Analysis of sizes and state of ovarian maturity in yellowfin tuna (*Thunnus albacares*) captured in the Gulf of Mexico

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Abstract

The yellowfin tuna Thunnus albacares is the second most important fishery in Mexico, due to its production costs and commercial value"
The species is fished on both coast of the country, with the Pacific Ocean presenting productions lightly higher than that of the Gulf of Mexico where, in spite of the above statement, tuna catches have recently shown a downward trend. For this reason, analysis is required of the size and stage of ovarian maturity and it is necessary to determine whether capture size is the primary reason behind the decline in the yellowfin tuna fishery Three tuna fishing trips were conducted in the Gulf of Mexico in order to gather data pertaining to fork length (Lf) and gonads Histological sections were obtained from the latter for analysis and determination of maturity stage. The results showed that males were predominant (40%) among the individuals for which the sex could be differentiated in the catches of T. albacares. The Lf values in the catch, were between 75 and 162 cm. However, variations in this parameter were found between sexes. The relationship between length and weight showed that the males are larger than the females, however, the equationgiven by the parameters of a=0.9406 and b= 3.4504, demonstrated growth of positive allometric type in both sexes. There was progressive development in the state of ovarian maturity over the months of capture. Chromatin nuclear (CN) was the most frequent phase within primary ovarian development (November, February, March), stages were present, although these did not present a direct relationship to fork length.

Key words: fishery, yellowfin tuna, ovarian development, Gulf of Mexico.

Introduction

The tunids are a group of fishes that represent the most important fishery resource in the seas and oceans worldwide (Collette and Nauen, 1983). They are of great ecological importance since they serve as biomarkers for the state of ecosystem health, being one of the apex predators in the levels of the trophic chain (Olson and Watters, 2003). They are also commercially important due to the fact that they provide a significant percentage of the fishery products that contribute to global food security. In Mexico, the yellowfin tuna *Thunnus albacares* is the second most important fishery because of its production value and commercial cost. The species is fished on both coasts of the country, with the Pacific Ocean presenting a production slightly higher than that of the Gulf of Mexico. However, since the year 2006, a downward trend has been reported in the catch of the species (Ramírez-López, 2007; Quiroga- Brahms, 2012; SEMARNAT, 2014; DOF, 2015).

The Mexican national fishery commission CONAPESCA (2013) indicated an annual production for the Pacific Ocean of 149, 475 t, while the Gulf of Mexico contributed annual catches that exceeded 1,000 t (INP, 2001). In the Gulf of Mexico, *T. albacares* is caught off the state of Veracruz throughout the year, although catches are higher from May to August and lower from February to April, since during the latter period the resource becomes more dispersed and located to the north in international waters (Gonzáles *et al*., 2001; Sosa *et al*., 2001; Wong, 2001). In this context, there are indications of a decline in the fishery production of the species, falling from 1,362 t in 2003 to 938 t in 2006. At a general level, tunid catches in the Gulf of Mexico have also decreased from that year (Jurado-Molina and Ramírez-López, 2008).

The yellowfin tuna is considered of great ecological importance, since it serves as an "indicator" of the presence of high velocity prey that are difficult to catch using traditional fishing methods (Olson and Boggs, 1986). Another reason for its ecological importance is the fact that it is often found associated with certain species of sharks, birds and marine mammals (Au, 1991). This is in addition to the fact that larger sized organisms occupy the highest trophic levels of the food chains (Olson and Watters, 2003).

With respect to its habits, *T. albacares* passes its whole life relatively close to the surface of the tropical, subtropical and temperate oceans and seas worldwide (Blackburn, 1965). It is characterized by being a highly migratory species (United Nations Convention on the Law of the Sea-UNCLOS, 1982), presenting great displacements mainly for the purposes of feeding and reproduction (Cayre, *et al*., 1991; Fonteneau and Marcille, 1993). In this way, migratory displacement from African waters to the Gulf of Mexico is presented by the species in order to reproduce (DOF, 2015), and spawn. This process takes place in different months of the year, but the highest peaks are presented during the summer (Solana-Sansores and Ramírez-López, 2006). Study of aspects of its distribution and reproductive cycle are thus of great interest to many researchers.

It is relevant to mention the bluefin tuna (*Thunnus thynnus*), since it is the most important species of tunid fisheries worldwide due to the fact that its commercial value is very high, leading to its high exploitation. Consequently, from the 1950s onwards, populations of the species have presented a strong decline without having had an opportunity for the stocks to recover (ICCAT, 2016).

In this context, the commercial markets have found an alternative in the yellowfin tuna with which to meet the high demand for consumption. However, despite the importance of this and other tunid species in Mexico, the stocks of their populations in the Gulf of Mexico are in decline (Solana-Sansores and Ramírez-López, 2006; Jurado-Molina and Ramírez-López, 2008), as shown by recent records of low catches by the tuna fishing fleet, regardless of the management and conservation actions that have been implemented (DOF, 2015, updated at 11/05).

It has recently become understood that the fisheries of tuna and other highly migratory species require international cooperation for their conservation and consequent management. From this perspective, international agreements have arisen to address the responsibility for legislation and regulation of the fisheries of these species of high commercial interest, including the Inter-American Tropical Tuna Commission (IATTC) in the eastern Pacific; the Indian Ocean Tuna Commission (IOTC), and the

International Commission for the Conservation of Atlantic Tunas (ICCAT), of which Mexico has been an active member since 2002 (García *et al*., 1994; Estrada-Jiménez and Ramírez-López 2008).

For its part, Mexico applies its own Mexican Official Norms, including NOM-023-SAG/PES-2014, which acts to regulate the exploitation of tunid species by longline vessels in waters with federal jurisdiction of the Gulf of Mexico and Caribbean Sea.

For this reason, and recognizing both the economic and ecological importance of the species, the present study conducted an analysis of the sizes and sexes of the captured individuals, related to the state of maturity of the organisms, since it is known that determination of the sexual proportion, as well as the series of changes that take place in the phase of maturity, are of great importance in terms of acquiring complete knowledge of the general biology of a commercially exploited species (Holden and Raitt, 1975). With this study, it was intended to provide valuable information, from a reproductive and populational perspective, pertaining to the biology of this species.

In addition to the updating of data regarding the presence of yellowfin tuna in the Gulf of Mexico, and considering the reproductive conditions of the populations, a basis could be established for the application of a closed season. For this reason, it is also necessary to foster other studies that will allow close monitoring of the status of the fishery of this species.

Material and methods

Three trips were made on board tuna fishing vessels (of the longline fleets that operate in the Gulf of Mexico) during November 2015, and February and March 2016, of 25, 18 and 25 days in duration, respectively. On each trip, measurements were made of the fork length (Lf), taken from the snout to the center of the fork in the caudal fin (ICCAT, 1999), using a measuring tape. The sex of each individual was determined where possible by a visual analysis of the gonads at the time of capture.

Samples of the gonads of the females were collected by cutting a transversal section four to five cm wide in the anterior, middle and posterior parts of each individual (Hunter, 1985. and Zudaire *et al.*, 2010). The samples were then fixed in 10% formol (Montoya-López *et al.*, 2006), previously mixed with Phosphate-buffered Saline (PBS) for improved conservation.

The samples of the gonadic tissue were washed under running water to dilute the excess formol and deposited in 15% saccarose and then 30% saccarose for one hour each before cutting the sections on a freezing microslicer.

For staining, the Hematoxilin-Eosin technique was used, as applied to scombrids (Cruz-Castán *et al*. 2013). Modifications were made to this technique, in terms of the time of inclusion of the samples, in order to obtain better results.

From the total number of sampled organisms, separating males, females and non-differentiated individuals captured during the sampling period, the sexual proportion was determined. To obtain the distribution of sizes and weights, the minimum and maximum reference values of the fork length (Lf) of the organisms were used, in which the class mark (CM), and the lower (Ll) and upper (Lu) limits were obtained, using intervals of five cm. The absolute frequency of the sizes of the captured organisms was calculated. This procedure was also used for the analysis of frequency in weight. As a function of this, it was also determined whether or not there were any significant differences between sizes below or above 100 m, applying the Lilliefors normality test.

An analysis was conducted of the sizes of individuals captured during November 2015, and February and March 2016, from which the average Lf values were calculated for each sex, while also obtaining the minimum and maximum values. This same procedure was applied to the determination of weights.

To determine the growth type of the *T. albacares* population found in the sampling period of November 2015 to March 2016, a linear regression analysis was performed of the natural logarithms of Lf and Total weight (Wt), separated according to sex and also at global level. This analysis used the intersection (a) and slope (b) of the linear regression to establish the potential relationship between Lf and Wt, in the following manner:

Wt = e (intersection). Lf slope

Wt = a. Lf b

The 95% confidence intervals of the parameters were estimated, with the standard error Φ (Se) and the t-Student distribution (Zar, 1999):

IC = Φ ±Se*t (n-1(95%))

If the confidence interval b did not include the three, the growth was considered allometric in type. In the contrary case, growth was considered isometric in type. On the other hand, if b was greater than three, a positive allometric growth type was considered and if b was lower than three, a negative allometric growth type was considered (Ricker, 1975).

In order to analyze the stages of gonadal maturity and identify their relative frequency, an average was calculated for each stage in each sampling month. Likewise, the stage of maturity was determined with respect to the size at capture at general level and for each sampling month. Determination of the stage of maturity in the females was based on the descriptions presented in the studies of Zudaire *et al*. (2010) and Montoya-López (2006).

RESULTS

A total of 276 individuals captured during the three sampling trips were analyzed, of which 95 were females, 109 males and 72 could not be differentiated. In terms of the sexual proportion, this gave representative equivalents of 34, 40 and 26% of the total catch, respectively.

Overall, the parameter Lf presented a minimum of 75 cm and a maximum of 162 cm, with an average value of 132 cm. The frequency of sizes revealed two modal groups; the first comprised the tunas with Lf of between 125 and 135 cm, corresponding to females and non-differentiated individuals, while the second group presented Lf values of 140 to 145 cm, and was represented by females and males (Fig. 1a).

In the case of the frequency of weights, the highest was represented by non-differentiated individuals of between approximately 17.5 and 25 kg, followed by the males at between 42.5 and 47.5 kg (Fig. 1b).

a

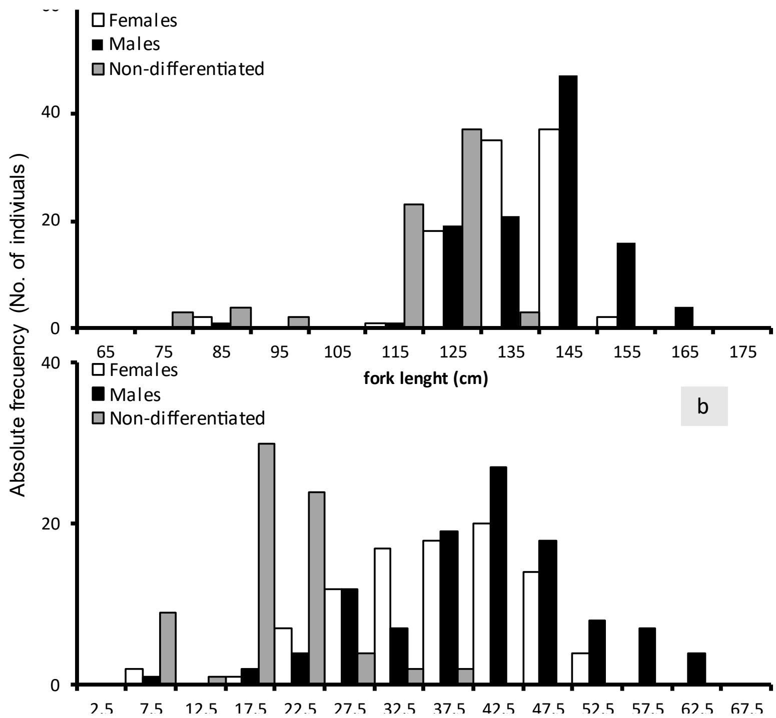
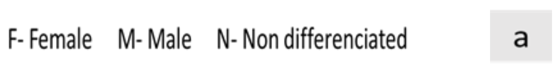


Figure 1. Distribution of size (fig. a) and weight (fig. b) of *Thunnus albacares* captured in the Gulf of Mexico.

The sizes presented average values with similar tendencies across sampling months. The males presented sizes with an average Lf of 142.6 cm in November, with minimum and maximum values of 120 and 157 cm, respectively. Likewise, the average Lf value for the males in February was 143.2 cm Lf, with minimum and maximum values of 90 and 162 cm, respectively. In March, the average Lf value at capture for the males was 137 cm, with minimum and maximum values of 124 and 151 cm, respectively. In the case of the sizes of the females on capture, in November, the average Lf value was 134 cm, with minimum and maximum values of 90 and 146 cm, respectively. In February, the average Lf value was 138.2 cm, with minimum and maximum values of 86 and 153 cm, respectively. Finally, in March, the average Lf value was 136.5 cm, with minimum and maximum values of 125 and 149 cm, respectively (Fig. 2a).
Regarding weight, for all three sampling trips, the highest average values were presented by the males at between 39.1 and 42.7 kg, followed by the females at between 34.5 and 38.3 kg (Fig. 2b).



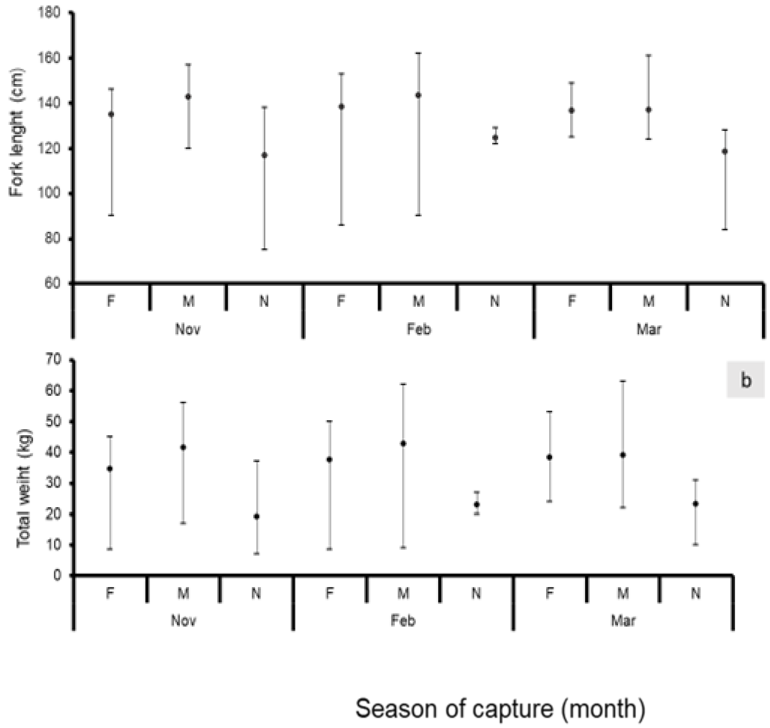
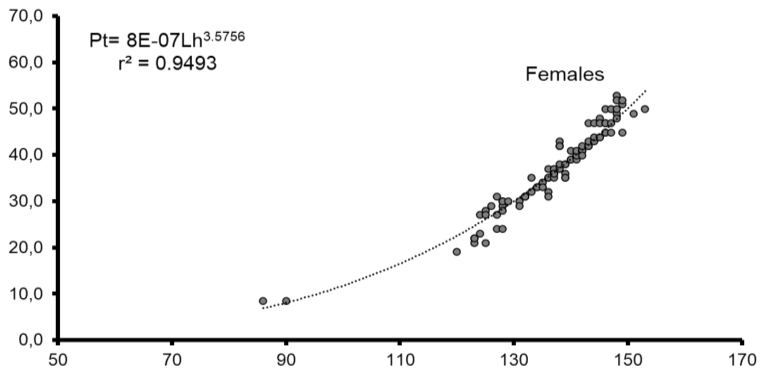


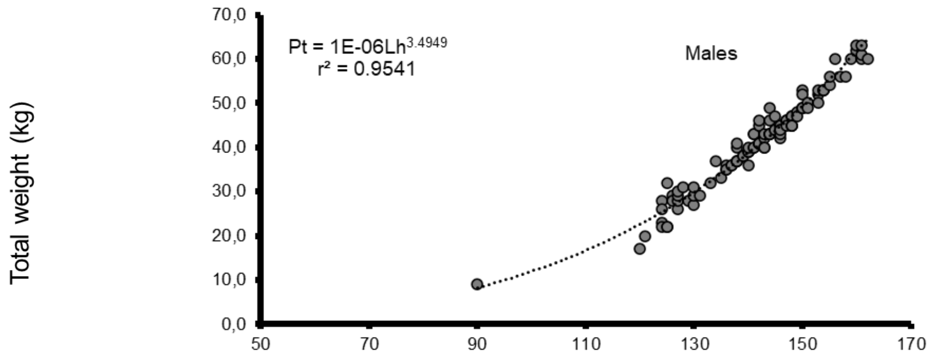
Figure 2. Size and average weight of *Thunnus albacares* captured during the three months of sampling.

The potential model applied to obtain the equation of fit of the variables of Lf and Wt for both sexes and for the sexes separately showed that, for the females, the equation was $Wt = 8^{-7} \cdot Lf^{3.5756}$, with 95% confidence intervals of 3.59^{-7} - 1.91^{-6} for *a*, and 3.41 - 3.75 for *b* (Fig. 3a). For the males, the model was $Wt = 1^{-6} \cdot Lf^{3.4949}$ and the 95% confidence intervals were 5.09^{-7} - 2.5^{-6} for *a*, and 3.34 - 3.64 for *b* (Fig. 3b). In general, for the linear regression, the equation was $Wt= 1^{-6} \cdot Lf^{3.4504.}$ with 95% confidence intervals of 8.99^{-7} - 2.46^{-6} for *a*, and 3.34 - 3.55 for *b*. (Fig. 3c).

(a)



(b)



(c)

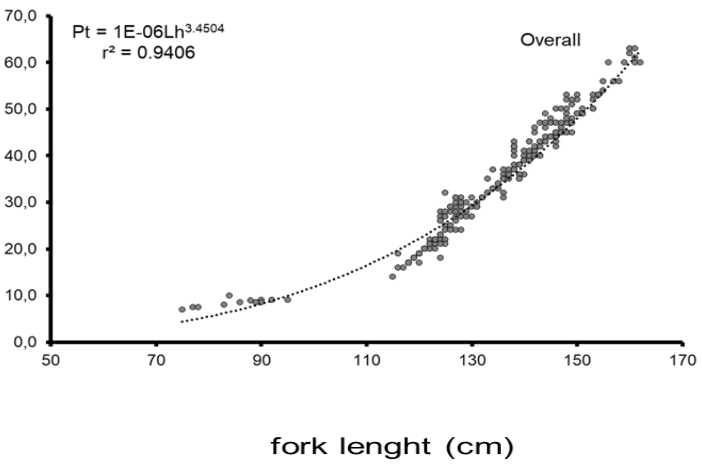


Figure 3. Regression between fork length and total weight of female and male individuals of *Thunnus albacares* captured in the Gulf of Mexico.

The presence of four stages of ovarian maturity was determined. In the sampling month of November, most of the females were in the chromatin nuclear (CN) phase within the primary development. By February, the frequency of the CN phase had decreased and the frequency of the perinuclear (PN) phase had increased. By March, both of these phases had decreased, and the phase of formation of the cortical alveolus (FCA) was presented. Albeit with very little frequency, the primary vitellogenic (PV) phase was also presented in March (Fig. 4).

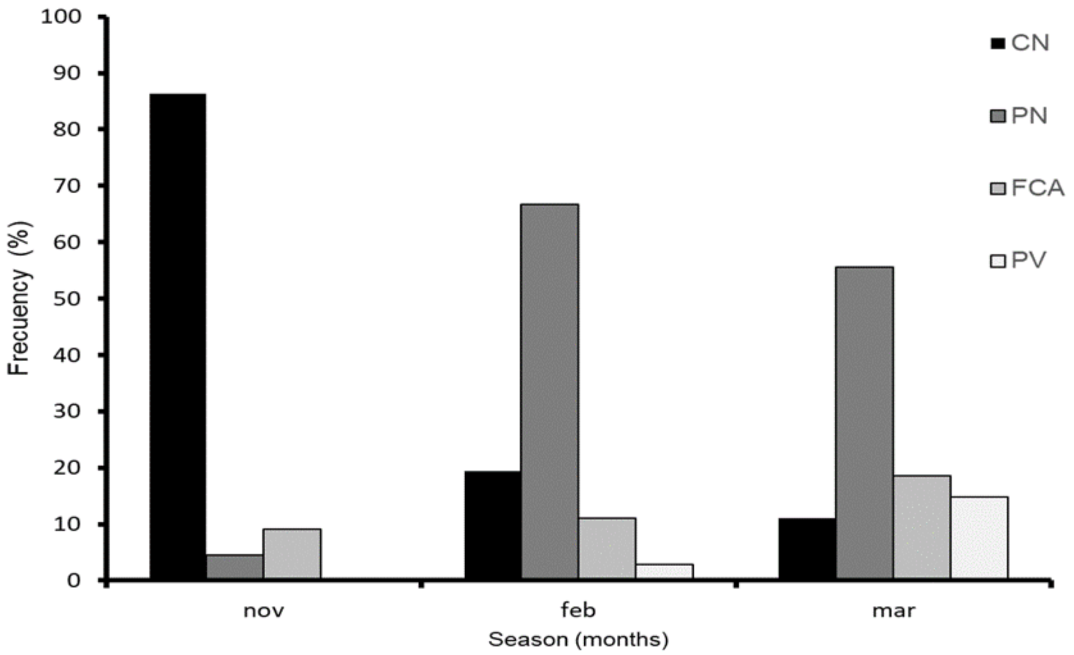


Figure 4. Frequency of stages of sexual maturity in *Thunnus albacares* per sampling month. CN = Chromatin nuclear; PN = Perinuclear; FCA= Formation of the Cortical Alveolus and PV = Primary vitellogenic.

The phases of maturity presented a relationship to the size of females caught, since the phases CN, PN and FCA corresponded to Lf values of less than 139 cm, while the phase PV was found in females with Lf values greater than 140 cm. It should be noted that not all of the phases were found throughout all of the sampling months, e.g., the phase PV, which was not found in the month of November, but was recorded in February and March.

There was a relationship between size and presence of ovarian stages depending on the month of sampling; in November, February and March, females with Lf values of less than 143 cm were found in the stages of CN, NP and FCA. However, the PV stage appeared

in individuals with Lf values from 125 up to 145 cm during February and March, when the presence of oocytes in the CN stage was no longer observed (Figure 5).

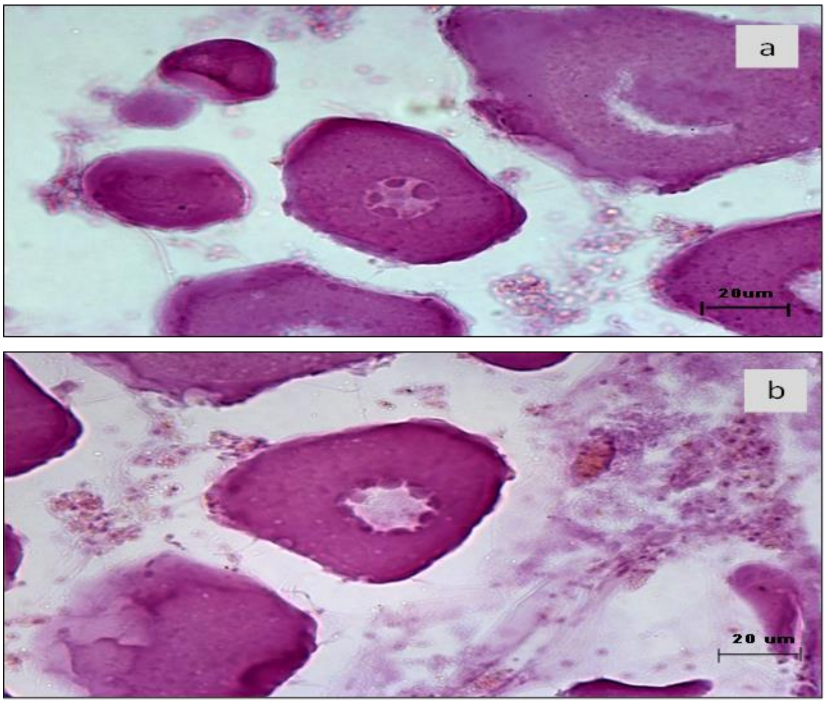


Figure 5. Stages of gonadal development in the primary phase. a) Female in the sampling month of November with Lf value of 123 cm. b) Female in the sampling month of February with Lf value of 86 cm (magnification 40X).

The histological sections observed under the microscope provided information regarding the degree of ovarian development in the females and presented a progressive stage in the chromatin nuclear phase where, with progress towards the perinuclear development, the nucleoli begin to migrate towards the periphery of the nucleus in November and February, and in the larger sizes. With a more advanced degree of development, the formation of the cortical alveolus was found. This was characterized by the presence of small lipidic drops on the cytoplasm.

Moreover, histological sections were analyzed from individuals with Lf values of between 146 cm and 153 cm from February and March, in which were found developed oocytes in the PV phase. In addition to these phases of gonadal development, females with Lf values of between 135 cm and 146 cm were also found with oocytes in the phase of atresia.

DISCUSSION

The yellowfin tuna (*T. albacares)* is a highly migratory species that travels immense horizontal distances at the surface of the sea. Most of the tunas perform vertical displacements in the water column, such that they can be found from the surface down to 200 m in depth, where they are vulnerable to the accumulated risk of fishing in different locations and in all of the phases of their life cycle; i.e., it is possible to capture from young specimens to adults of up to 30 years of age (García *et al.*, 1994).
Different captures are thus reported in different regions, as occurred in the studies of Sun *et al.* (2006) in the Pacific Ocean and Domingo *et al*. (2008) in the western Atlantic Ocean, who reported a sexual proportion with a predominance of males, at 60% of the total individuals captured. This is similar to the

results of the present study, in which the males predominated, at 40% of the total number of differentiated individuals captured.

In this respect, Blackburn (1965) states that, in relation to the distribution of this species in the water column, young tunas form large shoals close to the surface, while the adults prefer deeper waters (although they can also be found near the surface). This could explain why, in this study, males comprised the highest proportion found, with the understanding that, in this species, the males are of greater size than the females. On the other hand, given the migratory capacity of the yellowfin tuna, its risk of capture increases over the course of its life cycle, which to a large degree complicates the establishment of suitable strategies of exploitation, since this is an oceanic species that constitutes a multinational biological resource (Gonzedo-López, 2005). As a consequence, there is great variability of capture sizes in its fishery, as reported by Solana-Sansores and Ramírez-López (2006), who obtained Lf values that ranged from 11 to 190 cm. These data differ from those of the present study, since the capture size interval found was between 75 and 162 cm. This could be due to the difference in sampling period given that the present study was only conducted in the period from November to March, while that of Solana-Sansores and Ramírez-López *Op cit*, was conducted over the course of a whole year.

In this regard, Domingo *et al*. (2008) state that size differences exist according to the month of sampling, recording an average Lf value on capture of 111.5 cm in the Pacific Ocean during the period October to March (1998-2006). However, in the study conducted by Zhu *et al.* (2011) exploring age and growth, the authors reported an average Lf value on capture of 175.9 cm in the central Pacific Ocean and eastern Pacific of China from February to November, in contrast to the present study where an average Lf value of 132 cm was recorded. These variations could have been an artifact of the particular method utilized to capture the individuals, since the fisheries of the Pacific Ocean use purse seine nets, which capture entire shoals comprising tunas of all sizes while, in the Gulf of Mexico, the fisheries exclusively use longlines, which is considered a selective fishing technique.

Regarding the length-weight relationship, the results of the present study showed that the value of b=3.4504 "differed significantly from the value of a=0.9406. Since the confidence interval of the value *b*, both in females ($t = 41.74$ $P < 0.05$) and males ($t = 47.12$, $P < 0.05$), did not include the three, it was concluded that the general growth of *T. albacares* is positive allometric in type ($t=65.87$, $P<0.05$). Other studies have reported that the growth of the individuals often depends on the physiological characteristics of the species (Jatmiko *et al*., 2014), which means that they weigh more than they measure, generating disproportionate growth. The results of that study coincide with that reported by Zhu *et al.* (2011), which also examined *T. albacares*, but in regions of the western and central Pacific Ocean. Likewise, the results coincide with those of the study of Zhenhua Ma *et al*. (2016), which was conducted in the region south of China, and reported that the length-weight relationship of the individuals in a population are affected by factors such as temperature, salinity and food (widely linked to the quality and quantity of their consumption). These are factors that were not considered in the present study, but which could be analyzed in future studies. Nevertheless, the sex and state of sexual maturity were considered, and these presented a close relationship to the growth type presented by the species.

Regarding the stage of ovarian maturity, it has been stated that the presence of *T. albacares* is permanent in the Gulf of Mexico, for which reason it is subject to fishing throughout the year, with the summer months presenting the highest catches due to the increased proximity of the fish to coastal waters for the purposes of reproduction (DOF, 2015).

Given that this study analyzed samples taken exclusively in November, February and March, the results show the presence of only four stages, three of which are within the primary phase of ovarian development. Likewise, the studies conducted by Zudaire *et al*. (2010, 2013) state that the development of oocytes is asynchronous, which means that various stages can be found within the same sample. As a function of this, these authors state that the individuals with Lf values greater than 100 cm present more advanced stages in the region of the western Indian Ocean.

Since the present study analyzed only three months of captures of the yellowfin tuna, the results can be considered preliminary, for which reason it is considered necessary to increase the sampling effort annually and to examine catches over the course of the entire year, in order to determine whether there is greater variation over one or perhaps more years. The information compiled as a result could serve to suggest measures of assistance in the taking of decisions regarding the establishment of norms and specific management plans for the fishery of the yellowfin tuna practiced in the Gulf of Mexico

CONCLUSIONS

The results related to sizes and stage of ovarian maturity corresponding to the fishery of the yellowfin tuna (*T. albacares*) of the Gulf of Mexico determined that:

Males predominate in the populations, accounting for 40% of the total number of differentiated individuals captured in the longline fishery of the Gulf of Mexico.

The current average capture size is a fork length of 132 cm, with a range among the captured individuals of 75 cm to 162 cm.

The growth of the yellowfin tuna is allometric positive in type.

Most of the captured females are immature and in the primary development phase. Prominent in this phase is the chromatin nuclear stage in the month of November.

It is necessary to extend the duration of the sampling in order to obtain more data pertaining to the sizes of the individuals captured, as well as a greater number of gonads collected, in order to determine whether high variation exists in the presence of other stages according to size and to sampling month.

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