Faculty of Science

Size, sex and distribution of *Scylla serrata* on Inhaca Island, Mozambique

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Florentzson, (2008)

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Abstract

Inhaca Island is located of the coast of Africa, in Mozambique, and is considered a suitable place for marine research due to its big variety of pristine habitats. The large portunid crab *Scylla serrata* (Forsskål 1775) is a commercially important species in Mozambique and is abundant in estuaries and mangrove swamps regularly flooded by seawater, like in Saco Bay on Inhaca. The island became part of a reserve in 2008, but *S. serrata* are still being harvested from Saco Bay by the local community, who have reported experiencing a decline in both catch sizes and landings in the past few years. To estimate the current population structure of *S. serrata* on Inhaca, a fishing effort was made in Saco Bay to study size distribution, sex ratio and size at sexual maturity and compare the findings with earlier studies from the area. The crabs were caught using baited creels which were emptied and rebaited once a day. Because size and sex may differ between different microhabitats, the fishing effort was separated into three different areas: the mudflat, channel and the mangrove. Results showed a habitat preference for the mangrove by *S. serrata* whereas fewer and smaller individuals were caught on the mudflat. Of the animals caught, 26% were found to have reached sexual maturity and it was estimated that 50% (CW_{50}) of the males and females had reached maturity at a size of 123 mm and 143 mm for males and females respectively. This indicates an increase in size of reaching sexual maturity when comparing to a report with samples collected in Saco Bay between the years 1997 – 1999, which estimated CW_{50} to 110 and 100 mm. Mean CW size and catch day $^{-1}$ were found to have increased significantly since 2008. Hence, the perception by the local community is not supported by these results which would rather indicate a viable population on Inhaca.

Sammanfattning

Ön Inhaca ligger på Afrikas östkust i Moçambique och anses vara en lämplig plats för marin forskning på grund av det stora utbudet av orörda habitat. Den stora simkrabban *Scylla serrata* (Forsskål 1775) är en kommersiellt viktig art i Moçambique och är vanlig i estuarier och mangroveträsk som regelbundet översvämmas av havsvatten, så som i Saco Bay på Inhaca. Ön blev en del av ett reservat 2008, men *S. serrata* fiskas fortfarande i Saco Bay av det lokala samhället som har upplevt en nedgång i både fångststorlekar och landningar under de senaste åren. För att uppskatta den nuvarande populationsstrukturen för *Scylla serrata* på Inhaca, har en fiskeansträngning gjorts i Saco Bay för att studera storleksfördelning, könsfördelning och storlek vid könsmognad samt att jämföra resultaten med tidigare studier från samma område. Krabborna fångades med agnade burar som tömdes och agnades på nytt en gång om dagen. Eftersom storlek och kön kan skilja sig mellan olika mikrohabitat, delades fiskeansträngningen in i tre olika områden: lerbotten, floden och mangroveskogen. Resultaten visade att *S. serrata* hade en habitatpreferens mot mangroven medan färre och mindre individer fångades på lerbottnen. Av de djur som fångats hade 26 % nått könsmognad och CW_{50} uppskattades till 123 mm och 143 mm för hanar respektive honor. Detta tyder på en ökning av storlek vid könsmognad när man jämför med en rapport med prover som tagits i Saco Bay mellan åren 1997 - 1999, som uppskattade CW_{50} till 110 mm och 100 mm. Genomsnittlig CW storlek och fångst per fisketillfälle visade sig ha ökat signifikant sedan 2008. Uppfattningen av det lokala samhället stöds därför inte av dessa resultat utan skulle tvärtom tyda på en livskraftig population på Inhaca Island.

1. Introduction

The large portunid crab *Scylla serrata* (Forsskål 1775) is the most widespread species of the genus Scylla and is found in viable populations throughout all the Indo-west Pacific, Australia and east Africa (Keenan et al., 1998). This commercially important species, commonly known as mud crab (or mangrove crab), is abundant in estuaries and mangrove swamps regularly flooded by seawater (Barnes et al., 2002; Keenan et al., 1998). *S. serrata* is believed to be the largest of the portunid crabs with up to 2 kg in weight and a carapace width (CW) of 200 mm (Rezaie-Atagholipour et al., 2013).

Mud crabs are nocturnal organisms and reside in burrows within the mangrove forest at low tide as a refuge from predators. The burrow also functions as reservoir for water and food (Barnes et al., 2002; Hill., 1976). As the mangrove floods, the crab becomes active and feed omnivorously on dead fish, crustaceans and molluscs (Nirmale et al., 2012). Little is known about *S. serrata* movement patterns but it is believed that mud crabs stays within a smaller area of 1-2 km^2 if the living conditions are sufficient. The exception being when females go offshore to spawn (Hill., 1975; Hill., 1978).

S. serrata is a commercially important species in Mozambique and the crab is harvested by local fishermen using traditional artisanal fishery (Macia et al., 2014). The mud crabs large size and meat quality makes it popular in the tourism industry and is served as a local delicacy in restaurants (Mirera, 2011). Because the investment needed for this kind of fishery is low, there is great potential in expanding the mud crab exploitation. Furthermore, this species is known to survive in air for up to five days which favour regional trades (Angell, 1992; Macia et al., 2014).

The *S. serrata* fishery in Mozambique is considered to be at a small-scale, but when more people are moving to the coastal area along with a growing tourism industry, higher demand for the marine resources might occur (Barnes et al., 1998). The abundance of mud crab may alternate over the year in subtropical areas due to a decrease in activity and feeding at temperatures below 20^{o}C (Hill, 1980). The feeding also creases 2-14 days prior to moulting which may result in lower catches. (Williams et al., 1982). In order to maintain a sustainable use of mud crabs in the future, more information regarding size structure, sex balance and reproductive parameters are needed to establish guidelines regarding fishery management (Macia et al., 2014; Robertson & Kruger, 1994).

Minimum landing size (MLS) within the fishery industry is usually determined depending on the size at which the target species becomes sexually mature (Robertson & Kruger, 1994). To keep the *S. serrata* population viable in Mozambique, the crabs must be given a chance to reproduce before harvested. A study in Natal, located 300 kilometers south of Maputo in South Africa, concluded that 50% (CW_{50}) of the males and females had reached maturity at a size of 92 and 123 mm, respectively (Robertson & Kruger, 1994). Today, South African fishery regulations have a MLS of 114-115 mm for both sexes. By this regulation, only 16% of the females caught in Natal were sexually mature. If the demand grows, it might result in a decrease in the *S. serrata* population (Robertson & Kruger, 1994).

Inhaca is a 52 km^2 island, located 35 kilometers east of Maputo in Mozambique ($25^{0}56´40''$-$26^{0}04´57''$ S, $32^{0}54´36''$-$32^{0}57´33''$ E) (deBoer & Longamane, 1996). Although Inhaca Island became part of the Ponta do Ouro Partial Marine Reserve (PPMR) in 2008, there is still legitimate crab fishing on the island. In a study carried out between the years 1997 - 1999, CW_{50} of the *S. serrata* crabs were estimated to 110 and 100 mm for males and females, respectively (Macia et al., 2014). The island currently holds a population of approximately 5605 inhabitants and 5991 number of tourists each year (Instituto Nacional de Estatística, 2010; Estaco de Biologia Maritima da Inhaca, 2015). The human population has

increased around 15% since the crab study was carried out in the late 90's. Increased number of people may increase the pressure on natural resources such as the crab population and the local community at Inhaca has expressed that they have experienced a decline in both catch sizes and landings in the last few years (Ada, personal communication). Selective removal of the largest specimen may cause a decline in size at maturity.

The purpose of this study is to examine the population structure of *Scylla serrata* at Inhaca Island and compare the current population status with an earlier report by Johan Florentzson from 2008 made in the same area. The sex-ratio and animal size (CW) will be documented and reproductive stage will be determined by dissection. As earlier studies have shown that size and sex may differ between different microhabitats within the same geographic area, fishing effort will be separated into mangrove, mudflat as well as channel areas. The null hypotheses are that: size and catch per unit effort on *Scylla serrata* at Inhaca Island have not changed over time for both sexes and that sex distribution and size at sexual maturity on *Scylla serrata* at Inhaca Island have not changed over time for both sexes.

2. Materials and methods

2.1 Study area

Inhaca Island has a semidiurnal tide with a maximum fluctuation of 3.9 meters (deBoer & Longamane, 1996). There is a large bay located in the southern part of the island called *Saco da Inhaca*. This bay is consistent of six different habitat types (the channel, channel bank, mangrove, mudflat, sandbank and sandflat). Three of these areas are included in this study (for details: Appendix I). Saco Bay is an ecosystem dominated by mangrove forest where *Avicennia marina* (white mangrove) with pneumatophores (pencil-like aerial roots) sticking up from the ground is common. *Rhizophora mucronata* (red mangrove) and *Bruguiera gymnorhiza* (black mangrove) are two other species dominating the mangrove (Ada, personal communication; deBoer & Longamane, 1996; Kalk, 1995). North of Saco da Inhaca is the marine research station, called Estação de Biologia Marítima da Inhaca, located on the west coast of the island.

The study area for this thesis is situated in Saco Bay, where big parts of the estuary becomes exposed during low tide. These fluctuations makes cage-fishing for mud crabs advantageous due to difficult access and strong currents when Saco Bay is flooded (Florentzson, personal communication). The specimens used in this study were caught between May and June 2015, during the cold season, and all the sampling and laboratory procedures were carried out at the marine biology station. The monthly mean water temperature and standard deviation during this study was 24.1 ± 0.4 $^{\circ}$C and 21.9 ± 1.0 $^{\circ}$C respectively.

2.2 Sampling techniques

Crabs were caught in baited rectangular cages with two entrances. Seven cages were used during the time of sampling, in which two varied somewhat in construction (for details: Appendix II). The measurements of the cages limited the catchable portion of the local stock to the approximate 40 – 170 mm carapace width. Animals smaller than 40 mm would be able to escape through the netting and animals larger than 170 mm were too big to be able to enter the cage. The cages were placed randomly on three different substrates: channel, mangrove and mudflat. Care was taken to position the cages at least 5 meters apart from each other within a substrate and a minimum of 100 meters were separating the substrates. The mangrove and the channel were fished on during nine days each. When the cages were placed on the mudflat area they were completely exposed during low tide which put them at risk for looting. Eight days of fishing on the mudflats had to be eliminated from this study because of

suspected looting as the cage was found opened and there were no crabs within. Thus total number of days fished on the mudflat was 8+9=17 days. The crabs that were caught in the cages were collected in buckets and brought back to the station for further analysis. The emptied cages were rebaited and left to fish overnight. Fish bought locally was used as bait, and *Sillago sihama* (silver smelt) and *Platycephalus indicus* (bartail flathead) were the most common species. *Gerres filamentosus* (whipfin silver-biddy), *Gerres acinaces* (longtail silver biddy) and *Otolithes ruber* (tigertooth croaker) were also used a few times and care was taken to use 2-3 cm thick pieces every time independent of species. The cages were checked at low tide once a day during the six weeks of sampling.

Slide calipers were used to measure between tips of the ninth lateral spines and both carapace width (CW) and internal carapace width (ICW) were determined as described in Keenan et al., 1998 (for details: Appendix III). This was done to avoid bias since only measuring CW alone might be less reliable if the animals have lost one or two of their ninth lateral spines (Florentzson, 2008). CW was measured on 116 specimens and ICW on 105 specimens. Carapace length (CL), wet weight and sex (identified by observing abdomen width as described in Shelley, 2011) were documented for all 116 crabs (for details: Appendix III). All specimens were euthanized one day prior to dissection by placing them in a freezer in which they froze solid within 5 hours.

2.3 Laboratory procedures

Stage of sexual maturity was determined by exposing gonads through dissection by removal of the upper carapace. The crabs were left to thaw in room temperature four hours prior to dissection and the upper carapace was then removed to expose the internal tissues, including gonads. The inside of all dissected crabs were photographed for further analysis on sexual maturity.

2.4 Estimates of size at maturity

All specimens were assessed as either sexually mature or immature based on the visibility of gonads on the photographs. The specimens where then sorted into one of six size classes depending on their carapace width and the percentage of mature individuals within each size class were calculated (see results for details). The males proved more difficult to determine for maturity than females, as the hepatopancreas sometimes had smeared and thereby covered the male gonad on the photographs. Males where therefore only classified as mature if there was as a clear visual of the gonads. All sexually mature specimens should have visible gonads during this time of year (Macia et al., 2014). CW_{50} for each sex were calculated by adding the CW of the smallest sexually mature crab with the CW of the biggest immature crab and divide it by two. This rough method was applied because of the small sample size of mature individuals.

2.5 Statistics

IBM SPSS Statistics 22 was used to determine the statistical significance of the results. After inspecting plots and running a Shapiro-Wilk's test (Shapiro & Wilk, 1965) all data were shown to be approximately normally distributed. Two factorial ANOVAs with substrate and sex as independent factors were conducted separately for three different dependent variables: ICW, CW and number of individuals caught per day. Post-hoc Tukey HSD tests were conducted after each of these ANOVAs. Two factorial ANOVAs with year and sex as independent factors were conducted separately for two different dependent factors: CW and catch per unit effort. $p<0.050$ was used as a significance level at all times.

3. Results

3.1 Catch and size

The size distribution had a peak at around 90 – 130 mm and the mean size (and standard deviation) of the 116 *S. serrata* caught in this study was 114.2 (±21.2) mm in CW (Fig. 1). The ICW mean of 110.7 (±19.8) mm is based on 105 out of 116 specimens. The largest crab was a female measuring 164 mm in CW and was caught in the mangrove forest. Four *Portunus pelagicus* were caught on the mudflat and were documented as by-catch.

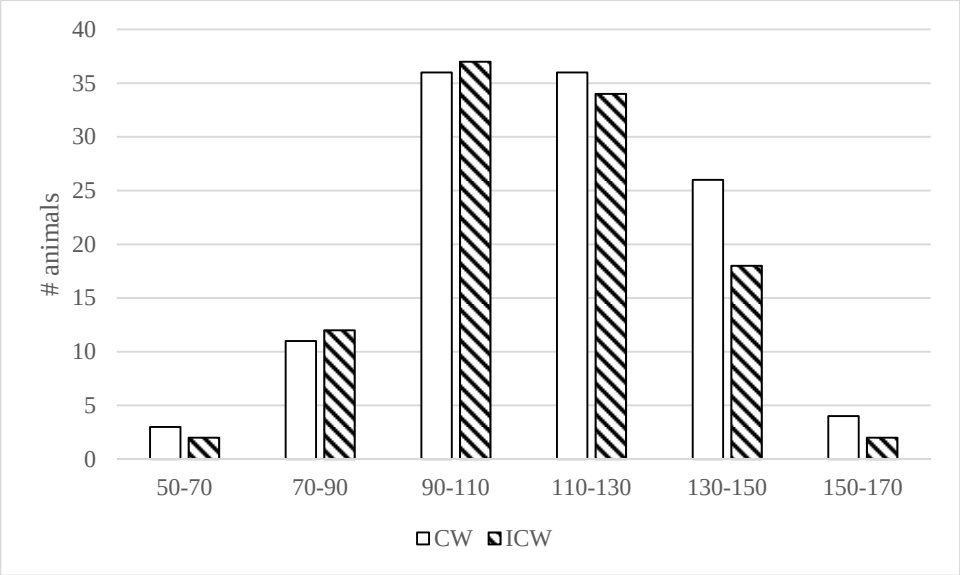

Fig. 1. Carapace width (CW, n=116) and internal carapace width (ICW, n=105) for *Scylla serrata* caught during May to June 2015 at Saco Bay, Inhaca Island, Mozambique. Size distribution presented as number of animals caught within each 20 mm size class.

Both CW and ICW were subjected to a two way analysis of variance (ANOVA) with sex and substrate as independent variables. For CW, the main effect for substrate ($F(2, 110) = 4.0$, $p = 0.021$) showed a significant difference between the mudflat (100.9 ±4.8 (mean ±SE)), channel (120.8 ±2.7) and the mangrove forest (115.8 ± 2.8) but the main effect for sex ($F(1, 110) = 0.004$, $p = 0.951$) did not show a significant different between males (114.9 ±2.4) and females (112.9 ±22.6) (Fig. 2a) . The interaction effect between sex and substrate was not significant ($F(2, 110) = 1.94$, $p=0.148$). A Tukey HSD post hoc test showed that the mudflat differed significantly from both the channel ($p=0.001$) and mangrove forest ($p=0.009$) but no such relation was found between the channel and mangrove forest ($p=0.521$). For ICW, all effects were showed to be insignificant with a yielded F of $F(2, 99) = 1.98$, $p=0.144$ for substrate, $F(1, 99) = 0.45$, $p=0.503$ for sex and $F(2, 99) = 2.66$, $p=0.075$ for the interaction effect (Fig. 2b). This may be due to the smaller sample size for ICW.

(a.)

(b.)

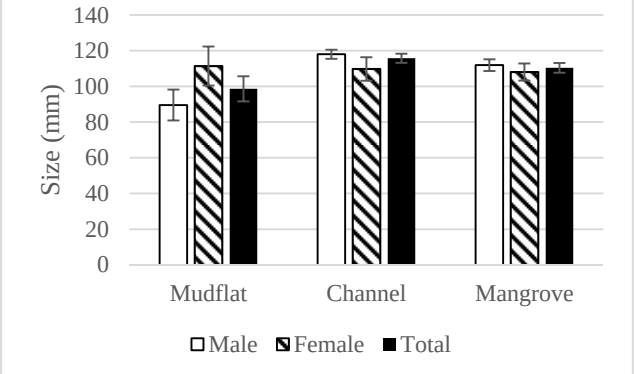

Fig. 2a. Carapace width for *Scylla serrata* caught on different substrates at Saco Bay, Inhaca Island, Mozambique. Number of replicates for each substrate: mudflat n=23, channel n=33 and the mangrove forest n=60. Fig. 2b. Internal carapace width for *Scylla serrata* caught on different substrates at Saco Bay, Inhaca Island, Mozambique. Number of replicates for each substrate: mudflat n=12, channel n=33 and the mangrove forest n=60. Values are given as mean ± SE.

The catch per unit effort during the entire study was 4.3 crabs day $^{-1}$ independent of substrates for all seven cages combined. A two-way ANOVA with sex and substrate as independent variables showed how catch day $^{-1}$ differs significantly between substrates ($F(2, 48) = 7.82$, $p<0.001$) (Fig.3). *S. serrata* was most abundant in the mangrove forest and a post hoc Tukey HSD test showed how the average catch day $^{-1}$ was significantly higher compared to the mudflat ($p=0.001$) and the channel ($p=0.02$). No significant difference could be found between catches made on the mudflat and the channel ($p=0.560$). The average catch day $^{-1}$ was found to be significantly different between males and females ($F(1, 48) = 8.23$, $p=0.006$) but no interaction effect between sex and substrate was found ($F(2, 48) = 0.35$, $p=0.707$).

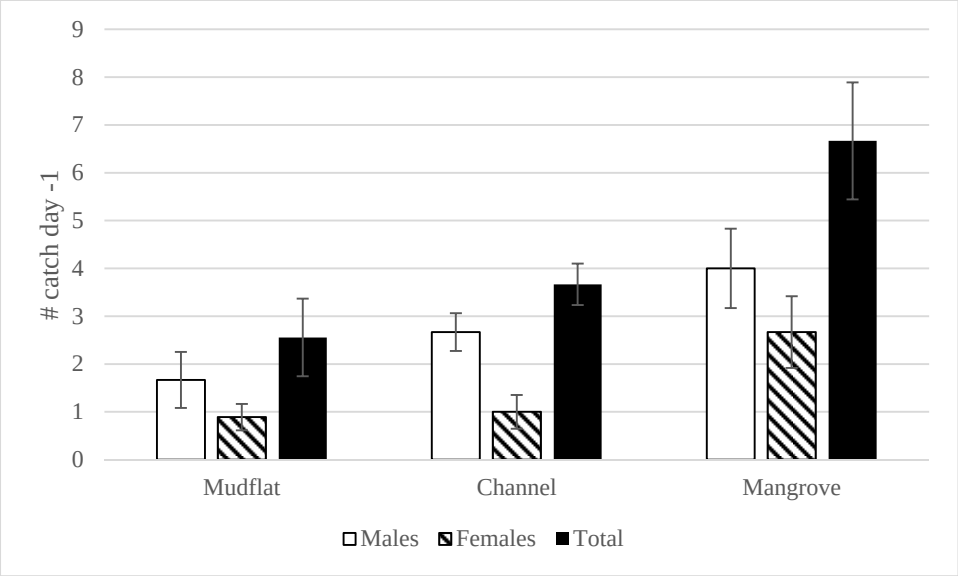

Fig. 3. Number of *Scylla serrata* caught per day for each substrate at Saco Bay, Inhaca Island, Mozambique. Fishing occasions n=9 per substrate and number of cages per day n=7. Values are given as mean ± SE.

The relationship between wet weight and CW are very similar between males and females in the smaller sizes but as they grow bigger in CW, the males started to weigh more (Fig.4). After the split of the two curves, the female curve is straightened out while the male curve continues to rise and starts to weigh more at the same CW.

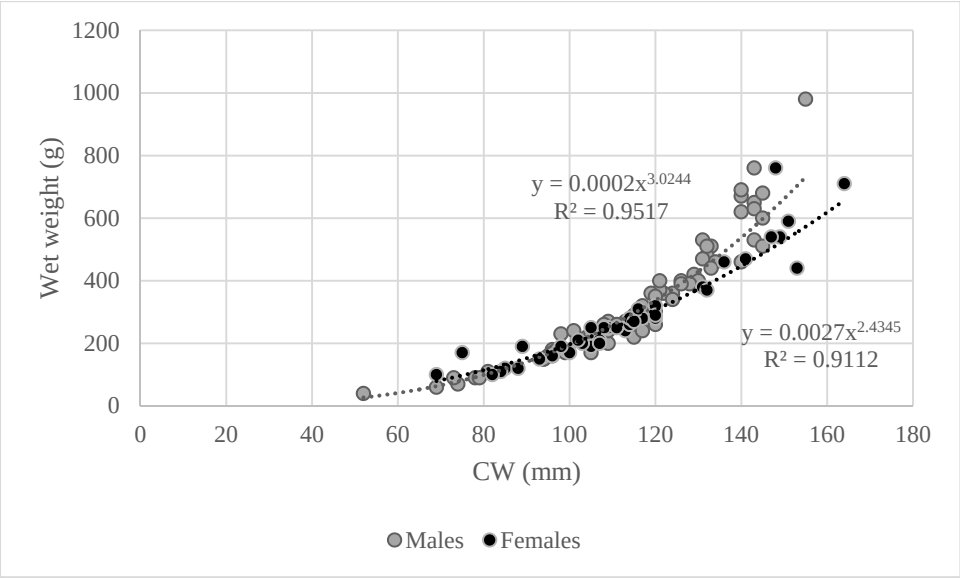

Fig. 4. Relationship between carapace width (CW) and wet weight for males (n=75) and females (n=41) for *Scylla serrata* caught during May to June 2015 at Saco Bay, Inhaca Island, Mozambique. One power trendline for each sex with associated equations and R^2-value.

3.2 Sex distribution

The sex distribution in crabs caught in Saco Bay, when not comparing substrates, was 65% males and 35% females. The sex ratio only fluctuated around 10% between substrates (Fig. 5).

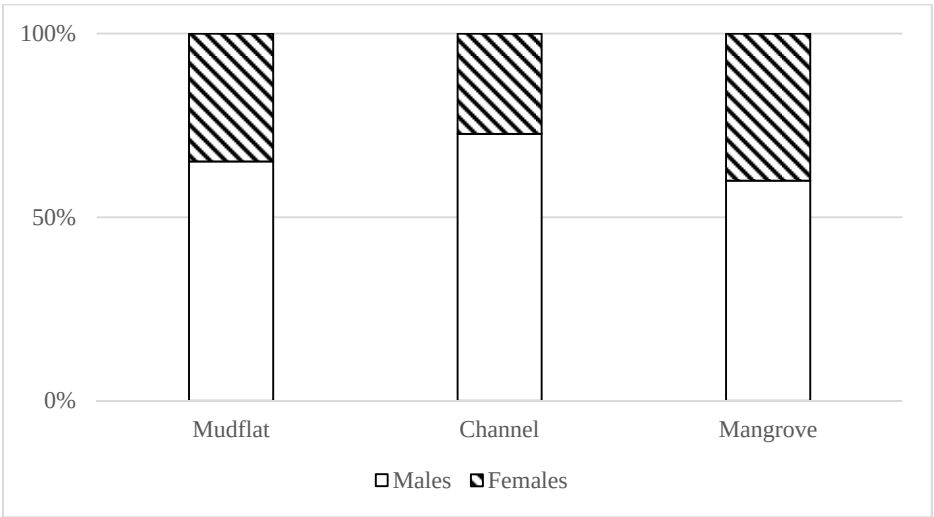

Fig. 5. Sex distribution for *Scylla serrata* caught on different substrates in Saco Bay, Inhaca Island, Mozambique. Number of replicates for each substrate; mudflat n=23, channel n=33 and the mangrove forest n=60. There were 8, 9 and 24 females caught on the mudflat, channel and the mangrove forest respectively.

3.3 Size at maturity

Seven females out of 41 were found to have reached mature age and these were between 136-164mm in CW (Fig. 6). Mature females were only found in the two largest size classes and CW_{50} was estimated to 143 mm.

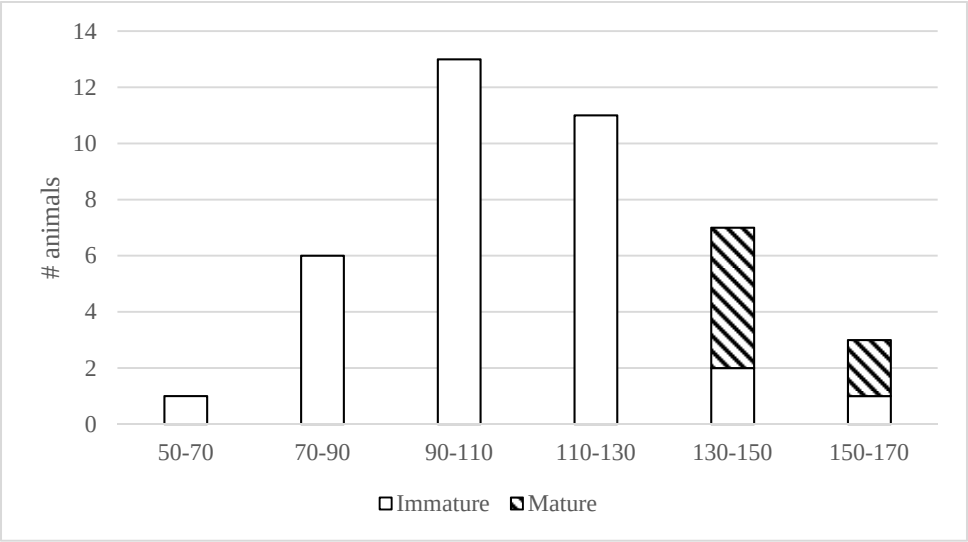

Fig. 6. Carapace width (CW, n=116) and the number of mature females for *Scylla serrata* caught during May to June 2015 at Saco Bay, Inhaca Island, Mozambique. All animals were separated into 20 mm size classes.

Out of the 75 males, 23 had well -defined gonads and where classified as mature. The mature males were between 107-155 mm in CW and were represented in all but the two smallest size classes (Fig. 7). CW_{50} was estimated to 123 mm.

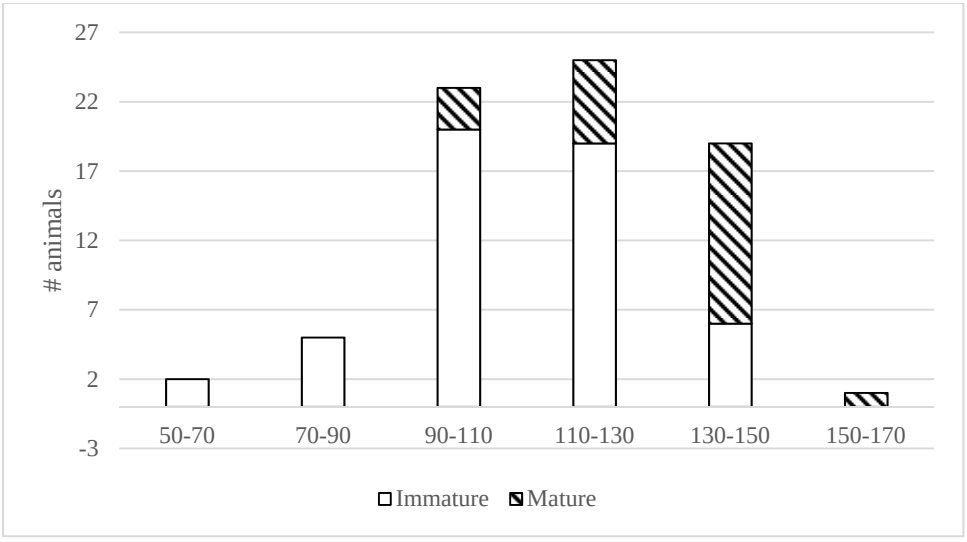

Fig. 7. Carapace width (CW, n=116) and the number of mature males for *Scylla serrata* caught during May to June 2015 at Saco Bay, Inhaca Island, Mozambique. All animals were separated into 20 mm size classes.

3.4 Comparisons (2008 – 2015)

Both CW and catch per unit effort were subjected to a two way analysis of variance with sex and year as independent variables. For CW, the main effect for sex ($F(1, 138) = 2.9$, $p= 0.08$) showed a non-significant difference between females (109.7 ±4.0) and males (M=101 ±3.0) but the main effect for year ($F(1, 138) = 11,7$, $p< 0.001$) did show a significant different

between the years 2008 (96.9 ±4.5) and 2015 (113.9 ±2.1) (Fig. 8). The interaction effect between sex and year was significant (F(1, 138) =4.5, p=0.035).

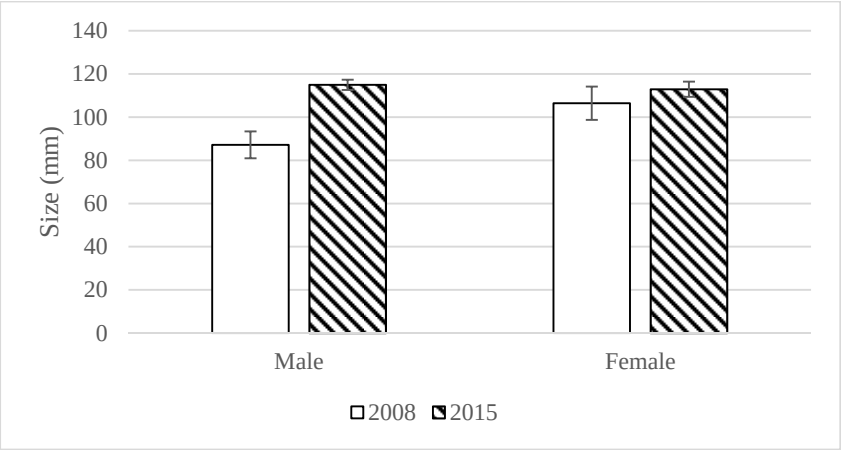

Fig. 8. Mean carapace width (CW) for *Scylla* at Saco Bay, Inhaca Island, Mozambique. Data from year 2008 is collected by Florentzson, (2008), and year 2015 by the author. Number of replicates 2008: males n=17 and females n=9. Number of replicates 2015: males n=75 and females n=41. Values are given as mean ± SE.

A significant difference between males (M=0.19 SD=0.26) and females (M=0.10 SD=0.18) were found for catch per unit effort with a yielded F of F(1, 126) =10.7, p<0.001 (Fig. 9). There was a significant difference between the years 2008 (M=0.03 SD=0.05) and 2015 (M=0.31 SD=0.27) with a yielded F of F(1, 126) =85.3, p<0.000 as well as a significant interaction effect (F(1, 126) =7.2, p<0.008).

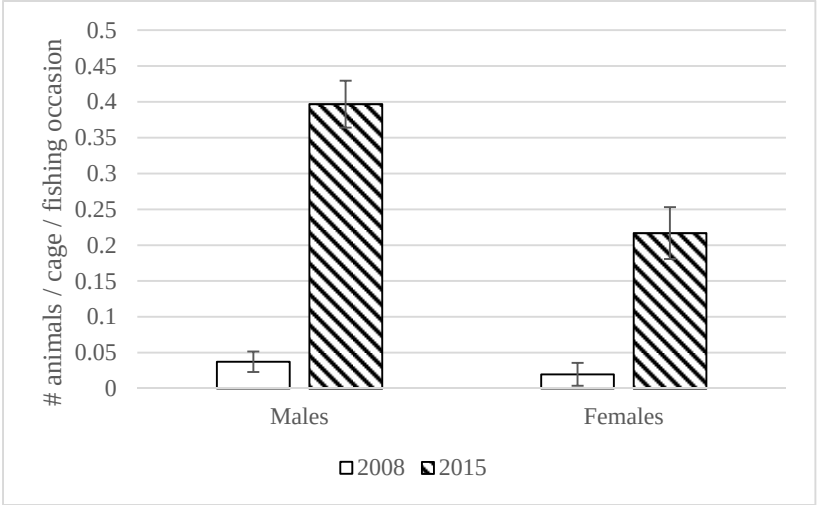

Fig. 9. Number of S*cylla serrata* caught per fishing occasion per cage at Saco Bay, Inhaca Island, Mozambique. Data from year 2008 is collected by Florentzson (2008), and year 2015 by the author. 2008: fishing occasions n= 38, number of cages n= 12. 2015: fishing occasions n=27, number of cages per day n=7. Values are given as mean ± SE.

4. Discussion

Since all specimens were brought back to the marine station for dissection, no recapture data could be collected, and hence, no estimation of population size can be made. However, the perception by the local community regarding a declining *S. serrata* population does not agree

with the results that have been shown in this study. The fact that both significantly more and larger specimens where encountered in this study compared to 2008 indicates that these is a viable mud crab population on Inhaca Island. The exploitation of *S. serrata* does not seem to be increasing with the growing number of inhabitants on Inhaca. However, the method that has been used needs both environmental (such as temperature) -and psychological factors (such as moult condition) to be right to not cause bias in catchability results (Williams et al., 1982). To strengthen the results when using this method, other authors have applied a second non-bias method. Morrissy & Caputi (1981) perfected the catchability of baited drop nets by draining the ponds used to estimate catchability of *Cherax tenuimanus* (marron). Alternative fishing methods for *S. serrata* in Saco Bay are limited since diving is not possible because of bad visibility, and mud crabs would not be easily caught in a trawl due to their ability to bury themselves in the mud (Williams et al., 1982). Because of this, a small part of the *S. serrata* population is excluded which may cause bias in the conclusions made. However, statistical tests indicates that the normal distribution of the population have been captured.

The mudflat area differed significantly from the channel and mangrove forest both when comparing mean size and catch per unit effort. Both smaller and fewer individuals were caught on the mudflat compared to the other habitats. *S. serrata* showed a higher habitat preference towards the mangrove area. These results contradict the findings by Florentzson (2008) where no significant difference could be detected between catches made on the mudflat, in the mangrove or in the channel (Florentzson, 2008). A study made in Deception Bay, northern Australia, showed that juvenile crabs stay resident within the mangrove area while the sub adults migrate out to the mudflat to feed at low tide (Hill et al., 1982). The adult mud crabs in Deception Bay are believed to stay in the subtidal zone and were only occasionally caught in the intertidal zone during the warmer season (Hill et al., 1982). This is consistent with the results from this study which was performed during the cold season. The high abundance of *S. serrata* found within the mangrove forest also agrees with these results. The distribution of crabs in Saco Bay may be a result of mud crab movement patterns in different stages of their lifecycle.

Knowledge about *S. serrata* movement patterns between habitats are limited, however, some authors argue that the movement patterns are closely related to the habitat they live in and the availability of alternative feeding grounds (Hyland et al., 1984). Mud crabs that reside in narrow mangrove fringes, where the intertidal zone is limited, tends to remain in the same area (limited to 1 km^2) whereas crabs that live in the open have access to a bigger intertidal area and might undergo a larger movement in order to find food or avoid intraspecific competition (Hill, 1975; Hill, 1978; Hubatsh & Meynecke, 2015; Hyland et al., 1984). Sustainable food resources within the mangrove forest may have reduced the movement between habitats in Saco Bay but no conclusions can be made.

The relationship between weight and CW was very similar between males and females in the smaller sizes but as they grow bigger in CW, the males started to weigh more. Females tend to reduce their chelae growth as they grow bigger, while males tend to do the opposite (Pinheiro & Hattori, 2006). Males being larger and heavier is a common phenomenon among crabs and bigger claws enable them to protect the females successfully during and after copulation (Pinheiro & Fiscarelli, 2009). This is supported by Macia et al. (2014), who showed a similar relationship for *S. serrata* between the years 1997 - 1999 and whose power equations are identical to this study (Macia et al., 2014). Mature females utilize much of their energy into egg production which reduces their somatic growth. (Ferkau & Fischer, 2006; Pinheiro & Fiscarelli, 2009; Pinheiro & Fransozo, 2002).

The high abundance of *S. serrata* might correlate with the low numbers of *Portunus pelagicus* encountered during this study. *P.pelagicus* were only captured on the mudflat where *S. serrata* was shown to be the least abundant. Previously, Florentzson (2008)

found no habitat preference for *S. serrata* in Saco Bay and encountered *P.pelagicus* on all substrates. Furthermore, CW has increased significantly since 2008 and the largest specimens were found in the channel and the mangrove forest where *P.pelagicus* were absent. Little is known about the interspecific competition between these species, but *S. serrata* is known to display agonistic and cannibalistic behaviour towards other individuals of its own species (Hubatsh & Meynecke, 2015; Williams et al., 1982). These are only speculations at this point, and further studies are required to establish the relationship between these two species.

The sex ratio was not found to differ significantly between males and females which concords with Florentzson (2008). The sex distribution was not significantly different between substrates, which indicates an even sex distribution throughout Saco Bay. The sex ratio in an area might fluctuate over the year due to females' tendency to migrate offshore to spawn (Hill, 1975). Since the migration mainly occurs during the warmer season one could expect a more equal sex distribution in the colder season, which is confirmed by this study.

26 % of the specimens were found to have reached sexual maturity and CW_{50} (123 mm and 143 mm for males and females respectively) shows an increase in size of reaching sexual maturity when compared to an older study (Macia et al., 2014) In the late 1990, CW_{50} were estimated to 100 mm and 110 mm for males and females respectively which shows an increase of 19% and 23% respectively (Macia et al., 2014). Some authors imply that size at sexual maturity may change as a compensatory response to changes in conditions, e.g. biomass. Hence, an increased biomass may cause decelerated growth (Dominguez-Petit et al., 2008). Shifts in environmental factors, such as NAO-index and upwelling may also favour decelerated growth and late maturation (Dominguez-Petit et al., 2008; Engelhard & Heino, 2004a). Dominguez-Petit et al. (2008) argue that the size at which an individual is sexually mature is affected by its environment which they support by showing how fast size at sexual maturity for *Merluccius merluccius* (European hake) has changed over. An observation by Engelhard and Heino (2004a) suggested that when the age at maturity declined, due to a decrease in population size, size at maturity increased for *Clupea harengus* (Norwegian herring). Individuals that mature at a greater size have experienced a longer period of faster growth and feeding (de Roos et al., 2006). Populations where animals reach a mature stage at a large size are more vulnerable to harvesting and it might cause a potential decline in reproductive output as a consequence. If the South African fishery regulations regarding *Scylla serrata* were implemented on Saco Bay's stocks, it might cause an evolutionary regime shift towards earlier maturation at a smaller size (de Roos et al., 2006). Because of the small sample size of mature individuals, no further investigations could be conducted within each size class. Furthermore, no visual differences could be detected and defined for establishing different maturation stages. When different maturation stages were investigated in Saco Bay in the late 1990's, mature females were always present in the samples, and during May and June, no females with immature gonads were encountered (Macia et al., 2014). This indicates that all specimens that had reached mature age in this study should have fully mature gonads at this time of year. To establish a greater accuracy regarding sexual maturity stages in further studies, a more detailed histological investigation is needed. This was not possible during this study due to primitive working conditions at the marine station.

5. Conclusions

This study has shown that size and catch per unit effort have increased for both sexes on Inhaca Island between the years 2008 - 2015, which indicates a stable population with current exploitation pressure. The perception of a declining population of *S. serrata* is not supported,

but in a scientific point of view, a more comprehensive investigation is needed to make conclusions about the population structure in Saco Bay. However, *S. serrata* is an important source of protein for the local community, so if a more comprehensive study were to be conducted on Inhaca, it should, from an ethical point of view, have the least possible impact on the ecosystem.

The sex distribution has not changed between the times of sampling, but only 26% of the specimens were found to have reached sexual maturity during this study. These mature specimens were at a much larger size than those found in 1999. The mud crabs on Inhaca are showing signs of later maturation, which would benefit fast growing individuals within the population because. This later maturation may cause a potential decline in reproductive output that could put the population at risk. Further studies are needed to determine why this is occurring and to establish sustainable fishery regulations in Mozambique.

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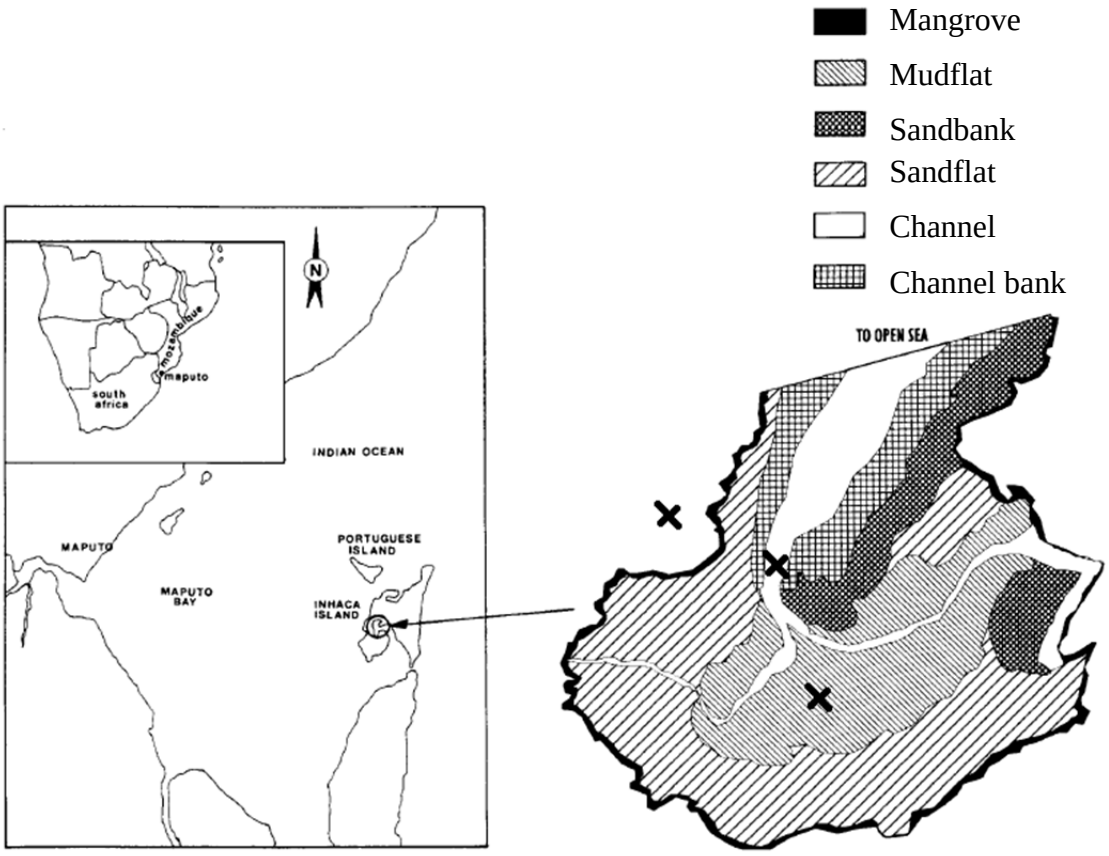
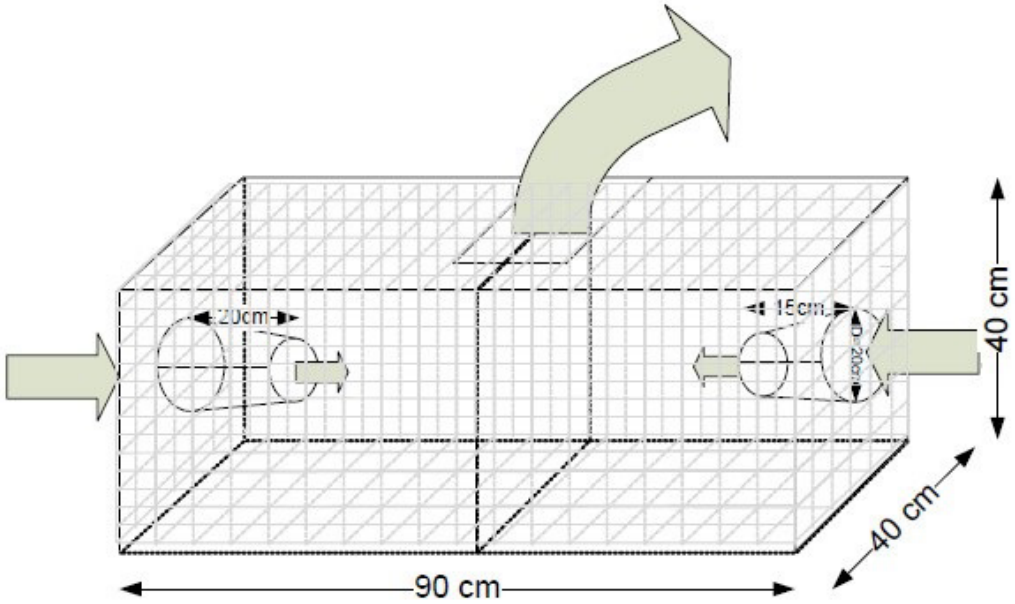
Appendix I
Location of Inhaca Island and Saco Bay with all its habitats. The cages were placed on the mudflat (26° 03’097’’S, 32° 91’233’’E), in the channel (26° 03’098’’S, 32° 91’234’’E) and in the mangrove fringe (26° 03’265’’S, 32° 91’563’’E) and are marked out as X on the map.

(deBoer & Longamane, 1996)



Appendix II
Measurements of the cages

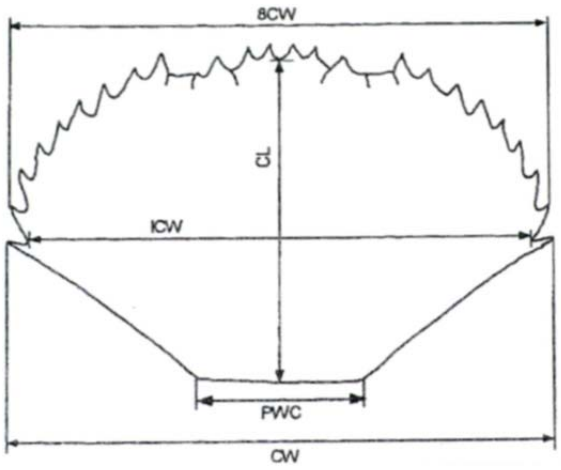
(Florentzson, 2008)



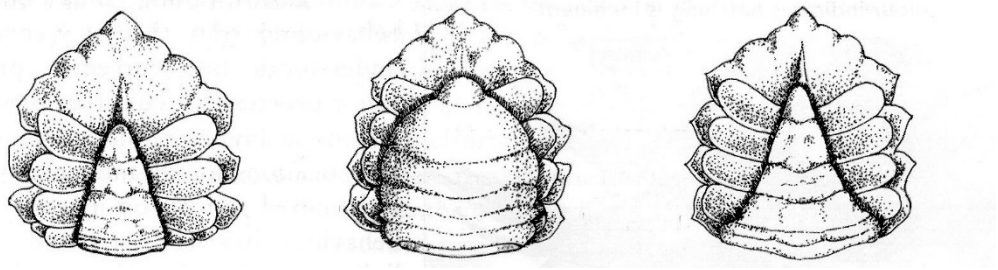
Five of the cages had a 15 cm long entrance (as shown on the right side in the picture) with a mesh size on 4x4.5 cm (Picture 1). The remaining two cages differed some in their construction with an entrance on 20 cm in which one of the cages were equipped with a hatch on top (left side of the picture). Mesh size differed as well because of reparation and was 3x3.5 and 4x4, respectively.

Picture 1. A photograph of one of the cages in Saco Bay on the mudflat. The cages were wedged between two sticks (as in the picture) to prevent the cages from drifting away with the tide. The picture is taken the 23rd of May 2015 on Inhaca Island, Mozambique, 2015 by the author.

Appendix III



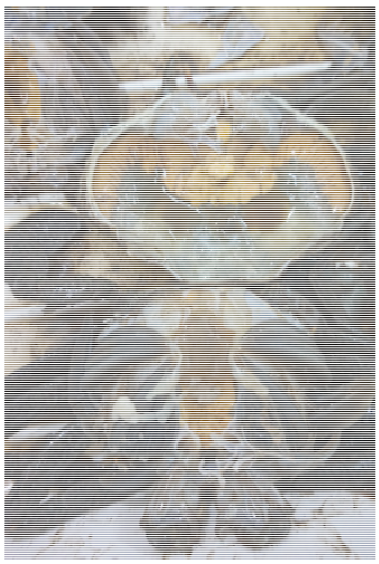
(Keenan et al., 1998)



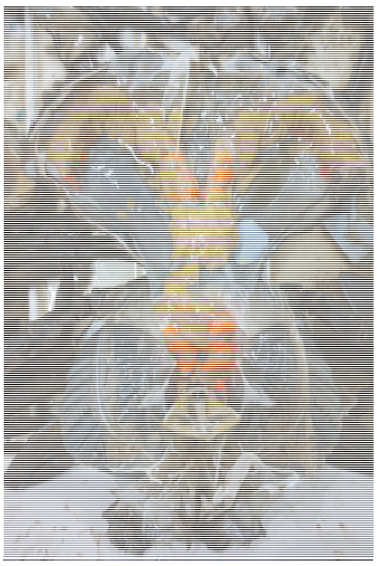
(Shelley et al. 2011)

Abdomens of immature, mature female and mature male *Scylla serrata* (Picture 2a & b).

(a.)



(b.)



Picture 2a & b. A sexually mature male (a.) and female (b.) with visible gonads. The pictures are taken on Inhaca Island, Mozambique, 2015 by the author.