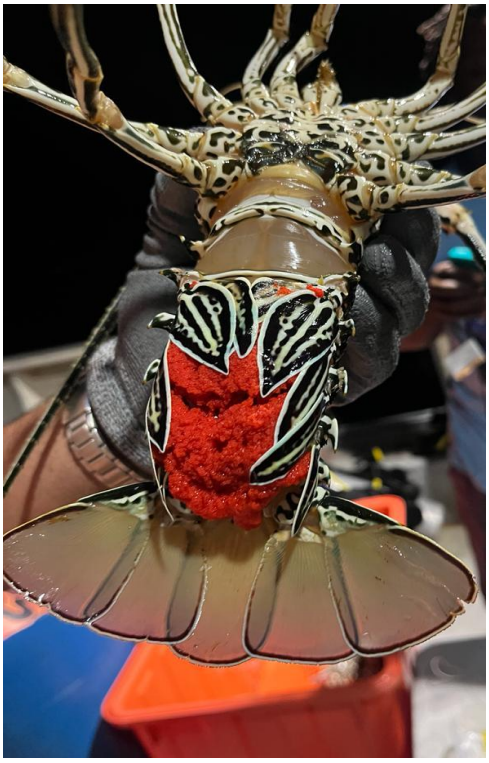
SURVEY OF SPINY LOBSTER IN GRANITIC AND CORALLINE ISLAND ON MAHÉ PLATEAU (ZONES 2 & 3)



FINAL REPORT

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TABLE CONTENTS

Acknowledgements **6**
Abstract **7**
1. Introduction **8**
1.1. Life History 8
1.2. Overview Of Spiny Lobster Fisheries Globally 9
1.3. Seychelles Spiny Lobster Fishery 10
2. Methodology 13
2.1. Survey Approach 13
2.2. Survey Area 13
2.3. Site Selection 15
2.4. Survey Technique 17
2.4.1. Underwater Survey 17
2.4.2. Habitat Survey 18
2.4.3. Night Survey 19
2.5. Biological Sampling 20
2.6. Data Analysis 21
2.6.1. Standardising Data 22
2.6.1.1. Density In Number And Weight By Zones 22
2.6.2. Proportion Between Surveys 23
2.6.3. Habitat 23
2.6.4. Length- Weight Relationship 24
2.6.5. Size Frequency Distribution 25
2.6.5.1. Berried Females 25
2.6.6. Sex Ratio 26
3. Results **26**
3.1. Catch Composition 27
3.1.1. Species Composition 27
3.1.2. Sex Composition 28
3.1.3. Mean Density By Survey Zones 29
3.1.3.1. Mean Density In Numbers 29
3.1.3.2. Mean Density In WEIGHT 30
3.1.4. Proportions Between Surveys 31
3.1.5. Population Size Structure 33
3.1.5.1. Carapace Length By Species 33
3.1.5.2. Carapace Length By Zones And Species 35
3.1.5.3. Mean Size Between Surveys 37
3.1.6. Berried Females 37
3.1.7. Proportion By Substrate 41
3.1.8. Comparison By Substrate Between Survey 43
4. Key Survey Results 45
5. Discussion 47
5.1. Species Composition 48
5.2. Abundance And Weight 48
5.3. Size Indicator 50
5.3.1. Carapace Length 50
5.3.2. Mean Carapace Between 1991 And 2023 Survey 51

5.3.3. Species By Sex....51
5.4. Sex Ratio....51
5.5. Length- Weight Relationship....52
5.6. Reproduction....53
5.7. Comparison Between 1991 And 2023....54
5.8. Habitat....55
5.9. Study Limitations....57
6. Conclusion....57
7. Recommendations....58
8. References....59
Appendix 1....68
Appendix 2....70

FIGURE CONTENTS

Figure 1: Schematic of lobster external body plan; A) dorsal view *Panulirus versicolor*; B) ventral view *Jasus edwardsii*. Modified diagram by Gabriel (2021). Source: (Chan, 2010; Woods and James, 2003: Swainston, 2015). 9

Figure 2: Survey stations around the inner granitic and coralline islands on the Mahé Plateau. Red; rocky substrate, blue; coral substrate, white triangle; rock islets, colour boxes; survey zones. The map was populated in QGIS 3.26. 14

Figure 3: Schematic of survey transects using the diving and snorkelling method. Transect length of 200 m and 5 m width on each side. Designed by Gabriel. K, 2023....19

Figure 4: Difference between male and female lobsters. A-D) Features of female lobsters. E-G) Features of male lobsters. H) Dorsal view of the carapace length measurement location. **Source:** Seychelles Fisheries Authority survey pictures. 21

Figure 5: Photographs of species catch composition sampled from October and November 2023. A) *Panulirus longipes*; B) *Panulirus penicillatus*; C) *Panulirus versicolor*. Note: SN - scientific name; CN - common name; LN - local name. **Source:** MNHN (2024) and Tin-Yam (2010). 28

Figure 6: Mean density of lobsters (number/m^2) per species by zones sampled during the 2023 survey. Each bar represents the mean density in numbers per square metre within the respective survey zone. Error bars depict standard error +/- 1. **N.B**; One station was surveyed on Bird Island, and the standard error bar is not applicable....30

Figure 7: Mean density of lobsters (kg/m^2) per species by zones sampled during the 2023 survey. Each bar represents the mean density in numbers per square metre within the respective survey zone. Error bars depict standard deviations. **N.B:** One station was surveyed on Bird Island, standard error bar not applicable. 31

Figure 8: The proportion of lobsters surveyed between 1991 and 2023 around Mahé Island. **N.B:** The 1991 survey was limited to stations around Mahé Island due to engine issues. 32

Figure 9: Size frequency distribution of female and male of three lobster species sampled during the 2023 survey. Frequency represents the counts of each size class. The dashed black line highlights the minimum size limit of 7.5 cm (CL). 34

Figure 10: Box plot of the size distribution of females and males of all three species sampled. The text value is the mean and the median depicted by the black straight line. 35

Figure 11: Box plot of the size distribution of lobsters sampled during the 2023 survey. A) Distribution across survey zones. B) Distribution across survey zone by species. **N.B**; Aide (n=9) and Praslin Ridge (n=4) were excluded from the analysis due to the small sampling size. 36

Figure 12: Length frequency of all the berried females by species (*Panulirus penicillatus*; n =55, *Panulirus longipes*; n =46, *Panulirus versicolor*; n = 5) captured during the entire survey 2022/2023. O; bright orange, newly formed, R bright red, newly formed, B; brownish intermediate stage; and DB, dark-brown ready for release. Black dashed line fishery minimum size limit of 7.5 cm. 38

Figure 13: Length-weight relationship of males and females lobster by species collected during the 2023 survey.....40

Figure 14: Proportion of lobster species observed across habitats in all survey zones. 41

Figure 15: Box plot of standardised number of lobsters per transect area by substrate type sampled during the 2023 survey. A) Lobster catches by habitat type. B) Species by habitat type. 42

Figure 16: Mean carapace length (cm) per species by substrate type sampled during the 2023 survey. 43

Figure 17: Proportion of lobster observed across different habitats around Mahé Island between 1991 and 2023 surveys. **N.B:** The 1991 survey was limited to stations around Mahé Island due to engine issues. The habitat sampled in 2023 surveyed was mainly coral and rock only.....44

TABLE CONTENTS

Table 1: Stratification of survey stations using habitat type and reef morphology.....17

Table 2: Sampling summary and species composition of Panulirus sp. across surveyed zones. 27

Table 3: Mean carapace length (cm) of female and male lobsters by survey years.....37

Table 4: Parameters of the length (carapace length (cm)) – weight (body weight (kg)) regression analysis ($W= a L^b$). The coefficients a and b, the coefficient of determination (R^2), the regression F value and the categorisation of allometry. 39

Table 5: Post hoc pairwise comparisons of **mean density in numbers per m^2 by zone using Dunn's Test**. P values were adjusted with the Bonferroni method.....68

Table 6: Post hoc pairwise comparisons of **mean density in numbers per m^2 by zone of *Panulirus penicillatus* using Dunn's Test**. P values were adjusted with the Bonferroni method.....68

Table 7: Post hoc pairwise comparisons of **mean density in numbers per m^2 by zone of *Panulirus versicolor* using Dunn's Test**. P values were adjusted with the Bonferroni method. 68

Table 8: Post hoc pairwise comparisons of **mean density in weight (kg) per m^2 by zone Dunn's Test**. P values were adjusted with the Bonferroni method.....69

Table 9: Post hoc pairwise comparisons of **mean density in weight (kg) per m^2 by zone of *Panulirus penicillatus* using Dunn's Test**. P values were adjusted with the Bonferroni method..69

Table 10: Post hoc pairwise comparisons of **male carapace length by species using Dunn's Test**. P values were adjusted with the Bonferroni method. 70

Table 11: Post hoc pairwise comparisons of **female carapace length by species using Dunn's Test**. P values were adjusted with the Bonferroni method.....70

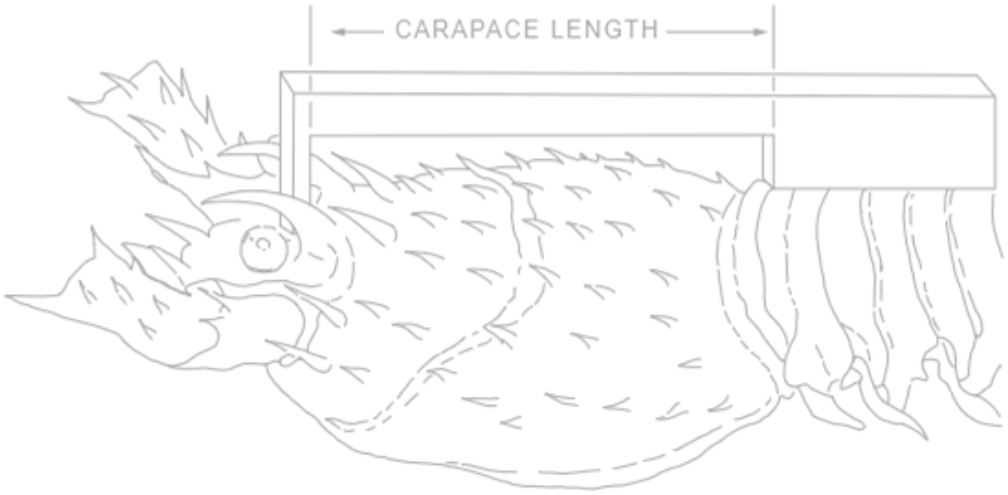
Table 12: Post hoc pairwise comparisons of **carapace length by zone using Dunn's Test**. P values were adjusted with the Bonferroni method. 70

Table 13: Post hoc pairwise comparisons of ***Panulirus penicillatus*** **carapace length by survey zones using Dunn's Test**. P values were adjusted with the Bonferroni method.....71

Table 14: Post hoc pairwise comparisons of **female *Panulirus penicillatus* carapace length by survey zones using Dunn's Test**. P values were adjusted with the Bonferroni method. 71

Table 15: Post hoc pairwise comparisons of **male *Panulirus penicillatus* carapace length by survey zones using Tukey**. P values were adjusted with the Bonferroni method.....71

Table 16: Post hoc pairwise comparisons of ***Panulirus penicillatus*** **mean carapace length by habitat type using Dunn's Test**. P values were adjusted with the Bonferroni method. 72



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ABSTRACT

This study investigated the abundance and spatial distribution of spiny lobsters around the granitic and coralline islands on the Mahé Plateau, Seychelles. Four surveys conducted from October to November 2023 focused on specific habitats to capture variations in lobster populations. Results indicated higher mean density in remote islands on the Mahé Plateau, such as Denis and Bird Island, with lower densities around La Digue per square metre. Species-specific patterns emerged; *P. penicillatus* was more abundant and heavier at Denis Island, while *P. versicolor* showed low mean density across zones, with a significant presence around the Mahé West sites. *P. longipes* was more prevalent around the Mahé West and South sites, but there was no statistically significant difference in abundance between the 2 areas. Carapace lengths were smaller around the main islands and largest around the 2 remote Islands surveyed. The *P. longipes* and *P. versicolor* were statistically significantly larger in coral habitats compared to rock habitats, while *P. penicillatus* were larger in rock habitats. *P. longipes* and *P. versicolor* had higher proportions below the size limit of 7.5 cm compared to *P. penicillatus,* being the largest of the former species. A negative allometric growth pattern was observed, indicating lobsters were lighter relative to carapace length, with a sex ratio of 0.85:1, favouring females. The 1991 survey comparison showed a reduction in overall mean size, a reduction in survey zones decline in proportion in Mahé North and South sites and increases in Mahé West and East sites. Overall habitat preference was not evident; however, species-specific differences were observed with *P. penicillatus* favouring coral habitats. We found a greater abundance associated with coral habitats. Given uncertainties in lobster biology, ecology, and reproductive dynamics, and potential fishing impacts, additional research is necessary to understand the mechanisms driving distribution patterns on the Mahé Plateau. Extending efforts to the outer islands is essential for understanding lobster spatial distribution and abundance. This will contribute to more informed management strategies for a sustainable lobster fishery in Seychelles.

1. INTRODUCTION

1.1. LIFE HISTORY

Achelata or 'pincer-less' (chelae) crustaceans are a group of marine decapods within the class Malacostraca, which includes Palinuridae (Spiny lobsters), Synaxidae (Furry lobster) and Scyllaridae (Slipper lobsters; Palero et al., 2009; Bracken-Grissom et al., 2014). The Palinuridae family has 54 extant species, of which the Panulirus genus (spiny lobsters) exhibits the highest diversity with 24 species/subspecies (Briones-Fourzán, 2014). Spiny lobsters (herein referred to as "lobster"), also known as Rock lobster (Australia), Langouste (France), Langustas (Spain), or 'Oumar' (Seychelles), occupy habitat in shallow waters to over 600 m (Booth, 2001). Generally, they are distributed throughout the tropical and subtropical regions from the Indo-Pacific (North and South America), Atlantic Ocean, the Mediterranean seas, India, Asia, Australia, New Zealand, and the Pacific Islands (Kanciruk, 1980; Petersen et al., 2012). Lobsters can be distinguished by a segmented body fused to the cephalothorax (head and thorax), a cylindrical carapace with spines, frontal horns above the eyes, 5 pairs of pereopods (walking legs), long flagella, and antennae (**Figure 1**; Pitcher, 1993).

Like other crustaceans, lobsters grow through ecdysis (moulting or shedding of carapace) and possess a meroplanktonic lifecycle with phyllosoma-puerulus life stages (Briones-Fourzán, 2014; Ventura et al., 2015; Barret, 2019). Lobsters are external brooders whereby females can produce over 1 million small, sized eggs in each brood (Marzouqi et al., 2008; Musbir et al., 2018). Brood size can vary between species and body size, and changes with environmental parameters (e.g., seasonality; Pérez-González et al., 2012; Green et al., 2014; Musbir et al., 2018). Compared to Aves (birds) and Mammalia (mammals) groups, in lobster, parental care is non-existent after both phyllosoma-puerulus life stages, during which survival is influenced by various environmental factors (Pollock and Melville-Smith, 1993; Green et al., 2014; Baeza et al., 2016). Larger brood size and selectively small-sized eggs increase the overall survival probability of a cohort (Pollock and Melville-Smith, 1993). These nocturnal opportunistic scavengers are highly

active in low-light conditions and feed on a broad food spectrum ranging from macroalgae (surf-grass Phyllospadix spp., calcareous algae), live prey (gastropods, bivalves, crustaceans, etc.), to dead decaying matter (Radhakrishnan et al., 2019).

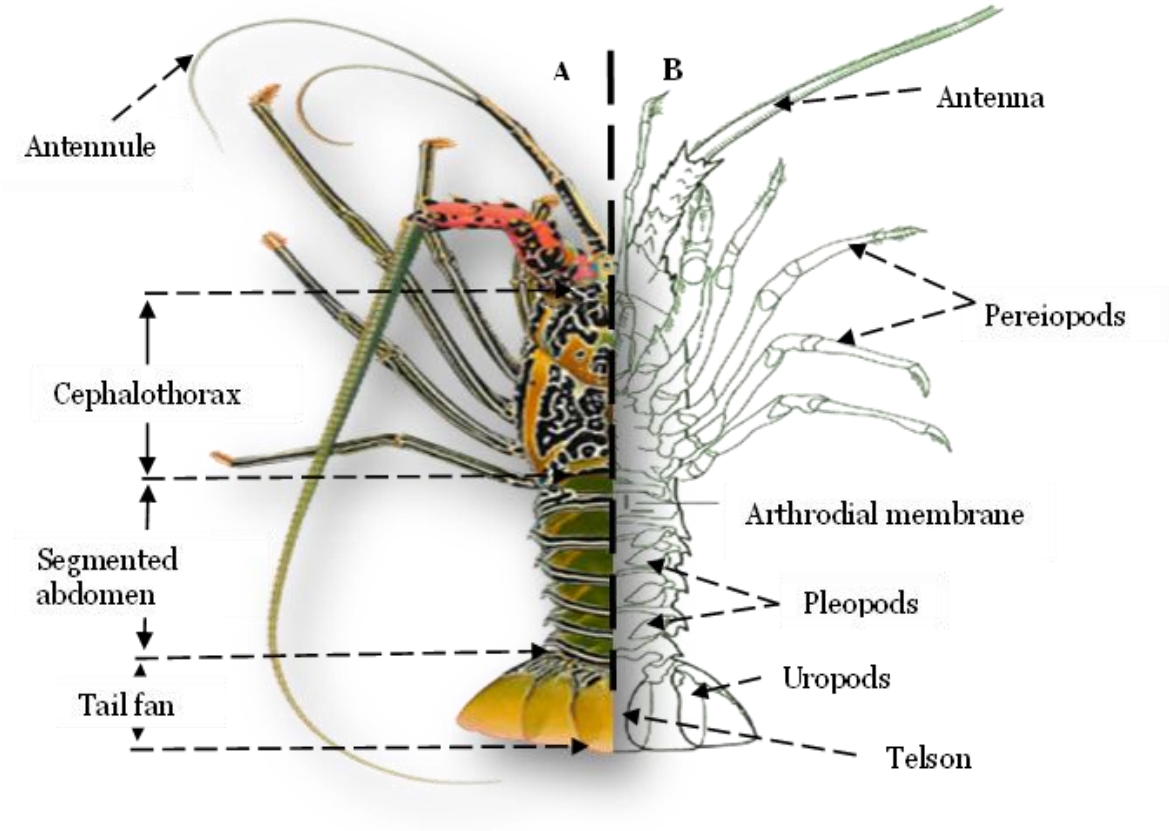


***Figure 1**: Schematic of lobster external body plan; A) dorsal view Panulirus versicolor; B) ventral view Jasus edwardsii. Modified diagram by Gabriel (2021). Source: (Chan, 2010; Woods and James, 2003: Swainston, 2015).*

1.2. OVERVIEW OF SPINY LOBSTER FISHERIES GLOBALLY

Since the 19th century, lobsters have been a lucrative resource with increasing marketable demands, especially for the tourism industry (Radhakrishnan et al., 2019). In 2017, the annual landed catch of lobster (*Palinuridae*), including the clawed lobsters (*Nephropidae*), was 315,469 metric tons globally (Barret, 2019). The demand for lobster meat remains high. Amongst the Panulirus species, only a few (*P. argue* Caribbean, *P. polyphagus* India, *P. cygnus* Australia) have significant economic importance, for mostly small-scaled

artisanal fishers and many small developing countries like Belize (Monnereau and Pollnac, 2012; Giraldes et al., 2015; Higgs et al., 2016). Some countries also have recreational take (Phillips et al., 2010; Long, 2017). Different methods are used for capturing lobsters across many countries which include, traps, pots, nets, spears, skin diving, hooka and scuba diving (Munro, 2000; Marzouqi et al., 2008; Seychelles Fishing Authority [SFA], 2022). Depending on the species and regions, these methods can be used alone or in combination (Munro, 2000). In Zanzibar, the localised fishery utilises skin diving, spearing and 'Dema' traps, whilst Hawaiian catches the *P. marginatus* (Banded spiny lobster) and *P. penicillatus* (Pronghorn spiny lobster) solely from using traditional traps (Munro, 2000). To date, most stocks are exploited, some to the point of full exploitation or overexploitation, leading to the depletion of many global stocks (Pitcher, 1993; Spanier et al., 2015; Cau et al., 2019). Limited access, minimum size restriction, TAC (total allowable catch), fishing gear limit, and release of berried females are standard management measures implemented in different countries that seek to prevent overexploitation (Penn et al., 2015).

1.3. SEYCHELLES SPINY LOBSTER FISHERY

In Seychelles, the lobster fishery began in the 1980s and has since become a crucial source of financial income for local fishers (Bautil, 1991). The lobster fishery focuses primarily on the shallow coastal waters surrounding the inner granitic islands. The fishery targets four main species: *Panulirus penicillatus*, also known as the Pronghorn spiny lobster "Oumar gro latet" (Oliver, 1791); *Panulirus longipes*, the Long-legged spiny lobster "Oumar rouz" (A. Milne Edwards, 1868); *Panulirus versicolor*, the Painted spiny lobster "Oumar ver" (Latreille, 1804); and *Panulirus ornatus*, the Ornate spiny lobster "Oumar blan" (SFA, 2023). These species are typically found in fringing carbonate reefs and granitic reef structures, including crevices, burrows, and coral overhangs (Holthuis, 1991).

Lobster fishing in Seychelles typically targets different locations around the inner granitic islands. Fishing activities take place from dusk to dawn using small outboard vessels to

access different coastal grounds (Radhakrishnan et al., 2019; SFA, 2023). These trips usually involve two to four individuals, lasting approximately five hours on average (SFA, 2023). Most fishing trips occur at night, though a few occur during the day, particularly scuba diving. Several fishing techniques are practised locally, including scuba diving, snorkelling, and traps (SFA, 2023). However, the most prevalent method among fishers is hand collection by snorkelling or skin diving. This method entails fishers using snorkelling gear and underwater flashlights to extract lobsters from crevices in the reef habitat. Scuba diving and trap fishing methods are utilised to a lesser extent and contribute to a smaller percentage of the overall catch.

In the 1970s, the Seychelles lobster fishery experienced a significant rise in landings. This increase was largely influenced by the tourism industry, which became particularly noticeable when the fishery was re-opened after a six-year closure from 1983 to 1989. Subsequently, in 1991, a fishery-independent survey was conducted around Mahé island to collect lobster biological information. Using older, less robust methods, the data suggested that the Maximum Sustainable Yield (MSY) of lobsters was around 3.5 metric tonnes (MT; Bautil, 1992). Further to this, recommendations were introduced to reduce fishing efforts due to the limited stock (Mees et al., 1998; Bautil, 1992). It is important to note the MSY estimates reported in Bautil (1992) are considered relatively weak and are no longer considered reliable.

The fishery is currently managed through several management measures aimed at promoting sustainability. These measures include seasonal restrictions, typically spanning 2 to 3 months, limited licence allocation, and capping the number of divers per licence holder. Divers are also prohibited from retaining lobsters below 75 mm carapace length or berried females of any lobster species (SFA, 2023). Despite these efforts to manage the lobster fishery, Illegal, unreported and unregulated (IUU) fishing practices remain a significant issue affecting the lobster resource. Hence the fishery has experienced significant declines in catches over the past decade (SFA, 2023).

Reported catch landings have shown inter-annual variation. In the 2020/2021 fishing season, the highest recorded landings were 6.14 MT, the third highest over 12 years of opening seasons (SFA, 2021). This is 41% higher than the historical mean of 4.4 MT (SFA, 2021). However, in the subsequent years, recorded landings were 2.05 MT in 2021/2022 and 3.32 MT in 2023, respectively. It is important to note that these catches are not directly comparable due to differences in fishing duration between the seasons. These fluctuations in landings become more apparent when the fishery remains open for 3 to 4 consecutive seasons. Additionally, persistent illegal fishing poses a significant challenge in the lobster fishery. Hence not all the catches are represented by reported figures due to the high proportion of underreported landings despite efforts to deter such activities.

A pre-season fishery-independent survey, known as the Participatory Lobster Monitoring Programme (PLMP), is conducted annually to assess the stock (Barret, 2019; Bautil, 1991). The survey uses several stock indicators, including size and CPUE (Catch Per Unit Effort, both in terms of numbers and weights), to determine whether the fishery will reopen or remain closed[1] (SFA, 2023). However, it is important to note that the PLMP survey does not equate to a comprehensive fishery-independent survey. With almost three decades since the last fishery-independent survey, the Seychelles Fishing Authority acknowledged the need for a new comprehensive fishery-independent survey. The survey aimed to evaluate the abundance and distribution of the lobster population throughout the granitic and coralline islands of the Mahé Plateau.

The survey was undertaken from October to November 2023, and the findings are reported here. The objectives of this survey were, for the 4 *Panulirus* species, 1) to obtain fishery-independent abundance and spatial distribution data; 2) to gather morphological and habitat information; and 3) to conduct tagging to monitor recovery, movement and growth. The results from this survey will help provide evidence-based recommendations for the management of the lobster fishery.

[1] Note: The lobster fishery was opened for 2 months early in January and February 2023 and remained closed in 2024.

2. METHODOLOGY

2.1. SURVEY APPROACH

The initial intention was for the survey to completely emulate the 1991 Lobster Assessment Survey. However, there was no well-defined methodology for the 1991 site selection and the sampling protocol used for the underwater transect (how the transect was surveyed and its length and width were not clearly documented). This necessitated adopting a new survey approach altogether. Certain aspects of the 1991 survey were retained, 1) Collaborating with local fishers to utilise their expertise in searching and catching lobsters. This collaboration ensured the survey methods were practical and grounded in local expertise. 2) The sampling protocol for collecting morphological data was largely retained, with a few additional data were collected; these were carapace length measurements, sex, species, weight, and reproductive markers were retained. New information was recorded, compared to the 1991 survey, including tagging information, shell state, and physical state. However, the shell and physical state of lobsters were not analysed in this report due to insufficient data. 3) Similar survey areas allowed the survey to cover the same general regions of interest, which is crucial for understanding long-term trends in lobster populations and habitat conditions. However, the main limitation in directly comparing the 1991 and 2023 surveys lies in the differences in survey methodologies. As previously mentioned, these differences limit the direct comparison of results and impact the ability to make certain historical comparisons.

2.2. SURVEY AREA

The survey was conducted in the inner islands of the Mahé Plateau. The Mahé Plateau encompasses clusters of granitic and coralline islands rich in various marine habitats, composed of consolidated and unconsolidated calcium carbonate (limestones) and/or granitic substrates/ structures with and without direct coral growth which provide essential habitats for spiny lobster populations (**Figure 2**; McClanahan et al., 2000; United Nations Environment Programme [UNEP], 2005; Mair and Beckley, 2012). The island's

reef topographic varies depending on the degree of exposure to wave action which from continuous and regular fringing reefs to reef margins are highly irregular with numerous channels to granite cliffs submerged steeply into the ocean (Wagle and Hashimi, 1990; McClanahan et al., 2000). The islands are exposed to south equatorial currents flowing from a westerly direction that changes during the northwest monsoon (November to March) to equatorial counter currents flowing in an easterly direction (Mair and Beckley, 2012). The survey focused on the waters surrounding granitic and coralline islands (**Figure 2**).

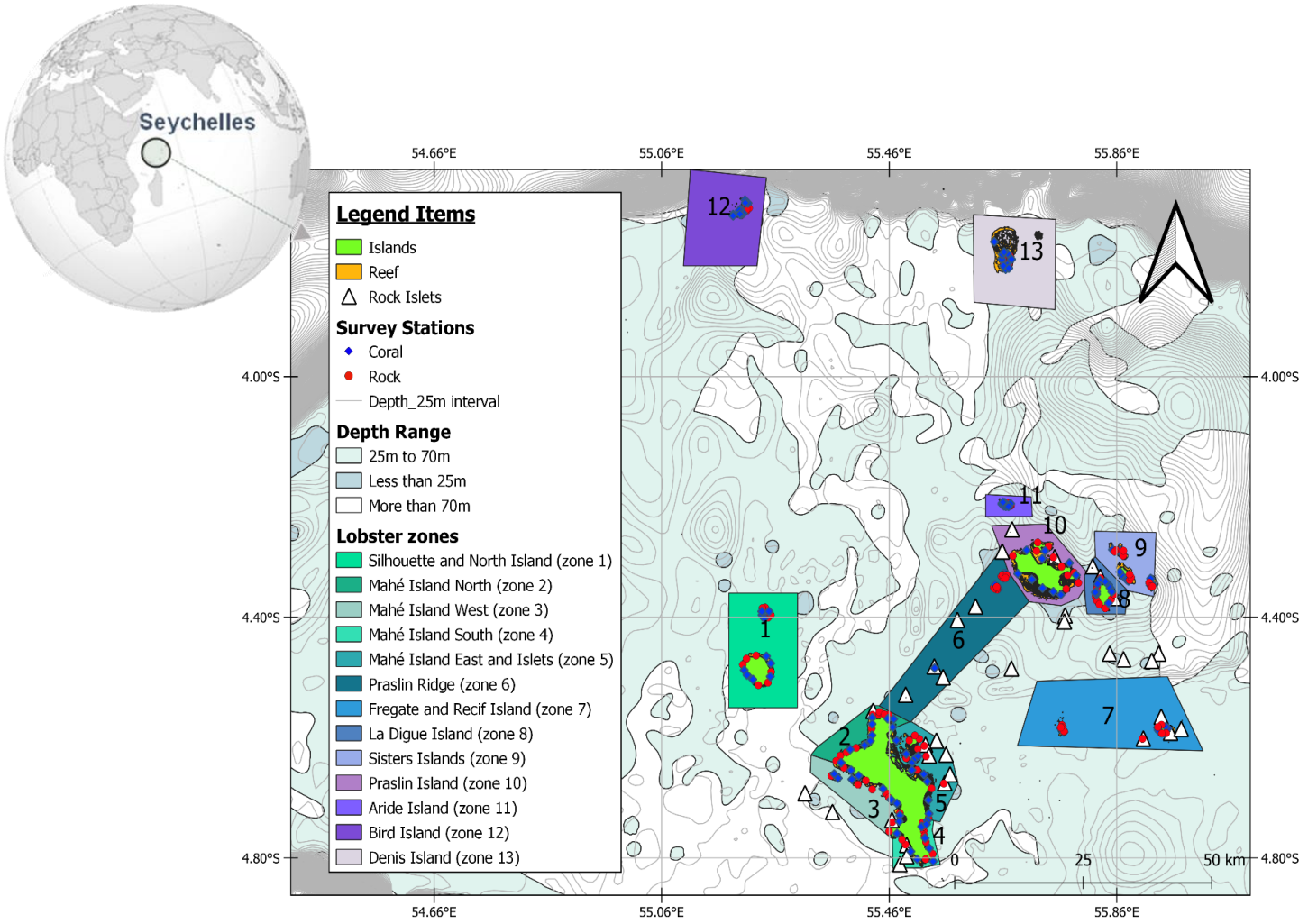


Figure 2: Survey stations around the inner granitic and coralline islands on the Mahé Plateau. Red; rocky substrate, blue; coral substrate, white triangle; rock islets, colour boxes; survey zones. The map was populated in QGIS 3.26 (Gabriel. K, 2023).

2.3. SITE SELECTION

The selection of survey sites (referred to as survey stations herein) was undertaken using the fishing zones established in the 1995 spiny lobster report published by the Seychelles Fisheries Authority (Domingue and Boullé, 1995). The fishing zones were adjusted to include 13 zones instead of the original 20 zones from Domingue and Boullé (1995; **Figure 2**). This adjustment accommodated logistical constraints, including limited survey days and travel time between zones. Some zones were merged to streamline survey operations and ensure comprehensive coverage. Given that lobsters occupy specific habitats, the fishery catch data from 2012 to 2022 was used to inform survey stations based on the habitat type. The number of lobsters caught in each habitat was then divided by the total number of lobsters caught to determine the percentage of lobsters in each habitat. Subsequently, the proportion obtained in each habitat was multiplied by a targeted number of sampling stations to obtain the number of stations within each habitat stratum to be surveyed.

A two-layer stratified random design was used within each survey zone. The design was based on the benthic (habitat type) and geographic data files (reef morphology) for the Mahé Plateau obtained from the Allen Coral Atlas (Allen, 2020). Data on benthic substrate and reef topography is almost non-existent for the Mahé Plateau, and the Allen Coral Atlas provided a comprehensive estimate. Stratification by depth was not possible because the accessibility to bathymetric data has also proven to be challenging, especially in shallow waters.

Prior to the allocation of survey stations, a literature review was undertaken to determine the preferred habitat type for the 4 *Panulirus* species and their depth range, which mostly ranges from 1 to 50 m (Holthuis, 1991; Pitcher, 1993; Chakraborty and Radhakrishnan, 2015). It is important to note that depth is not reported in the fishery data, hence the literature review. Considering safety aspects, especially for nighttime dives in deeper waters, 15 m was the maximum depth surveyed. As the data files from Allen Coral Atlas

provided habitat types as far as 5 m and the reef morphology to 15 m, both parameters were used in conjunction to account for the depth range (1 - 15 m).

Certain habitat types and reef morphology from the Allen Coral Atlas were excluded. Habitats where lobsters are unlikely to be found, such as sand or rubble, were considered unfavourable and excluded. Deep lagoons, reef slopes, land and deep water were also excluded from the analysis of reef morphology data. According to the habitat type from the fishery catches, corals and rocks were the most frequently found habitats with lobsters. Consequently, habitats were categorised into these two habitat types.

Survey stations were then stratified across the 13 survey zones using habitat and reef morphology data to ensure an even distribution of stations in each zone. A grid was created within each survey zone with grid cells every 0.001 (approximately (~) 100 m) of a degree. Subsequently, this grid was delimited according to each type of sampling substrate present within the respective zone. For example, the grid covering a specific zone was first overlaid on the rock polygons creating a grid of survey points covering all the rock substrates. Similar process was done for the coral substrates. Within each habitat type, the appropriate number of grid points were randomly selected and became the survey sampling stations. Alternative stations were also randomly selected to serve as backup if the identified stations were in unsamplable areas (e.g. station in deep water). As a higher proportion of lobsters were caught in the rock substrate, more survey stations were allocated in this substrate type to reduce variance in the data.

Using the Geographic Information System Software (QGIS) version 3.26.3, the base layer of the Mahé Plateau, the Google Satellite imagery and the Allen Coral Atlas were used simultaneously. The satellite imagery provided a visual context of where the survey stations were, while the Allen Coral Atlas provided detailed habitat data. This combined approach facilitated the relocation of survey stations not situated within the designated habitat strata or found on the beach. Cross-referencing the survey stations with the imagery and habitat data ensured survey stations were located in suitable habitats.

A total of 126 survey stations were randomly selected across the 13 survey zones. There were 88 survey stations for rock and 42 survey stations for coral (**Table 1**). Each zone had approximately (~) 10 survey stations, of which 6 survey stations were in rocks, and 4 were in corals (**Table 1**). Approximately 32 survey stations were identified to be surveyed per leg, with 4 stations per day under favourable sea conditions.

Table 1: Stratification of survey stations using habitat type and reef morphology.

Strata code	Combined strata classification		*Planned stations per zone	+Planned total stations
	Substrate type (5 m)	Reef morphology (15 m)		
●	Rock	Back Reef Slope	6	88
	Rock	Inner Reef Flat		
	Rock	Outer Reef Flat		
	Rock	Reef Crest		
	Rock	Shallow Lagoon		
	Rock	Sheltered Reef Slope		
	Rock	Terrestrial Reef Flat		
◆	Coral	Back Reef Slope	4	42
	Coral	Inner Reef Flat		
	Coral	Outer Reef Flat		
	Coral	Reef Crest		
	Coral	Shallow Lagoon		
	Coral	Sheltered Reef Slope		
	Coral	Terrestrial Reef Flat		
Total			**10**	**126**

Note: *Planned station per zone is number of stations to survey per 1 survey zone. + Planned total stations are all stations to survey in either rock or coral habitats.

2.4. SURVEY TECHNIQUE

2.4.1. UNDERWATER SURVEY

Underwater Visual Census (UVC) has been identified as the most suitable non-destructive technique to survey macroinvertebrates, including lobsters (Watson et al., 1995; Hill and Wilkinson, 2004; Patterson et al., 2007). During the day, a 200 metre (m) transect with a 10 m width (5 m on each side) was set on each survey station. The transect rope was methodically deployed at a height of ~1 m above the benthic substratum and secured

with sinkers (heavy chains) on either end of the transect rope. Random sinkers were placed along the transect rope to prevent the transect from dislodging by drag or swells. The number of sinkers was not definite and depended on multiple factors, such as survey station, habitat, or sea condition. The transect rope was deployed parallel to shore when surveying near land and with the current in areas without land in sight.

Prior to transect deployment, a snorkelling inspection was conducted on each survey station to assess the habitat suitability for lobsters. This allowed the survey team to visually inspect the station, identifying key features like corals, rocks, or other structures that serve as shelter for lobsters. This preliminary assessment helped ensure that the chosen stations offer adequate lobster habitat, optimising the survey's effectiveness. The following criteria were used based on the habitat characteristics:

- If the proportion of shelter in the habitat was 20% or more, the transect was deployed, and underwater surveys were conducted day and night.
- If the proportion of shelter in the habitat was less than 20%, a search was conducted within 10 m of the predetermined survey station to locate suitable habitats.

This approach ensured that survey efforts were concentrated in areas with the highest likelihood of supporting lobsters, maximising the effectiveness of data collection. Detailed information was recorded for each survey station, including the sampling date, station number, and site name, along with other parameters, such as sea state and moon phase, before the start of the survey. The underwater survey was divided into two phases: day and night. The daytime survey focused on assessing the habitat biotype, while the nighttime was centred on recording and capturing lobsters.

2.4.2. HABITAT SURVEY

Once the transect was deployed, a habitat survey was conducted by snorkelling or scuba diving depending on depth which was influenced by the tidal heights. This allowed the scientific team to inspect and familiarise themselves with the survey surroundings. The survey team, comprising 2 scientific divers, swam one along each side of the transect

rope, covering the designated length and width of the survey area. During the habitat survey, divers visually assessed and recorded the percentage cover of coral, rock, sand, seaweed, rubble, and seagrass within the surveyed area. Additional information was also recorded, such as the minimum and maximum depth of the surveyed location, GPS position coordinates, and general observations.

2.4.3. NIGHT SURVEY

At each survey station, 2 Underwater Visual Census (UVC) methods were used based on the depth gradients: SCUBA diving at 5-15 m and snorkelling at 0-5 m^2 (**Figure 3**). The survey team comprised 4 individuals divided into teams of 2, with 1 scientific diver paired with 1 commercial diver. A total of 2,000 m^2 area was surveyed per transect [3]. Each team surveyed one side of the 200 m x 10 m transect, which is 1,000 m^2, in a systematic 'S' shape and searched for lobsters. The commercial diver collected all lobsters along and within the transect. The scientific diver counted and recorded the number of lobsters and species missed (not captured) by the commercial fishers within the transect. Details such as time in/out, survey direction, transect length/width (m), current direction/strength, visibility (m), water temperature (◦C) and general observation were also recorded.

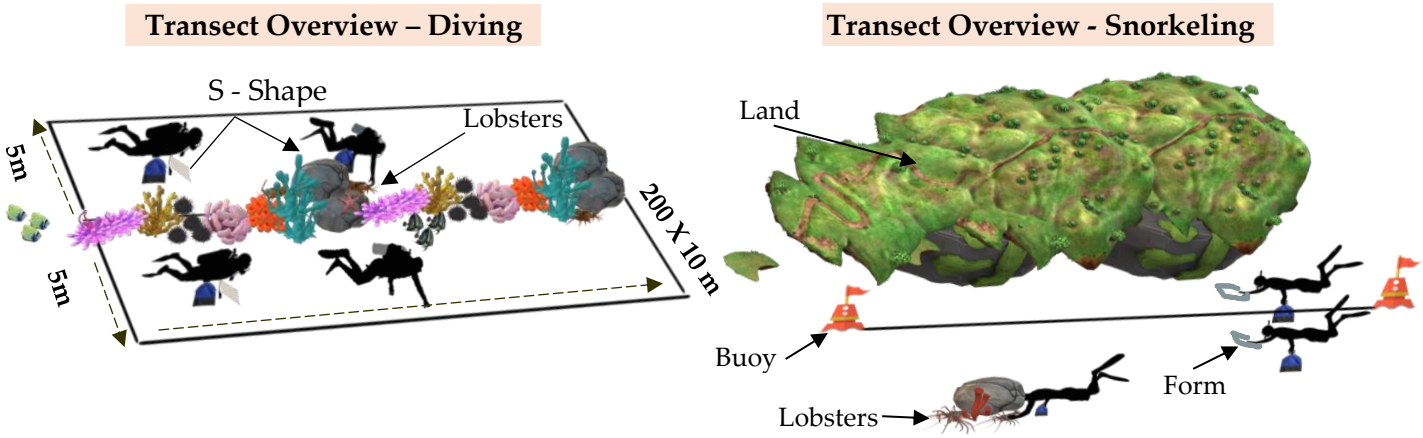


Figure 3: Schematic of survey transects using the diving and snorkelling method. Transect length of 200 m and 5 m width on each side. Designed by Gabriel. K, 2023.

[2]**Exception:** Survey techniques were adjusted based on conditions like swell, surge, habitat topography, and tide levels, particularly in coastal areas where specific depth criteria were set for each technique.

[3]**Exception:** Two survey sites, 1 Denis and 1 Bird Islands, a 400 m x 10 m transect, were conducted due to reef structure and complexity.

2.5. BIOLOGICAL SAMPLING

Biological information was obtained from the subset of lobsters collected by the commercial diver from each team. As these species are dioecious (separate reproductive organs), the sexes were distinguished based on several physical characteristics. Females were identified by examining the base of the 3rd pereopods for the genital aperture (gonopore), fork-like shaped 5th pereopod, and large pleopods/swimmeret with short slender hair-like appendages for egg attachment under the abdomen (**Figure 4 A, B&C**; Powell and Eriksson, 2013). Conversely, male lobsters were identified by the distinctive genital aperture on the basal segments of the 5th pereopods (walking legs), 5th pereopods with pointy tips, and single pleopods swimmeret under the abdominal segment (**Figures 4 E, F&G**; Powell and Eriksson, 2013).

Species were identified by their distinctive morphological colouration. Morphometric data for each species, including individual body weight (grams (g)) and carapace length (millimetre (mm)) were measured and recorded. Reproductive markers such as sperm plaque, berried state (**Figure 4 D&I**) and setae hair were also observed and recorded. Additional information was also recorded, such as the shell conditions (pre-moult, inter-moult, and post-moult) and the physical state (injuries, lesions, blisters, or leg/antennae damage). The carapace length (mm) was measured from the notch between the frontal horns (near the eye stalk) to the carapace posterior margin (cephalothoracic length; Model: 150 Vernier Caliper Locking Screw, Range 200 mm, Jaw 40 mm, precision ±0.05 mm; **Figure 4 H**). The body weight (g) measurement was obtained using a high-precision digital scale (Model: Jadever - JWP, accuracy ±0.01 g). For each berried female (i.e with eggs) caught, the colouration of the egg mass (i.e., post extrusion stage) was recorded using an egg colour spectrum from orange (reddish in *P. versicolor*) in newly fertilised individuals to brownish colour before hatching (**Figure 4 I**). After sampling, all lobsters were released.

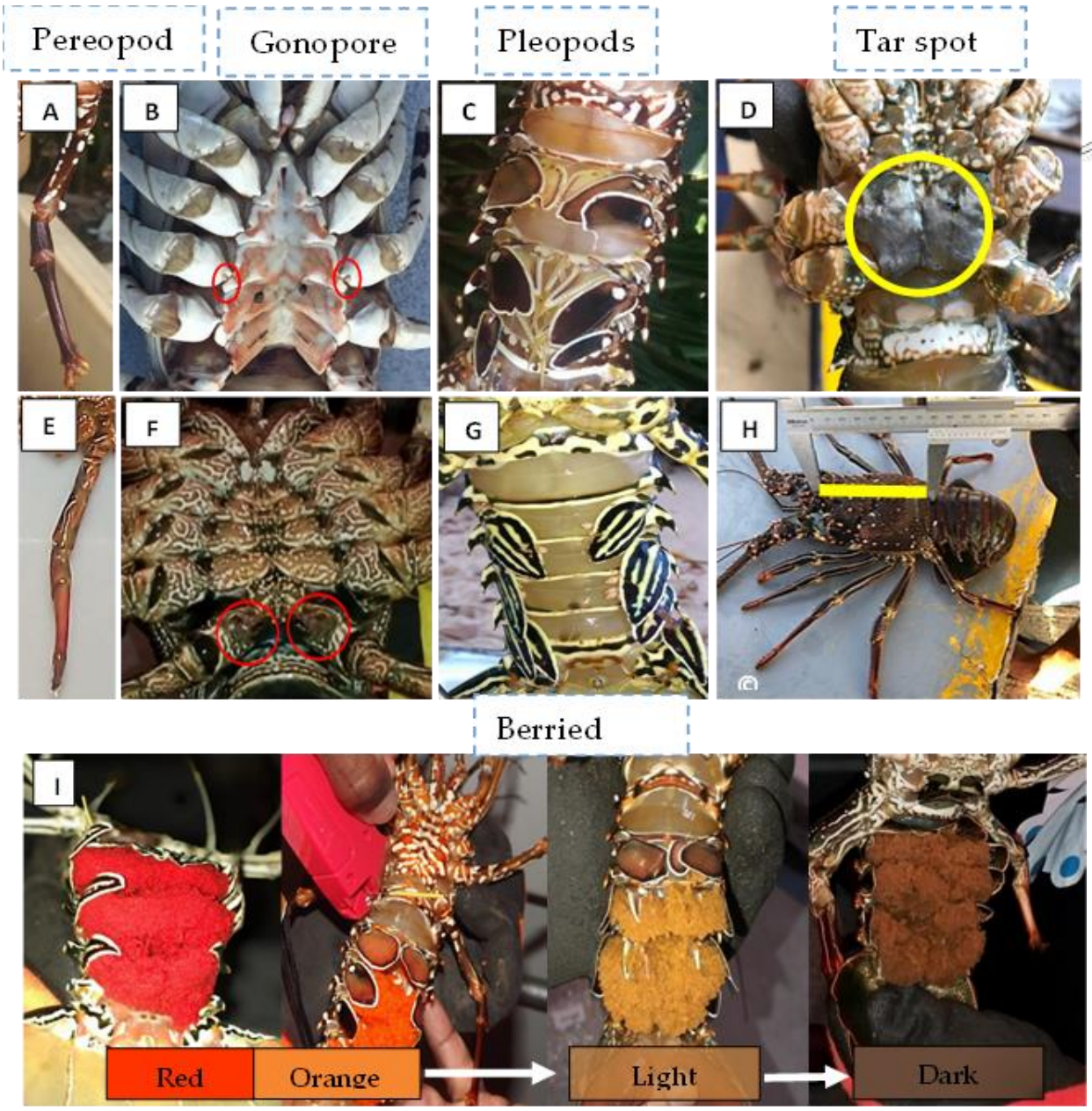


Figure 4: Difference between male and female lobsters. A-D) Features of female lobsters. E-G) Features of male lobsters. H) Dorsal view of the carapace length measurement location. ***Source:*** *Seychelles Fishing Authority survey pictures.*

2.6. DATA ANALYSIS

The R software (version 4.2.2) and Microsoft Office Excel software (Windows 10) were used for the statistical analysis and production of graphs. A significance threshold of $p < 0.05$ was used.

2.6.1. STANDARDISING DATA

2.6.1.1. DENSITY IN NUMBER AND WEIGHT BY ZONES

Lobster density in different zones was calculated by using the total number of both caught and missed (not captured) lobsters for each species at each sampling station. The sum was divided by the transect area to standardise the number of lobsters per square metre at each station. Subsequently, the standardised total numbers of lobsters for each species within each zone were aggregated and divided by the number of sampling stations in that zone, yielding the mean number of lobsters of each species per station per square metre for each zone [1].

$$1)\ \boldsymbol{Mean\ Lobsters_{k,j}} = \frac{1}{\boldsymbol{N_k}} \sum_{i \in k} \frac{\boldsymbol{Total\ lobster_{i,j}}}{\boldsymbol{Transect\ area_i}}$$

where mean lobsters are the mean number or weight of lobsters for species j per station per square metre in zone k; N_k is the number of sampling stations in zone k; $i \in k$ indicates that station i is within zone k; Total lobsters is the total number or weight of lobsters (sampled + missed) for species j at station i; Transect area i is the area of the transect at station i. Kruskal-Wallis non-parametric test was used to assess differences in lobster density per species between survey zones, followed by post hoc Dunn Test analysis upon significance.

Body weight was standardised using the same approach [1]. Before standardising by area and stations the weight of the uncaptured (missed) lobsters needed to be estimated. The individual weight of the missed lobsters was estimated as the mean individual weight of the lobsters on the transect [2] (by species). The weight of missed lobsters at a station was calculated by multiplying the mean individual weight of each species sampled at the station by the number of missed lobsters of that species at the station. The value was then added to the total weight of lobsters sampled at the station by species [3].

$$2)\ \boldsymbol{Mean\ Weight} = \frac{\boldsymbol{\sum Weight\ (kg)}}{\boldsymbol{N^0 of\ Lobster\ collected\ (per\ species\ )}}$$

$$3)\ \textbf{\textit{Raised Weight}} = \textbf{\textit{Mean Weight}} * \textbf{\textit{N}}^{0}\textbf{\textit{of Lobsters missed (per species)}}$$

Kruskal-Wallis non-parametric test was used to assess differences in lobster density per species between survey zones, followed by post hoc Dunn Test analysis upon significance.

2.6.2. PROPORTION BETWEEN SURVEYS

The number of lobsters caught by the 1991 and 2023 surveys could not be directly compared because of the differences in survey methodology. The distribution of catch among the zones, however, could be compared by examining the proportion of the total survey catch in each zone during the two surveys. The proportion in each zone by species was calculated by dividing the standardised mean number of lobsters per station in each zone (from e.q; 1) by summing the standardised mean number of lobsters per station across all the zones [4].

$$4)\ \textbf{\textit{Proportion}}_{\textbf{\textit{zone,species,}}} = \frac{\textbf{\textit{Mean count per station}}_{\textbf{\textit{zone,i,species,j}}}}{\sum_{\textbf{\textit{all zones,i}}} \textbf{\textit{Mean count per station}}_{\textbf{\textit{zone,i,species}}}}$$

where j is species and i is zone.

2.6.3. HABITAT

The standardised number of lobsters caught by species per substrate type was summed to get the proportions for each species in different habitats. These proportions were then aggregated to determine the total proportion of lobsters by species across all substrates. Then, the proportion of a species in a given habitat was divided by the total proportion to assess the overall proportion of a species in a specific habitat [5].

$$5)\ \textbf{\textit{Overall Proportion}} = \frac{\textbf{\textit{Total proportion}}_{\textbf{\textit{j,i}}}}{\textbf{\textit{Total proportion}}_{\textbf{\textit{j}}}}$$

where Total proportion represents the total proportion of lobsters for species j in substrate type i, and Total proportion represents the total proportion of lobsters for species j across all habitats.

The Mann-Whitney U test was used to evaluate differences in standardised relative abundance between habitats for each species. Subsequently, rank-biserial correlation of effect size was used to measure the magnitude of differences between groups. The Mann-Whitney U test or Kruskal-Wallis was used to determine the significance of differences in mean carapace length per species between habitats.

2.6.4. LENGTH- WEIGHT RELATIONSHIP

The Length - Weight Relationship (LWR) is an important parameter in giving a general understanding of individual growth (Ndiaye et al., 2015). The length-weight relationship is typically exponential: $W = aL^b$. This equation can be linearised for easier computation by taking the natural logarithm of each side of the equation (6).

$$6)\ \ In\left(Weight\ (kg)\right) = In\ a + b\ In\ (Carapace\ Length\ (cm))$$

where ln (weight (kg)) is the ln-transformed weight of lobster; ln (carapace length (cm)) in the ln-transformed carapace length of lobster (notch between the frontal horns to the carapace posterior margin); ln (a) = intercept; and b is the slope parameter.

A linear regression analysis was conducted to fit the relationship between carapace length and body weight. The degree of correlation between the data and the modelled values was quantified using the R-squared (r^2) value. The F-test was assessed to evaluate the statistical significance of the variance explained by the regression model. Growth patterns were determined by the value of 'b' the slope. If 'b' is equal to (=) 3 then the growth is isometric (shape stays consistent as individuals grow). However, if 'b' is less than (<) or more than (>) 3 it is considered as allometric growth. The allometric growth can be positive or hyper-allometric (> 3; larger body with increasing length) or negative hypo-allometric (< 3: slimmer body with increasing length) (Cusba et al., 2017).

A two-tailed t-test with 5% significance level was used to determine the significance of the coefficients for carapace length in relation to allometric growth analysis.

2.6.5. SIZE FREQUENCY DISTRIBUTION

Length frequency histograms were used to summarise the distribution of the carapace length for each species by sex and survey zones. Lobsters were categorised into carapace length size classes, ranging from 3.6 to 14.9 cm with a 0.5 cm bin size. A box plot was used to visually compare sexes by species. The mean carapace length was further investigated by species, sex, and survey zones. Sites with less than 10 lobsters were excluded from mean calculations. The difference in carapace length between sexes by species was examined using the Mann-Whitney U non-parametric test (Wilcoxon rank-sum test). To test carapace differences between survey zones, ANOVA followed by the post hoc Tukey Test was used when normality and equal homogeneity were met. However, the Kruskal-Wallis non-parametric test was used to test carapace differences between survey zones, followed by post hoc Dunn Test analysis upon significance. The proportion of lobsters below the minimum size limit of 7.5 cm carapace length was for each sex by species also calculated (7):

$$7)\ \ \boldsymbol{Proportion\ of\ substrate\ type_{f\ or\ m}} = \frac{\boldsymbol{N\ f\ or\ m, < 7.5\ cm}}{\boldsymbol{N\ total\ per\ species}}$$

where N is the number of females or males with carapace lengths below 7.5 cm, and N total is the total number of observations in each species.

2.6.5.1. BERRIED FEMALES

Carapace length size distribution of berried females by species was summarised using histograms. Carapace length ranged from 5.1 to 12.4 cm, with a bin size of 0.5 cm. Mean carapace length was calculated, and the percentage of berried females per species below the fishery size limit of 75 mm carapace length was investigated.

2.6.6. SEX RATIO

The sex ratio was calculated by species to provide insight into the reproductive potential of the three species under study. The sex ratio is given as the number of males per female (M:F) [8].

$$8)\ Sex\ Ratio = \frac{Nm}{Nf}$$

where, Nm is the number of males and Nf is the number of females.

3. RESULTS

A total of 80 survey stations were surveyed between October and November 2023, coinciding with the end of the Southeast Monsoon season in Seychelles (**Table 2**). The survey was divided into 4 survey legs spread over 10 sampling days to ensure comprehensive coverage of the study area and optimise sampling efficiency. Sixty-three percent (63%) of the planned sampling was successfully achieved, while unfavourable sea conditions prevented surveys at 36% of the survey stations. Ninety-six percent (96%) of the survey transects were undertaken using snorkelling. Lobsters were observed at 70 stations, with successful catches at 66 stations. The remaining 14 stations yielded no catch. In total, 809 lobsters were observed, of which 328 were seen but not collected (missed; **Table 2**). Four hundred and eighty-one (481) lobsters weighing 264 kg were captured, measured, tagged and released during the survey. Of these, 2 *P. longipes* were not tagged, with 1 male being too small and the other female being a recapture.

Table 2: Sampling summary and species composition of Panulirus sp. across surveyed zones.

Leg	Stations counts	Sampled stations	Menhours	Species	Captured				+Observed
					Female		Male		
					№	Kg	№	Kg	№
1	31.5	25	28.4	*Panulirus longipes*	21	8.0	18	7.0	15
				Panulirus penicillatus	5	4.2	9	10.5	20
				Panulirus versicolor	12	3.9	13	5.7	11
2	31.5	24	32	*Panulirus longipes*	76	23.6	40	15.3	58
				Panulirus penicillatus	16	10.4	26	21.9	10
				Panulirus versicolor	15	4.5	18	5.4	56
3	31.5	18	22.7	*Panulirus longipes*	15	5.6	14	5.9	12
				Panulirus penicillatus	24	18.2	21	31.6	7
				Panulirus versicolor	4	4.1	4	2.2	7
4	31.5	13	19.1	*Panulirus longipes*	12	6.3	9	4.0	14
				Panulirus penicillatus	55	28.1	48	35.6	109
				Panulirus versicolor	4	1.7	2	0.8	9
Total:	126	80	102.1		259	188	222	146	328

* **Menhour:** Total transect time (hours) per station multiplied by the number of men snorkelling or diving. **+Observed** are lobsters seen but missed. **N.B:** Raw data.

3.1. CATCH COMPOSITION

3.1.1. SPECIES COMPOSITION

The catch composition consisted primarily of 3 out of the 4 commercially exploited species, namely the *P. longipes*, *P. penicillatus* and *P. versicolor* (**Figure 5**). *Panulirus ornatus* was not observed or caught during the survey, thus rendering it the rarest species of all 4. *Panulirus longipes* were the most abundant species in numbers, with 43% (206), followed by *P. penicillatus* at 42% (204) and *P. versicolor* at 15% (71) of the catch. In terms of weight, *P. penicillatus* dominated with a total of 160 kg, followed by *P. longipes* 75 kg and *P. versicolor* 28 kg. Compared to the 1991 survey, the species composition was 65.5% *P. penicillatus*, 26.5% *P. longipes* and 8% *P. versicolor*.

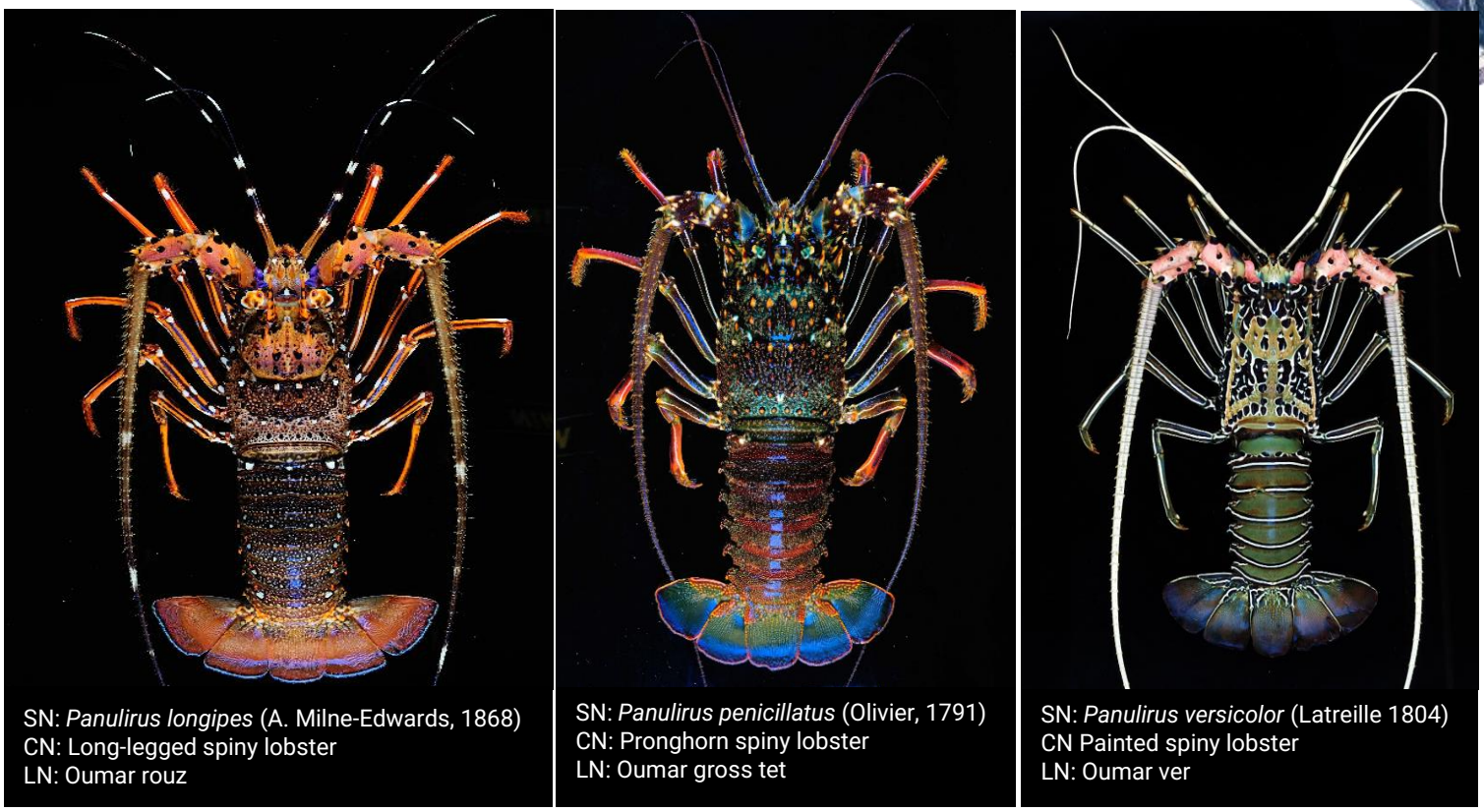


Figure 5: Photographs of species catch composition sampled from October and November 2023. A) Panulirus longipes; B) Panulirus penicillatus; C) Panulirus versicolor. Note: SN - scientific name; CN - common name; LN - local name. Source: MNHN (2024) and Tin-Yam (2010).

3.1.2. SEX COMPOSITION

The sex composition consisted of 259 (54%) females and 222 (46%) males, representing an overall sex ratio of 0.85:1. The male-to-female ratios varied amongst the three lobster species. *Panulirus longipes* had a higher proportion of females, with a ratio of 0.6:1. *Panulirus penicillatus* had an equal distribution of males and females, with a ratio of 1:1. *Panulirus versicolor* had a slight dominance of males, with a ratio of 1.1:1.

3.1.3. MEAN DENSITY BY SURVEY ZONES

3.1.3.1. MEAN DENSITY IN NUMBERS

The mean density of lobsters in numbers (number/m^2) varied across survey zones (**Figure 6**). La Digue exhibited the lowest overall density (mean (μ)= 0.00064 ± standard error (SE)= 0.0005 number/m^2), while Denis showed a higher density (μ=0.088 ± SE=0.002 number/m^2; **Figure 6**). La Digue had a significantly lower number of lobsters per m^2 compared to other survey zones (**Table 5 Appendix 1**) [4].

Catch trends suggest that more remote survey zones located farther from the main islands (Mahé, La Digue, and Praslin), such as Denis (μ=0.0088 ± SE=0.002) and Bird (μ=0.0048 ± SE = NA[5]), had a higher mean density of *P. penicillatus*. Denis had statistically significantly more *P. penicillatus* per m^2 compared to La Digue (μ=0.00014 ± SE =0.001) and Mahé North (0.00013 ± SE=0.00008; **Table 6 Appendix 1**) [6]. La Digue and Mahé North had statistically significantly lower densities than other survey zones (**Table 6 Appendix 1**). *Panulirus versicolor* had a generally low mean density across all zones, with Mahé West (μ=0.0013 ± SE=0.0004) having significantly more *P. versicolor* per m^2 compared to La Digue with the lowest mean density (μ=0.000045 ± SE= 0.00005; **Figure 6**; **Table 7 Appendix 1**) [7]. In contrast, *P. longipes* had a higher mean density per m^2 near the main islands, particularly Mahé West (μ=0.0025 ± SE= 0.0006) and Mahé South (μ=0.0026 ± SE =0.001). However, no statistical significance was observed [8].

[4] Kruskal-Wallis: $\chi^2_{(12)} = 27.86$, $p < 5.800e\text{-}03$

[5] Standard error could not be calculated due to an insufficient number of surveyed stations

[6] Kruskal-Wallis: $\chi^2_{(12)} = 40.553$, $p < 5.819e\text{-}05$

[7] Kruskal-Wallis: $\chi^2_{(12)} = 27.688$, $p < 6.073e\text{-}03$

[8] Kruskal-Wallis: $\chi^2_{(12)} = 15.466$, $p > 0.217$

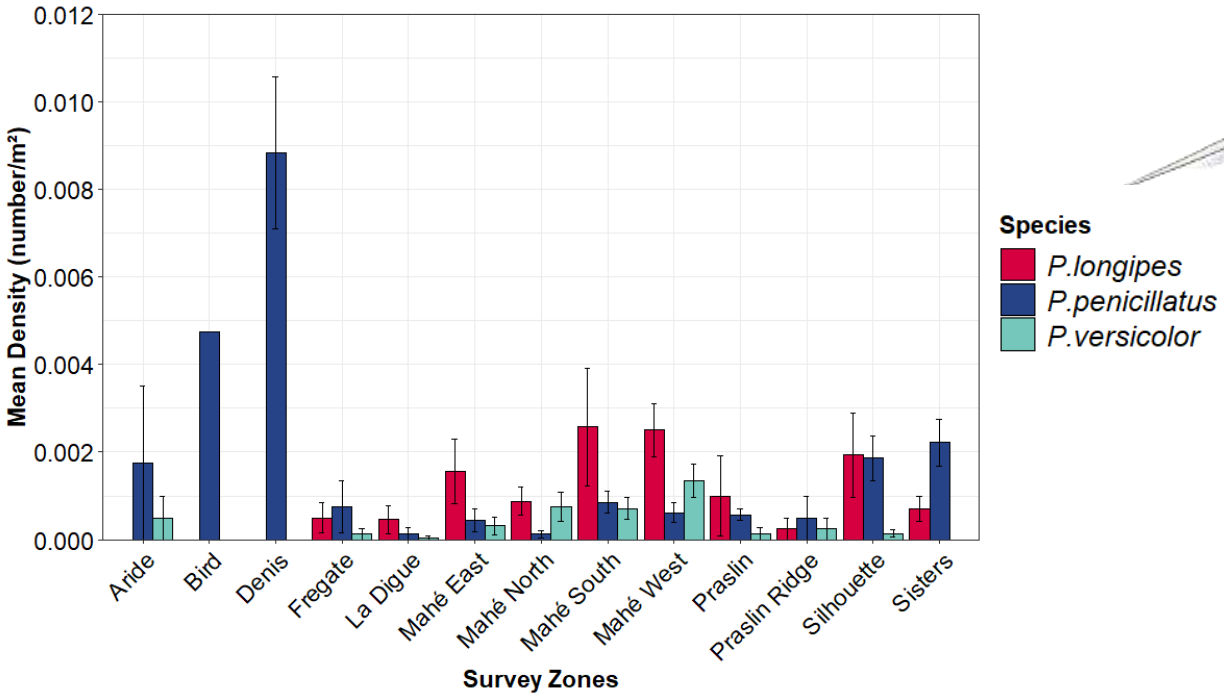


*Figure 6: Mean density of lobsters (number/m²) per species by zones sampled during the 2023 survey. Each bar represents the mean density in numbers per square metre within the respective survey zone. Error bars depict standard error +/- 1. **N.B**; One station was surveyed on Bird Island, and the standard error bar is not applicable.*

3.1.3.2. MEAN DENSITY IN WEIGHT

A similar trend was observed in the mean density of lobsters by weight (kg/m^2). La Digue had the lowest overall density (μ= 0.00043 ± se=0.0004 kg/m^2), while Denis showed a higher density (μ=0.0051 ± se=0.002 kg/m^2; **Figure 8**. La Digue had a significantly lower mean density in weight of lobsters per m^2 compared to other survey zones[9] (**Table 8 Appendix 1**). *Panulirus penicillatus* were statistically significantly heavier at Denis (μ= 0.0051 ± se=0.002 kg/m^2) and lighter at La Digue per m² compared to other survey zones[10] (**Table 9 Appendix 1**).

In contrast, *P. versicolor* had the lowest mean density in weight overall. The highest mean density per m^2 was observed in Mahé West (μ= 0.00043 ± se= 0.0001 kg/m^2) and Mahé

[9] Kruskal-Wallis: $\chi^2_{(12)} = 25.071$, $p < 1.449e\text{-}02$

[10] Kruskal-Wallis: $\chi^2_{(12)} = 39.008$, $p < 1.049e\text{-}04$

South (μ=0.00036 ± se=0.0002 kg/m^2; **Figure 7**). While *P. longipes* had higher density near the main islands, particularly Mahé South (μ=0.00089 ± se=0.0005 kg/m²) and Mahé West (μ= 0.00084 ± se=0.002; **Figure 7**). No statistically significant difference was observed for the 2 species between survey zones[11&12].

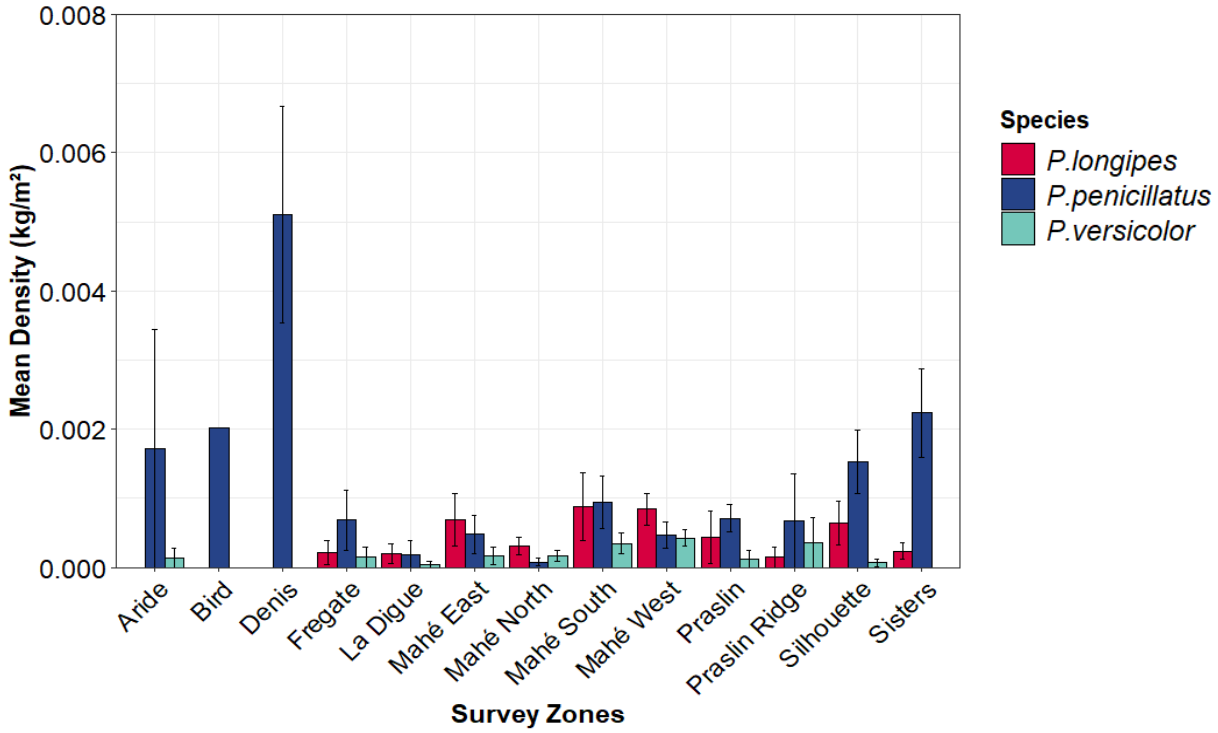


*Figure 7: Mean density of lobsters (kg/m^2) per species by zones sampled during the 2023 survey. Each bar represents the mean density in numbers per square metre within the respective survey zone. Error bars depict standard deviations. **N.B:** One station was surveyed on Bird Island, standard error bar not applicable.*

3.1.4. PROPORTIONS BETWEEN SURVEYS[13]

Distribution patterns across Mahé Island varied, with apparent shifts from the 1991 and 2023 surveys (**Figure 8**). In 1991, *P. longipes* exhibited the highest proportions in Mahé North and Mahé South, each at 31% (0.31), while Mahé West had the lowest proportion at 17% (0.17). *Panulirus penicillatus* was predominantly found in Mahé South with a high proportion of 65% (0.65), whereas Mahé North had a lower proportion of 17% (0.17).

[11] Kruskal-Wallis: $\chi^2_{(11)} = 19.327$, $p > 0.055$

[12] Kruskal-Wallis: $\chi^2_{(12)} = 14.216$, $p > 0.287$

[13] Note: The proportion is displayed by species caught in each survey zone for both surveys.

Panulirus versicolor displayed a relatively balanced distribution among Mahé North, Mahé West, and Mahé South, with proportions of 38% (0.38), 32% (0.32), and 30% (0.30), respectively. No *P. versicolor* and *P. penicillatus* was caught in Mahé East (**Figure 8**).

In 2023, there were noticeable changes in distributions (**Figure 8**). The proportion of *P. longipes* increased in Mahé South to 34% (0.34) and in Mahé West to 33% (0.33), while it decreased to 12% (0.12) in Mahé North. *Panulirus penicillatus* showed a trend towards a more even distribution, with a decreased proportion in Mahé South to 42% (0.42) and increased proportions in Mahé West (0.30, 30%) and Mahé East (0.21, 21%). *P. versicolor* shifted significantly towards Mahé West, increasing to 43% (0.43) while decreasing in Mahé North to 24% (0.24) and Mahé South to 23% (0.23). In Mahé East, *P. versicolo*r accounted for 10% (0.10) of the sampled population.

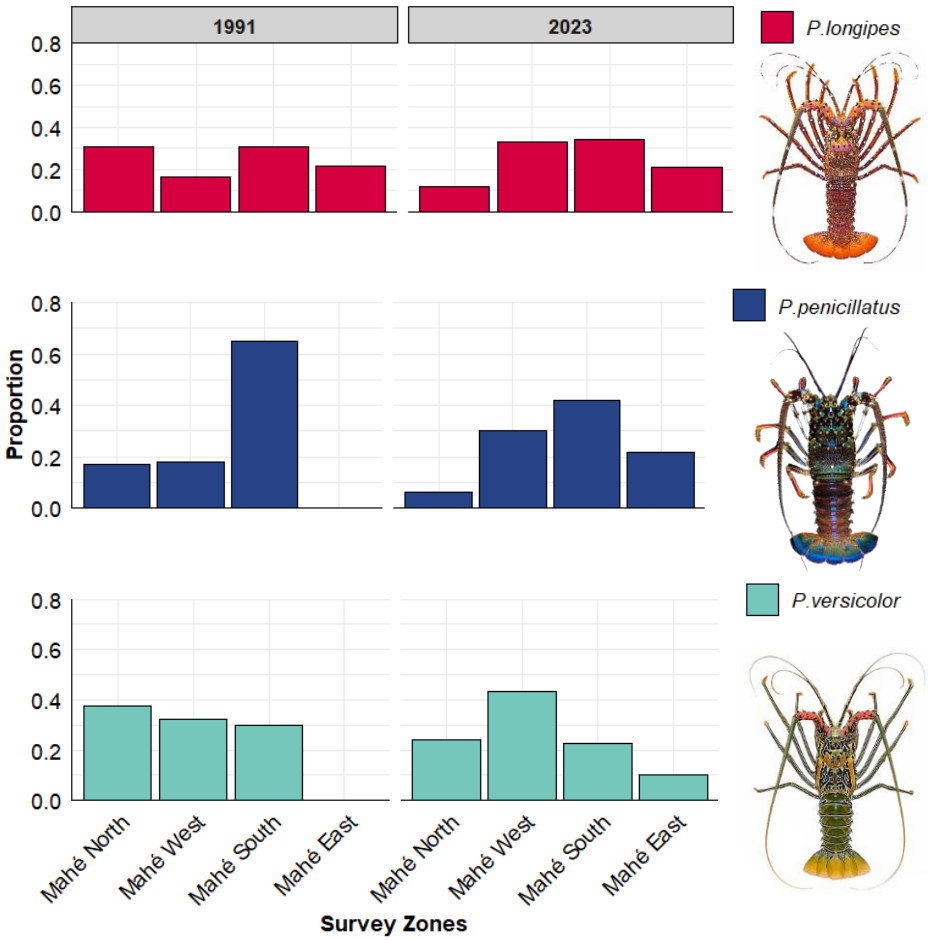


*Figure 8: The proportion of lobsters surveyed between 1991 and 2023 around Mahé Island. **N.B:** The 1991 survey was limited to stations around Mahé Island due to engine issues.*

3.1.5. POPULATION SIZE STRUCTURE

3.1.5.1. CARAPACE LENGTH BY SPECIES

Panulirus longipes carapace length distribution ranged from 3.6 to 10.5 cm (**Figure 9**). The carapace length of females ranged from 4.6 to 9.4 cm, with a mean of 6.6 cm, a mode of 6.1 cm, and a median of 6.3 cm. Males ranged from 3.6 to 10.5 cm, with a mean of 7 cm, a mode of 8.9 cm, and a median of 6.6 cm. Individuals with a carapace length of 6 cm were the most abundant in both males and females of *P. longipes* (**Figure 9**). Sixty-six percent (66%) of females and 34% of males were below the 7.5 cm size limit (**Figure 9**). On average, male *P. longipes* had a significantly larger carapace length than females [14] (**Figure 10**).

Panulirus penicillatus carapace length ranged from 4.5 to 15 cm. The female carapace length ranged from 4.8 to 12.4 cm, with a mean of 8.6 cm, a mode of 8.1 cm, and a median of 8.5 cm. Males ranged from 4.5 to 15 cm, with a mean of 10.1 cm, a mode of 9.8 cm, and a median of 10 cm. Individuals with a carapace length of 9 cm for females and 9 and 11 cm for males exhibited the highest abundance of *P. penicillatus* (**Figure 9**). Fifty-eight (58.5%) of females and 41.5% of males were below the 7.5 cm size limit (**Figure 9**). Similarly to *P. longipes,* the male *P. penicillatus* had significantly larger carapace length on average than females [15] (**Figure 10**).

Panulirus versicolor carapace length ranged from 4.3 to 11.4 cm (**Figure 9**). Female *P. versicolor* carapace length ranged from 4.3 to 11.4 cm, with a mean of 7 cm, a mode of 5.5 cm, and a median of 6.7 cm. Males ranged from 4.5 to 11.4 cm, with a mean of 6.8 cm, a mode of 6.1 cm, and a median of 6.1 cm. In *P. versicolor,* individuals with a carapace length of 5.5 cm exhibited the highest abundance in both males and females of *P. versicolor* (**Figure 9**). Fourty-eight (48%) of females and 52% of males were below the size

[14] Mann Whitney: U =4133, $p < 0.0263$

[15] Mann Whitney: U =3266, $p < 4.493e\text{-}06$

limit of 7.5 cm. Compared to *P. longipes and P.* penicillatus, the male *P. versicolor* carapace lengths were not statistically significantly different from females [16] (**Figure 10**).

Male and Female *P. penicillatus* were significantly larger ($p < .05$) compared to *P. longipes* and *P. versicolor* [17&18](**Figure 10; Table 10 Male, Table 11 Female Appendix 2**).

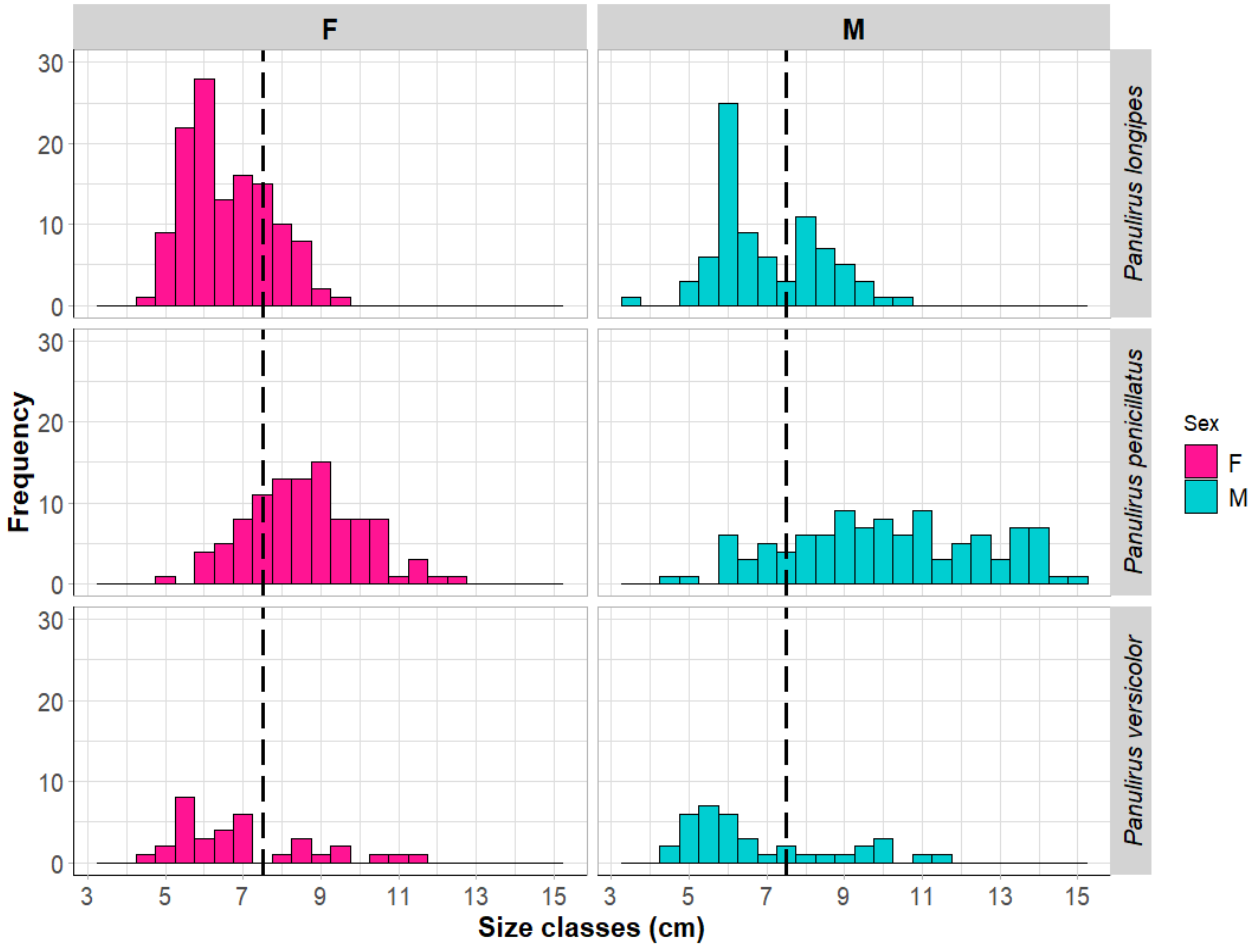


Figure 9: *Size frequency distribution of female and male of three lobster species sampled during the 2023 survey. Frequency represents the counts of each size class. The dashed black line highlights the minimum size limit of 7.5 cm (CL).*

[16] Mann Whitney: U =714, p > 0.3307

[17] Kruskal-Wallis: $\chi^2_{(2)}$ =86.38, p = < 2.2e-16

[18] Kruskal-Wallis: $\chi^2_{(2)}$ =80.28, p = < 2.2e-16

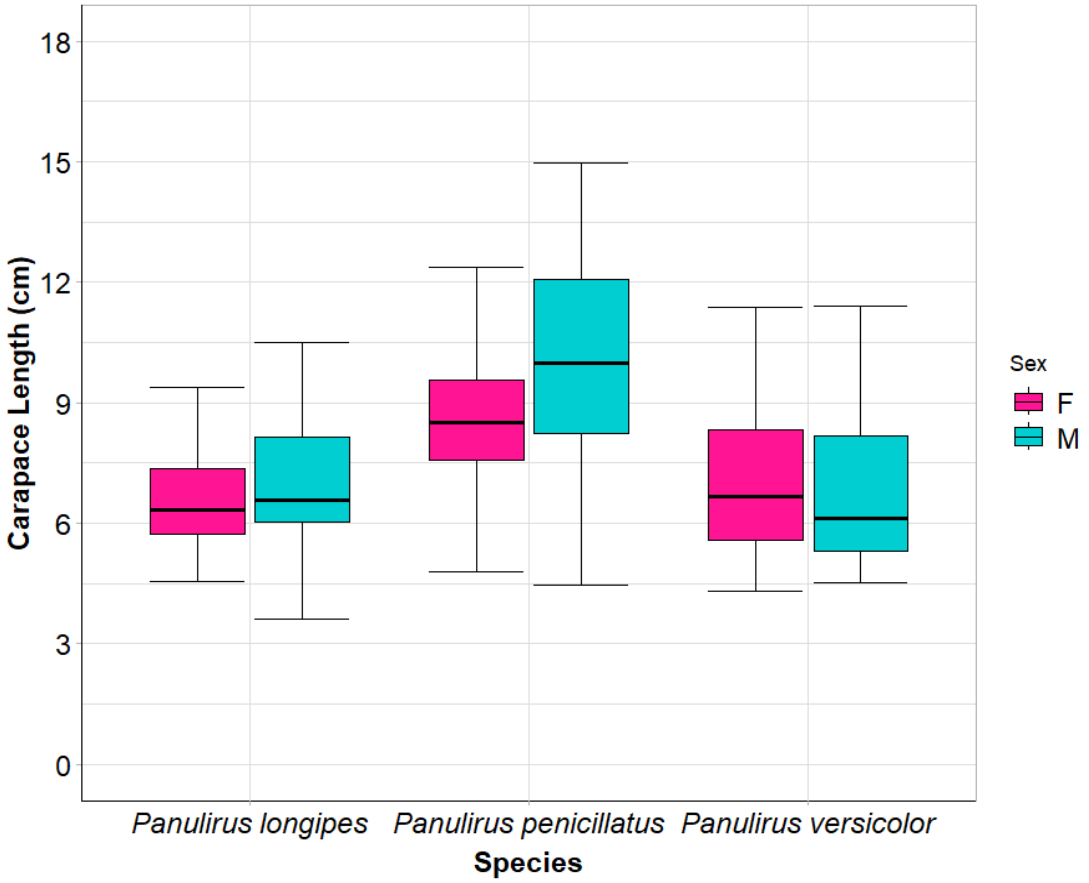


Figure 10: Box plot of the size distribution of females and males of all three species sampled. The text value is the mean and the median depicted by the black straight line.

3.1.5.2. CARAPACE LENGTH BY ZONES AND SPECIES

The Sister Islands had the highest mean carapace length of 9.4 ± SD = 2.5, with a median of 9 cm and mode of 6.1 cm, indicating significantly larger lobsters compared to other survey zones [19] (**Figure 11 A; Table 12 Appendix 2**). Mahé North had significantly smaller lobsters exhibiting the lowest mean length of 6.6 cm ± standard deviation (SD) = 1.6, with a median of 6 and mode of 5 cm compared to other survey zones[17] (**Figure 11 A; Table 12 Appendix 2**). The species distribution across survey zones showed *P. penicillatus* around Sisters Islands (μ = 10 cm ± SD = 2) were significantly larger on average compared

[19] Kruskal-Wallis: $\chi^2_{(10)}$ =64.416, p = < 5.241e-10

to Bird (μ = 7.9 ± SD = 1.6) and Denis (μ = 8 cm ± SD = 1.9)[20] (**Figure 11 B; Table 12 Appendix 2**). Conversely, *P. penicillatus* surveyed at Bird (μ = 7.8 ± SD = 1.6) were significantly smaller than other survey zones (**Figure 11 B; Table 12 Appendix 2**). No statistically significant difference (*p >.05*) in the mean carapace length of *P. longipes* was observed between the survey zones[21] (**Figure 11 B**). Comparison between survey zones for *P. versicolor* was not conducted due to the small sample size.

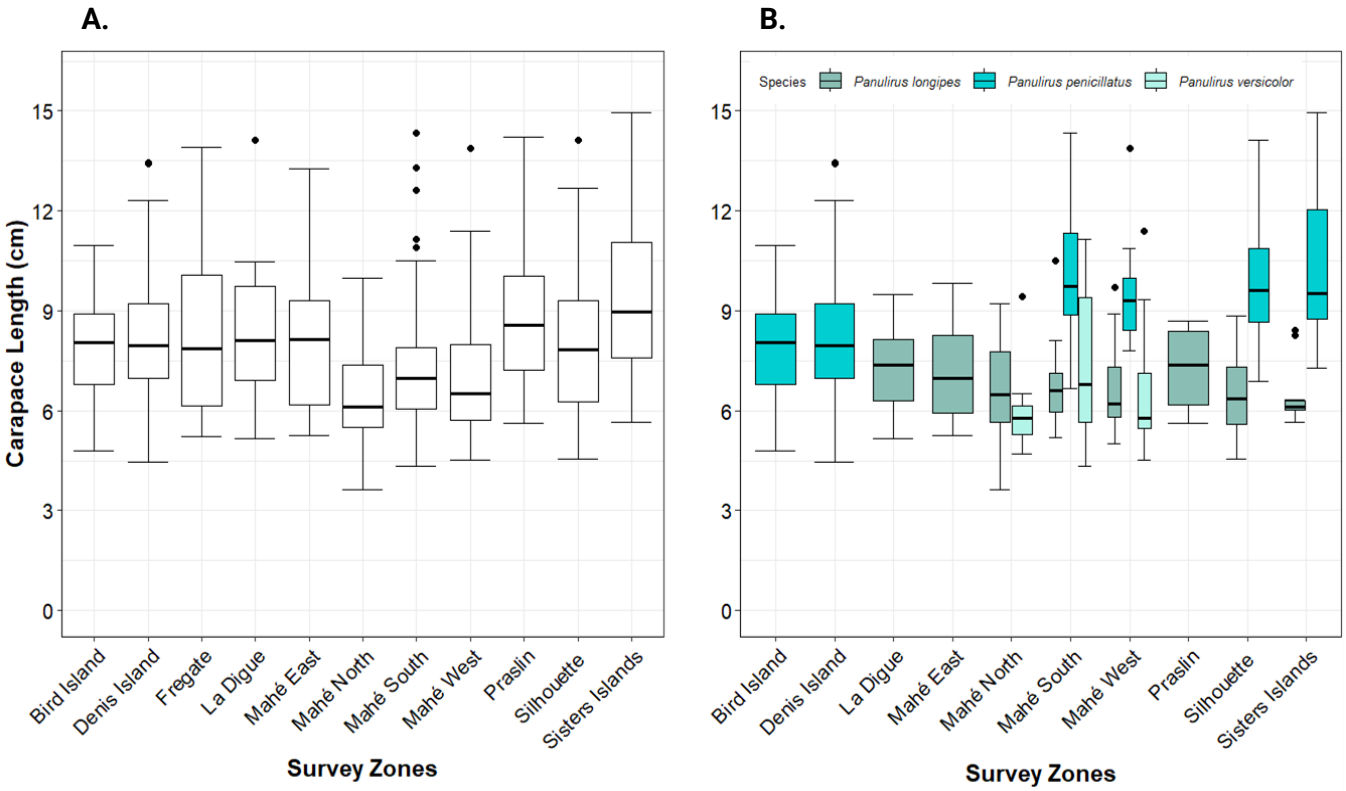


*Figure 11: Box plot of the size distribution of lobsters sampled during the 2023 survey. A) Distribution across survey zones. B) Distribution across survey zone by species. **N.B**; Aide (n=9) and Praslin Ridge (n=4) were excluded from the analysis due to the small sampling size.*

The mean carapace length of female *P. penicillatus* (μ = 7.6 cm ± SD =1.4) caught around Bird was significantly smaller than around Sisters Islands (μ = 9 cm ± SD =1.3), Silhouette (μ = 9 cm ± SD =1.3; **Table 13 Appendix 2**) [22]. While female *P. penicillatus* caught from

[20] Kruskal-Wallis: $\chi^2_{(5)}$ =33.6, p = < 2.847e-06
[21] Kruskal-Wallis: $\chi^2_{(7)}$ =10.016, p = > 0.187
[22] Kruskal-Wallis: $\chi^2_{(3)}$ =22.539, p < 5.037e-05

Sisters Island were significantly larger than Denis and Bird (**Table 14 Appendix 2**)[20]. Male *P. penicillatus* around Sisters Islands (μ = 11.7 cm ± SD =2.3) were statistically significantly larger than on Denis (μ = 9.1 cm ± SD =2.4; **Table 15 Appendix 2**)[23]. No statistically significant difference (*p >.05*) was observed in mean carapace length for females and males *P. longipes*, respectively [24 & 25]. Comparison for *P. versicolor* was not conducted due to the small sample size.

3.1.5.3. MEAN SIZE BETWEEN SURVEYS

The carapace length between 1991 and 2023 decreased by an average of 2.7 cm for female and 4.9 cm for male (**Table 3**). A further decline in mean carapace length was observed *P. longipes* (0.5 cm female and 1.8 cm male) and *P. versicolor* (1.4 cm female and 3.9 cm, male). Whilst male *P. penicillatus,* increased by 0.8 cm (Table 4). Species-specific trends indicate that male lobsters typically display a larger mean carapace length than females.

Table 3: Mean carapace length (cm) of female and male lobsters by survey years.

Sex	Female		Male	
Surveys	1991	2023	1991	2023
Panulirus penicillatus	9.6	9.2	9.6	10.4
Panulirus longipes	7.1	6.6	8.7	6.9
Panulirus versicolor	7.9	6.5	10.6	6.7

3.1.6. BERRIED FEMALES

The survey yielded 110 berried females (i.e: with eggs), representing 42% of the total females sampled. The highest number of berried females were sampled in November (58, or 53%), while 52 (47%) were sampled in October. *P. penicillatus* had the most berried females, with 59 (53%) individuals, followed by *P. longipes* with 46 (15%) and *P. versicolor* with 5 (0.05%) individuals.

[23] ANOVA = $F_{(3)} = 6.295$, $p < 0.0034$
[24] Kruskal-Wallis: $\chi^2_{(3)} = 6.056$, $p > 0.109$
[25] Kruskal-Wallis: $\chi^2_{(3)} = 0.285$, $p > 0.963$

The berried females of *P. longipes* had carapace lengths ranging from 5.1 cm to 9.2 cm, with a mean of 7 cm (**Figure 12**). The majority of females presented first-stage egg development (O2; light orange) with higher frequency in carapace lengths of 6.5, 7.5, and 9.5 cm. Fifty-three percent (53%) were below the size limit of 7.5 cm (**Figure 12**).

The carapace length for berried *P. penicillatus* ranged from 6.2 cm to 12.4 cm, with a mean carapace length of 8.7 (**Figure 12**). The majority of females presented first-stage egg development (O2; light orange) with higher frequency in carapace lengths of 8.5 to 9 cm. Twenty percent (20%) were below the size limit of 7.5 cm (**Figure 12**).

Panulirus versicolor carapace length ranged from 5.5 cm to 11.4 cm with a mean carapace length of 7.8 cm. The majority of females presented first-stage egg development (O2; light orange) with higher frequency in carapace lengths of 5.5, 6.5 and 11.5 cm. Sixty percent (60%) berried females were below 7.5 cm (**Figure 12**). It is important to note for this species, the sample size was small.

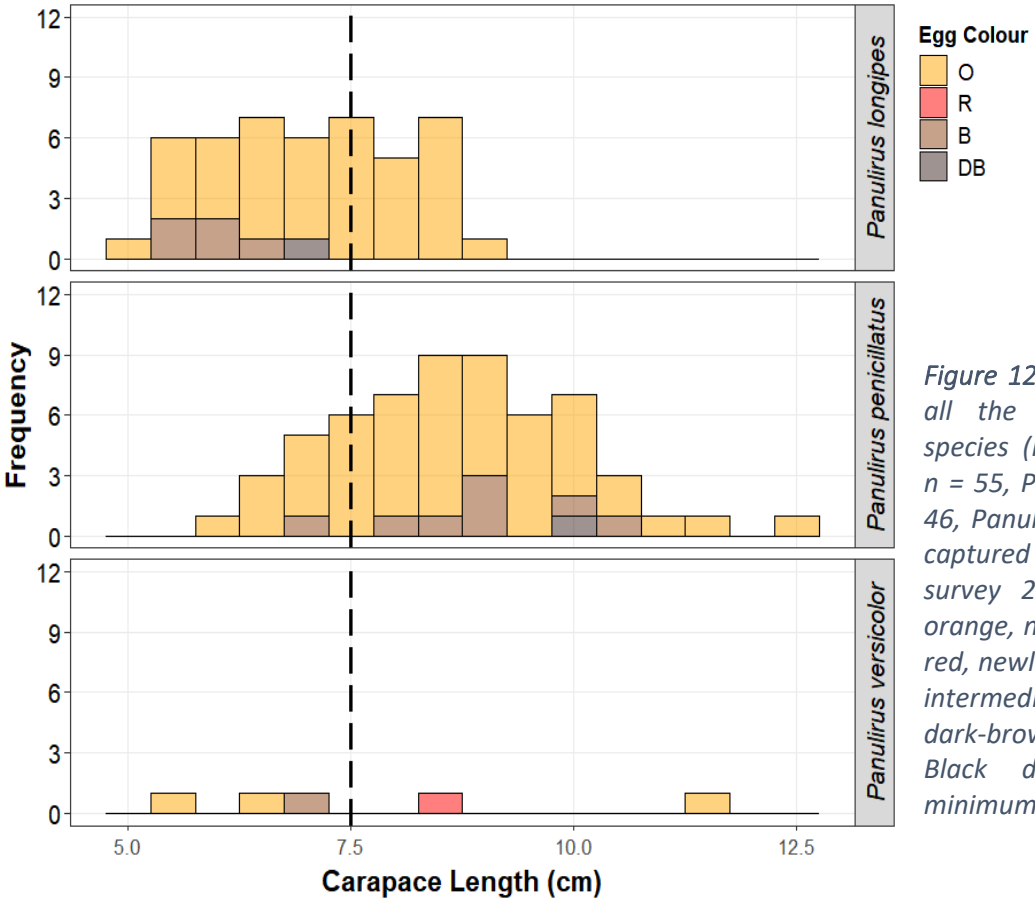


Figure 12: Length frequency of all the berried females by species (Panulirus penicillatus; n = 55, Panulirus longipes; n = 46, Panulirus versicolor; n = 5) captured during the entire survey 2022/2023. O; bright orange, newly formed, R bright red, newly formed, B; brownish intermediate stage; and DB, dark-brown ready for release. Black dashed line fishery minimum size limit of 7.5 cm.

The relationship between carapace length (cm) and body weight (kg) was analysed for males, females and all lobsters across the three lobster species (*P. longipes, P. penicillatus,* and *P.* versicolor; **Table 4** and **Figure 13**). The coefficient of determination, the R^2 values ranged from 0.79 to 0.96 across all species and sexes. These values suggest carapace length is a strong predictor of body weight. The b slope or growth coefficient deviated significantly from the expected value of 3 ranging from 2.47 to 2 (*p <.05*; **Table 4**), indicating negative allometric growth or hypoallometric growth. This trend in which slower body weight gain relative to increased carapace length was consistent across all species and sexes. All regression models were statistically significant (*p < .05*; **Table 4**), supporting the goodness of fit.

Conversely, the sex coefficients and interaction terms did not differ significantly (p > .05) between males and females (*P. longipes*: p = 0.197 (sex coefficient) and p = 0.270 (interaction term), *P. penicillatus*: p = 0.155 (sex coefficient) and p = 0.178 (interaction term), *P.* versicolor: p = 0.417 (sex coefficient) and p = 0.366 (interaction term).

Table 4: Parameters of the length (carapace length (cm)) – weight (body weight (kg)) regression analysis ($W= a L^b$). The coefficients a and b, the coefficient of determination (R^2), the regression F value and the categorisation of allometry.

Species		a	b	R^2	Regression F statistic	Equation Natation	Allometry	Allometry Sig
Panulirus longipes	All lobsters	0.002772	2.52	0.89	*F* (1,202) =1631 p< 2.2e-16*	Weight (g)= 0.002772 × Carapace length (cm)$^{2.52}$	-A	t-test (203) = -54.26 p < 0.012*
	Male	0.002266	2.61	0.93	*F* (1,102) =1028 p< 2.2e-16*	Weight (g)= 0.002266 × Carapace length (cm)$^{2.61}$	-A	t-test (103) = -56.04 p < 0.011*
	Female	0.003088	2.47	0.85	*F* (1,98) =716.7 p< 2.2e-16*	Weight (g)= 0.003088× Carapace length (cm) $^{2.47}$	-A	t-test (99) = -23.54 p < 0.027*
Panulirus penicillatus	All lobsters	0.002172	2.58	0.91	*F* (1,204) =2199 p< 2.2e-16*	Weight (g)= 0.002172 × Carapace length (cm)$^{2.58}$	-A	t-test (205) = -47.91 p < 0.013*
	Male	0.001853	2.65	0.96	*F* (1,79) = 2487 p< 2.2e-16*	Weight (g)= 0.001853 × Carapace length (cm)$^{2.65}$	-A	t-test (80) = -36.46 p < 0.017*
	Female	0.002748	2.48	0.79	*F* (1,123) =383.8 p< 2.2e-16*	Weight (g)= 0.002748× Carapace length (cm)$^{2.48}$	-A	t-test (124) = -32.29 p < 0.020*
Panulirus versicolor	All lobsters	0.001035	2.87	0.91	*F* (1,69) = 674.2 p< 2.2e-16*	Weight (g)= 0.001035 × Carapace length (cm) $^{2.87}$	-A	t-test (70) = -26.78 p < 0.024*
	Male	0.002266	2.78	0.90	*F* (1,35) = 339.5 p< 2.2e-16*	Weight (g)= 0.002266 × Carapace length (cm) $^{2.78}$	-A	t-test (36) = -19.41 p < 0.033*
	Female	0.001035	2.98	0.91	*F* (1,32) =323.6 p< 2.2e-16*	Weight (g)= 0.001035 × Carapace length (cm) $^{2.98}$	-A	t-test (33) = -17.57 p < 0.036*

a= constant, b = regression coefficient, R^2 = coefficient of determination, * *p* < 0.05 (overall significance of the regression model), + = positive allometry, - = negative allometry, *= *p* <0.05 (two tailed t-test of b value, b=3).

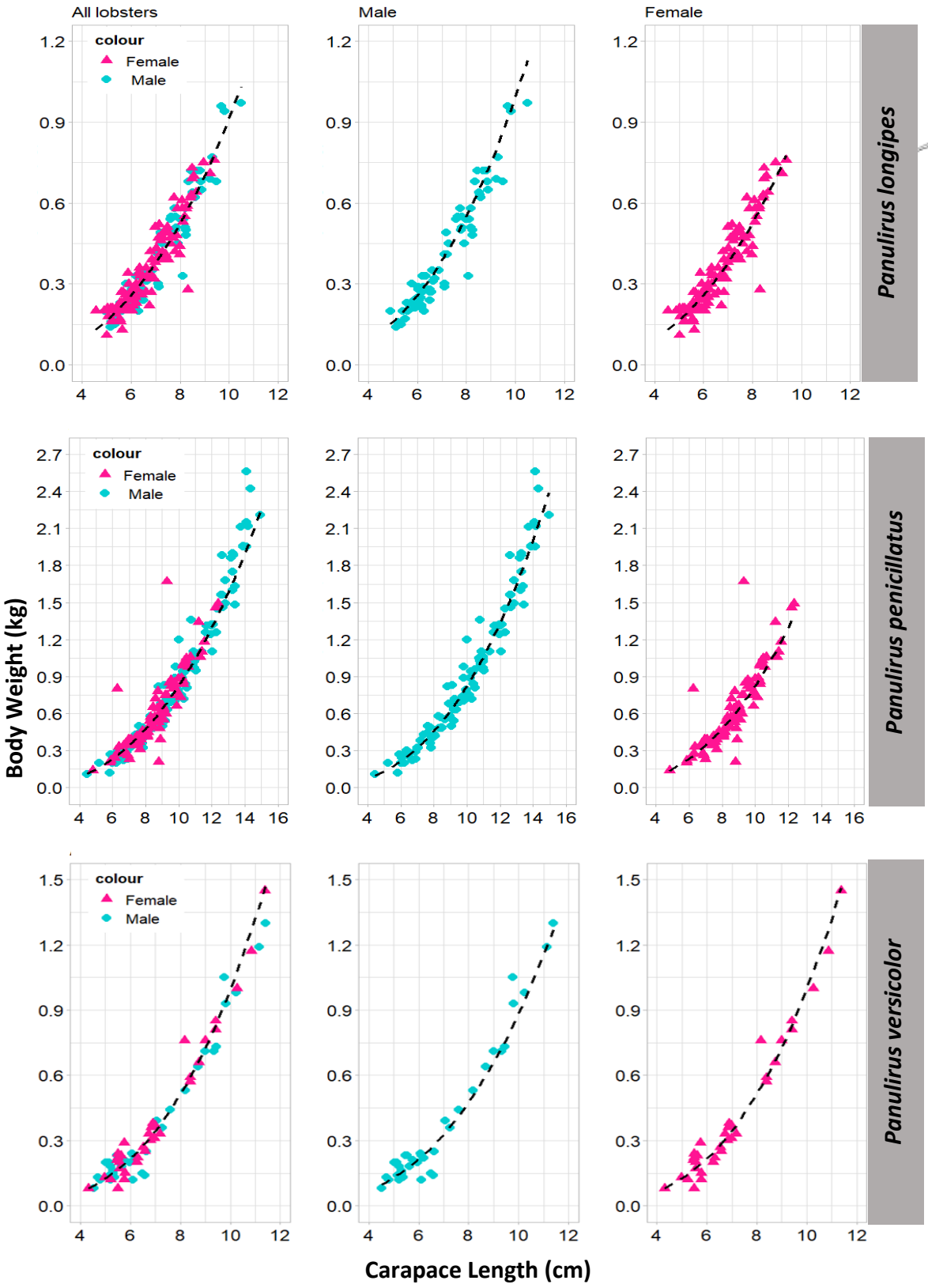


Figure 13: Length-weight relationship of male and female lobsters by species collected during the 2023 survey. Note; data was transformed from ln (natural log) to exponential

3.1.7. PROPORTION BY SUBSTRATE

The rocky habitat supported a higher proportion of the lobster population, with 0.61 (61%) and the coral habitat, to a lesser extent, with 0.39 (39%). *Panulirus versicolor* strongly preferred rocky habitats with a proportion of 0.73 (73%) and less dominant in coral habitats with 0.27 (27%). Similarly, the proportion of *P. longipes* in rocky habitats was higher at 0.65 (65%), and in coral habitats had a smaller proportion of 0.35 (35%). In contrast, *P. penicillatus* was more abundant in coral habitats, with a proportion of 0.63 (63%) and less prevalent in rocks, with 0.37 (37%; **Figure 14**).

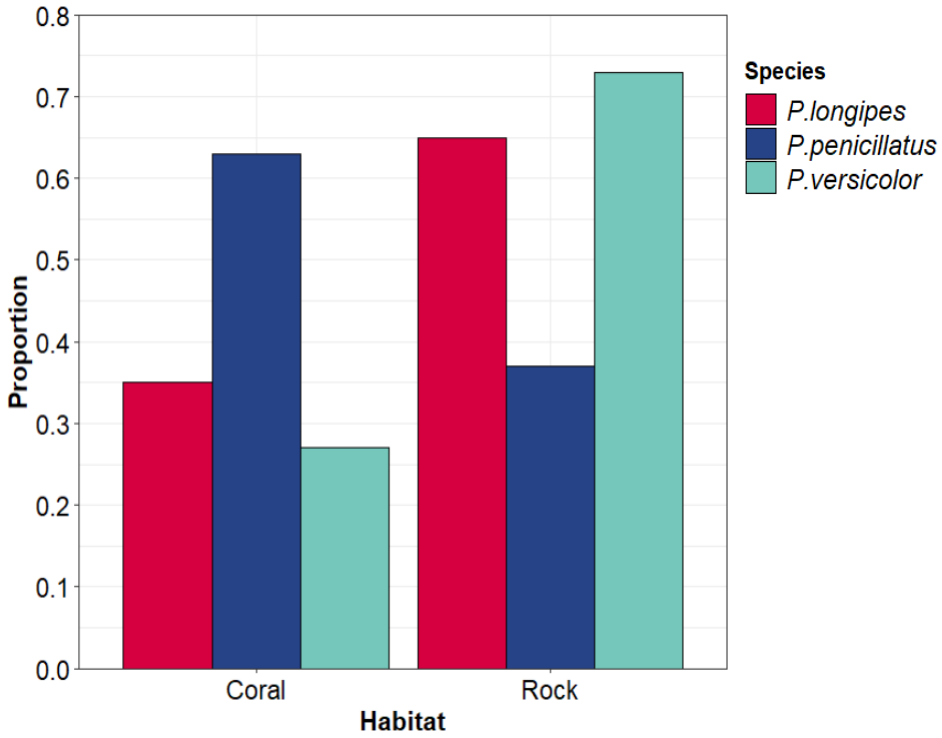


Figure 14: Proportion of lobster species observed across habitats in all survey zones.

Rock was the habitat type yielding the highest catch (**Figure 15 A**). However no significant difference (*p >.05*) in catch between habitat type [26]. The rank-biserial correlation (r) yielded an effect size of 0.016, suggesting small difference in catch by habitat type, with 'Rock' having a slightly higher catch area on average (**Figure 15 A**).

[26] Mann – Whitney: $U = 1422$, $p = > 0.870$

Species-specific differences were evaluated across catch and habitat type were observed by habitat type (**Figure 15 B**). *Panulirus penicillatus* was significantly more in coral habitat [27]. The rank-biserial correlation (r), yielded an effect size of 0.31. This suggests a moderate effect, indicating a moderate tendency for catch to differ between habitat types, with Coral having a higher catch area on average (**Figure 15 B**). However, no statistical significance in abundance by habitat was observed for *P. longipes* [28] and *P. versicolor*[29]. The rank-biserial correlation (r) yielded an effect size of 0.22 and 0.25. This suggests a small effect, indicating a slight tendency for the catch to differ between habitat types, with Rock having a slightly higher catch area on average (**Figure 15 B**).

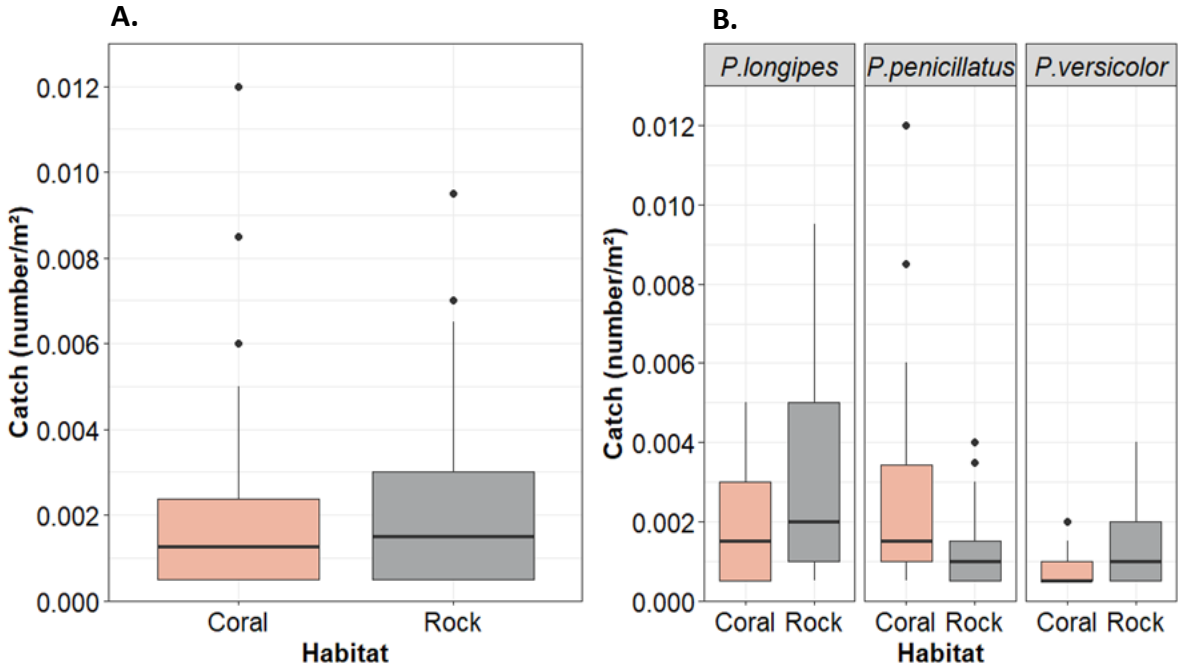


Figure 15: Box plot of standardised number of lobsters per transect area by substrate type sampled during the 2023 survey. A) Lobster catches by habitat type. B) Species by habitat type.

Mean carapace length (cm) for *P. penicillatus* in rock habitat (μ = 10 cm ± SD =2.0) were statistically significantly larger on average compared to *P. penicillatus* in coral (μ = 8.84 cm ± SD =2.2; **Figure 16**) [30]. *Panulirus longipes* in coral habitat (μ = 7.2 cm ± SD =1.36)

[27] Mann – Whitney: $U = 296$, $p = < 0.041$

[28] Mann – Whitney: $U = 133$, $p = > 0.174$

[29] Mann – Whitney: $U = 71$, $p = > 0.192$

[30] Mann – Whitney: $U = 2821.5$, $p = < 6.332e\text{-}05$

were statistically significantly larger on average compared to *P. longipes* in rock (μ = 6.6 cm ± SD =1; **Figure 16**) [31]. However, *P. versicolor* in coral (μ = 7.7 cm ± SD =2.1) *was not* statistically significantly different than in rock habitat (μ = 6.6 cm ± SD =1.7; **Figure 16**) [32]. *Panulirus penicillatus* in coral and rock habitat was statistically significantly larger on average compared to *P. longipes* and *P. versicolor* [33] (**Table 16 Appendix 2**). Lobsters in coral habitat (μ = 8.2 cm ± SD =2.1) had larger mean carapace length (cm) compared to lobsters surveyed in rock habitat (μ = 7.6 cm ± SD =2.2) [34].

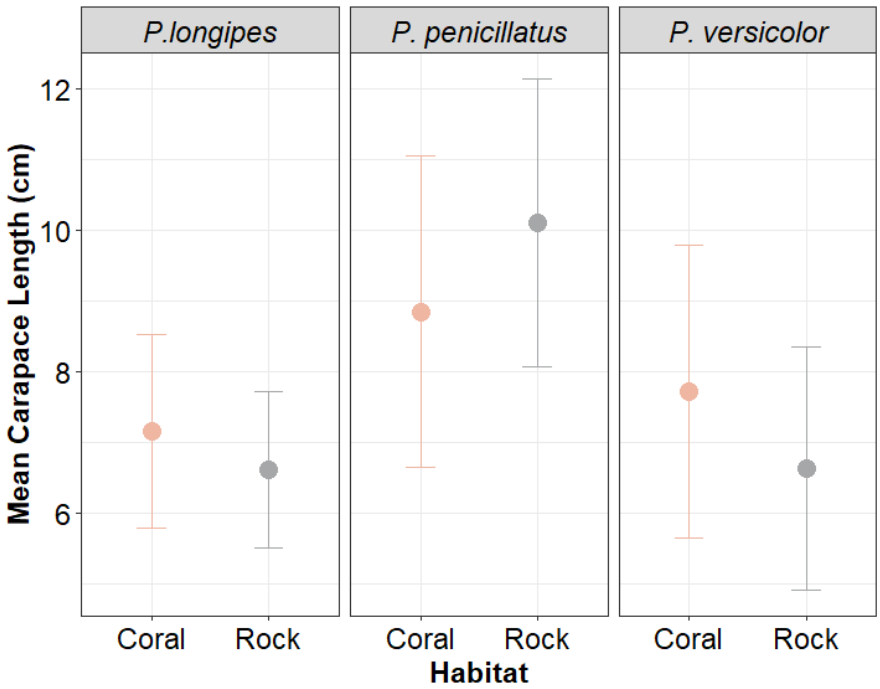


Figure 16: Mean carapace length (cm) per species by substrate type sampled during the 2023 survey.

3.1.8. COMPARISON BY SUBSTRATE BETWEEN SURVEY

The 1991 and 2023 surveys reported the highest proportion of lobsters within rock habitats (**Figure 17**). In 1991, *P. longipes* had a high proportion of 0.66 (66%) in rock

[31] Mann – Whitney: $U = 5351$, $p = < 5.004e-03$

[32] Mann – Whitney: $U = 664.5$, $p = > 0.051$

[33] Kruskal-Wallis: $\chi^2_{(5)} = 174.3$, $p < 2.2e-16$

[34] Mann – Whitney: $U = 32326$, $p = < 4.372e-05$

habitats, followed by coral habitats with a proportion of 0.34 (34%). *Panulirus penicillatus* had the highest proportion in rock habitats at 0.46 (46%), coral at 0.43 (43%), and a small minority in sand habitats at 0.10 (10%). While *P. versicolor* was predominantly found in rock habitats at 0.72 (72%), followed by coral habitats at 0.28 (28%). Both *P. longipes* and *P. versicolor* were not recorded in sand habitats.

In 2023, the proportion of *P. longipes* increased to 0.78 (78%) in rock habitats and decreased to 0.22 (22%) in coral habitats. The proportion of *P. penicillatus* in rock habitats increased to 0.86 (86%), with a decrease of 0.14 (14%) in coral habitats. *Panulirus versicolor* decreased in proportions of 0.69 (69%) in rock habitats and 0.31 (31%) in coral habitats.

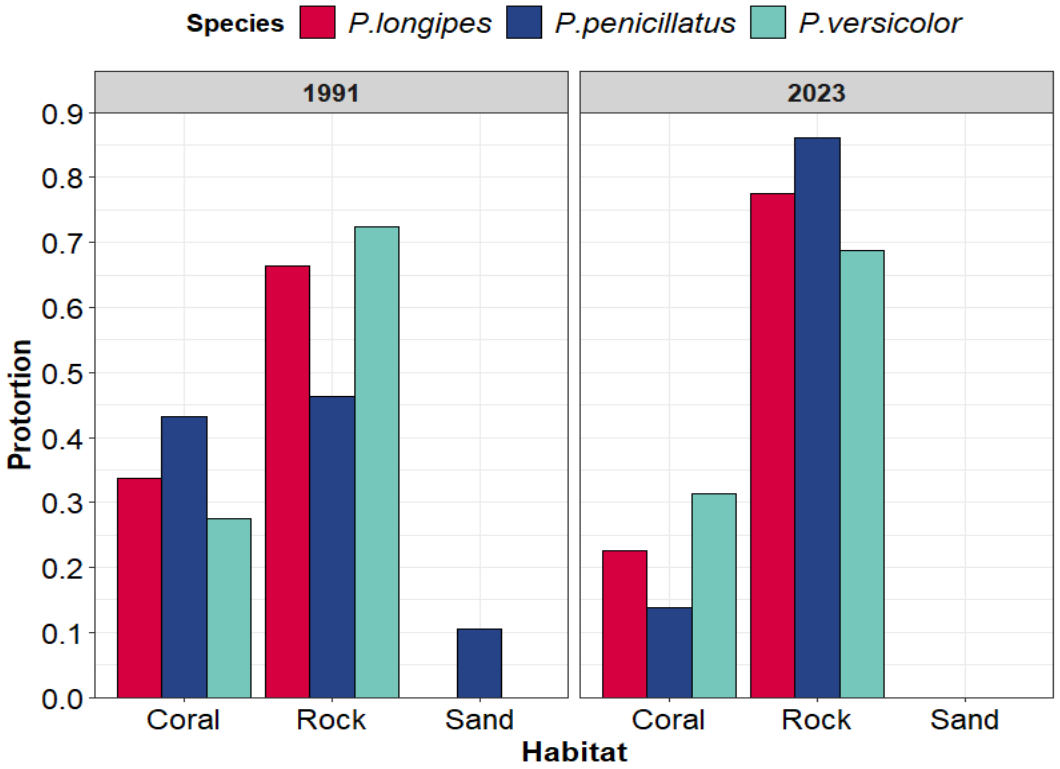
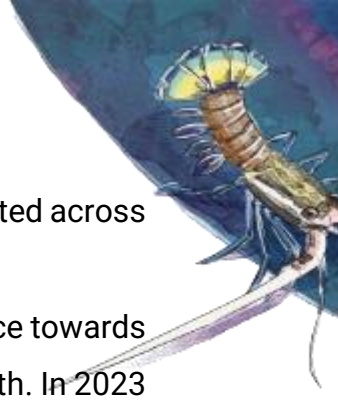


*Figure 17: Proportion of lobster observed across different habitats around Mahé Island between 1991 and 2023 surveys. **N.B:** The 1991 survey was limited to stations around Mahé Island due to engine issues. The habitat sampled in 2023 surveyed was mainly coral and rock only.*

4. KEY SURVEY RESULTS

- Overall, the study highlights spatial variations in abundance, the impact of fishing pressure around main islands, sexual dimorphism, and growth dynamics in the spiny lobster population.
- Survey conducted in 4 legs covering 80 survey stations in 13 zones.
- Lobsters encountered in all the survey zones.
- Three commercially significant species were primarily caught:
    - *Panulirus longipes* (43% of the catch by number, weighing 75 kg)
    - *Panulirus penicillatus* (42% of the catch by number, weighing 160 kg)
    - *Panulirus versicolor* (15% of the catch by number, weighing 28 kg)
    - *Panulirus ornatus* was not observed. However, this does not mean this species is not present on the Mahé Plateau.
- Mean Density in numbers and kg per m^2:
    - **Species;**
        - *Panulirus penicillatus* was significantly more abundant and heavier on Denis Island compared to La Digue.
        - *Panulirus versicolor* had significantly more abundant on Mahé West with no significant difference in weight (kg) for this species caught across the zones.
        - *Panulirus longipes* was more abundant and heavier on Mahé South. No statistical significance observed in both metrics across survey zones.
    - **By survey zones;**
        - Denis Island had significantly more and heavier lobsters per m^2.
        - La Digue Island had significantly fewer and lighter lobsters per m^2.
- Comparison between 1991 and 2023 surveys:
    - **Species;**
        - *Panulirus longipes* abundance increased in Mahé South and West but decreased in Mahé North.



        - *Panulirus penicillatus* abundance was more evenly distributed across all regions, reducing its dominance in the south.
        - *Panulirus versicolor* showed a significant shift in abundance towards the west, with decreased abundance in the North and South. In 2023 this species was observed in Mahé East, where it was previously absent.
    - **Mahé survey zones only:** Declines in lobster proportions in Mahé North and South while increases were observed in Mahé West and East.
- **Carapace length:**
    - Lobsters caught on Sisters Island had the highest mean carapace length (μ = 9.4 ± SD = 2.5) compared to Mahé North (μ = 6.6 cm ± SD = 1.6).
    - Both male (μ = 10.1 cm) and female (μ = 8.6 cm) *Panulirus penicillatus* were larger on average compared to the other two species.
    - Males generally had larger carapace lengths than females in *Panulirus longipes* (M; μ = 7 cm, F; μ = 6.6 cm), and *Panulirus penicillatus* (M; μ = 10.1 cm, F; μ = 8.6 cm), while in *Panulirus versicolor* (M; μ = 6.8 cm, F; μ = 7 cm), there was no significant size difference between sexes.
    - A significant proportion of individuals across all species had carapace lengths below the 7.5 cm size limit, with females more frequently below the size limit than males in *Panulirus longipes* (M; 34%, F; 66%) and *Panulirus penicillatus* (M; 41.5%, F; 58.5%). While *Panulirus versicolor* males were more below the size limit there was a balanced distribution between males (52%) and females (48%). A higher abundance of younger and smaller individuals is typical in a population, but a disproportionate number of larger ones may indicate catchability issues or ecological factors affecting population structure.
- *Panulirus penicillatus* had the highest number of berried females and a wider range of carapace lengths compared to other species.

- **Habitat:**
    - Rocky habitats support a higher proportion of the lobsters compared to coral habitats.
    - *Panulirus versicolor* and *Panulirus longipes* show a strong preference for rocky habitats.
    - *Panulirus penicillatus* was more abundant in coral habitats. When comparing between surveys *Panulirus penicillatus* exhibited the most pronounced preference for rock in survey zones around Mahé.
- Although rock habitat yielded the highest catch, differences in catch between habitat types were not statistically significant.
- The abundance of *Panulirus longipes* in coral habitats was statistically significantly larger on average compared to *Panulirus longipes* in rock.
- The abundance of *Panulirus versicolor* in coral was not statistically significantly different than in rock habitat.
- The abundance of Panulirus penicillatus in coral and rock habitats was statistically significantly larger on average compared to *Panulirus longipes* and *Panulirus versicolor*.
- Male to Female sex ratio was 0.85:1, with variations among species: *Panulirus longipes* had more females (0.6:1), *Panulirus penicillatus* had equal distribution (1:1), and *Panulirus versicolor* had slightly more males (1.1:1).

5. DISCUSSION

Following the previous surveys of the lobster resource held in the early 1990s (Bautil, 1992), this study provides an updated insight into the state of the spiny lobster resource around the granitic and coralline islands on the Mahé Plateau.

5.1. SPECIES COMPOSITION

Panulirus longipes dominated the species composition compared to *P. penicillatus* in the fishery (SFA, 2023). Similar observation was noted with the PLMP survey, whereby the former species dominated throughout the survey years. This shift is assumed to be influenced by several factors, including species-specific biological traits, fishing practices and regulatory measures such as size limits. *P. longipes* is generally smaller than *P. penicillatus* (Chauvet and Farman, 1994; Radhakrishnan et al., 2019). Since the fishery has a size limit, larger *P. penicillatus* might be preferentially targeted and retained, leading to their dominance in fishery catch. Consequently, *P. longipes*, being smaller in size, might be less targeted and, therefore, are more frequently observed in surveys where all individuals, regardless of size, are recorded.

5.2. ABUNDANCE AND WEIGHT

There is a distinct spatial heterogeneity in species distribution across the survey zones. Remote zones such as Denis and Bird Island exhibited higher mean density in both numbers and weight than zones around the main islands (Mahé, La Digue, and Praslin). One significant factor influencing these variations is the accessibility to licenced fishers or IUU fishers (SFA, 2023). Being more distant from the main islands, these survey zones likely experience less anthropogenic impacts such as fishing pressure or less human disturbance, allowing lobster to thrive, hence higher densities observed. One particular study conducted in Rottnest Island, Australia reported that lobster density was 34 times higher in unfished areas compared to areas with frequent fishing (Babcock et al., 2007). Perhaps habitat quality is another driving factor; a highly complex habitat without frequent human disturbance influences greater species abundance and diversity (Nothdurft and Webb, 2007; Wynne and Côté, 2007). For instance, the density of the Caribbean spotted spiny lobster (*Panulirus argus*) significantly increased in good-quality habitat, which consists of undamaged reef habitats and enough macro habitat for protection (Wynne and Côté, 2007).

Conversely, survey zones near the main islands are more accessible to licensed fishers or IUU fishers and, hence, could experience higher fishing pressure. Increased fishing activity can lead to lower lobster densities. Iacchei et al. (2005) stated that due to fishing activity, the abundance of the California spiny lobster (*Panulirus interruptus*) was reduced by 31% in areas designated for recreational fishing and 70% in commercial fishing areas. It is important to note that during the 2023 fishing season, the Catch per Unit Effort (CPUE) around Mahé island had one of the lowest CPUE despite having the highest catch of all the fishing locations (SFA, 2023). This may indicate that the lobster populations around Mahé could be under stress and experiencing localised depletion.

Despite the fishery being closed for 1 year after remaining open for 4 consecutive seasons this may signal the possibility of continuous fishing, i.e.; IUU fishing. The extent and impact of lobster loss due to IUU fishing in the Seychelles remains unknown, but reports from licensed fishers suggest it is a significant problem that could exceed the total licensed catches per fishing season. Unsustainable fishing practices pose a threat by potentially causing shifts in the ecosystem, decreasing lobster populations, and disrupting the livelihoods of licensed fishers. In the South Florida spiny lobster fishery, illegal harvesting and overfishing have decreased reproductive contributions and yield-per-recruit. Estimates suggest illegal activities range from 20% to 50% of the fishery (Lyons, 1986). Although management measures have been implemented for two decades, illegal activities often undermine these efforts by increasing fishing mortality beyond sustainable levels (SFA, 2023).

Furthermore, travelling to distant fishing grounds involves higher expenses such as fuel expenditure, vessel type, technology, and safety concerns, leading fishers to prefer areas closer to home ports, which significantly influences their spatial behaviour (Daw, 2008). Caddy and Carocci (1999) used the "friction-of-distance" concept to predict that resources closer to home ports would be exploited more intensively due to lower costs associated with distance. Conversely, more distant sites would have more pristine stocks as they are expected to be exploited less intensively.

Species-specific density was observed in the survey between the 2 most common species caught in the fishery. *Panulirus penicillatus* density was higher on remote islands while *P. longipes density was higher* around the main islands. This assumes that there is potential pressure on the *P. penicillatus* population around the main island. Given the biological differences between the 2 latter species, *P. longipes* matures at a smaller size. Consequently, a higher proportion of this species under the fishery size limit, leading to increased abundance (Goviden et al., 2015).

5.3. SIZE INDICATOR

5.3.1. CARAPACE LENGTH

Spatial variability in lobster mean carapace length across survey zones indicates that lobsters, *P. penicillatus*, especially at Sister Islands, are larger than those at Mahé North. Localised factors such as lower fishing pressure, habitat quality, prey availability, and environmental conditions likely support healthier lobster populations at Sister Islands. The 1-year fishery closure and fewer fishing license allocations near Praslin Island and La Digue Island, compared to Mahé Island, likely reduce fishing pressure around Sister Islands. This results in larger lobsters, as fisheries tend to reduce mean size by selectively removing larger individuals (Leitão, 2019; Tewfik et al., 2020). This fishery effect is observed across various species, including lobsters (Leitão, 2019; Tewfik et al., 2020). Such changes can reshape ecosystem and have significant ecological and socio-economic implications. According to Porobic et al. (2019), the depletion of large-sized lobsters can lead to an increase in sea urchin populations in Juan Fernández archipelago in Chile, potentially causing a regime shift in the ecosystem. Reduced fishing pressure thus correlates with larger lobster sizes and supports a robust population of larger lobsters around Sister Islands (Wynne and Côté, 2007; SFA, 2023). Interestingly, survey zones around Mahé Island, specifically Mahé North, South, and West, have lower lobster sizes compared to other zones. This is likely due to higher fishing efforts in these areas during the open season (SFA, 2023).

5.3.2. MEAN CARAPACE BETWEEN 1991 AND 2023 SURVEY

The general trend in the mean carapace length indicates a decline between 1991 and 2023 surveys, suggesting potential stressors impacting these populations over time. Species-specific trends also indicate decrease in the mean carapace size of lobsters. While most species and genders showed a decrease in mean carapace length, male *P. penicillatus* exhibited an increase. Perhaps the undersize cohort surveyed in 2022 may have had more time to mature due to a faster growth rate (SFA, 2022; Radhakrishnan et al., 2019), which could explain why the mean size of male *P. penicillatus* has increased despite the overall decline in other species and genders.

5.3.3. SPECIES BY SEX

Male lobsters typically exhibit larger carapace lengths compared to females, a phenomenon consistent across many crustacean species and attributed to sexual selection pressures (Dichmont and Brown, 2010; Cothran, 2020). *P. penicillatus*, both males and females, attain a larger size compared to the *P. longipes* and *P. versicolor*. This difference in size is a characteristic of the species and is not necessarily related to sex. The length-weight relationships for *P. penicillatus* show that both males and females have higher body weights for a given carapace length compared to *P. longipes* and *P. versicolor*. This indicates that *P. penicillatus* has a different growth pattern, allowing it to grow larger than the 2 other species (Wardiatno, 2020).

5.4. SEX RATIO

The sex ratio of 0.85 males for every female observed in the sampled population indicates a slight predominance of females. In contrast, the fishery reported a sex ratio of 2.2:1, dominated by males (SFA, 2023). According to license conditions, berried females must be released. This potentially indicates that licence fishers are complying to this requirement by releasing berried females.

Species-specific sex ratio indicated more females observed in *P. longipes*. In contrast, a balanced sex ratio, such as *in P. penicillatus* and *P. versicolor*, had equal representation of both sexes. *Panulirus longipes* is a smaller species than *P. penicillatus* and *P. versicolor*, with a significant proportion of berried females found below the size limit, which explains the skewed sex ratio with more females observed. For larger species like *P. penicillatus* and *P. versicolor*, a balanced 1:1 sex ratio suggests that the fishery is likely harvesting both males and females at sustainable levels. Potentially suggesting that current management practices, including the non-retention of berried females and adherence to size limits, are successfully maintaining population balance and reproductive health.

5.5. LENGTH- WEIGHT RELATIONSHIP

The Length- Weight Relationship (LWR) indicates the carapace length increases faster than weight gained across all species and remains consistent regardless of sex. This implies lobsters may be experiencing similar growth patterns for both sexes across species as they are maturing. Similar findings have been reported in the same species of lobsters (*P. penicillatus*: Almahy and Ali, 2022); *P. versicolor*: Situmorang et al., 2021). and other species (Basking shark: Ahnelt et al., 2020). Almany and Ali (2022) reported *P. penicillatus* in the Sudanese Red Sea coast exhibited negative allometric growth in both sexes and mixed female/male lobsters. They also reported that the hypoallemetric growth pattern influenced the decreased condition factor (i.e. overall health) of the species.

Organisms, particularly lobsters, are influenced by various intrinsic and extrinsic factors that affect their growth patterns. Environmental factors such as water temperature, salinity, dissolved oxygen levels, food availability and substrate type are crucial determinants of growth trajectories (Amin et al., 2022). Moreover, individual heterogeneity, metabolic phenotype, social behaviour, and physiological traits within populations also impact growth patterns, with dominant individuals often exhibiting faster growth rates due to resource competition (Chuan, 2017; Amin et al., 2022).

Resource allocation theory is significant in shaping the growth patterns of various organisms. According to studies, resource allocation strategies reflect adaptations that involve trade-offs among different pathways, such as foraging for high-quality resources versus acquiring lower-quality ones (Monson et al., 2022). In the case of *P. versicolor*, findings supported resource allocation theory by revealing a disproportionate allocation of resources to defensive structures during early ontogeny to enhance survivorship (Childress and Herrnkind, 2001).

The growth patterns of lobsters are complex, showing variations in allometric growth both between males and females and within populations (Situmorang et al., 2021). With findings reporting isometric growth conditions in both sexes or one sex may display positive allometric growth while the other demonstrates negative allometry or remains isometric (Situmorang et al., 2021). This variation can be attributed to the surrounding characteristics in which the lobster inhabits, linking up environmental, ecological, and physiological influences. Further research is needed to fully understand these dynamics and their implications.

5.6. REPRODUCTION

Significant variability in carapace lengths and reproductive stages were observed among *P. longipes*, *P. penicillatus* and *P. versicolor*. The smallest berried females observed were 6.2 cm (*P. penicillatus*), 5.5 cm (*P. versicolor*) and 5.1 cm (*P. longipes*). Compared to the latter 2 species, *P. penicillatus*, being the most abundant species with berried females, showed a wider range of carapace lengths and a higher mean length. Interestingly, the prevalence of first-stage egg development across all species suggests that there may be synchronous spawning amongst the species (Triay-Portella et al., 2017). The high percentage of *P. longipes* berried females below the size limit of 7.5 cm highlights the importance of existing size-specific and the release of berried females' management measures that have been implemented to protect these species. Such measures are

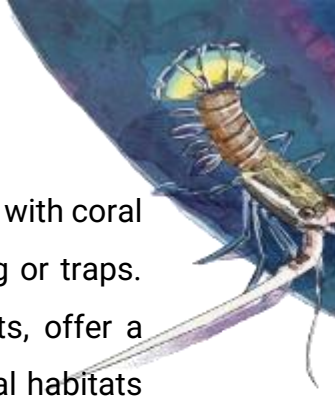
crucial for ensuring the sustainability of these species and the overall health of the marine ecosystem.

Variation in egg colouration indicates the population is reproducing with a range of reproductive stages, ensuring a continuous influx of juveniles into the population (Ikhwanuddin et al., 2015), which is a positive sign for population stability and resilience. However, egg colouration on its own is not the most reliable indicator of reproductive dynamics, as the success of fertilisation remains uncertain.

Additionally, the small sample size of females with eggs is inconclusive in understanding the reproductive behaviour of spiny lobsters. As spawning is the basis of recruitment (Annala and Eayrs 2010; De Croos et al., 2011), further research on gonad development using histological analysis is needed to understand the reproductive biology of spiny lobster in Seychelles. To predict future recruitment, seasonality, location, spawning duration, size at maturity and fecundity, a comprehensive understanding of reproductive biology and other population parameters is necessary. For example, in the Australian Western Rock Lobster (*Panulirus cygnus*), larvae settlement data are used to predict recruitment and catches three to four years ahead (Miethe et al., 2016). Parameters such as the size at maturity, fecundity and recruitment are important inputs to analytical stock assessments, which help determine stock status (Slipke et al., 2002; Caddy, 2004). Subsequently, stock status can be incorporated within a formal harvest strategy, prompting appropriate management responses.

5.7. COMPARISON BETWEEN 1991 AND 2023

Shifts in lobster distribution around Mahé Island between the 1991 and 2023 surveys can be attributed to complex anthropogenic interaction of fishing, climate change or environmental alterations (Steneck et al., 2013; Crawford et al., 2015). However, the main critical factor contributing to the decline in lobster population is the fishing pressure/ IUU fishing. Localised IUU fishing or continuous fishing can significantly influence catch distribution and possibly contribute to the shifts in lobster spatial distribution over time.



This localised pressure can create depletion hotspots. It is possible that areas with coral habitat can be targeted by IUU fishers either using SCUBA diving, snorkelling or traps. Coral habitats, being more concealed and deeper than coastal rock habitats, offer a degree of seclusion from law enforcement officers; hence, overfishing in coral habitats may push lobsters to seek refuge in less exploited rock habitats.

Due to the extended time gap between surveys, habitat alterations induced by rapid climate change also likely played a significant role in altering lobster distribution around Mahé Island (Gudka et al., 2018). Specifically, the decline observed in lobster populations within coral habitats from 1991 to 2023 can be attributed to the deterioration of these habitats caused by coral bleaching events (Obura et al., 2017). As a consequence, lobsters are likely to migrate to areas with more suitable environmental conditions (Tepker et al., 2023), e.g., rocks or areas with less fishing activity. This shift highlights the adaptive response of lobsters to changing environmental conditions, with implications for ongoing monitoring and management strategies in the region. It is important to note the limitations of comparing the 2 data points collected over a 22-year gap. This extended period makes it difficult to draw definitive conclusions about the effects of climate change and coral bleaching on lobster distribution. While the data may indicate potential shifts, it's important to interpret these observations cautiously, given the complex and multifactorial nature of ecosystem changes. Hence direct comparison between surveys was not possible between the 2 survey years.

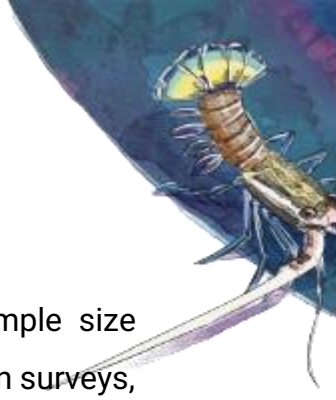
5.8. HABITAT

Although these species show a higher proportion in rocky habitats, the lack of statistical significance between habitats indicates a relatively balanced distribution across habitats. This could be attributed to similar conditions, such as shelter and food availability in these habitats (Perez, 1996; Sun et al., 2022). Spiny lobsters tend to exhibit similar diets between carbonate and granite reefs, suggesting despite narrow home ranges, spiny

lobsters can move between reef types highlighting their dietary plasticity (Sardenne et al., 2021).

Panulirus penicillatus showed species-specific preference for coral habitat, which is assumed to be due to the availability of prey sources. Another possible explanation could be during the survey, these lobsters might have been out feeding in corals, explaining their prevalence in coral habitats. For instance, the California spiny lobster *Panulirus interruptus* has been associated with rocky habitats during the day and feeds on red algae (Plocamium cartilagineum) at night, indicating nocturnal movement to specific feeding areas before returning to their resident home (Withy-Allen and Hovel, 2013). *Panulirus penicillatus* individuals in rock habitats tend to be larger, potentially due to less competition or more effective predator avoidance strategies. Rocks habitat provide larger crevices offering better protection, which may support larger lobsters. Individuals in coral reefs may allocate more energy towards defensive behaviours influencing smaller average sizes.

Panulirus versicolor and *P. longipes*, for instance, may have adapted behaviours and physiological traits influencing their size in different habitats. Species-specific resource exploitation or predator avoidance could lead to size differences. Intense competition for food may be alleviated by dietary specialisation, resulting in no strong preference. (Sardenne et al., 2021). Sardenne et al. (2021) reported that the diet composition of P. versicolor consisted of slightly more molluscs and algae, which is a characteristic of a lower tropic level position than the other 2 species. It is important to note that both area and fishing activity are likely to influence length distributions rather than habitat alone. Further research is needed to understand the interaction between habitat, distribution, and abundance of lobsters.



5.9. STUDY LIMITATIONS

This study had several limitations. A major constraint was the small sample size collected to assess the state of the stock. Additionally, the long period between surveys, combined with sample collection across different years, introduces variability and uncertainty to the results, lacking a consistent time series to assess the resource. Comparisons between surveys are somewhat limited to Mahé Island due to mechanical problems in the 1991 survey, which led to abandoning the initial survey plan. The inability to survey all 126 sites due to the persistent southeast monsoon caused unfavourable conditions, leading to either anchoring or abandoning the survey sites. Not all preselected survey stations were found unsuitable for lobsters on-site, requiring more time to search for ideal habitats. Additionally, only 1 transect was conducted per survey sites.

6. CONCLUSION

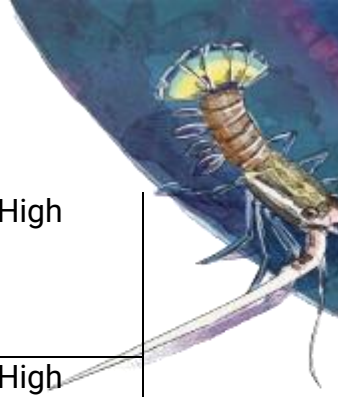
The research provides a snapshot of the relative spatial abundance, distribution, size variation, and habitat influence on lobster species within the surveyed granitic and coralline islands of the Mahé Plateau. The survey had certain limitations, such as survey timing compared to the 1991 survey and weather conditions preventing all stations from being surveyed. The study highlights spatial variations in density with Denis Island having higher lobster compared to survey zones around main islands. Fishing pressure may impact the population dynamics, with areas subjected to more pressure exhibiting smaller or lighter lobsters, in this case, survey zones around Mahé Island. This observation implies potential overexploitation or unsustainable fishing practices in these regions. Illegal fishing is a major issue affecting lobster fishery, underscoring the need for stricter regulations and enhanced enforcement to ensure compliance. Such measures are essential not only to protect the lobster populations but also to sustain the livelihoods of licensed fisher's dependent on these resources. The inability to make a direct comparison of the 1991 and 2023 surveys arose from the differences in survey

methodologies. This experience highlights the importance of standardising methodologies for future surveys to enable more seamless comparisons over time and the need to document any changes in methodologies to provide context for future researchers. Overall, the findings emphasise the complexity of managing lobster populations for long-term sustainability. The exploring alternative fishing grounds beyond the Mahé Plateau could potentially alleviate pressure on local populations, contingent upon conducting a thorough stock assessment to better understand the current status of lobsters.

7. RECOMMENDATIONS

Based on the insights of this study and gaps identified, several research and management recommendations are being proposed:

Proposed Recommendations	Priority Level
Survey	
Conduct a quantitative stock assessment using both fishery-dependent and fishery-independent data to evaluate the status of the spiny lobster stock over time.	High
Continue regular surveys to monitor population trends, abundance, distribution, and size structure. Invest in research on habitat preferences, reproductive biology, and responses to fishing pressure.	High
Depending on the reliability of fisheries-dependent or independent assessments, conduct a comprehensive fisheries-independent survey every five years to obtain an updated status of the lobster resource on the Plateau.	High
It is recommended that monitoring, control, and surveillance is strengthened to discourage illegal fishing activities throughout the year.	High
Investigate reproductive cycles, fecundity, and larval dispersal to understand recruitment dynamics and juvenile hotspots, identifying nursery sites can inform targeted closures or seasons. Larval and juvenile data can predict future fishery recruitment.	High
General	
Expand research efforts to include outer islands, aiming to explore lobster populations to alleviate pressure on the Mahé Plateau.	High



Stakeholder engagements should be undertaken regularly to foster collaboration between scientists, fisheries managers, fishers and other stakeholders to highlight the importance of data collection, knowledge sharing and to develop effective management strategies.	High
Implementation of an education and awareness campaign focused on sustainable fisheries and the importance of regulations to promote compliance and best harvesting practices	High
Investigate the possibility of implementing a post-harvesting tagging program to try and combat the IUU. This is one major challenge of the lobster fishery or another fishery.	High
To develop a harvest strategy with the assistance of the FishPath team, to ensure sustainable fisheries management for the lobster fishery.	High
Investigating the role of artificial reefs in supporting lobster populations.	Medium
Investigating Spiny Lobster Puerulus Settlement Around Mahé Island.	Medium
Undertake genetic studies to investigate the stock structure of lobster species resources on the Mahé Plateau.	Low
Investigate the influence of environmental factors, such as temperature, predation pressure, and habitat quality on lobster population.	Low
Conduct a survey to understand the distribution and abundance of the rare *Panulirus ornatus*.	Low
Use tagging and telemetry to track movement patterns and habitat use, providing insights for spatial management.	Low

It is important to note that the implementation of these proposed recommendations will depend on available resources such as time, budget, and personnel—and their alignment with specific management or organisational goals. It is also important to acknowledge the existing limitations in institutional capacity and funding, which may impact the realisation of some of these recommendations.

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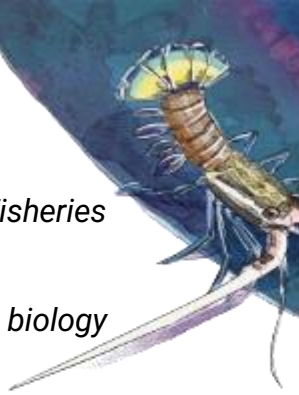

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APPENDIX 1

*Table 5: Post hoc pairwise comparisons of **mean density in numbers per m² by zone using Dunn's Test**. P values were adjusted with the Bonferroni method.*

№	Comparison Groups	Carapace Length (cm)	
		Adjusted P value	Significance level
1	La Digue - Mahé South	1.730e-03	P <.05
2	La Digue - Mahé West	1.420e-03	P <.05
3	La Digue - Silhouette	2.266e-02	P <.05
4	La Digue - Sisters	4.533e-02	P <.05

Significance level at 0.05. Non-statistical significance was omitted from the list due to list length.

*Table 6: Post hoc pairwise comparisons of **mean density in numbers per m² by zone of Panulirus penicillatus using Dunn's Test**. P values were adjusted with the Bonferroni method.*

№	Comparison Groups	Carapace Length (cm)	
		Adjusted P value	Significance level
1	Denis Island - La Digue	3.300e-03	P <.05
2	Denis Island - Mahé North	1.141e-02	P <.05
3	La Digue - Silhouette	3.250e-02	P <.05
4	La Digue - Sisters	2.031e-03	P <.05
5	Mahé North - Sisters	1.390e-02	P <.05

Significance level at 0.05. Non-statistical significance was omitted from the list due to list length.

*Table 7: Post hoc pairwise comparisons of **mean density in numbers per m² by zone of Panulirus versicolor using Dunn's Test**. P values were adjusted with the Bonferroni method.*

№	Comparison Groups	Carapace Length (cm)	
		Adjusted P value	Significance level
1	La Digue - Mahé West	3.262e-02	P <.05

Significance level at 0.05. Non-statistical significance was omitted from the list due to list length.

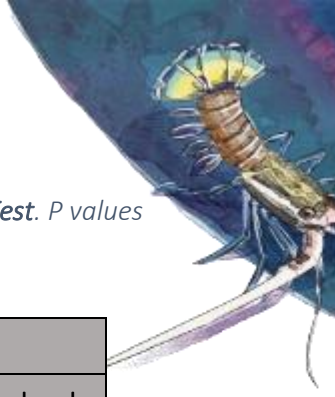

*Table 8: Post hoc pairwise comparisons of **mean density in weight (kg) per m² by zone Dunn's Test**. P values were adjusted with the Bonferroni method.*

№	Comparison Groups	Carapace Length (cm)	
		Adjusted P value	Significance level
1	La Digue - Mahé South	2.514e-03	P <.05
2	La Digue - Mahé West	1.261e-02	P <.05
3	La Digue - Silhouette	2.402e-02	P <.05
4	La Digue - Sisters	3.955e-02	P <.05

Significance level at 0.05. Non-statistical significance was omitted from the list due to list length.

*Table 9: Post hoc pairwise comparisons of **mean density in weight (kg) per m² by zone of Panulirus penicillatus using Dunn's Test**. P values were adjusted with the Bonferroni method.*

№	Comparison Groups	Carapace Length (cm)	
		Adjusted P value	Significance level
1	Denis Island - La Digue	4.637e-03	P <.05
2	Denis Island - Mahé North	1.217e-02	P <.05
3	La Digue - Silhouette	4.882e-02	P <.05
4	La Digue - Sisters	3.546e-03	P <.05
5	Mahé North - Sisters	1.628e-02	P <.05

Significance level at 0.05. Non-statistical significance was omitted from the list due to list length.

APPENDIX 2

*Table 10: Post hoc pairwise comparisons of **male carapace length by species using Dunn's Test**. P values were adjusted with the Bonferroni method.*

№	Comparison Groups	Carapace Length (cm)	
		Adjusted P value	Significance level
1	*Panulirus longipes - Panulirus penicillatus*	1.141e-14	P <.05
2	*Panulirus longipes - Panulirus versicolor*	6.518e-01	ns
3	*Panulirus penicillatus - Panulirus versicolor*	1.295e-11	P <.05

Significance level at 0.05. ns; nonsignificant difference.

*Table 11: Post hoc pairwise comparisons of **female carapace length by species using Dunn's Test**. P values were adjusted with the Bonferroni method.*

№	Comparison Groups	Carapace Length (cm)	
		Adjusted P value	Significance level
1	*Panulirus longipes - Panulirus penicillatus*	1.446e-19	P <.05
2	*Panulirus longipes - Panulirus versicolor*	4.954e-01	ns
3	*Panulirus penicillatus - Panulirus versicolor*	3.046e-07	P <.05

Significance level at 0.05. ns; nonsignificant difference.

*Table 12: Post hoc pairwise comparisons of **carapace length by zone using Dunn's Test**. P values were adjusted with the Bonferroni method.*

№	Comparison Groups	Carapace Length (cm)	
		Adjusted P value	Significance level
1	Denis - Mahé North	1.381e-03	P <.05
2	Praslin - Mahé North	3.203e-03	P <.05
3	Silhouette - Mahé North	3.955e-02	P <.05
4	Sisters Islands - Mahé North	1.148e-05	P <.05
5	Denis - Mahé West	5.477e-05	P <.05
6	Sisters Islands - Mahé West	1.451e-07	P <.05
7	Praslin - Mahé West	1.810e-03	P <.05
8	Silhouette - Mahé West	1.707e-02	P <.05
9	Sisters Islands - Mahé South	1.975e-03	P <.05

Significance level at 0.05. Non-statistical significance was omitted from the list due to list length.

*Table 13: Post hoc pairwise comparisons of **Panulirus penicillatus carapace length by survey zones using Dunn's Test**. P values were adjusted with the Bonferroni method.*

№	Comparison Groups	Carapace Length (cm)	
		Adjusted P value	Significance level
1	Bird Island - Mahé South	4.142e-02	P <.05
2	Denis Island - Mahé South	4.438e-02	P <.05
3	Bird Island - Silhouette	1.007e-02	P <.05
4	Denis Island - Silhouette	3.649e-03	P <.05
5	Bird Island - Sisters Islands	1.262e-03	P <.05
6	Denis Island - Sisters Islands	1.302e-04	P <.05

Significance level at 0.05. Non-statistical significance was omitted from the list due to list length.

*Table 14: Post hoc pairwise comparisons of **female Panulirus penicillatus carapace length by survey zones using Dunn's Test**. P values were adjusted with the Bonferroni method.*

№	Comparison Groups	Carapace Length (cm)	
		Adjusted P value	Significance level
1	Denis Island - Silhouette	3.774e-03	P <.05
2	Bird Island - Sisters Islands	2.457e-02	P <.05
3	Denis Island - Sisters Islands	1.236e-04	P <.05

Significance level at 0.05. Non-statistical significance was omitted from the list due to list length.

Table 15: Post hoc pairwise comparisons of male *Panulirus penicillatus* carapace length by survey zones using Tukey. P values were adjusted with the Bonferroni method.

№	Comparison Groups	Carapace Length (cm)	
		Adjusted P value	Significance level
1	La Digue-Denis	7.000e-03	P <.05
2	Mahé South-Denis	2.112e-01	ns
3	Silhouette -Denis	3.721e-01	ns
4	Mahé South-La Digue	6.809e-01	ns
5	Silhouette -La Digue	3.880e-01	ns
6	Silhouette -Mahé South	9.769e-01	ns

Significance level at 0.05. ns; non-statistical significance.

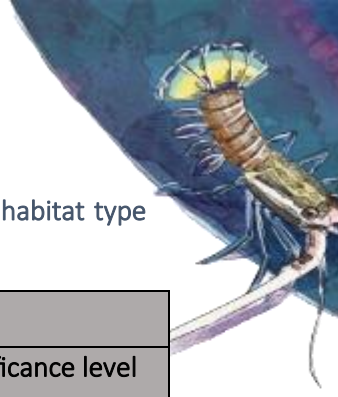

Table 16: Post hoc pairwise comparisons of ***Panulirus penicillatus*** mean carapace length by habitat type ***using Dunn's Test***. P values were adjusted with the Bonferroni method.

№	Comparison Groups	Carapace Length (cm)	
		Adjusted P value	Significance level
1	*P. penicillatus*. Coral - *P. penicillatus*. Rock	8.519e-03	P <.05
2	*P. penicillatus*. Rock - *P. versicolor*. Coral	9.841e-04	P <.05
3	*P. penicillatus*. Coral - *P. versicolor*. Rock	2.005e-10	P <.05
4	*P. penicillatus*. Rock - *P. versicolor*. Rock	2.506e-18	P <.05
5	*P. penicillatus*. Coral - *P. longipes*. Coral	8.786-05	P <.05
6	P. *penicillatus*. Rock - *P. longipes*. Coral	2.521e-11	P <.05
7	*P. penicillatus*. Coral - *P. longipes*. Rock	1.158e-16	P <.05
8	*P. penicillatus*. Rock - *P. longipes*. Rock	5.191e-27	P <.05

Significance level at 0.05. ns; non-statistical significance.