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Research Article

Biological parameters of the common eel (*Ophichthus remiger*) in the tropical Eastern Pacific: Implications for fisheries management and sustainable conservation

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ABSTRACT. *Ophichthus remiger*, commonly known as the common eel, is commercially important in Ecuador because Asian markets have high demand. Since industrial fishing began in 2004, no systematic population monitoring has been conducted, limiting understanding of the species' population dynamics and challenging sustainable management efforts. This study provides essential biological parameters of *O. remiger* in the Gulf of Guayaquil, Ecuador, including size structure, sex ratio, length-weight relationship, and size at first sexual maturity (SFSM), estimated as the median length at sexual maturity (L_{50}). Between August 2013 and December 2014, 17,186 specimens were sampled monthly using bottom longlines and traps. The results indicate a captured length range of 24 to 138 cm, with females comprising 61% of the population among sexed specimens (n = 5,876). Reproductive activity occurs year-round, with peak the gonadosomatic index in October and April. The condition index (K) is not different between females and males, there are no differences in the length-weight relationship; the specimens exhibit allometric growth. The SFSM, expressed as L_{50}, was 56.7 cm for females (95% CI: 56.2-57.2 cm; n = 1,847) and 63.2 cm for males (95% CI: 62.6-63.8 cm; n = 1,109). Based on the estimated size at 50% sexual maturity (L_{50}), minimum capture sizes of approximately 57 cm total length (TL) for females and 63 cm TL for males are recommended as a management reference for *O. remiger* in the Gulf of Guayaquil. These data provide a robust basis for sustainable management measures, crucial to conserving this high-demand species in international markets.

Keywords: *Ophichthus remiger*; female-male ratio; length-weight relationship; reproduction; median length at sexual maturity; spawning; tropical Eastern Pacific

INTRODUCTION

The family Ophichthidae, within the order Anguilliformes, encompasses a diverse range of eels adapted to marine demersal habitats and includes two subfamilies: Myrophinae, characterized by small species with caudal fins adapted for benthic environments, and Ophichthinae, or snake eels, distinguished by elongated bodies and pointed caudal tips suited to sandy and muddy substrates (McCosker et al. 2020). Species within the genus *Ophichthus* have an extended pelagic larval phase lasting 10 to 12 months, which dispersal and

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limits restricts geographic distribution, resulting in a more constrained biogeography than marine species with shorter larval dispersal periods (Galán et al. 2007).

In the Eastern Pacific, the genus *Ophichthus* shows considerable taxonomic diversity, with at least 91 documented species, including *O. remiger*, *O. triserialis*, and *O. zophochir* as the most prevalent (McCosker & Rosenblatt 1998, McCosker et al. 2020). These species exhibit specific latitudinal distributions, reflecting adaptations to the region's unique oceanographic conditions (McCosker & Rosenblatt 1998). Recent taxonomic revisions have consolidated previously distinct species (*O. ater*, *O. callaensis*, *O. dicellurus*, and *O. pacifici*) under the designation *O. remiger*, which enhances taxonomic precision and facilitates a more consistent approach in biological studies and fishery management efforts (https://www.marinespecies.org/aphia.php?p=taxdetails&id=125647).

The morphology and ecology of *O. remiger* enable adaptation to benthic niches across a broad bathymetric range (15 to 800 m) in the Eastern Pacific, from Nicaragua to Chile (Castillo 1992, 2000, Vera 2006, Galán et al. 2007, Murase et al. 2014). Its elongated, cylindrical body, lack of pelvic fins, and grayish dorsal coloration, along with scaleless skin, support its survival in low-oxygen environments (0.5-1 mg L^{-1} dissolved oxygen) (Castillo et al. 2000, Vera 2006, Galán et al. 2007). *O. remiger* is a carnivorous species with a diet composed of crustaceans, fish, and cephalopods, with cannibalistic tendencies observed in larger individuals, underscoring its role as a predator within the benthic ecosystems of the tropical Eastern Pacific (Castillo et al. 2000, Galán et al. 2007). Its tolerance to temperatures between 10 and 21.6°C (preferably around 15°C) and salinities ranging from 34.05 to 35.37 enables it to thrive in highly variable environmental conditions, contributing to its adaptive success in these complex ecosystems (IMARPE 1991, Castillo 1992, Galán et al. 2007, Cortés & Merino 2020).

The increasing demand for *O. remiger* in European and Asian markets, particularly in Japan as a substitute for higher-value eel species such as *Anguilla anguilla* and *A. japonica*, has led to intensified exploitation in Peru and Ecuador (Arancibia 2000, Casadevall et al. 2001, Chicaiza 2005, Galán et al. 2007, Martina 2018). Despite significant harvests, Ecuador's 2023 landing was around 450 t (FAO 2025), but the lack of systematic monitoring of the industrial fishery since 2004 hinders accurate assessments of population status (Chicaiza 2005). This context highlights an urgent need for fundamental biological data, including size structure, sex ratio, and growth parameters, to inform fisheries management strategies that ensure the long-term sustainability of this resource (Nadon et al. 2015, Ault et al. 2019, Mahadevan et al. 2020, Mendoza-Nieto et al. 2022, Nemba 2020).

The size at first sexual maturity (SFSM) and other biological parameters of *O. remiger* are essential for assessing population health and detecting potential fishing pressures that may impact reproductive and ecological dynamics (Hossain et al. 2012, Magqina et al. 2021). Shifts in these indicators can reveal both exploitation intensity and changes in environmental conditions, making them vital tools for designing sustainable fishery management policies (Hossain et al. 2008). Without a detailed understanding of these parameters, long-term conservation strategies are less effective, particularly in regions facing high fishing pressure (Correa-Herrera & Jiménez-Segura 2013, Carvalho et al. 2021).

This study characterizes key biological parameters of *O. remiger* in the Gulf of Guayaquil, a region of high biodiversity and productivity in the tropical Eastern Pacific (Robertson & Cramer 2009, Nürnberg et al. 2015, Enright et al. 2021). The objective is to establish a robust scientific foundation by gathering essential data on size structure, sex ratio, length-weight relationship, and SFSM to support effective fisheries management strategies. These data are crucial to ensure the long-term viability of the species and to maximize the ecological, economic, and social benefits derived from its sustainable exploitation (Svedaung et al. 1996, Okamura et al. 2009, Yokouchi et al. 2018).

MATERIALS AND METHODS

Study area

This study was conducted in the Gulf of Guayaquil, situated along the southwestern coast of Ecuador in the Pacific Ocean (Fig. 1). The gulf, the largest estuary on the western coast of South America, is bounded by the city of Guayaquil to the north and extends southward to the border with Peru (Twilley et al. 2001, Pinto & Slowey 2021). The region is known for its high productivity and biodiversity, providing a crucial habitat for demersal species like *O. remiger*. However, intensive human activities in surrounding areas, including urban and industrial settlements, have led to heavy metal pollution (Troccoli-Ghinaglia & Prado-España 2017, Calle et al. 2018, Navarrete-Forero et al. 2019, Alava et al. 2020).

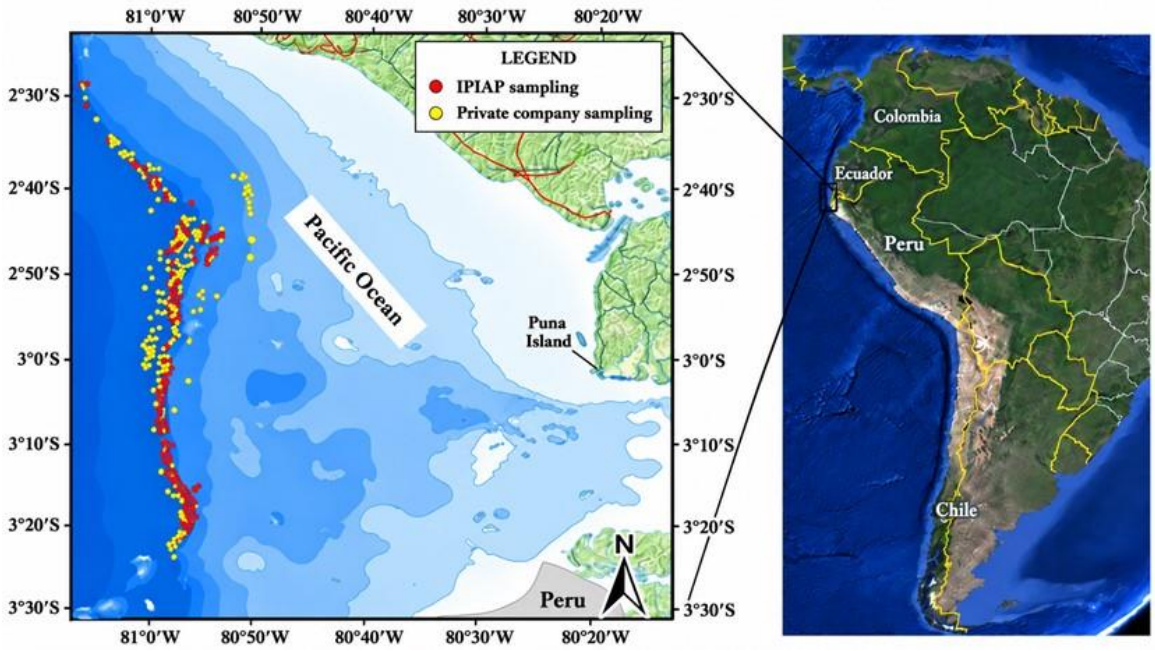


Figure 1. Geographic location of fishing sites for the common eel (*Ophichthus remiger*) in the Gulf of Guayaquil, Guayas Province, Ecuador, South America. The map shows the general fishing area and specific coordinates, highlighting strategically selected sites based on the known habitat distribution of *O. remiger*. Ecuadorian Aquaculture and Fisheries Research Institute (IPIAP, by its Spanish acronym) sampling indicates the fishing areas where biological samples of *O. remiger* were collected by the IPIAP during the study period. The map was generated using Google Maps to ensure accurate and clear visualization of the geographic and environmental context of the study area.

Sample collection

Researchers collected *O. remiger* specimens between August 2013 and December 2014 through both industrial and artisanal fishing as part of a research program led by the Ecuadorian Aquaculture and Fisheries Research Institute (IPIAP, by its Spanish acronym). This fishery operates year-round. Biological information was collected by onboard fisheries observers during fishing operations. During each fishing set, observers recorded catch information and measured randomly selected *O. remiger* specimens from the available catch, without prior stratification by size, sex, or other biological characteristics. In addition, a monthly subsample was transported to the laboratory for detailed biological examination. Approximately 60 specimens were obtained from each of two vessels, yielding about 120 specimens per month for laboratory analyses. Specimens were captured using bottom-set longlines and traps specifically designed for this species (Fig. 2). The longline comprised a main nylon line of 3/8 inches in diameter and a total length of 2,915.65 m, with branch lines fitted with rings to secure traps at 3.64 m intervals. To anchor the structure to the seabed, 50-lb weights were placed every 40 traps, and each end of the line was equipped with buoys extending 364 m, with additional floats and flags for surface visibility.

The traps, constructed from PVC and tailored to capture demersal species such as *O. remiger*, had a cylindrical structure measuring 50 cm long and 17 cm in diameter, with 1/2-inch perforations to facilitate submersion. One end of each trap had a removable lid for bait placement and retrieval, while the opposite end had a conical entrance to ease eel entry and prevent escape. *Auxis thazard* (known locally as "botellita") was used as bait due to its strong odor and bloody appearance. This technique was used at depths of 100 to 200 m, about 40 nm from the coast, to optimize selective capture of *O. remiger*. Over the study period, 17,186 eels were captured, with 86.8% from industrial fishing operations and 13.2% from artisanal methods (Fig. 3).

Sex ratio

Each specimen was measured for total length (TL) with an accuracy of ±1 cm using an ichthyometer, and total weight (TW) was recorded using a precision scale with ±0.1 g accuracy. Sex identification was conducted

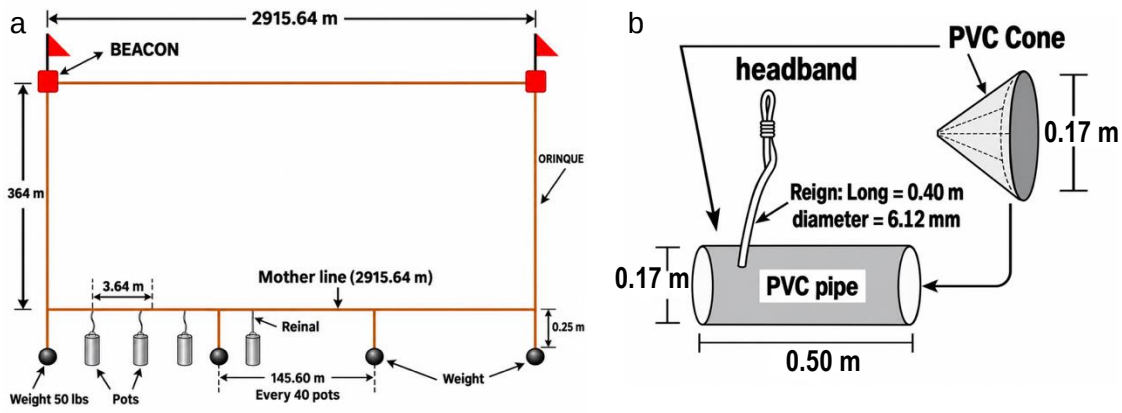


Figure 2. Configuration of the horizontal bottom-set longline with traps used for capturing *O. remiger* in the Gulf of Guayaquil, Ecuador. a) Structure of the longline, illustrating the main line, branch lines with attached traps, weights, and buoy system designed to maintain positioning on the seafloor. b) Structure of the trap, highlighting the cylindrical PVC frame, dimensions, perforations for submersion, bait compartment, and conical entrance designed to facilitate entry and prevent escape of captured individuals. This configuration was optimized to selectively capture demersal species in the study area.

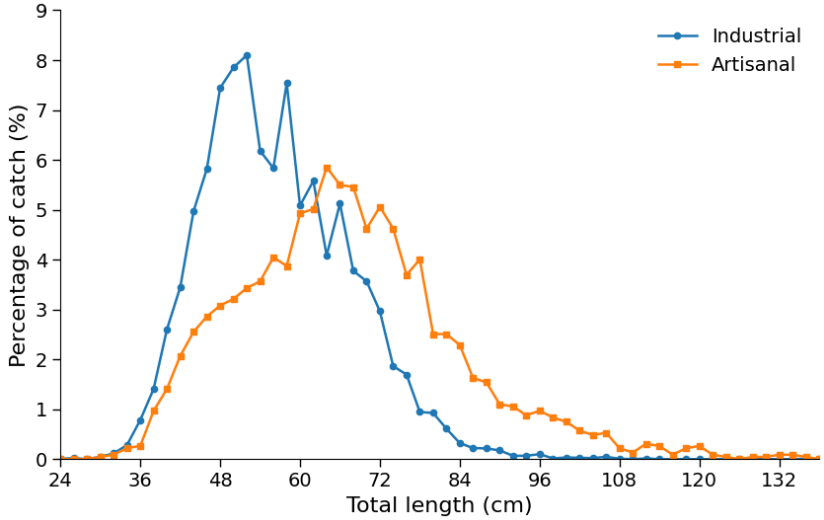


Figure 3. Percentage catch of *O. remiger* by length class (cm) in the Gulf of Guayaquil, Ecuador, separated by industrial and artisanal fishing sectors. The data show a differential distribution of captures, with the industrial sector catching a higher proportion of juveniles, while the artisanal sector catches a higher proportion of larger eels.

through gonadal inspection, allowing for analysis of sex ratios in the total sample as well as across monthly intervals to observe potential seasonal variations. A chi-square test (χ^2) was used to assess whether the observed sex ratio significantly deviated from an expected 1:1 ratio (Zar 1999).

Length-weight relationship analysis

The relationship between total length and weight (TL/TW) was calculated for both sexes using a power regression model. Sex-based differences in the growth coefficient were evaluated through Analysis of covariance (ANCOVA). The isometric exponent (*b*) was compared to the theoretical value of 3 using Student's *t*-test to determine whether the growth pattern was allometric or isometric (Andrade & Campos 2002). Residual normality of the log-transformed length-weight regressions was assessed separately for males and females using the Shapiro-Wilk test, whereas homoscedasticity was evaluated using the studentized

Breusch-Pagan test. Statistical significance was established at $P < 0.05$. The *t*-statistic was computed with the following formula, adapted from Pauly (1984):

$$t = \frac{sd(x)}{sd(y)} \times \frac{|b_i - 3|}{\sqrt[2]{1-R^2}} \times \sqrt[2]{n_i - 2}$$

where t is the *t*-student statistic, sd(x) and sd(y) are the standard deviations of the logarithm of TL and TW, respectively, for each analyzed group; b_i is the fitted exponent, R^2 represents the coefficient of determination, and n_i is the sample size.

Gonadosomatic index

To evaluate reproductive condition, the gonadosomatic index (GSI) was calculated as the ratio of gonad weight to total body weight, multiplied by 100. This index was recorded over the study period to identify reproductive patterns and potential spawning cycles.

Fulton's condition factor analysis (K)

To assess the physical condition of the specimens, Fulton's condition factor (K) was used, a commonly applied index in studies evaluating the health and general condition of fish. The condition of the eel under study was calculated using K, adapted to the specific parameters of *O. remiger* with the following equation: $K = 100 \times W\ L^{-3}$, where K represents the condition factor, W is the body weight in grams, and L is the total length of the eel in centimeters (Froese 2006, Barrett et al. 2016, Ravikumar et al. 2023). The factor of 100 is used to normalize K close to unity. Higher K values indicate a better physical condition of the individual, which may be associated with greater food availability or an optimal reproductive state (Froese 2006).

Size at first sexual maturity (SFSM)

The SFSM was defined as the length at which 50% of individuals of each sex reached maturity. The probability of sexual maturity as a function of total length was estimated using a logistic model fitted by maximum likelihood in R software (Roa et al. 1999): $P(L) = 1 / (1 + \exp[-(\beta_0 + \beta_1 L)])$, where P(L) is the probability that an individual of total length L is sexually mature, β_0 is the intercept, and β_1 is the slope parameter. The median length at sexual maturity (L_{50}) was calculated as the length at which P(L) = 0.5, according to: $L_{50} = -\beta_1 \beta_0$.

Sexual maturity was determined through visual inspection of the gonads, following a maturity scale adapted from IMARPE (1993), which distinguishes the stages as I (virginal), II (initial maturity), III (advanced maturity), IV (spawning), and V (spent).

This modified scale enabled precise identification of *O. remiger* maturity stages, suggesting specific growth and reproductive patterns essential for fisheries management of this species in the Gulf of Guayaquil.

RESULTS

The data show that the industrial fishing sector (86.8%) in the study region predominantly captures juveniles. In contrast, the artisanal sector, which operates in coastal areas, reports a higher proportion of larger individuals (Fig. 3). Analysis of capture lengths showed that females ranged from 24 to 138 cm, with an average of 61.8 ± 15.6 cm. In contrast, males ranged from 27 to 117 cm, with an average of 58.1 ± 12.2 cm (Fig. 4). Captures were primarily concentrated in the 36-84 cm TL range.

The sex ratio analysis, based on 5,876 eels, demonstrated a predominance of females (61%) compared to males (39%), yielding a female-biased sex ratio of 1.6:1 (Fig. 5). This bias was statistically significant in most months ($P < 0.05$), except in August 2014 ($P > 0.05$). Sex-ratio information could not be analyzed separately for the industrial and artisanal fisheries because the biological database did not retain a fishing-sector identifier for each sexed specimen. Therefore, the sex-ratio estimates presented here correspond to the combined biological sample and should not be interpreted as sector-specific patterns. Sex-ratio by size class showed no notable differences in the 36-60 cm range, whereas females predominated from 63 cm onward (Fig. 6).

The length-weight relationship was best fit by a power model: $W_t = 0.0004L_t^{3.2815}$ for females and for $W_t = 0.0003L_t^{3.3224}$ males, with an R^2 of 0.934 in both cases, indicating positive allometric growth (Fig. 7). ANCOVA analysis showed no significant differences in slopes and intercepts ($P > 0.05$). Residuals showed significant departures from normality in males ($W = 0.774$, $P < 0.001$) and females ($W = 0.750$, $P < 0.001$), whereas no evidence of heteroscedasticity was detected in males (BP = 0.530, $P = 0.467$) or females (BP = 1.192, $P = 0.275$).

Reproductive activity was observed throughout the year, with peaks in October 2013 and April 2014 (Fig. 8). Maximum GSI values were recorded in October 2013 and in April, August, and December 2014 (Fig. 9). K showed no significant differences between sexes ($P > 0.05$), with average values ranging from 0.12 to 0.16 for females and 0.12 to 0.15 for males (Fig. 10).

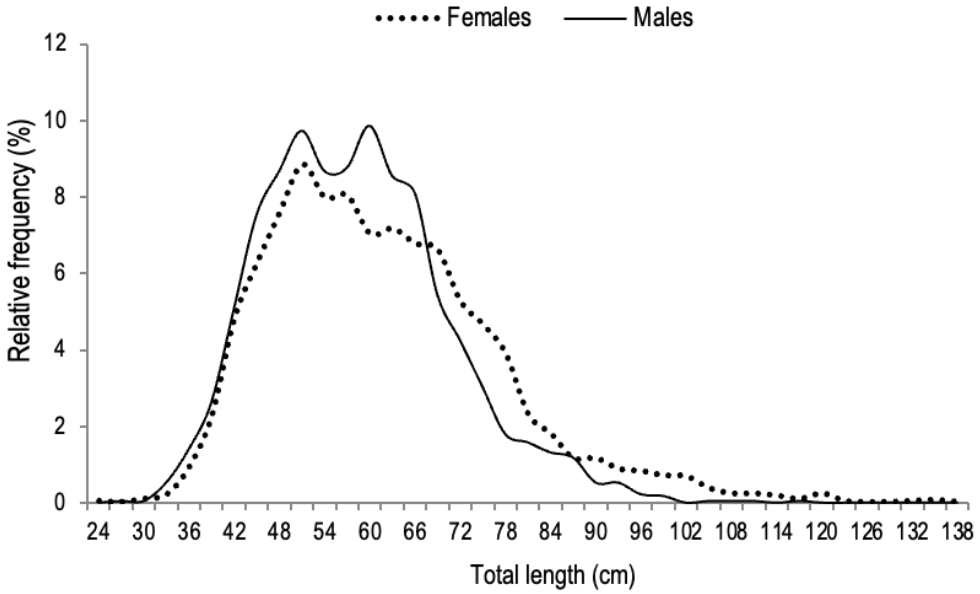


Figure 4. Relative frequency (%) of total length of female and male *O. remiger* captured in the Gulf of Guayaquil, Ecuador. *O. remiger* specimens exhibit a total length range of 24 to 138 cm for females and 27 to 117 cm for males, with the highest concentration of captures occurring within the 36 to 84 cm interval.

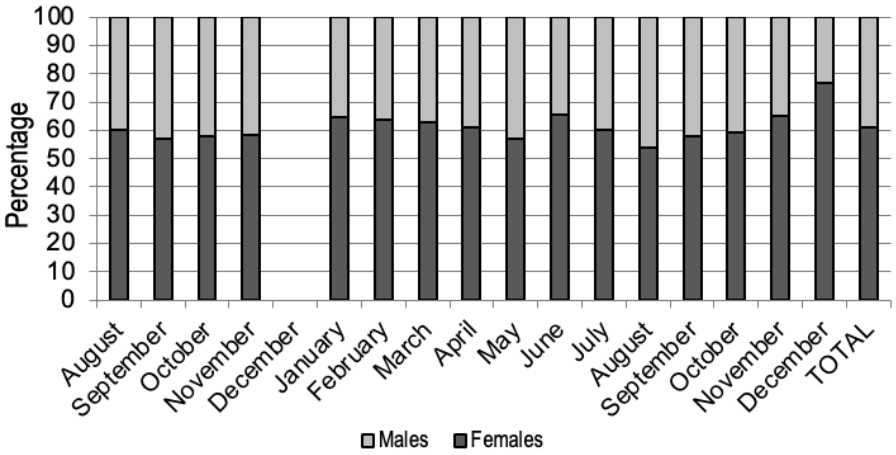


Figure 5. Monthly sex ratio of *Ophichthus remiger* in the Gulf of Guayaquil from August 2013 to December 2014. No samples were available for December 2013. Females comprised 61% of the sexed specimens and males 39%, corresponding to an observed female-to-male ratio of 1.6:1 (n = 5,876). Deviations from the expected 1:1 sex ratio were evaluated using a chi-square test (χ^2). Significant differences between sexes were detected in most sampled months ($P < 0.05$), whereas no significant deviation from the 1:1 ratio was detected in August 2014 ($P > 0.05$).

The SFSM in *O. remiger* was determined to be 56.7 cm for females and 63.2 cm for males (Fig. 11).

DISCUSION

This study addresses the significant gap in species-specific knowledge of *O. remiger* in the Gulf of Guayaquil, a commercially valuable species at risk of overexploitation due to inadequate regulation (Galán et al. 2007). Limited research on *O. remiger* population biology critically limits the development of sustainable fishery practices. Previous studies have predominantly focused on the biological parameters of other commercially relevant marine species, neglecting detailed assessments of *O. remiger*, which are essential for proper management (Frisk et al. 2001, Jensen et al.

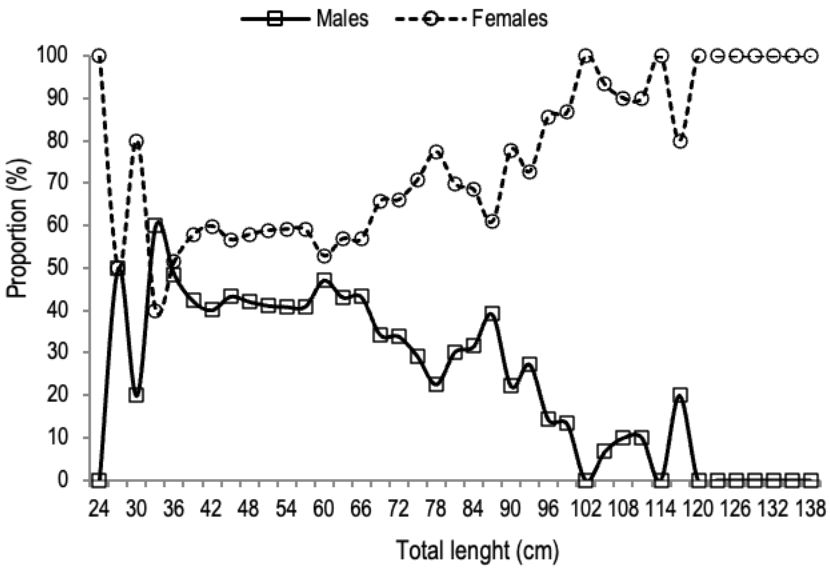


Figure 6. Size-specific sex ratio of female and male *O. remiger* captured in the Gulf of Guayaquil, Ecuador, from August 2013 to December 2014 (n = 5,862; 3,584 females and 2,278 males). The sex ratio was relatively balanced between males and females in the 36-60 cm total length (TL) range, whereas females predominated from 63 cm TL onwards.

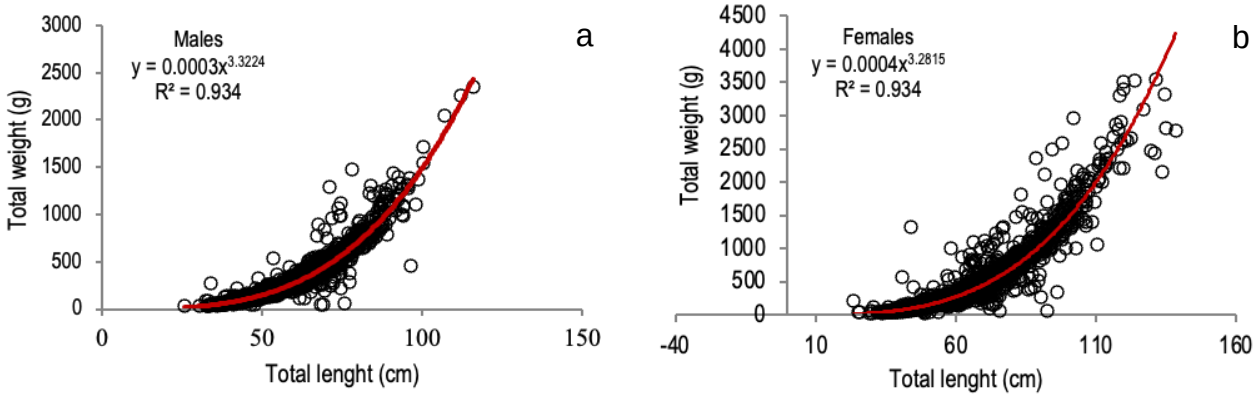


Figure 7. Length-weight relationship of *O. remiger* captured in the Gulf of Guayaquil, Ecuador, from August 2013 to December 2014. a) Females (n = 3,584) and b) males (n = 2,275). The length-weight relationship followed a power model in both sexes, with allometric exponents of 3.2815 for females and 3.3224 for males (R^2 = 0.934 for both sexes).

2005, Stergiou & Karachle 2006, Pajuelo et al. 2008, Bettoso et al. 2015, Nguyen et al. 2020, Córdoba-Rojas et al. 2024). Consequently, this study has concentrated on characterizing the size structure, sex ratio, length-weight relationship, and SFSM of the *O. remiger* population in the Gulf of Guayaquil, providing a critical foundation for sustainable management.

The results reveal marked sexual dimorphism, with females reaching larger sizes than males, which could suggest an adaptive reproductive strategy. The length-weight relationship shows positive allometric growth in both sexes, indicating robust physical condition and abundant resources. Furthermore, the sex ratio leans toward females in size classes above 63 cm, suggesting differential vulnerability to capture and underscoring the need for protective measures, such as seasonal fishing closures during the main reproductive pulses identified in October and April. According to the SFSM, the minimum catch sizes would be 57 cm for females and 63 cm for males, values that coincide with findings in other regions of the Eastern Pacific (IMARPE 1991, Vera 2006). This background suggests interregional variability in L_{50}, possibly influenced by fishing pressure that captures larger specimens and by

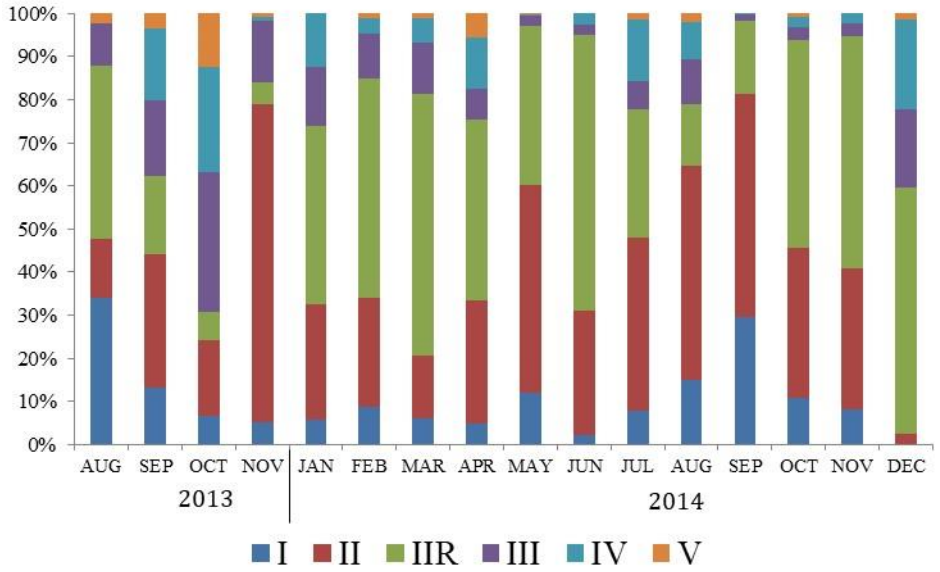


Figure 8. Monthly distribution of gonadal maturity stages in female *O. remiger* from the Gulf of Guayaquil, Ecuador, from August 2013 to December 2014. Monthly sample sizes were: Aug 2013, n = 132; Sep 2013, n = 143; Oct 2013, n = 120; Nov 2013, n = 119; Jan 2014, n = 169; Feb 2014, n = 296; Mar 2014, n = 342; Apr 2014, n = 267; May 2014, n = 380; Jun 2014, n = 316; Jul 2014, n = 77; Aug 2014, n = 246; Sep 2014, n = 307; Oct 2014, n = 129; Nov 2014, n = 449; and Dec 2014, n = 77. No samples were available for December 2013. Maturity stages correspond to I: virginal, II: initial maturity, IIR: recovery, III: advanced maturity, IV: spawning, and V: spent.

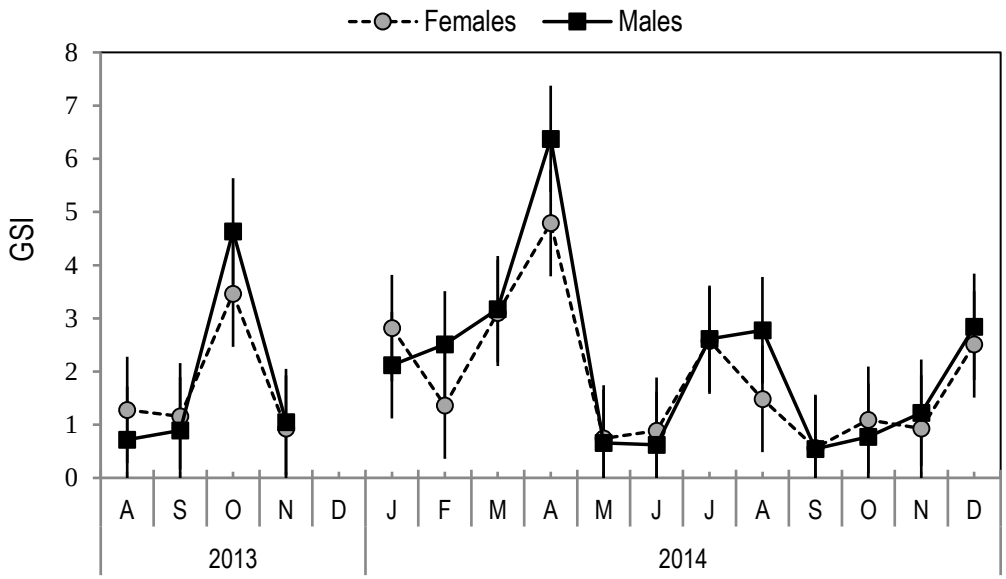


Figure 9. Monthly variation in the gonadosomatic index (GSI) of female and male *O. remiger* in the Gulf of Guayaquil from August 2013 to December 2014. Values are presented as monthly mean ± standard deviation (SD). Monthly sample sizes (males/females) were: Aug-2013, 96/146; Sep-2013, 108/143; Oct-2013, 88/121; Nov-2013, 84/119; Jan-2014, 92/169; Feb-2014, 167/296; Mar-2014, 203/342; Apr-2014, 170/267; May-2014, 287/380; Jun-2014, 166/316; Jul-2014, 51/77; Aug-2014, 209/246; Sep-2014, 222/307; Oct-2014, 88/129; Nov-2014, 238/449; and Dec-2014, 23/77. No data were available for December 2013.

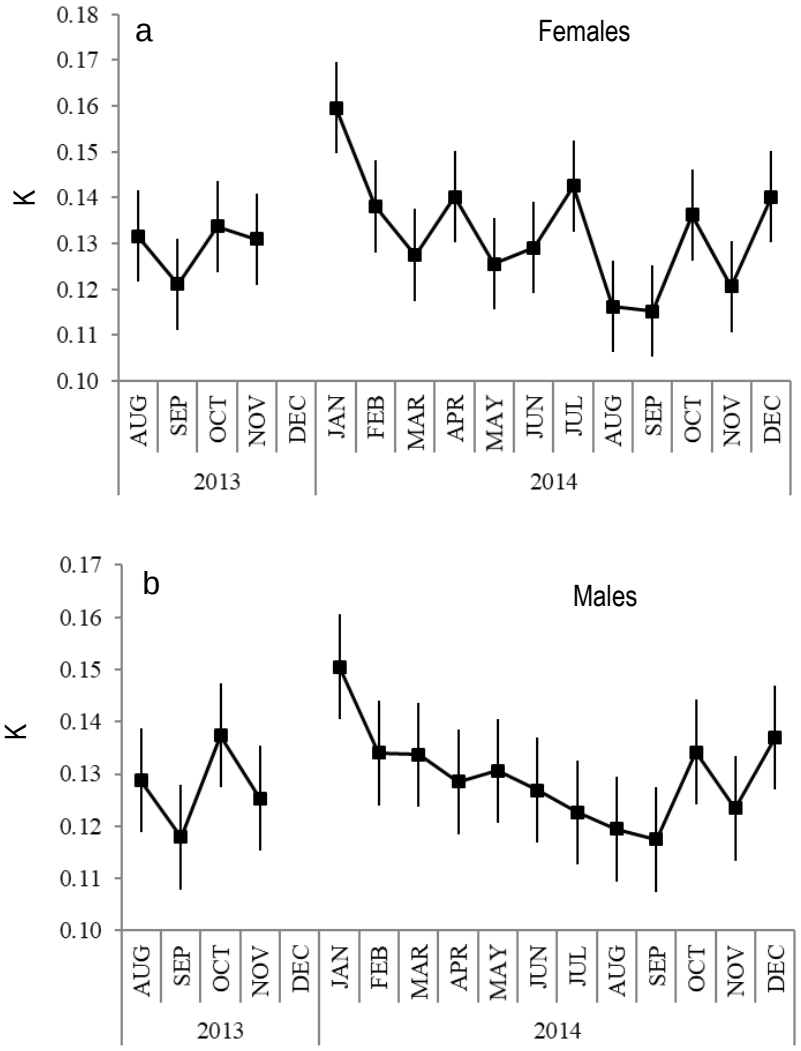


Figure 10. Monthly variation in Fulton's condition factor (K) for a) female (n = 3,584) and b) male (n = 2,278) *O. remiger* in the Gulf of Guayaquil from August 2013 to December 2014. Values are presented as monthly means ± standard deviation (SD).

environmental factors that affect specimen development and growth. These findings support management recommendations for responsible fishing practices for *O. remiger* and offer a model for sustainable practices in the Eastern Pacific, an area experiencing increased fishing pressure.

The management of the *O. remiger* fishery in Ecuador was regulated through Ministerial Agreement No. 202 of 2013 (MAGAP 2013), which established seasonal fishing closures in July and October and required the return to the sea of specimens measuring 40 cm total length or less. Subsequently, Ministerial Agreement MAGP-SRP-2026-0038-A temporarily lifted these seasonal closures for the industrial fleet during 2026, while maintaining the remaining management provisions and introducing specific requirements for biological and fishery monitoring (MAGP 2026). These regulatory developments highlight the importance of incorporating updated biological evidence into adaptive fisheries management. The median lengths at sexual maturity estimated in the present study (56.7 cm for females and 63.2 cm for males) exceed the 40 cm regulatory threshold, supporting a reassessment of size-based management measures. Furthermore, the reproductive pulse observed in October provides biological evidence relevant to evaluating seasonal fishing restrictions, while the additional reproductive peak in April suggests that this period should also be considered in future assessments. The monitoring requirements established

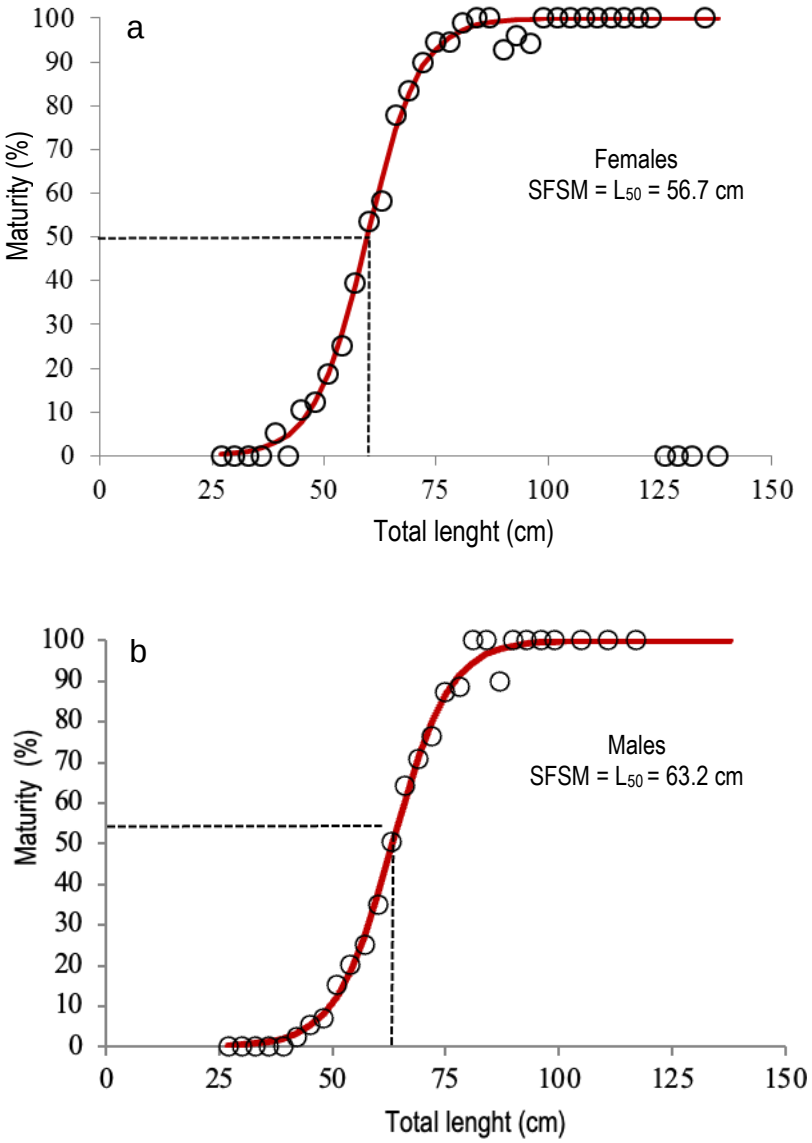


Figure 11. Size at first sexual maturity in female and male *O. remiger* captured in the Gulf of Guayaquil, Ecuador. L_{50} represents the total length at which 50% of individuals are sexually mature, estimated at 56.7 cm for females and 63.2 cm for males based on cumulative frequency analysis in relation to gonadal development stages.

in the 2026 agreement, including catch per unit effort, mean body length, the proportion of individuals measuring 40 cm or less, and population structure, provide an opportunity to integrate reproductive parameters into fisheries assessments. However, because the present study is based on data collected during 2013-2014, further monitoring is required to assess current population conditions and the biological consequences of the temporary suspension of seasonal closures.

The distribution of *O. remiger* captures between the industrial and artisanal sectors shows marked selectivity, shaped by each fleet's operating areas and the species' population structure (Fig. 3). Industrial fisheries, which operate beyond 8 nm and at greater depths, capture more juveniles. In contrast, artisanal fisheries, constrained to coastal waters, predominantly capture adult individuals. This finding aligns with studies showing an ontogenetic distribution pattern among anguillids, with juveniles congregating in deeper waters and adults in shallower waters less than 73.2 m deep (Castillo et al. 2000, Galán et al. 2007, Miller et al. 2021). The physiological adaptation of adult *O. remiger* to migrate and spawn at depths

exceeding 500 m in epipelagic and mesopelagic zones, coupled with diurnal inactivity and nocturnal vertical migrations from burrows between 15 and 800 m to warmer waters for feeding, explains the variability in capture rates at different depths (Helfman 1986, Castillo 1992, 2000, Van Ginneken & Maes 2005, Vera 2006, Galán et al. 2007, Matić-Skoko et al. 2012, Murase et al. 2014). Habitat distribution of *O. remiger* is likely influenced by factors that affect resource availability and catch rates in the demersal benthic system, such as substrate type, depth, fishing area, season, and bait type. Anguilliformes have important olfactory capabilities; they possess many olfactory lamellae (Kasumyan 2004, Liu et al. 2005), resulting in a heightened sense of smell. Because *O. remiger* exhibits both diurnal and nocturnal behavior, it likely relies heavily on chemoreception to locate prey, as fatty fish like mackerel attract more eels as bait than lean fish like mullet and drum. Furthermore, larger individuals appear to migrate to different distribution areas in winter, potentially to spawn, leaving smaller individuals from later cohorts in deeper recruitment zones. This hypothesis is supported by monthly modal variations, where larger individuals disappear from the study area (Galán et al. 2007).

The comparative analysis of capture sizes for *O. remiger* in Ecuador, Peru, and Chile reveals significant differences in average sizes, reflecting local fishing practices and pressures (Table 1). The average length is 49.1 cm in the Gulf of Guayaquil, 45 cm in Paita, Peru (IMARPE 1991), and 58.5 cm from Valparaíso to Concepción, Chile (Arancibia 2000). This pattern may be attributed to the incidental nature of eel catches in Chile, where they appear as bycatch in industrial trawling operations targeting crustaceans such as *Pleuroncodes monodon* and *Cervimunida johni*, nylon shrimp (*Heterocarpus reedi*), and common hake (*Merluccius gayi*) (Galán et al. 2007). In Ecuador, a temporal analysis documented a reduction in minimum capture size from 41 to 24 cm and an increase in the maximum from 119 to 138 cm, accompanied by a decrease in the mean from 66.5 to 49.1 cm. In contrast, Peruvian fisheries in 1991 and 1993, compared with 2005, show reductions in all measured parameters (IMARPE 1991).

The size structure also shows marked sexual dimorphism, with females reaching 24 to 138 cm and males 27 to 117 cm, with average sizes of 61.8 and 58.1 cm, respectively (Figs. 4, 6). Females dominate the larger size classes (≥70 cm), with a high juvenile capture rate (Figs. 4, 6). Between 36 and 60 cm, the sex ratio is balanced. Still, females predominate beyond 63 cm, supporting findings by Chicaiza (2013) and suggesting a 1:1 sex ratio in early life stages, with a later shift toward females, or possibly greater female vulnerability to fishing gear due to their larger size (Galán et al. 2007). The reproductive strategy of *O. remiger*, whereby larger females optimize fecundity and spawning success, aligns with studies on other species (Clark 2000, Castillo et al. 2000, Casadevall et al. 2001, Chicaiza 2005, Galán et al. 2007, Avaca et al. 2012, Le & Duong 2023). The presence of juveniles in deeper waters suggests habitat segregation to minimize competition and maximize resource utilization (Shine 1989), a strategy observed in other anguillids (Galán et al. 2007). The high juvenile catch rate and scarcity of large adults may indicate concerning overexploitation, threatening population regeneration by reducing the proportion of reproductive adults essential for species continuity (Svedäng 1999, Hutchings 2000, Hsieh et al. 2010, Zgliczynski & Sandin 2017). Similar trends in Piura, Peru, show that average capture sizes dropped from 59.5 cm in 1993 to 40 cm in 2009, underscoring the importance of management measures; regulations since 2010 helped recovery to 48.8 cm by 2016 (IMARPE 2017). In Ecuador, fishing efforts target immature individuals because the Asian market demands young specimens with specific texture and tenderness, and this concern is further emphasized by the lack of a legal framework to implement recommended management measures (Chicaiza 2005).

The analysis of the sex ratio (Fig. 5) reveals a marked female bias, with females comprising 61% of the population and a female-to-male ratio of 1.6:1. This pattern aligns with previous studies, such as Chicaiza (2013) in Ecuador, who reported a 1.8:1 female bias, and Chicaiza (2005), who documented ratios as high as 1:2 in regions like Posorja, Esmeraldas, and Puerto López. Similar trends have been observed elsewhere; for instance, Vera (2006) reported a 1.76:1 female ratio in Tumbes, Peru, and Galán (2007) reported a 1.02:1 ratio on Isla Lobos de Afuera, Peru. Castillo et al. (2000) documented female predominance in Paita, Peru, with annual male-to-female ratios ranging from 1:1.08 to 1:5.9 between 1990 and 1997. This female-biased pattern is also observed in related species, such as *Ophichthus rex* (4:1, Clark 2000), *O. rufus* (7.7:1, Casadevall et al. 2001), and *C. conger* (2.1:1, Matić-Skoko et al. 2012), suggesting that this tendency may be associated with shared biological and ecological factors among eel species. Statistical analysis of the sex ratio ($P < 0.05$) indicates that various factors may be contributing to this disparity, including differential mortality between sexes, spatial distribution, density at

Table 1. Comparative analysis of capture sizes of *O. remiger* across different localities in Ecuador, Peru, and Chile. The table summarizes the minimum, maximum, and mean sizes recorded in each country, highlighting regional differences in this species' capture-size distribution.

Capture size (cm)					
Investigation	Minimum	Maximum	Average	Location	Country
Chicaiza (2005)	41	119	66.5	Guayaquil coastline	Ecuador
This job	24	138	49.1	Gulf of Guayaquil	
IMARPE (1991)	23	90	45.0	Paita	Perú
Galán (2005)	22	61	36.47	Island Lobos de Afuera	
IMARPE (1993)	34	110	65.21	Tumbes	
IMARPE (2023)	-	.	48.8	Piura and Tumbes Regions	
Arancibia (2000)	32	82	58.5	Valparaíso to Concepción	Chile

the time of hatching, and heightened female susceptibility linked to their larger body size (De Leo & Gatto 1996, Tzeng et al. 2000, Huertas & Cerdà 2006, Bevacqua et al. 2011, Kendall & Quinn 2013). Fishing practices that preferentially target larger specimens disproportionately affect females, increasing their risk of capture (Carver et al. 2005, Hamilton et al. 2007). This selective capture of large females not only reduces their presence in the population but also directly impacts the fecundity and reproductive capacity of the species, threatening population stability and underscoring the urgent need for regulatory measures that promote sustainable fishing practices (Heppell et al. 2006, Barneche et al. 2018, Sørdalen et al. 2018).

The size-weight relationship analysis of *O. remiger* captured in the Gulf of Guayaquil conforms to a power model for both sexes, with exponents of 3.2815 for females and 3.3224 for males. A coefficient of determination (R^2) of 0.934 in both cases (Fig. 7). These results demonstrate positive allometric growth, consistent with findings in *C. conger* (Matić-Skoko et al. 2012, Chicaiza 2013). Positive allometry suggests better body condition in larger individuals, reflecting high morphological plasticity likely influenced by the Gulf of Guayaquil's productive variability, an environment subject to oceanographic fluctuations that affect resource availability. The lack of significant differences in the length-weight relationship between sexes, confirmed by Analysis of covariance (ANCOVA, $P > 0.05$), indicates similar weight gain rates across sexes, as documented in *O. rex* (Clark 2000). Exponents above three further suggest that larger individuals have greater adaptive capacity, which is essential for reproductive success and resilience to fishing pressure.

The reproductive dynamics of *O. remiger* in the tropical Eastern Pacific, as illustrated in Figure 8, indicate a continuous spawning pattern throughout the year. This pattern is characterized by interannual variability in reproductive stages, a strategy well suited to species in tropical environments with stable temperatures and abundant food resources. The continuous presence of individuals in various reproductive stages, with monthly observations of specimens in early maturity (stage II) and peaks of spawning-phase individuals (stage IV) in September 2013 and in January, April, July, August, and December 2014, suggests fractional spawning. This strategy allows for multiple reproductive episodes annually, optimizing productivity and resilience under fluctuating environmental conditions. Our findings align with observations by Chicaiza (2005), who reported heightened reproductive activity for *O. remiger* between October and February. During this period, most males were in late maturity stages (IV and V), indicating peak spawning activity, while females were predominantly in either post-spawning recovery (stage II) or active spawning (stage IV). This temporal distribution underscores a period of intense reproductive activity, crucial for recruitment and the subsequent addition of new individuals to the population (Chicaiza 2005). Similarly, the Instituto del Mar del Perú (IMARPE 2017) reported a prevalence of individuals in initial maturity stages (stage II) in the Piura region from 2010 to 2016, with representation rates between 58 and 82%, while the proportion of actively spawning individuals (stage IV) remained notably lower. Although reproductive activity occurred throughout the year, reproductive intensity varied over time, with periods of increased spawning activity that may support targeted reproductive closures. Comparative studies further support the continuous and fractional spawning nature

of *O. remiger*, as happens in *O. rufus* (Casadevall et al. 2001). For instance, Vera (2006) in Tumbes, Peru, observed a higher representation of individuals in early maturity stages (II) and a significantly lower proportion of spawning individuals (IV). This trend aligns with Castillo et al. (2000) in Colán and Sechura Bay, Peru, where sexually mature individuals in initial maturity stages predominated throughout the year from 1993 to 1997. Although reproductive activity remained generally low across most seasons, a slight increase (20%) was observed in autumn. In Lambayeque, Peru, Galán et al. (2007) also reported a high proportion of virginal (stage I) and early-maturity (stage II) individuals, with limited advanced maturity (1.09%) in autumn and spring 2005, suggesting this period is more likely a recruitment phase than a peak spawning season. The prevalence of juveniles and the scarcity of adult individuals further support this characterization. These findings underscore *O. remiger*'s adaptive reproductive strategy, marked by fractional spawning and continuous reproductive potential, which supports population stability in dynamic environments and under fishing pressure. Although reproductive activity continues year-round, identifying periods of increased activity provides a basis for considering seasonal closures to protect spawning stocks.

The GSI values (Fig. 9) reveal significant reproductive peaks for both sexes of *O. remiger*, with marked elevations observed in October 2013 and in April, August, and December 2014. These findings align with previous studies, such as Chicaiza (2013), which documented similar peaks in July and October, reinforcing the concept of fractional spawning. This reproductive strategy, common in demersal species inhabiting tropical environments, allows for gonadal maturation multiple times throughout the year, facilitated by favorable environmental conditions and abundant food availability (Castillo et al. 2000, Vera 2006) also reported increases in GSI during January and June in Tumbes, Peru, while Galán et al. (2005) observed predominant recruitment in Peru between August and September, highlighting the need for regionally tailored fishery management strategies. The synchronized GSI peaks in both males and females suggest a coordinated reproductive cycle that maximizes reproductive efficiency. Observed interannual variation, such as fluctuations in peak timing and intensity between 2013 and 2014, may reflect recruitment patterns driven more by juvenile survival than by adult abundance (Francis & Jellyman 1999). Demographic factors likely affect reproductive timing, potentially with effects comparable to those induced by environmental variability (Durif et al. 2006, Yokouchi et al. 2018). This demographic influence is particularly relevant, as many fish species spawn progressively earlier in the season and produce additional egg batches over extended periods as they age, thereby increasing their spawning lifespan (Kjesbu et al. 1996, Lowerre-Barbieri et al. 1998, Murawski et al. 2001, Lambert 2008, Stige et al. 2017). Interannual variability in spawning is key to reproductive success because it shapes offspring's initial environment and the timeframe for their development (Wright & Trippel 2009). This variability could be influenced by shifts in the Guayaquil Gulf Stream, which impact larval survival rates by altering their migratory routes (Rypina et al. 2016). Climate change further amplifies these effects by modifying current intensity and stability, thereby affecting the oceanographic and temperature conditions larvae encounter (Vaughan et al. 2021). By reducing the average spawning duration within an eel population, fishing pressure may increase variability in reproductive success and diminish the population's long-term reproductive potential (Dekker 2003, Friedland et al. 2007, Bonhommeau et al. 2008). GSI data support considering annual temporary fishing closures during the main reproductive pulses identified in October and April. However, observed interannual variability in reproductive activity highlights the need for continued long-term monitoring to assess the temporal consistency of these peaks and refine the timing of future closure strategies.

The average K values for *O. remiger* specimens captured in the Gulf of Guayaquil (Fig. 10) ranged from 0.12 to 0.16 for females and from 0.12 to 0.15 for males, with no statistically significant differences between sexes ($P > 0.05$). These results align with Galán et al. (2007), who reported averages of 0.11 for males and 0.12 for females in populations from Isla Lobos de Afuera, Callao, Peru. Similarly, Chicaiza (2013) reported K values in the Gulf of Guayaquil averaging 0.15 for males and 0.12 for females. In studies of other species in the genus, Clark (2000) reported a condition index of 0.13 to 0.20 for both sexes of *O. rex* in the northern Gulf of Mexico. Likewise, Matić-Skoko et al. (2012) reported length and weight values of 23.4-144.0 cm and 43.8-6180.0 g, respectively, for *C. conger*, with K values of 0.34 and 0.21 at various development stages. The results indicate that *O. remiger*'s physical condition in the Gulf of Guayaquil is stable, reflecting consistent access to food resources and suggesting a balanced ecosystem. The stability of K between sexes highlights the adaptive capacity of the species and an efficient reproductive

Table 2. Size at first sexual maturity (SFSM) in female and male *O. remiger* across various localities in Peru and Ecuador based on historical research and the present study. This table compares SFSM values and illustrates regional and temporal variation in maturation size parameters for both sexes.

SFSM (cm)					
Investigation	Females	Males	Years	Locality	Country
IMARPE (1991)	55	50		Paita	Peru
Vera (2006)	57.3		2004-2006	Tumbes	
Chicaiza (2005)	62.0	75.0	2004-2005	Facing the Gulf of Guayaquil, Puerto López and the Esmeraldas zone	Ecuador
Chicaiza (2013)	63.7	65.3	2012	South central zone of the Guayaquil Gulf	
This study	56.7	63.2	2013-2014	Gulf of Guayaquil	

strategy. Variations in K during reproductive peaks, attributed to the gonadal cycle, are characteristic of tropical species with continuous reproduction. The consistency of K reinforces its value as an indicator of trophic availability and population health, essential elements for fisheries management and ecosystem sustainability in the region.

The regional comparison of SFSM (L_{50}) for *O. remiger* highlights how fishing pressure affects this species' reproductive biology. In Ecuador, L_{50} values reach up to 75 cm in some areas (Chicaiza 2005), while in Paita, Peru, L_{50} values are smaller, with females maturing at 55 cm and males at 50 cm (IMARPE 1991) (Table 2). The analysis of L_{50} in *O. remiger* from the Gulf of Guayaquil revealed median lengths at sexual maturity of 56.7 cm for females and 63.2 cm for males, determined through cumulative frequency and gonadal state analyses (Fig. 11). Compared to other regions with higher fishing pressure, such as Peru, where L_{50} has been estimated at 74 cm, the lower L_{50} observed in the Gulf of Guayaquil suggests regional variability likely influenced by environmental factors and fishing intensity (IMARPE 1991). Temporal analysis in Ecuador indicates a decreasing trend in SFSM for both sexes, whereas in Peru, an increase in female SFSM over time is observed. The earlier maturation observed in females relative to males may reflect an adaptive response to fishing pressure, reducing the size at sexual maturity. This pattern aligns with findings in other overexploited demersal species, where fishing pressure selects for early-maturing individuals (De Roos et al. 2006). The size at which all females would be actively participating in reproduction (L_{100}) is estimated at 63 cm, while for males it is approximately 75 cm. Vera (2006) reported similar values, with an L_{100} of 67 cm for females in a study conducted in Tumbes, Peru.

The analysis of capture and recruitment dynamics for *O. remiger* highlights the need to regulate fishing effort, especially during peak recruitment periods, to prevent overexploitation. This species, characterized by slow growth and late sexual maturity, underscores the need for conservation policies grounded in long-term data that can assess trends in population structure and the impacts of fishing. Establishing continuous monitoring programs of at least five years is recommended to gather sufficient data to adjust capture regulations according to observed changes. Implementing management measures to protect juveniles and reduce recruit mortality is essential to ensure effective recruitment into the reproductive segment of the population. Such strategies should include regulations that limit capture by size and sex, thereby protecting reproductive individuals and supporting long-term population recovery.

To further support sustainable management, genetic studies are advised to identify variations in population structure, while capture-recapture studies would help estimate mobility and dispersal. Together, these analyses would provide a robust basis for a fisheries management approach that considers genetic and demographic variability (Kodeeswaran et al. 2024), thus contributing to the conservation of *O. remiger* across its distribution range. These distribution and behavior patterns emphasize the need for sector-specific management measures to protect juveniles and reduce recruit mortality, ensuring adequate recruitment and population sustainability.

In conclusion, this study provides a solid scientific foundation for developing management strategies that promote the sustainability of *O. remiger* in the Gulf of Guayaquil. Based on the estimated size at 50% sexual maturity (L_{50}), minimum capture sizes of approximately 57 cm TL for females and 63 cm TL for males are recommended as biologically based reference points for fisheries management. Implementing these minimum capture sizes, along with seasonal fishing

closures during the main reproductive pulses identified in October and April, and continued monitoring of population structure, sex ratios, and reproductive dynamics, would support the conservation and sustainable management of this commercially valuable species. These findings not only guide local management but also support regional fisheries policies that secure *O. remiger*'s sustainability amid growing fishing pressure in the southeastern Pacific.

These biological reference points may also inform periodic evaluations of Ecuador's fisheries management regulations, particularly in the context of the temporary suspension of seasonal closures during 2026 and the associated requirements for continued biological and fishery monitoring.

Credit author contribution

D. Chicaiza: conceptualization, validation, methodology, formal Analysis, project administration, investigation, writing-original draft, review and editing; H. Flores: conceptualization, validation, methodology, formal Analysis, review and editing; U. Avendaño & M. Montúfar-Romero: methodology, validation, writing, review and editing; R. Gozzer-Wuest: funding acquisition, project administration, supervision, review and editing. All authors have read and accepted the published version of the manuscript.

Competing interests

The authors declare no competing interests.

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Ethics / legal compliance

The authors declare that they did not violate or omit any ethical or legal standards in conducting this research.

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