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STUDY OF SOME REPRODUCTIVE PARAMETERS OF YELLOWFIN TUNA (*THUNNUS ALBACARES*) LANDED AT THE ABOBO-DOUMÉ CANOE LANDING SITE (CÔTE D'IVOIRE)

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ABSTRACT

The albacore (*Thunnus albacares*) is one of the large migratory fish species regularly landed by the small-scale coastal fishery at the Abobo-Doumé canoe wharf in Côte d'Ivoire. This study focuses on determining several reproductive parameters of this species. This was achieved by monitoring the gonadosomatic ratio (GSR), the hepatosomatic ratio (HSR), the condition factor (K), and the macroscopic appearance of the gonads in females and males, as well as by determining the sex ratio within the studied population. The results show that the sex ratio favors females, who constituted the majority during the study period, with a predominance of mature females. The gonado-somatic ratio (GSR) remained relatively stable throughout the sampling month. The highest peak was recorded on Thursday, the 2nd (0.28), followed by two other, less significant peaks, observed on Thursday, the 1st (0.24) and Thursday, the 4th (0.18), respectively. Variations in the hepatosomatic ratio (HSR) were also relatively consistent throughout the study period, despite a few peaks recorded on Saturday, October 1 (0.82) and Thursday, October 4 (0.71), reflecting variations in liver metabolic activity. Analysis of all these parameters indicates that albacore exhibit reproductive activity during the month of October, which corresponds to the sampling period.

Keywords: *Thunnus albacares*, Reproduction, Gonadosomatic ratio, Hepatosomatic ratio, Condition factor, Sex ratio

1 INTRODUCTION

Tuna fishing has been taking place in the Atlantic Ocean since the late 19th century by Basque line fishermen operating from the ports of Dakar and Conakry. The boats target yellowfin tuna, which is heavily concentrated in front of the Cayar

trenches in Senegal and on the Conakry shelf in Guinea [1]. Yellowfin tuna is a fish that belongs to the mackerel family and the Thunnus genus. It's a big migrator found in the tropical and temperate waters of the Atlantic Ocean. This fish, often caught as bycatch by longliners and other tuna boats flying the Spanish and French flags, has also been actively fished by Ivorian artisanal fishers since the 1970s ([2]; [3]). Globally, knowledge about yellowfin tuna (*Thunnus albacares*) has improved a lot thanks to international fishery and stock monitoring programs. Worldwide catches of this species increased sharply since the 1980s before leveling off, reaching around 1 to 1.2 million tons per year in recent decades, or more than 25% of the world's tuna catches ([4]; [5]). In Côte d'Ivoire, the first tries at tuna fishing with live bait took place in 1954. The first two equipped boats caught Yellowfin Tuna near the 'bottomless hole,' between 8 and 12 nautical miles south of Abidjan [1]. In both artisanal and industrial fisheries in Côte d'Ivoire, Yellowfin Tuna (*Thunnus albacares*) is, after Skipjack (*Katsuwonus pelamis*), one of the main species caught and makes up more than a third of the tuna landings. Across the Atlantic Ocean, annual Yellowfin Tuna catches are still significant and have been estimated at around 140,000 tons in recent years. This species is continuously monitored by the International Commission for the Conservation of Atlantic Tunas (ICCAT) to ensure the resource is used sustainably [6]. Given the various inter-state fishing agreements, the development of both industrial and artisanal fisheries (national and foreign), and the capacity of Abidjan port to accommodate ships and process tuna, we are seeing intensive tuna fishing in Ivorian waters. Among the targeted species, yellowfin tuna plays an important role in the catches landed by industrial, trawler, and artisanal fisheries at the Abidjan fishing port. Making up most of the tuna sold in markets, restaurants, 'garbadromes,' and elsewhere, because of its affordable price and accessibility to everyone, today Yellowfin Tuna has significant economic importance. Given this growing demand from the population, doesn't intensive fishing of this species have harmful effects on the existing stock in Ivorian waters? For a rational and sustainable management of the resource in question, reviewing the knowledge on the reproduction of the Yellowfin Tuna species is more than necessary. It is with this in mind that our study aims to assess the reproductive status of the yellowfin tuna (*Thunnus albacares*) landed at the Abobo-Doumé fishing dock, through the macroscopic description of the gonads and the analysis of the gonadosomatic index (GSI), the hepatosomatic index (HSI), and the condition factor (K).

2 METHODOLOGY

2.1 Overview of the fishing area (Exclusive Economic Zone: EEZ)

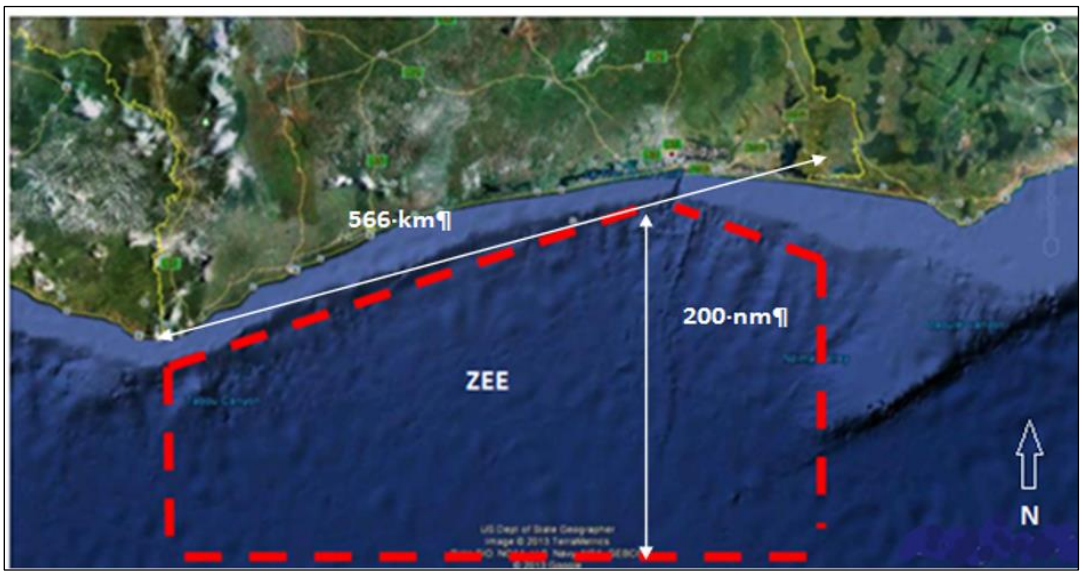


Figure 1: Delimitation of the Exclusive Economic Zone of Côte d'Ivoire: the red lines represent the boundary of this zone [11]

Côte d'Ivoire is located in West Africa, between 4°30′ and 10°30′ North latitude and 2°30′ and 8°30′ West longitude, on the northern edge of the Gulf of Guinea. It covers an area of 322,462 km^2 and opens to the South onto the Atlantic Ocean. Its exclusive economic zone (EEZ), which extends up to 200 nautical miles from the coast, covers about 204,600 km^2 (Figure 1) ([1]; [7]). This area is an important space for fishing activities, especially tuna fishing ([8]; [9]). One of the main species caught is yellowfin tuna (*Thunnus albacares*), a key species in tuna fisheries in the Gulf of Guinea [10].

2.2 Sampling

Individuals of yellowfin tuna (*Thunnus albacares)* of various sizes, ranging from 48 to 108 cm, were sampled daily at the Abobo-Doumé canoe landing site. Sampling was conducted early in the morning, from 6:00 a.m., during the arrival of artisanal fishing canoes. The landed fish were measured and weighed. The fork length (FL) was measured in

centimeters, from the tip of the snout to the center of the notch of the tail fin, using an ichthyometer. The total weight was measured in kilograms using a BAXTRAN electronic scale with a capacity of 15 kg and an accuracy of 0.01 g. An incision was then made in the abdominal cavity to carefully remove the internal organs and gonads. The gonads were separated individually and then examined with the naked eye to determine the sex of the individuals. The macroscopic stage of sexual maturity was determined according to the scales proposed by [12] and [13]. Finally, the gonads as well as the different internal organs, including the liver and stomach, were weighed individually using the same electronic balance. All the collected information was grouped by week and by sex.

2.3 Macroscopic stages of sexual maturity

The determination of the sexual maturity stages of yellowfin tuna was done by directly observing the structure of the gonad (color, consistency, vascularization, and the volume it occupies in the abdominal cavity) and based on [10] scale in Table 1. This scale defines 5 stages for males and females.

Table 1: Macroscopic appearance of the different stages of maturation [10]

Stages	Caractéristiques externes	
	Males	**Females**
I	Immature: very thin, flat, ribbon-shaped testicles, but sex can be determined with the naked eye	Immature: ovaries are long and thin, but sex can be determined with the naked eye
II	Start of maturation: testes are swollen and triangular in cross-section, no milt in the central canal	Start of maturation: ovaries are swollen but no oocytes visible to the naked eye
III	Advanced maturation: discharge of semen under slight pressure or gentle squeezing of the testicles	Advanced maturation: swollen ovaries, oocytes visible to the naked eye
IV	Mature: large testicles, with easy release of milt.	Mature: very swollen ovaries, translucent oocytes, coming out easily from the follicles.
V	Emission: flaccid testicles, filled with blood; dark red surface, no semen in the central channel.	Spawning: after spawning: ovaries are elongated, hollow, and floppy with an orange to reddish color, with reduced vascularization.

2.4 Sex ratio (SR)

The sex ratio is an important biological parameter of a population's structure. It refers to the ratio between the number of males and the number of females, or the proportion of one sex compared to the total number of individuals whose sex has been determined. In yellowfin tuna (*Thunnus albacares*), this parameter can vary depending on the size of the individuals and the sampling area [14]. In the yellowfin tuna, sexual dimorphism is not pronounced. Therefore, determining the sex ratio can only be done after evisceration, followed by a macroscopic identification of the sex through direct observation of the gonads. It was determined on a weekly basis. Its formula is as follows [15]:

$$SR = \frac{M}{F}$$

Where F = number of females; M = number of males

2.5 Calculation of the mean size of male and female yellowfin tuna

The average size of males and females is calculated by adding up all the measured sizes and dividing by the total number (N) of the sample.

$$Tm_A = \frac{\sum LF}{Nt}$$

TmA: average of the female sample,

FL: Fork Length.

$$Tm_B = \frac{\sum LF}{Nt}$$

TmB: average of the male sample.

2.6 Gonadosomatic Index (GSI)

The Gonadosomatic Index is used to indicate the development stage of the gonads and to determine the spawning periods during a species' sexual cycle [16]. In fact, the temporal evolution of the GSI in a mature fish generally follows three phases. The first phase is when this index is at its minimum, corresponding to the biological rest period. The second phase is when the GSI begins to increase, corresponding to the oocyte maturation phase, and finally, the third phase is when it starts to decrease, corresponding to the actual spawning period. The formula used to calculate the individual GSI is as follows:

$$GSI = \frac{W_g \times 100}{T_w}$$

- Wg = weight of the gonad (g);
- Tw = total weight of the fish (g)

2.7 Hepatosomatic Ratio (HSR)

In fish, the liver plays an important role in processes related to the development of reproductive products. It has been shown in females of certain fish that this organ is responsible for the synthesis of vitellogenin, the main precursor protein of egg yolk [17]. This ratio is calculated to see the influence of the liver on the gonad. The formula for this hepatosomatic ratio (HSR) is equal to one hundred times the liver weight divided by the body weight (total weight) [18].

$$HSR = \frac{L_w}{T_w} \times 100$$

- L_w = Liver weight (g).
- T_w = total fish weight (g).

2.8 Condition Factor (K)

The condition factor (K) helps reflect the plumpness of the fish in relation to the effects of ecological and physiological factors. It allows us to assess how lean or bulky a fish is ([19]; [20]). The condition factor is defined by the ratio between the fish's weight and size. It was determined by sex and by week. The condition factor is given by the formula [20]:

$$K = \frac{Tw}{Fl^3} \times 100$$

- Tw = Total weight of the fish (in g);
- Fl = fork length of the fish (in cm).

2.9 Statistical analyses

The software Statistica version 7.1 was used to perform the statistical analyses. A Student's t-test at the 5% level was used to compare the average of each sex in the different size classes. This test was also used to compare the Gonadosomatic Index (GSI) of males and females and the Hepatosomatic Index (HSI) of females and males.

3 RESULTS

3.1 Description of the gonads

3.1.1 Female gonads

In female albacore, the pair of gonads is asymmetric. They are spindle-shaped with tapered ends and their color ranges from light yellow to dark yellow, or sometimes red. Depending on the maturity stage, the oocytes can be visible with more or less pronounced vascularization. The minimum and maximum sizes of the extracted gonads range from 16.5 cm to 34 cm in both females and males.



Figure 2: Photograph of the female gonad at stage IV

3.1.2 Male gonads

The testes are paired, asymmetrical, and white in color. They are also elongated and swollen. The two gonads are joined at the posterior part.



Figure 3: Photograph of the male gonad at stage IV

3.1.3 Sex ratio

Figure 4 shows the evolution of the sex ratio in yellowfin tuna throughout October 2025. Out of a total of 202 sampled specimens, 108 were females, which is 54.82%, and 89 were males, making up 45.18%. The sex of 5 fish could not be determined. They represented 2.47%, and this percentage was not considered in the data analysis. The student's t-test

used to compare males and females shows that there is no significant difference (p = 0.263). The sex ratio indicates a predominance of females in the population, with only slight monthly variation.

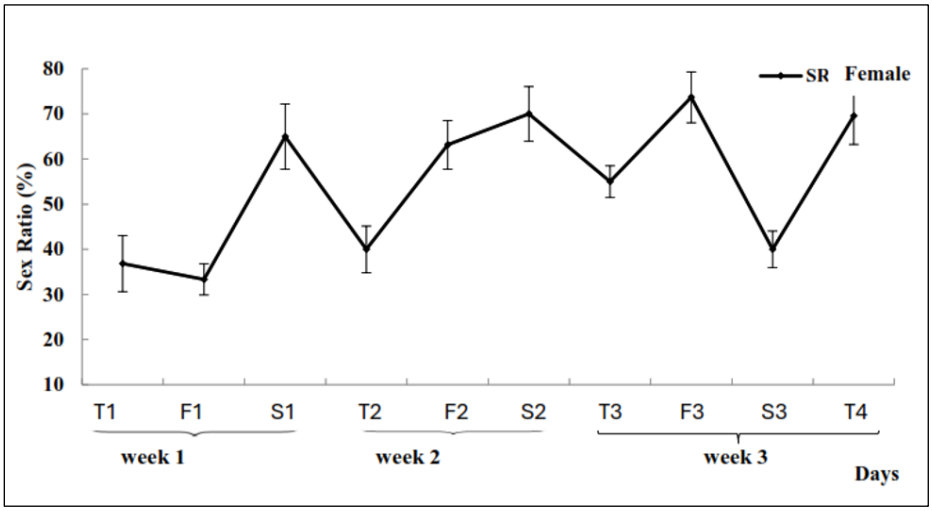


Figure 4: Evolution of the sex ratio in female yellowfin tuna landed by artisanal fishers at the Abobo-Doumé canoe landing site **in October 2018.**

3.2 Frequency of macroscopic stages of sexual maturity

All maturation stages were observed in our sample during our work, except for stage V in males.

3.3 Female cases

Figure 5 shows the frequency of the macroscopic sexual maturity stages in female yellowfin tuna. In the subsample of 108 females, all stages of macroscopic development were observed. Stage III individuals are the most numerous at 28%. They are followed by those at stages IV, II, V, and I, with respective percentages of 24, 20, 15, and 13.

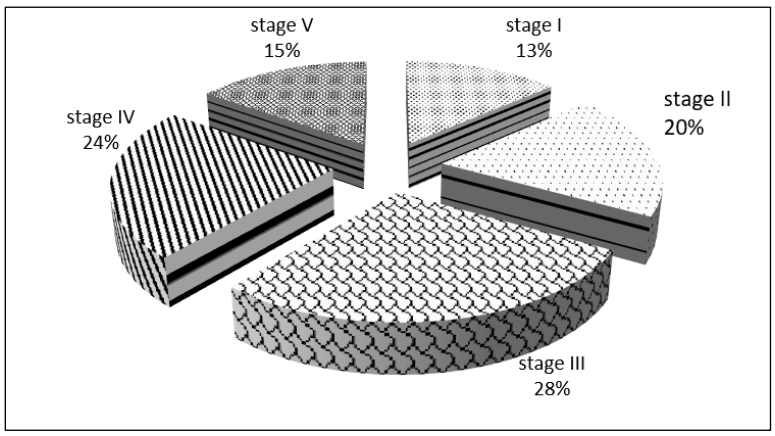


Figure 5: Frequency of macroscopic sexual maturity stages in female yellowfin tuna landed at the Abobo-Doumé canoe landing site **in October 2018.**

3.4 Males cases

Figure 6 highlights the frequency of macroscopic sexual maturity stages in male yellowfin tuna. In this case, unlike the females, not all sexual maturity stages were recorded in October. Stage V was completely absent in the catches. Our subsample of 89 males was mainly made up of specimens from stages I to IV. Stage II is by far the most dominant, representing about half of the population (50%). The other stages, I, III, and IV, are represented by 22%, 26%, and 2%, respectively.

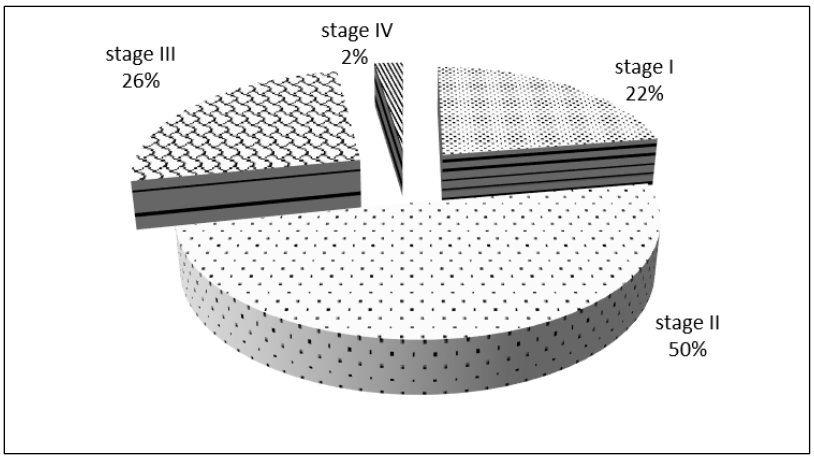


Figure 6: Frequency of macroscopic stages of sexual maturity in male yellowfin tuna landed at the Abobo-Doumé canoe landing site **in October 2018.**

3.5 Gonadosomatic Index (GSI)

The variation in GSI for females and males is shown in Figure 7. Females' cases: The GSI varies throughout the month. The highest peak is observed on Thursday the 2nd, followed by two smaller peaks on Thursday the 1st and Thursday the 4th. The lowest value is reached on the Friday of the first week at 0.09. On the other days of the week (Saturday 2, Thursday 3, Friday 3, and Saturday 3) this ratio doesn't very much, being 0.13, 0.14, 0.15, and 0.12 respectively. Males' cases: For males from the October captures, the GSI varies little; however, slightly higher values are observed on Friday the 2nd and Saturday the 3rd, with 0.12 and 0.11. The student's t-test used to compare the GSI of females and males shows a significant difference (p = 0.001).

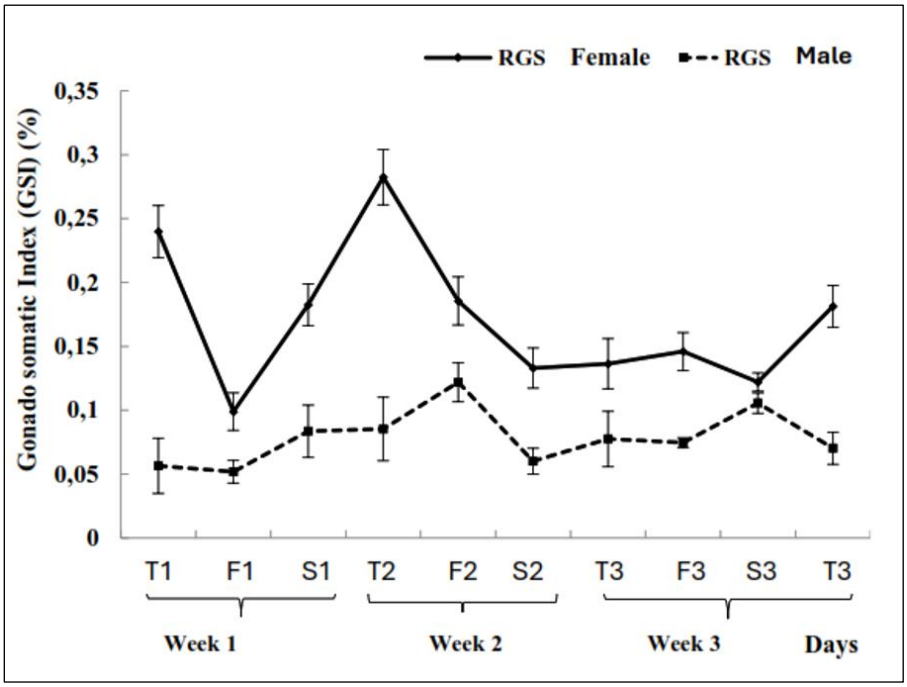


Figure 7: Evolution of the GSI of the female and male yellowfin tuna landed at the Abobo-Doumé canoe landing site in October 2018.

3.6 Hepato-Somatic Ratio (HSR)

The hepato-somatic ratio in females is shown in figure 8. The variation is pretty consistent throughout the sampling period, although two small peaks were observed. The first is on Friday the 1st at 0.70, and the second on Saturday the 3rd at 0.45. Figure 8 also shows the evolution of the hepato-somatic ratio (HSR) in males. The HSR stays fairly stable over the study period as well, but two small peaks stand out: on Saturday the 1st (0.82) and Thursday the 4th (0.71). The students t-test used to compare the HSR of females and that of males shows a significant difference (p = 0.0001).

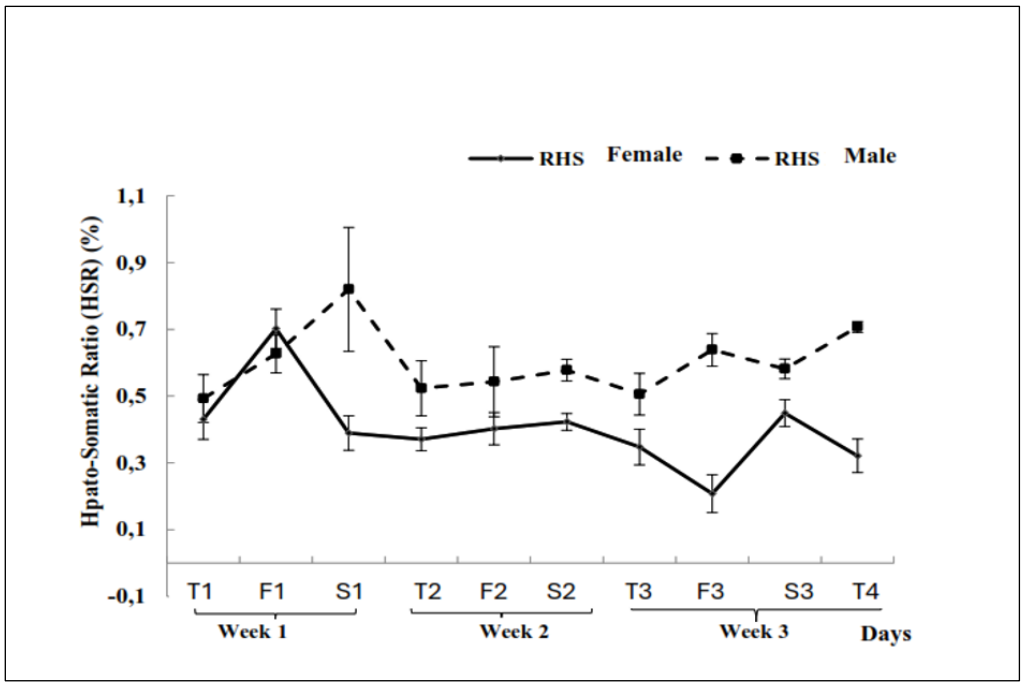


Figure 8: Evolution of the HSR of female and male yellowfin tuna landed at the Abobo-Doumé canoe landing site **in October 2018.**

3.7 Condition Factor (K)

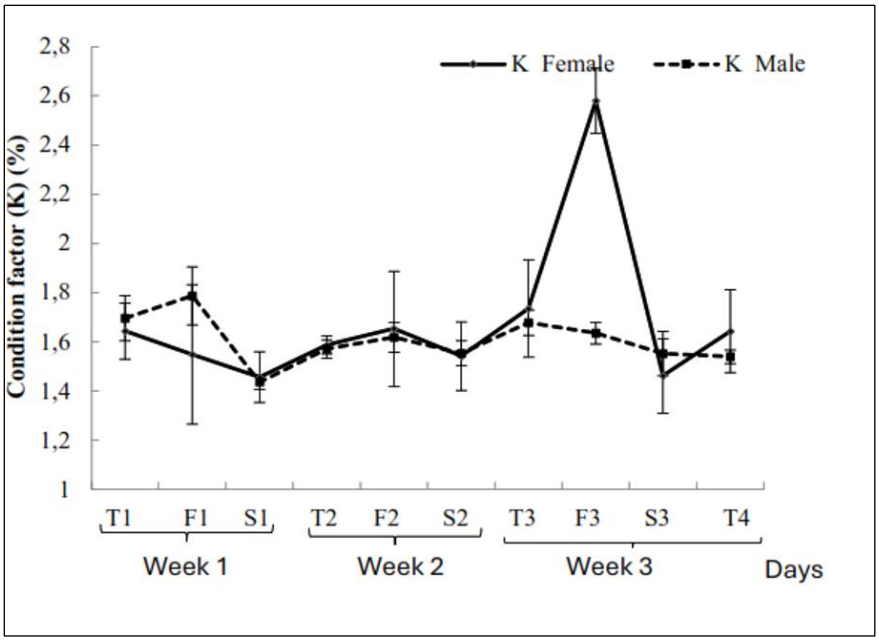


Figure 9: Evolution of the condition factor K of female and male yellowfin tuna landed at the Abobo-Doumé canoe landing site in October 2018.

Females' cases: Figure 9 shows the evolution of the condition factor K in female yellowfin tuna during the month studied. This index shows some fluctuations, reflecting variations in the physiological state of the fish. The maximum value was recorded on Friday the 3rd, with a plumpness of 2.58. During the rest of the period, the condition factor remained relatively stable at a value of 1.64. In males, the condition factor K remains generally stable throughout the study period. A slight increase in plumpness is observed on Friday 1, before returning to relatively constant values, respectively 1.55 and 1.53.

4 DISCUSSION

The reproduction of yellowfin tuna was looked at through the analysis of various calculated biological indices. The sex ratio shows a predominance of females in the catches up to an average size of 77.22 cm. This finding agrees with observations made on yellowfin tuna in different ocean regions, where a higher proportion of females is generally seen in small to medium size classes, while males gradually become dominant in the larger size classes ([21]; [22]). This change in the sex ratio could be explained by growth differences between the sexes, higher natural mortality among adult females, or differences in behavior and vulnerability to fishing gear. Recent studies on tunas indeed point out that female growth can slow down after sexual maturity and that their natural mortality can be higher than that of males, which helps explain their lower presence in larger size classes; ([21];[23]). So, the significant number of mature females observed in October might reflect the start or preparation of the reproductive period in the study area. In males, unlike females, immature individuals are dominant. This situation seems to be better explained by the structure of the sampled population or by the selectivity of the fishing gear. Although differences in maturation dynamics between the sexes may exist, the hypothesis that males release their gametes well before females and then return to stage II cannot be confirmed based solely on the results obtained. Observations in the Gulf of Guinea actually show that males and females can have significant reproductive activity during the same periods. [24] notably observed strong reproductive activity in both females and males, particularly in December and January. The dominance of immature males in our sample therefore seems more related to the composition of the sample and the characteristics of the fishing. Finally, the very short duration of the sampling period is an important limitation that could skew the interpretation of the observed maturity stage structure. The evolution of the gonadosomatic index (GSI) appears relatively stable over the month studied. This stability could reflect little variation in reproductive activity during the sampling period. However, on its own, it doesn't allow us to say for sure that the different specimens had already spawned. In fact, in yellowfin tuna (*Thunnus albacares*), the GSI increases during gonad development and usually reaches high values in females during the reproductive phase, before decreasing after spawning. The work of [25] shows that the GSI increases during ovarian maturation, with the highest values in females at advanced maturity and spawning stages, then drops sharply during the regeneration phase. In the eastern Atlantic Ocean, [26] also observed, in yellowfin tuna sampled at Abidjan port, significant reproductive activity of females during the warm period, especially between December and January, as well as a cumulative profile of the gonadosomatic and hepatosomatic indices during ovarian development. Thus, the relative stability of the GSI observed in our study could be more related to the short sampling period and the uniformity of the maturity stages of the individuals caught than to spawning already having been completed. The variation in the hepatosomatic index (HSI) is also fairly consistent during the period studied, despite the presence of some high values. These variations seem to be linked to changes in physiological condition and energy allocation during gonad development. In yellowfin tuna, [27] showed that the liver serves as an important lipid reserve that can be mobilized during ovarian maturation. However, the study conducted in Abidjan by [26] shows that the GSI and HSI generally follow a cumulative pattern during ovarian development, with the highest values found in reproductive females. So, seeing a peak in GSI before HSI in our study alone isn't enough to conclude that lipids accumulate in the liver first. This relationship should be confirmed through direct biochemical analyses of lipid content in the liver and gonads. The changes in the condition factor (K) in females show variations over the month studied. These fluctuations could reflect changes in the individuals' physiological state related to their maturation stage, feeding, and reproductive activities. In yellowfin tuna, [25] observed a decrease in the condition factor during maturation, with the lowest values found in females at the hydration stage, followed by an increase during the regeneration phase. In the eastern Atlantic, however, [26] did not show any clear trend in the condition factor that would indicate a specific energy allocation strategy during reproduction. The relative stability of the K factor in the males we observed in our study seems to reflect less variation in their body condition during the sampling period. However, this doesn't directly prove that the males aren't using their muscle reserves during reproduction.

5 CONCLUSION

The yellowfin tuna caught by artisanal fishermen and landed at the Abobo–Doumé canoe landing site shows a sex ratio favoring females. The student's t-test used to compare the GSI of females and males shows a significant difference ($p = 0.001$), which indicates that a spawning period was observed in albacore during the warm season. Observing the macroscopic stages of sexual maturity confirms that most of the females encountered are in their reproductive period, with mature females being dominant. However, among males, the immature ones are dominant. Tracking the hepatosomatic index (HSI) showed that in both females and males, the variation is practically consistent throughout the entire sampling period. The condition factor K in female yellowfin tuna fluctuated throughout the month studied, showing that the fish's fat reserves, and body condition depend on physiological activities.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare that they have no conflict of interest regarding the publication of this article.

Author Contributions

The first author collected the data, processed the information, and wrote the first draft of this article. The other authors reviewed and corrected the manuscript. All authors have read and approved the final manuscript.

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