United Nations Educational, Scientific and Cultural Organization
GRÓ FTP Fisheries Training Programme Under the auspices of UNESCO

grocentre.is/ftp Final Project 2021

LIFE HISTORY OF THE FIVE MAIN COMMERCIAL SHRIMP SPECIES (*PENAEIDAE FAMILY*) IN COASTAL WATERS OF EL SALVADOR

Diana Elizabeth Barahona Hernández
Ministerio de Agricultura y Ganadería
Centro de Desarrollo de la Pesca y la Acuicultura, El Salvador.
diana.barahona@mag.gob.sv

Supervisors:
Ingibjörg G. Jónsdóttir: ingibjorg.g.jonsdottir@hafogvatn.is
Klara Björg Jakobsdóttir: klara.jakobsdottir@hafogvatn.is
Haraldur Arnar Einarsson: haraldur.arnar.einarsson@hafogvatn.is

ABSTRACT

This study describes some aspects of the biology and biomass estimates of the most commercially important shrimp species to El Salvador. These species are by order of importance, the white shrimps, *Penaeus vannamei*, *P. californiensis*, and *P. stylirostris*, followed by red shrimps, *P. brevirostris*, and brown shrimps, *P. californiensis*. Life history parameters were estimated with a focus on variability between fishing zones and depths. Most of the shrimp species showed differential distribution influenced by the interannual variations, bathymetry, and recruitment variations. In 2019 the biomass was 33% higher compared with 2015 and *P. vannamei* was the most representative 67% in 2019. Length frequency distribution and mean length at sexual maturity show sexual dimorphism and males become mature before females. CPUE estimations show that white shrimps are harvested all year round but during January and February the catches per unit effort increased. The red shrimp's most important months for harvesting were from August to January. A data collection program is suggested to obtain time-series data that can contribute to assessment of the resources and provide tools to the decision-makers.

Key words: Penaeid shrimp, biomass, biology, resource assessment, life history, El Salvador.

This paper should be cited as:
Barahona Hernández, D.E. 2021. *Life history of the five main commercial shrimp species (Penaeidae family) in coastal waters of El Salvador.* GRÓ Fisheries Training Programme under the auspices of UNESCO, Iceland. Final project.
https://www.grocentre.is/static/gro/publication/1788/document/BarahonaHernández21prf.pdf

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

El Salvador is a Central American country with Guatemala to the West, Honduras to the North and East, Nicaragua to the East, and to the South lies the Pacific Ocean. The country is located between latitudes 13°N and 14°N. The climate on the coast is tropical with average temperatures between 23°C and 28°C. The year is divided into the rainy season (May - October) and the dry season (November - April), though the climate has undergone drastic changes through time (JICA, 2002).

The coastline of El Salvador is 321 Kilometres from the Paz River on the Guatemalan boundaries (West) to the Gulf of Fonseca which is shared with Honduras and Nicaragua and its continental shelf increases from west to east. The coastal characteristics are due to El Bálsamo mountain range, the Jucuarán mountain range and the Conchagua volcano, these geographic systems divide the Salvadorean coast into six different hydrographic areas, namely the Western Coastal Plain, cliff coast associated with the El Bálsamo mountain range, Central coastal plain, cliff coast associated with the mountain range of Jucuarán, Eastern Coastal Plain and the Gulf of Fonseca Coast (Gierloff-Emden, 1976; MARN, 2007; JICA, 2002).

In the 1950s, shrimp fishing started in El Salvador with the arrival of ships from the United States. FAO recommended a limit of 43 trawlnet vessels, which was reached between 1956 and 1958, but the number of vessels increased to 60 in 1959 (JICA, 2002; Zelaya Cruz, Hernández, Candray, Galdámez Olmedo, & López Rivera, 2015). The number of vessels continued to increase, achieving the highest number of active vessels during the 90s with 105 vessels. However, the number of vessels has been gradually decreasing over time since the year 2000 (JICA, 2002; Salazar Linares & Barahona Hernández, 2008; Zelaya Cruz, Hernández, Candray, Galdámez Olmedo, & López Rivera, 2015). Currently, the fishing effort is limited to 55 trawlers by law.

Historically inshore shrimp fisheries were mainly carried out with hand lines and rowing canoes. In the 1960s, the fishing grounds of the coast of El Salvador produced more shrimp than any comparable area between Mexico and Panama, even though it is the smallest country of Central America. Moreover, in the 1960s fibre-reinforced plastic, outboard motors, gill nets, and longline were introduced throughout the coastal zone. Up to the mid-1980s, shrimp gillnet fishery was intensified, and in the early 1990s, the inshore trawling for shrimp within three nautical miles began. Before the improvements of the artisanal fisheries with the shrimp gillnet, the only shrimp fishery was in the lagoons and estuaries where canoe fishermen took juvenile shrimp with cast nets and traps. These traditional fishing methods are still used in those areas today (Gross, 1973; JICA, 2002).

The main marine target species in El Salvador are, in order of importance: shrimps, sharks, dolphinfish, and snappers. The fishing gear that is used in El Salvador is mainly gillnet, followed by, in order of importance: cast net, handline, longline, harpoon, manual extraction of mollusks and pot (OSPESCA, 2009 - 2011). For the industrial fisheries in El Salvador, there is one longline vessel, 55 shrimp trawlnet vessels, and 8 tuna fisheries vessels (CENDEPESCA, 2021). For the artisanal sector, there are 13,300 fishing boats and 27,600 fishermen, where 19,200 are marine artisanal fishermen. (OSPESCA, 2009 - 2011).

The marine artisanal sector in El Salvador produces 40% of the seafood, and the industrial sector provides 51.6%, which is divided primarily by tuna fisheries with 44.7%, trawl net fisheries with 6.7%, and longline fisheries with 0.2% (FAO, 2014).

The shrimp trawl net fishery is a multispecies fishery, where the main target species are the white shrimps (*Penaeus vannamei, P. stylirrostris,* and *P. occidentalis*), brown shrimps (*Penaeus californiensis*), and the pink or red shrimp (*Penaeus brevirostris*). These species have similar life histories, and their occurrence depends on their habitat requirements. In general, they spend their adult phase on muddy sea bottoms in a range of depths around 2 to 95 m, depending on the species. When they are in the planktonic stage before being post larvae, they move to the estuaries or coastal lagoons where they settle and turn to benthos stage as subadults, then they move from estuaries to nearby ocean waters to spawn, where they finish their lifespan of a little over a year (Gross, 1973; SCDNR, 2021).

1.1 Problem statement

According to the General Law of Fisheries and Aquaculture in the second Article, the hydrobiological resources distributed in the jurisdictional waters are part of the National patrimony. It states that the protection and sustainable development of these resources are in the social interest, especially under the optimal utilisation (Art. 3) (Asamblea Legislativa de El Salvador, 2001).

The General Directorate of Fisheries and Aquaculture (CENDEPESCA, Spanish acronym established by law) is the competent authority to apply the Law (Art. 8), and at the same time, is the body in charge of promoting and carrying out research on fisheries (Art. 10c) (Asamblea Legislativa de El Salvador, 2001).

Management of fisheries resources is a responsibility that the law confers to CENDEPESCA. However necessary data for stock assessment analysis has not been collected on regular basis due to the lack of resources and prioritisation.

The trawlnet fishery is still very important for the economy in the fishing communities but there are dispersal data in scientific surveys and commercial tows that have not yet been analyzed yet due to lack of resources, other more important priorities, and because they were not the main objectives of those research surveys.

As mentioned before, El Salvador used to be the best producer of shrimp species in the region (Gross, 1973) but nowadays, shrimp is considered overexploited. To promote sustainable use of shrimp, there is a need to assess the shrimp stock to provide more guidance and advice to manage it.

1.2 Rationale

Tuna industrial fishery is the most important productive sector in El Salvador, but it is driven by foreign investment. If fishery production driven by foreign investment would come to a halt, the fishery national production would decrease to a minimum with unforeseen consequences. The second most important fishery production comes from shrimp production, which is a national (local) driven operation and thus contributes to food security and job generation.

To effectively support recommendations to decision-makers regarding the shrimp fisheries and their sustainable utilisation, it is important to have an integrated background regarding the managed species, considering the life history patterns and the abundance and distribution between hydrogeographic zones and depths as well.

1.3 General Objective

The overall objective of this study is to determine life history patterns, such as length distribution, maturity stages, and length at first maturity for males and females of the Salvadorean stocks of the white, brown, and red shrimps (the Penaeidae family), with a focus on variability between fishing areas and depth. The results will be used to provide advice on how to improve the management of the shrimp fisheries.

1.3.1 Specific objectives

- To determine distribution by fishing areas and depth of the five main commercial Penaeid species
- To estimate biomass indices in the fishing zones by location and depth
- To estimate life history parameters (length distribution, maturity stages, and length at first maturity for males and females)
- To establish catch per unit effort for group species

2 LITERATURE REVIEW

2.1 Coastal marine zone of El Salvador

According to El Salvador´s Environment Law, the Coastal Marine Zone is defined as the coastal strip extending 20 kilometres from the coastline inland, as well as the marine zone that includes the open sea, from the surface down to a depth of 100 metres. This zone encompasses the habits where local marine species are distributed (Asamblea Legislativa de El Salvador, 1998).

From west to east, the marine area of El Salvador, including the land, is divided into six sections; the western coastal plain, cliff coast associated with El Bálsamo mountain range, central coastal plain, cliff coast associated with the mountain range of Jucuarán, eastern coastal plain, and the Gulf of Fonseca coast (Gierloff-Emden, 1976; MARN, 2007).

Considering the Salvadorean sea area, and the hydrographic characteristics, the fishing areas are divided into four zones according to (López, 1982) based on (Gierloff-Emden, 1976):

> **Zone I:** The borderline with Guatemala (the Paz River) to Acajutla port, which has extended beaches with sandy characteristics, and inserted estuaries with coastal lagoons. The main estuaries in the area are Bola de Monte and Barra de Santiago, influenced by the rivers' freshwater discharges. These coastal lagoons have big extensions of mangrove forests. In addition, Punta Remedios is one of the most distinctive marine zones, being a terrace extended into the sea, which becomes a rocky

reef with coral patches at depths greater than 20 meters. Temperature on average 28°C and transparency readings around 10 m in the dry season.

Zone II: From Acajutla to Puerto de La Libertad, with a steep coastline associated with the El Bálsamo mountain range which extends throughout the coastline area. It is characterised by cliffs, terraces, and inlets formed by the striations of the mountains, with heights greater than 30m above average sea level. The bathymetry of the area is distinguished by an abrupt change in depth in the first 50 m of seabed where it is common to find vertical walls of rocky substrate 50 m or deeper.

Zone III: From La Libertad to the mouth of Lempa River, characterised by extended beaches and the second principal estuary, Jaltepeque, as well as the most important river in the country, Lempa River. Both have large extensions of salty forests and wetlands in their radius of influence.

Zone IV: From the Lempa River to Meanguerita island, where Jiquilisco bay and Gulf of Fonseca are the most important estuary bodies in the country with socioeconomic and environmental importance. This zone has large extensions of salty forests and wetlands in its radius of influence. The steep coastline associated with the Jucuarán mountain range extends between El Espino beach and El Cuco beach characterised by cliffs and terraces with rocky terraces that penetrate the sea forming a rocky substrate. In the eastern area, between El Cuco beach and Punta Amapala, the area is characterised by extended beaches, estuaries of medium-flow rivers, and small inlets. Meanguerita Island is located in the Gulf of Fonseca, where it is influenced by the Goascorán River, the estuary, and nearby islands.

The estuaries along the coastline are bordered by saline forests, distinct from the surrounding coastal plains. These plains feature a step-like formation created by the accumulation of fine sediment (mud), resulting in alluvial land (MARN, 2007). There are two forms of estuaries depending on the balance between the freshwater discharge from the river connected to them and the volume of salty water carried by the tidal wave. In high flow rivers (Grande de Sonsonate, Jiboa, Lempa, Grande de San Miguel, Goascorán), a delta is formed surrounded by channels of fine sediment where both forces are in balance. A large number of lower flow channels form coastal lagoons known as estuaries or bays that are characterised by sand bars, with the formation of islets or islands in their interior, or they connect with the sea and main channels with strong currents of tides (MARN, 2007).

In El Salvador the mangrove forests in estuaries have a coverage of around 40,000 hectares, the largest extensions are Bahia de Jiquilisco, Estero de Jaltepeque, Bahía de La Unión and Barra de Santiago. There are also scattered patches of forest in San Juan, Metalío, Barra Salada, Barra Ciega, San Diego, El Esterón and El Icacal (MAG, 2012). Bahía de Jiquilisco and Bahía de La Unión are ecosystems that support the largest fishery production of the North Central American Pacific (MARN, 2012).

The beaches and sand deposits are constantly being modified by erosion and sedimentation processes. The perpendicular transport to the coastline exposes a sheet of boulders mainly in the rainy season when the components of the waves coming from the southern hemisphere transport a greater volume, intensifying the return currents that erode the upper sheet (MARN, 2007). Precipitation is the origin of the transport of terrigenous sediments by rivers towards the sea. Short periods (by days) with heavy rainfall (100 mm or more) inject large amounts of sediment into the marine strip in the form of feathers whose dimensions, again, depending on the balance of forces of the river flow, the tidal wave and wind effort (MARN, 2007).

2.2 Penaeid shrimp biology and life history

Shrimps are mostly found in shallow waters or moderately deep. Most of the commercial shrimps are caught on the continental platform at depths of less than 100 m, mostly benthic species in the adult stage. They live in different types of seabeds, like rocky, sandy, muddy, shelly gravel, or a mixture (Fischer, et al., 1995).

The *Penaeus* species are dioecious (separate males and females that do not change sex during their lives), and they spawn in the open ocean, at the depth of 10 to 80 m. The eggs hatch a few hours later, releasing the nauplius and protozoea stages, which are planktonic, and transported by the currents to the coast. In the case of *P. styliorostris*, *P. occidentalis*, and *P. vannamei*, they arrive as a post-larvae stage, approximately 3 weeks after spawning, between 6 and 14 mm. The post-larvae invade the estuaries or coastal lagoons leaving behind the planktonic stage to become part of the benthos of those areas. In these food-rich bottom areas, they go through a stage of accelerated growth quickly reaching a juvenile stage, and as they increase in size, they return to the drainage areas of coastal lagoons or estuaries where they become subadults. Shortly thereafter, these shrimps migrate to the sea, following their growth process, to reach the reproduction areas. There, the females mature, release the eggs, and give rise to a new cycle (Figure 1). Most of the shrimps in the reproduction areas are less than one year old (Fischer, et al., 1995).

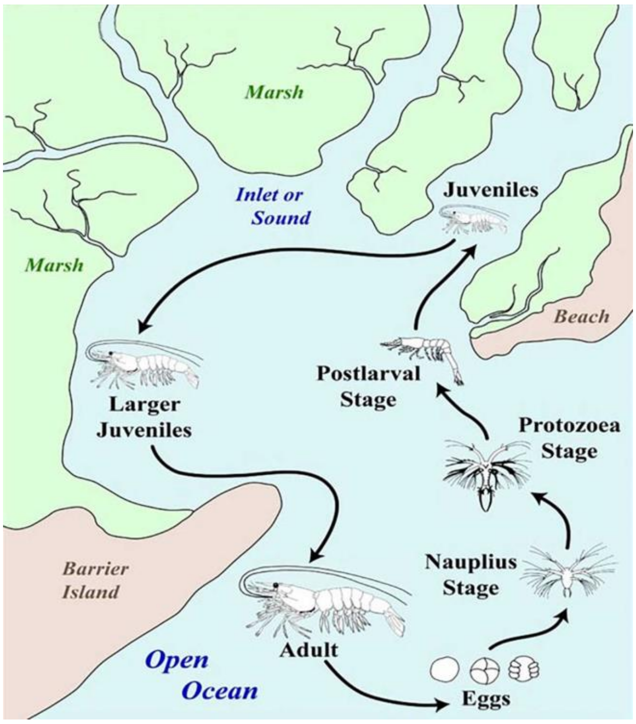

Figure 1: Life cycle of Penaeid shrimps (SCDNR, 2021).

P. californiensis is considered to complete their life cycle without entering the estuaries (López-Martínez, Arreguín Sánchez, Hernández Vásquez, Herrera Valdivia, & García Juarez, 2002; Leal - Gaxiola, 1999). Other authors mentioned that *P. californiensis* remains in the Sonora estuary for 1 to 4 weeks (Romero-Sedano, Aragón-Noriega, Manzano-Saravia, Salinas-Savala, & García-Juárez, 2004; Leal - Gaxiola, 1999). *P. brevirostris*, is classified as oceanic, and completes its life cycle without entering the estuaries (Rodriguez de la Cruz, 1981).

Crustaceans exhibit prominent sexual dimorphism (Accioly, et al., 2013). Females often grow larger and reach larger sizes compared with males due to sex hormones giving place to morphological differences between sexes and sexual dimorphism (Gopal, Gopikrishna, & Krishna, 2010).

The main five commercial shrimp species in El Salvador, are grouped as red, brown, and white shrimps. The red shrimps are *Penaeus brevirostris,* brown shrimps are *P. californiensis* and the white shrimps are *P. vannamei, P. stylirrostris,* and *P. occidentalis.*

The red shrimp, known as camarón Rojo, *Penaeus brevirostris,* Kingsley 1878, can reach a maximum size of 20.8 cm of total length. They mostly live in sandy seabeds and occasionally in silt or clay areas. They are mainly found between 20 to 180 m. The brown shrimp, known as camarón café, *Penaeus californiensis,* Holmes 1900, can reach 24 cm of total length, they inhabit sandy or muddy grounds, and are found between 2 to 180 m but mostly between 25 and 50 m depth (Fischer, et al., 1995).

The Western white shrimp, known in Spanish as Camarón blanco del Pacífico, and known in El Salvador as Camarón rayado or mandarin, *P. occidentalis* Streets 1871, can reach 24 cm of total length. They are found in the continental platform between 2 and 160 m depth, but the vast majority is between 2 and 27 m. Therefore, it is considered a shallow-water species and is associated with muddy areas (Fischer, et al., 1995)

The blue shrimp, known as camarón azúl in Spanish, *Penaeus stylirrostris* Stimpson 1874, males can reach 21.4 cm and females can reach 26.3 cm of total length. They live between 5 and 45 m of depth but prefer shallow waters, less than 30 m. It is associated with muddy or sandy bottoms with an important proportion of clay and slime (Fischer, et al., 1995).

The whiteleg shrimp, known as Camarón patiblanco, and camarón maleante or cola Verde in El Salvador, *Penaeus vannamei* Boone 1931, can reach 23 cm in total length. This species has been caught between 5 and 72 m depth, but in coastal waters, they can be found between 1 and 4 m. It is characterized in muddy or sandy-muddy grounds (Fischer, et al., 1995).

The fishing fleet concentrates on the white shrimp from October to April and avoids the pink shrimps during that time. The catch-per-day for whites is highest in October to March, and the best months are November through February. However, the largest whites are taken from April to July when the catches of that species are lowest (Gross, 1973).

2.3 El Salvador´s Fisheries production

The registering of fisheries production in El Salvador started in 1950, mainly with artisanal fisheries. In the early 1960s, the shrimp trawl fisheries-initiated operations, in particular to export to the U.S.A.

In 2002, the general statistical data collecting methods changed because Japan contributed with a new methodology, after that, an increasing trend in catch of other species other than tuna is well observed (FAO & MAG, 2016) (Figure 2), At the same time, the tuna industry started operations under the Salvadorean flag. Marine species harvested in national waters, in 2019 were 37,647 t and in the case of freshwater production of 1,796t, the marine catch differences are higher than the freshwater catches (FAO, 2021).

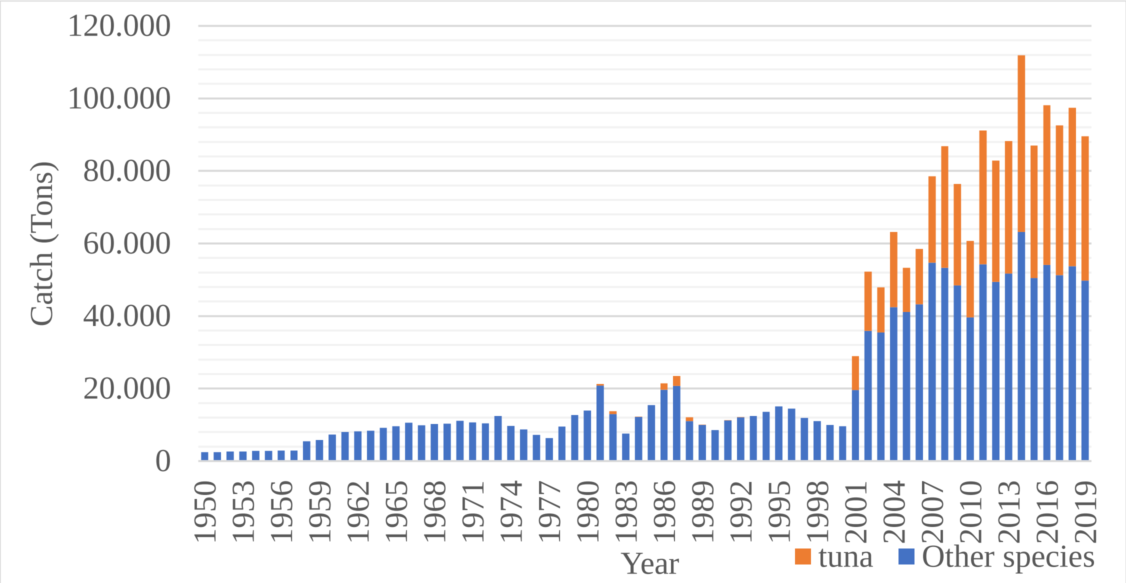

Figure 2: Fisheries production in El Salvador, comparison between overseas tuna fisheries and national waters fisheries, 1950 to 2019. Source: (FAO, 2021).

2.4 Shrimp trawl net fisheries in El Salvador

The shrimp trawl net fishery started towards the end of the 50s and the fishing effort recommended by FAO during that time was 43 vessels in 1955. Due to pressure from companies, the fishing effort was increased to 60 vessels in 1959 and over time the fishing effort increased, reaching its highest number during the 1990s with 105 vessels (JICA, 2002; Zelaya Cruz, Hernández, Candray, Galdámez Olmedo, & López Rivera, 2015; CENDEPESCA, 2020). In 1960 the total catch of white shrimps in trawlnet fisheries was 2,026,417 kg, but since 2009 there has been a collapse, but recently there is a trend towards recovery apparently because of the close season established by law (Figure 3) (Barahona & Galdámez, 2020).

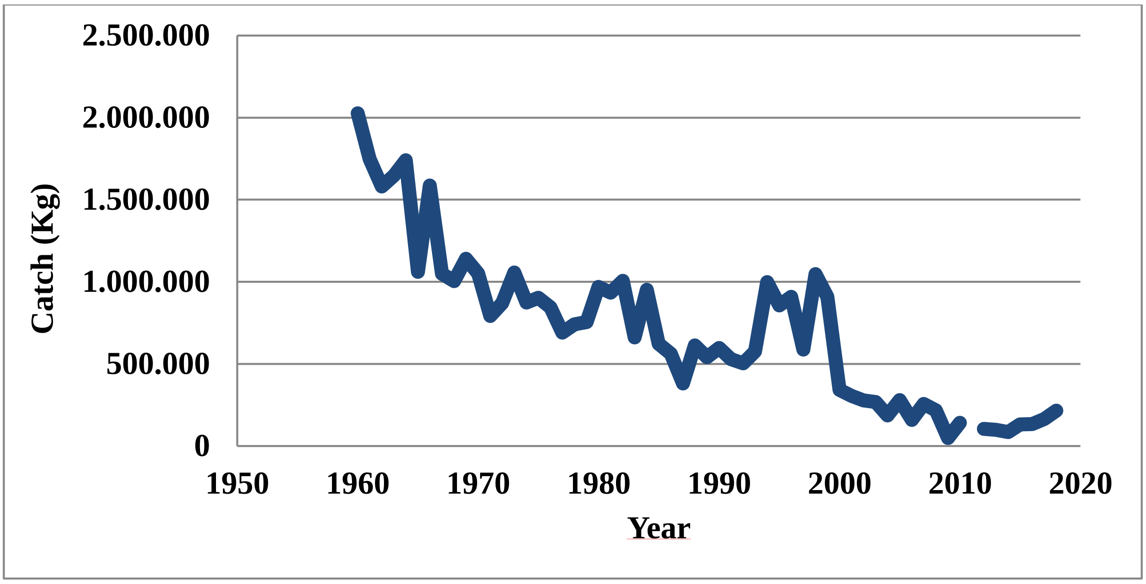

Figure 3: Catch trend of white shrimps on trawl net fisheries in El Salvador, 1960 - 2019.

3 METHODOLOGY

3.1 Study area

The coastline of El Salvador extends from 13° N and 88° W to 14° N and 90° W, the outer edge of its Coastal-Marine Zone is located between 10° N and 90° W and 11° N and 92 ° W, delimiting an approximate area of 100,000 km^2 of oceanic waters (MARN, 2007).

From West to East, the marine area of El Salvador is usually divided into six fishing areas as mentioned before, but for this research and according to the hydrographic configuration of El Salvador, the fishing zones were divided into four zones according to (López, 1982), based on (Gierloff-Emden, 1976) as follows:

Zone I: borderline with Guatemala to Acajutla port, characterized by many seasonal rivers with mud, sand-mud, peat sediments, and sand beaches

Zone II: Acajutla to Puerto de La Libertad, with rocky coasts, and some temporal fluvial sources and estuaries

Zone III: Puerto de La Libertad to the mouth of the Lempa River, with many sediment sources and beaches, but mainly sandy type and;

Zone IV: from the mouth of the Lempa River to Meanguerita island, presents with rocky and sandy beaches (Figure 4).

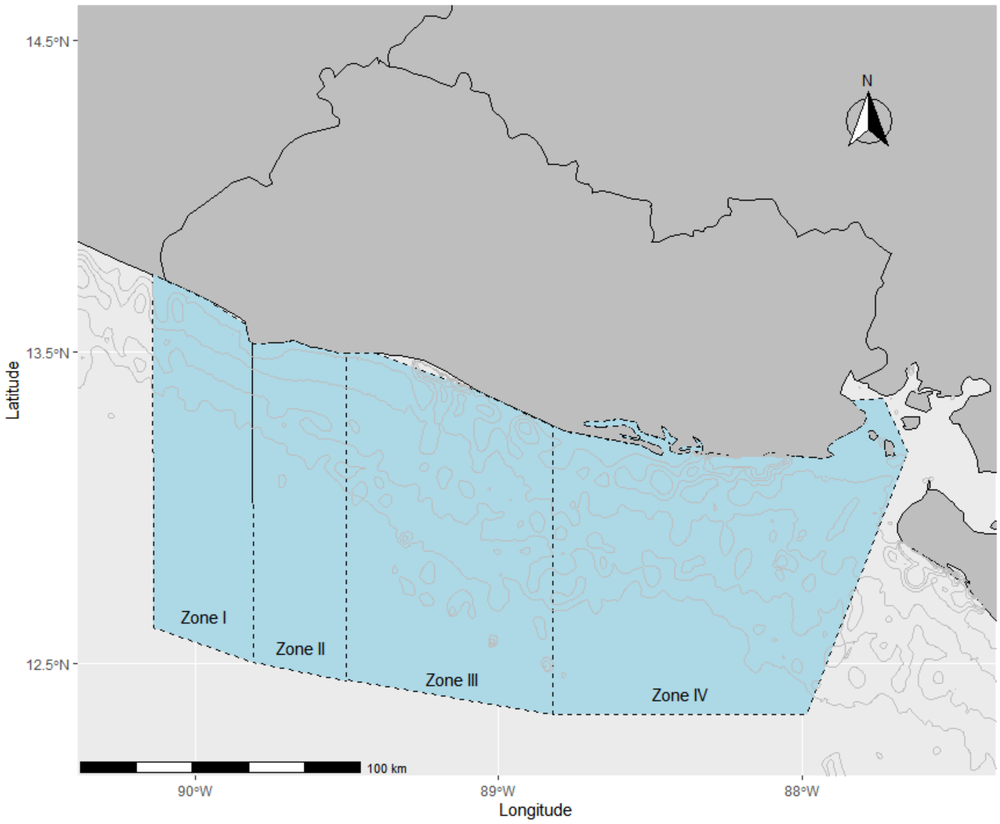

Figure 4: Fishing zones established by hydrogeographic characteristics in El Salvador Coast according to (López, 1982), based on (Gierloff-Emden, 1976).

3.2 Study design

3.2.1 Data Source

3.2.1.1 Surveys

Two surveys were conducted, the first in 2015 and the second in 2019, to study the abundance and distribution of shrimp. The shrimp trawl fisheries were carried out with Florida-type fishing vessels, with two trawlnets each vessel, one starboard and the other on the port side.

In 2015, the survey area was from the first to the sixth Nautical Mile and took place in the rainy season from August 31st to September 8th. Two trawl nets were used, with a nominal mesh size of 44 mm (1 ¾") in the net and codend, headline with 13.95 m, groundline with 16.5 m, and the otter board with dimensions of 1 x 2.5 m (Table 1).

A total of 42 stations were sampled over 7 transects, with 6 stations sampled at each transect (Figure 5). The time of each haul lasted between 27 to 32 minutes with a mean of 31 minutes. In all stations, data of depth, and geo-referenced position were taken. The depth range at each transect was between 11 to 52.75 m (Table).

The total catch of the two trawl nets per station was weighed and separated per group of commercial interest (target species and bycatch). When the total catch of shrimps was 1 kg or less, all shrimp species and individuals were processed; and when the catch was between 1 and

10 kg, a subsample of 1 kg was taken. The processing consisted in sorting them into species group and weighted as shrimp species, total length was measured, and sex and maturity stage were recorded for all shrimps in the subsample. The number of measurements were weighted when catches were more than 1kg.

A total of 747 shrimps were sampled, where the white shrimps totalised 629 individuals, divided into 379, 85, and 165 for *Penaeus vannamei, P. stylirrostris,* and *P. occidentalis* respectively. For the red shrimps (*P. brevirostris*) a total of 105 and for the brown shrimps (*P. californiensis*) a total of 13 individuals. The number sampled was scaled to represent the total catch.

In 2019, another survey was performed from the end of May and the first days of June at the transition of the dry season to the rainy season. Two trawlnets were used with a nominal mesh size of 50 mm (2”) in the net and cod-end including a small mesh lining (1.1 cm of mesh size) inside the codend. The headline was 22.86 m, groundline 27.43 m, and the otter board with dimensions of 1.22 x 2.44 m (Table 1).

A total of 45 stations were sampled from 9 transects (5 stations per transect). The depth range was 8.5 to 29 m (Figure 5 and Table). The hauling time ranged between 28 and 42 minutes with a mean of 33 minutes. Depth and georeferenced positions were collected at each station.

The total catch of both trawlnets per station were weighed and a sample of approximately 40 kg was collected and sorted into species. All the five principal commercial shrimp species were collected from the total catch and sorted by species. Total length and weight were measured, and sex and maturity stages were recorded.

The maturity stages were considered as Maturity stage I as Immature, Maturity stage II as Developing, Maturity stage III as ripe, and Maturity stage IV as Spawned and under the process of reabsorbing (Salazar Linares, Barahona Hernandez, & Pacheco Ulloa, 2006).

Total length and weight of catches per haul of *Penaeus vannamei* were collected in a survey in 2008 from two trawls, starboard and port side trawls, and changed side every five hauls, but only 9 hauls were effective. One trawl had a codend with a nominal mesh size of 44 mm, while the other had 50 mm. The mesh sizes were not measured, but the nominal mesh was the full mesh or from the middle point of knots. The net material was polypropylene (pp) and twine twisted with a thickness of 1.5 mm diameter. Separately length measurements of shrimp and total weight from both codends were recorded. This data was used to perform a gear comparison between the two mesh sizes.

Table 1: Main characteristics of the fishing vessels used in 2015 and 2019 surveys.

	Survey in 2015	**Survey in 2019**
Period of time	August - September	May - June
Number of stations	42 stations	45 stations
Range of Depth	11 – 52.75 m	8.5 – 24 m
Net and codend nominal mesh size	44 mm (1 ¾”)	50 mm (2”)
Headline length	13.95m	22.86m
Groundline length	16.5m	27.43m
Otter board	1 x 2.5m	1.22 x 2.44m

Table 2: Distribution of transects by fishing zone and range of depth in the surveys conducted in 2015 and 2019.

Year	Fishing zone	Transect number	Depth range (m)	Number of Stations
2015	1	1	11 to 44	6
	2	2	29 to 52.7	6
	3	3	22 to 41.2	6
		4	14.8 to 31.5	6
	4	5	14.5 to 25.5	6
		6	12.5 to 24.1	6
		7	16.4 to 38.3	6
2019	4	1	8.5 to 23.5	5
		2	8.7 to 23.4	5
		3	10.4 to 23	5
		4	8.5 to 23.2	5
	3	5	8.8 to 23.5	5
		6	8.5 to 23	5
	1	7	12 to 24	5
		8	12 to 20.6	5
	3	9	17.4	1
	2	9	20 to 29	4

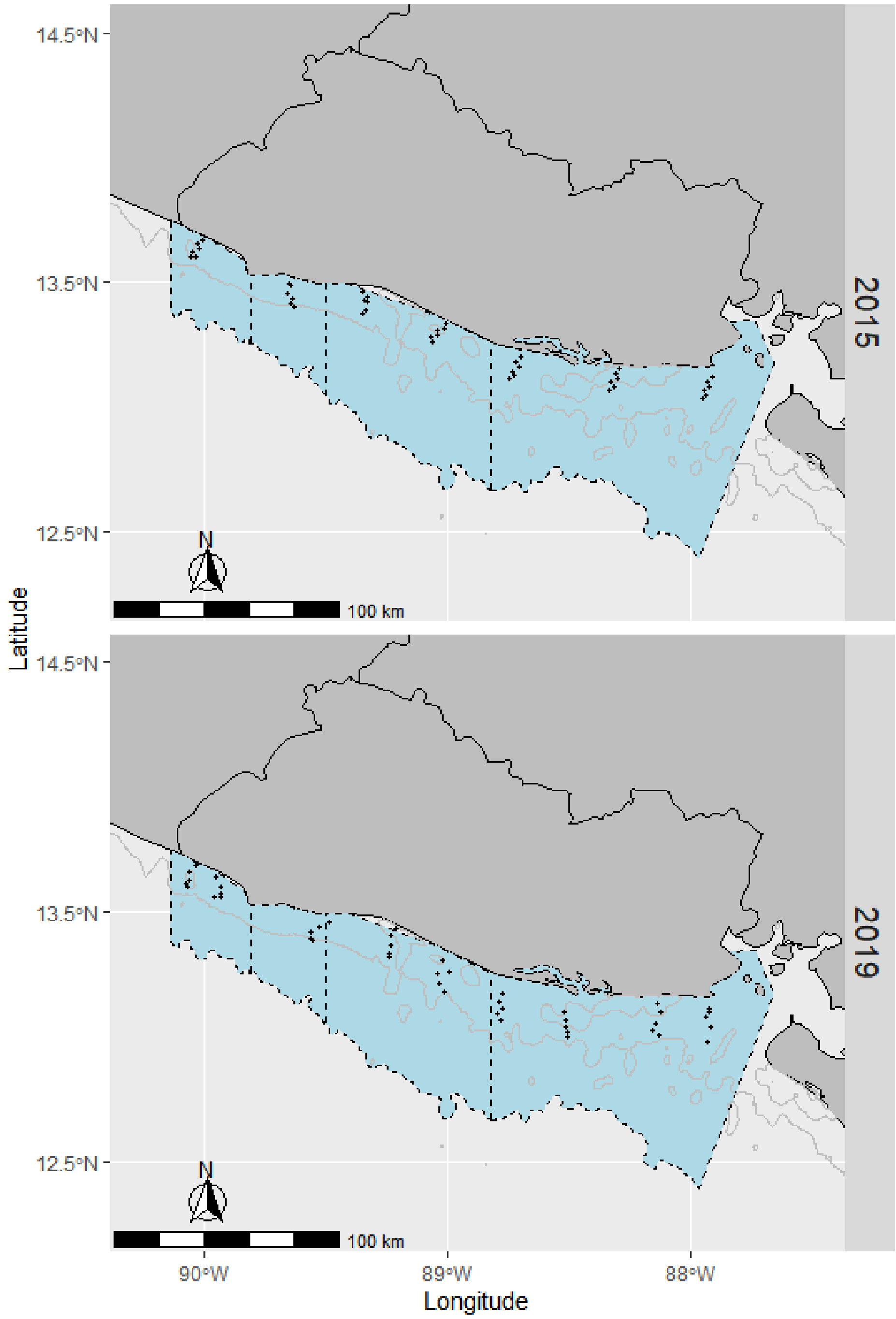

Figure 5: Distribution of stations in the surveys in 2015 and 2019 (Zelaya Cruz, Hernández, Candray, Galdámez Olmedo, & López Rivera, 2015); (Barahona & Galdámez, 2020).

3.2.1.2 Commercial catch

Data were collected from commercial shrimp trawlers during two time periods. From January to October 2021, total length, sex, and maturity stage data were taken from a particular commercial fishing vessel, where mostly the target species were the pinky or red shrimp, *P. brevirostris*, and brown shrimp, *P. californiensis*, with 3,355 and 2,125 individuals respectively, followed by *P. vannamei*, *P. stylirrostris* and *P. occidentalis* with 468,110 and 46 individuals respectively.

Logbook data from one commercial fishing vessel was collected from October 2020 to October 2021. A total of 1,450 hauls with a depth range of 22 to 132 m were recorded. The shrimp species were aggregated as white shrimps (*P. vannamei, P. stylirostris,* and *P. occidentalis*), red shrimp (*P. brevirostris*), and brown shrimp (*P. californiensis*).

3.2.2 Data analysis

The fishing gears for the surveys in 2015 and 2019 are different with the mesh size of net and codend. In the first survey, were the codend had a nominal mesh size of 44 mm (1 ¾") and in the second survey was codend used with a nominal mesh size of 50 mm (2"). To compare the potential difference of catchability by length group using different mesh sizes. Therefore, it was necessary to perform a gear comparison between those two nominal mesh sizes used to determine if they were significantly different in the catch between codends.

The total lengths were sorted by length class to estimate the weight of samples, from individual weight, to have an estimated total number of shrimps in each codend. To determine the rate of catch from each length group and each station, Fitted Generalized Linear Binomial Model was used with class length from the rate of each nominal mesh size of 44 mm (1 ¾") and 50 mm (2") connected with their respective catchweight with the Catch comparison rate, CC_l, as followed (Veiga-Malta, Feekings, Herrmann, & Krag, 2018):

$$CC_l = \frac{nt1_l}{(nt1_l + nt2_l)}$$

Where $nt1_l$ is the number of shrimps of length *l* of the given species collected in the codend of nominal mesh size of 44 mm (1 ¾"), and $nt2_l$ is the number of shrimps in given length group (*l*) collected in codend with the nominal mesh size of 50 mm (2"). CC_l range from 0.0 to 1.0, where the value of 0.5 means that both nominal mesh sizes have equal catch efficiency for a specific length, under the condition that both codends were fishing equally.

The respective interval confidence was determined, and the bootstrapping method was used to boost the poor data into an average of 10 times with 1,000 random repetitions.

3.2.3 Abundance, distribution patterns, and Biomass index

The base map of the four fishing zones was taken from (González-Murcia & Hernández, 2010) and QGIS 3.22. was used to obtain the georeferenced points of the limits of the four fishing zones. The raster data of El Salvador and surrounding areas were taken from (Natural Earth, 2009 -2022). The bathymetry grid data was obtained from The General Bathymetric Chart of the Oceans (GEBCO, 2021); The Coordinate Reference System used is the EPSG code 2432. Through these, the fishing zones were modified for this research and limited to 100 m depth according to the range of distribution of the shrimps (Fischer, et al., 1995) and the transects' position for surveys from 2015 and 2019, which were near the coast. Furthermore, the size of the zones was estimated, Zone I: 1,346.655 km^2, Zone II: 1,315.841 km^2, Zone III: 4,653.976 $km^{2,}$ and Zone IV: 7, 595.226 km^2.

To estimate the distribution and abundance, the swept area or effective path swept, a, was estimated from the Sparre and Vennema (1998) method from:

$$a = D * hr * X2; \quad D = V * t$$

Where the Distance, *D*, is equal to the Velocity of the trawl on the ground when hauling; *V*, by the time of the tow, *t*; *hr* is the length of the head rope and *X2* is the fraction of the head rope length, hr, which is equal to the width of the path swept by the trawl. The value of *X2* used in this research was as Pauly (1980) suggested from 0.5 (Sparre & Venema, 1998). The same value of *X2* was used in Nicaragua, bordering with El Salvador (Gutiérrez García & Eslaquit, 2009).

The hauling time in both surveys, 2015 and 2019, are between 27 to 42 minutes, because of that, the catches and haul area were standardised into an hour, and the abundance (*A*) or Catch Per Unit of swept Area (CPUA) were estimated as follows:

$$A = \frac{C_w/t}{a/t} = \frac{C_w}{a}$$

In where the abundance, *A*, is the Catch in Kilograms by time spent hauling standardised in an hour of time, *t*, divided into the swept area, *a*, per hour of time, *t*.

The abundance was estimated per station and plotted by year, by species.

The Biomass Index was calculated using the method identified by Cochran (1977) in (Björnsson, et al., 2007) as follows:

$$I_{strata} = \frac{\sum_{strata} z_i}{N_{strata}}$$

$$I_{region} = \sum_{region} I_{strata}$$

Where *I*, is the Biomass index, for *strata*, which refers to each fishing zone, and for *region*, which is the four areas in total, i.e., the coastal zone until the 100 m depth. *I*, refers to each station per each transect.

3.2.4 Life history parameters

For the life history parameters, length distribution, maturity stages, and the length at first maturity (L_{50}) were determined.

To understand the behavior of sex ratio and maturity stage process in a continuous period of time, data from 2021 were analysed, from January to October.

Length at first maturity (L_{50}) was estimated with the "sizeMat" package version 1.1.2 (Torrejon-Magallanes, 2020). The data analysed were those in the reproductive period, 2019 (May) and 2021 (April and May) according to the author of sizeMat. The variables were fitted to a logistic function as:

$$P_{CS} = \frac{1}{1 + e^{-(\beta_0 + \beta_1 \times X)}}$$

Where, P_{CS} is the probability of an individual being mature in a determined *X* length; $beta_0$ is the intercept and $beta_1$ is the slope, which are estimated parameters. The L_{50} is calculated as follow:

$$L_{50} = \frac{-beta_0}{beta_1}$$

3.2.5 Catch-per-unit-effort (CPUE)

The collected data from the logbooks of 2020 and 2021 were analysed to obtain the CPUE as follows:

$$CPUE = \frac{Catch\ (Kg)}{Effort\ (hours\ of\ towing)}$$

All plotting and statistical analysis were conducted using RStudio V1.4.1717 (R Core Team, 2021).

4 RESULTS

4.1 Gear comparison between codends with a nominal mesh size of 44 and 50 mm

The data from nine effective stations were collected with catch from two codends with a nominal mesh size of 44 mm (1 ¾”) in one, and 50 mm (2”) in the other, attached on trawls towed side by side. A Generalized Linear Model was applied to the data, utilizing a bootstrapping process. This involved generating 1,000 resamples, from which 10 average outcomes were calculated, resulting in relatively narrow confidence intervals. Even with the outcome of a higher number of shrimps with size under 12mm in 44mm mesh size in codend, and a higher number of shrimp larger than 16mm in 50mm mesh size in codend, there are no significant differences (Figure 6**).**

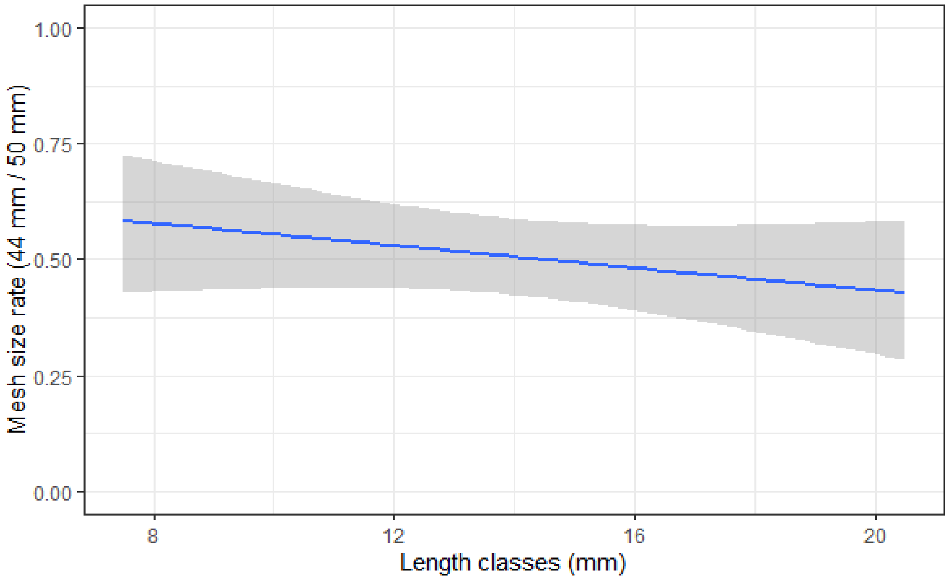

Figure 6: Bootstrapped Rate of 44 mm (1 3/4") and 50 mm (2") mesh size catch for each length group through Fitted Generalized Linear Binomial Model (blue line), with Confidence Interval (grey) in shrimps (Penaeidae family) trawlnets.

The gray area of the confidence interval covers the 0.5 proportion line for all length classes, meaning it is not significantly different between the codends. Note this is taken from a small sample with a boost of bootstrapping method.

4.2 Abundance and distribution patterns

From the five species under study, *P. vannamei* was the most abundant species with the highest total abundance of 1,008 kg/km^2 in 2015 and 730 kg/km^2 in 2019 followed by *P. brevirostris* with a total abundance of 151 kg/km^2 in 2015 and 366 kg/km^2 in 2019. The other three species were less abundant. The total abundance of *P. californiensis* was 14 kg/km^2 in 2015 but much higher in 2019 reaching 264 kg/km^2. Similar for *P. occidentalis*, the total abundance was 94 kg/km^2, but almost threefold higher in 2019 reaching 248 kg/km^2. In contrast, the highest abundance of *P. stylirrostris* was 132 kg/km^2 in 2015 but lower in 2019 with 88 kg/km^2. The western coast of El Salvador tends to have higher abundance compared to the east coast, particularly in Fishing zone II, where the abundance was between 25 to 60 kg/km^2 in 2015, but in 2019, in the transition of the dry to the rainy season the abundance increased considerably from around 160 to 200 kg/km^2.

In the 2015 survey, the pinky, or red shrimps, *Penaeus brevirostris*, were distributed throughout the 4 fishing zones. The highest abundance was at the deepest haul, at 52.7 m depth in zone II with an abundance of 67 kg/km^2. In 2019, *P. brevirostris* was distributed in zone II at shallower depths between 27.7 and 29 m in abundance of more than 200 kg/km^2. These species tend to be in deeper waters compared to the other species (Figure 7, and Figure 8).

Figure 7: Distribution and abundance of the 5 principal commercial species in 2015 and 2019 in the four fishing zones with depths down to 100 m.

In 2015 the distribution of brown shrimp, *P. californiensis*, was restricted to the western part of the study area, specifically in zones I and II (Figure 7), at 36.6 to 46.5 m depth (Figure 8). In 2019, the distribution was along the coast, in all 4 zones decreasing in Zone IV from west to east (Figure 7), at depth between 8.7 to 24 m, with highest abundance in the depth of 20 m (Figure 8). In 2015, the abundance is not significantly different between Zone I and II, but in the transition between dry and rainy season, i.e., May in 2019, the abundance tends to decrease from west to east (Figure 9).

In 2015 the distribution of *P. occidentalis* was different, compared to previous species as its distribution was highest in the eastern zones, zone III, and mostly in zone IV (Figure 7), in a depth of range of 12.5 to 38.3 m with higher abundance around 35 m (Figure 8). In 2019, this species was distributed along the coast except in Zone II, the western part of zone IV with a depth of range of 8.5 to 23.4 m, with more abundant between the depth range of 10 to 20 m (Figure 8). The abundance in zones I, III, and IV did not exceed 50 kg/km^2 (Figure 9).

P. stylirrostris, in 2015 was distributed along the coastal area, except for zone II. In 2019, the highest distribution was in the central area of the country´s coast, mainly in zone III (Figure 7). In 2015, depth distribution was mostly 12.5 to 28.6 m. In 2019, the depth range was between 8.5 to 23 m, but mostly between 12 and 13 m with 55% of the total abundance of that year (Figure 8). Overall, catches are small showing no spatial nor temporal variation (Figure 9).

The distribution for *P. vannamei* in 2015, was highest in the western and central areas (Zone I to Zone III), and the depth range was between 14.8 and 52.7 m with major abundance between 20 to 30 m with the 67% of the total abundance for that year, and with 20% with the depth range of 40 and 50 m. The abundance between the areas were very different, where zone IV was not abundant at all, zone III had around 50 kg/km^2. In the case of zone II, the abundance was variable, around 25 and 90 kg/km^2, but in zone I there was more abundance compared with the other zones, with a range between 120 to 170 kg/km^2. In 2019, the distribution was along the fishing zones I, III, and IV with a range of depth from 8.5 to 24 m with more abundance in zone I and III (Figure 7, Figure 8 and Figure 9).

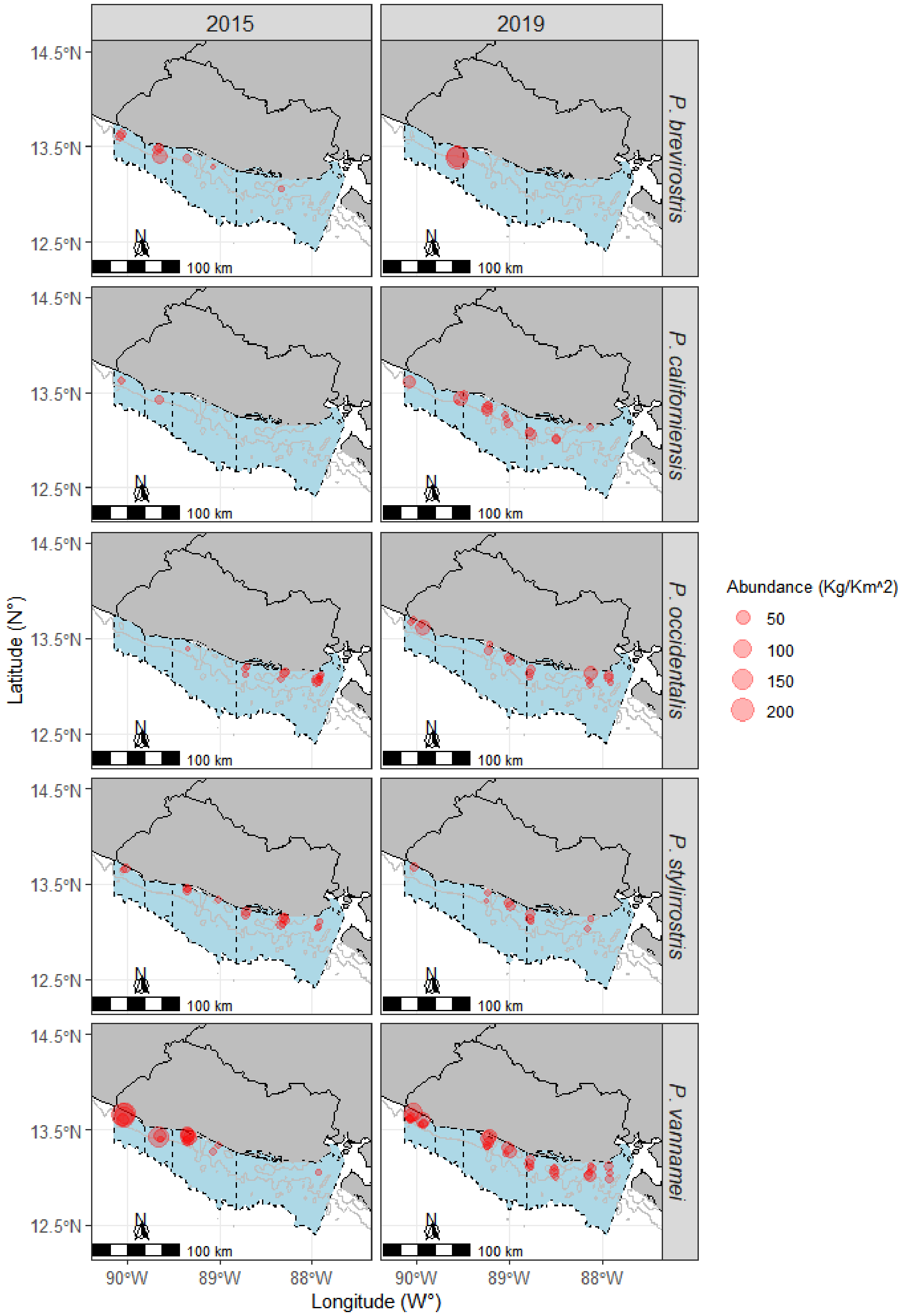

Figure 7: Distribution and abundance of the 5 principal commercial species in 2015 and 2019 in the four fishing zones with depths down to 100 m.

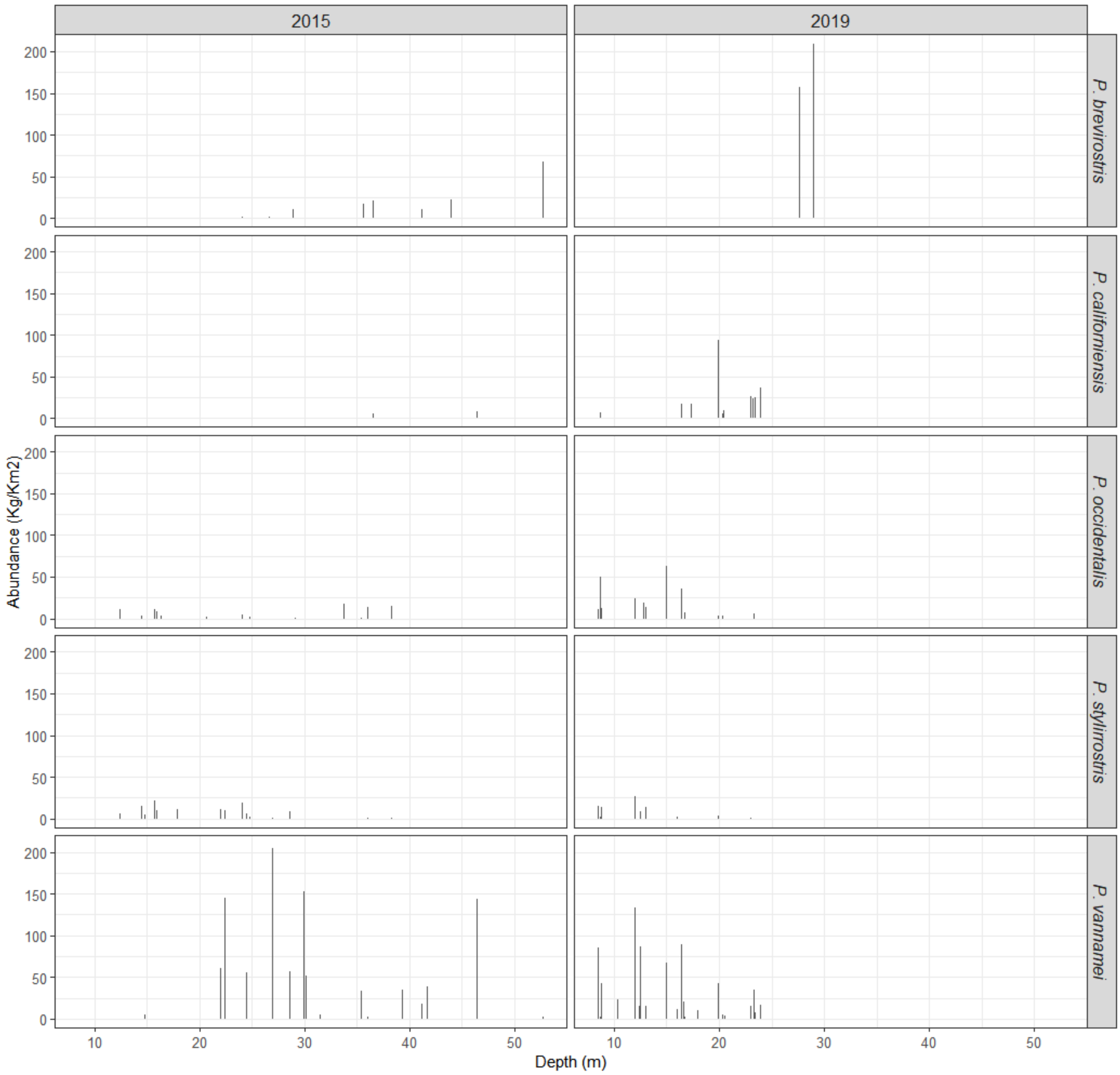

Figure 8: Abundance of the five commercial shrimps based on depth recorded on surveys in 2015 and 2019 in El Salvador.

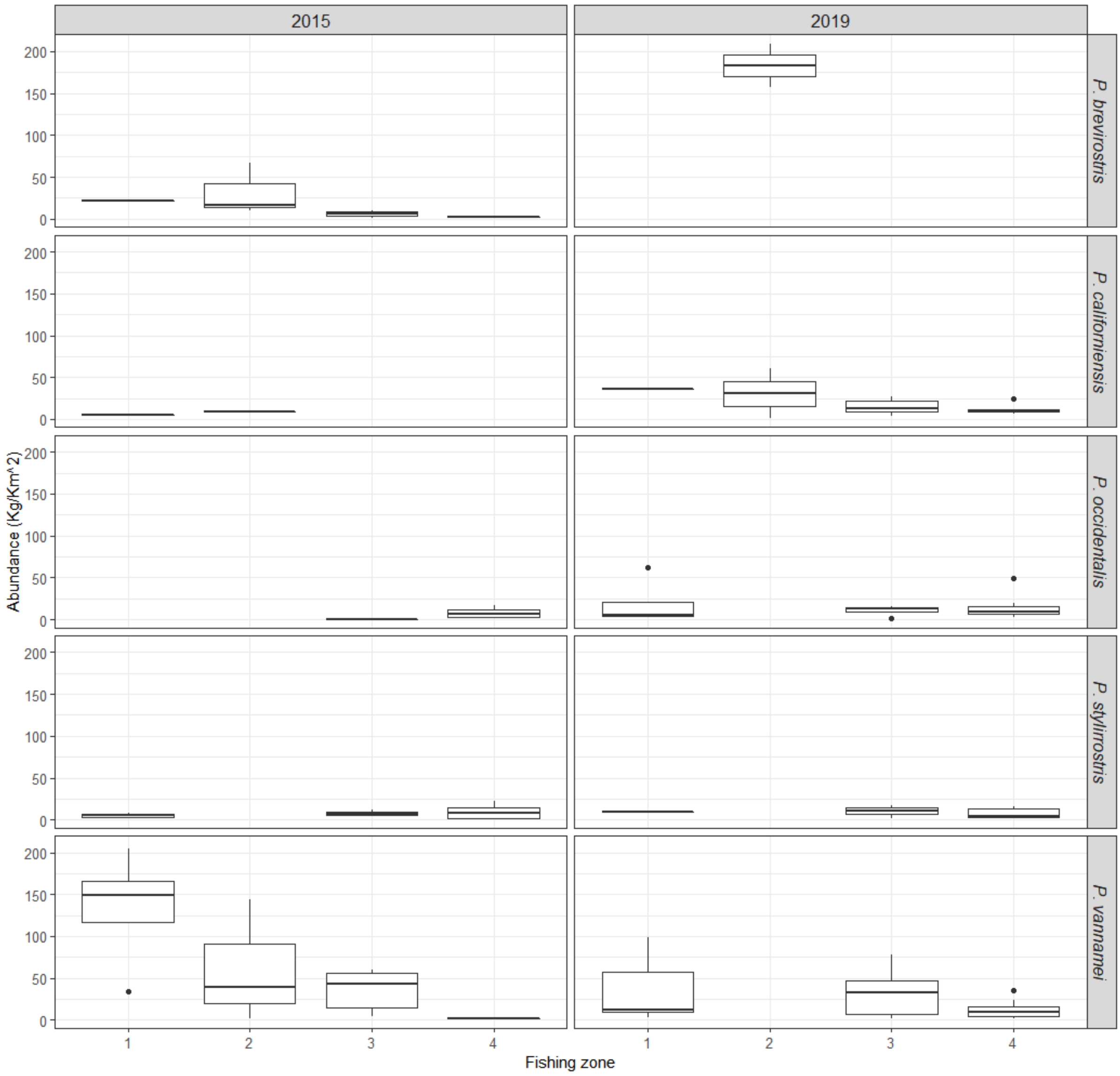

Figure 9: Schematic plot distribution of the abundance per each fishing zone of the 5 main commercial species of the Family Penaeidae in El Salvador.

4.3 Biomass index

The calculated total biomass index for the five species was 170,511kg in 2015 and 226,067 kg in 2019. *P. vannamei* presented the highest biomass index value with a total of 115,124 kg in 2015 and 91,314 kg in 2019. The biomass index was higher for *P. vannamei*, in zone I and III in 2015. In 2019, zone I had smaller index, but zone III was the highest followed by fishing zone IV (Figure 10).

P. brevirostris presents the second-highest biomass values after *P. vannamei*, with 15,083 kg in 2015, and 50,208 kg in 2019. In 2015 *P. brevirostris* was distributed in all zones but mainly within zone II. In 2019 it occurred only in zone II. *P. californiensis* totalised 1,311 kg of biomass in 2015 with a presence only in zones I and II. In 2019 it occurred in all four zones with a total of 38,677 kg with the highest value in the zone III (Figure 10).

The *P. occidentalis* and *P. stylirostris* had the lowest biomass compared with the other three species mentioned above. In 2015, *P. occidentalis* totalises biomass of 16,697 kg in zones III and IV, while in 2019, in zones I, III, and IV, it totalised 32,142 kg, mostly in zone IV. The biomass index of *P. stylirostris*, in 2015 and 2019 was 22,296 kg and 13,728 kg respectively, with more biomass in zone IV in 2015 and zone III in 2019. For both species, there was no occurrence in zone II (Figure 10).

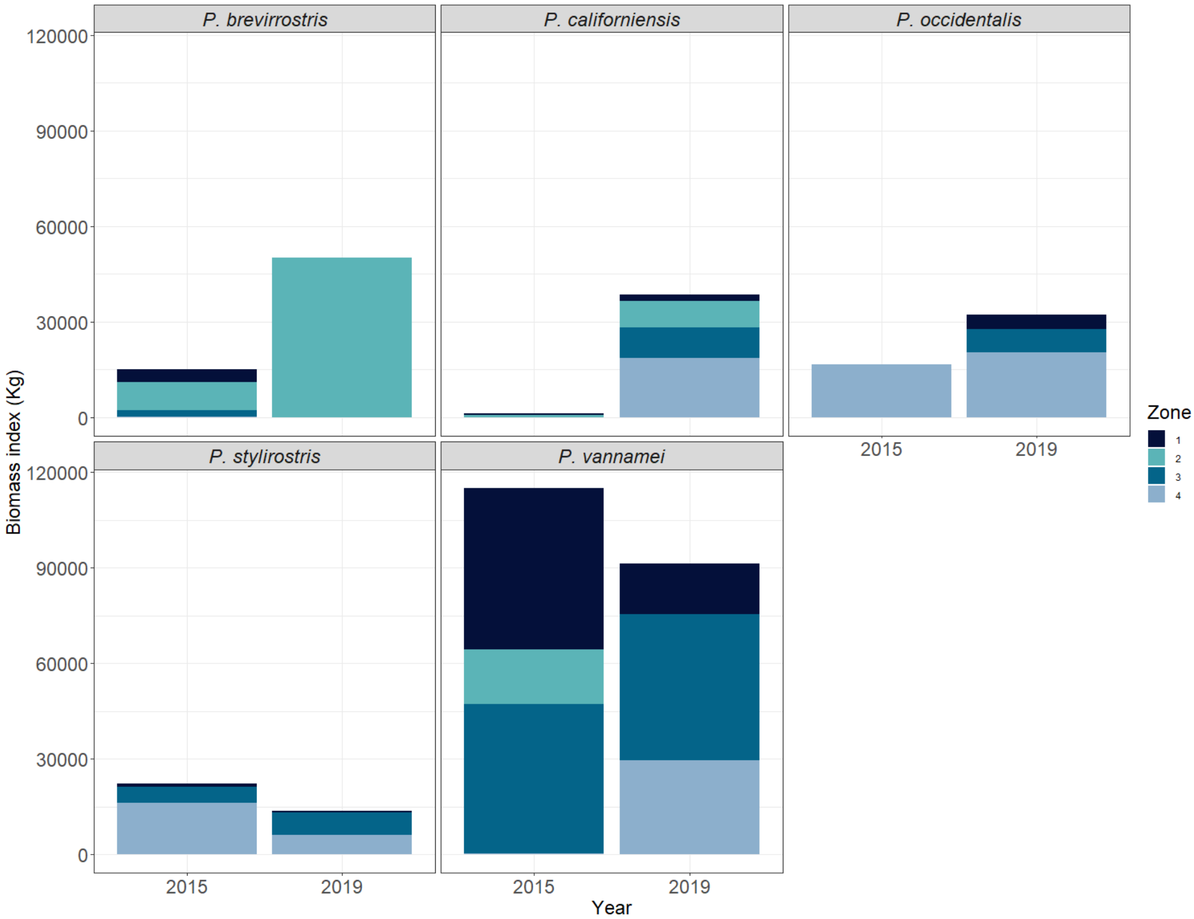

Figure 10: Biomass index (kg) for the five commercial species of shrimp (Penaeidae family) in the four fishing areas of El Salvador in 2015 and 2019.

4.4 Life history parameters

In 2015 a total of 747 shrimps were measured, where the white shrimps totalised 629 individuals, divided into 379, 85, and 165 for *Penaeus vannamei*, *P. stylirrostris*, and *P. occidentalis* respectively. For the red shrimps (*P. brevirostris*) a total of 105 and for the brown shrimps (*P. californiensis*) a total of 13 individuals (Table 3).

In the year 2019, a total of 1,736 shrimps were sampled. 1,038 individuals belong to white shrimps, of them, 808 are *Penaeus vannamei*, 68 *P. stylirrostris*, and 162 *P. occidentalis.* In the case of red shrimps, *P. brevirostris*, 354 individuals, and for *P. californiensis*, brown shrimps, 344 individuals were collected and sampled (Table 3).

Furthermore, in 2021, from January to October a total of 6,104 shrimps were sampled, divided into 468 *Penaeus vannamei*, 110 *P. stylirrostris*, 46 *P. occidentalis*, 3,355 *P. brevirostris*, and 2,125 *P. californiensis* (Table 4).

Table 3: Individuals sorted by shrimp species, sex, and maturity stage in the trawl net surveys of 2015 and 2019 in El Salvador.

	Males				Sub	Females					Sub	N/D sex	Grand
Maturity stage	1	2	3	4	Total	1	2	3	4	N/D	Total		Total
2015	62	157	122	7	348	100	80	35	78	1	294	105	747
P. brevirrostris	23	16	8		47	11	17	23	2		53	5	105
P. californiensis		2	4		6	2	2	3			7		13
P. occidentalis	13	27	27	3	70	25	18	3	16		62	33	165
P. stylirrostris	9	11	8	1	29	14	4		17	1	36	20	85
P. vannamei	17	101	75	3	196	48	39	6	43		136	47	379
2019	19	114	630	77	840	51	223	560	60		894	2	1736
P. brevirrostris	3	13	140	14	170	9	48	114	13		184		354
P. californiensis		11	141	9	161	6	18	129	28		181	2	344
P. occidentalis		14	50	11	75		5	77	5		87		162
P. stylirrostris	1	9	34	13	57		4	7			11		68
P. vannamei	15	67	265	30	377	36	148	233	14		431		808
Total	81	271	752	84	1188	151	303	595	138	1	1188	107	2483

Table 4: Individuals sorted by shrimp species, sex, and maturity stage in commercial trawl net fisheries of 2017, 2018, and 2021 in El Salvador.

	Males				Sub	Females					Sub	Grand
Maturity stage	1	2	3	N/D	Total	1	2	3	4	N/D	Total	Total
2017				1125	1125					1243	1243	2368
P. spp				44	44					50	50	94
P. brevirostris				125	125					187	187	312
P. californiensis				109	109					87	87	196
P. occidentalis				4	4							4
P. stylirostris				40	40					40	40	80
P. vannamei				803	803					879	879	1682
2018				638	638					814	814	1452
P. spp				100	100					105	105	205
P. brevirostris				165	165					231	231	396
P. californiensis				40	40					59	59	99
P. occidentalis										6	6	6
P. vannamei				333	333					413	413	746
2021	276	817	1469		2562	1019	1165	1237	121		3542	6104
P. brevirostris	148	478	885		1511	583	632	530	99		1844	3355
P. californiensis	108	213	387		708	360	407	628	22		1417	2125
P. occidentalis			3		3	32	11				43	46
P. stylirostris	3	39	26		68	9	27	6			42	110
P. vannamei	17	87	168		272	35	88	73			196	468
Grand Total	276	817	1469	1763	4325	1019	1165	1237	121	2057	5599	9924

4.4.1 Length frequency distribution

Red shrimps, *Penaeus brevirostris*, presented a range of length in 2015 from 80 to 225 mm, with n of 105 individuals, where 50% were concentrated around 145 to 170 mm. In 2019 the length was distributed from 80 to 160 mm with n of 354 individuals and was concentrated from 105 to 140 mm. In 2019, the length distribution was bimodal (Figure 11). Plotting sex separately demonstrates sex dimorphism, i.e., the length distribution of males is smaller than females (

Figure 11).

A comparison of the length-frequency was made between sex and maturity for this species, and as a result, we established that, males get mature (maturity stage 3) at smaller sizes compared to females (Figure 13).

In 2021, commercial catch samples for *P. brevirostris* presented length-frequency between 40 to 230 mm and the average was 94 mm. As in previous years, dimorphism between sexes was present (Figure 14).

The length range of the brown shrimps, *Penaeus californiensis*, in 2015, was between 130 and 215 mm. In 2019, the length range was between 90 to 212 mm. Comparing both years, in 2015 seems that the total length was higher than in 2019 but the number of samples were not representative (

Figure 11). In the year 2019, as red shrimp, the distribution was bimodal. Plotting sex separately shows length distribution of males were smaller than the females (Figure 12). In 2021, with a length range between 42 and 230 mm, males present the length distribution in smaller sizes, where dimorphism is well noticed (Figure 14). Regarding the maturity stage related to the length distribution, the males become mature at a smaller size compared to females (Figure 15).

A total of 165 individuals of *Penaeus occidentalis* were sampled in 2015, with a range of total length between 110 and 230 mm, and 162 individuals in 2019 with a range of total length between 125 to 220 mm. In 2021, the length-frequency distribution was between 47 and 172 mm. This species does not present double cohorts and doesn't have a difference between the distribution and sex (

Figure 11, Figure 12, and Figure 16). Regarding the length-frequency related to the sex and maturity stage, it does not seem to be different (Figure 16).

The species with fewer samples measured were the *P. stylirostris,* with n of 86 and 68 individuals for 2015 and 2019 respectively. The range of total length was between 100 to 225 mm for the first year and 110 to 185 mm for the second year. The data were not enough to see any trend that separated them by year and length, and neither by sex and maturity stages due to limited data (

Figure 11 and Figure 12). In 2021, with a length distribution from 128 to 220, in Figure 16 with an n of 111 individuals, the male's length distribution shows a trend to be smaller than females.

In the case of the most abundant species, *P. vannamei,* with 379 individuals sampled in 2015, the total length range was between 81 to 220 mm, and of the 809 individuals sampled in 2019, the range of total length was from 52 to 210 mm. The distribution of the length in 2015 was larger compared to 2019, around 50% of the distribution was between 160 and 180 mm, while in 2019, the same percentage was between 125 to 150 mm (

Figure 11). When the total length data of both years are aggregated by sex, it was found that males tend to be smaller from 120 to 180 mm (Figure 12). The length-frequency desegregated by sex and maturity stage showed that most individuals sampled were between maturity stages II and III (Figure 17).

For the case of 2021, the length distribution was between 102 to 200 mm. Males present smaller sizes than females, suggesting a sexual dimorphism (Figure 16).

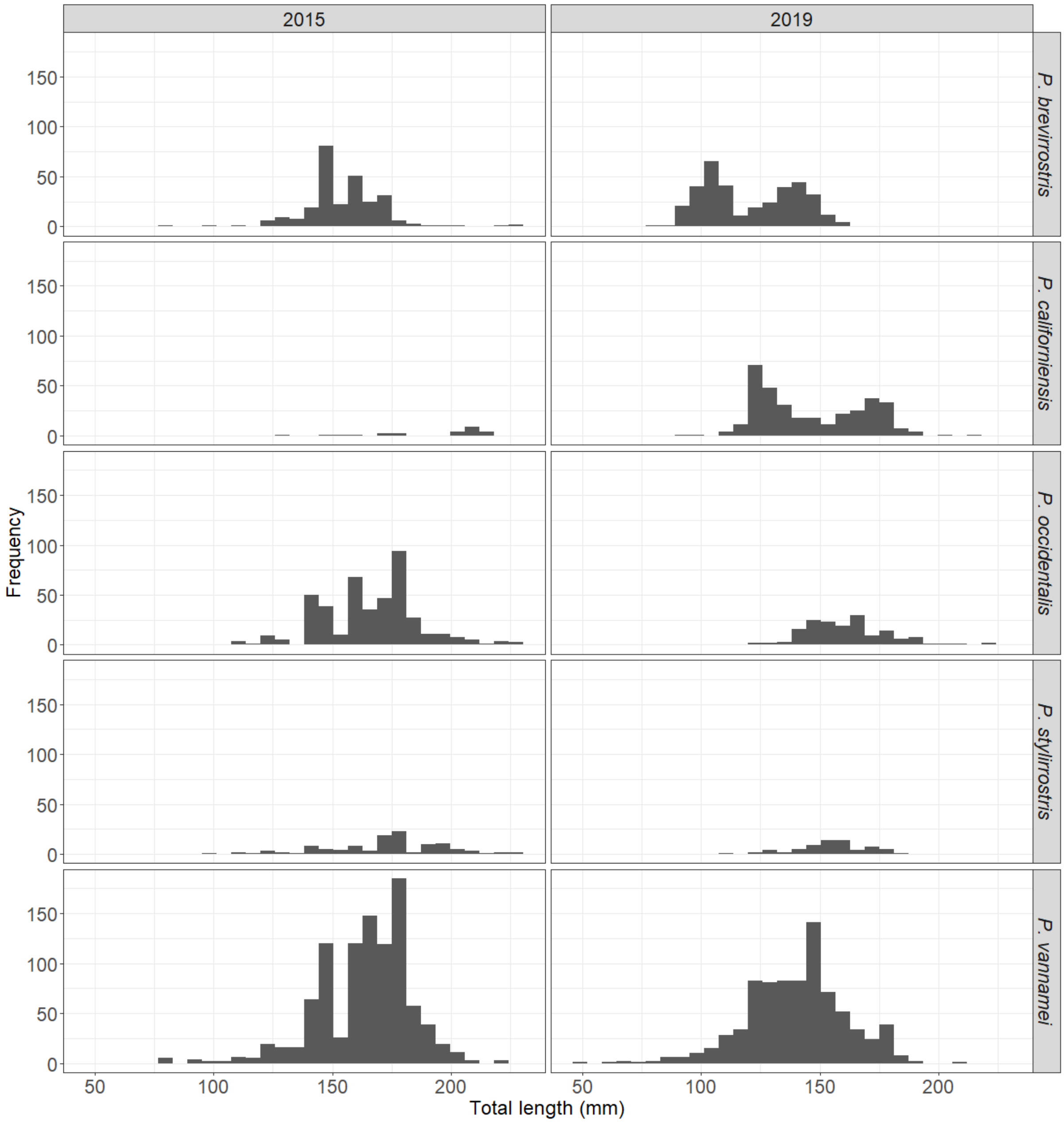

Figure 11: Length distribution frequency for *Penaeus brevirostris*, *P. californiensis*, *P. occidentalis*, *P. stylirostris*, and *P. vannamei* in the years 2015 and 2019 in El Salvador.

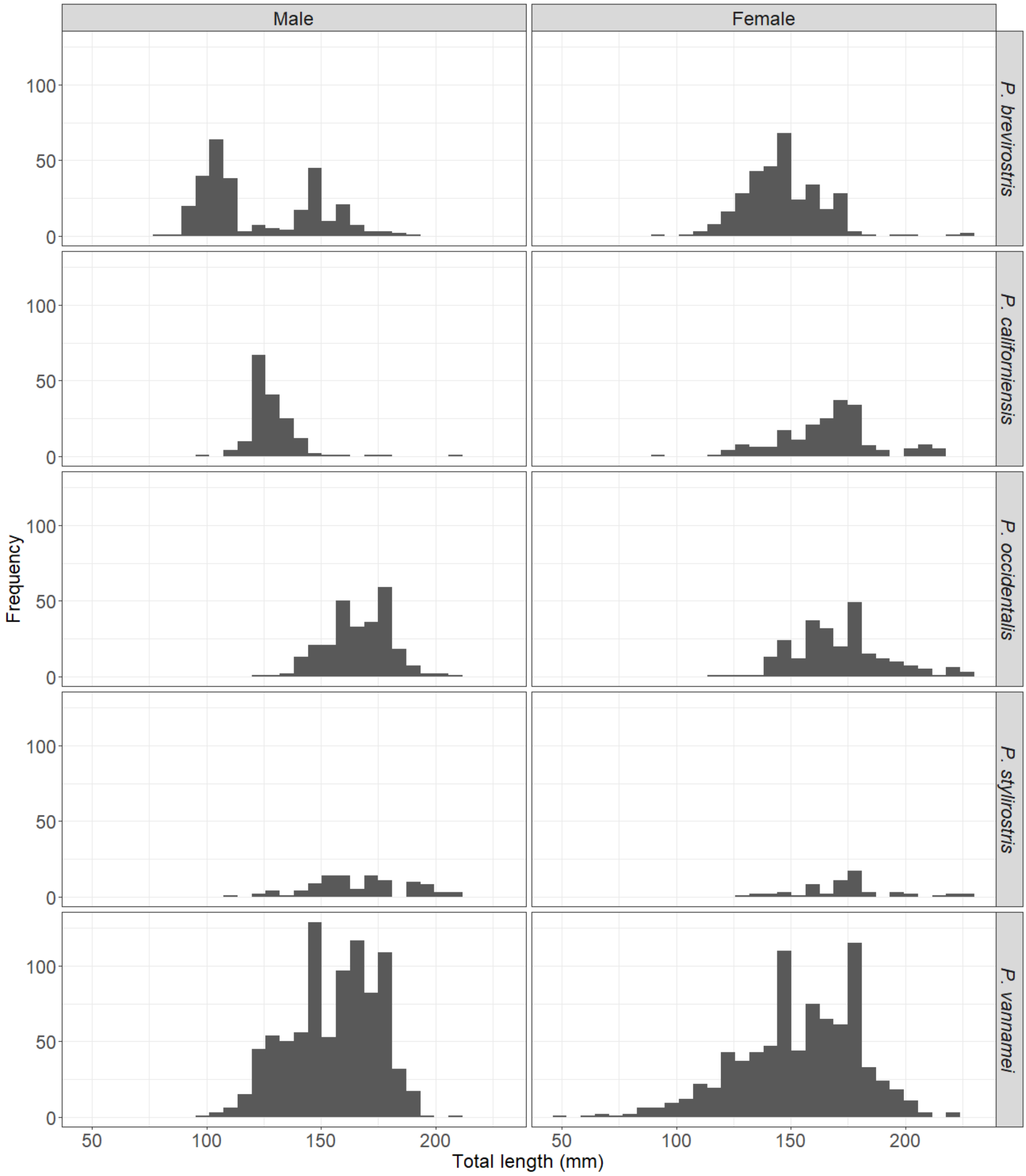

Figure 12: Length Frequency distribution of the commercial shrimp species by sex in the 2015 and 2019 surveys, El Salvador.

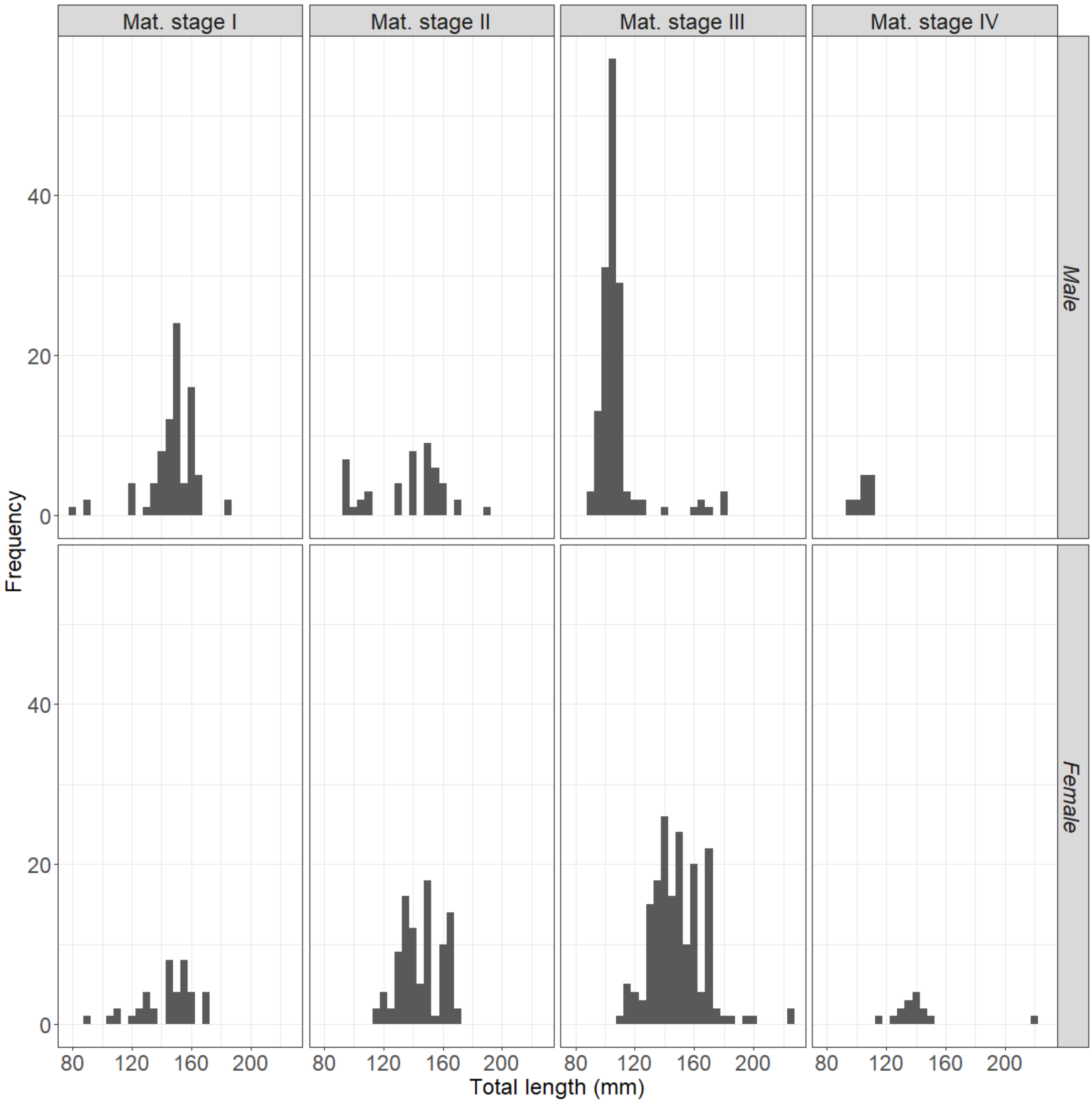

Figure 13: *Penaeus brevirostris* length-frequency distribution by sex and maturity stage (Mat. Stage I: Immature, II: Developing, III: Ripe and IV: Spawned) in the surveys of 2015 and 2019 in El Salvador.

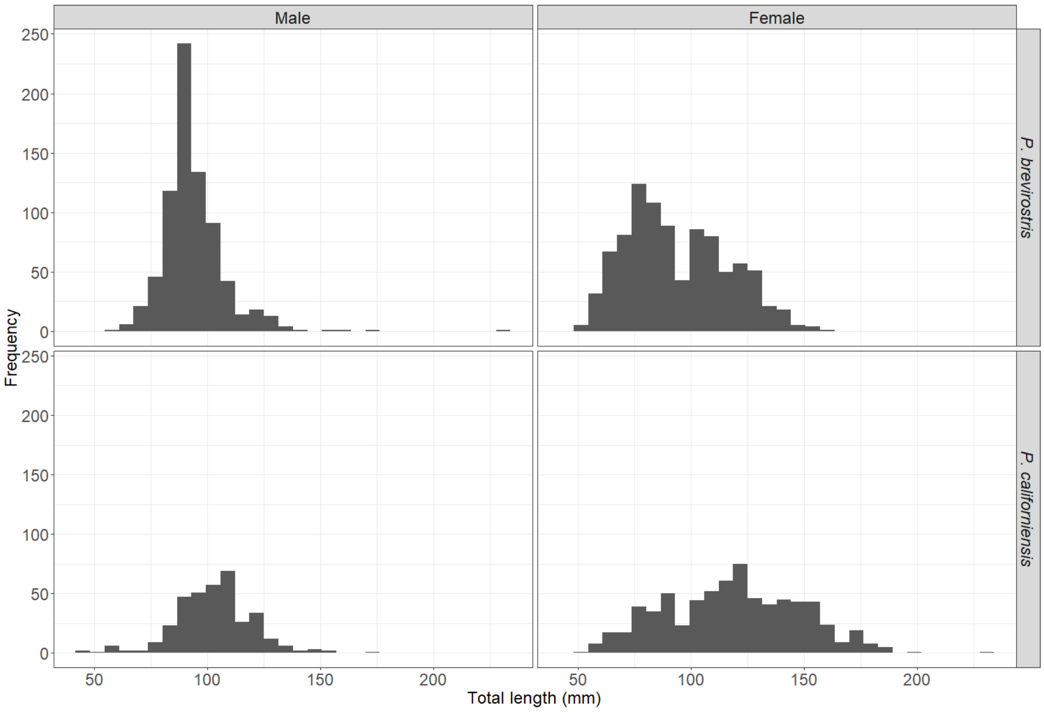

Figure 14: Length Frequency distribution of *P. brevirostris* and *P. californiensis* by sex in the commercial fisheries in 2021, El Salvador.

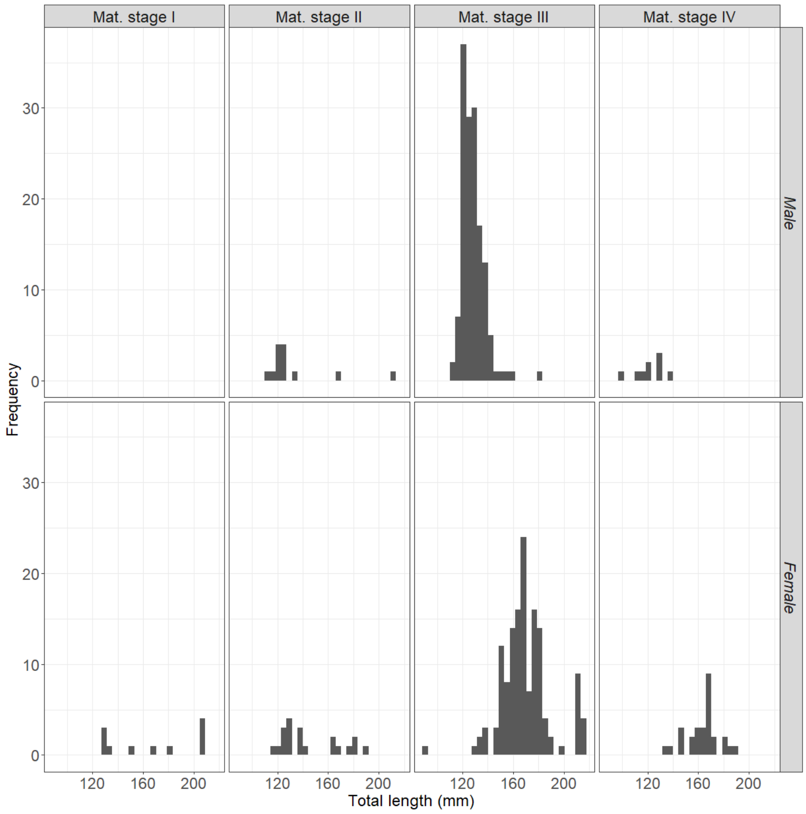

Figure 15: *Penaeus californiensis* length-frequency distribution by sex and maturity stage (Mat. Stage I: Immature, II: Developing, III: Ripe and IV: Spawned) in the surveys of 2015 and 2019 in El Salvador.

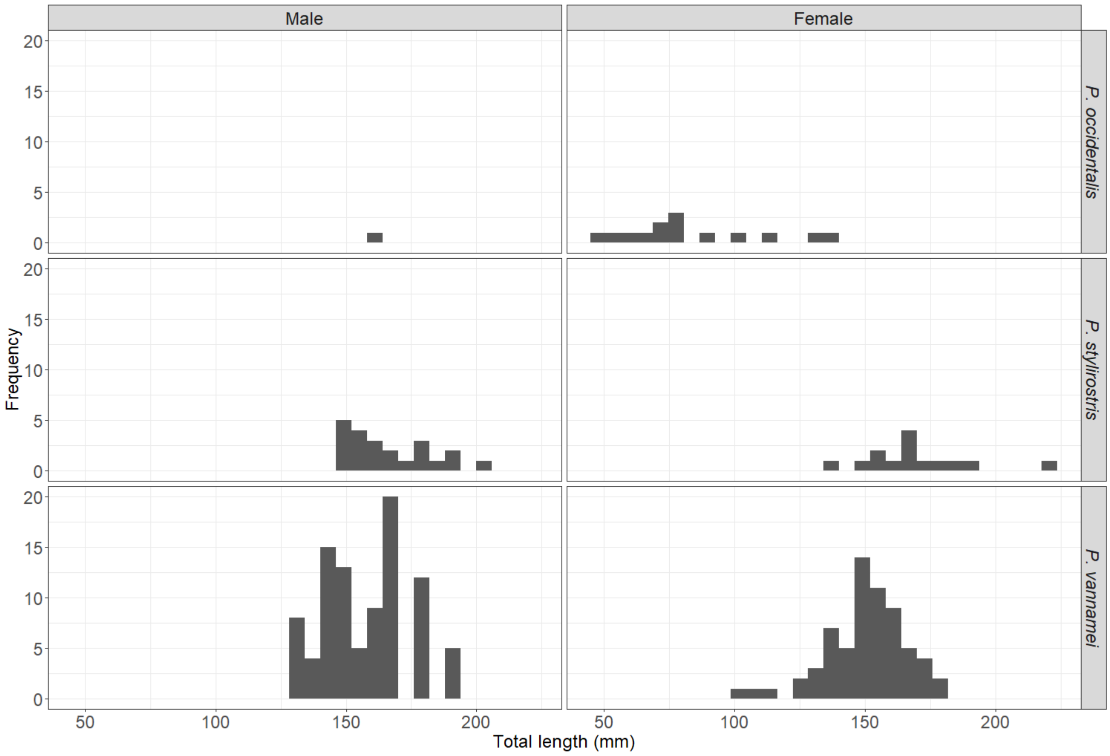

Figure 16: Length Frequency distribution of *P. occidentalis*, *P. stylirostris,* and *P. vannamei* by sex in the commercial fisheries in 2021, El Salvador.

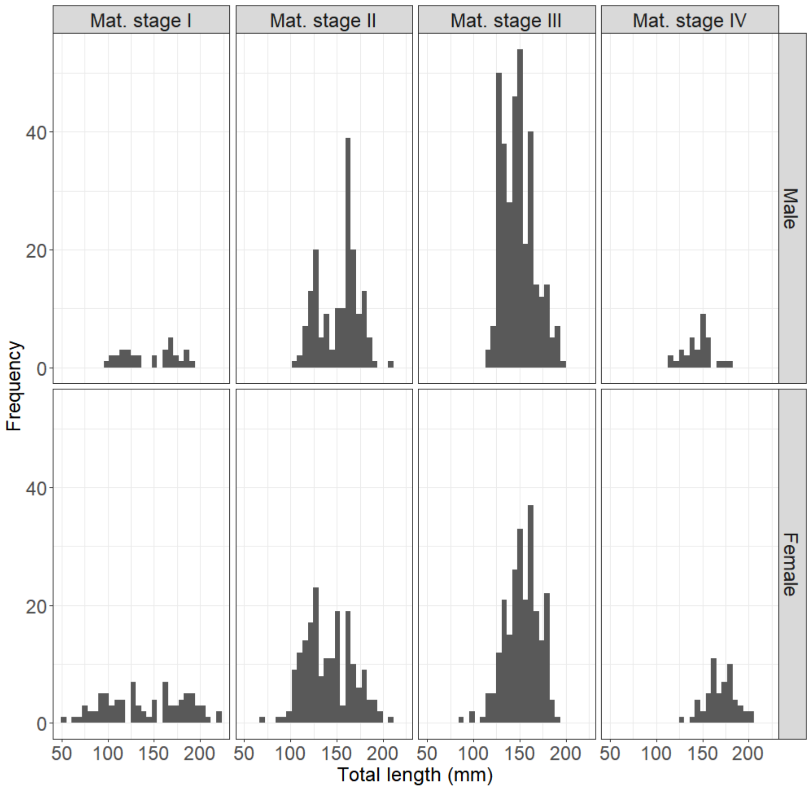

Figure 17: *Penaeus vannamei* length-frequency distribution by sex and maturity stage (Mat. Stage I: Immature, II: Developing, III: Ripe, and IV: Spawned) in the surveys of 2015 and 2019 in El Salvador.

4.4.2 Sex ratio and maturity stages

In 2021 the sex ratio between males and females in *P. brevirostris*, was 1:1.22. Between January and February, the immature conditions (stages I and II) were dominant, but with increasing maturity, males had higher maturity levels than females in April, where males were more mature than females (Figure 18). In the case of *P. californiensis*, the sex ratio for males and females was 1:2 and females were dominant in all months. Immature individuals were dominant from January to April, but in May started to mature, reaching the highest peak in August, and replacing the immature stage until October (Figure 18).

In the case of *P. occidentalis*, sample data were not enough, but January was the only month with enough data and during that month they were immature (Figure 18). The sex ratio between males and females was 1:14. It was the same situation with *P. stylirostris*, that data was not sufficient; during March both sexes were immature but in April the maturity level increased only for males (Figure 18). Sex ratio for males and females was 1.62:1.

For *P. vannamei*, the sex ratio for males and females was 1.39:1, and males were dominant in March and April. Males mature before females (March and April), but in July, females were dominant and mature than males (Figure 18).

4.4.3 Mean size at sexual maturity (L_{50})

Data from reproductive periods, May 2019 and in 2021 during April and May, were analysed to obtain the L_{50}. In 2019, data were analysed only for *P. vannamei* and *P. stylirostris* due to insufficient data for the other species.

L_{50} for *P. vannamei* was 125.6 mm and 134.7 mm for *P. stylirostris* (

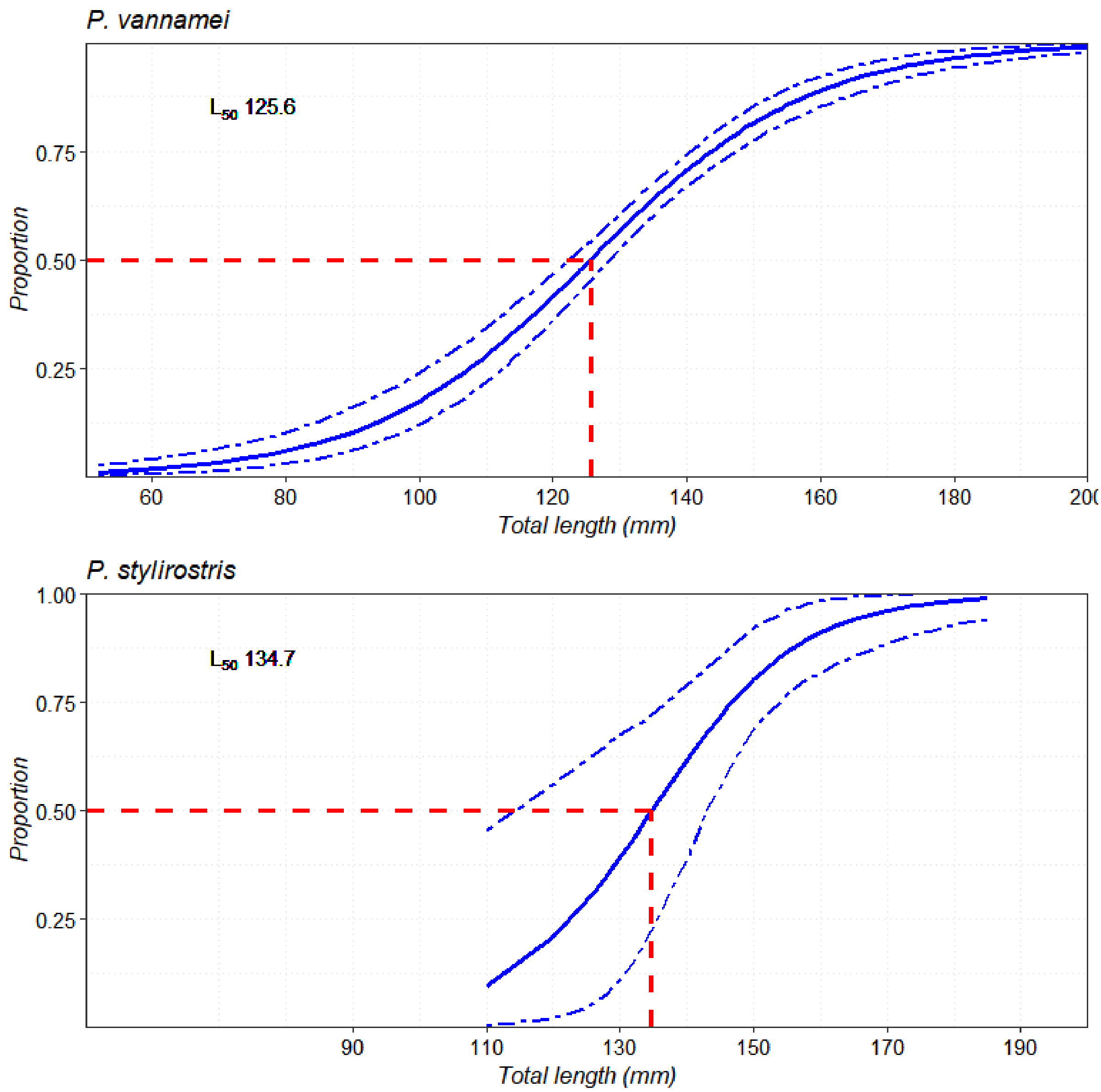

Figure 19). In the case of *P. vannamei*, L_{50} was determined by sex; L_{50} for females was 135.1 mm, and 121.9 mm for males (Figure 20), showing a dimorphism pattern, where the male L_{50} is lower compared with the females.

Additionally, from the commercial samples in 2021, L_{50} for *P. brevirostris* and *P. californiensis* were estimated; the results were 89.6 and 104.2 mm respectively (Figure 21). From this data, L_{50} was estimated for both sexes for *P. brevirostris*; L_{50} for females was 108.2 and 84.8 mm for males, and where sexual dimorphism is shown, L_{50} was lower for males than females. In the case of *P. californiensis*, L_{50} was 104.2 for both sexes, and L_{50} was1 25 mm for females (Figure 22). However, it was not possible to estimate L_{50} for males, nor was it possible to estimate L_{50} for *P. occidentalis*, due to poor data.

Figure 18: Sex (1, Male and 2, Female) and maturity stages for the five main commercial species, Penaeidae family, in 2021, El Salvador.

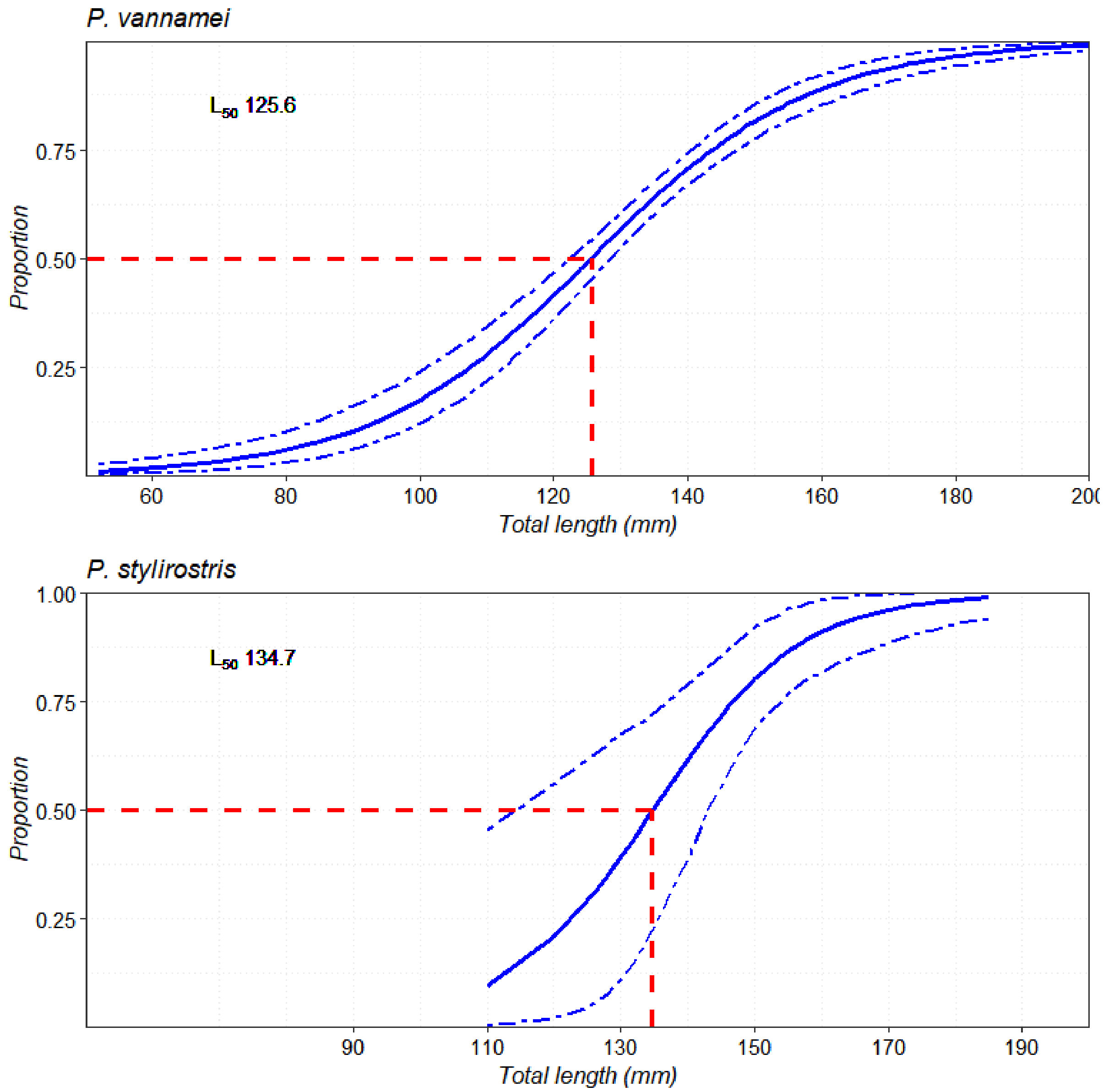

Figure 19: Mean size at sexual maturity, L_{50}, for *P. vannamei* and *P. stylirostris* in reproduction period, 2019, El Salvador.

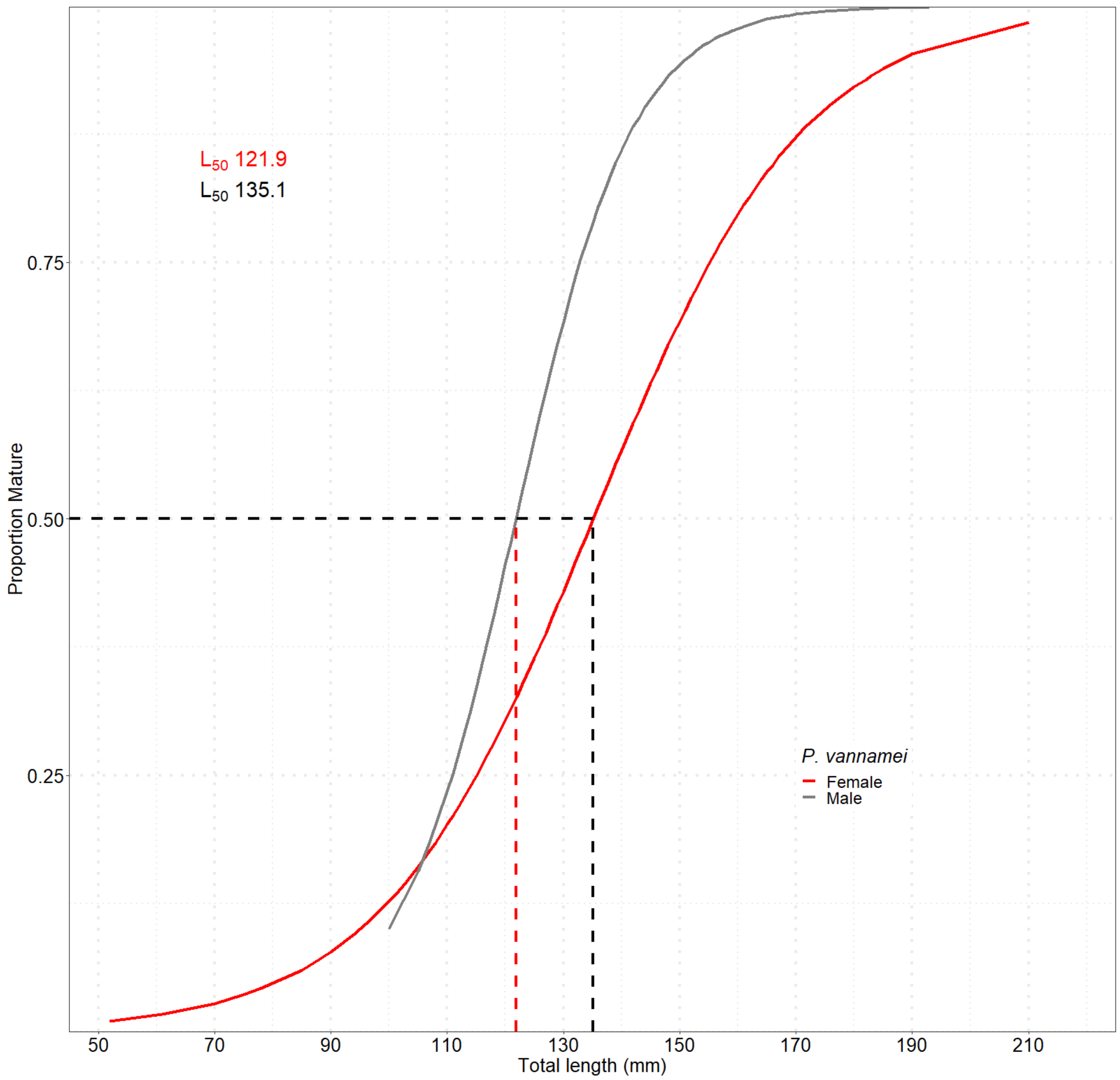

Figure 20: Mean size at sexual maturity, L50, for *P. vannamei* for male and female in reproduction period, 2019, El Salvador.

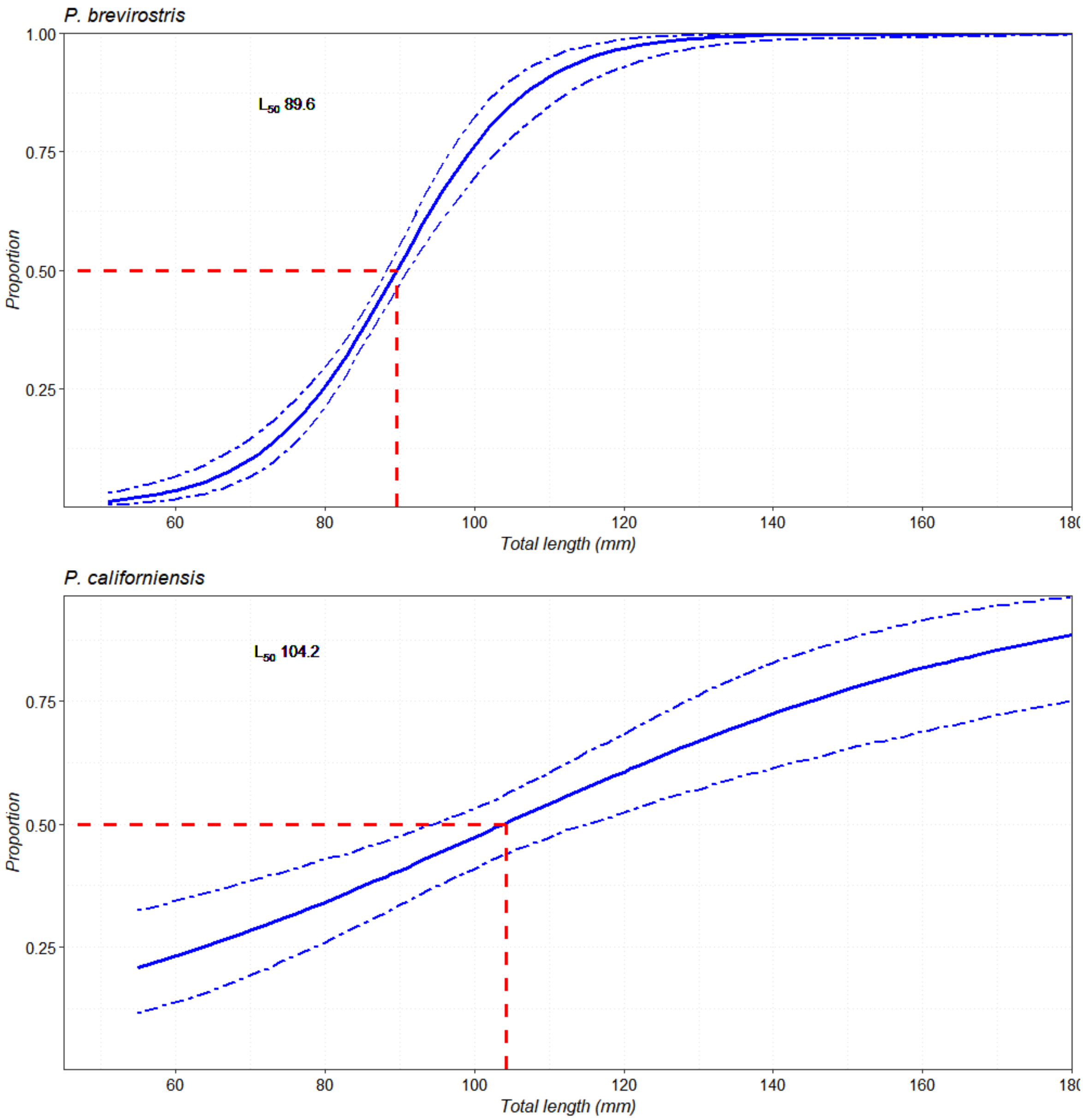

Figure 21: Mean size at sexual maturity, L50, for *P. brevirostris* and *P. californiensis* in reproduction period, 2021, El Salvador

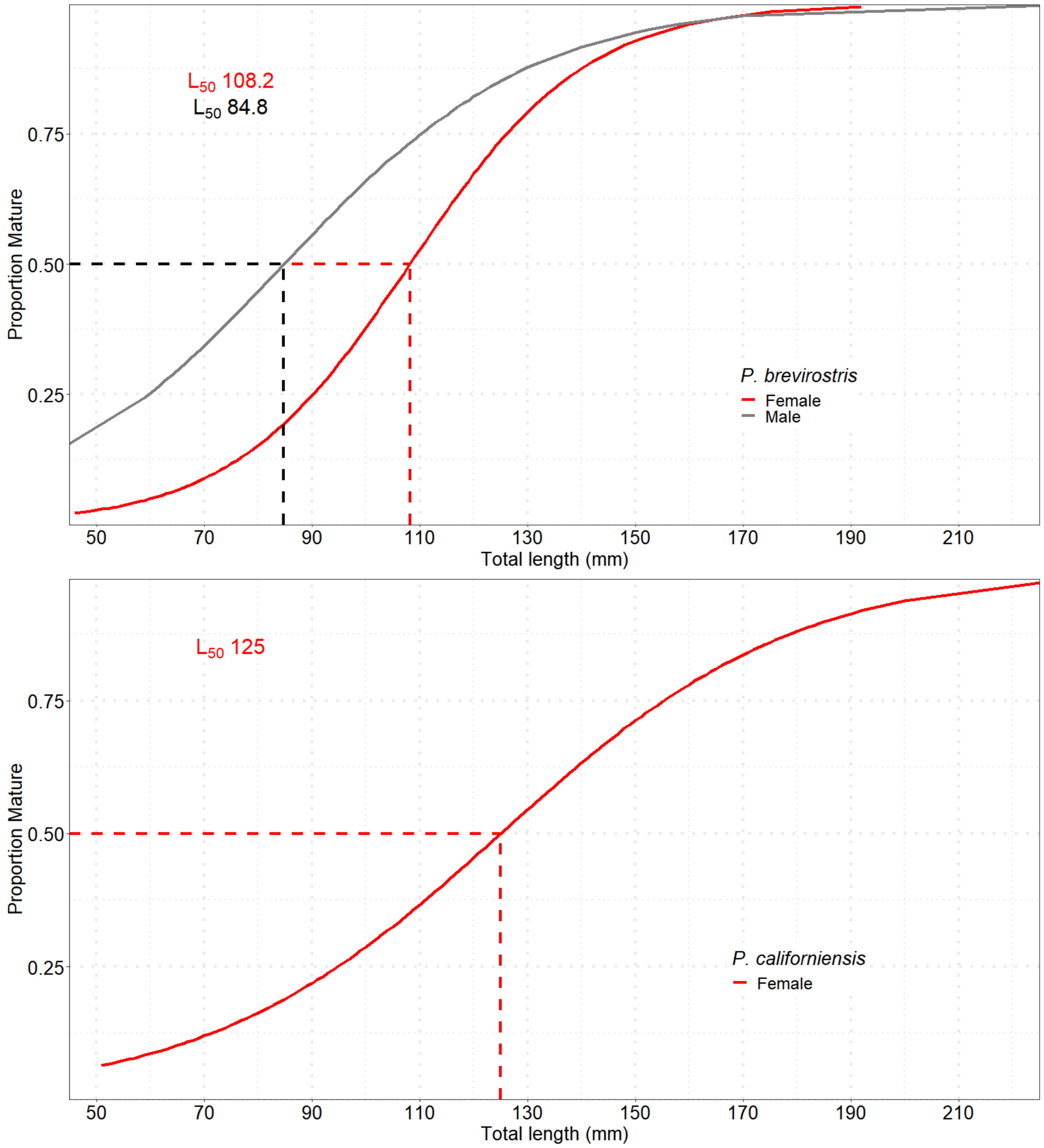

Figure 22: Mean size at sexual maturity, L50, for *P. brevirostris* for male and female and *P. californiensis* for female in reproduction period, 2021, El Salvador.

4.5 Catch Per Unit Effort (CPUE)

The CPUE for the commercial fishing vessel showed that white shrimps are caught all months, but they peak during January and February. Between August and January, the red shrimp production per unit effort is higher and continuous. Brown shrimps do not seem to be a target species and are caught incidentally with other species. However, their catch appears to be linked to red shrimp fishing patterns (Figure 23).

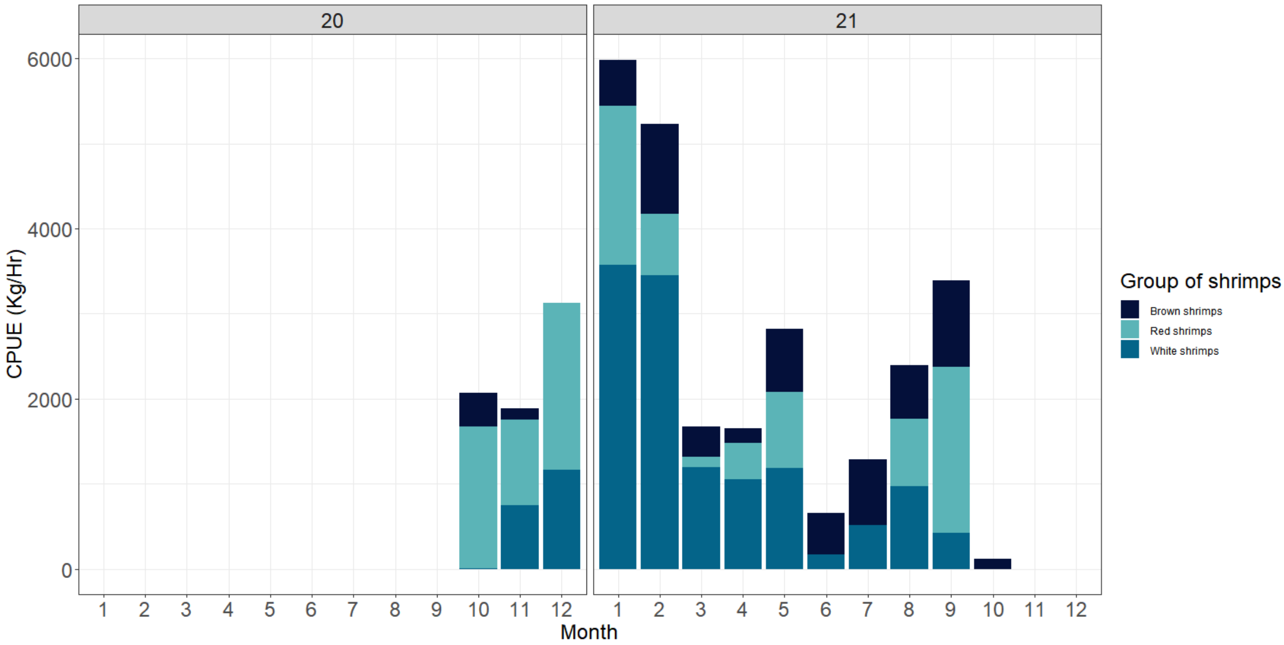

Figure 23: Catch Per Unit Effort (CPUE) for one commercial fishing vessel in El Salvador.

5 DISCUSSION

The overall scope of this study was to determine life history patterns of the Salvadorean stocks of white, brown, and red shrimps (Penaeidae family) with a focus on variability between fishing areas and depth. The results will be used to provide recommendations on how to improve the assessment and management of the shrimp fisheries. During this research, it was strongly recommended to collect data over a continuous period to effectively assess shrimp populations. Since current policies are primarily based on *P. vannamei*, the results of this study offer valuable insights into the other four species, which it is important to take into account.

5.1 Distribution and abundance

This study confirms earlier findings of the bathymetric distribution of these species. At bathymetric level, white shrimps prefer shallower areas than the brown and, in particular, red shrimps, (Ruiz-Luna, Meraz-Sánchez, & Madrid-Vera, 2010; López Martínez & Espinoza Navarrete, 2005; Salazar Linares, Barahona Hernandez, & Pacheco Ulloa, 2006; Fischer, et al., 1995; Pérez Farfante, 1988).

P. brevirostris was more abundant in the western area. One reason for this could be the topographical differences in the continental shelf of El Salvador. The continental shelf is narrower in the western area compared with the east (Sætersdal, Bianchi, Strømme, & Venema, 1999). In Zones I and II, the depth isobaths were similar, but the depth range was wider in the eastern part. This may be one of the reasons that *P. brevirostris* was more abundant in the western area (Pérez Farfante, 1988; Fischer, et al., 1995; López Martínez & Espinoza Navarrete, 2005). Several other factors could be affecting the distribution patterns of *P. brevirostris*, and seasonal variability in depth distribution has been suggested (Garduño-Argueta & Calderon-Perez, 1995). Moreover, a study has shown that a high value of females rather than males can attribute to a distribution pattern by sex in the Nicoya Gulf (Palacios Villegas & Vargas Barquero, 2000).

The five species in this study have a regional distribution from Baja California to Perú, and all have commercial importance. The white shrimps (*P. vannamei, P. occidentalis,* and *P. stylirostris*) are the commercially most important group followed by the red shrimp and brown shrimp (*P. brevirostris* and *P. californiensis*). This order of commercial importance is similar to that of other countries of Central America (OSPESCA, 2009 - 2011), Mexico (Instituto Nacional de Pesca, 2012) and Colombia (Barragan, 1997).

Of the five species, *P. vannamei* is the most abundant in the Gulf of California, Mexico, with catch proportions similar to those reported in this study: 52% *Penaeus vannamei*, 34% *P. californiensis*, 12% *P. brevirostris*, and 2% blue shrimp (*P. stylirostris*) (García & Le Reste, 1986; López-Martínez, et al., 2005). However, *P. occidentalis* was not reported in that study. In El Salvador, *P. vannamei* is also the species with the highest catch (Salazar J. , 2008).

The different distribution and abundance of the five shrimp species depend on the specificity of each species under analysis. According to (García & Le Reste, 1986; López-Martínez, et al., 2005), there are interannual variations in the distribution and abundance of Penaeids species with fishing effort being a possible influencing factor. Thus, it is important to analyse these variations through good data collection.

Recruitment variation can also affect the distribution and abundance. These factors are dependent on the survival rate during the early life stages of Penaeids inside estuaries. Other factors can be temperature, solar activity, salinity, and climate condition that can affect the larval period and hence, recruitment. Nevertheless, it is considered that rainwater and overflows tend to benefit survival and growth (García & Le Reste, 1986).

The variation on distribution and abundance observed in this study concur with the variability observed in May 2000, the distribution and abundance for the white shrimps in Zones III and IV were more abundant, and in May 2006, both zones were abundant as well as Zone I (Salazar Linares & Barahona Hernández, 2006; Salazar Linares, Barahona Hernandez, & Pacheco Ulloa, 2006).

Distribution and abundance may also be related to reproduction and recruitment. Most of the species need the estuaries to complete the life cycle. They can concentrate near the mouth rivers or mouth of estuaries, and Zones I, III, and IV have part of the most important estuaries and river mouths. On the contrary, Zone II does not have important estuaries or rivers. Nevertheless, that should be analysed in future studies.

For better knowledge on the life cycle and distribution of the shrimp species, it is recommended to obtain more information from surveys and/or commercial boats regarding length, sex, and maturity. These samples should be sampled from the continental shelf as well as from estuaries throughout the year.

The biomass index of the five shrimp species varied between species and zones. This can be related to their respective biological process, i.e., growth, reproduction, mortality, and recruitment, as well as fishing effort intensity, and oceanography conditions (García Borbon, 2019).

Data were not available to compare the distribution of the shrimp fleet activity to the biomass indices. It is recommended to have long-term monitoring of fisheries activities for comparison. Furthermore, data from commercial fisheries can be used to monitor the status of the stock, into stock assessment models, and to give advice on fisheries.

5.2 Life history parameters

The Interannual variation also has influenced the length-frequency distribution; the late migration of shrimps of larger size from estuaries can change the recruitment curve, that moves into larger sizes (García & Le Reste, 1986). Notwithstanding, there were some cases that the bimodal patterns were present in this research, especially for *P. brevirostris*, *P. californiensis*, and *P. vannamei*. It was not well presented in *P. stylirostris* and *P. occidentalis* because there was not enough data.

Bimodal tops have been observed for *P. brevirostris* and three modal groups were seen in January (Instituto Nacional de Pesca del Ecuador, 2016).

In general, crustaceans present a sexual dimorphism (Accioly, et al., 2013). In addition, the five shrimp species also present a sexual dimorphism (Aragón Noriega, 2005; Palacios Villegas & Vargas Barquero, 2000; Manzano Sarabia, 2003; González Acuña, 2016). Furthermore, the dimorphism is well noticed in the mean size at sexual maturity (L_{50}) in this research as well as other reports (González Acuña, 2016; Accioly, et al., 2013; Ramos-Cruz, 2012; Palacios Villegas & Vargas Barquero, 2000).

Periods of maximum level of maturity of *P. brevirostris* is in May, August, and January with two periods of spawning, May to September and January to February (Barreiro Güemes, 1986) in (Manzano Sarabia, 2003). *P. californiensis,* has a reproduction peak in October (Instituto Nacional de Pesca del Ecuador, 2016) but in this study seems to be all year round.

Peak of maturity for *P. vannamei* in El Salvador was during May and June (Salazar Linares & Barahona Hernández, 2008) However, the results of this study showed that the most representative period was March and April. The maturity period for *P. stylirostris* is in May (García-Juarez, 2012). Another study mentions that the reproductive period is from March to September but with a peak from May to June (Aragón Noriega, 2005) which is similar to the results of this study. Unfortunately, there were not enough data to see a pattern for the other shrimp species.

5.3 Catch Per Unit Effort

In 2008 the higher catch per unit effort for white shrimps was from November to December and in 2009 from January to February (Barahona Hernández, 2010) which concur with the results of this study. It was reported that from October 2007 to January 2008, the period of recruitment is higher (Barahona Hernandez & Salazar Linares, 2008).

As in distribution and abundance, interannual variation can influence the trends of catch per unit effort that can be in the short or long term (García & Le Reste, 1986), therefore, for a programme of collecting data from the fishermen in a continuous period of time to relate the interannual variation as well as the effort.

Those years that have positive anomalies of rain and temperature, or El Niño occurrences, had an increase in the CPUE for white shrimps, but La Niña events decrease the CPUE in El Salvador in a study made from the period (Salazar Linares J. L., 2007). These comparisons were made yearly, then it is recommended to analyse the trend during the months to verify those variations relating to the CPUE.

5.4 Issues and Recommendations

In El Salvador, there is no permanent programme for collecting biological data for stock assessment and/or recommendation. Data scarcity, particularly relating to shrimp fisheries compounds wider issues to assess the fisheries resources. To achieve the goals of this study, it was difficult to find proper data because the data collected previously in El Salvador had different objectives. Therefore, the methodology and fishing gear were different and worthy according to their respective main goals. However, it is important to assess the population dynamic of the resources over time. In order to compare the data of the two surveys used in this study (in 2015 and 2019), it was necessary to analyse them through a gear comparison technique to see if the selectivity of the trawls differed. Nevertheless, there was not enough information, i.e., there is still uncertainty with regards to the comparison of the trawls.

To obtain robustness in stock assessment, it is necessary to design a program to collect data periodically to obtain a basis to understand the behavior of the Penaeids species. This knowledge can lead to better understanding of life history and behavior related to El Niño South Oscillation, as well as interannual variations. Therefore, it is recommended that a research protocol be established to study the shrimp fisheries. To compare data with some confidence standardised procedures are proposed. This protocol needs to consider the fishing gears, operational facts, and collecting data procedures, in addition to performing analysis on the data collection.

To assess shrimp stocks properly, it is necessary to obtain regular data preferably by a survey that will gather fisheries independent data. The first step is to establish the main goals of the research. After that, it is necessary to define the study area based on all available information, i.e., the knowledge of the fishermen, research, and eco sound. Same sources are used, if possible, to determine where it is trawlable to find suitable locations for the stations. The fishing gear must stay the same over time to make it comparable between years, even if the style becomes older or different compared with the commercial fleet. Mesh size of the survey trawl should be smaller than of the commercial, because smaller individuals are needed to estimate length distributions and recruitment (Sparre & Venema, 1998; Einarsson, 2021).

Furthermore, it is important to involve the fishermen in collecting samples used to measure length and record sex and maturity. According to law, fishermen must provide information, then it is necessary that before renewing the licences, data provision in an appropriate system to assess the stock should be required. Fishermen must understand why the data are collected because possible bias can occur. Then it is required to train the fishermen and the sampling workload should not be excessive (Veiga-Malta, Feekings, Herrmann, & Krag, 2018), but the help of fishermen is valuable, especially when there are not enough human resources to collect the data, as in the case of El Salvador. With this data it is possible to study, i.e., changes in abundance, distribution, and the size composition of the catch.

After facing significant challenges during this process and considering the lack of human resources, it is recommended that analyzing the distribution of hauls using the VMS will provide valuable insights into the abundance of shrimp within each zone.

As mentioned before, the trawlers are multispecies fisheries, and even the bycatch was not part of the goals for this study, it is strongly recommended to assess these resources as part of the ecosystem in which the shrimps exist.

6 CONCLUSIONS

- Distribution and abundance according to each species are different, this can be influenced by the interannual variation, bathymetry, and recruitment variations.
- The biomass indices on shrimp species are related to their respective biological process, oceanographic conditions, and fishing effort. Biomass was 33%, more in 2019 than in 2015, and *P. vannamei* is the most representative, i.e., between 40 to 67% of total biomass.
- The bimodal groups in length frequency and the mean size at sexual maturity shows that these species present sexual dimorphism.

- The CPUE shows that white shrimps' greatest productivity fishing period was in January and February; for red shrimps was from September to January. Brown shrimps are produced all year round with no specific high production.
- Standardise sampling programmes, both fisheries independent and dependent data, which is required to assess the shrimps' stocks and provide a recommendation based on robust data.

ACKNOWLEDGEMENTS

First and foremost, I want to thank almighty God for the opportunities and for showing me the way forward, as well as all the blessings he has given me during this training process.

Totally grateful to GRÓ FTP for the opportunity to be part of this programme, as well as for selecting all the right people in the training group, and for the orientation during the process of carrying out the research project. To the FTP team, Mary, Julie, Agnes, Stefán, Tumi, Thor, and Zaw, thanks for what we don't see but that requires a lot of effort.

I want to acknowledge the Ministry of Agriculture and Livestock for the opportunity to allow me to come to this programme and support me. To OSPESCA for being the intermediary so that this opportunity could materialise.

I want to thank the MFRI for allowing us the use of the facilities and equipment for the development of the training and the research project.

Warm and sincere thanks to my supervisors, Inga, Klara, and Halli for sharing with me their knowledge, as well as the patience and guidance they gave me during the process of this project; you have no idea what it has meant to me.

And special thanks to Julián Burgos who help me during the process of this research with his knowledge, guidance, and patience.

Rodrigo Zelaya, Cecilia Montis, Marlene Galdámez, and Natalia Galdámez for helping me back home with the data provision, and the help you provided to me.

To my beloved family and husband, thank you for encouraging me always to follow my dreams, this is for you!

7 REFERENCES

Accioly, I., Lima-Filho, P., Santos, T., Barbosa, A., Santos Campos, L., Souza, J., Molina, W. (2013). Sexual dimorphism in Litopenaeus vannamei (Decapoda) identified by geometric morphometrics. *Pan-American Journal of Aquatics Sciences*, 8(4): 276-281.

Aragón Noriega, E. A. (2005). Reproductive output of the blue shrimp, Litopenaeus stylirostris (Decapoda: Penaeidae) in the Gulf of California Coast at Agiabampo, Sonora-Sinaloa, México. *Journal of Shellfish Research*, Vol. 24, No. 2, 597-601.

Asamblea Legislativa de El Salvador. (1998). Ley de Medio Ambiente. Decreto No. 233.

Asamblea Legislativa de El Salvador. (2001). *Ley General de Ordenación y Promoción de Pesca y Acuicultura, Decreto No. 240.* San Salvador: Ministerio de Agricultura y Ganadería.

Barahona Hernández, D. (2010). *Propuesta de período de veda en época de reclutamiento del camaron marino para el año 2010.* Santa Tecla: MAG / CENDEPESCA.

Barahona Hernandez, D., & Salazar Linares, J. L. (2008). *Pesquería del Camarón Litopenaeus vannamei en El Salvador.* Santa Tecla: MAG / CENDEPESCA.

Barahona, D. E., & Galdámez, A. M. (2020). *Evaluación del estado actuak de las especies de camarón y camaroncillo en la Costa Salvadoreña.* Santa Tecla: CENDEPESCA / MAG.

Barragan, J. (1997, March). *Population parameters of Penaeus californiensis in the Gulf of Guayaquil, Ecuador.* Retrieved from digitalarchive.worldfishcenter.org: https://digitalarchive.worldfishcenter.org/bitstream/handle/20.500.12348/2581/na_2893.pdf?sequence1=

Barreiro Güemes, M. (1986). *Estudio sobre la madurez y desove de Penaeus californiensis y Penaeus vannamei (Crustacea Decapoda, Penaeidae) en la costa sur de Sinaloa.* Memorias del primer intercambio académico sobre investigaciones del mar de Cortés. Hermosillo, Sonora, México.

Björnsson, H., Sólmundsson, J., Kristinsson, K., Steinarsson, B. Æ., Hjörleifsson, E., Jónsson, E., . . . Sigurðsson, Þ. (2007). *Stofnmæling botnfiska á Íslandsmiðum (SMB) 1985-2006 og Stofnmæling botnfiska að haustlagi (SMH) 1996-2006 Undirbúningur, framkvæmd og helstu niðurstöður.* Reykjavík: Hafrannsóknastofnunin.

CENDEPESCA. (2020). *Estadísticas pesqueras. Unpublished.* Santa Tecla.

CENDEPESCA. (2021). Sistema de Registro Nacional de Pesca y Acuicultura. El Salvador.

Einarsson, H. A. (2021, November). Fishing gear selectivity. (D. E. Barahona Hernandez, Interviewer)

FAO & MAG. (2016). *Plan Nacional de Desarrollo Sustentable de la Pesca y la Acuicultura de El Salvador: 2015 - 2030.*

FAO. (2014). *Contribución de la Pesca y la Acuicultura a la segguridad alimentaria y el ingreso familiar en Centroamérica.* Panamá.

FAO. (2021). *Fisheries and Aquaculture Statistics. Global Capture Production 1950 - 2019 (FishstatJ).* FAO Fisheries Division.

Fischer, W., Krupp, F., Schneider, W., Sommer, C., Carpenter, K. E., & Niem, V. H. (1995). *Guía FAO para la Identificación de especies para los fines de la pesca. Pacífico Centro-Oriental. Vol. I. Plantas e invertebrados.* Roma: FAO.

García Borbon, J. (2019). *Variabilidad en la biomasa de camarón café (Farfantepenaeus californiensis) en Bahía Magdalena - Almejas, Baja California sur, México.* La Paz, Baja California Sur: Centro de Investigaciones Biológicas del Noroeste, S.C. .

García, S., & Le Reste, L. (1986). *Ciclos vitales, dinámica, explotación y ordenación de las poblaciones de camarones peneidos costeros.* Roma: FAO Doc. Téc. Pesca 203.

García-Juarez, A. R. (2012). Propuesta de manejo para la pesqueria de camarón azul (Litopenaeus stylirostris) en el alto Golfo de California. In j. López-Martínez, & E. Morales-Bojórquez, *Efectos de la pesca de arrastre en el Golfo de California* (pp. 355-384). México: Centro de Investigaciones Biológicas del Noroeste, S.C. y fundación Produce Sonora.

Garduño-Argueta, H., & Calderon-Perez, J. (1995). Seasonal depth of the crystal shrimp, penaeus brevirostris (Crustacea: Decapoda, Penaeidae), and its possible relation to temperature and oxygen concentration off southern Sinaloa, Mexico. *Fishery Bulletin*, 397-402.

GEBCO. (2021, December). *GEBCO*. Retrieved from Gridded Bathymetry Data: www.gebco.net

Gierloff-Emden, H. G. (1976). *La Costa de EL Salvador: Monografía morfológica - Oceanográfica.* Ministerio de Educación.

González Acuña, R. I. (2016). *Princpales aspectos biológicos Reproductivos de Farfantepenaeus californiensis (Holmes, 1900) en el mar ecuatoriano (Septiembre 2015 - Agosto 2016.* Guayaquil: Universidad de Guayaquil.

González-Murcia, S., & Hernández, N. R. (2010). Length-Weigth relationship and diet of the deep-sea demersal fish Lophiodes spirulus (Lophiidae) in El Salvador Pacific waters. *Mesoamericana 17 (1)*, 35-43.

Gopal, C., Gopikrishna, G., & Krishna, G. (2010). Weight and time of onset of female-superior sexual dimorphism in pond reared Penaeus monodon. *Aquaculture*, 300: 237-239.

Gross, G. B. (n.d.). Shrimp Industry of Central America, Caribbean Sea, and Northern South America. *Marine Fisheries Review*, Reprint 971. Vol. 35, Nos. 3-4. NOAA.

Gutiérrez García, R., & Eslaquit, B. (2009). *Resultados del primer monitoreo realizado al camarón costero del Pacífico de Nicaragua. Noviembre - Diciembre 2008.* Managua: Centro de Investigaciones Pesqueras y Acuícolas CIPA/INPESCA.

Hernández-Padilla, J. C., Zetina-Rejón, M. J., Arreguín-Sánchez, F., Nieto-Navarro, J. T., & Hernández-López, A. (2018). Spatio-temporal distribution of four commercial shrimp species in the southeastern Gulf of California, México. *Lat. Am. J. Aquat. Res*, 46(4): 727-734.

Instituto Nacional de Pesca. (2012). *Plan de Manejo de la pesquería de Camarón del Pacífico Mexicano.* SAGARPA, CONAPESCA, INAPESCA, FUNDACION PRODUCE.

Instituto Nacional de Pesca del Ecuador. (2016). *Informe Técnico: Determinación del estado actual de la biomasa del recurso camarón rojo y cafe, mediante prospección biológica pesquera, fuera de las 8 (ocho) millas náuticas del perfil costero ecuatoriano (Agosto 2015 - agosto 2016).* Ministerio de Agricultura, Ganadería, Acuacultura y Pesca.

JICA, J. (2002). *The Study on Artisanal Fisheries Development in The Republic of El Salvador.* IC Net Limited.

Leal - Gaxiola, A. (1999). Análisis de la variabilidad interanual en el patrón reproductivo y talla de primera madurez sexual del camarón café Farfantepenaeus californiensis (Holmes 1900) en el litoral sonorense. *Tesis de Licenciatura*. Mazatlán, Sinaloa, México: Facultad de Ciencias del Mar, Universidad Autónoma de Sinaloa.

López Martínez, W., & Espinoza Navarrete, J. (2005). *Estructura poblacional y ubicacion geográfica y batimétrica de las Especies: Farfantepenaeus californiensis, F. brevirostris, Litopenaeus vannamei, L. stylirostris y L. occidentalis en la costa Salvadoreña.* San Salvador: Universidad de El Salvador.

López, J. (1982). *Proyecto Evaluación del Stock Pescable de "Langostino chileno" en las Costas de El Salvador.* El Salvador: Multipesca, S.A.

López-Martínez, J., Arreguín Sánchez, F., Hernández Vásquez, S., Herrera Valdivia, E., & García Juarez, A. (2002). Dinámica poblacional del camarón café Farfantepenaeus californiensis (Holmes, 1900) en el Golfo de California: Variabilidad Interanual. In M. Hendrickx, *Contribuciones al estudio de los crustáceos del Pacífico Este.* (pp. 209-219). UNAM.

López-Martínez, J., Rábago-Quiroz, C., Nevárez-Martínez, M., García-Juárez, A., Rivera-Parra, G., & Chávez-Villalba, J. (2005). Growth, reproduction, and size at first maturity of blue shrimp, Litopenaeus stylirostris (Stimpson, 1874) along the east coast of the Gulf of California, Mexico. *Fisheries Research*, 71 (2005) 93 - 102.

MAG. (2012). *Cobertura Forestal de la República de El Salvador, C.A.* Santa Tecla: Dirección General de Ordenamiento Forestal, Cuencas y Riego.

Manzano Sarabia, M. (2003, Noviembre). Distribucion y abundancia del camarón café Farfantepenaeus californiensis en el Sistema Lagunar de Agiabampo, Sonora-Sinaloa, México. *Tesis para obtener grado de Maestro en Ciencias. Uso, manejo y preservacion de los recursos naturales (Orientación en Biología Marina)*. La Paz, Sonora-Sinaloa, México: Centro de Investigaciones Biológicas del Noroeste, S.C.

MARN. (2007). *La Zona Costero Marina de El Salvador*. Retrieved from Ministerio de Medio Ambiente: https://www.snet.gob.sv/ver/oceanografia/oceanografia+en+el+salvador/la+zona+costero+marina+de+el+salvador/

MARN. (2012). *Política Nacional de Medio Ambiente.* Ministerio de Medio Ambiente y Recursos Naturales.

Natural Earth. (2009 -2022, December 2021). *Natural Earth*. Retrieved from www.naturalearthdata.com

OSPESCA. (2009 - 2011). *Encuesta Estructural de la Pesca Artesanal y la Acuicultura en Centroamérica 2009 - 2011.*

Palacios Villegas, J., & Vargas Barquero, M. (2000). Longitud a la primera madurez, ciclo reproductivo y crecimiento del camaron blanco (Penaeus occidentalis, Decapoda: Penaeidae) en la parte interna del Golfo de Nicoya, Costa Rica. *UNICIENCIA*, 13-19.

Pérez Farfante, I. (1988). *Illustrated Key to Penaeoid Shrimps of commerce in the Americas.* Washington, D.C.: NOAA Technical Report NMFS 64.

R Core Team. (2021). *R: A language and environment for statistical computing. R foundation for Statistical Computing, Vienna, Austria*. Retrieved from https://www.R-project.org/.

Ramos-Cruz, S. (2012). Aspectos biológicos y poblacionales del camaron blanco Litopenaeus vannamei (Boone1931) durante la veda de 2006 en el golfo de Tehuantepec, México. *CICIMAR Oceánides*, 27(1): 11-24.

Rodríguez de la Cruz, M. (1981). Aspectos pesqueros del camarón de alta mar en el Pacífico Mexicano. *Ciencia Pesquera*, 1(2): 1-19.

Rodriguez de la Cruz, M. (1981). Aspesctos pesqueros del camarón de altamar en el Pacífico Mexicano. *Ciencia pesquera. Instituto Nacional de la Pesca*, 2:1-19.

Romero-Sedano, J., Aragón-Noriega, E., Manzano-Saravia, M., Salinas-Savala, C., & García-Juárez, A. (2004). Período reproductivo del camarón café Farfantepenaeus californiensis (Holmes, 1900) en la laguna costera de Agiabampo, Sonora/Sinaloa, México. *Ciencias marinas*, 30(3): 465-475.

Ruiz-Luna, A., Meraz-Sánchez, R., & Madrid-Vera, J. (2010). Patrones de distribución de la abundancia de camarón comercial en el noroeste de México, modelados con sistemas de información geográfica. *Ciencias marinas*, 36 (2): 107-120.

Sætersdal, G., Bianchi, G., Strømme, T., & Venema, S. (1999). *The Dr. Fridtjof Nansen Programme 1975-1993. Investigation of fisheries resources in developing regions. History of the programme and review results.* Rome: FAO Fisheries Technical Paper No. 391.

Salazar Linares, J. L. (2007). *La lluvia, El Niño, La Niña y la Pesquería del camarón blanco en El Salvador.* Santa Tecla: MAG / CENDEPESCA.

Salazar Linares, J. L., & Barahona Hernández, D. E. (2006). *Esfuerzo pesquero y biomasa de camarones blancos (Litopenaeus vannamei, L. stylirostris, L. occidentalis) disponible en aguas marinas salvadoreñas durante el priodo de 1976 a 2006.* Santa Tecla, El Salvador: MAG - CENDEPESCA.

Salazar Linares, J., & Barahona Hernández, D. (2008). *Pesquería del camarón blanco, Litopenaeus vannamei en El Salvador.* Santa Tecla, El Salvador: MAG CENDEPESCA.

Salazar Linares, J., Barahona Hernandez, D., & Pacheco Ulloa, R. (2006). *Estado de las poblaciones de camarones y camaroncillos durante mayo y octubre de 2006.* Santa Tecla, El Salvador: MAG-CENDEPESCA.

Salazar, J. (2008). *Pesca del Camarón blanco, Litopenaeus vannamei en El Salvador.* Santa Tecla, El Salvador: Ministerio de Agricultura y Ganadería and Centro de Desarrollo para la Pesca y la Acuicultura.

Salazar, J. L., Barahona-Hernández, D. E., & Hernández-Rodríguez, N. R. (2016). *Evaluación Biológica Pesquera del Camarón Marino en la Costa Salvadoreña.* Santa Tecla, El Salvador: Centro de Desarrollo de la Pesca y la Acuicultura.

SCDNR. (2021). *Guide to the Salt Marshes and Tidal Creeks of the Southeastern United States.* Retrieved from S. C. SEA GRANT CONSORTIUM: https://www.saltmarshguide.org/guide/ecological-setting/

Sparre , P., & Venema, S. (1998). *Introduction to tropical fish stock assessment. Part 1. Manual.* Rome: FAO Fisheries technical Paper No. 306.1, Rev 2.

Torrejon-Magallanes, J. (2020). *Package "sizeMat".* Retrieved from The Comprehensive R Archive Network: https://cran.r-project.org/web/packages/sizeMat/sizeMat.pdf

Veiga-Malta, T., Feekings, J., Herrmann, B., & Krag, L. A. (2018). When is enough, enough? Quantifying trade-offs between information quality and sampling effort for fishing gear selectivity data. *PLoS ONE*, 13(6): e0199655. .

Zelaya Cruz, R. S., Hernández, M. A., Candray, M. A., Galdámez Olmedo, N. B., & López Rivera, B. (2015). *Incorporación de la gestión de la Biodiversidad en las actividades de pesca y turismo en los ecosistemas costeros marinos.* San Salvador: Gef, MARN, MAG, PNUD.