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Reproductive of Atlantic Horse Mackerel, *Trachurus trachurus* (Linnaeus,1758, Carangidae) in the Western Coast of Libya

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Trachurus trachurus, reproductive biology, fecundity, GSI, maturity, Mediterranean Sea, Libya.

ABSTRACT

This work describes key reproductive traits of Atlantic horse mackerel *Trachurus trachurus*, collected from the western Libya coast between February 2019 and February 2020. A total of 1334 Specimens was examined to estimate sex ratio, size at maturity, seasonal reproductive activity, fecundity, and abdominal fat condition. Females were abundant than males, giving an overall sex ratio of 1:1.5. The estimated length at 50% maturity was 203 mm TL for combined sample; males matured at a slightly larger length (208 mm TL) than females (204 mm TL). Monthly changes in gonadosomatic index and gonad stage composition indicated a main spawning period extending through winter and spring, with highest females GSI in February varied the highest male GSI in December. Potential annual fecundity varied from 64,000 to 1,290,000 eggs in females measuring 160-319 mm TL and increased with fish size. Abdominal fat scores were highest before the main spawning period and declined during gonad development, suggesting that stored energy contributes to reproductive investment. The results provide local baseline information that can support stock assessment and fisheries management for *Trachurus trachurus* in Libyan waters.

Trachurus trachurus **(Linnaeus,1758, تكاثر سمك الماكريل الأطلسي Carangidae) في الساحل الغربي لليبيا**

هند السيد نصير1*، إكرام فرج كرة2*، محمد الهاشمي الشارف3*، ايمان محمد بوغريس4*، منال علي ارحومة5*

تقدم هذه الدراسة تحليلا لبيولوجيا تكاثر أسماك الصاورو الأسود (*Trachurus trachurus*) في المنطقة المقابلة للساحل الغربي الليبي خلال الفترة من فبراير 2019 إلى فبراير 2020، حيث تم تحليل 1334 عينة. بينت النتائج انحياز في نسبة الجنس لصالح الإناث بنسبة (1:1.5). كان الطول عند أول نضوج جنسي (L50) 203 ملم لكلا الجنسين، مع ملاحظة أن الذكور تنضج عند طول أكبر بقليل (208 ملم) مقارنة بالإناث (204) ملم. من خلال مؤشر الحالة التناسلية (GSI) تبين أن موسم وضع البيض الرئيسي يقع خلال فصلي الشتاء والربيع، حيث بلغت الإناث ذروتها خلال شهر فبراير، بينما بلغت الذكور ذروتها خلال شهر ديسمبر. تراوحت الخصوبة السنوية المتوقعة ما بين 64,000 إلى 1,290,000 بيضة للأسماك التي يتراوح طولها ما بين 160 إلى 319 ملم، مع زيادة في الخصوبة بزيادة حجم الأسماك. كما وُجد أن مخزون الدهون في منطقة البطن كان في أعلى مستوياته خلال فصل الشتاء، وكان هذا مرتبطًا بتطور الغدد التناسلية مما يشير إلى أهميته في عملية التكاثر. وتُعدّ هذه النتائج بيانات أساسية مهمة لإدارة مصايد اسماك الصاورو الاسود في المياه الليبية.

INTRODUCTION

Trachurus trachurus, is a small pelagic fish carangid commonly known as the Atlantic horse mackerel. It belongs to the family Carangidae within the order Carangiformes, adiverse group that includes numerous coastal and offshore species (Froese and Pauly, 2022).
Three horse mackerel species occur regularly in Mediterranean waters: the *T. trachurus*, *T. mediterraneus*, and *T. picturatus*. The Atlantic horse mackerel *has a broad* distribution in the eastern Atlantic and Mediterranean Sea, occurring along European and African coasts. It occupies pelagic habitats from nearshore waters to offshore areas and may occur down to approximately 200m depths (Whitehead et al., 1984, Moazzam and Osmany, 2024).The species forms schools and shows seasonal and spatial movements that vary with habitat, prey availability, and reproductive condition (Abaunza et al., 2003; Rumolo et al., 2017; ICES, 2021).
Atlantic horse mackerel has ecological and economic importance. It serves as prey for larger fish, seabirds, and marine mammals, and it supports commercial fisheries in several Mediterranean regions. The species is a fast-swimming predators and a batch spawner, spawning may occur over an extended differ among areas, (Costa, 2009; El Achi *et al.*, 2021). Previous work from the western coast of Libya described the feeding habits and biological aspects of *T. trachurus* (Ensair *et al.*,2022). However, detailed reproductive information from the Libyan southern Mediterranean coast of Libya remains limited. Local estimates of maturity, spawning period, sex ratio, fecundity, and energy storage are needed to improve stock assessment inputs support region-specific fisheries management and conservation efforts. In order to address this knowledge gap, this work aimed to study its reproductive biology of *T. trachurus* in the western of Libyan, with emphasis on sex ratio, length at 50% maturity, spawning seasonality, fecundity, and abdominal fat dynamics.

MATERIALS AND METHODS

Between February 2019 and February 2020. 1334 specimens of *T. trachurus* were collected with a commercial trawler off the Western Coast of Libya-Tripoli (Fig. 1) with at least 70 individuals from each month. In the laboratory. The total length (TL), the fork length (FL) and weighed (W) were measured for each specimen. Fish were dissected, and the gonads were extracted, weighed to the nearest 0.01g, and classified macroscopically according to the maturity scale of (Costa, 2009).

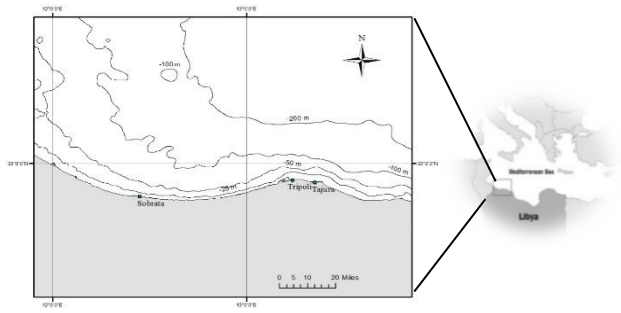

Fig. (1): Map of the western Libya coast showing the sampling area for *T. trachurus*.

Deviation of the sex ratio from parity (1:1) was tested using a chi-square test. Length 50% maturity (L_{50}) was estimated from the proportion of mature fish in 10 mm length classes. A logistic model was fitted to the maturity data, and L_{50} was derived from the fitted maturity ogive.

$$\psi(L) = m_{\infty}\left(1 + e^{\left(-\frac{L-L_{50}}{\delta_L}\right)}\right)^{-1}$$

The spawning period was inferred from monthly patterns in mean of gonadosomatic index (GSI) and the monthly distribution of maturity stages.

GSI was expressed as gonad mass relative to somatic body mass using the equation below:

GSI (%) = [gonad weight / (total body weight- gonad weight)] X 100

Potential fecundity was estimated from five mature ovaries using the gravimetric method of Hunter et al. (1985), based on counts of advanced pre-spawning oocytes. Abdominal fat was scored in four categorized following Attwood et al. (2010). Stage 0 no visible abdominal fat. Stage 1 indicated thin fat strind less than 5mm thick are clearly visible. Stage 2 indicated enlarged fat strands covering more than half of the abdominal organs. While stage 3 indicated extensive fat covering more than half of the abdominal organs extending along the dorsal surface of the gas bladder.

RESULTS AND DISCUSSION

Sampled fish measured 100-370 mm, weighed 9-409 g. Females dominated the sample. A total of 799 females measured 120 - 370 mm TL, while 535 males measured 100 - 349 mm TL. The overall sex ratio was 1 male to 1.5

females and differed significantly from the expected 1:1 ratio ($X^2 = 52.2$, df = 1, $p < 0.05$).
For the pooled sample, L_{50} was estimated at 203 mm TL (delta=27.6 mm). Males reached L_{50} at 208 mm TL (delta =38 mm), while females reached L_{50} at 204 mm TL (delta =20.5 mm), (Fig. 2 and 3). The smallest males and females with developing gonads measured 132 mm TL and 140 mm TL, respectively.

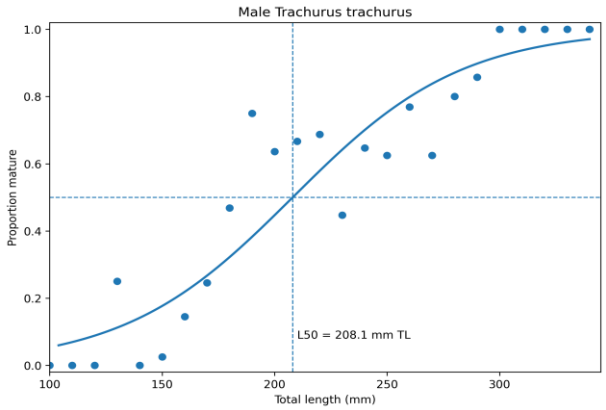

Fig. (2): Maturity ogive used to estimate male L_{50} in *T. trachurus*.

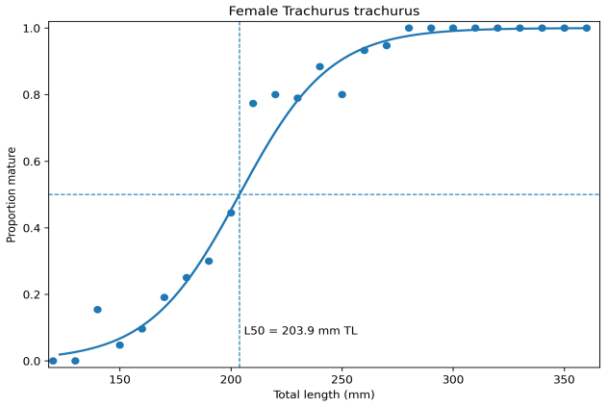

Fig. (3): Maturity ogive used to estimate female L_{50} in *T. trachurus*.

In the present study, Atlantic horse mackerel (*T. trachurus*) ranged in total length from 100 to 360 mm and weighed between 9 and 409 grams. This size range aligns with previous findings from the Mediterranean Sea, where *T. trachurus* typically exhibits a broad size distribution that reflects various age classes and growth stages. For example, studies conducted along the Catalan coast have reported size ranges from approximately 90 mm to over 350 mm TL, with corresponding variations in weight (Van Beveren et al., 2016, Recasens et al., 2008). Similarly, research from the southern Mediterranean, including the Strait of Sicily has documented that *T. trachurus* populations commonly range from 40 to 350 mm in TL. This broad size distribution encompasses both juveniles and adult, further confirming the presence of multiple age classes within the population and supporting the characteristic growth variability of the species in the region (Basilone et al., 2017).

The female-biased sex ratio observed in this study is consistent with several Mediterranean reported for horse mackerel. female predominance can reflect sex-specific growth, survival, catchability, and seasonal aggregation during reproduction. Similar female-biased sex patterns have been reported for *T. trachurus* and related horse mackerel stocks during reproductive periods (Rahmani et al., 2020; Ferreri et al., 2019; Rodríguez-Castañeda et al., 2024)

Males matured at a slightly larger size than females, with L_{50} values of 208.1mm TL and 203.9 mm TL, respectively. The smallest developing males and females were recorded at 132mm TL and 140mm TL. These estimates are higher than those reported from Béni-Saf Bay, Algeria, where females and males reached first maturity at 149mm TL and 156 mm TL, respectively (Rahmani et al., 2020). However, they fall within the broader maturity range reported for *T. trachurus* in previous studies, where length at first maturity ranges from 160 to 250mm TL, with values commonly around 210mm TL Comparable Mediterranean estimates close to 190-220 mm TL, have also been reported (Abaunza et al., 2003; Carbonara et al., 2012; Ferreri *et al.*, 2019). Differences among areas may reflect temperature, productivity, fishing pressure, and population structure. In the present study, the maturity pattern suggests that females enter the spawning population at a slightly smaller size than males.

GSI increase during winter and remained elevated through spring in both sexes (Fig. 4). Ovarian GSI was high from November to March, then declined sharply from April to June. A smaller increase occurred in July, followed by minimum mean values in September when GSI reached 0.21% in male and 0.25% in females (Fig. 5). Individual GSI ranged from 0.01 to 13.1% in females and from 0.01 to 13. 9% in males. The highest mean female GSI occurred in February (4.47±0.23%), whereas males peaked in December (2.47±1.16%). Overall, male GSI values were lower than female values.

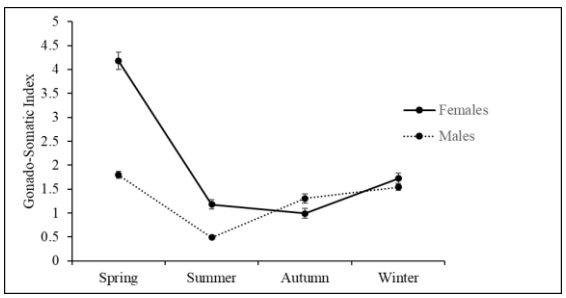

Fig. (4): Seasonal mean gonadosomatic index (GSI±SE) for male and female of *T. trachurus* from western coast of Libya.

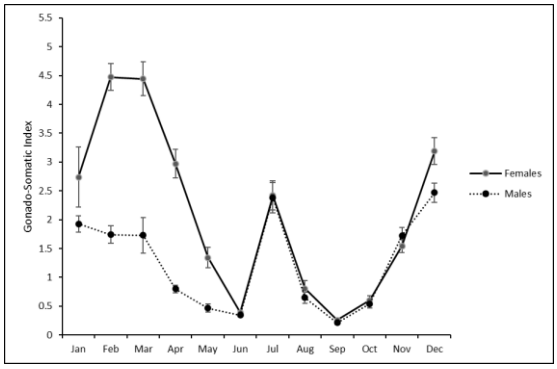

Fig. (5): Monthly variation in GSI for male and female in *T. trachurus.* Error bars represent one standard error.

A pronounced peak in GSI was observed during winter and spring, with ovarian GSIs elevated from November through March, followed by a rapid decline from April to June. A smaller secondary peak occurred in July, while GSIs reached their lowest values in September. Females exhibited a peak mean GSI in February and males peak earlier in December. Male GSI values were consistently lower than those of females, consistent with the typical reproductive investment disparity between sexes (Lowerre-Barbieri et al., 2023).

Similar season reproductive pattern has been reported in related horse mackerel species, including *T. mediterraneus* from the Black Sea, suggesting that reproductive timing may among areas and species according to local environmental conditions (Kutsyn, 2021). The earlier male GSI peak observed in the present study may indicate slight temporal differences in reproductive development between sexes. Comparable sex-related variation in maturity has been reported for *T. trachurus* in the central Mediterranean (Ferreri et al., 2019).

"Immature" fish with gonad stage of 1 or 2 are not expected to spawn in the current season, but those with a gonad stage of 3 or 4 were considered to be actively reproducing. Ripe gonads were absent in males from March to October. In contrast, two months later. females with ripe gonads were absent from June to October, also, no stage ripe gonads were caught in January for both males or females, the majority of active males dominated in December (94%) while females were dominated in March. (96%).

All gonads recorded in September were inactive in both sexes. Spent males occurred in November and December whereas spent females occurred in May, June, November, and December (Fig. 6)

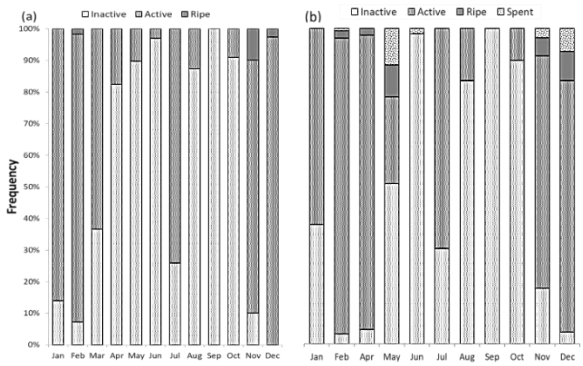

Fig. (6): Monthly frequency of gonad stages in male (a) and female (b) *T. trachurus*

The relationship between potential annual fecundity and fish was examined using total length and body mass.

Fecundity estimates from five mature females ranged from 64.000 to 1,290,000 eggs for fish measuring 160-319 mm TL. Fecundity increased with both total length and body mass (Fig. 7).

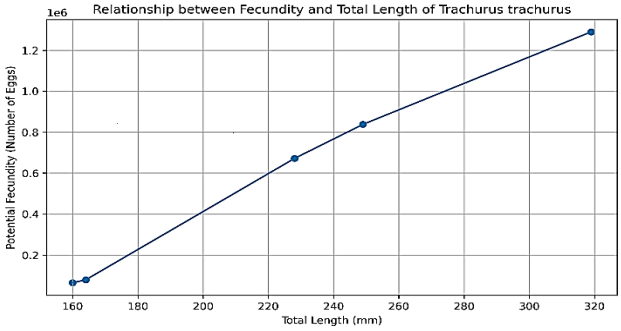

Fig. (7): Relationship between fecundity and total length for five mature females *T. trachurus*

In our study potential annual fecundity exhibited a linear and marked increase with the total length, demonstrating a strong positive relationship between fecundity and the size of mature females. This pattern is consistent with findings from other Mediterranean and Atlantic populations of *T. trachurus*, where larger females typically produce significantly more eggs than smaller individuals.

Fecundity in *T. trachurus* reported generally increases with female size, as larger females tend to produce oocytes than the smaller individuals ICES (2021) reported positive relationship between potential fecundity and both fish length and weight, supporting the role of female body size in reproductive output. Similar size -related patterns have also been reported for horse mackerel, with batch fecundity estimated at about 172-209 oocytes g^{-1} female weight and potential annual relative fecundity ranging from 1040 to 3280 oocytes g^{-1} female weight (Abaunza et al., 2003) therefore, the positive association between fecundity and female size

observed in the present study agrees with the general reproductive pattern reported for *T. trachurus.*

The average seasonal abdominal fat score was 0.21 and 0.22 for males and females respectively, the abdominal fat for both sex reaches a high point in the winter, no males with abdominal fat were catch in Spring, females showed a minimum score of abdominal fat in Spring (Fig.8 a). The stage (5: Partly spent) were recorded the highest abdominal fat comparing with all stages. (2: Early ripening) had greatest amount of abdominal fat while late ripening and ripening had a low amount of fat. In fact, storage abdominal fat in fish synchronizes with starts partially on spending the eggs.

The summer season showed a significant replenishment of abdominal fat stores in both sexes after the spawning season. The relationship between fat trend and the ovarian stages revealed that abdominal fat declines in lockstep with the growth of the eggs. In contrast, abdominal fat increases steadily before spawning season start. (Fig. 8b).

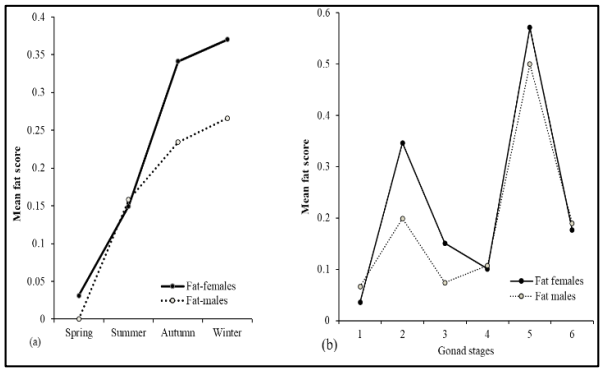

Fig. (8): Mean abdominal fat of *T. trachurus*.by season and sex. (a) and by gonad stages (b).

This study showed that GSI peaked in both sexes during winter and spring, consistent with the period of high fat storage, suggesting using fat for gonad development and gamete production. Winter exhibits high abdominal fat scores, suggesting this period serves as a crucial phase for building energy reserves (Kaçar et al., 2016) mention that high winter reserves are a common strategy for fish species to prepare for energy-demanding activities like reproduction. Also, fat depletion and GSI decline reinforce the connection between fat reserves and gonad growth.

Abdominal fat dynamic closely mirrors reproductive cycles, with fat reserves accumulating prior to spawning and depleting during gametogenesis, underscoring the importance of lipid storage in supporting reproductive effort (Van Damme et al., 2014). The timing of gonad maturation stages and spawning activity is influenced by environmental factors such temperature and food availability, which vary across the Mediterranean and adjacent seas, leading to spatial differences in reproductive timing and intensity (ICES, 2021).

.CONCLUSION

This study aimed to characterize the reproductive biology of *Trachurus trachurus* along the western coast of Libya by examining sex ratio, size at first maturity, spawning seasonality, fecundity, and energy storage patterns.

The result shows a clear female-biased sex ratio (1:1.5), with length at 50 % maturity estimated at 203 mm TL. Males matured at slightly larger sizes than females. Spawning activity was strongly seasonal, with a main peak during winter and spring, confirmed by GSI trends and gonad staging. Fecundity increased markedly with body size, ranging from 64.000 eggs to 1290.000 eggs. Abdominal fat reserves peaked before spawning and declined during gonad development, indicating a direct role of lipid storage in supporting reproduction.

Some limitations sould be considered the study covered a single annual cycle and one geographic area, which may not capture interannual variability or broader spatial differences.

Fecundity estimates were based on a limited number of samples. Despite these constraints, the study provides baseline reproductive data for *T. trachurus* in Libyan waters, with clear value for stock assessment and fisheries management.

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