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Reproductive Biology of *Uca tangeri* (Eydoux, 1835) in the Saloum Delta National Park (Senegal): Sex Ratio, Sexual Maturity, and Fecundity

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Abstract

The study of the reproductive biology of *Uca tangeri* was carried out in the Parc National du Delta du Saloum (PNDS), Senegal. A total of 2160 individuals were sampled between August 2023 and July 2024 at the Bakadadji, Missirah and Bettenty stations. The overall sex ratio (M:F = 1.21:1) was found to be significantly different from parity ($\chi^2 = 10.141$, $P < 0.05$), with males dominating at most stations. Size at first sexual maturity (CW50) was estimated at 13.3 mm carapace width in males and 10.7 mm in females, with a very high correlation (0.89 to 1). The fecundity of ovigerous females ranged from 8100 to 28,076 eggs, with an average of 21,655 ± 15,317 eggs for an average perimeter of 0.753 ± 0.087, an area of 0.040 ± 0.008 and an average diameter of 0.247 ± 0.028. All these parameters have provided the information needed to understand the biology of *Uca tangeri* and manage it sustainably.

Keywords

Uca tangeri, Reproduction, Sex Ratio, Sexual Maturity, Fecundity, Saloum Delta

1. Introduction

Uca tangeri is a species of decapod crustacean belonging to the Ocypodidae family. These fiddler crabs are characterized by their sexually dimorphic claws; the main claw of males is much larger than the minor claw, while in females, both claws are the same size [1]. *U. tangeri* leads a semi-terrestrial existence in the intertidal zone, very often in muddy areas, more or less far from the water's edge and in mangroves. Fiddler crabs play a major ecological role in intertidal ecosystems, contributing to bioturbation, the recycling of organic matter, and the maintenance of mangrove productivity [2]-[6]. Among them, *U. tangeri* (Eydoux, 1835) is the only representative of the genus on the Atlantic coasts of West Africa and Europe and is a bioindicator species for the quality of coastal habitats [7].

The Saloum Delta National Park is located in western Senegal, in the coastal area north of Gambia, and occupies a large part of the Sine-Saloum Delta. It has a wide variety of ecosystems, such as mangroves dominated by mangrove trees, wooded Sudanese savannas, sandy coastlines, forests, lagoons, and islands. The park is an exceptionally rich natural refuge, listed as a UNESCO World Heritage Site since 2011, classified as a biosphere reserve since 1980, and a Ramsar site since 1984. This natural treasure is currently exposed to growing anthropogenic pressures (overfishing, mangrove deforestation, and salinization). In this context, studying the reproductive parameters of *U. tangeri* is essential to understanding its population dynamics and proposing sustainable conservation measures.

The present study aims first to determine the sex ratio of the *U. tangeri* population in the Saloum Delta, then to estimate the size at first sexual maturity (CW_{50}) in both sexes, and finally to analyze the fecundity of ovigerous females.

2. Materials and Methods

2.1. Study Area

Monthly sampling from August 2023 to July 2024 was carried out during low tide in the mangrove ecosystems of the PNDS located in the Fatick region of Senegal (between 13˚35 and 14˚15 North Latitude and 16˚03 and 16˚50 Longitude) (**Figure 1**). Three villages were selected for this study: Bakadadji, Missirah, and Bettenty (**Figure 1**), chosen for their proximity to mangrove ecosystems and the fact that almost all of the local populations depend on these environments for their socioeconomic activities. The villages of Missirah and Bettenty are subject to significant anthropogenic pressure on the mangroves, mainly due to overfishing, logging, and domestic waste disposal, making them particularly interesting areas for assessing the impact of these disturbances on *Uca tangeri* populations. Conversely, Bakadadji is located in a less disturbed area, closer to the heart of the Saloum Delta National Park (PNDS), and thus serves as an ecological reference site. In each village, two stations were selected based on (i) the likelihood of exposure to human activities and (ii) their geographical location, which allowed us to capture spatial variability representative of the anthropization gradient observed between the periphery of the protected area and more natural areas.

The physicochemical parameters of interstitial water in burrows vary slightly between sites. Average temperatures range from 29.59˚C in Bakadadji to 32˚C in Bettenty, with a pH that remains generally neutral (6.87 - 7.23). Electrical conductivity is higher in Missirah (88.01 mS/cm) and Bettenty (76.71 mS/cm) than in Bakadadji (59.06 mS/cm), with much higher salinity (30.41 psu). Dissolved

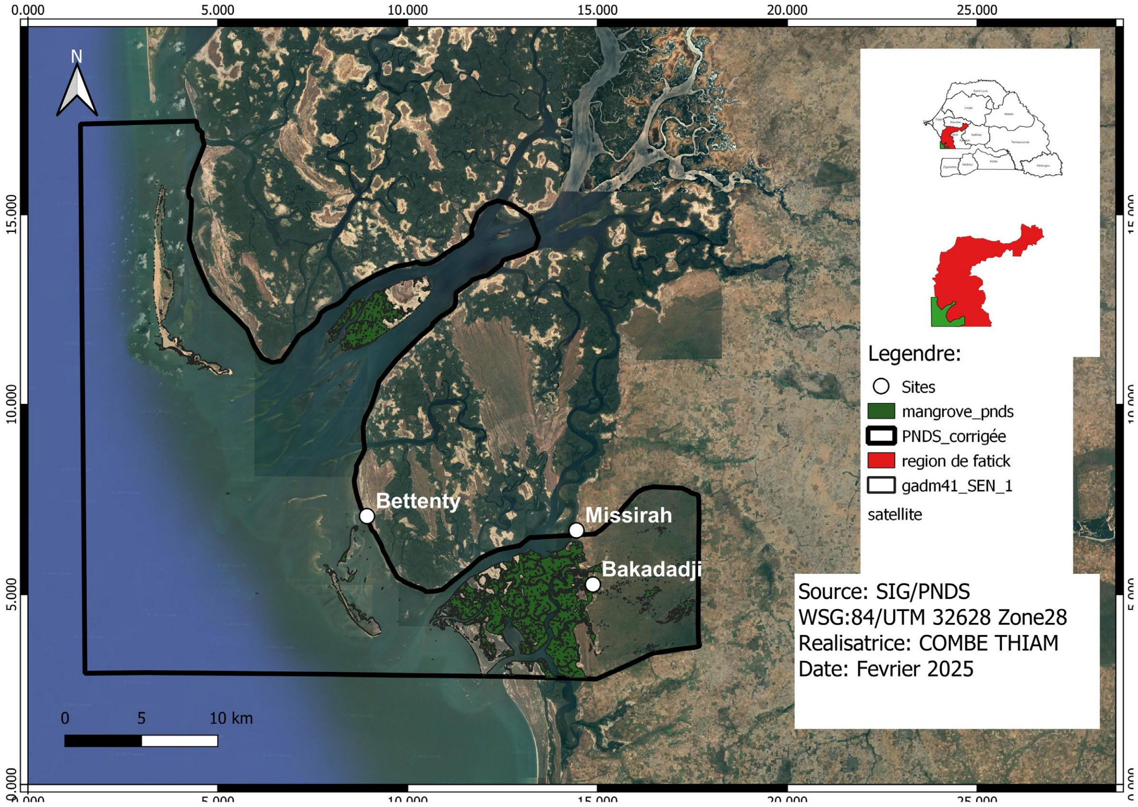

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Figure 1. The PNDS map showing collection sites (Bakadadji, Missirah, and Bettenty).

oxygen concentrations remain low throughout the park (0.89 - 1.95 mg/L), with the lowest values recorded at Bettenty.

2.2. Methodology

Specimens were collected on foot along the riverbank and were generally captured by hand in their burrows at low tide. The individuals collected were immediately placed in a 500 ml bottle containing formaldehyde at 10˚C for 24 hours, then transferred to a bottle of 70˚ alcohol for preservation and transport. In the laboratory, the following parameters were recorded using a 0.02 mm precision caliper and a 0.01 g precision scale: carapace width (CW), abdomen width (AW), weight (P), claw weight (Pp), gonad weight (Pg), and hepatopancreas weight (Phs). The maturity stages of the gonads were then determined on the basis of macroscopic characteristics. It should be noted that each abdomen of an ovigerous female was removed and stored in 70% alcohol.

Sex ratio

The sex ratio is the ratio of males to females in a given population. It is expressed as a percentage:

$$\text{Masculinity rate} = \frac{M}{M+F} \times 100$$

where M: number of males;

F: number of females.

Variations in these rates were analyzed based on the number of samples of each sex collected each month within each size group.

In order to determine the distribution of males and females compared to the expected 1:1 ratio, the sex ratio values obtained were subjected to statistical analysis using a chi-square goodness-of-fit test at a significance level of 5% ($P < 0.05$), the formula for which is as follows [8]:

$$x^2 = \sum \frac{(O-E)^2}{E}$$

where, O = observed = number of males in the sample and E = expected = number of males theoretically expected when the ratio is 1:1.

Criteria for classifying stages of gonadal maturity

We based our study on the models described by [9]-[12] on ocypodidea decapods to provide a more accurate description of the evolution of gonadal maturation in *Uca tangeri*. It is divided into six stages in females and five in males, based on color, texture, size, and gonad/hepatopancreas ratio (**Table 1**).

Table 1. Gonadal maturity scale for *Uca tangeri*.

Stage	**Description in males**	**Description in females**	**Gonads/ Hepatopancreas ratio**
IM—Immature	Testicles and vas deferens not visible; juvenile morphology	Thin, translucent, undifferentiated ovaries	—
RU—Rudimentary	Filiform testicles, slightly visible, pale yellow to colorless	Filamentous ovaries, thin, colorless to whitish.	—
ED—Developing	Visible testicles, white, occupying a small part of the cavity; vas deferens beginning to coil (translucent)	Small, H-shaped ovaries, light yellow in color	≈1:4 (♂); 1:8 - 1:10 (♀)
DE—Developed	Convoluted, developed testes, milky white to pinkish; vessels differentiated into three parts.	Large, lobed, bright orange ovaries occupying half of the cavity	≈1:2 (♂ et ♀)
AD—Advanced	Very large gonads, well-coiled vas deferens	Lobed ovaries, very large, dark orange with ovules visible to the naked eye	≈9:10
SP—Spent/Repos	Reduced, flaccid testicles	Thin, flaccid, orange ovaries, sometimes H-shaped	≈1:10

Gonadosomatic index (GSI)

To describe the reproductive cycle and determine the egg-laying period of *U. tangeri*, the gonadosomatic index (GSI) was calculated and its periodic variations were analyzed [13] [14]. Variations in the GSI reflect changes in gonadal weight over the course of the year.

$$\text{GSI} = \frac{\text{Pg}}{\text{PT}} \times 100$$

where PG: fresh weight of ovaries or testes (g) PT: total wet weight of the animal (g).

The gonado-hepatopancreas ratio (GHR) was calculated by expressing the weight of the gonads in relation to the weight of the hepatopancreas. This allows the stage of gonadal maturity to be determined.

$$\text{GHR} = \frac{\text{Pg}}{\text{Php}}$$

The average GSI was compared between sexes and stations using the non-parametric Wilcoxon and Kruskal-Wallis tests because the data do not follow a normal distribution.

Size at first sexual maturity (CW_{50})

The size at first sexual maturity is assessed based on the width at which 50% of specimens are mature according to the different stages of gonadal development. The CW_{50} size was determined using a logistic function that relates the proportions of mature individuals to the width of the crab [15]. This function is in the form:

$$P = \frac{1}{1 + e^{-r(\text{CW} - \text{CW}_{50})}}$$

where *P*: proportion of mature individuals; CW: crab width; CW $_{50}$: width at which 50% of individuals are mature; *r*: constant of the equation (or determination of the slope of the curve).

The adequacy of the model was assessed using the coefficient of determination (R^2) and the significance test ($p < 0.05$). The relative frequency of adults (%) and the result of the logistic equation for each size class were obtained and plotted in graphs.

This approach is commonly used in the study of the reproductive biology of crustaceans, particularly in fiddler crabs [11] [16]-[18].

Fecundity

The pleopods were placed in Petri dishes filled with seawater and the eggs were detached by gradually adding a 2.4% sodium hypochlorite (NaClO) solution. The egg-free pleopods were then separated by gently shaking them in a beaker filled with 250 ml of seawater. Finally, three 1.5 ml subsamples were taken using a pipette and the eggs were counted using a manual counter under a stereomicroscope. The average value obtained was then extrapolated for the entire suspension to estimate the total number of eggs [17] [19]-[21].

In order to determine the dimensions of the *U. tangeri* eggs, images were digitized using LAZ-EZ software, taking 5 images per egg mass from each individual. The diameter, perimeter, and surface area of each oocyte were measured automatically (using a macro) using Image J software. The first step was to adjust the original image, then binarize it to customize the objects in the image (eggs). Next, a series of erosion and dilation functions was used to separate the objects and eliminate artifacts.

2.3. Data Analysis

The data were analyzed using Microsoft Office Excel 2013 and Rstudio software.

3. Results

- Sex ratio

A total of 2,160 specimens were collected at the PNDS at three sites over a 12-month period from August 2023 to July 2024. Of these, 1197 (55.42%) were male and 963 (44.58%) were female. The sex ratio of 1.21:1 ($\chi^2 = 10.141$, df = 1, p-value = 0.001 < 0.05) is very significantly different from 1:1, showing a predominance of males in the sample. Analysis of the sex ratio of the *Uca tangeri* population according to size classes reveals extreme classes, particularly those between 7.2 - 10.2 mm and 31.2 - 35.7 mm, which are composed exclusively of males, while the 10.2 - 11.7 mm interval contains only females. Beyond these classes, between 11.7 and 31.2 mm, both sexes coexist, with a sex ratio slightly favoring males (1.07:1) (**Figure 2**).

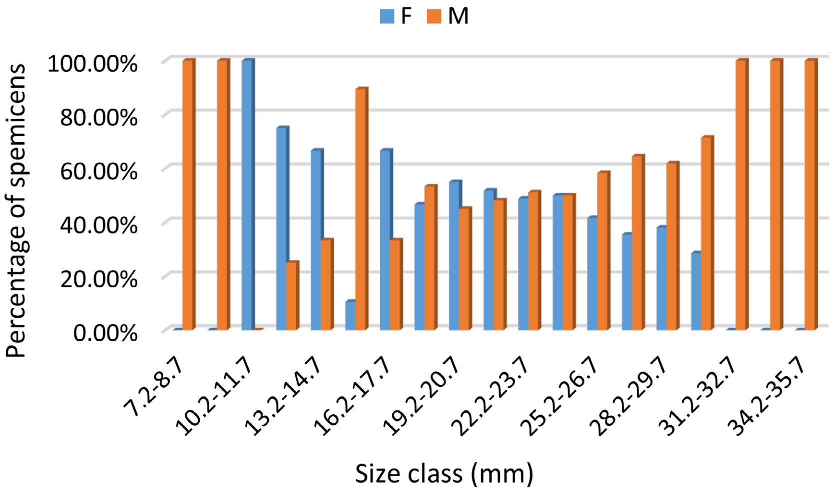


Figure 2. Sex ratio of the *U. tangeri* population by size class.

The variation in the sex ratio of *U. tangeri* according to the month shows a high male-to-female ratio at all three sites. Bakadadji shows a marked dominance of males throughout most of the year (1.30:1), except in September, when there is a strong dominance of females (1:8). Missirah shows a fairly balanced annual fluctuation in sex ratio of 1.05:1, with a slight excess of males in November (ratio of 4) and females in July (ratio of 2.06). At Bettenty, a constant male predominance was observed throughout the year (average sex ratio of 1.1:1). This dominance peaks in August and March with ratios of 4:1 and 6:1 in favor of males, respectively. However, a reversal in the sex ratio is noted in June and July, when females are proportionally more numerous with ratios of 1:1.4 and 1:1.2 (**Table 2**).

- Gonadosomatic index (GSI)

The average gonad/hepatopancreas ratio (GHR) in *U. tangeri* was calculated based on gonads whose maturity levels ranged from developmental stages (stage 3). This ratio allows us to label the gonads at a stage of maturity. These data show us that there is a direct relationship between the volume occupied by the gonads and the hepatopancreas. In females, as the gonads develop, the size of the hepatopancreas decreases, hence the variation in proportions at different stages (Table 3). In contrast, the variation in the average GHP ratio in male *U. tangeri* is very small between stages (1/4).

Table 2. Variation in the sex ratio of *Uca tangeri* according to month at the three sites.

Month	**Sex ratio = Number of males: Number of females**		
	Bakadadji	**Missirah**	**Bettenty**
August 23	2.25:1	1:1	4:1
September	1:8	1:1	1.04:1
October	1.1:1	1:1	1.1:1
November	2:1	4:1	1:1
December	1.23:1	1.29:1	1.06:1
January 24	1.15:1	1:1	1.2:1
February	1.8:1	1:1	1.4:1
March	1.5:1	1:1	6:1
April	1:1	1.05:1	1:1
May	1:2.29	1.63:1	1:1.02
June	1.13:1	1.5:1	1:1.4
July	1:1.29	1:2.06	1:1.2
Total	1.30:1	1.05:1	1.1:1

Table 3. Average gonad/hepatopancreas ratio (GHR) in males M and females F according to gonadal maturity stages (GMS).

GMS	**GHR**	
	F	**M**
Developing (3)	2/10	1/4
Developed (4)	7/10	1/4
Advanced (5)	25/10	1/4
Spend (6)	3/10	

The monthly evolution of the GSI and the frequency of gonadal maturity across all sites shows that, overall, the species *Uca tangeri* is very active in reproduction, with mature individuals found throughout the year in varying proportions. The GSI highlights significant differences between sexes and seasons in *Uca tangeri*. The average GSI in females (2.26) differs significantly (W = 46607, $P < 0.05$) from that in males (0.46). The SGR of females is higher in the warm season (2.36) than in the cold season (1.92) (W = 27021, $P < 0.05$). In contrast, seasonal variations in SGR are not very pronounced in males (0.37 to 0.50) (Table 4).

In females, the GSI curve shows two phases separated by months (February, October, and November) with the lowest GSI values of 0.08, 0.75, and 0.74, respectively. The first phase extends from March to September and peaks in July with an GSI of 2.53, while the second phase covers December and January with a maximum level of 2.35. In males, the variation is low throughout the year, with an oscillation of 0.19 in November and 0.59 in June, which corresponds to the peak (**Figure 3** and **Figure 4**).

Table 4. Comparison of GSI by sex according to season (Sc = warm season, Sf = cold season, F = female, M = male).

Sex	Seasons	GSI	P-value
F	Sc	2.36	8.95e−30
M	Sc	0.50	
F	Sf	1.92	3.22e−8
M	Sf	0.37	

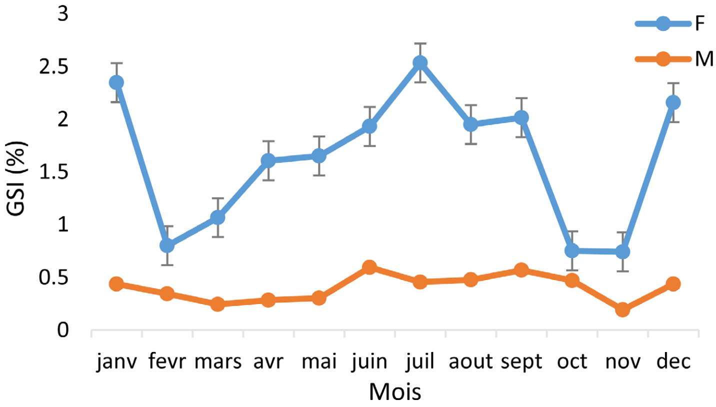


Figure 3. Monthly change in GSI in *Uca tangeri*.

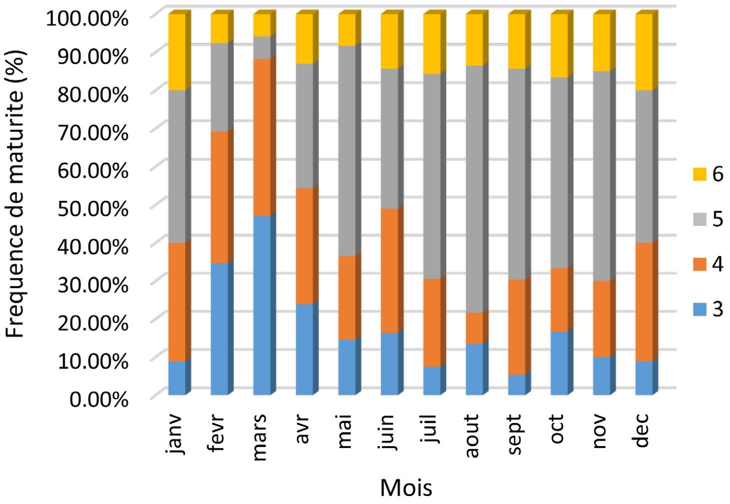


Figure 4. Gonad maturity frequency by month.

The seasonal variation in the gonadosomatic index (GSI) in *Uca tangeri* indicates two reproductive cycles in Bakadadji: in females, the first cycle runs from November to January and peaks in January with a value of 2.63, followed by a marked decline in February with a GSI of 0.32. The second cycle is marked by a gradual increase from March to July, reaching a peak in August with an GSR of 3.04, followed by a slight decline in September, which is even more pronounced in October (1.75) (**Figure 5(a)**). In Missirah, the GSI of females is relatively low compared to other sites and shows continuous reproductive activity throughout the period, but marked by a peak in July (2.01) followed by a gradual decline until September (0.88) (**Figure 5(b)**). In Bettenty, the monthly evolution of the GSI highlights two reproductive periods, as in the other sites. In females, the first period extends from April to October and reaches its maximum level from July to September with an GSI of approximately 3.27. The second period increases gradually from November to December and peaks in January (2.35), followed by a marked decline until March (1.12), which is the reproductive rest period (**Figure 5(c)**). At all sites, the seasonal variation in GSI in males is low and stable between 0.14 and 0.69.

The average GSI in females (Bettenty = 3.01, Bakadadji = 2.17, and Missirah = 1.73) differs significantly between stations ($K^2 = 12.91$, $df = 2$, $P < 0.05$) (**Figure 6**). The populations of Bettenty have a different GSI than those of Bakadadji ($P <$

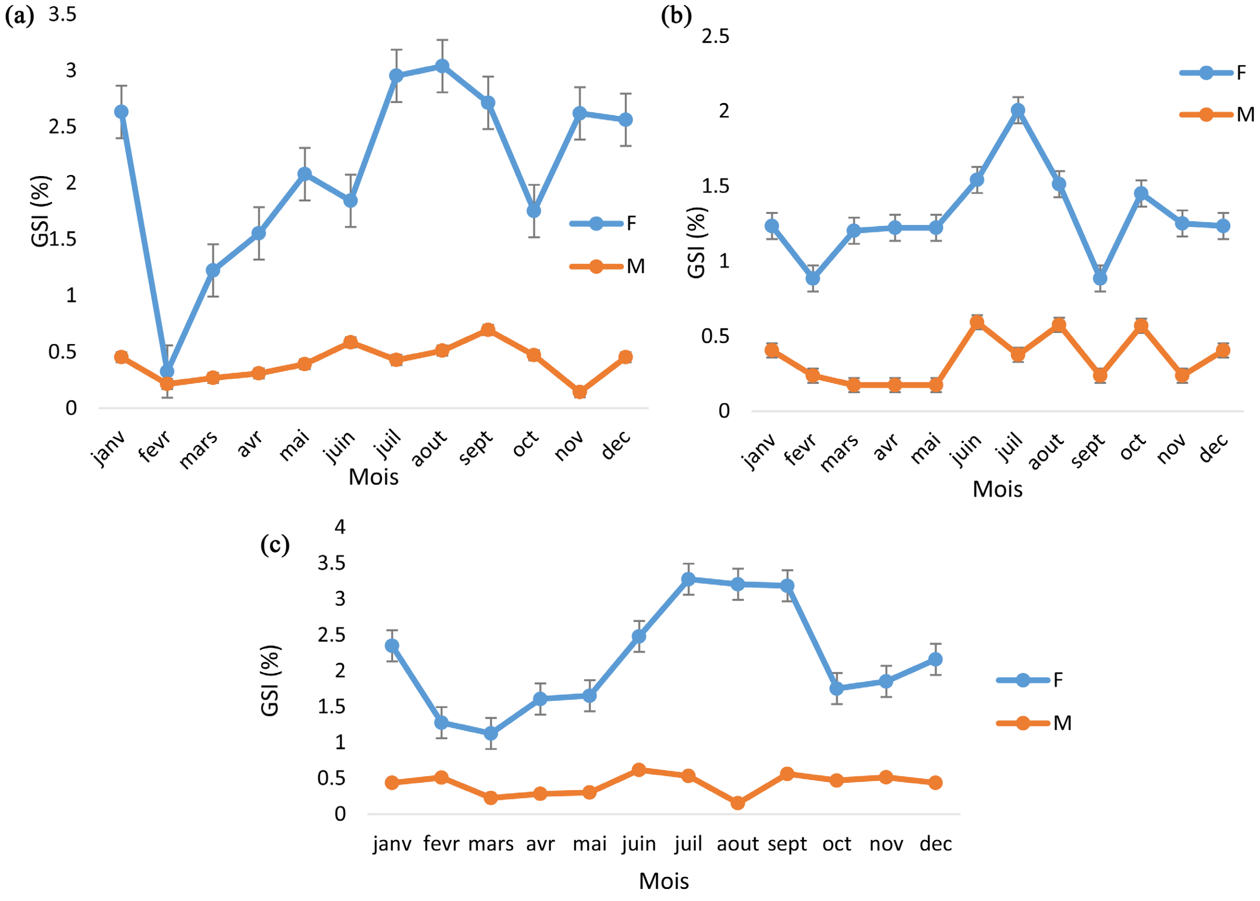


Figure 5. Monthly change in GSI in *Uca tangeri* according to sites: (a) Bakadadji; (b) Missirrah; (c) Bettenty.

0.05) and Missirah ($P < 0.05$), while there is no difference between Bakadadji and Missirah ($P > 0.05$) according to the post-hoc test (Wilcoxon pairwise, Bonferroni) (**Figure 6**).

Table 5. Comparaisons post-hoc (Wilcoxon pairwise, Bonferroni).

	Bakadadji	Bettenty
Bettenty	0.04405	-
Missirah	1.00000	0.00069

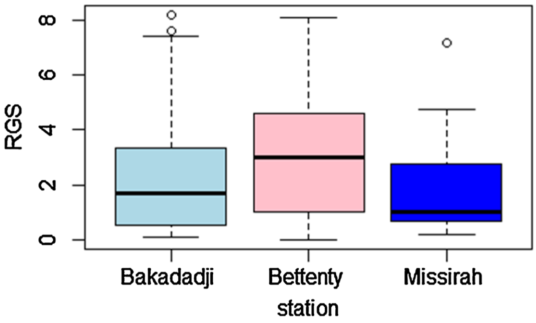


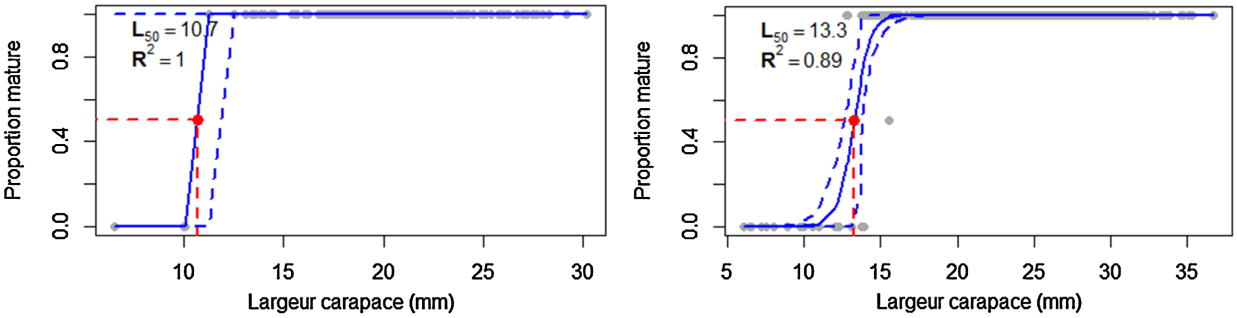
Figure 6. Boxplot of GSI comparisons between females at different stations.

- Size at first sexual maturity (CW_{50})

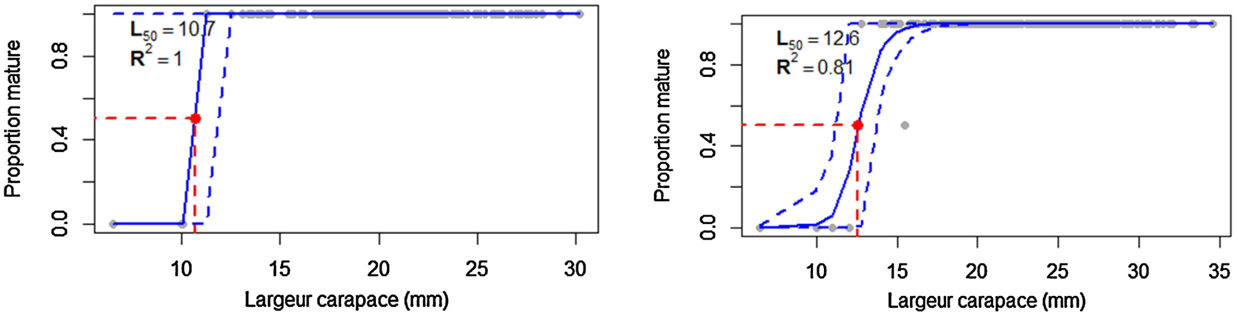
The percentage of sexual maturity was calculated for individuals whose developmental stages began at 3. The sizes at first sexual maturity for *Uca tangeri* were 13.3 mm for males and 10.7 mm for females, with very strong correlation coefficients (0.89 to 1) (**Figure 7(aa')**). Across all sites, female *Uca tangeri* reach sexual maturity at a smaller size than males ($t = -6.904$, $P < 0.05$). In Bakadadji, the sizes at first sexual maturity (CW_{50}) for females and males are 10.7 mm and 12.6 mm, respectively (**Figure 7(bb')**). In the Bettenty samples, the size at first sexual maturity in males is identical to that in Bakadadji (12.6 mm), while that of females is 11.2 mm (**Figure 7(dd')**), which is close to that of females in the Misssirah population (11.1 mm), associated with males whose CW_{50} (13.7 mm) (**Figure 7(cc')**) is higher than at other sites, with a very strong correlation $R^2 = 1$.

- Fecundity

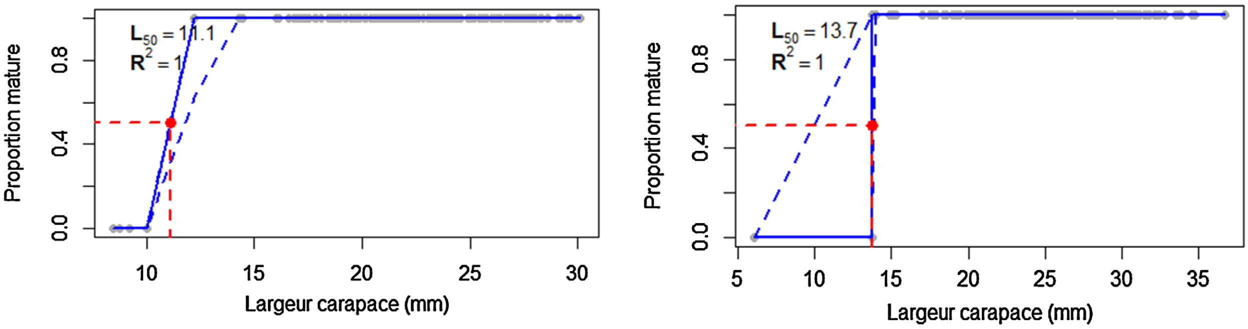
Fecundity was estimated on 30 ovigerous females ranging in size from 15.56 to 29.2 mm (CW) carrying 8,100 and 28,076 eggs on their pleopods, respectively. The number of eggs ranged from 4937 (CW = 17.34) to 77,867 (CW = 24.16). The average fecundity of the eggs was 21,655 ± 15,317 eggs for an average perimeter of 0.753 ± 0.087, an area of 0.040 ± 0.008, and an average diameter of 0.247 ± 0.028. The fecundity of *Uca tangeri* shows marked spatial variation between the three stations studied, although this is not statistically significant ($K^2 = 1.3382$, $P > 0.05$). Missirah stands out with the highest fecundity values (mean = 29,275 and median = 23,184), followed by Bettenty (mean = 24,948 and median = 16,750), while Bakadadji has the lowest values (mean = 19,007 and median = 15,973) (**Figure 8**).



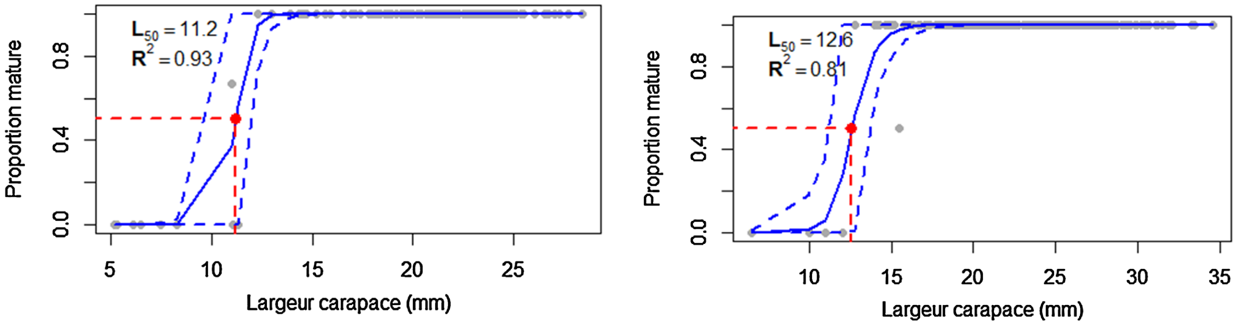
(a) All sites combined: females (a') All sites combined: males



(b) Bakadadji: females (b') Bakadadji: males



(c) Missirah: females (c') Missirah: males



(d) Bettenty: females (d') Bettenty: males

Figure 7. Size at first sexual maturity in *Uca tangeri*.

As the conditions for using a parametric analysis were not met, the Kruskal-Wallis test (non-parametric) was used to compare fecundity between the three stations. Fecundity is not significantly different between Bakadadji, Missirah, and Bettenty ($K^2 = 1.01$; $P = 0.51$). The same result was obtained when comparing the average surface area between stations ($K^2 = 0.412$; $P = 0.82$). With regard to the average diameter and perimeter, as the conditions for using a parametric analysis were met, the variance test (Anova) was used. This showed that there was no significant difference between the average diameter and perimeter of eggs laid by *U. tangeri* at the three stations ($F = 0.36$; $P = 0.70$) (Table 6).

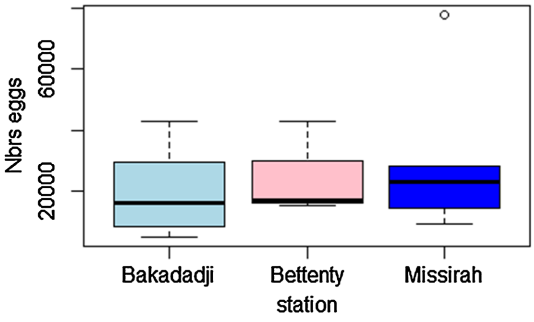


Figure 8. Fecundity by station.

Table 6. Comparison of the fecundity parameters of *U. tangeri* at the three stations (Bakadadji, Missirah, and Bettenty); Mean = mean; SD = standard deviation; Area = surface area; Perim = perimeter; Diam = diameter; K^2 = Kruskal-Wallis test (non-parametric); F = ANOVA test (parametric) and P = P-value.

Parametres	Bakadadji		Missirah		Bettenty		Test		
	Moy	Sd	Moy	Sd	Moy	Sd	K^2	F	P
Fecondite (nbr eggs)	19,007	11,659	29,275	24,820	24,948	15,545	1.338		0.51
Area (mm^2)	0.043	0.0063	0.042	0.007	0.038	0.007	0.412		0.82
Perim (mm)	0.779	0.066	0.774	0.061	0.739	0.070		0.36	0.70
Diam (mm)	0.248	0.019	0.253	0.019	0.242	0.022		0.3	0.74

4. Discussion

The sex ratio of *Uca tangeri* shows a very significant predominance of males (1.21:1) over females in the PNDS. This trend is consistent with several observations made on other populations of *Uca tangeri* in West Africa. Studies conducted in the Mbo River in Nigeria revealed a sex ratio of 1.2:1 in favor of males [16], while studies conducted in the mangroves of the Bonny River reported varying ratios depending on the site, ranging from 4:1 at Eagle Island to 1:2.6 at Rumuolumeni [17]. Similarly, in the mangroves of Lagos, males outnumbered females with a ratio of 1:0.6 [18]. These results confirm that the numerical preponderance of males is a recurring trend within *Uca tangeri* populations, probably influenced by their morphology, which makes them more visible, and their reproductive behavior, which makes them more active and more exposed, particularly during courtship. On the other hand, females lay eggs and incubate them in their burrows for a period of time, making them less visible, which can lead to sampling bias. The gender imbalance could be explained by a high mortality rate among females, which is about 20% higher than among males [22]. According to [23] [24], predation is the most significant cause of mortality among fiddler crabs in the Caeté estuary (Brazil), and males are more likely to escape predators by shedding their large claws when attacked [25] [26]. The energy constraints associated with reproduction may contribute to the high mortality rate among female *Uca tangeri* [24].

Sexual variation according to size class can be explained by several biological and ecological factors. Male dominance in smaller size classes could reflect differential recruitment or faster growth in males during the early post-larval stages. At the other extreme, the exclusive presence of males in the larger sizes (>31.2 mm) could indicate longevity or correlate with previous observations in fiddler crabs, which show that males of the genus *Uca* can reach sizes larger than females, probably related to sexual selection and the growth of the major claw, used in competition and courtship [7] [24] [27]. As for the exclusively female class 10.2 - 11.7 mm, it could correspond to a key physiological stage, perhaps linked to the first sexual maturity in females, or a phase in which they become temporarily more accessible for sampling due to particular behavior (migration to the surface, increased activity, etc.). In the intermediate range (11.7 - 31.2 mm), both sexes coexist with a sex ratio slightly favoring males (1.07:1), which is probably explained by a combination of several ecological and behavioral factors [24] [27]. In addition, higher post-reproductive mortality among females, particularly ovogous females, could explain their lower representation in the upper classes [28].

The monthly distribution of sexes between sites favors males at all three sites. At Bakadadji, the only peak in females occurred in September, with a ratio of 1:8. This could be linked to a reproductive phenomenon. According to our results, September is part of the intense breeding season for *Uca tangeri*. The sex ratio in Missirah is fairly stable, which may be linked to more consistent ecological conditions. The sex ratio in Bettenty is dominated by males almost all year round, with peaks in August and March of 4 and 6. These results can be explained by the territorial behavior of males, who remain on the surface to defend burrows or attract females [27]. This reversal of the ratio by females (1.4 and 1.2) in June and July could be linked, on the one hand, to migratory movements associated with reproduction, where females travel to areas more favorable for egg-laying [29], thus making them more accessible for sampling. On the other hand, their morphology makes them easier to capture.

The gonad/hepatopancreas ratio (GHR) is a key indicator of reproductive biology in crustaceans. It allows the distribution of energy resources within the organism to be assessed. An increase in this ratio suggests an active reproductive phase, while a decrease may indicate a resting phase or physiological stress. Although this study was conducted on closely related species, the conclusions could be applied to *Uca tangeri* due to physiological similarities. In our study, the high GSI observed at the advanced ovarian maturation stage (25/10) indicates a high mobilization of energy towards reproduction. This result is consistent with the observations of [26] on *Uca tangeri*, whose average ovarian weight (1.07 g) and gonadosomatic ratio (GSI = 6.2) clearly exceed liver weight. Similar trends have been reported by [27] in *Uca rapax*, with an RGH of 9/10 at the advanced stage, as well as by [28] in *Callinectes danae* (Decapoda, Portunidae) in the Ubatuba region (Brazil). The increase in RGH could be explained by the fact that during the reproductive period, the largest proportion of energy is allocated to gonadal development, accompanied by a gradual reduction in hepatopancreatic tissue. Conversely, the low RGH (during development and at rest) of 2/10 may indicate low energy storage at the beginning of the gonadal maturation period (reproduction) and after spawning. The information provided by these authors [10] on *U. rapax* and [11] on *Callinectes Danae* correlates with our results at respective GHRs of 1/10 and 1/8, which are slightly lower. In males, the RGH is low and constant throughout the different stages of development. However, the study by [11] on *Callinectes Danae* differs from our results, with RGHs that increased from ¼ in the developing stage to 1/2 in the developed stage. This variation in the RGH ratio may be difficult to explain because no exact data on the same species of *Uca* has been found. It could also be due to a low energy requirement during the development of male gonads.

The evolution of RGS and gonadal maturity frequency show that female *Uca tangeri* have continuous reproductive activity, but with seasonal peaks during the warm season (June to September) and sometimes during the cold months (December to January), depending on the location. Our results are comparable to those reported by authors [30] [31], who described, in a manner similar to our data, that reproduction in tropical fiddler crabs is very common and continuous. The main spawning peaks occur during the summer and subsequently decline in winter. However, they are not in line with the work of [32] in Spain, which states that female *Uca tangeri* only reach their peak gonadal development during the period from May to July with an GSI > 2, which is not entirely outside our spectrum in the warm season. The differences suggest that environmental factors (temperature, photoperiod, tides, etc.) probably influence reproduction, which may be crucial for the management and conservation of these populations. In contrast [33], who studied *Uca longisignalis* and *Uca spinicarpa* in the Gulf of Mexico, observed that females of *U. spinicarpa* reached their maximum ovarian development in winter, with a longer period lasting until February (sup 0.08) and also in summer (June-July) with a much lower amplitude (GSI < 0.04), which is partly similar to our results, whereas the data on *Uca longisignalis* are the opposite of our results. The gonadal development pattern in female *U. inversa* during the study period of [17] shows continuous reproduction with a lower GSI in June and September, while gonadal development peaks in January, July, and December. Contrary to our study, according to the interpretations of [34], the reproduction of *U. lactea* is seasonal and extends from June to August, with a peak in July. [35] reported that ovigerous females of *Uca uruguayensis* were found from May to August. [36] studied the monthly variation in the gonadal index of *U. annulipes* on the southwestern coast of India. It was high during the months of July to March, with a peak in December (GSI = 5.51). Some authors have studied the periodicity of reproduction in a species based on the frequency of ovigerous females encountered during the year. This is the case of [37], who studied the reproductive cycles of four species of Uca crabs in a mangrove estuary in South Africa. According to this study, the percentage of ovigerous females was highest in March-April, with a single peak for *U. annulipes*, *Uca chlorophthalmus* reproduced steadily from December to April, while *Uca urvillei* experienced a prolonged summer reproduction peak from January to May, followed by a smaller peak from August to October. The breeding season for *U. hesperiae* began earlier, from October to November, and continued until April-May. Oviparous *Macrocephalus grandidieri* females were collected throughout the year. As pointed out in [12], the *Ocypode quadrata* population on the sandy beach of southeastern Brazil has seasonal reproductive activity from October to April. This high variability in the reproductive cycle from one species to another is certainly linked to intertidal zoning, latitude, temperature, and food availability.

The higher GSI in Bettenty than in Bakadadji and Missirah could indicate different ecological conditions (food, salinity, substrate, etc.), different population densities influencing reproductive pressures, and different reproductive strategies among populations.

The low and continuous GSI in male *Uca tangeri* indicates continuous gonadal maturation. The same phenomenon was found in male *U. annupiles*, whose GSI varies between 0.04 in May and 0.99 in July in the studies by [36]. Low GSI in males is quite common in certain crab species, which may be due to the fact that male gonads represent a small proportion of total body mass or simply lower energy expenditure in reproductive structures.

Separate studies of GSI in male Ocipodidae are virtually non-existent, and even less so for the species *Uca tangeri*.

Thus, size at first sexual maturity CW_{50} is influenced by sex. In our study, male *Uca tangeri* reach maturity later than females. This phenomenon appears to be observed in several crab species (*U. vocons*, *U. rapax*, *Callinectes ornatus*, *Callinectes danae*, *Neosarmatium meinerti*, *Macrophthalmus depressus*, *and Eurytium limosum*) by the authors [12] [38]-[43] in their work (**Table 6**). The difference in CW_{50} size between males and females could be explained, on the one hand, by the fact that during the breeding season, females devote more energy to gonadal development than to somatic growth and, on the other hand, by the fact that, in brachyuran crabs, males can be considered mature when they are able to carry females during pre-copulatory embrace and copulate successfully [44] [45], hence their larger size. According to [23] [46], in Ocipodidae crabs, larger males may have a better chance of obtaining females for copulation and winning more intraspecific fights.

Differences in environmental conditions (such as temperature and salinity) where *Uca tangeri* populations live are likely to result in different growth rates,

Table 6. Comparative table of gonadal CW_{50} for *Uca tangeri* and other species

Species	Tail.prem.mat.sexuelle:CW_{50}		Sites	References
	Females	Males		
U. tangeri	10.7	12.6	Bakadadji	This Study
	11.1	13.7	Missirah	This Study
	11.2	12.6	Bettenty	This Study
U. vocons	23.27	23.88	Mozambique	Litulo (2005)
U. rapax	12.1	14.8	Itamambuca (bresil)	Castiglioni & Negreiros-Fransozo, 2006
U. rapax	11.4	13.6	Ubatumirim	Castiglioni & Negreiros-Fransozo, 2006
Callinectes ornatus	32.6 40.43	38.5 43.95	Bresil	Mantelatto & Fransozo, 1996 Cardim *et al.*, 2022
Callinectes danae	57.29	60.41	Bresil	Cardim *et al.*, 2022
Neosarmatium meinerti	15.6	17.3	Mozambique	Litulo, 2005
Macrophthalmus depressus	13.4	13.6	Mozambique	Litulo *et al.*, 2005
Eurytium limosum	11.6	12.3	Bresil	Guimarães & Negreiros-Fransozo, 2002

which could lead to variations in the onset of sexual maturity. *Uca tangeri* crabs in Bakadadji reached maturity at a smaller size compared to those in Missirah and Bettenty. According to [46], various factors such as food supply, population density, competition, predation, or even subtle changes in the substrate can influence the size at first sexual maturity. Furthermore, fluctuations in these parameters can induce significant variations that outweigh latitudinal factors for certain species such as *Hemigrapsus oregonensis* and *Scyra acutifrons* (Dana, 1851). If a population lives in an environment rich in food resources, its individuals will likely grow faster than in a harsh environment. This variation can lead to differences in the size at which animals reach sexual maturity [47]. Other factors that can determine differential growth rates among crabs and, consequently, different sizes at sexual maturity are variations in molt growth or the number of molts to maturity [46].

Indeed, fecundity is specific to each species and varies considerably depending on latitude, habitat configuration, and food availability, according to [48] [49]. It can also differ between populations of the same species of fiddler crab living in sites with different environmental conditions at different latitudes. This is true even in the narrowest latitudinal gradients, suggesting that habitat interferes with brood size [50] [51]. Our results show that the ovigerous female of *U. tangeri* carrying the largest number of eggs (77,867 eggs) beats the record set by [32] (77,100 eggs with CW = 24 mm) in Cadiz, Spain, and far exceeds that of [50] (45,915 eggs with CW = 26 mm). On the other hand, we obtained a minimum number of eggs of 4937 produced by a female (CW = 17.34) compared to the work of [32] (9300 eggs with CW = 15 mm) and [50] (9442 eggs with CW = 18 mm). These differences in the number of eggs laid could be explained by the different environmental conditions (temperature, salinity, and food supply). The average fecundity estimated for *U. tangeri* (21,655 eggs) in our study is much higher than that estimated for other Uca genera in some previous studies [33] (nearly 20,000 eggs for *U. longisisgnalis* and 10,000 for *U. spinicarpa*); by [21] (1599 ± 842 eggs in *Uca annulipes* in the Costa do Sol Mangrove, Maputo Bay, southern Mozambique); by [51] (11,045.37 ± 565.7 eggs in *Uca vocan* in Saco da Inhaca, southern Mozambique); by [52] (8829 eggs in *U. thayeri* in the mangroves of Formoso Rio); by [53] (2009) (4984 ± 2493.8 eggs in *U. rapax* in the tropical coastal lagoon, southeastern Brazil) and [54] (1822 eggs in *U. annulipes* to 9667 eggs in *U. vocans* in the mangroves of Inhaca Island, Mozambique). Conversely, the fertility of *U. tangeri* is significantly lower than that of *U. rapax* (28,500 eggs) according to [55]. This reflects a variation in the number of eggs within a species (*U. tangeri*) and between other species, which could be a consequence of environmental conditions such as water temperature, salinity, habitat quality, or food availability, which induce growth in crab size, leading to fluctuations in fecundity.

The average diameter of *U. tangeri* eggs at PNDS is 0.247 ± 0.028 mm ≈ 0.25 mm, with a range of 0.213 to 0.278. These dimensions are close to those reported in [50], which stated that the average diameter of *U. tangeri* is 0.24, slightly lower than that in our study. Similar values have also been reported for *U. rapax* in southeastern Brazil [53] and in Florida-Portugal [56], where the average egg diameter is 0.24 ± 0.01 mm. Comparable similarities are observed in *Uca lactea* [57]; *U. longisignalis* [58]; *U. triangularis* and *annulipes* [50], suggesting that the average egg size in most species of the genus *Uca* is around 0.24 mm. However, differences can be noted in certain species that produce larger eggs, namely *Uca subcylindrica* with an average diameter of 1 mm [59], 1.06 ± 0.01 mm according to [58]; *Uca burgesi* (Dmoy = 0.36 mm) according to [60] [61]; and *Uca tetragonon* (Dmoy > 0.25 mm) according to [61] [62]. These differences in egg size depend on the species, but for the same species, they may depend on environmental conditions (temperature, salinity, and food availability) that can determine the physiological state of the female during reproduction. The egg diameter found at Missirah (0.253 ± 0.019) is the highest compared to the other sites. One hypothesis proposed in this study to explain the large size of the eggs, but not verified, is that the population of *U. tangeri* inhabiting this area consists of large individuals, as larger females tend to produce larger eggs.

Statistical analyses (Kruskal-Wallis and ANOVA) reveal that there are no significant differences in the measured parameters (fecundity, surface area, perimeter, diameter) of *Uca tangeri* between the three stations studied. These results corroborate those of [63], which states that the fertility data (surface area, perimeter, and diameter) of *Ethmalosa fimbriata* are statistically insignificant in Mbour and Joal. This suggests that the environmental conditions or other factors likely to influence these parameters are relatively homogeneous or that the natural variability within each station is such that the inter-station differences are not statistically significant.

Despite the rigor of the methodology, certain limitations should be mentioned.

Manual collection of individuals may introduce sampling bias, particularly because individuals smaller than 5 mm could not be included, and excavation of sediments for collection of individuals was not feasible in the mangrove ecosystem studied. Furthermore, macroscopic classification of gonads, although commonly used, is based on visual criteria that alone do not allow the exact stage of gonadal maturity to be determined with precision. Although these constraints limit the generalizability of the results, they nevertheless provide valuable basic information on *Uca tangeri*. Given the major ecological role of this species within mangrove ecosystems, further research, particularly focused on bioassessment, is essential to better characterize the health of these environments.

5. Conclusion

This article reports the initial findings in response to questions about the reproductive biology of *Uca tangeri* in West Africa, specifically in Senegal. The study highlights the sex ratio in favor of males, the stages of gonadal maturity, seasonal variation in the reproductive cycle, size at first sexual maturity, and the fecundity of the species. These results thus provide a baseline for long-term monitoring and the implementation of sustainable management strategies within the PNDS.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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