Seasonal growth differences of larval *Hyporhamphus picarti* (Hemiramphidae) in the Sine Saloum estuary, Senegal

J. Döring | S. I. Neumann | H. Sloterdijk | W. Ekau

Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany

Correspondence
Julian Döring, Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany. Emails: julian.doering@leibniz-zmt.de; julian.doering@me.com

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Summary
The African halfbeak *Hyporhamphus picarti* (Hemiramphidae) is one of the most abundant species within the ichthyoplankton community of the Sine Saloum estuary (Senegal). A year-round occurrence of larvae suggests that the Sine Saloum is an important spawning habitat for this species. Annual fluctuations in water temperature, however, can have severe impacts on the survival probabilities of marine fish larvae. To determine whether temperature has an effect on the growth of *H. picarti* during its larval development, larval age at length and somatic growth rates were investigated for two contrasting spawning seasons in 2014: February (cold season, 20.8°C) and June (warm season, 26.4°C). In both months *H. picarti* larvae were sampled at the mouth of the Saloum River using neuston nets. Sagittal otoliths’ increments were counted to estimate the larva age at a given standard length (SL). The age of larvae ranged between 2 and 22 days, with SL of 3.86–21.68 mm, respectively. In order to describe larval age at length during the contrasting spawning seasons, two distinctive Gompertz functions were applied. Accordingly, specimens sampled in June (0.94 ± 0.17 mm per day) exhibited significantly higher somatic growth rates than those sampled in February (0.60 ± 0.06 mm per day). These findings suggest that water temperature is an important factor influencing larval growth in *H. picarti*. Information concerning the early life stages of *H. picarti* are scarce and the results of the present study may contribute to a better understanding of the species’ biology and ecology.

1 | INTRODUCTION

Temperature fluctuations can have severe effects on the early life stages of marine fishes. These effects on larval survival can be either indirect by altering the primary production of the ecosystem and thus food availability (Vidy, 2000), or direct by affecting the metabolism and thus various physiological processes which influence the growth in fishes (Green & Fisher, 2004). Also, differentiations during fish ontogeny and the larval locomotive activity are influenced by temperature (Blaxter, 1992). Even further, water temperatures affect the time of hatching, the larval size during hatching, and the time until complete digestion of the yolk (Gracia-López, Kiewek-Martínez, & Maldonado-García, 2004). The swimming speed and the swimming behaviour of fish larvae are decisive for the success in catching of prey organisms and for escaping from predators. In addition, temperature influences the time in which a suitable habitat can be reached and occupied, even against currents (Green & Fisher, 2004). A rapid increase in body length generally enhances the survival probability of fish larvae and juveniles. Since growth rates are positively correlated with water temperature, it can be concluded that this parameter is the major factor influencing survival probabilities of marine fish early life stages (Houde, 1989).

The Sine Saloum estuary in Senegal is severely affected by climatic changes (Gning, Vidy, & Thiaw, 2007). Until the 1970s the system used to be species-rich and supported a high-yielding fishery. Due to a decline in precipitation and rising temperatures in the Sahel zone over the past decades, this estuary transformed into an...
inverse system, with a permanently reversed salinity gradient. The hypersaline conditions in the upper reaches of the estuary (salinity up to 130), as well as strong fishing pressure, led to an immense reduction in the annual catch rates (around 50%–80%) (Villanueva, 2015). Water temperatures in most tropical regions are relatively constant over the year and only fluctuate a few degrees. Because of upwelling processes at the Senegalese coast, however, temperatures vary annually by around 10°C in the Sine Saloum estuary (Green & Fisher, 2004; Vidy, 2000).

The family Hemiramphidae is one of the five families of the order Beloniformes, which populate the warm waters of the Pacific, the Indian Ocean and the Atlantic (Collette, 2004). Individuals of this family generally exhibit rapid growth rates and reach sexual maturity during the first year of their life (McBride & Thurman, 2003). They usually spawn during the warm months of the year, concordantly with high abundances in zooplankton (Jones, Ye, Ayvazian, & Coutin, 2002). The African halfbeak Hyporhamphus picarti inhabits coastal waters and lagoons along the West African coast from the Mediterranean Sea until Angola (Froese & Pauly, 2017). Still, information about the distribution of early life stages and spawning areas in this particular species are scarce. A recent study has shown that H. picarti is the third most abundant species in the ichthyoplankton of the Sine Saloum estuary with all the year-round occurrence, peaking especially from February (cool and dry season) to June (warm and dry season) (Sloterdijk, Brehmer, Müller, Döring, & Ekau, 2017).

Here we examine the growth of H. picarti larvae from two different seasons to determine the impact of temperature on the species' growth performance. We used sagittal otoliths to compare somatic growth rates between the two seasons.

2 | MATERIALS AND METHODS

2.1 | Sampling area

The Sine Saloum estuary is located 100 km south of Dakar and extends over an open water surface of approximately 800 km² (from 13°55’ and 14°10’ N to 16°03’ and 16°50’ W). This coastal ecosystem is characterized by very little freshwater input: with the exception of isolated groundwater deposits and small inflow of rivers, rainfall is the main water supply in the system. The river system consists of three main branches: the Saloum, Diomboss, and Bandiala. The water column of these main branches is well mixed and reaches a depth of between 10 and 15 m. The climate in the Sine Saloum region is characterized by a dry season (from November to June) and a short warm rainy season (from July to October) (Gning et al., 2007; Simier, Blanc, Aliaume, Diouf, & Albaret, 2004; Sloterdijk et al., 2017).

2.2 | Sampling

Samples for this study were collected during a field experiment designed to investigate the seasonal distribution pattern of fish larvae in the Sine Saloum estuary (Sloterdijk et al., 2017). We chose specimens from two stations (S1 and S2) of the February 2014 and from one station (S1) of the June 2014 sampling campaign (Figure 1). H. picarti larvae were sampled at both stations inside the Saloum River in February and June 2014 using two vertically connected neuston nets (30 × 15 cm, 500 µm mesh size). The nets were attached to a catamaran (Hobie Cat 15), which was towed by a motorboat at a speed of two to three knots. This setup facilitated the
collection of larvae located just below the water surface (0–30 cm). Each haul lasted ten minutes and took place in the direction of the current. Fish larvae were fixed immediately after the haul with a 30% ethanol/sea water solution and stored in an electric cooling box. At the laboratory, fish larvae were successively transferred to 50% and 70% ethanol. Water temperatures (°C) and salinities (practical salinity scale) were determined at each station with a multi-probe (WTW 3430).

2.3 | Age determination

Larval stages of *H. picarti* were identified using descriptions by Collette, McGowen, Parin, and Mito (1984) and Arias & Drake (1990). For age and growth determination, a total of 134 larvae were examined (54 in February and 80 in June). Larval standard lengths (SL ± 0.01 mm) were measured using a calibrated stereomicroscope micrometre (Stemi SV 11 and Stemi 2000-C, Zeiss). The sagittal otoliths (Figure 2) were dissected and stored in immersion oil for several days. In order to assess the age of *H. picarti* larvae at a given length, otolith daily growth increments were counted (core to edge) along the otolith’s largest diameter using a stereo microscope (Axioskop, Zeiss) at 200–500× magnification (Campana & Neilson, 1985; Sponaugle, 2009). Increments were counted three times by the same reader, and counter read once by an additional reader. If the results of the counts of both persons deviated by more than one increment, the respective otolith was discarded. We followed the assumption of Nakaya et al. (2008) that formation of first growth increment in the genus Hyporhamphus starts within 24 hr after hatching. Otolith diameter and increment widths were measured using ImageJ 1.49 (Rasband, WS, US National Institutes of Health, Bethesda, MD, http://imagej.nih.gov/ij/).

2.4 | Growth model

Larvae sampled in February were pooled across the sampling stations. Given the narrow range of lengths analyzed, relationship between otolith diameter (OD; μm) and larval standard length (SL; mm) was investigated using linear regression models. The relationship between SL and larval age (in days) was modeled using the Gompertz growth curve (GGC):

Equation 1: \[ SL_t = SL_0 \times e^{k(1-e^{-Gt})} \]

Daily somatic growth rate thus can be described with 1st derivate of Equation 1:

Equation 2: \[ \frac{dSL_t}{dt} = SL_0 \times k \times Ge^{k(1-e^{-Gt}) - Gt} \]

where \( SL_t \) is the larval length at a given time \( t \), \( SL_0 \) is the larval length on the day of hatching, and \( k \) the specific growth rate. \( G \) characterizes the exponential decline of the specific growth rate.

2.5 | Statistical analyses

To investigate the effect of the covariable “sampling month” on the otolith growth, dependent and independent variables were log-transformed and analysis of covariances (ANCOVA) was performed. Data on somatic growth rates did not meet the assumptions of homogeneity and equal variances. Thus, a nonparametric Mann–Whitney

**Figure 2** Location of the sagittal otoliths in Hyporhamphus picarti larvae of 4.6 mm (a), and 15.05 mm (ventral view, b)
U-test was employed to test for significant differences in larval growth between sampling months. All statistical analyses were carried out in JMP 10.0.1 (SAS Institute Inc., Cary, NC, www.jmp.com).

3 | RESULTS

3.1 | Physical parameters

Water temperature and salinity at stations S1 and S2 in February 2014 differed only slightly (see Table 1). The values for the salinity of station S1 from the Saloum River also differed little between the two seasons (February and June). On the other hand, the temperature differed markedly at station S1 with a difference of about 6°C when comparing the two sampling months.

3.2 | Otolith and somatic growth

The standard length (SL) of analysed H. picarti larvae varied between 4.65 and 16.38 mm in February, and 3.86 to 21.68 mm in June. For both months, the relationship between otolith diameter (OD) and SL could be adequately described by linear functions (Figure 3): OD = 13.23 + 13.37 × SL (n = 54; r² = .97) in February and OD = 8.082 + 13.76 × SL (n = 80; r² = .96) in June 2014. No significant differences in the slopes and intercepts of both regressions could be detected between months.

The estimated age of the sampled larvae varied between 3 and 21 days in February, and 2 to 22 days in June. The relationship between fish size (SL) and age (days, t) was described by the following Gompertz models (Figure 4): SL₁ = 2.88 × e^{2.32t[1−e^{−t/2.11}]} (n = 54; r² = .91) in February and SL₂ = 1.46 × e^{2.96(1−e^{−t/11.10})} (n = 80; r² = .91) in June 2014. The average somatic growth rates (± standard deviation [SD]) were significantly higher in larvae sampled in June (0.94 ± 0.17 mm per day) than in February (0.60 ± 0.06 mm per day) (Mann–Whitney U-test, Z = 5.26, n₁ = 21 and n₂ = 21, p < .0001; Figure 4).

4 | DISCUSSION

For the first time, the present study estimated the age and somatic growth rates of larval H. picarti. The smallest individual measured 3.86 mm SL, showing two growth rings, suggesting that the species spawns in the lower reaches of the Sine Saloum estuary.

For the sampling area, a temperature difference between February and June 2014 of around 6°C was documented. We did not observe a difference in the relationship between larval size and otolith diameter among seasons, as described in past studies. Slowly growing larvae, however, may have larger otoliths at a specific length than faster growing ones or vice versa (Fey, 2006; Mosegaard, Svedäng, & Taberman, 1988). In our case a potential decoupling effect between otolith and somatic growth can therefore be regarded as negligible (Munk, 1993). A comparison of larval growth rates in the two seasons showed significant differences for 10 days old specimens. Further, larvae sampled in

TABLE 1 Physicochemical parameters measured at the stations S1 and S2 in the Saloum River in February and June 2014

| Sampling month | Station | Temperature [°C] | Salinity |
|----------------|---------|-----------------|---------|
| February       | S1      | 20.8            | 37.3    |
| February       | S2      | 21.7            | 38.1    |
| June           | S1      | 26.4            | 36.1    |
June reached a maximum growth rate of 1.1 mm per day with values comparable to those estimated for H. brasiliensis with 1.2 mm per day (Berkeley & Houde, 1978). The rapid downward trend shown in the curve beyond an age of 15 days can most likely be attributed to limited representativeness of large specimens in our catches (net selection).

Primary production at the mouth of hypersaline estuaries has been described as rather constant throughout the year (Papè & Gabel, 1990), thus an influence of water temperature on prey item abundance can be neglected. In addition, direct effects of water temperature on somatic growth and survival in marine fish larvae are generally regarded as stronger than the indirect ones exhibited by enhanced food availability (Houde, 2008). If favourable feeding conditions are assumed, elevated growth potential will allow for rapid accumulation of biomass and consequently lead to higher survival potential (Houde, 1989) in larvae developing in June. Still, mortality rates generally increase with temperature in marine fish larvae, reinforcing the notion that a further increase in water temperature may have a negative impact on the abundance of H. picarti larvae in the Sine Saloum estuary (Pepin, 1991).

In contrast to the Mediterranean Sea, where a seasonality in the species’ reproduction has been described (Jaafour, Yahyaoui, Rabbi, Sadak, & Amara, 2015), spawning of H. picarti in the Sine Saloum estuary occurs all year round with a maximum from February to June (Sloterdijk et al., 2017). A protracted spawning period is a feature commonly observed in species of diverse families inhabiting the system, such as bonga shad Ethmalosa fimbriata (Clupeidae), sicklefin mullet Liza falcipinnis (Mugilidae), striped mojarrar Gerres nigri (Gerreidae), and black-chinned tilapia Sarotherodon melanotheron (Cichlidae) (Döring, Tiedemann, Stäbler, Sloterdijk, & Ekau, 2017; Panfill, Thior, Ecoulín, Ndaiye, & Albaret, 2006; Sloterdijk et al., 2017).

Our results underline the important role of the Sine Saloum estuary as a spawning habitat for H. picarti. Conditions for a rapid larval growth appear to be more favourable during the warm season (June), enhancing the recruitment probability of early life stages developing during this time of year. The obtained results contribute to a better understanding of the distribution, developmental biology, and recruitment probability of H. picarti in West African waters.

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ORCID

J. Döring http://orcid.org/0000-0003-3165-1079

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