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# UPDATE INFORMATION ON THE SPAWNING OF YELLOWFIN TUNA, *Thunnus albacares*, IN THE WESTERN CENTRAL ATLANTIC

by
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## *SUMMARY*

*Information on the spawning of yellowfin tuna (*Thunnus albacares*) from the western central Atlantic is updated from data collected in 1999. Spawning was analyzed based on oocyte development from ovary samples collected. Of the 133 ovaries used in the updated analysis, 1.5% (2 ovaries) of the sampled specimens were considered mature inactive, 2.3 % (3 ovaries) were considered maturing, 50.4% (67 ovaries) were identified as mature, 12% (16 ovaries) were considered ripe, 31.5% (42 ovaries) were identified as ready-to-spawn, and 2.3% (3 ovaries) were in spawned condition. Average batch fecundity for yellowfin tuna was estimated to be $2.1\times10^{6}$ oocytes (n=6), which ranged from $1.2\times10^{6}$ for a 132 cm FL (31.8 kg DWT) to $4.0\times10^{6}$ for a 142 cm FL (42.7 kg DWT) female. The average cost of a single spawning is about 0.83% of body weight. Spawning continues to take place in the Gulf of Mexico between May and August and in the southeastern Caribbean Sea between July and September.*

## *RÉSUMÉ*

*L'information sur la reproduction de l'albacore (*Thunnus albacares*) de l'Atlantique centre-ouest est actualisée grâce aux données recueillies en 1999. La reproduction a été analysée sur la base de l'évolution des ovocytes prélevés sur des échantillons d'ovaires. Sur les 133 ovaires utilisées dans l'analyse actualisée, 1,5% (2 ovaires) des spécimens échantillonnés ont été jugés matures inactifs, 2,3% (3 ovaires) ont été considérés en cours de maturité, 50,4% (67 ovaires) ont été identifiées comme matures, 12% (16 ovaires) ont été jugées matures, 31,5% (42 ovaires) ont été identifiées comme étant prêtes à la reproduction, et 2,3% (3 ovaires) étaient en condition de reproduction. La fécondité moyenne par lot d'albacore a été estimée être de $2{,}1x10^{6}$ ovocytes (n=6), s'inscrivant dans une fourchette allant de $1{,}2x10^{6}$ pour une femelle d'une longueur à la fourche de 132 cm (31,8 kg poids manipulé) à $4{,}0x10^{6}$ pour une femelle d'une longueur à la fourche de 142 cm (42,7 kg poids manipulé). Le coût moyen d'une seule reproduction est d'environ 0,83% du poids corporel. Le frai se poursuit dans le Golfe du Mexique, entre mai et août, et au sud-est de la mer des Caraï bes, entre juillet et septembre.*

## *RESUMEN*

*Se actualiza información sobre el desove del rabil (*Thunnus albacares*) del Atlántico central oeste a partir de datos recogidos en 1999. El desove se analizó en base al desarrollo del oocito a partir de muestras de ovarios recogidas. De los 133 ovarios utilizados en el análisis actualizado, el 1,5% (2 ovarios) de los especimenes muestreados fueron considerados maduros inactivos, el 2,3% (3 ovarios) fueron considerados en proceso de maduración, el 50,4% (67 ovarios) fueron identificados como maduros, el 12% (16 ovarios) fueron considerados como maduros con huevos, el 31,5% (42 ovarios) fueron considerados listos para*

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*desovar, y el 2,3% (3 ovarios) ya había desovado. La fecundidad media del grupo para el rabil se estimó en 2,1x10$^6$ oocitos (n=6), que oscilaba de 1,2x10$^6$ para una hembra de 132 cm FL (31,8 kg de peso limpio) a 4,0x10$^6$ para una hembra de 142 cm FL (42.7 kg de peso limpio). El coste medio de un único desove es aproximadamente del 0,83% del peso corporal. El desove continúa teniendo lugar en el Golfo de México entre mayo y agosto y en el Caribe sureste entre julio y septiembre.*

*KEYWORDS*

*Yellowfin tuna, Spawning, Western Central Atlantic.*

## 1. INTRODUCTION

Information on the spawning of yellowfin tuna, *Thunnus albacares*, is necessary to obtain accurate estimates of the spawning potential of the population and for developing hypothesis of yellowfin tuna movements in the Atlantic. Most of the studies in reproduction of yellowfin tuna in the Atlantic have been accomplished in the eastern Atlantic, as a result of the intensive fishery in the Gulf of Guinea and adjacent waters by French and Spanish fleets (ICCAT, 1991). Based on these studies, it has been concluded that the major spawning grounds for yellowfin tuna were located in the Gulf of Guinea. This information and the fact that yellowfin tuna has transatlantic migrations, based on tag recapture information, were used to propose a single stock for the Atlantic (ICCAT, 1997). However, preliminary reproductive data collected from the US and Venezuelan Longline Pelagic Observer Programs from 1994-1998 revealed that yellowfin tuna have a protracted spawning season that takes place from May to November in the Gulf of Mexico and southeastern Caribbean (Arocha *et al.*, 2000). Although preliminary, the data suggests the importance of the spawning grounds in the western tropical Atlantic. This paper updates the spawning information collected during 1999 by the previously mentioned observer programs and discusses the contribution of the spawning yellowfin tuna to the different fisheries in the northwestern Atlantic.

## 2. MATERIAL AND METHODS

From January to December 1999, observers from the US Pelagic Observer Program (NMFS-SEFSC) and the Venezuelan Pelagic Longline Observer Program (ICCAT/EBRP – FONAIAP) recorded forklength (FL, cm) as well as other morphometric data on a total of 3,535 yellowfin tuna caught in the western Atlantic between 0°N and 55°N (Fig. 1), while on board, sex identification and biological samples were collected to estimate female maturity.

Female maturity was determined from sections of 133 ovaries collected from yellowfin tuna between 120 and 173 cm FL. Gonad maturation was determined based on the most advanced type of oocyte development (Arocha *et al.*, 2000) and on the diameter corresponding to the 95$^{th}$ percentile of the size frequency distribution (Cayre and Laloe, 1986). Oocyte diameter was measured at random using a video analyzing system linked by a video camera to a dissection microscope. Frequency distributions of 400-500 oocytes were developed to obtain stages of gonad development.

Batch fecundity ($B_f$) was estimated as the product of the mean of three counts of hydrated oocytes per unit of weight ($\overline{H}_o$) and the ovary weight ($O_w$), from specimens that had not spawned. The cost of a single spawn was estimated as the product of unit wet weight of a hydrated oocyte and the relative batch fecundity (calculated as $B_f$ ' fish dressed weight). Spawning frequency was estimated as the frequency of ripe females (ovaries with migratory nucleus and hydrated oocytes) during the main spawning season (Hunter and Macewiz, 1985). Spawning season and location was based on specimens with migratory nucleus and hydrated oocytes in the ovaries.

## 3. RESULTS

Based on the most advanced group of oocytes in frequency distributions of oocytes, two specimens had frequency distributions of primary (<50 µm) and perinucleolar stage oocytes (50-200 µm). Three specimens had previtellogenic oocytes (250-300 µm) as the most advanced group of oocytes in their distributions. 67 specimens had different stages of development of vitellogenic oocytes (290-600 µm) as the most advanced group in their distributions. 16 fish had migratory nucleus stage (550-600 µm) oocytes as the most advanced group. And in the final stage of gonad maturation, 42 yellowfin tuna specimens had ovaries showing hydrated oocytes at different stages of development (700-1100 µm) in their gonads.

In terms of gonad maturation, the two specimens (1.5%) with primary and perinucleolar stage oocytes were considered to be in a resting condition or mature inactive, as both fish had adult sizes (160 and 173 cm FL). Of the specimens considered mature active, the three (2.3%) with previtellogenic oocytes were considered to be in a maturing stage and the 67 fish (50.4%) with vitellogenic oocytes were considered as mature females. The ripe and ready-to-spawn stage of gonad maturation included, the 16 fish (12.0%) that had migratory nucleus stage oocytes as their most advanced group and the 42 specimens (31.6%) that had hydrated oocytes in their gonads, respectively. Only 3 (2.3%) samples were found to be in a spawned condition.

Based on the size frequency distribution of oocyte diameter, the ripe and ready-to-spawn stage gonads had a mean 95$^{th}$ percentile diameter ($\overline{D}_{95}$) of 726 µm in ovaries with migratory nucleus oocytes and a $\overline{D}_{95}$ = 792 µm in gonads with hydrated oocytes, respectively. The mature, maturing and the resting stage gonads had a $\overline{D}_{95}$ of 639 µm, 474 µm, and 192 µm, respectively (Table 1).

The 1999 spawning season for yellowfin tuna started in March and appears to have ended in November, as observed from the presence of mature and ripe and ready-to-spawn females in the samples (Fig 2). The March spawning females were caught near the Equator and were not included in the northwestern Atlantic yellowfin tuna spawning season. During the spawning season, most of the mature and ripe and ready-to-spawn females were between the 130 and 150 cm FL size classes, followed by a second group between 155 and 170 cm FL (Fig. 3). Only a small fraction of reproductive active females were less than 130 cm FL. Locations of ripe and ready-to-spawn females were different in size and time of spawning (Fig. 4). Statistical differences were found in female size (FL) between the Gulf of Mexico and the southeastern Caribbean ($t_s$ = !5.990, $p$<0.0001, " = 0.05). The data showed that spawning females found in the Gulf were smaller than the ones found in the southeastrn Caribbean. Most of the spawning females in the Gulf of Mexico were caught between May and June, while the majority of the spawning females in the southeastern Caribbean were caught between July and September.

The spawning frequency estimated for yellowfin tuna in the northwestern Atlantic was based on the frequency of ripe and ready-to-spawn females (ovaries with migratory nucleus and hydrated oocytes) during the main spawning season. For the estimation of the spawning frequency, only the months from May to September were considered due to the relative high number of active specimens in those months. This represents a spawning season of 153 days, and thus the spawning frequency is estimated to be 3.35 days (Table 2). In addition, spawning frequencies were also calculated for yellowfin spawning in the Gulf of Mexico and in the southeastern Caribbean. In the Gulf of Mexico, the spawning frequency was estimated to be 3.18 days based on a 123 day spawning season (May – August) and the spawning frequency for the southeastern Caribbean was estimated to be 1.47 days based on a 92 day spawning season (July – September).

The estimated mean batch fecundity ( $\overline{B}_f$ ) for six females was $2.16 \times 10^6$ hydrated oocytes (Table 3). No relationship between batch fecundity and length was estimated due to the lack of fit. The estimated mean relative batch fecundity for the same fish was 54.2 oocytes per gram of body weight. The estimated mean cost of a single spawn was obtained from using hydrated stage oocytes from fish that had batch fecundity estimates, an estimate of the cost of a single spawn was calculated for every specimen included in the analysis (Table 3). Therefore, the estimated mean cost of a single spawn (excluding metabolic costs and behavioral activities) is about 0.83% of body weight. If a female spawned every 3.35 days, the average daily cost of spawning a batch of eggs would be estimated to be 0.25% of the body weight per day. Using the same estimate of the cost of a single spawn to estimate the average daily cost of spawning a batch of eggs in the Gulf of Mexico, spawning yellowfin tuna would invest 0.26% of their body weight per day, but in the southeastern Caribbean spawning yellowfin tuna would invest 0.56% of their body weight per day.

## 4. DISCUSSION

Since the quantification of the reproductive output in fishes, like yellowfin tuna, is important for population dynamics and management models used in stock assessments, the accurate information on reproductive dymanics should contribute to the evaluation of the effect of fishing on the reproductive potential of the population of fishes like yellowfin tuna in the Atlantic.

The information on the spawning of yellowfin tuna examined in this paper indicate that the mean 95$^{th}$ percentile oocyte diameter ( $\overline{D}_{95}$ ) used to separate the different stages of gonad maturation is not completely accurate because of the overlap in the size range of some stages. This situation occurred mainly between the mature and the ripe stage, mostly because is difficult to separate advanced vitellogenic oocytes from migratotory nucleus oocytes when viewed whole. It is necessary to look at the overall frequency distribution and examine the developmental stage of the oocytes in the most advanced group to be completely certain. A solution to this problem maybe to look at the 98$^{th}$ percentile to reduce the degree of range overlap, but it would require an increase in the sample size of the frequency distrbutions.

The spawning frequency obtained from this study is consederably larger than the ones encontered for yellowfin in the Coral Sea and in the eastern Pacific Ocean-EPO (McPherson, 1991; Schaefer,1996; Schaefer, 1998). But it is interesting to note that when the spawning frequencies are estimated by separate areas (Gulf of Mexico and southeastern Caribbean), the one estimated for the southeastern Caribbean Sea is comparable with the ones estimated for yellowfin in other areas. Nonetheless, the large spawning frequency estimates can be the result of using a less accurate method, which does not include the observation of post-ovulatory follicles, and by using the length of spawning season may result in a biased estimate. However, the high estimates could be the result of smaller, probably younger, spawning fish in the Gulf of Mexico that may require longer time periods to develop a spawning batch. In any case, it is important to continue to investigate this issue so accurate estimates of spawning frequency can be estimated, because they are an essential part in estimating potential annual fecundity at age which is used in the estimtaion of the spawning potential of the population.

Batch fecundity was estimated from fish that only had hydrated oocytes in their ovaries and had not spawned a batch. Migratory nucleus oocytes were not included in the estimations because they do not constitute a spawning batch, although they may form part of the batch, they may also be re-absorbed. Thus, using only hydrated oocytes from non-spawning fish reduces any overestimation in batch fecundity. The mean batch fecundity estimate of $2.1 \times 10^6$ hydrated oocytes was calculated from yellowfin tuna caught in the Gulf of Mexico, which are smaller fish that spawning yellowfin from the southeastern Caribbean Sea (from where no batch fecundity estimates were available). This mean estimate is comparable to estimates of batch fecundity in fish of 125 cm FL in the EPO (Schaefer, 1998), but fish of similar size to the ones caught in the Gulf (135-145 cm FL) had higher estimated mean batch fecundities (-3!4H$10^6$). Probably because in the EPO study, migratory nucleus stage oocyte were included in the batch fecundity estimates. It is evident from this study that estimates of batch fecundities from the southeastern Caribbean Sea are needed and to increase the effort in the Gulf of Mexico as well. This will ensure the estimation of batch fecundity at different sizes which will produce a batch fecundity relationship that would be used in the stock assessment models.

The spatial and temporal distribution of reproductive active females in the Gulf of Mexico and in the southeastern Caribbean Sea during the 1999 spawning season continues to support the evidence that there are two spawning grounds for yellowfin tuna in the western tropical Atlantic. The information obtained by Arocha *et al.* (2000) and in this study supports the evidence that spawning yellowfin occur in the Gulf of Mexico from May to August and in the southeastern Caribbean Sea, spawning occurs from July to November. It has also been demostrated that the two spawning groups are of different size. This results lead us to think that there are two distinctive spawning groups in the western tropical Atlantic.

Gaertner and Medina-Gaertner (1994) questioned the single stock hypothesis of yellowfin tuna in the Atlantic. These authors discussed three issues that supported the hypothesis (transatlantic migrations west-east, main spawning season is in the eastern Atlantic, the proportion of pre-adults in the west lead to propose an east-west migration) and concluded that the present migration model for yellowfin tuna in the Atlantic is presumptuous. Because the west-east migrations are the only known facts, there is no exchange between yellowfin tuna in U.S. waters and the southern Caribbean Sea. The authors also suggested that it is possible that the spawning area in the central Atlantic contributes to the fish caught off Brazil. From our study, we can conclude that spawning yellowfin tuna in the southeastern Caribbean contributes to the fishery off Venezuela and may contribute to the fishery off the Guyanas. The spawning fish in the Gulf of Mexico contributes to the fishery off the US and Mexico and may be the adults making the west-east transatlantic migrations. The lack of exchange between yellowfin tuna in the Gulf of Mexico and southeast US with the southern Caribbean continue to hold, despite the high return rate in tag recaptured of billfish for the past seven years (Marcano *et al.*, 2000). However, there may be an exchange between the fish spawned off Venezuela and those caught of northern Brazil.

From the results presented in this study, it becomes evident that there are many uncertainties in the reproductive dynamics of yellowfin tuna in the Atlantic, one of the most important is the degree of contribution to the spawning stock of the yellowfin caught in the western tropical Atlantic. Therefore, it is necessary to expand the collection of reproductive samples in the western tropical Atlantic; in order to reduce the uncertainties observed and to clarify the movement patterns yellowfin tuna has in the western tropical Atlantic.

**BIBLIOGRAPHY**


AROCHA, F., D. Lee, L. Marcano and J. Marcano. 2000. Preliminary studies on the spawning of yellowfin tuna, *Thunnus albacares*, in the western central Atlantic. ICCAT, Col. Vol. Sci. Pap., 51: 538-552.

CAYRE, P. and F. Laloe. 1986. Review of the gonad index (GI) and an introduction to the concept of its “critical value”: an application to the skipjack tuna, *Katsuwonus pelamis*, in the Atlantic Ocean. Mar. Biol., 90:345-351.

GAERTNER, D. and M. Medina-Gaertner. 1994. Análisis de la estructura del stock de atún aleta amarilla por medio de las frecuencias de tallas. ICCAT, Col. Vol. Sci. Pap., 42(2):290-299.

HUNTER, J. and B. Macewicz. 1985. Measurement of spawing frequency of multiple spawning fishes. NOAA Tech. Rep. NMFS 36:79-94.

ICCAT. 1991. Report of the yellowfin tuna program. ICCAT, Col. Vol. Sci. Pap., 36:1-586.

ICCAT. 1997. Report for Biennial Period, 1996-1997, Part I (1996), Vols. 1 and 2. Madrid, Spain.

MARCANO, L., F. Arocha, J. Marcano and A. Larez. 2000. Actividades desarrolladas en el programa expandido de ICCAT para peces de pico en Venezuela. Período: 1998 – 99. ICCAT, Col. Vol. Sci. Pap., 51:981-993.

McPHERSON, G.R. 1991. Reproductive biology of yellowfin tuna in the eastern Australian fishing zone, with special reference to the north-western Coral Sea. Aust. J. Mar. Freshwater Res., 42:465-477.

SCHAEFER, K. 1996. Spawining time, frequency and batch fecundity of yellowfin tuna, *Thunnus albacares*, from Clipperton Atoll in the eastern Pacific Ocean. Fish. Bull., 94:98-112.

SCHAEFER, K. 1998. Reproductive biology of yellowfin tuna (*Thunnus albacares*) in the eastern Pacific Ocean. IATTC Bulletin, 21(5):205-272.

**Table 1**. Descriptive statistics of oocyte diameter corresponding to the 95th percentile of the size frequency distribution of gonad stages in northwestern Atlantic yellowfin tuna.

| ***Oocyte stage*** | ***Mean*** | ***s.e.*** | ***range*** | ***n*** |
|---|---|---|---|---|
| Spawning (*H*) | 792 | 16 | 615 – 1047 | 42 |
| Ripe (*Mn*) | 726 | 7 | 685 – 789 | 16 |
| Mature | 639 | 5 | 448 – 715 | 67 |
| Maturing | 474 | 44 | 387 – 534 | 3 |
| Resting | 192 | 60 | 131 – 252 | 2 |

**Table 2.** Monthly proportion of ripe and ready-to-spawn and spawning frequency of northwestern Atlantic yellowfin tuna.

| | ***Ripe & Ready-to-Spawn Females*** | ***Total active females*** | ***% Ripe & Ready-to-Spawn Females*** | ***Spawning frequency (days)*** |
|---|---|---|---|---|
| May | 20 | 30 | 66.66 | |
| June | 6 | 18 | 33.33 | |
| July | 16 | 36 | 44.44 | |
| August | 5 | 20 | 25.00 | |
| September | 5 | 10 | 50.00 | |
| **Total** | **52** | **114** | **45.61** | **3.35** |

**Table 3.** Cost of a single spawn in percentage of dressed weight of 6 female yellowfin tuna in the northwestern Atlantic. For each sample, length (FL), dressed weight (DWT), ovary weight, batch fecundity, hydrated oocyte wet weight, and relative batch fecundity are given.

| **Sample number** | **FL (cm)** | **DWT (g)** | **Ovary wt. (g)** | $B_f$ **(#H)** | **Hydrated oocyte wet wt. (g)** | **Relative** $B_f$ | **Cost of single spawn (%)** |
|---|---|---|---|---|---|---|---|
| *99YFT020* | 138 | 38636 | 670.30 | 1340177 | 0.000210 | 34.68 | 0.7284 |
| *99YFT021* | 140 | 38182 | 967.5 | 2121919 | 0.000154 | 55.57 | 0.8558 |
| *99YFT022* | 142 | 40000 | 747.1 | 1379525 | 0.000174 | 34.48 | 0.6000 |
| *99YFT054* | 132 | 31818 | 596.8 | 1261547 | 0.000138 | 39.64 | 0.5471 |
| *99YFT055* | 147 | 43182 | 1363 | 2846056 | 0.000102 | 65.90 | 0.6722 |
| *99YFT056* | 142 | 42727 | 1474.4 | 4054581 | 0.000168 | 94.89 | 1.5942 |
| | | | | | | ***Mean cost of single spawn*** | ***0.8330*** |
| | | | | | | ***s.e.*** | ***0.1583*** |


**Figure 1.** Distribution of proportional nominal CPUE (number of yellowfin tuna / 100 hooks) of observer covered trips from the U.S. (rhombs) and the Venezuelan (circles) Pelagic Longline Observer Programs during the 1999 sampling season.

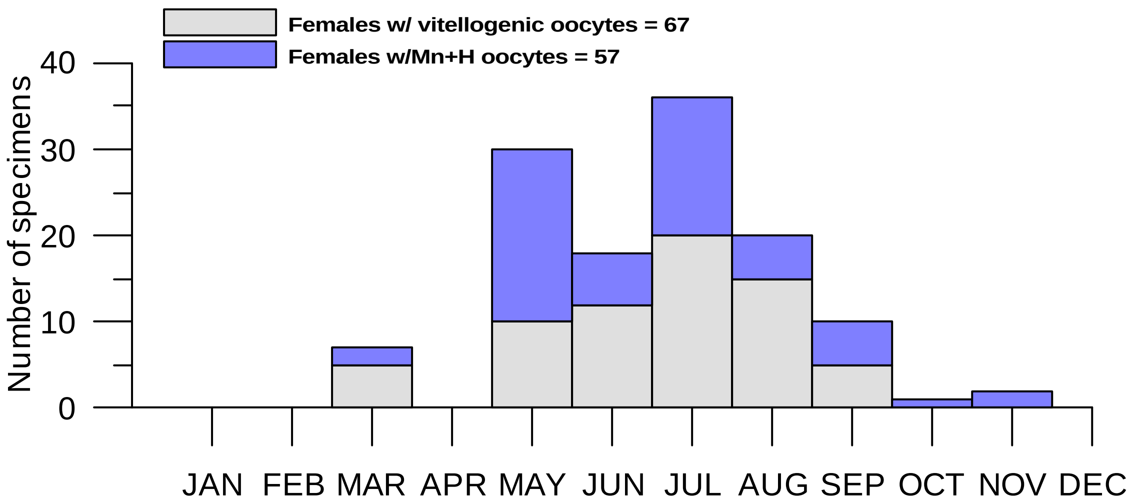


**Figure 2.** Frequency distribution of mature (w/ vitellogenic oocytes) and ripe (w/ migratory nucleus-Mn oocytes) and ready-to-spawn (w/ hydrated-H oocytes) females by month in the spawning areas of the northwestern Atlantic.

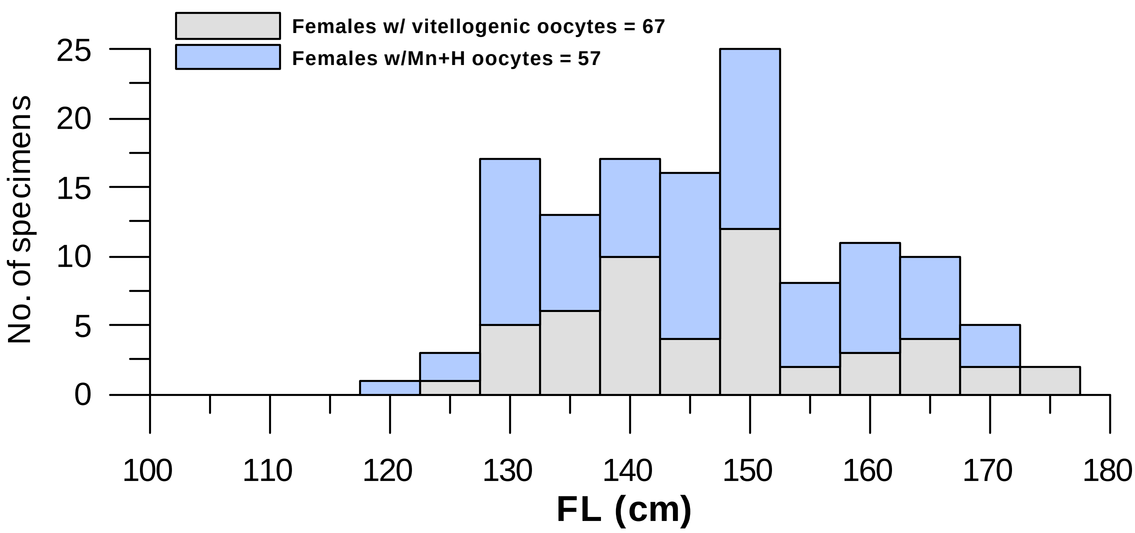


**Figure 3.** Size distribution of mature (w/ vitellogenic oocytes) and ripe (w/ migratory nucleus-Mn oocytes) and ready-to-spawn (w/ hydrated-H oocytes) females in the spawning areas of the northwestern Atlantic.

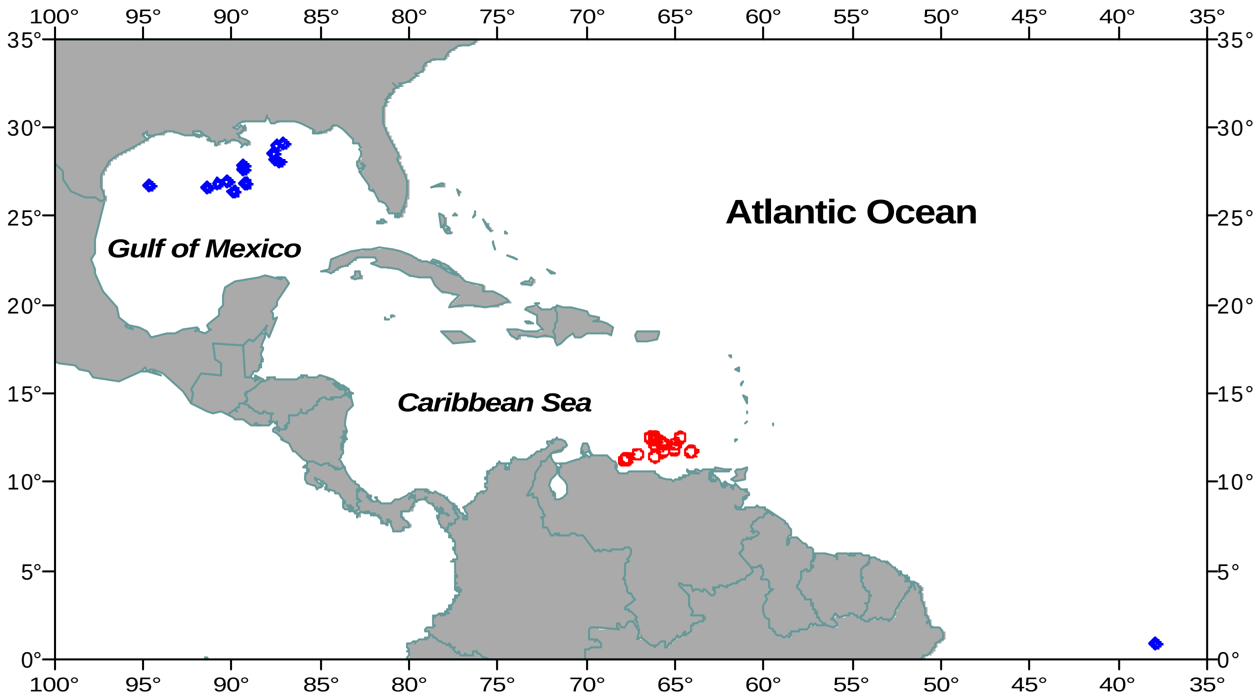


**Figure 4.** Spatial distribution of ripe (ovaries with migratory nucleus) and ready-to-spawn (ovaries with hydrated oocytes) yellowfin tuna females caught by vessels covered by the U.S. (rhombs) and the Venezuelan (circles) Pelagic Longline Observer Programs in 1999**.**