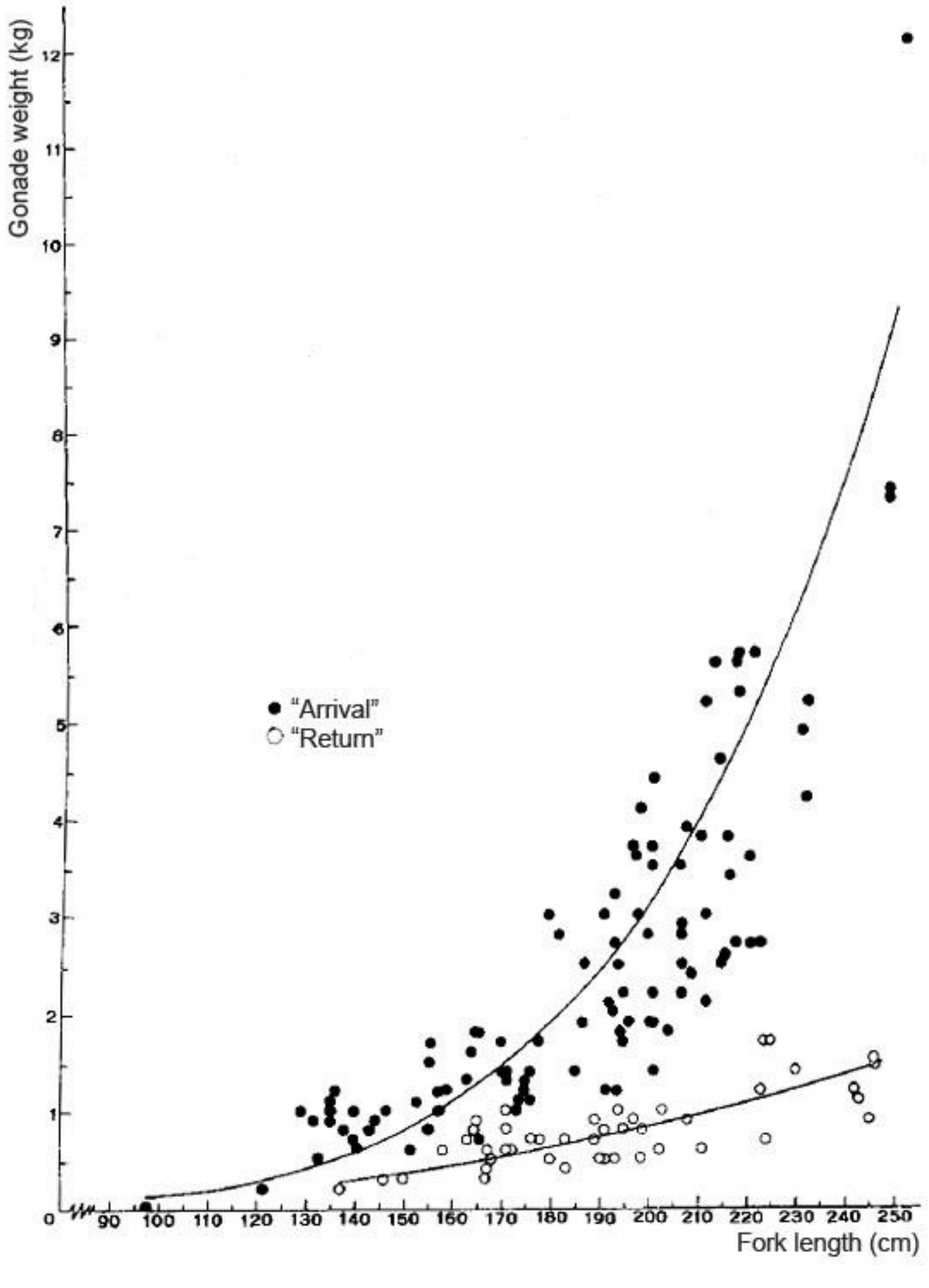

Figure 3. Correlation between the fork length and gonads weight. For "arrival" and "return" male tunas (Barbate, 1956 and 1958) (Rodriguez-Roda, 1964).

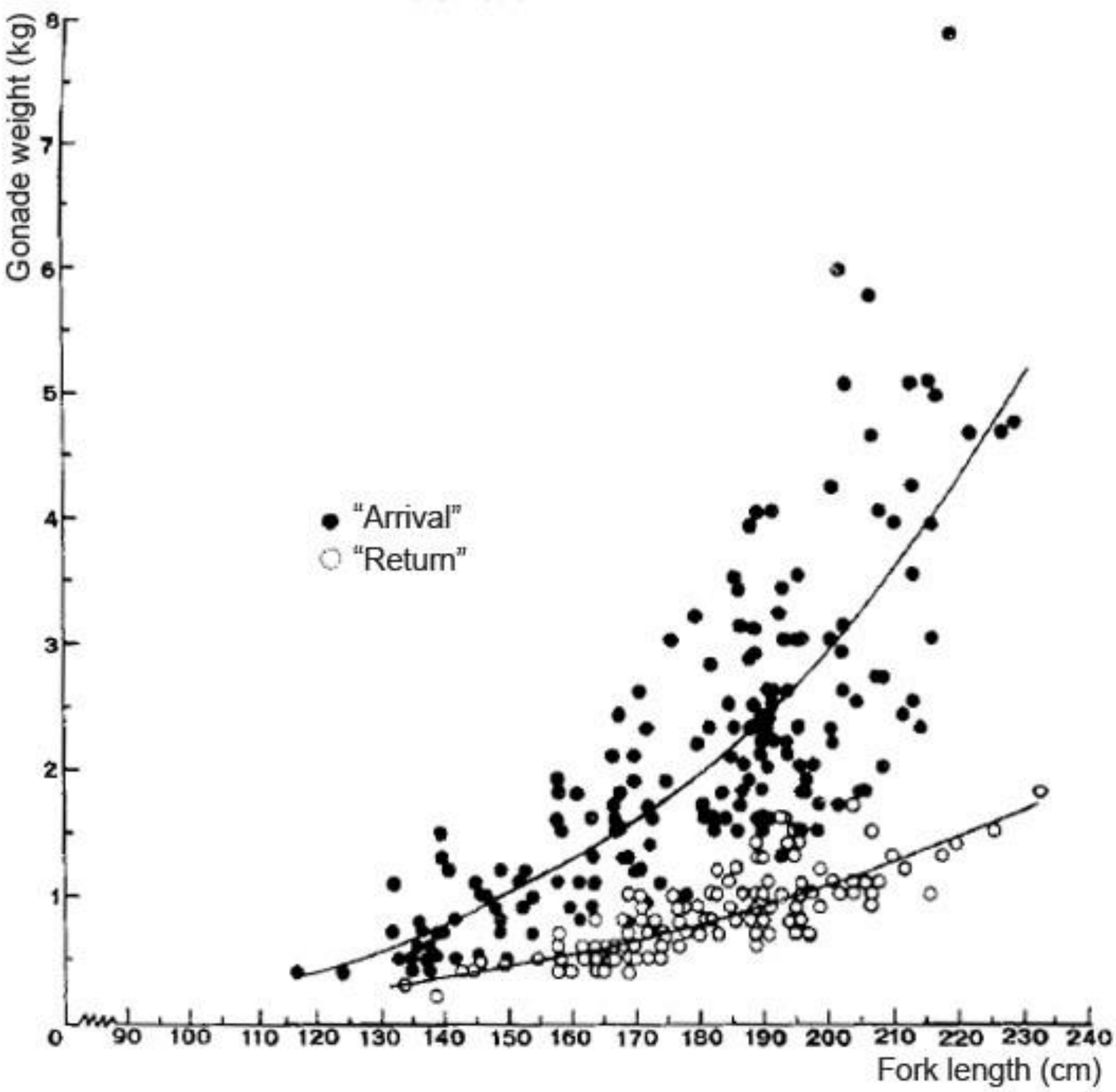

Figure 4. Correlation between the fork length and gonads weight. For "arrival" and "return" female tuna (Barbate, 1956 and 1958) (Rodriguez-Roda, 1964).

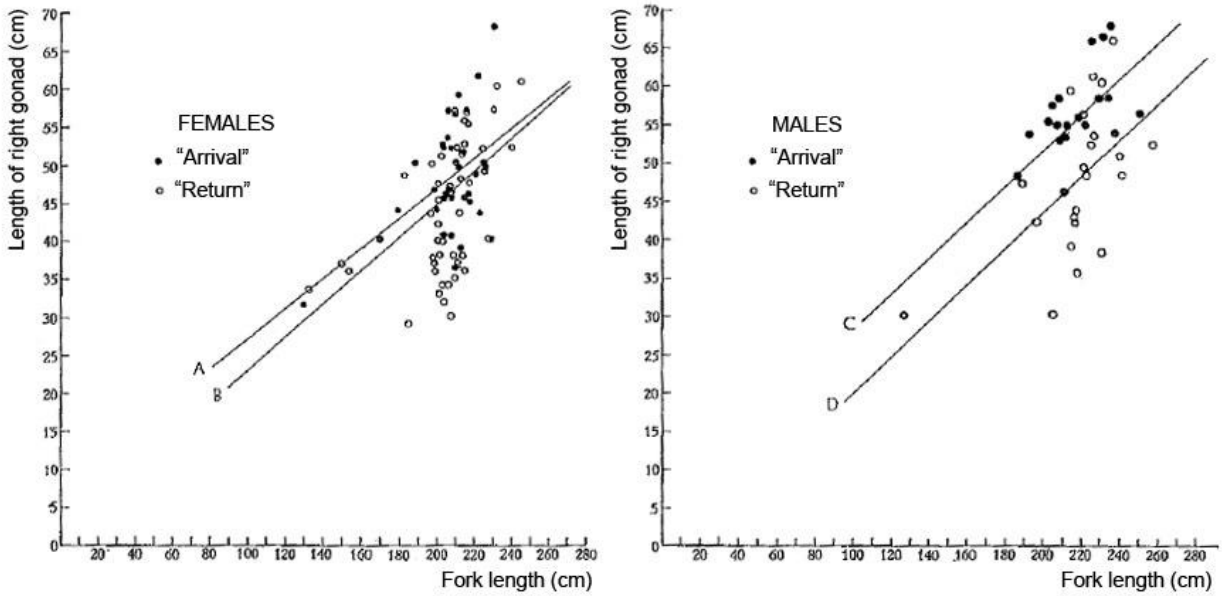

Figure 5. Correlation between the size (fork length, cm) of the bluefin tunas and the length of their respective right gonad (cm), for both "arrival" and "return" tunas and in separate for females and males (Rodriguez-Roda, 1967).

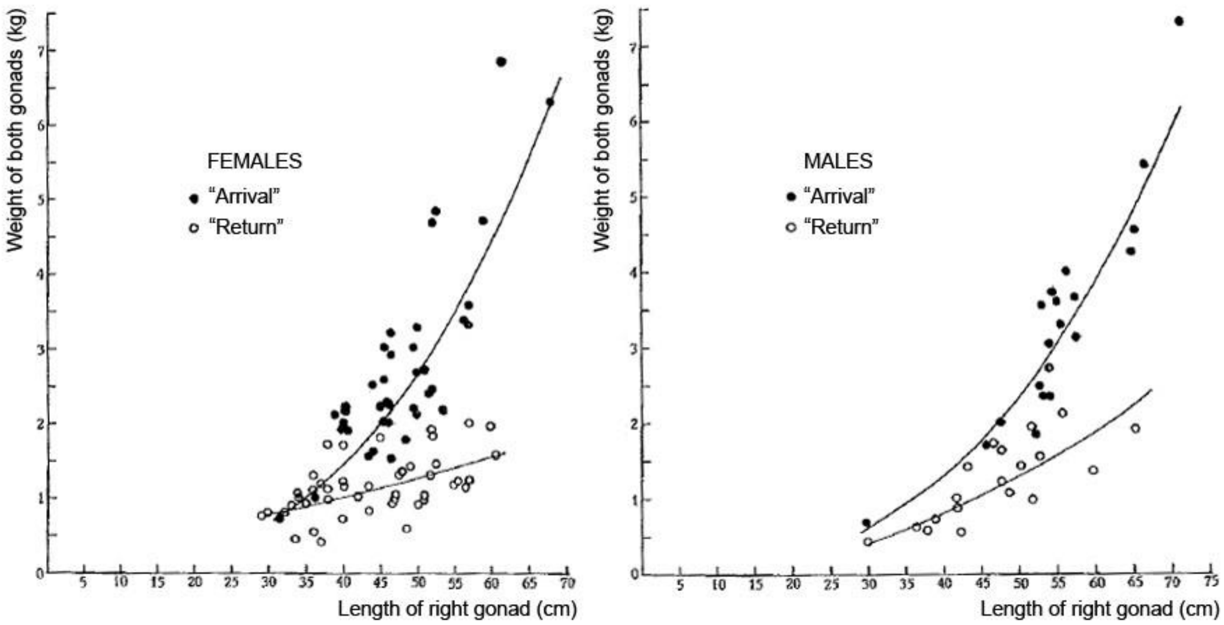

Figure 6. Correlation between the length (right gonad only) and weight of gonads (both gonads), for both "arrival" and "return" tunas and in separate for females and males (Rodriguez-Roda, 1967).

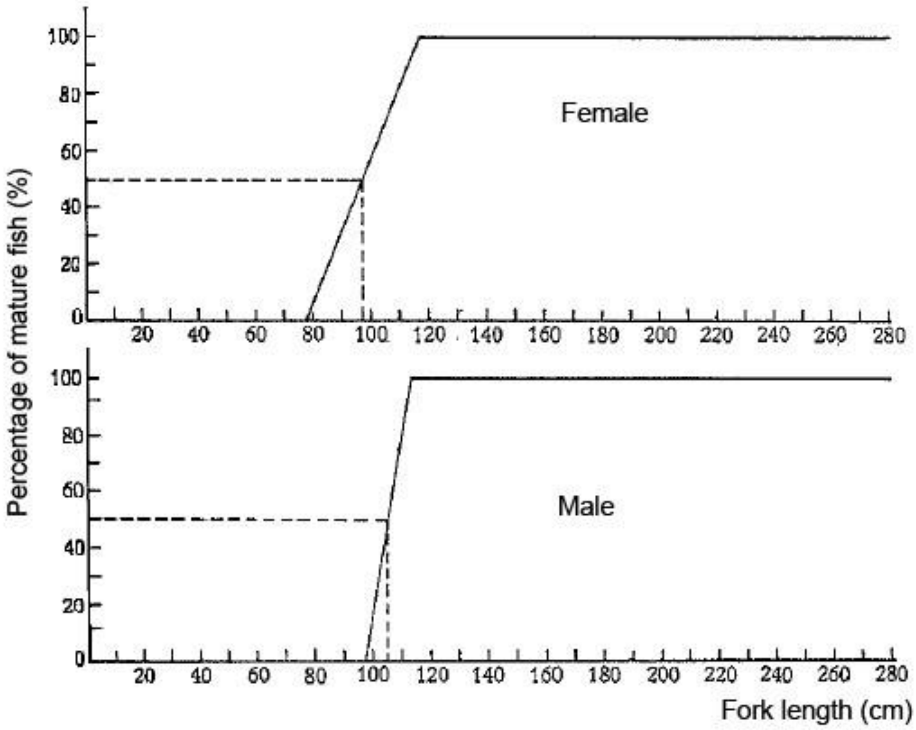

Figure 7. Maturity ogive for bluefin tuna – percentage of mature fish depending on the fork length (cm). Dashed line indicates the size on the first sexual maturity (50% of fish) (Rodriguez-Roda, 1967).

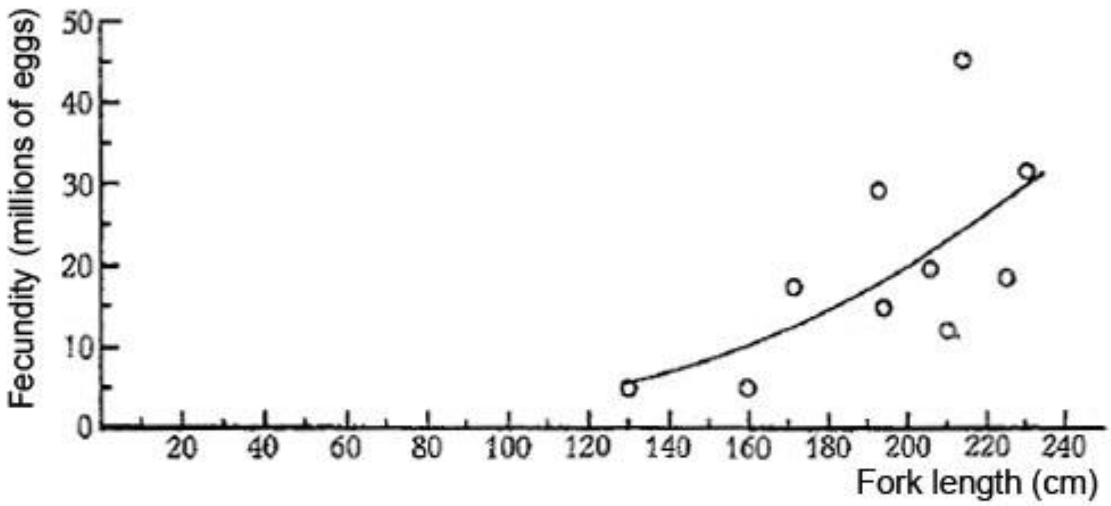

Figure 8. Correlation between the bluefin tuna size (fork length, cm) and absolute fecundity (in millions of eggs) (Rodriguez-Roda, 1967). Trend line corresponds to formula $F=2.292450*L^{3.012560}$

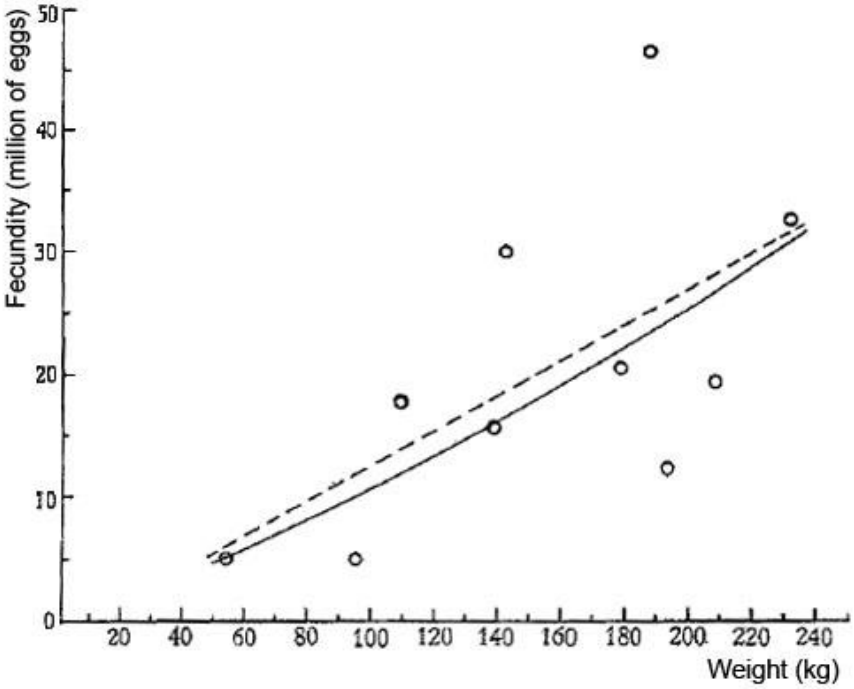

Figure 9. Correlation between the bluefin tuna weight (kg) and absolute fecundity (in millions of eggs) (Rodriguez-Roda, 1967). Trend line corresponds to formula $F=53451*W^{1.159489}$ (continuous line) or F=-1,220,717+138,068*W (dashed line).

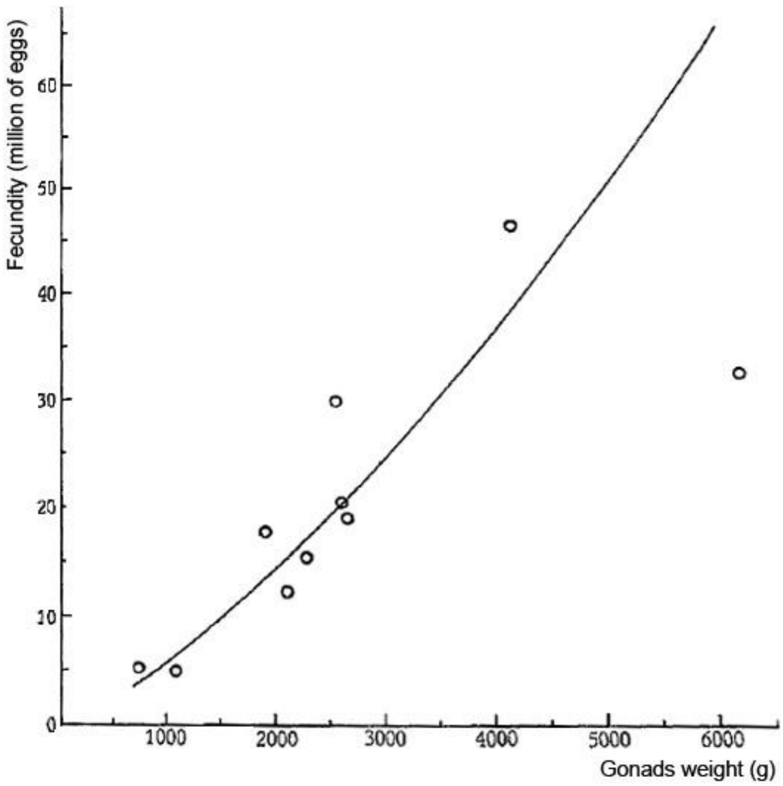

Figure 10. Correlation between the weight of both gonads (g) and absolute fecundity (in millions of eggs) (Rodriguez-Roda, 1967). Trend line corresponds to formula $F=553*W^{1.337073}$