**Size-frequency, length-weight, and length-length relationship of two species of halfbeaks (Family: Hemiramphidae) from the north coast of the Yucatan peninsula, Mexico**

**Length-weight relationship of two species of halfbeaks**

**ABSTRACT**

Size-frequency, length-weight relationships (LWRs), and length-length relationships (LLRs) for *Hemiramphus brasiliensis* (Linnaeus 1978) and *Hyporhamphus unifasciatus* (Ranzani 1841) from the north coast of the Yucatan peninsula in the Gulf of Mexico were studied. All specimens were collected from the artisanal fishery of halfbeaks, which is under development. 5,201 individuals (5,134 *H. brasiliensis* and 67 *H. unifasciatus*) were sampled and analyzed. The size-frequency analysis showed that individuals of *H. brasiliensis* among 31.5 to 34.5 length class dominated the fishery samples;however, the separation index (≥2) indicated signs of recruitment to the fishery in the last months of the year by identifying cohorts with a length below the average.Isometric growth pattern was found in females and pooled sex in *H. unifasciatus* and positive allometric growth in all and pooled sex in *H. brasiliensis.* The total length was 9% and 4.5% greater than the fork length for *H. brasiliensis* and *H. unifasciatus*, respectively. The size of *H. brasiliensis* (45.5 cm Total length) exceeds the reported in previous studies from the Gulf of Mexico and the Mexican Caribbean Sea and a new record of maximum length for *H. unifasciatus* (31cm Total length) is presented to FishBase database.

**Keywords:** mode, separation index, length class, *Hemiramphus brasiliensis, Hyporhamphus unifasciatus,* normal distribution

The halfbeaks are an epipelagic family of fish (Hemiramphidae) of the order Beloniformes (Cervigón et al*.* 1992, Nelson 1994) that inhabit the waters of the Atlantic, Pacific, and Indian oceans; they are characterized by having a lower jaw significantly longer than the upper jaw (Hughes & Stewart 2006). The halfbeaks are commercially exploited for their use as bait in recreational fishing, becoming an alternative resource for fishing communities (McBride & Thurman 2003, Oliveira et al*.* 2012).

In the Gulf of Mexico and the Mexican Caribbean Sea, five species of halfbeaks have been reported, divided into two genera, *Hemiramphus* (*H. balao* and *H. brasiliensis*), and *Hyporhamphus* (*H. meeki, H. roberti,* and *H. unifasciatus*). However, *Hemiramphus brasiliensis* (Linnaeus 1978) has been the most abundant and commercially exploited species (Berkeley & Houde 1978). In this region, studies on *Hemiramphus brasiliensis* have addressed fishing aspects, fish richness, reproductive biology, and feeding habits (Castro et al. 2002, McBride & Thurman 2003, Rosas et al. 2008). For the Yucatan peninsula coast, there are reports of commercial capture for *H. brasiliensis* (Zamorano et al. 2010) and incidental catch reports of *Hyporhamphus unifasciatus* (Ranzani 1841) in the artisanal shrimp fishery (Leal et al. 2009).

The size structure of exploited fishes can reveal several ecological and life-history traits, such as aquatic health, stock conditions, selectivity, and breeding periods (Beyer 1987). Besides, length-weight relationships (LWR) help calculate the total weight of a fish based on length observations (Siddique et al. 2015). In contrast, fishery managers use different measures of fish length for applications (total, furcal, and standard length). Thus, reliable length-to-length indicators are required for data conversions (Biolé et al. 2020).

This study was conducted on the north coast of the Yucatan peninsula (Mexico), in the southern littoral of the Gulf of Mexico, which includes the fishing ports of Progreso (22° 21′ N and 89° 49′ W) and Dzilam de Bravo (Fig. 1). Monthly samples were collected from December 2019 to December 2020 (development fishing permit No. PPF/DGOPA-121/19. # 121/19). For this, small boats with outboard motors and monofilament purse seines with a mesh size of 1” were used (locally known as “escribaneras”), supported by the knowledge and experience of the fishermen to detect halfbeaks schools. Incidental species (sardines and needlefish) were returned to the sea. Once caught, fish were kept in refrigeration for later identification at the laboratory according to the guides of Castro-Aguirre (1978) and Carpenter (2002). The specimens were measured to the nearest 0.1 cm to obtain the total length (TL) and fork length (FL). Subsequently, the total body weight (TW) was taken to the nearest 0.1 g. Based on the description of Oliveira et al. (2015), the sex was determined by macroscopic inspection of the gonads. The sex ratio was evaluated for both species (whole sample) with the chi-square test (χ2), comparing the observed and expected frequencies concerning a male:female ratio equivalent to a 1:1 ratio. The lengths and weights of males and females for each species were compared with the Kruskal-Wallis (H) test (Zar 1999).

To estimate the size-frequency distribution of each species, TL values were grouped into class intervals of 1 cm. The modes were determined based on the assumption that the length distribution for each mean (TL) or mode presents a normal distribution. In this study, we assumed that each mode corresponded to the same cohort in the fish population (Haddon 2001). The TL frequency distribution was visually inspected to detect new cohorts, and the initial values were deﬁned. The mean (μ) and standard deviation (σ) values for each curve were estimated using a likelihood function minimized through a nonlinear ﬁt using the Newton algorithm (Neter et al. 1996, Haddon 2001). Finally, the separation index (SI) was used to separate the samples with more than one modal group or cohort (Sparre & Venema 1992), using the equation:

where TLj and TLi are the mean TL of the modal groups j and i, respectively, and and are the standard deviations of the modal groups j and i, respectively. The relation between total length and weight in fish is typically a potential equation W = aTLb where W is the total weight (in g), TL is the total length (in cm), *a* is the intercept, and *b* is the exponent. The estimation of the *a* and *b* parameters for both species was carried out by linear regression analysis after log-log transformation: log(TW) = log(a) + b log(TL), where b represents the type of growth [i.e., either allometric (b ≠ 3) or isometric (b =3)]. Visual inspection of outliers for logarithmic values of total body length and weight was performed before the regression analysis to exclude the extreme values (Froese 2006). A Student’s t-test was used to demonstrate whether the slope of b was statistically different from 3 (Ahamed & Ohtomi 2014). The Fulton’s condition factor (K) was calculated for pooled, female, and male (whole sample) according to the equation K = 100 × W/TL3 (Froese 2006). The length-length relationship (TL vs. FL) was determined by linear regression using the equation TL= α + βFL and FL= α + βTL, where α is the intercept and β the slop.

A total of 5,201 fish were sampled in a range of 13 months (104 fishing trips), 5,134 fish belonged to the species *Hemiramphus brasiliensis* (Size range 20-45.5 cm TL) and 67 to *Hyporhamphus unifasciatus* (Size range 20-31 cm TL). *H. brasiliensis* was caught all year; contrastingly, *H. unifasciatus* was only collected in September and October. After sex separation, the male:female ratio of *H. brasiliensis* (1:1.71) was different from 1:1 (p-value 0.000), while the sex ratio of *H.* *unifasciatus* (1:1.23) didn´t show significant differences (p-value 0.3924). Regarding the sizes, significant differences were observed between the lengths of males (31.3 ± 3 cm TL) and females (32 ± 3.4 cm TL) of *H. brasiliensis* (H=92.6, p<0.05), as well as in the total weight, being the females heavier than males (H=26.23, p<0.05). *For H. unifasciatus*, the TL showed significant differences between sexes (H=4.2, p=0.04), with females being significantly larger (27.1 ± 2.5 cm TL) than males (26.3 ± 1.8 cm TL). However, they didn´t show significant differences in weight (H=0.72, p=0.39).

The analysis of size-frequency showed that individuals from *H. brasiliensis* between 31.5 to 34.5 sizes class dominated the fishery samples(mode 31.5 cm TL) and 25.5 to 28.5 sizes class for *H. unifasciatus* (mode 26.8 cm TL). Additionally, female dominance was observed in all class intervals of *H. brasiliensis*, as well as in most classes of *H. unifasciatus.* However, for *H. brasiliensis* two size class appeared in August, and the SI also detected it from September to December (Figure 2). The smallest size groups showed modes ranging from 25.22 to 25.97 cm TL.

The parameters *a* and *b* of the length-weight relations (LWR) were estimated for females, males, and a pool of both species; all regressions showed values of r2 > 0.94 (Table 1). The t-student test indicated that only females and pooled sex of *H. unifasciatus* showed an isometric growth pattern, unlike *H. brasiliensis* which showed a positive allometric growth pattern in all sexes and pool. In addition, for both species Fulton’s condition factor (K) was slightly higher in males; for *H. brasiliensis* Kwas 0.3146±0.024, 0.3255±0.026 and 0.3186±0.025, for females, males and pool, respectively. Whereas *H. unifasciatus* showed a K of 0.3591±0.021, 0.3783±0.022, and 0.3697±0.023 for females, males, and pool, respectively.

The results of length–length relationship are shown in Table 2. The regression analyses were statistically significant for slopes and intercepts (p< 0.001) for both species, showing a high correlation (r2 ≥ 0.99). The total length was 9% and 4.5% greater than the fork length for *H. brasiliensis* and *H. unifasciatus*, respectively.

In Mexico, the fishing licenses for development are given to evaluate the productive performance of new fisheries (which include goals such as research, exploration, conservation, aquatic resources assessment, development of new technologies, etc.) before opening them to commercial exploitation (DOF 14-03-2014). Therefore, the information analyzed in this study provides initial information to further the management of the new halfbeak fishery on the north coast of Yucatan.

The maximum sizes of *H. unifasciatus* (31.0 cm of TL) from the present work are higher than those reported in FishBase.org. Also, the size of *H. brasiliensis* (45.5 cm of TL) exceeds the reported in previous studies from the Gulf of Mexico and the Mexican Caribbean Sea (Galindo-Cortes et al. 2015, Zamorano et al. 2010). The analysis of the size-frequency distribution also provided valuable information to determine the composition of the catches. In this sense, the SI analysis showed signs of recruitment to the fishery (*H. brasiliensis*) in the last months of the year by identifying cohorts with a length below the average. In Brazil, the recruitment of *H. brasiliensis* and *H.* *unifasciatus* begins in March and extends to August (Lessa et al. 2004). However, for the Yucatan peninsula it is important to validate the above with studies of reproduction, and sexual maturity, accompanied with those of age and growth.

The male: female ratio of *H. brasiliensis* was similar to what has been reported in localities from Florida, with a higher proportion of females (McBride et al. 2003), but different from those reported in nearby locations in the Yucatan peninsula, where males are the majority (Zamorano et al. 2010). Meanwhile, *H. unifasciatus* showed a similar pattern to the reports from Brazil not showing significant differences in the male: female ratio (Lessa et al. 2004).

The length-weight relationship of *H. brasiliensis* showed a positive allometric growth pattern, similar to studies carried out in the Gulf of Mexico (Galindo-Cortes et al. 2015) but different from the reported in Venezuela (Longart et al. 2012), where it was found a negative allometric growth pattern (b = 2.6). These differences reflect the different environmental conditions in the study areas (geographical differences), stages of gonadal maturity, sex, fullness of the stomach, the condition factor, weather seasons, size variations, and number of fish observed. As well as the different types of feeding (Froese 2006, Longart et al. 2012).

The biometric characteristics of the halfbeaks populations in Yucatán raised in this study will act as valuable information for the fisheries management authority to prepare an applicable management rulebook for sustainable exploitation of this fishery resource.

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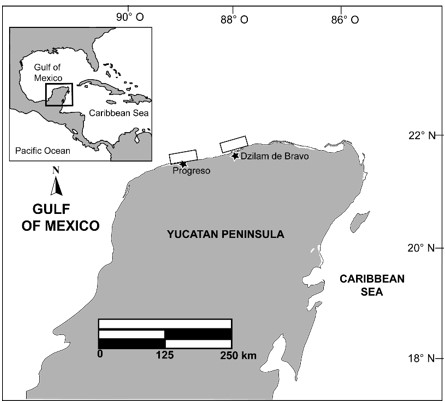
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Table 1. LWRsof *H. brasiliensis* and *H. unifasciatus* caught on the north coast of the Yucatan peninsula. \*New maximum length compared with those reports in Fishbase.org.

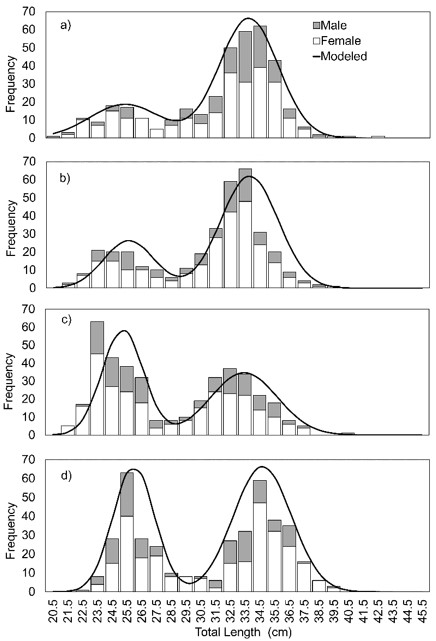
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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | Sex | n | TL range (cm) | W range (g) | *a* | 95% CI of *a* | *b* | 95% CI of *b* | *r2* |
| *H. brasiliensis* | Female | 3241 | 21.5-45.5 | 29.7-214.2 | 0.0026 | 0.0024-0.0028 | 3.05 | 3.03-3.08 | 0.95 |
|  | Male | 1891 | 20.0-40.0 | 28.3-208.0 | 0.0023 | 0.0020-0.0026 | 3.10 | 3.07-3.14 | 0.94 |
|  | Pool | 5132 | 20.0-45.5 | 28.3-294.2 | 0.0026 | 0.0024-0.0028 | 3.06 | 3.04-3.08 | 0.95 |
| *H. unifasciatus* | Female | 30 | 21.0-31.0\* | 34.1-105.9 | 0.0033 | 0.0016-0.0070 | 3.02 | 2.79-3.24 | 0.96 |
|  | Male | 37 | 20.0-29.5 | 27.7-93-0 | 0.0012 | 0.0005-0.0027 | 3.36 | 3.10-3.61 | 0.95 |
|  | Pool | 67 | 20.0-31.0 | 27.7-105.9 | 0.0026 | 0.0014-0.0047 | 3.11 | 3.93-3.29 | 0.95 |

Table 2. Length–length relationship of Total Length (TL) and Fork Length (FL) of *H. brasiliensis* and *H. unifasciatus* caught on the north coast of the Yucatan peninsula.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Species | n | Equation | α | 95% CI of α | β | 95% CI of β | *r2* |
| *H. brasiliensis* | 5132 | FL= α+βTL | 0.5139 | 0.4232-0.6046 | 0.9012 | 0.8983-9040 | 0.99 |
| TL= α+βFL | -0.1466 | -0.2476-0.0455 | 1.0951 | 1.0916-1.0985 | 0.99 |
| *H. unifasciatus* | 67 | FL= α+βTL | -0.7148 | -1.3470-0.0825 | 0.9837 | 0.9600-1.0074 | 0.99 |
|  |  | TL= α+βFL | 0.9688 | 0.3493-1.5883 | 1.0071 | 0.9828-1.0313 | 0.99 |

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**Fig. 1** Study area delimiting the halfbeaks catch zones with a rectangle in Progreso and Dzilam de Bravo on the north coast of the Yucatan Peninsula, Mexico



**Fig. 2** Size-frequency distributions (1 cm TL interval classes) for specimens of *H. brasilienses* (Linnaeus, 1978) caught off the north coast of Yucatan. Modes detected with SI in a) September, b) October, c) November, and d) December. The observed data are presented as bars, and the modeled data as lines