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Short Communication

Sexual maturity stage, reproductive indices, and fecundity in striped mullet female *Mugil cephalus* in Bahía de Buenaventura, Colombian Pacific coast

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ABSTRACT. The stage of sexual maturity, fecundity, and relationship of gonadosomatic (GSI), hepatosomatic (HSI), and hepatogonadal (HGI) indices in mullet *Mugil cephalus*, captured in Bahía de Buenaventura, was examined in the present study. With the help of artisanal fishermen, 21 specimens (all females) were collected in February 2024. The mullets measured in total length between 28.0 and 35.5 cm (30.8 ± 2.3 cm standard deviation) and weighed between 200.0 and 364.5 g (246.6 ± 43.6 g). The fecundity of females weighing 257.8 ± 48.9 g was estimated at 423,659 ± 103,208 oocytes. The GSI and HSI increased from 1.0 ± 0.4 to 6.4 ± 1.5% and from 0.8 ± 0.2 to 1.0 ± 0.1% in immature to mature females, respectively. Also, significantly different from each other, the values of the HGI in immature females were 72.2 ± 16.3%, compared to that of mature females of 17.2 ± 4.6%. Since the liver is responsible for the synthesis and production of vitellogenin, which is then taken up by the oocytes in the gonad (ovary), the HGI may also be a very useful indicator of sexual maturity in mullet, as well as for other fishes.

Keywords: Mugilidae; *Mugil cephalus*; hepatogonadal index (HGI); gonadosomatic index (GSI); hepatosomatic index (HSI)

INTRODUCTION

Mullets (taxonomic family Mugilidae) have a circumtropical distribution and are one of the main fish species consumed worldwide, especially in coastal and island communities. Although mullet fisheries still constitute around 70-80% of the available world production, their economic and culinary importance has led them to be cultivated for centuries. Today, they occupy the third place of marine/coastal species in culture after the Atlantic salmon (*Salmo salar*) and the milkfish (*Chanos chanos*), in tonnes annually (FAO 2022).

In Colombia, mullets are one of the most important fisheries on the Caribbean and Pacific coasts. They are mainly caught by hand with cast and trammel nets. Due to their popularity for food security and high market demand, many mullet populations have collapsed. In Colombia, this is reflected in a drastic decrease (from around 200 to 50 t annually) in fish landings of *Mugil cephalus* on the Pacific coast, reported from 1970 to 2014 (Selvaraj et al. 2020).

In attempts to reduce/replace marine fishing catches and meet the growing demand for seafood products, aquaculture is a promising agricultural activity that has taken great interest at the institutional and private business levels. Only in the last 10 years has global aquaculture production equaled and surpassed the total fishery catch (FAO 2022). This article is an observational study that contributes to establishing and developing the captive production technology of mullet *M. cephalus* in the Colombian Pacific region and its conservation in the wild. Establishing a breeding stock is essential to supply the seed, as is the case with any

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agricultural system. In this sense, the main objective was to evaluate the reproductive maturity status and reproductive indices of *M. cephalus* females in Buenaventura Bay, Colombia.

Sampling was carried out in Bahía de Buenaventura, Colombia's principal seaport on the Pacific coast. Local fishermen used their knowledge and know-how to determine the location of the mullets and estimate the numbers caught on a routine day fishing trip. On the recommendation of local fishermen and merchants, sampling was conducted in February (2024), which is believed to be the mullet's breeding season.

A total of 21 mullets were captured, which were fixed and preserved in a 10% neutral buffered formalin solution. Sex was determined by micro- and macroscopic examination of the gonads (Table 1); microanatomy samples were embedded in paraffin and stained with hematoxylin and eosin. Biometrics were performed, the liver and gonad were weighed (Table 1), and the total number of oocytes was estimated for each female. Length (total and standard) was measured with a ruler (± 1 mm), and weights were recorded using a scale (± 0.1 g). several biological indices were calculated to establish the state of sexual maturity (immature or mature) (Rizzo & Bazzoli 2020): the gonadosomatic index (GSI) and the presence or absence of vitellogenic oocytes were determined. Also, because the liver is an essential metabolic organ responsible for producing the yolk accumulated by the oocytes, the hepatosomatic (HSI) and hepatogonadal (HGI) indices were calculated. To record the GSI, the weight of the gonad (GW) was related to the body weight (BW) of the fish; thus, the proportion (percentage) indicative of the GSI [GSI = (GW / BW) × 100]. In turn, the equivalent HSI and HGI were related to the proportion of the weight of the liver (LW) about the BW of the fish and the gonad, respectively [HSI = (LW / BW) × 100; HGI = LW / GW) × 100]. Fecundity was estimated by counting only oocytes larger than 0.4 mm sifted through No. 40 mesh sieve (425 μm); oocytes with a larger diameter were in an advanced state of vitellogenesis (McDonough et al. 2003); easily identified as opaque and yellowish. Striped mullets are considered total spawners with synchronous oocyte development (Greeley et al. 1987, McDonough et al. 2003). To reduce the error of estimation on fecundity, five random samples of 0.05 g were taken from the middle region of both ovary sacs; the number of oocytes in the samples was subsequently counted and averaged. The average number of oocytes in the samples was multiplied by the total weight of the gonad to estimate the fecundity of each female (Das 1977, Greeley et al. 1987, McDonough et al. 2003). The diameters of oocytes in different samples were measured using a transparent ruler set on the stage of a stereoscope and viewed under 10x optical magnification. For each female, the average oocyte diameter was estimated and then recorded.

The oocytes were primarily round, and the largest had a slightly oblong edge, measuring between 0.4 and 0.6 mm (Table 2). Estimates for the number of oocytes (fecundity) were between 315,216 and 669,460, with an average of 423,659 ± 103,208 oocytes per female, 30.8 ± 2.8 cm TL, and an average weight of 257.8 ± 48.9 g; equivalent to about 1,223 to 2,597 oocytes per gram of body weight (Table 2).

The GSI and HSI indices increased from 1.0 ± 0.4 to 6.4 ± 1.5% and from 0.8 ± 0.2 to 1.0 ± 0.1% in immature to mature females, respectively. Also, significantly different from each other, the HGI values in mature females were 17.2 ± 4.6%, compared to that of immature females of 72.2 ± 16.3%, a quadruple difference (Table 3).

The results of this study confirm the presence of mature females in Bahía de Buenaventura in February. Although a small number of mullet was captured during a daytime fishing activity trip, the sample size should be considered appropriate, especially in establishing a breeding stock. Most importantly, the finding coincides with observations from experienced fishermen in the region. Correspondingly, this month is within the period that encompasses the spawning season of the species in other regions of the Pacific coast and the Gulf of Mexico (Finucane et al. 1978, Espino-Barr et al. 2016, Bhakta et al. 2024, Castellanos-Juárez et al. 2024).

Since mature females (no males) were captured within the bay, it can be assumed that a spawning aggregation has not occurred yet and may happen offshore, similarly to what occurs with the same species in other regions (Finucane et al. 1978, Soyinka 2014). Even so, the spawning grounds of striped mullets in the Colombian Pacific are unknown and must be determined.

In this study, the GSI was used to indicate gonadal maturity. The GSI increased from 1.0 ± 0.4 to 6.4 ± 1.5% in immature to mature females, and the GSI in mature females was between 4.6 to 9.7%. These values were within those reported for the species in different geographical regions (7.7 to 27.5%; McDonough et al. 2003, Ramos-Santiago et al. 2010). Also, comparing fecundity (315,216 to 669,460 oocytes) from mature females in Bahía de Buenaventura with figures of the

Table 1. Stage of sexual maturity, body size, and gonad and liver weights in female *Mugil cephalus*.

Female (mature or immature)	Weight (g)	Standard length (cm)	Gonad (g)	Liver (g)
Mature	301.5	26.8	21.0	3.0
Mature	266.4	24.3	17.5	2.4
Mature	208.9	25.0	9.9	2.0
Mature	222.9	24.0	15.8	2.3
Mature	364.5	28.5	17.9	4.6
Mature	252.9	26.3	11.5	2.7
Mature	238.1	22.5	15.1	2.3
Mature	222.3	23.8	13.3	2.5
Mature	213.4	23.5	20.7	2.7
Mature	287.2	24.6	21.4	2.7
Immature	321.2	27.0	2.8	2.4
Immature	230.1	23.0	1.8	1.3
Immature	267.4	25.5	4.9	2.2
Immature	235.2	24.4	3.1	2.7
Immature	262.5	23.5	3.8	2.8
Immature	211.1	23.0	3.2	1.7
Immature	236.4	24.0	2.2	1.9
Immature	200.0	24.0	1.4	0.7
Immature	200.1	22.0	2.1	1.5
Immature	243.0	25.3	1.5	1.4
Immature	192.9	27.0	1.7	1.3

Table 2. Estimates of body size and number of oocytes in mature female mullet *Mugil cephalus*.

Total length (cm)	Weight (g)	Number of oocytes (fecundity)	Oocyte diameter (mm)
30.8 ± 2.8	257.8 ± 48.9	315,216 - 669,460	0.4 - 0.6

same species in other regions, the numbers were within the ranges reported in the literature: 18,525 to 5,200,000 oocytes (Das 1977, Finucane et al. 1978, McDonough et al. 2003, Ramos-Santiago et al. 2010, Soyinka 2014, Rao & Babu 2016). Likewise, the diameters of oocytes (0.4-0.6 mm) from mature females were within the ranges reported in other populations (between 0.46 and 0.68 mm, McDonough et al. 2003). Egg production data for *M. cephalus* regarding fecundity, fertilization, and hatching rates were provided by Vallainc et al. (2021).

Although outside the framework of this study, it should be noted that in this study, one female with a low GSI (4.9%) contained the highest number of oocytes (669,460); similarly, other females in the study with a low GSI (4.6 and 4.7%), had figures with high numbers of oocytes (e.g. 357,880 and 315,216, respectively). Comparing these numbers with other studies outside the region, it should be of consideration that the mullet population in the Buenaventura region has been subjected to overfishing, resulting in a possible reduction in the size of reproductive individuals, and this topic should be investigated further. For an excellent and thorough recent review of sex ratio, fecundity, and length at first maturity in mullet, the readers are referred to Bhakta et al. (2024).

This study also used the HSI as an index of sexual maturity. Like the GSI, it increased significantly from 0.8 ± 0.2 to 1.0 ± 0.1% in immature to mature females, respectively. Similarly, in *M. cephalus*, increases in the HSI during gonadal development have been observed by others (Espino-Barr et al. 2016, Boubekeur & Ramdane 2021, Titouah et al. 2022, Ramos-Júdez et al. 2023).

In addition to another index, the authors propose the HGI as a valuable indicator of mullet sexual maturity. In this study, significant differences between the HGI of immature (72.2 ± 16.3%) and mature (17.2 ± 4.6%) females were discriminated. The HGI may be a viable index since the liver is responsible for the synthesis and

Table 3. Gonadosomatic (GSI), hepatosomatic (HSI), and hepatogonadal (HGI) indices are biometric indicators of reproductive activity in female mullet *Mugil cephalus*. *$P < 0.05$, t-statistic.

Female (Sexual maturity)	GSI (%)	HSI (%)	HGI (%)
Immature	1.0 ± 0.4	0.8% ± 0.2	72.2% ± 16.3
Mature	6.4 ± 1.5*	1.0% ± 0.1*	17.2% ± 4.6*

production of vitellogenin, which is then taken up by the oocytes in the ovary. The liver also changes in size according to the gonadal status in both females and males (Cerdá et al. 1996, Çek et al. 2001, Lubzens et al. 2010, Nunes et al. 2011, Bertolini et al. 2020, Rizzo & Bazzoli 2020, Liu et al. 2021). The HSI increases just before and during the early ripening of the gonad but then decreases as the gonad approaches sexual maturity (Rizzo & Bazzoli 2020). This study, in particular, is the possible reason for the inverse relationship between the HGI of immature and mature females, inferred from the mobilization of nutrients and the synthesis of vitellogenin (Vtg) by the liver in the early stages of vitellogenesis, followed by the production and release of Vtg for sequestration by oocytes.

The use of the HGI may be preferred instead of the HSI or GSI, especially because the relationship between the liver and gonad is directly linked to the formation and sequestration of the yolk, unlike the relationship between the gonad or liver and the somatic tissue, which can also increase or decline according to periods of nutrient availability and mobilization. It is also easier to display or visualize percentage differential values of the indices, with the HGI being on a numerical scale of whole figures (e.g. 72.2 to 17.2%) and HSI's typically being in decimals (e.g. 0.8 to 1.0%). Making things more complex, the practice and convenience of using GSI as an indicator of gonadal development or spawning readiness has been debated, particularly with species that are partial spawners or have protracted spawning seasons (de Vlaming et al. 1982), which may be the case for *M. cephalus*. Where, for example, in the northern hemisphere, the spawning season is long, occurring between October and April (Finucane et al. 1978, Rivas 1980, McDonough et al. 2003, Saoudi & Aoun 2014, Assem et al. 2015, Castellanos-Juárez et al. 2024). Although it is well established that there is a significant correlation between the GSI and female size and fecundity in many species, including *M. cephalus*, the spread of values for mullet GSI and fecundity are too large. For example, GSI percentages reported for the species ranged between 7.7 and 27.5% (McDonough et al. 2003, Ramos-Santiago et al. 2010).

After an extensive review of the literature, particularly after the popularization, beginning mostly with Bagenal (1967), of the concepts of relating sexual maturity in fish to gonad weights and fecundity, very few references were found, and none in mullets on the use of the HGI. However, the principles and advantages of using HGI as another indicator of sexual maturity in fish were proposed and have been discussed mainly by researchers in Russia (Krivobok 1964).

The results of this study present the first data on the breeding season and fecundity of the mullet *M. cephalus* in Bahía de Buenaventura. The data are not only useful for the characterization of fishing productivity but also as a comprehensive evaluation of realistic expectations on the reproductive output of the species (e.g. number of offspring) in the wild, especially during induced breeding practices; induced breeding is necessary for the technological and scientific development for the cultivation of the species. Advances in induced reproduction of mullets have been and still are one of the main obstacles to the cultivation of mullets in captivity. In the present study, there was a significant difference in the HGI between the immature and mature females, and to our knowledge, the first reported for the species, and certainly in the region. It may be very useful to consider using the HGI as a biometric indicator of sexual maturity in mullet and other fish.

Credit author contribution

L.N. García-Núñez: conceptualization, validation, methodology, formal analysis, writing-original draft; supervision, review, and editing; A. Rodríguez-Forero: funding acquisition, project administration, supervision, validation, methodology, review, and editing. All authors have read and accepted the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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