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Short Communication

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

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ABSTRACT. Size-frequency, length-weight, and length-length relationships 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 an exploratory fishery license. Five thousand two hundred-one 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 cm of total length (TL) class dominated the fishery samples; however, the separation index (≥2) detected two modes in the last months of the year, identifying a cohort with a length below the average (24.5 to 26.5 cm TL). The isometric growth pattern was found in females and pooled sex in *H. unifasciatus*, and positive allometric growth was found in males and *H. brasiliensis*. The TL 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 TL) 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 TL) was reported to the FishBase database.

Keywords: *Hemiramphus brasiliensis*; *Hyporhamphus unifasciatus*; mode; separation index; length class; 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 a significantly longer lower jaw 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, *H. brasiliensis* (Linnaeus, 1978) has been the most abundant and commercially exploited species (Berkeley & Houde 1978), being used as bait in local recreational fishing (Lara-Pérez-Soto 2000, Zamorano et al. 2010). Studies on *H. brasiliensis* in this region 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 catchreports of *H. unifasciatus* (Ranzani, 1841) in the artisanal shrimp fishery (Leal et al. 2008).

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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 help calculate a fish's total weight 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 (21°17'N, 89°39'W) and Dzilam de Bravo (21°23'N, 88°53'W) (Fig. 1). Monthly samples were collected from December 2019 to December 2020 (exploration fishing permit N°PPF/DGOPA-121/19, sheet number 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 in the first hours of sunrise. 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 obtain the total length (TL ± 0.1 cm) and fork length (FL ± 0.1 cm). Subsequently, the total body weight (TW ± 0.1 g) was taken. 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 (χ^2), comparing the observed and expected frequencies concerning a male: female ratio equivalent to a 1:1 ratio with significance set at $\alpha = 0.05$. The lengths and weights of males and females for each species were compared with the Kruskal-Wallis (H) test (Zar 1999).

For comparative purposes, TL values were grouped into class intervals of 1 cm to estimate the size-frequency distribution of both species. Furthermore, this interval presented a greater number of modes compared to the Sturges rule. 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):

$$-lnL\{TL|\mu,\sigma\} = -\sum_{i-1}^{n} L_i ln(\hat{p}_i) = -\sum_{i-1}^{k} L_i ln\left(\frac{\hat{L}_i}{\sum \hat{L}_i}\right),$$

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:

$$SI = \left(\frac{TL_j + TL_i}{0.5\left(S_j^2 + S_i^2\right)}\right) \geq 2,$$

where TL_j and TL_i are the mean TL of the modal groups j and i, respectively, and S_j^2 and S_i^2 are the standard deviations of the modal groups j and i, respectively. If SI < 2, separating the normal components of the frequencies observed was not feasible. The relation between TL and TW in fish is typically a power equation $TW = aTL^b$ where *a* is the intercept, and *b* is the slope. 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 ($b \neq 3$) or isometric ($b = 3$)]. Visual inspection of outliers for logarithmic values of TL and TW was performed before the regression analysis to exclude the extreme values (Froese 2006). A Student *t*-test was used to demonstrate whether the slope of *b* was statistically different from 3 (Ahamed & Ohtomi 2014). The condition factor was calculated for separated sexes and pooled sampled for both species, according to $K = 100 \times TW / TL^b$ (Bagenal & Tesch 1978), where b is the slope parameter from length-weight relationships. The length-length relation-ship (TL *vs*. FL) was determined by linear regression using the equation $TL = \alpha + \beta FL$ and $FL = \alpha + \beta TL$, where α is the intercept and β the slope.

A total of 5,201 fish were sampled during 13 months (104 fishing trips); 5,134 fish belonged to the species *H. brasiliensis* (size range 20-45.5 cm TL) and 67 to *H. unifasciatus* (size range 20-31 cm TL). *H. brasiliensis* was caught throughout the year; contrastingly, *H. unifasciatus* was only caught in September and October. After sex separation, the male-to-female ratio of *H. brasiliensis* (1:1.71) was different from 1:1 ($P < 0.05$), while the sex ratio of *H. unifasciatus* (1:1.23) did not show significant differences ($P > 0.05$). 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 TW, being the females

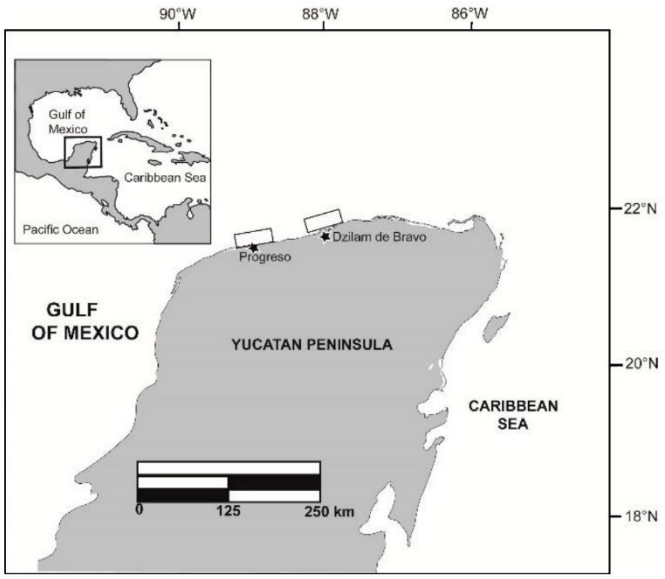

Figure 1. Study area delimiting the halfbeaks catch zones with a rectangle in Progreso and Dzilam de Bravo on the north coast of the Yucatan peninsula, Mexico.

heavier than males (H = 26.23, $P < 0.05$). For *H. unifasciatus*, the TL showed significant differences between sexes (H = 4.2, $P < 0.05$), with females being significantly larger (27.1 ± 2.5 cm TL) than males (26.3 ± 1.8 cm TL). However, they did not show significant differences in TW (H = 0.72, $P > 0.05$).

The size-frequency analysis showed that *H. brasiliensis* individuals between 31.5 to 34.5 cm sizes class dominated the fishery samples (mode 31.5 cm TL) and 25.5 to 28.5 cm sizes class for *H. unifasciatus* (mode 26.8 cm TL). Additionally, female dominance of *H. brasiliensis* was observed in all class intervals and most classes of *H. unifasciatus*. However, for *H. brasiliensis*, two size classes appeared in August, and the SI also detected it from September to December (Fig. 2). The smallest size groups showed modes ranging from 24.5 to 26.5 cm TL.

Parameters a and b of the length-weight relations were estimated for separated sexes, and a pooled sample was pooled for both species. All regressions showed values of $R^2 > 0.94$ (Table 1). The Student *t*-test indicated that the separated and pooled sex of *H. unifasciatus* showed an isometric growth pattern, unlike *H. brasiliensis*, which showed an allometric growth pattern in males and the pooled sample. In addition, condition factor (K) was 0.2621 ± 0.020 for females, 0.2687 ± 0.022 for males, and 0.2629 ± 0.021 for the pooled sample of *H. brasiliensis*. In comparison, *H. unifasciatus* showed a K of 0.2482 ± 0.054 for females, 0.1141 ± 0.007 for males, and 0.2415 ± 0.016 for pooled samples.

The results of the length-length relationship are shown in Table 2. The regression analyses were statistically significant for slopes and intercepts ($P < 0.05$) for each species, showing a high correlation ($R^2 \geq 0.98$). The TL was 9 and 4.5% greater than the fork length (FL) for *H. brasiliensis* and *H. unifasciatus*, respec-tively.

In Mexico, fishing licenses for exploratory fishery are given to evaluate the productive performance of new fisheries (which include goals such as research, conservation, aquatic resources assessment, and development of new technologies, among other aspects) before opening them to commercial exploitation (DOF 2014). Therefore, the information analyzed in this study provides baseline information for managing 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 (Zamorano et al. 2010, Galindo-Cortes et al. 2015). The analysis of the size-frequency distribution also provided valuable information to determine the composition of the catches due to the short life cycle of these species. Recruitment is often associated with the age/size at which fish (first size interval subject to fishing pressure) become available to the fishery and may involve a shift in habitat use (Myers 2002, Lorenzen & Camp 2019). For

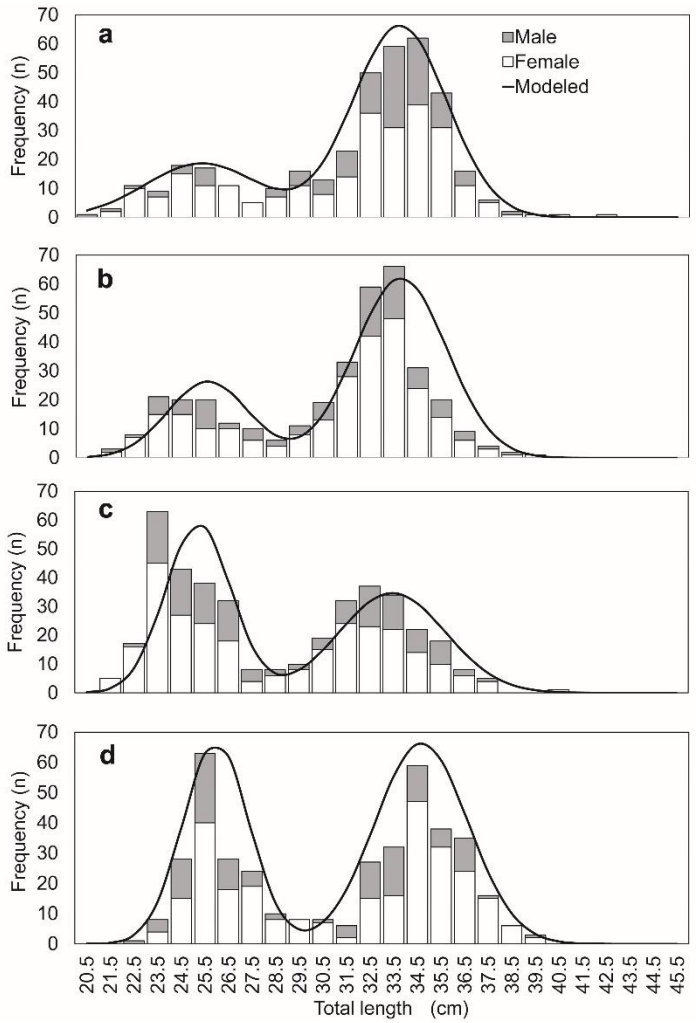

Figure 2. Size-frequency distributions (1 cm total length interval classes) for specimens of *Hemiramphus brasilienses* (Linnaeus, 1978) caught off the north coast of Yucatan. Modes detected with separation index in a) September, b) October, c) November, and d) December. The observed data are presented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

H. brasiliensis in Florida, USA, it has been recorded that in autumn, there is an incidence of small-length individuals of the immature phase (age = 0) and mature (size at 50% maturity = 19.8 cm FL) ones that are frequently found in fishing gear (McBride & Thurman 2003). In Brazil, *H. brasiliensis* and *H. unifasciatus* recruitment begins in March and extends to August (Lessa et al. 2004). In this sense, for the Yucatan fishery in the last months of the year, the SI analysis detected a cohort of *H. brasiliensis* with a length ranging from 24.5 to 26.5 cm TL, indicating possible recruitment to the fishery. However, for the Yucatan peninsula, it is important to validate it with studies of reproduction and sexual maturity, accompanied by age and growth studies.

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 more abundant (Zamorano et al. 2010). Meanwhile, *H. unifasciatus* showed a similar pattern to the reports from Brazil, which did not show significant differences in the male-to-female ratio (Lessa et al. 2004).

The length-weight relationship of *H. brasiliensis* showed a positive allometric growth pattern in males, 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 estimated 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, stomach fullness, condition factor, weather seasons, size varia-

Table 1. Length (TL)-weight (TW) relationship of *Hemiramphus brasiliensis* and *Hyporhamphus unifasciatus* caught on the north coast of the Yucatan Peninsula. *New maximum length compared with those reports in Fishbase.org.

Species	Sex	n	TL range (cm)	TW range (g)	*a*	95% CI of *a*	*b*	95% CI of *b*	r^2
H. brasiliensis	Female	3241	21.5-45.5	29.7-294.2	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
	Pooled	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	0.0025	0.0010-0.0063	3.11	2.83-3.39	0.95
	Male	37	20.0-29.5	27.7-93-0	0.0014	0.0007-0.0031	3.30	3.06-3.53	0.96
	Pooled	67	20.0-31.0	27.7-105.9	0.0024	0.0013-0.0046	3.13	2.93-3.33	0.94

Table 2. Length-length relationship of total length (TL) and fork length (FL) of *Hemiramphus brasiliensis* and *Hyporhamphus unifasciatus* caught on the north coast of the Yucatan Peninsula.

Species	n	Equation	α	95% CI of α	β	95% CI of β	r^2
H. brasiliensis	5132	FL= α + βTL	0.5139	0.4232-0.6046	0.9012	0.8983-0.9040	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	-1.0257	-1.9949-0.0564	0.9948	0.9585-1.0311	0.98
		TL= α + βFL	1.5940	0.6777-2.5104	0.9831	0.9473-1.0190	0.98

tions, and number of fish observed. As well as the different types of feeding (Froese 2006, Longart et al. 2012).

The biometric characteristics of the halfbeak populations in Yucatán raised in this study will be valuable information for the fisheries management authority to prepare an applicable management rule-book for the sustainable exploitation of this fishery resource.

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Credit author contribution

J.L. Cruz-Sánchez: funding acquisition, conceptualization, methodology, formal analysis, writing-original draft, supervision; A. Toro-Ramírez: funding acquisition, project administration, methodology, writing-original draft; G.R. Poot-López: methodology, formal analysis, validation, review, and editing. All authors have read and accepted the published version of the manuscript.

Conflict of interest

The authors declare no potential conflict of interest in this manuscript.

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