12-MONTHS ASSESSMENT OF THE MUD CRAB, *SCYLLA SERRATA*, STOCK AND FISHERY ON MAHÉ, PRASLIN AND CURIEUSE, SEYCHELLES

FINAL REPORT

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EXECUTIVE SUMMARY

In Seychelles, *Scylla serrata* is fished without control or supervision and is categorized as a data-poor fishery because there is not enough biological and fishing information on the targeted species to assess the status of the stock and establish reference points. In this context, this 12-month assessment of the mud crab fishery aims to 1) define the Seychelles *S. serrata* fishery through fishermen surveys; 2) compile and analyze stock assessment parameters of *S. serrata* within the Seychelles Inner Granitic Islands of Mahé, Praslin, and Curieuse.

To respond to these objectives a combination of online surveys and in-person interviews was employed to define the fishery and a 12-month trapping program has been established across 11 Sites across the three islands Mahé, Praslin and Curieuse.

Between October 2022 and October 2023, a total of 695 Traps were deployed over 11 Sites. A total of 163 *S. serrata* were caught, consisting of 68 females and 95 males. *S. serrata* were caught at 9 mangrove Sites except for Roche Caiman, Providence and Cap Samy. The overall Catch Per Unit Effort (CPUE), including data from both seasons and all municipalities, was 0.23 crab per trap per day. The Marine Protected Area, Curieuse, emerged as a vital contributor to sustaining a higher CPUE.

Exploitation rate near 0.50 obtained in this study indicates the need for application of suitable management. The limit of exploitation rate estimated and the reduce CPUE at fishing sites suggest that no larger scale commercial activity could be implemented on Mahé and Praslin. A precautionary approach would be to consider the stock of Mahé at the limit of exploitation and the implementation of sustainable management measure as a priority. The result has been showcased during fisherman interview on Mahé were the number of crabs caught has been one of the concerns of the fisherman (66.7 % think the fishery has become worse).

The report concludes with strategic recommendations, whereby yearly fishery independent surveys, minimum size limit, and the exploration of nature-based mariculture are proposed to ensure sustainability. Additionally, the potential for mud crab fattening in specific sites and a focus on hatchery-produced crablets are suggested measures.

The complexity of mud crab fishing practices and the diversity of perspectives among fishermen underscore the need for adaptive and collaborative management. The proposed recommendations aim to strike a balance between ecological health and community well-being, fostering a sustainable future for mud crab fisheries and aquaculture in Seychelles.

SYMBOLS AND ACRONYMS

AIR: Airport, Mahé

AnB: Anse Boileau, Mahé

AnR: Anse Royale, Mahé

CaS: Cap Samy, Praslin

CPUE: Catch per Unit Effort

CUR: Curieuse National Park, Curieuse

CW: Carapace Width

E: Exploitation rate

ELEFAN: Electronic Length Frequency Analysis

EnR: English River

F: Instantaneous fishing mortality

FAO: Food and Agriculture Organization of the United Nations

LFQ: Length-Frequency

LWR: Length-Weight Relationship

M: Natural mortality

MoF: Mont Fleuri, Mahé

μ: Statistic, Population Mean

ND: Nouvelle Decouverte, Praslin

PERMANOVA: Permutational Analysis of Variance

PL: Port Launay Mangrove RAMSAR Site, Mahé

PRO: Providence, Mahé

RC: Roche Caiman, Mahé

S. Serrata: Scylla Serrata

SD: Standard Deviation

SE: Standard Error

SFA: Seychelles Fishing Authority

SPGA: Seychelles Parks and Gardens Authority

VBGF: Von Bertalanffy Growth Function

WIO: Wester Indian Ocean

Z: Total instantaneous mortality

INTRODUCTION

The mud crab, *Scylla serrata*, is a portunid crab (family: Portunidae) broadly distributed throughout the Indo-Pacific Region, demonstrating a close ecological association with mangrove ecosystems. The life cycle of these crabs is complex, involving ontogenetic niche shifts, including an extended period in the planktonic phase where they go through five developmental stages before metamorphosis and settlement into habitats close to mangroves (Figure 1). The larval stage of *S. serrata* involves a zoeal phase followed by metamorphosis into the megalopa stage. Zoeal stage I is sensitive to salinities below 15–17.5 and temperatures below 20°C. The megalopa stage displays increased tolerance towards salinity (15–45) and low temperatures (20°C), but it does not develop into the first crab stage at salinities below 15 (Alberts-hubatsch et al., 2015).

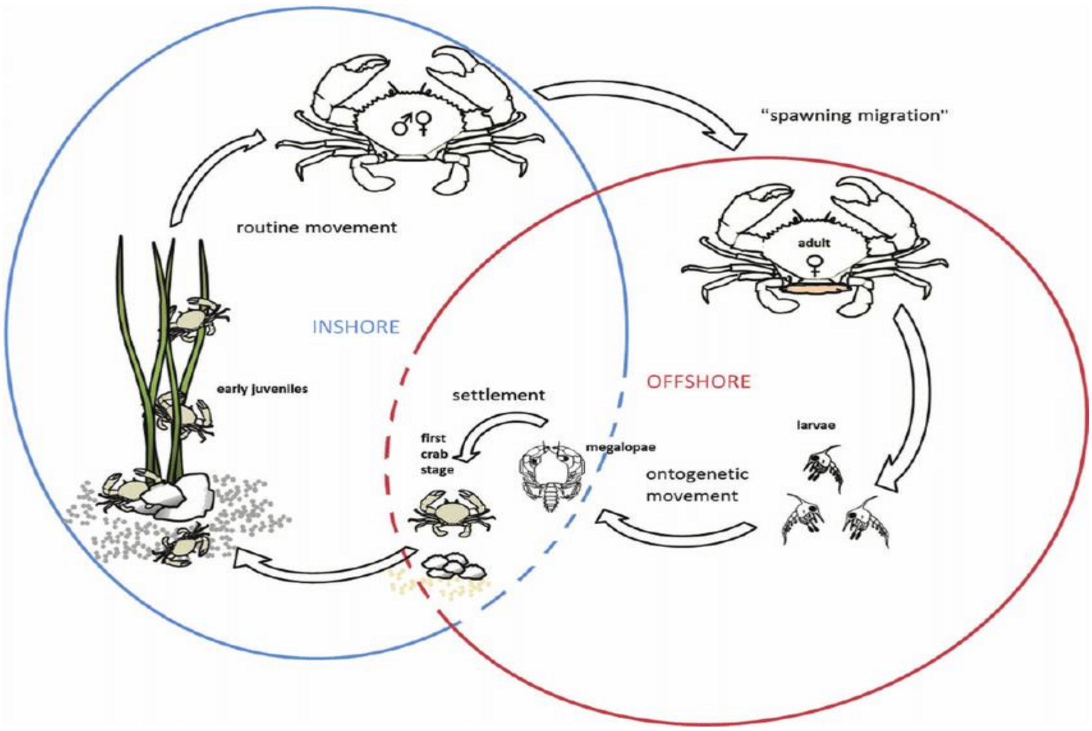


Figure 1. Scylla serrata life cycle from Alberts-hubatsch et al., 2015

As they grow, individuals move incrementally farther into the mangrove system. Adult mud crabs generally inhabit muddy estuaries and enclosures in mangrove ecosystems that are influenced by tidal waters. Sexually mature females undergo long-distance migrations to offshore waters to spawn and renew the cycle. In accordance with the findings of ovigerous mud crabs in bottom trawls while fishing for prawns offshore, it was concluded that female mud crabs move of up to 95 km offshore for spawning (Hill, 1994).

Crabs can reach sexual maturity in as little as 12–18 months in tropical latitudes but can take as long as 24 months in more temperate locations. Sexual maturity for *S. serrata* also occurs at different sizes throughout their geographic range. For example, male crabs in South Africa reach sexual maturity at a carapace width (CW) of 11–12 cm (Hill, 1994), compared with Pohnpei, which is quite close to the equator, where the maturity size is 1 cm larger at 12–13 cm CW (Perrine, 1978). Mud crabs typically only live for a maximum of three to four years, such that constant recruitment is necessary to keep the population replenished and stable (Bonine et al., 2008).

In the Western Indian Ocean (WIO), genetic analysis has identified a unique *S. serrata* metapopulation spreading from Kenya to South Africa and including the Indian Ocean islands, which are either far from (about 2000 km, such as the Seychelles and Mauritius) or close to (about 50 km, such as Zanzibar) mainland Africa (Fratini, 2010). The larvae of *S. serrata's* ability to drift at sea as part of the plankton for up to 4 weeks permits the larvae to travel around 1500 km (Doherty et al., 1995). This extended larval dispersal contributes to the colonization of habitats situated far from their parental origin, resulting in genetically diverse and well-mixed populations in the WIO.

While the largest populations of mud crabs are found in countries with the most extensive and mature mangrove ecosystems, such as those throughout Southeast Asia and Australia, there are nevertheless well-established mud crab populations throughout many smaller countries that contain mature mangrove forests, including the Seychelles Archipelago (Bijoux et al., 2022). Furthermore, *S. serrata* is one of the identified species for the novel Seychelles mariculture industry (SFA, 2019). In 2017, global capture production peaked at 69,863 tonnes, while global aquaculture achieved its highest output of 234,138 tonnes in 2019, playing a significant role in meeting market demands (FAO, 2023). *Scylla serrata*, among the four recognized Scylla species, exhibits the widest distribution; however, its contribution to aquaculture production is relatively minor. The predominant share is attributed to *Scylla paramamosain*, primarily sourced from Southeast Asia, particularly Vietnam. However, to this date, *Scylla* aquaculture still relies heavily on wild-caught crabs for seed stock, fattening, and soft-shelled crab production (Waiho et al., 2017). In Seychelles, *S. serrata* is fished without control or supervision and is categorized as a data-poor fishery because there is not enough biological and fishing information on the target species to assess the status of the stock and establish reference points (Bijoux et al., 2022). Only one study has been conducted to date by the team of Bijoux et al., in 2022, providing first stock assessment parameters in the lagoon of Astove Atoll.

In this context, this 12-month assessment of the mud crab fishery aims to 1) define the Seychelles *S. serrata* fishery through fishermen surveys; 2) compile and analyze stock assessment parameters of *S. serrata* within the Seychelles Inner Granitic Islands of Mahé, Praslin, and Curieuse. Thus, providing evidence-based recommendations for *S. serrata* fisheries and mariculture practices in Seychelles.

MATERIAL AND METHOD

Mud Crab fishers' surveys

Mud crab fishermen were interviewed using a standardized questionnaire (see Annex 1 for details). The questionnaire was made available online and promoted through social media using various platforms as well as on national television by the Seychelles Broadcasting Corporation during a press conference marking the initiation of the study in collaboration with SFA (see Annex 2). Recognizing a notable limitation in online response rates, additional efforts were made to identify fishermen on Mahé and Praslin through networking, primarily utilizing word-of-mouth approach. To overcome this challenge and enhance data collection, one-on-one interviews were conducted to ensure comprehensive and accurate information was obtained from each participant. This personalized approach was adopted to address the limitations associated with solely relying on online survey responses.

Sites Selection and Data Collection

The sites were selected subsequent to an inception workshop, involving consultations with the SFA team and based a report prepared by Advance Africa Management Services in 2018. Overall, the selection of sites was guided by 1) their potential for mud crab fattening activities, and 2) with insights gathered from traditional knowledge shared by fishermen regarding the capture of *S. serrata* (Table 1). The Curieuse site was selected due to its no-take zone management status, allowing for an assessment of differences with other fished areas. On Mahé, the Port Launay Mangroves, designated as a RAMSAR site, were chosen due to their extensive mangrove ecosystem. For Praslin, sites were selected based on Seychellois traditional knowledge for mud crab capture, obtained through consultations with the SFA and SPGA team.

Table 1. Selected site status and Aquaculture potential

Site	Island	Aquaculture Potential	Status
Airport (AIR)	Mahe	Commercial	Fished
Anse Boileau (ANB)	Mahe	Small Scale/experimental	Fished
Anse Royale (ANR)	Mahe	Small Scale/experimental	Fished
Cap Samy (CAS)	Praslin		Fished
Curieuse (CUR)	Curieuse		MPA
English River (ENR)	Mahe		Fished
Mont Fleuri (MOF)	Mahe		Fished
Nouvelle Decouverte (ND)	Praslin		Fished
Port Launay (PL)	Mahe		RAMSAR/ Fished
Providence (PRO)	Mahe		Fished
Roche Caiman (RC)	Mahe	Commercial	Fished

An initial empirical study utilizing mark-recapture data was conducted during the first three months of the study to assess its feasibility. However, the absence of recaptures in five consecutive sampling sessions each month indicated that the study's objectives were not achievable within the time constraints. Consequently, adjustments were made to the fieldwork approach to allow for a comparison of multiple sites. During data collection sessions staff from both SFA and SPGA was trained in the field survey methods used (see Annex 3).

Reconnaissance Survey

At each of the sites, a preliminary reconnaissance survey was conducted to evaluate the general vegetation composition, describe ecosystem transitions, verify suitable trap deployment areas, and document any pertinent site-specific information that could potentially influence the methodology or the study's outcomes.

Mangrove Habitat Characteristic

Small Plot Intensive Inventories (SPII) were conducted across mangrove areas using 5 m radius circular plots. During this process, GPS coordinates were recorded for the following observations: 1) identification and record of all plant species present; 2) % vegetation cover and determination of soil types, categorizing them as mud/silt, sand, or gravel (Figure 2).

Figure 2. Vegetation mapping and trap deployment, Curieuse

Trapping program

A trapping program was implemented to collect mud crab population parameters on three islands: Mahé, Praslin, and Curieuse (Figure 4). Each trapping session was categorized as either 'Northwest Monsoon,' covering the period from November through March, or 'Southeast Monsoon,' spanning from April to October (Chang-Sen, 2007). On Mahé, one to two different sites were trapped each month for a total of 8 sites sampled between October 2022 and October 2023 (Table 2). On Mahé, Port Launay (PL) was the only site trapped during both seasons. On Praslin, 2 sites were sampled, and on Curieuse, 1 site was sampled in December 2022 and April 2023, to account for potential variability due to monsoon seasonality. The management status of the sites was grouped into two categories: Marine Protected Areas (Curieuse) and Others. Due to crab and traps being stolen at Roche Caiman, Providence, and Cap Samy areas, these three sites

Figure 3: Folding trap used in the trapping programme (provided by SFA)

were removed from further analysis (no crab was sampled at these three sites).

At each site, 10 to 15 traps were randomly set in the mangrove rivers, spaced approximately 10 to 20 meters apart during the spring tides of the month. Individual traps were checked roughly every 10-12 hours, following a morning and evening schedule to verify catches and replenish bait. The number of traps and sessions varied due to occasional losses, theft, or limitations imposed by heavy rain during fieldwork. Traps were baited with 500 grams of rotten mackerel, which was replaced every session. Rectangular, collapsible knotted polyethylene mesh traps (0.60 m ø × 0.45 m and a 9 mm ø galvanised steel frame), 50 mm mesh (1 mm ø) with two 0.30 × 0.20 m semi-closed funnel entrances were used (**Error! Reference source not found.**).

Table 2. Trapping program summary

SEASON	YEAR	MONTH	ISLAND	SITE	TRAP DEPLOYED
SOUTHEAST MONSOON	2022	Oct	Mahe	PL	30
NORTHWEST MONSOON	2022	Nov	Praslin	CaS	35
NORTHWEST MONSOON	2022	Nov	Curieuse	CUR	60
NORTHWEST MONSOON	2022	Nov	Praslin	ND	40
NORTHWEST MONSOON	2022	Dec	Mahe	MoF	5
NORTHWEST MONSOON	2022	Dec	Mahe	PL	10
NORTHWEST MONSOON	2023	Jan	Mahe	MoF	35
NORTHWEST MONSOON	2023	Jan	Mahe	PL	46
NORTHWEST MONSOON	2023	Feb	Mahe	MoF	25
NORTHWEST MONSOON	2023	Feb	Mahe	PL	55
NORTHWEST MONSOON	2023	Mar	Mahe	PRO	29
NORTHWEST MONSOON	2023	Mar	Mahe	RC	15
SOUTHEAST MONSOON	2023	Apr	Praslin	CaS	24
SOUTHEAST MONSOON	2023	Apr	Curieuse	CUR	45
SOUTHEAST MONSOON	2023	Apr	Praslin	ND	27
SOUTHEAST MONSOON	2023	May	Mahe	AIR	49
SOUTHEAST MONSOON	2023	Jun	Mahe	AnR	41
SOUTHEAST MONSOON	2023	Jul	Mahe	EnR	30
SOUTHEAST MONSOON	2023	Aug	Mahe	AnB	46
SOUTHEAST MONSOON	2023	Oct	MM	PL	48

Table 3. Trap deployment over the different Sites. CUR: Curieuse Marine National Park, Curieuse; CaS: Cap Samy, Praslin; ND: Nouvelle Découverte, Praslin; MoF: Mont Fleuri, Mahé; RC: Roche Caiman, Mahé; PRO: Providence, Mahé; AnR: Anse Royale, Mahé; AIR: Airport, Mahé; EnR: English River; AnB: Anse Boileau, Mahé, PL: Port Launay, Mahé.

SITE	DEPLOYED TRAP	CANCELLED TRAP	TOTAL TRAP
AIR	49	4	45
ANB	46	6	40
ANR	41	2	39
CAS	59	2	57
CUR	105	2	103
ENR	30	0	30
MOF	65	3	62
ND	67	11	56
PL	189	3	186
PRO	29	8	21
RC	15	2	13
GRAND TOTAL	**695**	**43**	**652**

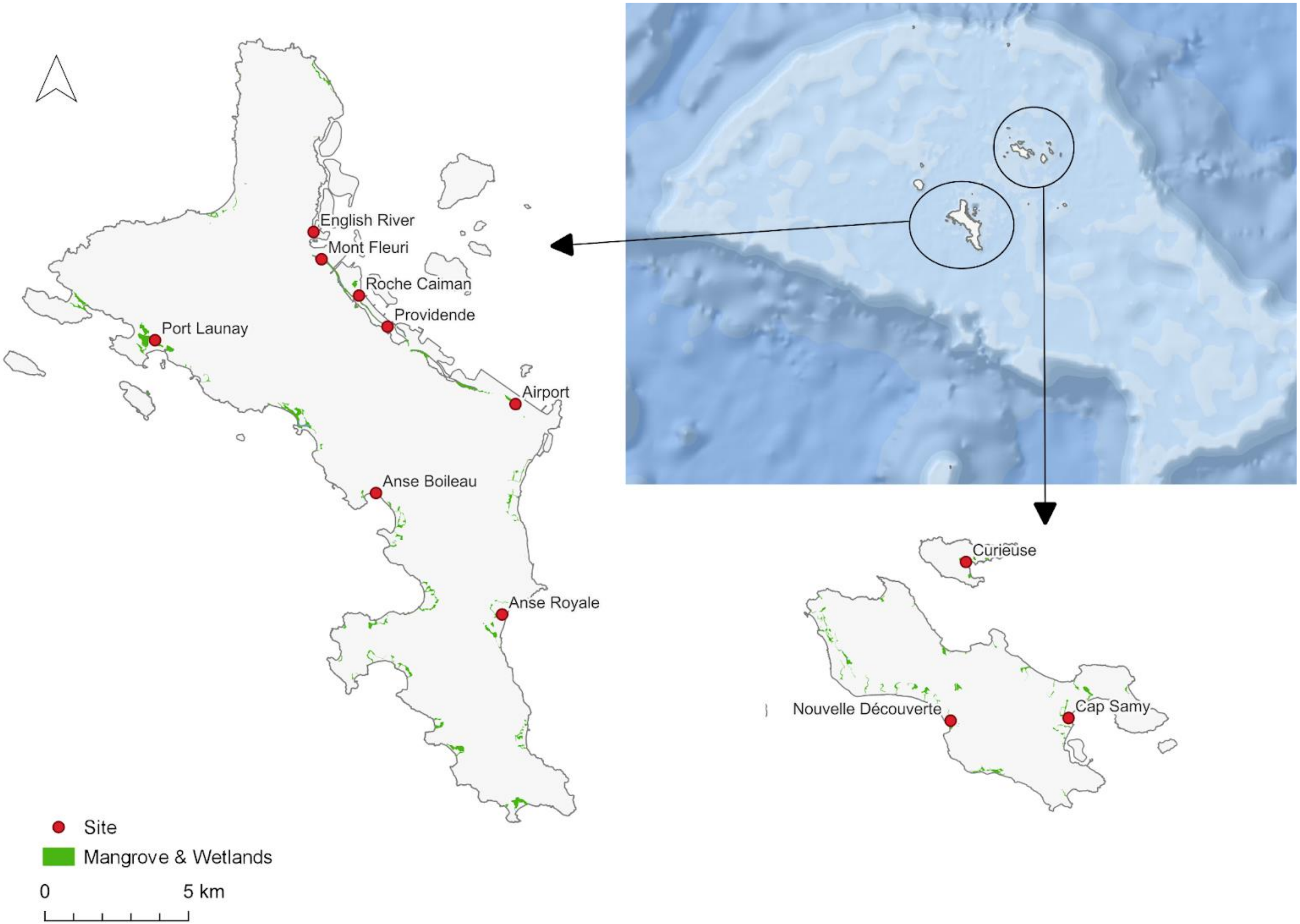


Figure 4. Location of the Sites(n=11) in Mahé (left), Praslin and Curieuse (bottom right)

Data Analysis

Size Structure, Biomass and Sex Ratio

Carapace width (CW) was measured for each captured individual. All measurements were taken with a caliper with a precision of 0.01 mm. The Length-Weight Relationship (LWR) was established using a power regression function, BW = aCW^b, with the regression parameters (a and b) estimated from Bijoux et al. (2022) and based on Toivio (2015).

Figure 5. Scylla serrata Carapace Width measurement (Left) and sex determination (Right)

The crab sex was identified according to the shape of the abdomen (triangular for males and rounded for females, Figure 5). The Sex Ratio was calculated as the ratio of the number of males to the number of females (*n* Males / *n* Females).

Catches per unit effort (CPUE; n crabs/trap/day) was calculated to compare mean catches as an approximation to abundances. Based on the LWR the CPUE was also calculated as g_{crabs}/trap/day

To investigate crab size distribution a 3-ways design was used with fixed factors Sex (*n*=2), Site (*n*=9), and Status (*n*= 2; MPA/ Other): *CW ~ Sex +Site +Status*

To investigate CPUE variability, 2-ways design was used with fixed factors Site (n=8) and Status (n= 2; No Take Zone). The following fixed-effect model were employed for both variables: *CPUE ~ Site + Status*

The seasonal variations in CPUE were assessed for the 3 Sites sampled during both season: Curieuse (CUR), Nouvelle Découverte (ND) and Port Launay (PL) using a 2-Factors design: *CPUE~ Season*Site*

Since the trap capture data did not fit to normality and homogeneity of variance assumptions, Permutational Analysis of Variance (PERMANOVA) was used following the method described by Anderson et al., (2001). PERMANOVA was chosen for univariate analyses because it allows for multi factor designs, considers an interaction term and does not assume a normal distribution of errors (Scyphers et al., 2011). This analysis was conducted to assess differences between Sites, Seasons, and Management Status, using the 'vegan' package in R (Oksanen et al., 2022). The PERMANOVA was calculated using Euclidean distance and generated a pseudo-F value, similar to the F statistic obtained in traditional ANOVA, but robust against deviations from normal distribution assumptions (Anderson, 2001). All factors were treated as fixed effects, and the analysis employed Type III sums of squares along with 9999 permutations of the residuals under a reduced model (Anderson, 2008). In instances where significant factor effects were identified, pairwise tests were conducted to explore which groups within a factor exhibited statistically significant differences.

Growth and Mortality Parameters

Growth, Mortality and Exploitation Rate parameters were estimated using Electronic length frequency analysis (ELEFAN). ELEFAN is a fishery assessment system that utilizes length-frequency (LFQ) data, readily accessible from catch records or independent scientific surveys. It was integrated in the FiSAT II program (FAO-ICLARM Fish Stock Assessment Tools; FAO, 2006). FiSAT II while user-friendly, is limited in its data import and automation capabilities. The TropFishR package addresses these limitations and offers greater flexibility for single species stock assessment with length-frequency data (Taylor and Mildenber, 2017). This package enables growth parameter estimation, incorporating two optimization techniques (simulated annealing and genetic algorithms), and a comprehensive array of tools for fisheries analysis using LFQ data (Mildenberger et al., 2017).

The growth parameters were estimated through the von Bertalanffy growth function (VBGF) using monthly CW frequency data (3 cm class interval) from TropFish R package (Mildenberger et al. 2017). The asymptotic length and von Bertalanffy growth factor were calculated by the two optimisation approaches of ELEFAN: (i) ELEFAN with simulated annealing (ELEFAN SA) and (ii) ELEFAN with a genetic algorithm (ELEFAN GA). The ELEFAN model with the best scoring fit (high Rn) was selected. Bootstrap experiments for ELEFAN GA were based on 1000 resamples. The initial estimation of asymptotic length ($L\infty$) was obtained from the Powell–Wetherall method following Mildenberger, 2017. TropFishR package was used to estimate the total instantaneous mortality rate (Z) according to the length-converted catch curve analysis and the approximation of Pauly, 1983 using the length frequency data. The natural mortality (M), due to predation, senescence, or disease (Sparre & Venema, 1998) was estimated by approximation using the VBGF growth parameters ($L\infty$ and k) (Then et al., 2015). The instantaneous fishing mortality rate, F, was deduced from the expression $F = Z - M$. The exploitation rate is defined as $E = F / Z$ and relative to the reference level of 0.5, provides a simple indication of the stock status (Gulland,1983).

RESULTS

Mud Crab Fishing Practices and Perspective

In this section the key findings derived from the responses of mud crab fishermen in the Seychelles are presented. The information gathered from the interviews provides valuable insights into the fishing practices, preferences, and perceptions of the fishermen, which are crucial for effective fisheries management.

In total 9 fishermen were directly identified though networking and 7 fishermen responded to the questionnaire. The interviewed mud crab fishermen were all biological male exhibited an age range from 37 to 63 years, reflecting a gender bias demography engaged in this fishery. Participants were distributed across various residential areas including Grand Anse Mahé, Les Mamelles, Pti barbarons, Anse Boileau, Anse a la Mouche, Bel Ombre and Baie Sainte Anne on Praslin. All respondents had substantial experience, fishing for mud crabs for five years or more, indicating a seasoned and knowledgeable group of fishermen.

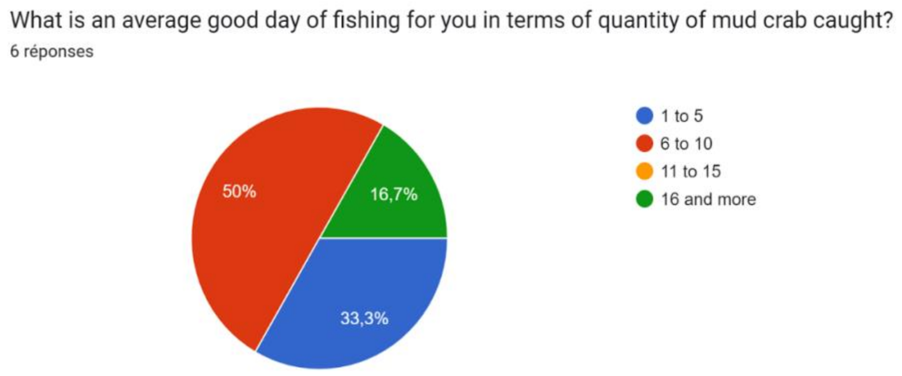
Fishing Practices Seasonality and Frequency

A variety of responses were noted regarding the seasonality of mud crab fishing, with some engaging year-round and others influenced by factors such as tides and lunar cycles, Upcoming tide and full moon being most important factor. Fishing frequency indicated diverse commitment levels of fishermen. This fishery is occasional with a maximum of 3 to 4 fishing sessions per month. Fishermen displayed flexibility in tidal preferences, choosing either low tide, high tide, or both based on their individual strategies and preferences. Lunar cycles, specifically full moons and new moons, were acknowledged by some fishermen as factors influencing their fishing efforts. Fishing activities occurred predominantly at night, aligning with the natural behavior of mud crabs.

The interviewees made mention of 13 locations where they fish for *S. serrata*, namely Plaisance, English River, Les Mamelles, Anse Boileau, Pti Barbarons (Anse Boileau), Cap Samy (Baie Sainte Anne), Mont Fleuri, Grand Police (Takamaka), Les Rochers, Anse la Mouche (Baie Lazare), Port Launay, Grande Anse Mahé, and Nouvelle Découverte (Grand Anse, Praslin). One fisherman reported the observation of *S. serrata* catch in slipper lobster nets at sea (~30m from the coast).

Catch and Usage Patterns

Fishermen reported diverse catch quantities, ranging from a minimum of 1 to 5 and reaching a maximum of 16 and more (Figure 6). The use of the catch is mainly for own consumption and/or distribution to family and friends. There is limited sale to local communities, markets, restaurants, and hotels in general (Figure 7). Price were estimated on average at 275 SCR per kilos. Males seems to be the main target in view of the greater quantity of meat in the Chelae/ claws.



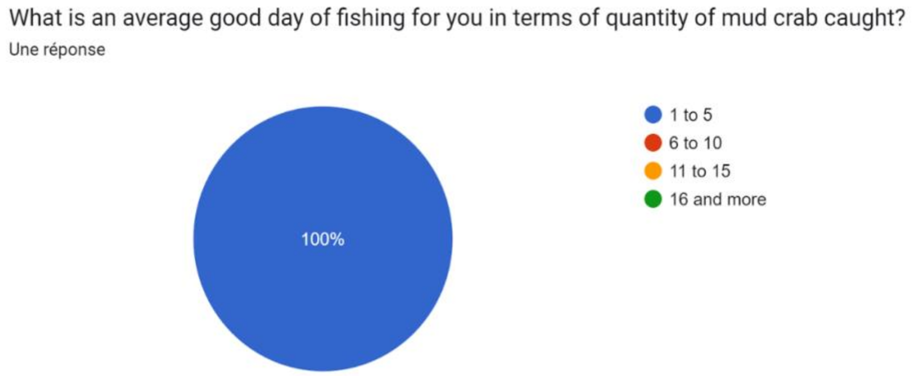


Figure 6. Average Catch for fisherman on Mahé (above) and Praslin (Below)

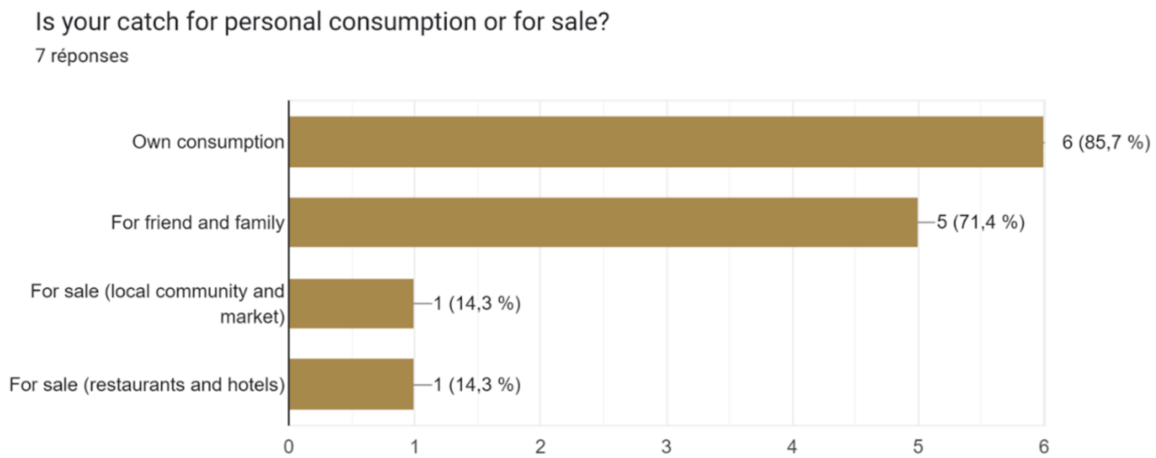


Figure 7. Reported Usage of Catch

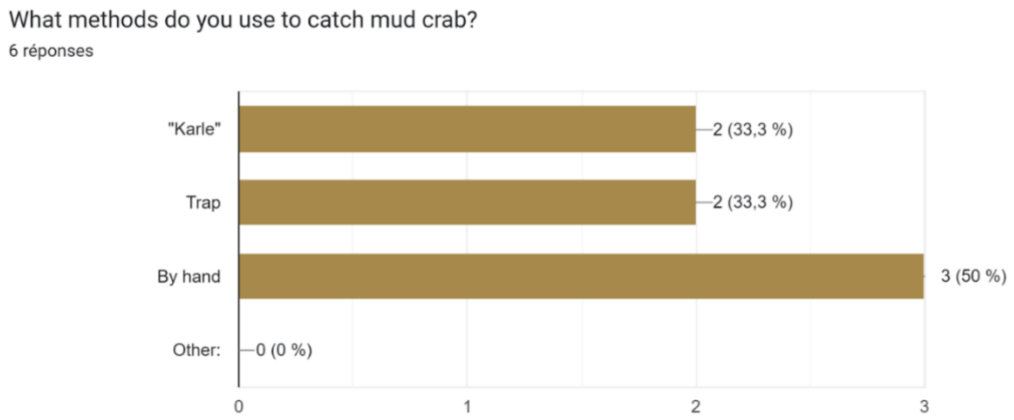


Figure 8. Gear and method of capture

Handpicking was the dominant fishing method amongst the respondent. This is followed by the use of traditional "Karle" and traps. One fisher reported using scoop nets or snares to capture the crabs (Figure 8). The number of mud crab fishing gear owned by the fishers ranged from 0 for those undertaking hand fish to a maximum of 4 traps and/or "Karle".

Perspectives on Fisheries Management

Respondents acknowledge observing a decline in mud crab populations over the last decade and expressed concerns of overfishing (Figure 9). They highlighted that the number of large crabs has also reduced. One fisherman also indicated that as a post reclamation impact he has observed significant decline in abundance of mud crab along the east coast area of Mahé

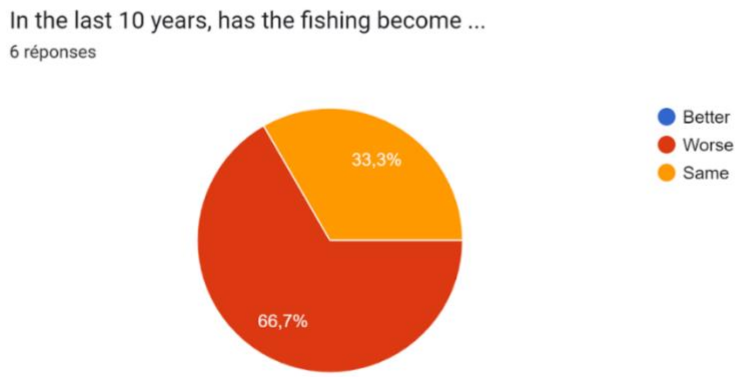


Figure 9. Vision of S. serrata catchability

Amongst the various management suggestions proposed introduction of regulated size limit was the most preferred option amongst the interviewed fisherman. The fishers were less receptive to the idea of implementing fishing license, open/close areas and a limit on the number of gears as management measures. There were mixed opinions on the introduction of open/close seasons, showcasing the need for careful consideration and stakeholder involvement in any regulatory frameworks (Figure 10). Some fisherman additionally propose release of ovigerous females.

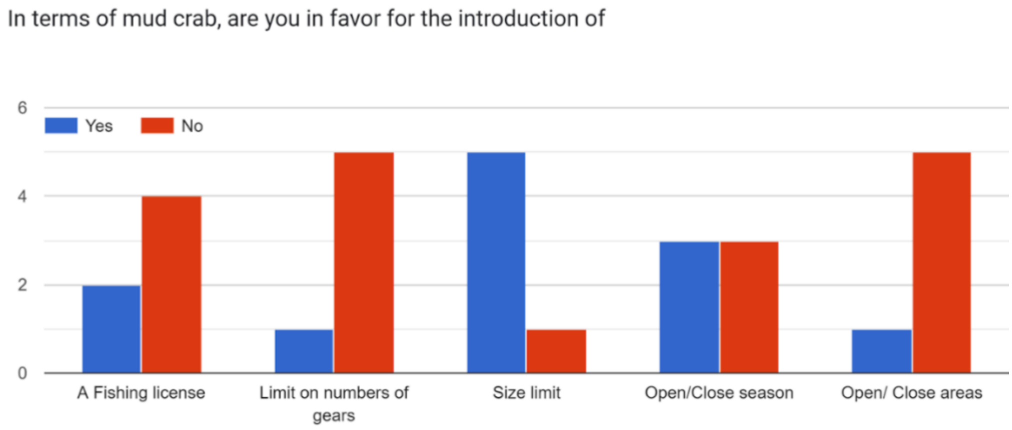


Figure 10. Perspectives of Scylla serrata fishery management

Trapping program

Between October 2022 and October 2023, a total of 695 Traps were deployed across 11 Sites. A total of 163 *S. serrata* were caught for a total of 60,646 g, consisting of 68 females and 95 males. *S. serrata* were caught at 9 mangrove Sites except for Roche Caiman, Providence and Cap Samy (Figure 11).

Table 4. Summary of the values of the carapace widths (CW, cm) and estimated total weights (BW, g) for females, males and juveniles of Scylla serrata caught off Inner Islands of Seychelles. N: number of individuals, Min: minimum, Max: maximum.

			CW (cm)			BW (g)		
		N	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Airport (AIR)	**Females**	6	16.9	**18.8**	17.55	716.4	**928.5**	787.9
	Males	5	5.1	16.1	7.94	34	944.8	229.3
	Total	11	5.1	18.8	13.18	34	944.8	534
Anse Boileau (AnB)	**Females**	7	10.3	14.4	12.33	214.6	485.2	341.4
	Males	12	8.9	12.4	10.1	157.3	428.9	237.1
	Total	19	8.9	14.4	10.92	157.3	485.2	275.5
Anse Royale (AnR)	**Males**	10	5.8	11.2	9.75	48.1	315.3	223.5
	Total	10	5.8	11.2	9.75	48.1	315.3	223.5
Curieuse (CUR)	**Females**	28	8.2	16	12.03	123.2	627	333.4
	Males	35	7.2	**19.4**	11.83	82.9	**1660.6**	462.7
	Total	63	7.2	19.4	11.92	82.9	1660.6	405.2
English River (EnR)	**Males**	1	14.7	14.7	14.7	717.6	717.6	717.6
	Total	1	14.7	14.7	14.7	717.6	717.6	717.6
Mont Fleuri (MoF)	**Females**	1	16.1	16.1	16.1	636.6	636.6	636.6
	Males	2	9.4	12.2	10.8	185.6	408.3	297
	Total	3	9.4	16.1	12.57	185.6	636.6	410.2
Nouvelle Découverte (ND)	**Females**	10	9.3	15.2	11.23	167.4	553.4	274.2
	Males	13	9.5	16.8	13.0	191.6	1074.6	542.7
	Total	23	9.3	16.8	12.23	167.4	1074.6	426
Port Launay (PL)	**Females**	16	9.3	16.2	12.43	167.4	646.3	348
	Males	17	9.2	13.4	11.15	173.9	542.3	324.3
	Total	33	9.2	16.2	11.77	167.4	646.3	335.8
Providence (Pro)	**Total**	0						
Roche Caiman (RC)	**Total**	0						
Cap Samy (CaS)	**Total**	0						
Total		**163**	**5.1**	**19.4**	**118**	**34**	**1660.6**	**378.5**

Size Structure, Biomass, and Sex Ratio

The carapace width of *S. serrata* caught ranged from 5.1 to 19.4 cm (μ_{CW} = 11.8 ±SD 2.8 cm). The largest male crab was caught in Curieuse (CW = 19.4 cm, BW = 1660.57 g, Figure 11) and the largest female was caught at the Airport, Mahé (CW = 18.8 cm, BW = 924.54 g). The analysis of CW per Sex suggest Females caught during the trapping program (μ_{CW}= 12.58 ±

SE_{CW} = 0.27 cm) were on average larger than the male caught (μ_{CW} = 11.20 ± SE $_{CW}$ 0.28; $F_{PERMANOVA}$ = 10.082 *p* = 0.003, Figure 12). PERMANOVA analysis suggested that neither Site ($F_{PERMANOVA}$ = 1.642, *p* = 0.142), or Status ($F_{PERMANOVA}$ = 0.105, *p* = 0.735) significantly affected the size distribution of the *S. serrata* population.

Overall the sex ratio of the *S. serrata* population tends be dominated by males ($\mu_{Sex\text{-}ratio}$= 1.36 ± SD 0.42) apart for the Airport Site where more females were caught during the trapping sessions (sex ratio= 0.83) (See Table 4).

Catch per Unit Effort

The overall CPUE, including data from both seasons and all municipalities, was 0.23 crab per trap per day. For the 9 Sites analyzed the management Status of the Site has a significant effect on the CPUE and the mean BW, the mean CPUE and mean BW per trap in the MPA Curieuse was significantly higher (F= 11.7379, p= 0.003; Figure 13, 14). CPUE did not differ significantly from Northwest monsoon to Southeast monsoon among the 3 sites (F=0.898, p=0.14) sampled.

Growth and Mortality Parameters

ELEFAN SA showed the best goodness of fit. The results of both methods for all populations are presented in Table 5. The L∞ estimation for *S. serrata* is 27. 53 cm. The computed growth curves produced with using those parameters were shown over its restructured length distribution. The total Mortality estimated from the catch curve was Z = 1.33 year-1. The natural mortality "M" obtained was 0.67 year-1 and the observed fishing mortality rate "F" was 0.65 year-1. The calculated exploitation rate is 0.49.

Table 5. Growth parameters and scores obtained from ELEFAN SA and ELEFAN GA for Scylla serrata population. The selected model was based on the highest Rn_max values, marked in bold.

Parameters	***ELEFAN SA***	***ELEFAN GA***
Asymptotic carapace length L∞ (cm)	27.53	21.68
Growth coefficient K ($year^{-1}$)	0.37	0.46
t_anchor	0.22	0.52
Amplitude of growth oscillation (C)	0.98	0.64
Summer point oscillation (ts)	0.12	0.46
Growth performance index phiL	2.45	2.34
Goodness of fit (Rn_max) score	**0.94**	0.57

Habitat Characteristic

Seven species of mangrove trees were identified including: *Avicennia marina, Bruguiera gymnorhiza, Ceriops tagal, Lumnitzera racemosa, Rhizophora mucronata, Soneneratia alba and Xylocarpus granatum* over the 11 Sites. The dominant mangroves species present did not impact the average catch rate of *S. serrata* at any of the Sites (Figure 16).

Figure 11. Carapace Width (CW) distribution of Scylla serrata captured from October 2022 to October 2023. CUR: Curieuse National Park, Curieuse; CaS: Cap Samy, Praslin; ND: Nouvelle Découverte, Praslin; MoF: Mont Fleuri, Mahé; RC: Roche Caiman, Mahé; PRO: Providence, Mahé; AnR: Anse Royale, Mahé; AIR: Airport, Mahé; EnR: English River; AnB: Anse Boileau, Mahé, PL: Port Launay, Mahé

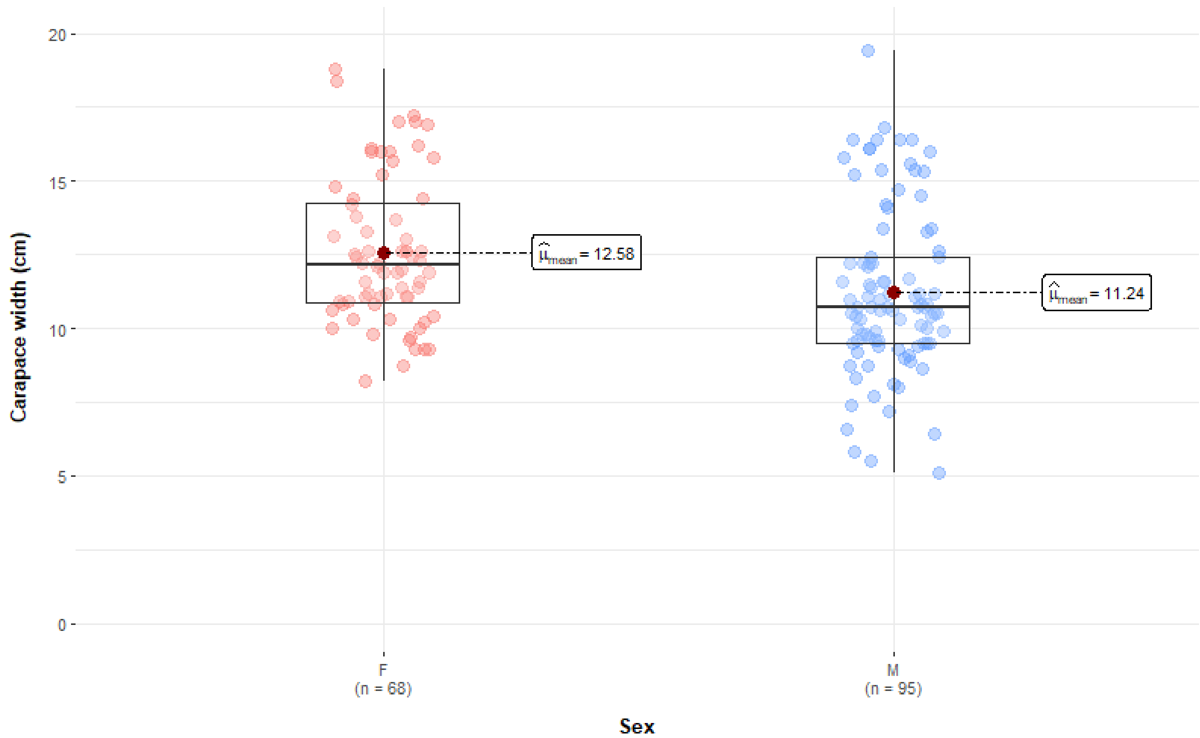


Figure 12. S. serrata mean Carapace Width (μ ±SE) per Sex (M= males; F= females).

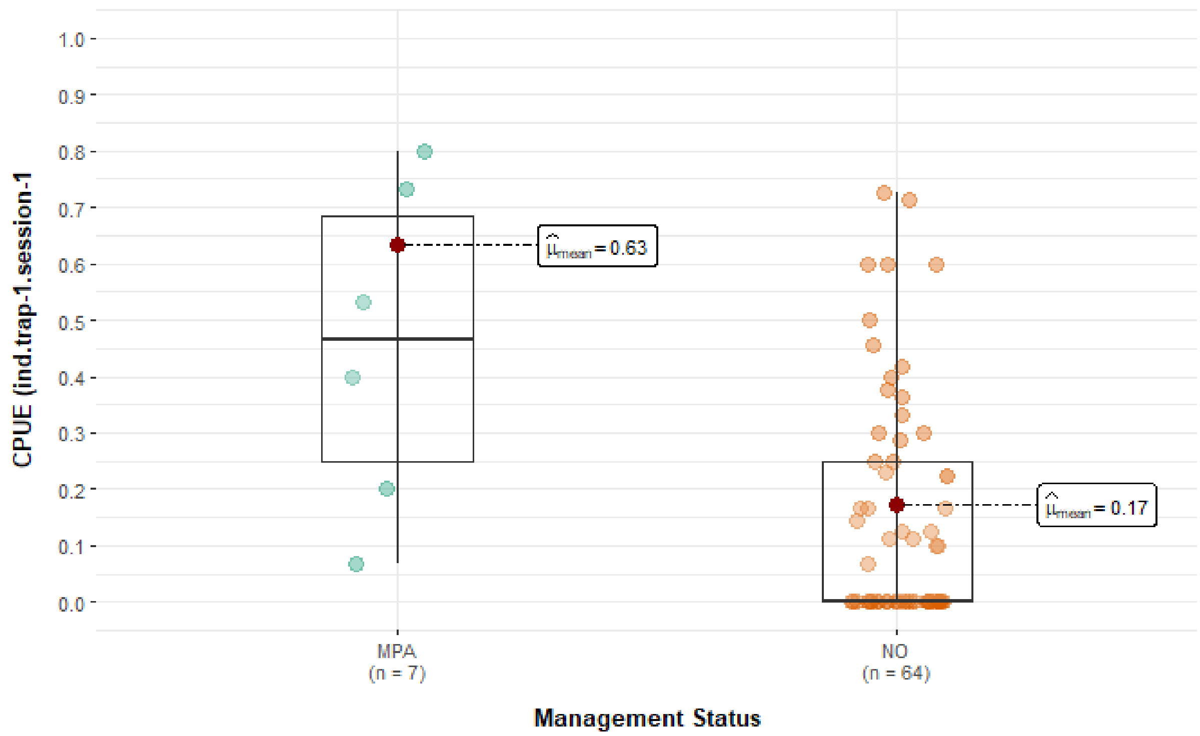


Figure 13. Mean CPUE (n crab caught per trap^{-1} per day^{-1} ±SE) per Management Status of Site (MPA = Marine Protected Areas; NO = Others).

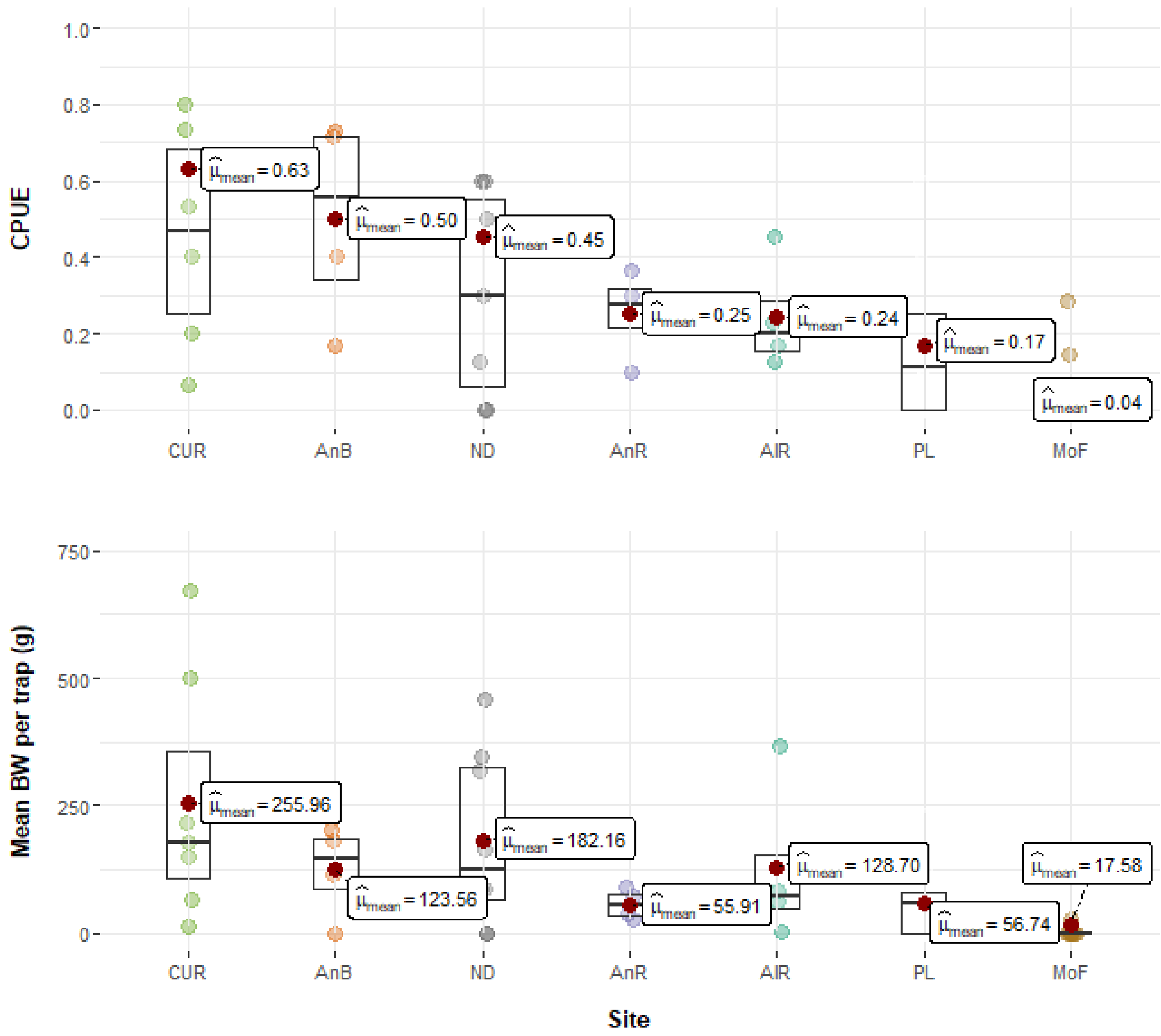


Figure 14. Catch per Unit Effort (above) and mean Body Weight per trap per day (BW; g; below) per Site. CUR: Curieuse National Park, Curieuse; CaS: Cap Samy, Praslin; ND: Nouvelle Découverte, Praslin; MoF: Mont Fleuri, Mahé; RC: Roche Caiman, Mahé; PRO: Providence, Mahé; AnR: Anse Royale, Mahé; AIR: Airport, Mahé; EnR: English River; AnB: Anse Boileau, Mahé, PL: Port Launay, Mahé.

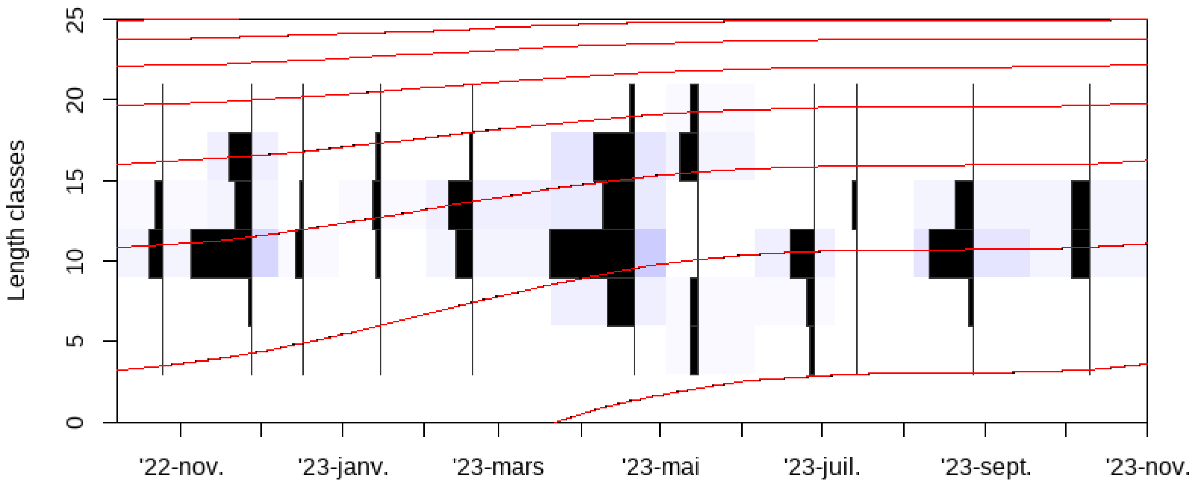


Figure 15. S. serrata estimated von Bertalanffy growth curves (Red line) from ELEFAN SA

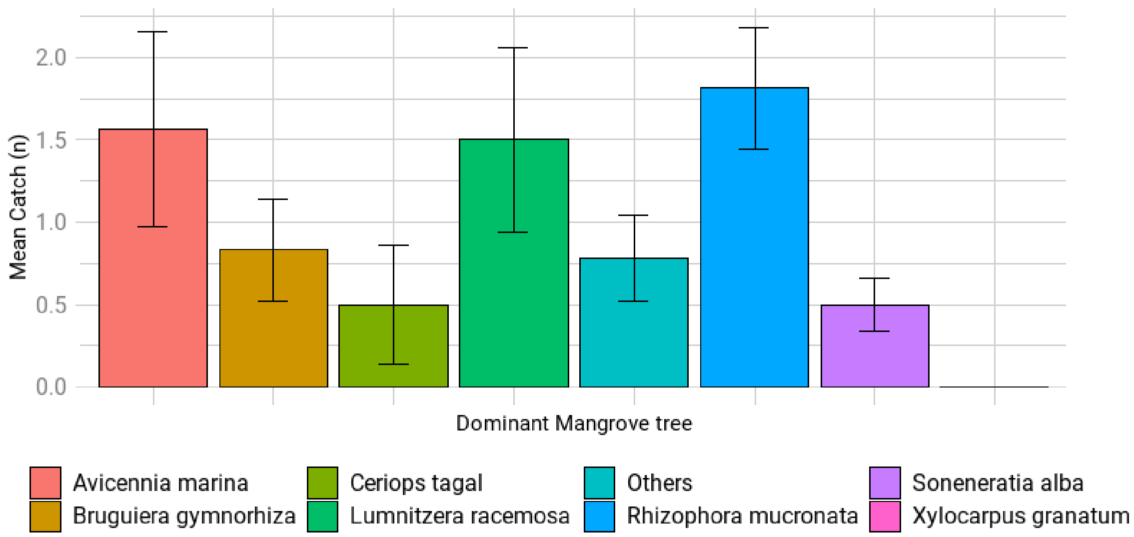


Figure 16. Mean catch of S. serrata across all sites as per the dominant mangrove species present

DISCUSSION

This study defined a foundational reference point for the stock assessment of *S. serrata* in Seychelles. The results incorporate growth and mortality parameters, utilizing data-poor fishery methodologies (Midenberger et al., 2017). CPUE, serving as an indicator of abundance, reveals distinct patterns among the sampled islands. The analysis suggests that the Curieuse Marine National Park effectively supports a higher abundance of *S. serrata*. In comparison, the heavily populated East Coast of Mahé experiences a reduced catch and smaller size of *S. serrata* caught. The no take zone status of the Curieuse Marine National Park has contributed to the local population growth and sustainability of *S. serrata*. Similar positive outcomes were observed in the Solitary Islands Marine Park, Australia, where a study spanning from December 1998 to April 2007 indicated a rapid post-closure recovery. Catches in unfished zones were 2 to 3 times greater compared to other areas (Butcher et al., 2014). These findings suggest that spatial protection measures can effectively sustain mud crab populations, offering a promising management strategy for crab species in Seychelles, especially during the implementation of Seychelles Marine Spatial Planning.

Figure 17. Juvenile S. serrata caught at Airport, Mahé

S. serrata can easily reach sizes above 20 cm CW, and maximum reported sizes seem to be slightly different in the different regions (22.8 cm in Pohnpei, Perrine, 1978; 23 cm in Kosrae, Bonine et al., 2008; 206 and 20.9 cm in Australia, Hill, 1994). Here, the biggest male crab was caught on Curieuse and measuring 19.4 cm. The ELEFAN model estimated a maximum length of 27 cm in the region. The length-classes per ages permit to translate the maximum CW crab captured to an age of 3.14 years; 14 cm to 1.95 years and 12 cm to 1.66 years. This estimated parameter is in accordance with others studies showing that individual crabs can achieve a maximum size that exceeds 20 cm CW over a life span on the order of 3 to 4 years (Figure 15; Bonine et al., 2008). For comparison, the age of *S. serrata* caught in Asahan sea, Indonesia, with the maximum carapace width of 17.5 cm was 4.57 years (Pane et al 2021). Although we did not explicitly evaluate maturity of captured crabs, we observed no cases (e.g., large, immature crabs) that contradicted size-maturity relations reported elsewhere (Bonine 2008). The numbers of total catch per sex limited analysis to differentiate parameters between male and female *S.serrata*. Growth rates of males and females are similar (Mirera & Motile, 2009), but as in many other brachyuran crab species, adult male mud crabs are heavier than females of the same size due to their bigger chelae/claw (sexual dimorphism). The observed sexual dimorphism in this species creates distinct fishery selectivity dynamics, with interviews indicating a prevalent tendency among Seychelles fishermen to target large male crabs. Notably, the absence in our catch of large male crabs on Mahé suggests intensive fishing pressure in this region. Furthermore, the observed male predominance in mud crab populations is evident, with a male-to-female ratio slightly exceeding 1.4:1. This finding aligns with similar observations made on Astove Island (Bijoux 2022), emphasizing a consistent trend in the region. However, this ratio stands in stark contrast to the considerably higher male-to-female ratios, reaching up to 3:1, reported in unfished populations such as in Kosrae, Micronesia (Bonine et al., 2008).

The exploitation rate of nearly 0.50 estimated in this study indicates the need for application of suitable management measures. Theoretically, when E = 0.50, then the stock of any aquatic species is considered to be at the optimum level. According to Gulland (1983), the yield was optimized when F = M; therefore, when E was more than 0.5, the stock is considered to be over fished. In our estimation Natural Mortality is close to Fishing Mortality, thus near equilibrium. However, the calculation for exploitation rate included data from Curieuse, a No Take Zone, thus potentially biasing the result for fishing mortality. In this context, A precautionary approach would be to consider the stock of Mahé at the limit of exploitation and the implementation of sustainable management measure a priority. The result is supported by results from the fisherman interview on Mahé were the numbers of crabs caught has been one of the concerns of the fisherman (66.7 % think the fishery become worse). The interviews with fishermen did not reveal significant commercial fisheries activity, indicating that the *S. serrata* populations primarily support traditional and subsistence fisheries. Moreover, the estimated limit of exploitation rate and the reduced CPUE at fishing sites suggest that implementing larger-scale commercial activities in Mahé and Praslin may not be viable. In response to this decrease, mariculture emerges as a potential solution, provided it incorporates a restorative component, including the release of juveniles into the wild.

In terms of sustainable management, the initiation of a mud crab fishery management plan in 1991 by the Northern Territory Government, Australia, is an excellent example supporting both commercial, recreational and indigenous fishing effort and in 2018 stocks were classified as sustainably fished in all management areas. This framework implemented in Australia involved the enforcement of various compliance measures including a recreational possession limit of 10 mud crabs per individual or 30 per vessel (Northern Territory Government, 2017), limit of the recreational trap or daily limit to 5 per person or 10 per vessel and the imposition of a prohibition on the capture of berried female mud crabs. Additionally, there was an adjustment in the minimum legal size (MLS) for female mud crabs, by increasing it from 130 mm carapace width (CW) to 140 mm (Robins et al. 2020). A significant management outcome in Australia resulted from the elevation of the minimum size limit for female mud crabs, providing a precautionary strategy to safeguard over 70% of females from direct fishing mortality until reaching maturity (Ward et al. 2007). The CPUE, expressed as kg per trap per day, serves as a primary indicator representative of mud crab abundance in the Northern Territory. The Northern Territory's management framework incorporates a harvest strategy with key indicators, including target and trigger reference points (Northern Territory Government, 2017).

The annual average CPUE target reference point is set at 0.6 kg per trap/ day, with an upper trigger reference point at 0.7 kg per trap/ day. If the April-May fisheries independent survey average CPUE falls below 0.3 kg per trap/ day, a seasonal closure of 3, 6, or 13 weeks, starting on October 1st, is implemented. A more stringent closure is enforced if the limit reference point of 0.2 kg per pot day is breached. In comparison, our assessment of the mud crab population in Seychelles indicates an overall mean CPUE of 0.12 kg per trap/day with a maximum of 0.25 kg per trap/day on Curieuse signaling a significative low abundance and biomass within this framework (Figure 14).

Figure 18. Polluted mangrove habitat in Anse Royale

During the fieldwork conducted for this study, only a few juvenile mud crabs were captured, and despite substantial search efforts across multiple sites, crablets were seldom encountered. Limited study indicates the occasional capture of mud crab megalopae within bays or estuaries (Walton et al., 2006, Dumas et al., 2012). Webley et al., (2009) suggest that, given the behavior exhibited by the crablets, seagrass beds may serve as potential nursery habitats for mud crabs. If this is the case, managing this habitat becomes crucial for maintaining the resilience of the population. Similar conclusions were drawn in the Astove Atoll by Bijoux (2022). This finding has multiple implications, particularly for potential aquaculture systems for mud crab fattening in Seychelles as the inadequate supply of seeds has consistently posed a primary challenge for most mud crab farmers (Rahman et al., 2017). Moreover, traditional grow-out farming heavily relies on seeds collected from the wild, a practice deemed unsustainable as it may lead to habitat degradation and threaten wild mud crab populations (Liew et al., 2023).

S. serrata exhibits a close association with the mangrove ecosystem and surroundings (Léoville et al., 2021). The degradation, fragmentation, and pollution of this crucial ecosystem could have a significant impact on the populations of *S. serrata* in Seychelles. For example, during sampling it was observed that some mangrove areas such as in Anse Royale has been significantly modified by human, there are high level of pollution and signs of eutrophication which could relate to nearby agricultural practices (Figure 18). Recognizing the interconnectedness between mud crab species, seagrass and mangroves underscores the importance of proactive conservation measures to preserve both the biodiversity of the mangrove habitat and the sustainability of *S. serrata* populations in the Seychelles Islands.

CONCLUSION AND RECOMMENDATIONS

Based on the preliminary insights and stock parameters gained from this study on mud crab, the formulation and implementation of a Mud Crab Fishery Management Plan are imperative. The following recommendations are proposed for effective management:

Fishery Independent Surveys: Conduct bi-annual surveys at key sites on Mahé, and it is highly recommended for the following three sites to be included amongst the chosen ones: Anse Boileau, Port Launay, and Airport. These surveys should focus on gathering reference points, utilizing Catch Per Unit Effort (CPUE) data. The information obtained will guide decisions on the implementation of management measures.

Minimum Size Limit: Establish a minimum size limit of 130 mm for both male and female mud crabs. This size limit is crucial for ensuring the sustainability of the mud crab population by allowing individuals to reach reproductive maturity before being harvested.

Release of berried females: Prohibit the catch and sale of berried females.

Habitat management: The quality of the habitat, including mangrove forests and seagrass beds, is a limiting factor for the sustainability of this species. Monitoring indicators of the quality of these habitats, including the percentage of vegetation cover and total extent, is an important framework to understand catch output. We recommend working on these indicators to enhance understanding and improve habitat management practices for the sustainable conservation of the species.

Study on Scylla Serrata Females: Gonad Maturation and Reproductive Ecology: Understanding the ecology and migration patterns of female *S. Serrata* would provide valuable data for nursery larval production from eggs, limited by the availability of berried females for collection. Moreover, implementing a ban during the peak breeding season is considered an effective strategy to facilitate the safe migration and spawning of berried females. However, the work conducted in this study did not allow for the identification of the peak season for berried females, given that our sites were situated within estuaries and inshore mangrove habitats. Ovigerous females undertake an offshore migration, potentially reaching up to 50 km offshore in the case of *Scylla serrata* (Hill, 1994). Additionally, berried females exhibit reduced susceptibility to conventional fishing methods, such as baited traps, as they cease feeding during their offshore migration. In this context, we recommend conducting a specific study on the maturity of *S. serrata* females using the gonado-somatic index as an indicator. The gonado-somatic index, calculated as the ratio of crab gonad weight to total body weight, proves particularly helpful in identifying peak months and percentages of gonad maturation for reproduction.

Hatchery-Produced Crablets: the importance of hatchery-produced seeds in mitigating the impact on wild populations, efforts should be directed toward developing and implementing successful mud crab seed production techniques. Challenges such as inadequate wild seed supply, cannibalism, disease outbreaks, and the lack of commercial species-specific formulated feeds need to be addressed to facilitate mass seed production.

Crablet from Outer Islands: It is important to conduct thorough research to ascertain the potential of Outer Islands such as Cosmoledo or Astove in seeding mud crab crablets for aquaculture or restocking purposes in the Seychelles Inner Islands. Exploring the viability of sourcing crablets from these Outer Islands holds great promise for enhancing aquaculture practices and supporting restocking initiatives within the Seychelles. This investigation aims to uncover the suitability of Outer Islands as potential crablet reservoirs, contributing valuable insights to the sustainable development and conservation of mud crab populations in the region.

Mud crab restocking: Restocking is a management approach involving the release of hatchery-bred mud crabs to enhance, conserve, or restore fisheries. Mud crab restocking associated with mangrove and seagrass restoration, aligned with initiatives such as TRASS in Praslin, can provide ecological, societal, and economic benefits. A potential site for piloting this approach is Nouvelle Découverte on Praslin.

Juvenile Mud Crab Study: Conduct a specific study on mud crab juveniles, employing dedicated methods to gather information on sink areas and recruitment patterns. A part of this research should focus specifically on seagrass beds to verify their importance as a nursery ground for this species. This research will enhance understanding of the early life stages of mud crabs, contributing to effective management strategies and provide the decision support as to whether or not mud crab fattening would be financially feasible in Seychelles.

In conclusion, the complexity of mud crab fishing practices and the diversity of perspectives among fishermen underscore the need for adaptive and collaborative management strategies. Balancing the conservation of mud crab populations with the socio-economic needs of fishing communities requires ongoing dialogue and collaboration between fishermen and fisheries managers. The recommendations outlined herein aim to contribute to the sustainable future of mud crab fisheries in the Seychelles, promoting both ecological health and community well-being.

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ANNEX

Annex 1: Standardized questionnaire used to undertake fishers survey

https://docs.google.com/forms/d/e/1FAIpQLSdgPd_be70V7NufCj__p-9dcAMklCLwdcXTtJebH2RiUb1OKg/viewform

Annex 2: Social media post informing the public on the stock assessment and fishers survey

- Article published in Seychelles Nation: https://www.nation.sc/articles/15002/survey-to-assess-stock-of-mudcrab
- Facebook post by Seychelles Nation journal: https://www.facebook.com/892374494444335/posts/survey-to-assess-stock-of-mudcrab-sfa-studies-its-potential-for-aquaculture-the-/1776095526072223/
- QR code to access online survey made available on SFA (Aquaculture) website: https://seychellesaquaculture.com/2022/09/21/mud-crab-stock-assessment/
- Details on the press conference and link to the online survey made available on SFA (Aquaculture) website: https://seychellesaquaculture.com/2022/09/15/mud-crab-survey-stock-assessment-press-conference/
- Article was published by Seychelles News Agency: http://www.seychellesnewsagency.com/articles/17408/Caught%2C+tagged+and+released+First+mud+crab+study+launched+in+Seychelles
- SBC 8 pm news on the 10th September 2022 (0:55-5:44 minutes): https://www.youtube.com/watch?v=5ZFNF9N9P6g

Annex 3: List of participants in the field training for mud crab data collection

#	Name	Organisation
1	Danroy Prudence	SFA - Aquaculture
2	Calvin Horner	SFA - Aquaculture
3	Ian Confiance	SFA - Aquaculture
4	Zachery Morin	SFA - Aquaculture
5	Danilla Adonis	SFA - Aquaculture
6	Jean-luke Bristol	SFA – Aquaculture
7	Andrew Esparon	SFA – Aquaculture
8	Steve Gappy	SFA – Aquaculture
9	Davis Monthy	SFA – Aquaculture
10	Nathalie Dufresne	SPGA
11	Sheril Decommarmond	SPGA