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The fisheries of Timor-Leste: A 4-year time series analysis covering the COVID-19 pandemic

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The fisheries of Timor-Leste: A 4-year time series analysis covering the COVID-19 pandemic

Authors

Sarah Jørgensen Veillat,[1] Alexander Tilley,[2] Joctan Dos Reis Lopes,[2] E. Fernando Cagua,[2] Lorenzo Longobardi,[2] Jeppe Kolding.[1]

Affiliation

[1] University of Bergen, Norway
[2] WorldFish

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Contact

WorldFish Communications and Marketing Department, Jalan Batu Maung, Batu Maung, 11960 Bayan Lepas, Penang, Malaysia. Email: worldfishcenter@cgiar.org

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List of abbreviations

CPUE	catch per unit effort
GDP	gross domestic product
ICT	information and communication technology
IRI	index of relative importance
MAF	Ministry of Agriculture and Fisheries
SIDS	Small Island Developing States
SSF	small-scale fisheries

Key terms, definitions and units

Catch: The total number (or weight) of fish caught by fishing operations. Catch should include all fish killed by the act of fishing, not just those landed. The component of fish encountering fishing gear, which is retained by the gear.

Catch per unit effort (CPUE): A measure of the relative abundance of a fishstock, calculated using a standardized and constant unit of effort in method or time. For example, the quantity of fish (kg) caught per 100 hooks, or the quantity of fish caught per fisher per hour. CPUE data can be fisheries dependent or independent, but requires the fishing gear to be the same. CPUE is gear-specific because of different probabilities of capture (so-called catchability), so comparing CPUE only by time across different types of gear is not possible without intercalibration.

Effort: The amount of fishing gear of a specific type used on the fishing grounds over a given unit of time (e.g. hours trawled per day, number of hooks set per day, or number of hauls of a beach seine per day) to be used to compare catch rates in the same fishery. When two or more kinds of gear are used, the respective efforts must be adjusted to some standard type before being added, sometimes referred to as the *effective fishing effort*. Across different fisheries or gear types, a standardized unit of effort must be used, such as time fishing per vessel or person (e.g. fisher days).

Fishing trip: Defined as an event when a fisher or a fishing vessel leaves the home site or port with the intention of fishing, travels to the fishing grounds or gleaning area, fishes for a certain time and returns to the site or port where its catch is landed, sorted or unloaded.

Gear: A tool or method used to catch or gather aquatic foods, such as hook-and-line, trawl net, gillnet, pot, trap, spear, manual collection, etc.

PDS trackers: GPS trackers manufactured by Pelagic Data Systems Inc. in San Francisco, California.

PeskAAS: The national fisheries monitoring system of Timor-Leste. The name is a pseudo acronym, derived from the Tetum word for fisheries (*peskas*) + **A**utomated **A**nalytics **S**ystem.

Trip length: The duration of a fishing or gleaning trip (with or without a vessel), measured in time (normally days or hours) between departure and return time and date.

Source: Fisheries and aquaculture ontology doi: 10.5281/zenodo.7381034

Executive summary

Small-scale fisheries (SSF) represent almost half of global capture fisheries production, supporting the livelihoods of millions of people worldwide and the food and nutrition security of billions. However, the general lack of data from these fisheries makes it difficult to ensure they are included fairly in decisions about ocean resources and how to manage resources for sustainability.

Timor-Leste has one of the highest rates of malnutrition in the world, and fisheries are an important potential growth sector to achieve national development objectives of alleviating poverty and eradicating malnutrition. This report uses a 3-year time series of catch and effort data from PeskAAS, the national fisheries monitoring system, to provide a baseline characterization trajectory of the country's fisheries.

The national fisheries fleet of Timor-Leste is exclusively small-scale, made up of approximately 4,554 smaller fishing vessels composed of about 60% motorboats and 40% canoes. Canoes are mostly single-person, while motorboats typically hold between one and 12 fishers depending on location and fishing type. The most common type of gear is gill nets. Fishing is predominantly nearshore, within 5 km of the coast, and focused on fringing coral reef habitats and the pelagic forereef zone. The presence of large saltwater crocodiles throughout the coastline of mainland Timor-Leste restricts most spearfishing activities to the island of Atauro.

Seasonal changes and mixed livelihoods such as smallholder agriculture drive seasonal differences in fishing effort, with September to December showing the highest effort and February to June the least.

Timor-Leste has an estimated average annual catch of 6781 t (SD ± 1157), with Atauro, Lautem, Bobonaro and Manatuto being the most productive municipalities. The catch composition in each area reflects the types of gear used and consists predominantly of small pelagic fish species (<30 cm) caught in gill nets. Atauro shows the most diverse catches, which frequently include small and large reef fish species. Large fish species (e.g. sailfish, stingray, barracuda, long tom) are sold for a higher price per kilogram than smaller species (on average 11 and 8 USD, respectively), with fishers retaining a high percentage of catches for household consumption. Of all the municipalities, Dili-based fishers sell their fish for the highest price because of their proximity to the capital and ability to save on transportation and trading.

The time series of data used encompasses the COVID-19 pandemic, and our findings suggest that SSF in Timor-Leste were fairly resilient to the impact. Although they experienced a decline in the market value of the catch, it does not appear to have been as influential as in other countries, where decreases in fishing effort were seen. It is possible that the limited export of aquatic foods from Timor-Leste, and its modest tourism sector, sheltered the fisheries from shocks seen in the fishing sector of other nations. This reflects the persistence of SSF to generate food and income where formal markets and global supply chains are extremely limited. With increasing attention and investment in the country's fisheries sector to achieve national development goals, it will be critical to consider if modernization and a focus on increasing production will benefit those with the most pressing food and nutritional needs, as well as environmental sustainability.

This report provides a benchmark against which to track the progress and development of the fisheries sector in Timor-Leste, and serves as a case study for low-cost digital monitoring of fisheries in data-deficient scenarios.

How to use this report

This report presents an analysis of fisheries catch and effort data generated through the PeskAAS fisheries monitoring system between 2018 and 2021. Due to the iterative co-design and co-development of PeskAAS with local stakeholders, monitoring started as a pilot project at five sites in 2017 and gradually increased to the national system it is today. Along this journey, the type and quantity of data collected from fishers changed slightly, and continuous vessel tracking was introduced with 100 boats in February 2018, then 400 boats later that year.

Currently, PeskAAS enumerators record the catches from a sample of fishing trips at 15 landings sites across the country on a daily basis, and approximately 200 motorised and unmotorised vessels send continual geolocation data. However, to integrate older data from fewer sites, where appropriate, the data are grouped into broad geographical categories of North coast, South coast and Atauro island.

In using this report, please keep in mind that the time series of data used may alter slightly according to the analysis being performed due to this iterative development of PeskAAS. For example, there was no accurate fish price information recorded prior to April 2019, or trip duration information recorded prior to June 2018. The precise time period used for each analysis is reported in the appropriate figure caption.

The latest data and near real-time analytics can be viewed by visiting the publicly available dashboard at www.peskas.org.

Data protection and permissions
All data is provided voluntarily, and collection is conducted with the permission of fishers. They have the option to not answer or to provide further data, or they can request that the data we hold for their fishing activities be deleted.

1. Introduction

SSF are an important part of global fish production, contributing at least 40% of global capture fisheries (FAO et al. 2022). Of the several million people engaged in SSF, over 90% live in developing countries and Small Island Developing States (SIDS), for whom fish is an essential source of food and income (Mills et al. 2011; FAO et al. 2012). In some high-income countries, where fisheries have been intensively monitored with quantitative data systems and governed by the state, monitoring has in general led to effective adjustments in management and fishing capacity so that fishstocks are recovering and/or fished at sustainable levels (Hilborn et al. 2020). The majority of the global marine SSF fleet is active in low- and middle-income countries, with 80% in Asia (FAO 2020). However, they are under increasing pressure to conform to data-driven management strategies (Béné and Friend 2011; Islam 2011; Kolding and Van Zwieten 2011; Kolding et al. 2014; Macusi et al. 2020). Fisher knowledge is critical in framing and evaluating fisheries-dependent data in a social-ecological context, but it is still rarely incorporated effectively into governance (Hind 2014).

> “*Managing fisheries is hard: it's like managing a forest,*
> *in which the trees are invisible and keep moving around.*
>
> ***– John Shephard***”

Monitoring and assessing fishstocks present a significant challenge for quantitative data collecting methods, so management relies principally on fisheries-dependent data, specifically data collected from fishing activities and landings, etc. Nevertheless, the dispersed and diverse operations of fishing activities and the challenges inherent in measuring and understanding trends in mobile stocks place demands and limitations on fisheries-dependent monitoring. This is especially true for SSF, which are often informal, dynamic and even more widely dispersed. As such, scientific management strategies are often based on assumptions under limited information, which can do more harm than good if there is also limited integration of local knowledge or a lack of understanding of social and cultural elements (Kolding and Van Zwieten 2011). Filling these gaps in our knowledge should be a priority to determine the level of resilience of SSF against crises and, if necessary, strengthen them.

SSF communities face formidable economic, social and geographical barriers in using technological approaches, such as the cost of equipment and the digital literacy to operate it. Yet, there has been a dramatic expansion of the development and testing of information and communication technologies (ICTs) for SSF (Fujita et al. 2018; Bradley et al. 2019; FAO and WorldFish 2020). One such ICT is PeskAAS, which was developed by WorldFish in partnership with the Timor-Leste Ministry of Agriculture and Fisheries (MAF) and has been scaled since 2017 (Box 1).

Box 1. The PeskAAS fisheries monitoring system

PeskAAS was co-designed with fisheries officers as a simple and cost-effective way to generate and analyze fish landings data in near real-time (Tilley et al. 2020). It is an interactive web-hosted application in which fisheries data trends are visualized with the goal of exploring data and improving decision-making processes for SSF managers. In 2019, the government formally adopted PeskAAS as the official national fisheries monitoring system of Timor-Leste. It now forms part of the fisheries management process and has improved and automated rapid, low-cost and accurate data generation for fisheries in Timor-Leste (Dam Lam 2022). For more information and to view the dashboard, please visit www.peskas.org.

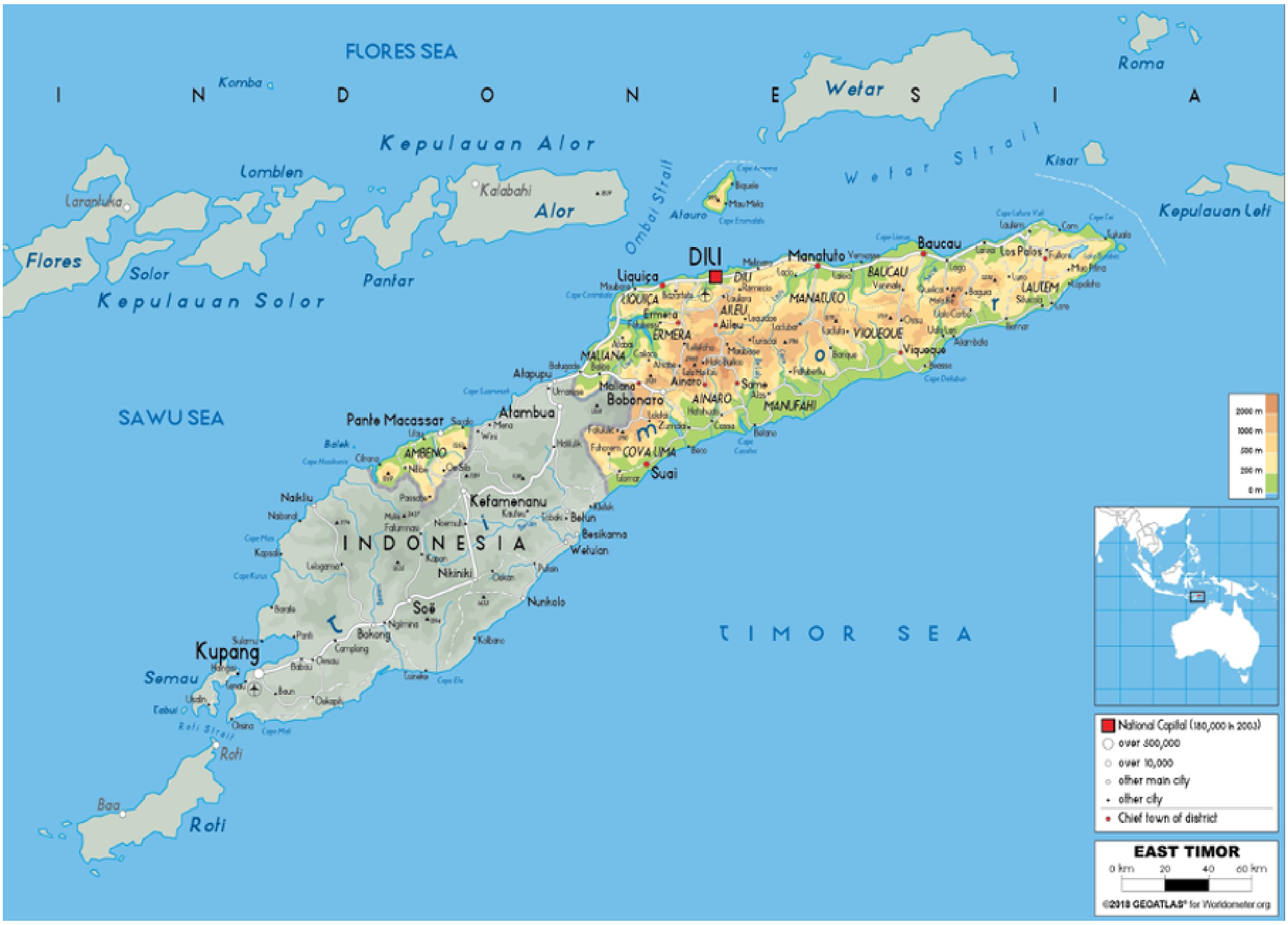
This report aims to summarize and analyze the first 3 years of data collected by PeskAAS to provide a series of benchmarks for the fisheries sector, against which trends and trajectories can be compared in years to come. Furthermore, this report is intended to provide information for fisheries stakeholders, including fishers, government, nongovernmental organizations and civil society organizations to guide new development and capacity building initiatives in the fisheries sector.

Although the impacts of the COVID-19 pandemic on fisheries are not a major focus of this report, the pandemic started during this data time series. This is thus used as a reference point in certain analyses, and a short analysis and discussion related to COVID-19 is included.

A fisherman carries his net along the shore in Atauro, Timor-Leste.

2. Study area

Timor-Leste, also known as East Timor, is one of the SIDS in Southeast Asia. It is surrounded by Indonesia to the west, north and east, and Australia to the south, with the Timor Sea in between (Figure 1). It has a coastline of 783 km and a total land area of approximately 14,954 km^2 (Lopes et al. 2019). The island of Atauro, off the north coast, with a land area of approximately 140 km^2, has a population of about 10,000 (General Directorate of Statistics 2015; Lopes et al. 2019). The country counts around 1.3 million citizens, which is expected to triple by 2050 (Molyneux et al. 2012). Most cities, including the capital, Dili, are located on the north coast, where the majority of the people live: over 60% of the total population lives on the north coast and about 20% on the south coast, with the remainder living inland (General Directorate of Statistics 2015). Most economic activity is centered around Dili, so the rural population experiences higher poverty rates than people living in urban areas (Moxham and Carapic 2013).



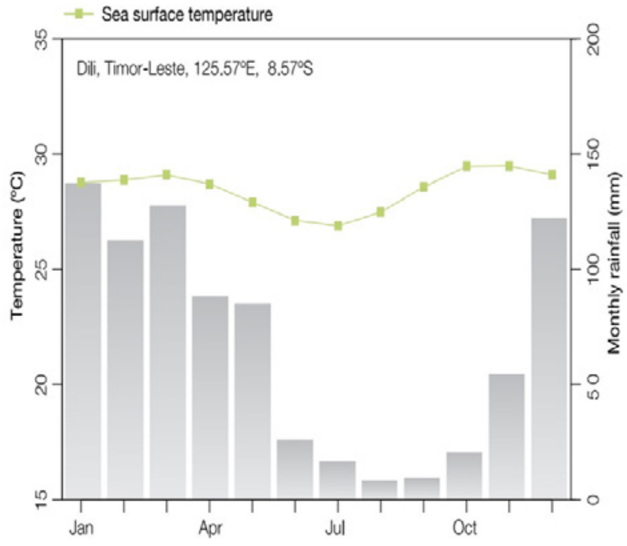
Note: The colors show the elevation from 0 m above sea-level (green) to 2000+ m above sea-level (orange brown). The size of the points shows the size of the cities. The small map on the right side shows the placement of the country compared to the rest of Southeast Asia and Australia.

Source: Geoatlas 2018.

Figure 1. Map of Timor-Leste and its surroundings.

Timor-Leste has a tropical climate, with temperatures at the coast ranging from 25°C to 30°C year-round, with pronounced wet (December to May) and dry (June to November) seasons (Figure 2) (Timor-Leste National Directorate of Meteorology and Geophysics et al. 2015). This seasonality pattern of rainfall experiences between-year fluctuations, caused by the El Niño-Southern Oscillation and the Indian Ocean Dipole (Australian Bureau of Meteorology and CSIRO 2014).

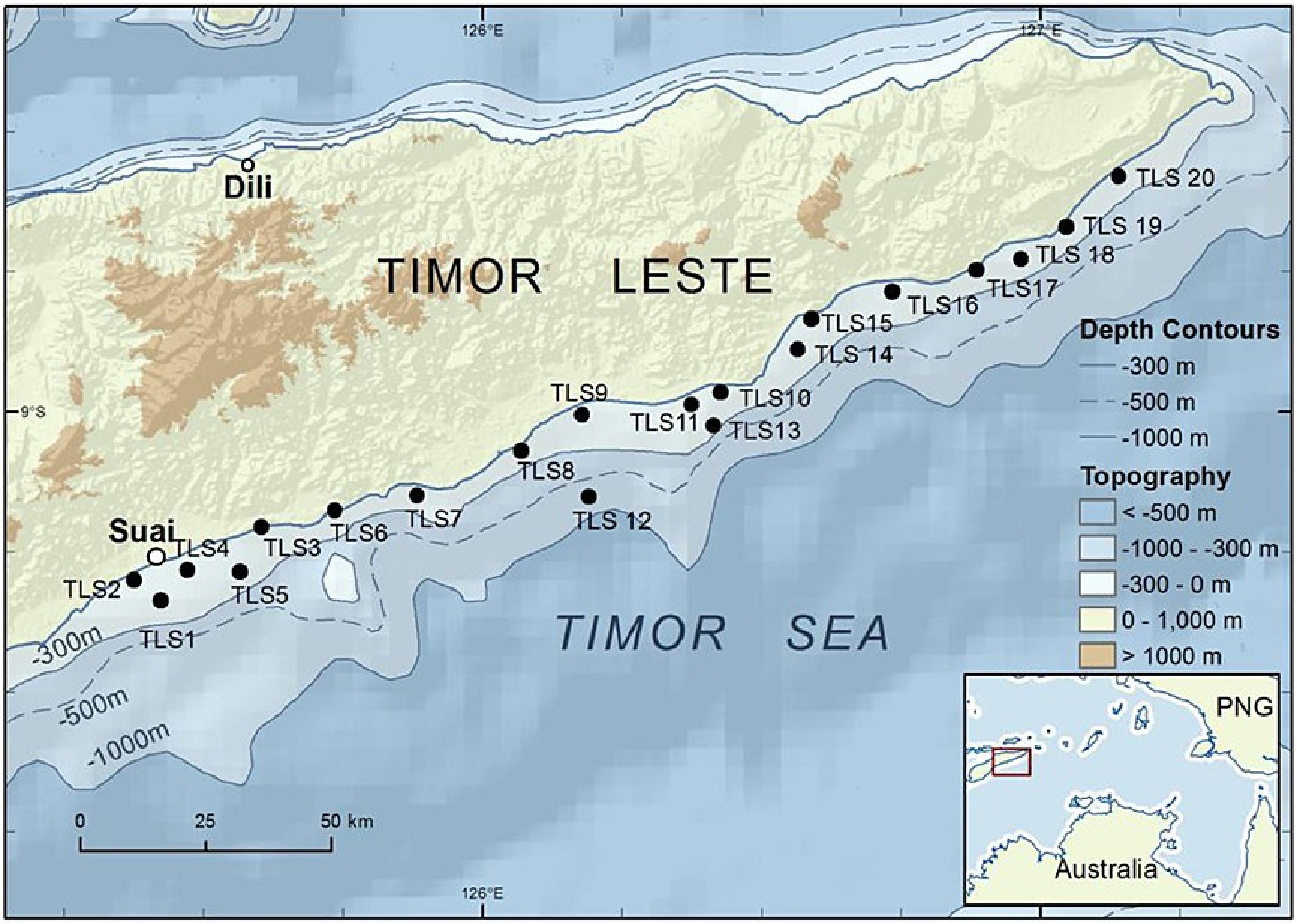
The mountain range separating the north coast from the south coast (Figure 1) causes different rainfall patterns on the two coasts (ADB 2014). The seas on the south coast are rougher than on the north coast because of cyclones coming from the Indian Ocean. The south coast has a shallow continental slope, while the north coast has a very steep slope, quickly descending several kilometers down (Figure 3). The coral reefs are predominantly fringing reefs, located for the most part on the north coast and around Atauro (ADB 2014).



Note: Seasonal rainfall (gray bars) and sea surface temperature (green squares) in Timor-Leste, measured in Dili.

Source: Timor-Leste National Directorate of Meteorology and Geophysics et al. 2015.

Figure 2. Seasonal rainfall and sea surface temperature in Timor-Leste.



Note: The light to dark blue scale shows the bathymetry from sea level down to 1000+ m deep. The maximum depth of the Timor Sea is said to exceed 5000 m.

Figure 3. Map of Timor-Leste and its coastal bathymetry.

The official languages of Timor-Leste are Portuguese and Tetum, but there are many other indigenous languages in use (Taylor-Leech 2009). The country was only recently declared a sovereign state by the UN in May 2002, after having suffered two brutal wars in 1979 and 1999 and a 24-year-long occupation by Indonesia (Braithwaite et al. 2012; Ingram et al. 2015). These calamities have left the country with high poverty rates and poor health services and infrastructure, and 36% of the population experiences chronic food insecurity because of poor quality and low quantity food (Grebmer et al, 2019; National Directorate of Food Security and Cooperation 2019; CARE 2020). During the Indonesian occupation, the commercial fishery played a significant role in the economy of Timor-Leste. But after the civil war in 1999, this plummeted as the infrastructure of the country was destroyed (Barbosa and Booth 2009). Hereafter, SSF became the dominant fishery in Timor-Leste.

Currently, annual per capita fish consumption among the Timorese population is just 17 kg in coastal communities and 5.2 kg in inland areas. This is particularly low when compared to the levels of other SIDS in the Pacific, such as 30–118 kg in Melanesia, 62–115 kg in Micronesia and 50–146 kg in Polynesia (Mills et al. 2013; FAO 2014; López Angarita 2019). Agriculture is responsible for most of the food production, engaging 90% of rural households (FAO 2015; Ximenes 2018). Most families involved in fishing have diversified livelihoods, with most of their time and energy being spent on agriculture and livestock farming (Mills et al. 2013). These livelihoods are, however, dynamic and vary according to season and climate (Mills et al. 2017).

For the purpose of this study, the coastal municipalities were grouped into three statistical areas: Atauro Island, the north coast and the south coast (Figure 4). The landing sites of Manatuto and Lautém are located on the north coast, so they have been assigned to the north coast region even though the municipalities extend between both coasts. The municipalities Ermera and Aileu do not have a coastline and are thus not included. These areas were chosen because of their difference in rainfall pattern, wave activity, marine landscape and demographics mentioned above.

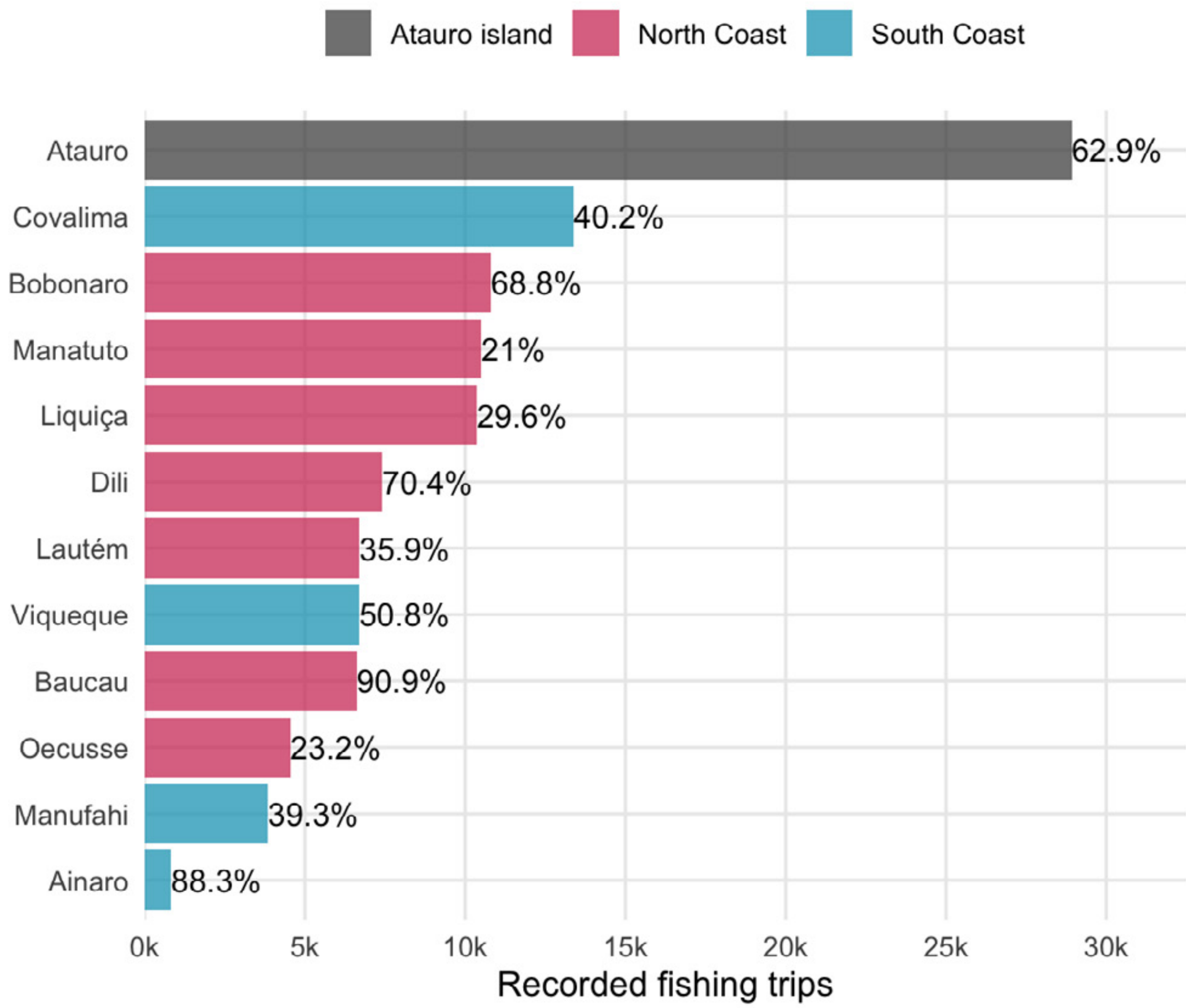
Note: The dots represent the landing sites where catch and trip information were recorded, though not all landing sites are shown on this map, only the ones where enumerators are presently active. The colors represent the different regions: Atauro Island (gray), north coast (red) and south coast (blue).

Source: Tilley et al. 2020.

Figure 4. A map of Timor-Leste and its municipalities.

Box 2. Summary statistics of recorded fishing trips.

The dataset used in this study consists of a total of 123,181 recorded fishing trips identified on the basis of 72,328 GPS tracks and 56,629 direct interviews with fishers at the landing site recording catch data. Of these fishing trips, 4.68% (5776) contain both GPS tracks and catch data. Atauro is the most represented municipality, approaching 30,000 recorded fishing trips, of which 62.9% were interviews recording catch data (Figure 5). All others counted fewer than 15,000 observations. Ainaro is the least represented municipality, counting 822 fishing trips, of which 88.3% were interviews recording catch data (Figure 5).



Note: The percentage on the bars represents the proportion of recorded fishing trips containing catch data coming from direct interviews.

Figure 5. Number of fishing trips recorded for each municipality.

3. Fishing fleet and gear

3.1. The sampled fishing fleet

Of the 2277 fishing boats registered in 2018 by MAF, 323 were used to report catch and/or tracking data to PeskAAS (Table 1). The 323 sampled boats include both motorboats, with either an inboard or outboard motor, and paddle canoes (Table 2; Plates 1 and 2).

The differences seen in the characteristics of the sampled fishing boats between the areas are likely influenced by social, geographic, economic and political factors. The north coast is where Dili and most of the economic activity is centered, so as the richer region more people appear able to invest in motorboats. By contrast, the south coast is characterized by predominantly paddle canoe fishing, which is likely a result of the isolation, poor road infrastructure and higher poverty rates of that part of the country (Braithwaite et al. 2012; Moxham and Carapic 2013; Ingram et al. 2015).

The capital required to invest in a motorboat is out of reach for most rural dwellers. Wooden boats can be made from locally available natural resources, while fiberglass boats are now being made in Timor-Leste. The latter are the focus of government funding schemes for fishers, but the entry and maintenance costs for rural fishers is still prohibitively high.

Region	Sampled boats	Registered fishing boats	Boats sampled
Atauro Island	89	348	25.6%
North coast	129	1463	8.8%
South coast	105	466	22.5%
Total	323	2277	14.2%

Note: Information on the number of registered fishing boats was obtained from the MAF (unpublished data).

Table 1. Total number of sampled and registered fishing boats per region.

Plate 1. Paddle-driven canoes in Timor-Leste.

Plate 2. A motorboat in Timor-Leste.

Region	Sampled boats	Boat type	Number of boats	Median boat length (m)	Boat material (fiberglass, wood, unknown)	Motor type (inboard, outboard, unknown)
Atauro	89	Motorboats	48 (54%)	8.0	3 (6.3%), 24 (50.0%), 21 (43.7%)	2 (4.2%), 46 (95.8%), 0 (0%)
		Paddle canoes	41 (46%)	5.0	1 (2.4%), 31 (75.6%), 9 (22.0%	NA
North coast	129	Motorboats	103 (80%)	6.0	34 (33.0%), 55 (53.4%), 14 (13.6%)	35 (34.0%), 57 (55.3%), 11 (10.7%)
		Paddle canoes	26 (20%)	4.5	0 (0%), 21 (80.8%), 5 (19.2%)	NA
South coast	105	Motorboats	30 (29%)	5.0	4 (13.3%), 20 (66.7%), 6 (20%)	12 (40.0%), 14 (46.7%), 4 (13.3%)
		Paddle canoes	75 (71%)	4.0	0 (0%), 65 (86.7%), 10 (13.3%)	NA
Total	323	Motorboats	181 (56%)	6.5	41 (22.3%), 99 (53.8%), 44 (23.9%)	49 (26.6%), 117 (63.6%), 18 (9.8%)
		Paddle canoes	142 (44%)	4.0	1 (0.7%), 117 (82.4%), 24 (16.9%)	NA

Note: Information on the number of registered fishing boats was obtained from the MAF (unpublished data).

Table 2. Vessels reporting catch and/or tracking data to PeskAAS.

3.2. Fishing gear

The different types of fishing gear used on Timor-Leste are gill nets, long lines, hand lines, spear guns, seine nets, cast nets and fishing traps, as well as manual collection (Figure 6).

To compare the different types of gear used, a percentage index of relative importance (%IRI) was used. IRI is originally used to calculate the relative importance of a species within a fishery, by taking into consideration the weight and abundance (numbers) of fish species caught and the frequency of occurrence all at once (Kolding 1989). The equation expressed as a percentage reads as follows:

$$\%IRI_i = \frac{(\%W_i + \%N_i) * \%F_i}{\sum_{j=1}^{S}(\%W_j + N_j) * \%F_j} * 100 \quad [1]$$

Where $\%W_i$ equals the percentage weight and $\%N_i$ the percentage number of each species *i* of the total catch, $\%F_i$ equals the percentage frequency of occurrence of each species in the total number of fishing trips, and S represents the total number of different species. This index can either be shown as a percentage (%IRI) or as a rectangle, where the percentage number of fish (%N), the percentage weight (%W) and the percentage of the frequency of occurrence (%F) are separately displayed relative to all other species. Although the original function of the equation is to calculate the index of importance of the species caught in a fishery, here it is also applied to the relative gear use in the fishery.

Gill nets are the most used type of gear by number of trips on both the north coast and Atauro (Figure 6), representing the highest proportion of both catch in weight and number of fish caught. On the north coast, gill nets make up 92% of the catch in weight and 98% of caught fish. The percentages are lower on Atauro, but gill nets still make up 62% of the catch in weight and 76% number of fish caught. The other types of gear used on Atauro are spearguns, seine nets and hand lines, collectively yielding about 34% of the total weight of the catch and 23% of the total catch in numbers. Hand lines are used somewhat frequently, for 14% of total fishing trips, but only result in a small proportion of the yield.

On the south coast, long lines are the most frequently used gear by number of trips, making up 76% of the total catch in weight and 60% of the total catch in numbers. Gill nets still make up 18% of the total catch in weight and 27% of the total catch in numbers, while only 5.6% of the total catch in weight and 13% of the total catch in numbers are caught by hand lines.

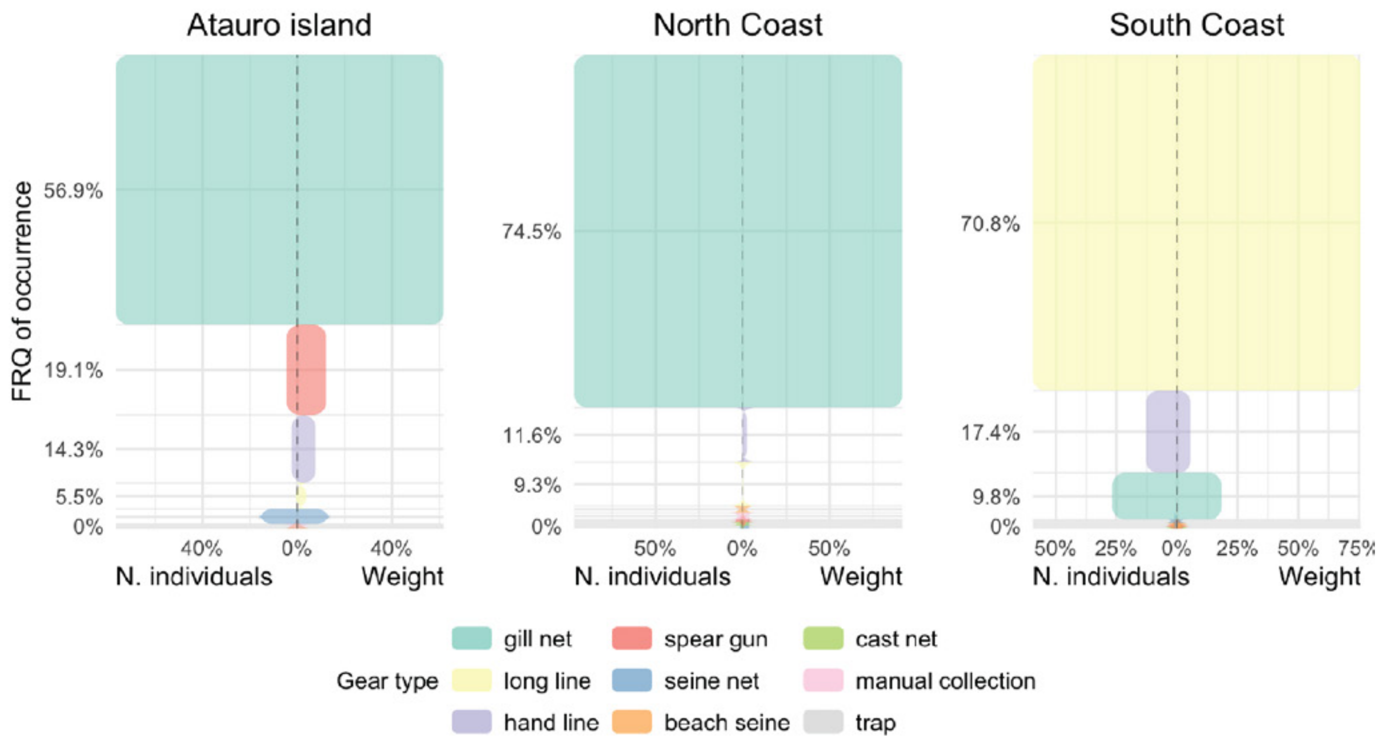
The differences in the constellation of the fishing gear used in the different areas are influenced by social, economic, cultural and geographical factors, as well as climate and natural factors. Atauro and the north coast are ecologically similar, with thin, fringing reefs close to the coast and a steep forereef slope descending to more than 4 km deep. However, open ocean fishing gear is rarely found on Atauro, as fishers prefer reef and nearshore pelagic fishing grounds (Mills et al. 2013). The choice of fishing boats and seasonal weather conditions also limit gear choice. The south coast experiences rough sea conditions for half of the year, so its fishing frequency is affected, as well as its range and gear used in paddle canoes. Atauro is the only area where spearfishing is common, as throughout the mainland coastline there are large and lethal saltwater crocodiles that regularly attack and kill fishers and coastal dwellers (Brackhane et al. 2018).

Plate 3. Gill nets used in Timor-Leste.

Plate 4. Hand lines used in Timor-Leste.

Plate 5. Spearfishing in Timor-Leste.

Plate 6. Fish traps used in Timor-Leste.



Note: The IRI considers the relative weight and number of fish caught per gear type, and the relative frequency of occurrence (%FRQ) of a gear type.

Figure 6. Gear composition using the %IRI of the landings (April 2018 to December 2021).

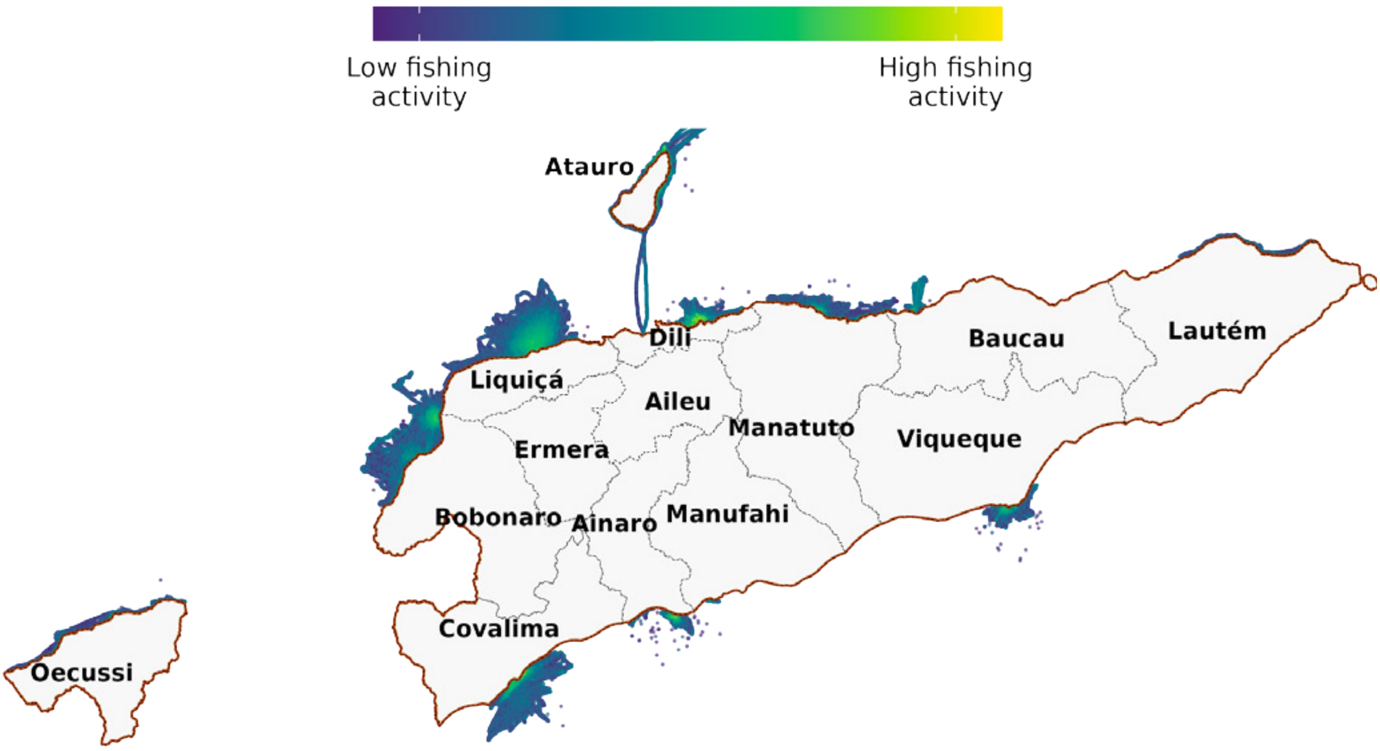
4. Effort and landings

4.1. Geospatial fishing effort

Solar-powered GPS units were installed on part of the Timor-Leste national fishing fleet to track the number of trips and to visualize geospatial fishing effort (Plate 7). These GPS units are produced by Pelagic Data Systems Inc. in San Francisco, California, and are hereafter referred to as PDS trackers. During a fishing trip, these trackers automatically record the location every 5 seconds.

Most of the fishing trips seem to be concentrated inshore around the coast and around the landing sites (Figure 7). As most marine productivity is in the surf zone, this is where a high concentration of fish can be found (Alongi et al. 2012). It also demands less labor and time and requires less fuel. There is some activity recorded between the island of Atauro and the mainland as well as to the Indonesian island of Wetar, north of Atauro. These are most likely taxiing and trading trips, and not for fishing. The same is probably the case for the activity seen in the western part of the north coast, where they are headed to Indonesia or to trade with Indonesian fishers at sea.

Plate 7. Solar-powered GPS unit (PDS-tracker) being installed on a fishing boat.



Note: Data from 80,163 trips using the tracking information sampled by the PDS trackers from May 2019 to August 2022.

Figure 7. Heat map of Timor-Leste visualizing the geospatial fishing effort.

4.2. Number of trips per month

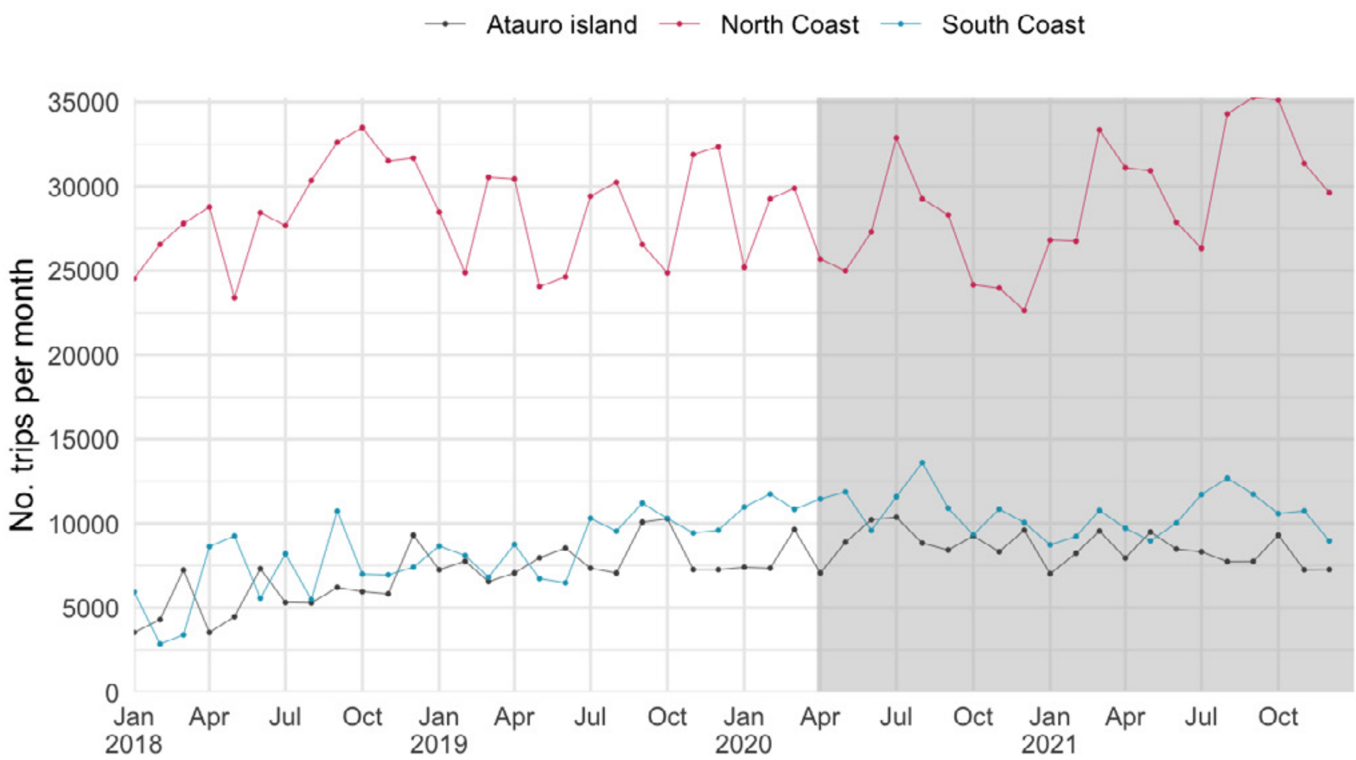
The total number of trips per month was calculated using the trips sampled by the PDS trackers on 454 vessels. Only a small percentage of the Timor-Leste fishing fleet is being tracked. As such, the monthly number of trips is estimated by averaging the number of trips a boat makes over a month and multiplying by the number of boats for each municipality, assuming that all boats are equally active.

There are considerably more fishing trips taken per month on the north coast than on Atauro and the south coast (Figure 8). This is a direct reflection of that area having the highest number of fishing boats registered and being where the majority of the country's population live (General Directorate of Statistics 2015).

4.3. Trip effort

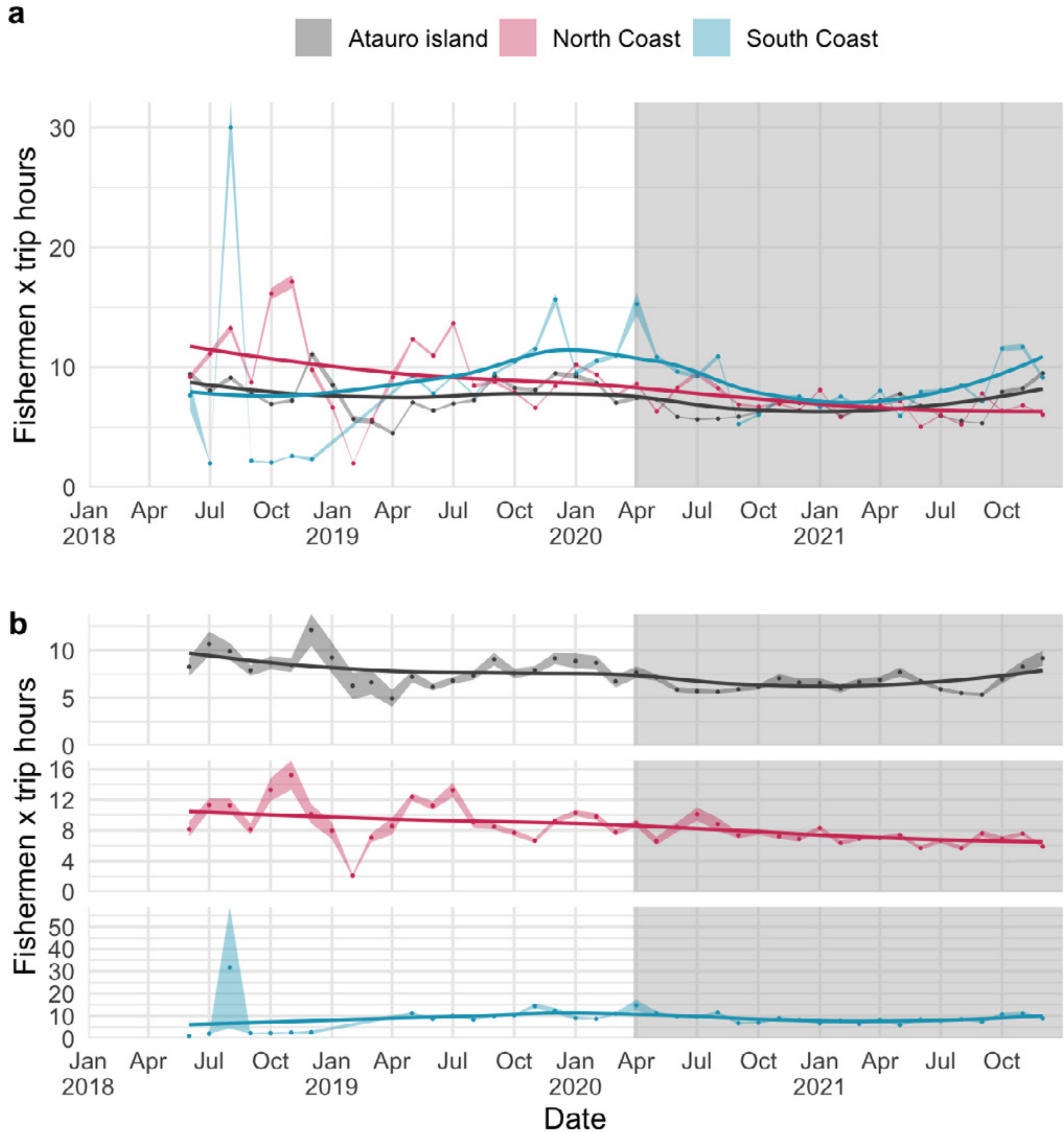
To calculate an effort unit (the trip effort), the duration of a trip (hours) was multiplied with the number of fishers (including women and children), resulting in an effort unit of fisher-hours.

The average trip effort (fisher-hours) of the three regions appears to be quite similar (Figure 9a). The mean trip effort mostly ranges between 5 and 15 fisher hours, with a peak reaching up to 30 fisher hours per month in the south coast. There seems to be no clear trends in trip effort over time among the regions, except for a slight decline in the north coast (Figure 9b).



Note: The gray shaded area defines the pandemic period starting from the COVID-19 lockdown on March 28, 2020.

Figure 8. Estimated total number of trips per month (January 2018 to December 2021).



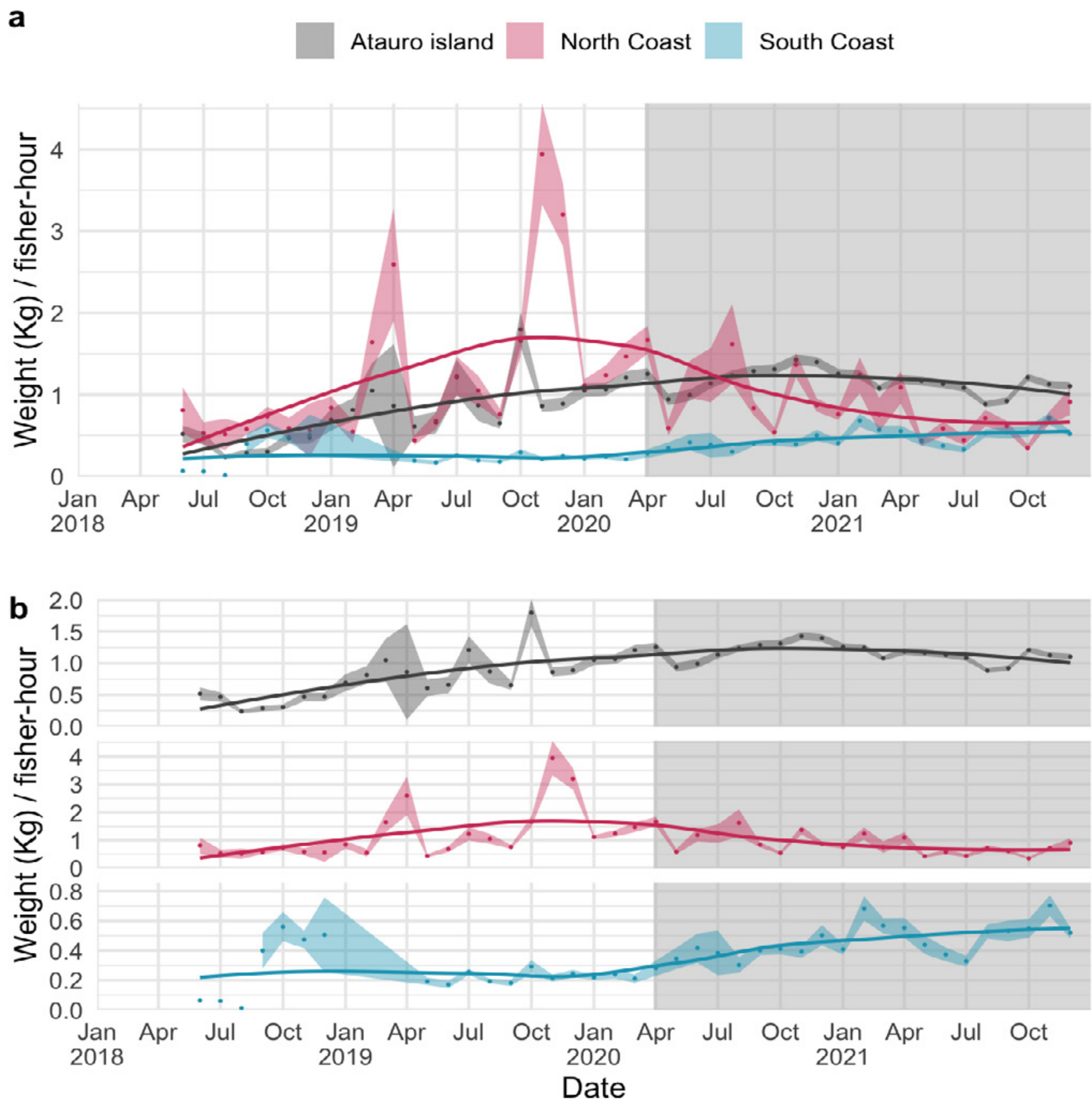
Note: The regions are plotted (a) together in one plot and (b) separately, where the y-axis has free scaling. The colored shaded areas represent the 95% confidence interval. The gray shaded area defines the pandemic period starting from the COVID-19 lockdown on March 28, 2020. No trip duration data was available prior to June 2018.

Figure 9. The mean monthly effort (fishers * hours) of a fishing trip (June 2018 to December 2021).

4.4. Catch per unit effort

For this report, a catch per unit effort (CPUE) was used, where the effort was standardized to one fisher and one trip hour (fisher-hour). The catch was calculated in kilograms. After 2019, the weight calculation was done on species level, whereas before 2019 it was more general.

The average CPUE per month (kg/fisher-hour) for Atauro and the north coast are quite similar, though the north coast has more high peaks (Figure 10). The south coast appears to generally have a lower CPUE than Atauro and the north coast. The CPUE of Atauro seems to increase up until the COVID-19 lockdown starts, after which it stays constant. The north shows no clear change of CPUE over time, whereas the CPUE of the south coast shows a slight increase after the start of the lockdown.



Note: The regions are plotted (a) together in one plot and (b) separately, where the y axis has free scaling. The shaded areas around the time series represent the 95% confidence interval. The lines are the local polynomial regression. The gray shaded area defines the COVID-19 pandemic period, starting from the lockdown on March 28, 2020. No trip duration data was available prior to June 2018.

Figure 10. The mean catch per unit effort (June 2018 to December 2021).

4.5. Catch composition

The fishery of Timor-Leste has a diverse catch composition (Plate 8) (Tilley et al. 2019). At least 53 different species were caught and identified, excluding species classified under "unknown" and "other." To handle the data and keep the results easier to follow, the species were aggregated into 10 functional groups: small pelagics, large pelagics, small reef species, large reef species, sharks and rays, crustaceans, shrimps, cephalopods, mollusks and unknown.

To compare the difference in functional groups caught between the areas, the %IRI was used (see equation 1).

Atauro shows the most even catch composition by functional groups of the three sampling regions (Figure 11). It is dominated by small pelagics in weight and numbers, while small reef species are the most frequently caught. The catch composition of the north and south coasts are both dominated by small pelagic species, though large pelagics are also caught relatively frequently and make up 13% of the weight of the catch in the north and 9% in the south.

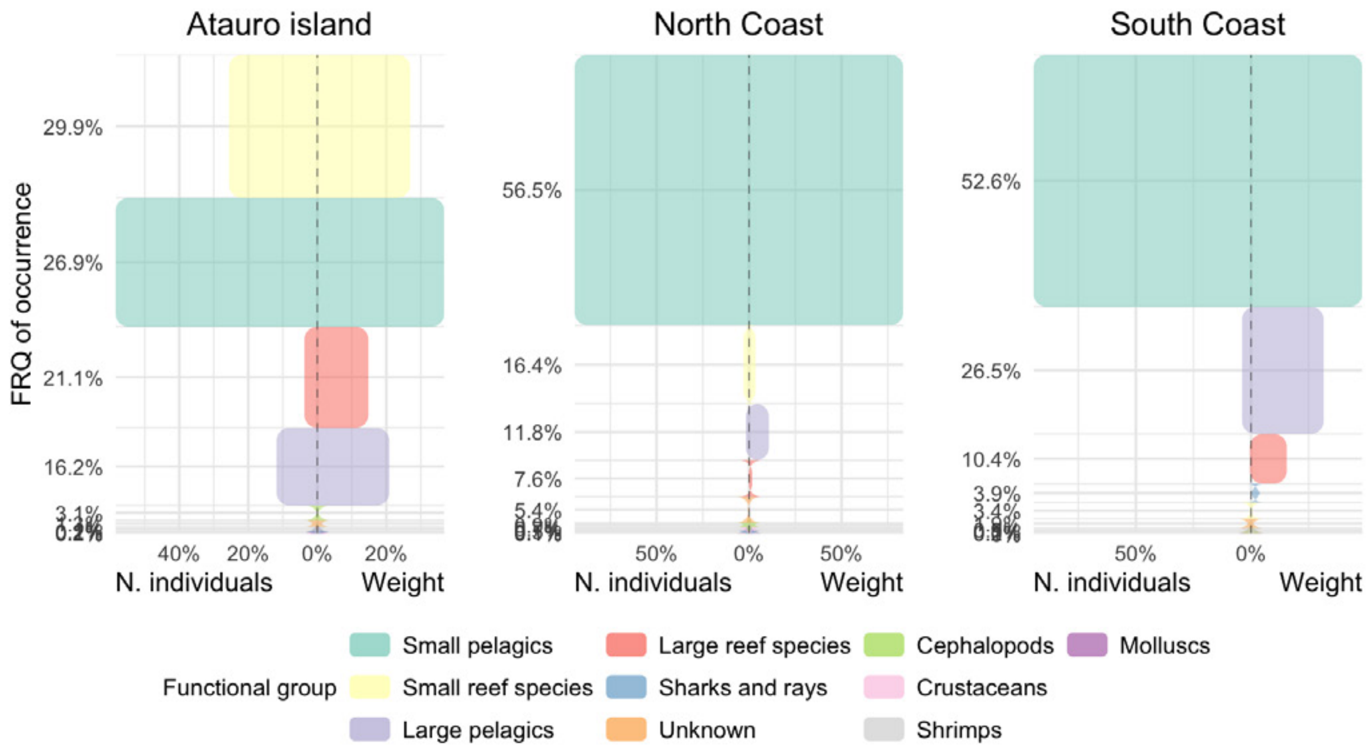
Looking at the catch composition of the four most used types of gear, it shows that gill nets catch primarily small pelagic species, both in weight and number (Figure 12). The weight of the catch of hand lines is dominated by large pelagics and large reef species, whereas small pelagics dominate the catch in numbers. When long lines are used, pelagic fish are primarily caught, of which large fish account for most of the weight of the catch and small fish for most of the catch in numbers. The catch of spear guns consists largely of reef species. Again, the large fish account for most of the weight of the catch and small fish for most of the catch in numbers. Cephalopods are caught in almost one-fifth of the fishing trips where spear guns are used.

The choice in gear type greatly influenced the catch composition of each area. The high frequency of occurrence of reef fish in the catch of Atauro reflects the scarcity of pelagic fishing gear on the island, as well as the use of spear guns. Larger fish are caught more on both the south coast and Atauro than the north coast, which is likely because fishers there use long lines, hand lines and spear guns more often.

Plate 8. Fish caught in Timor-Leste, including parrot fish, snappers, surgeonfish, breams, mackerel scad, barracuda and sardines, among others.

4.5.1. Catch composition by region

This section presents information on the composition of fisheries catches across all gear types in each of the three main regions.

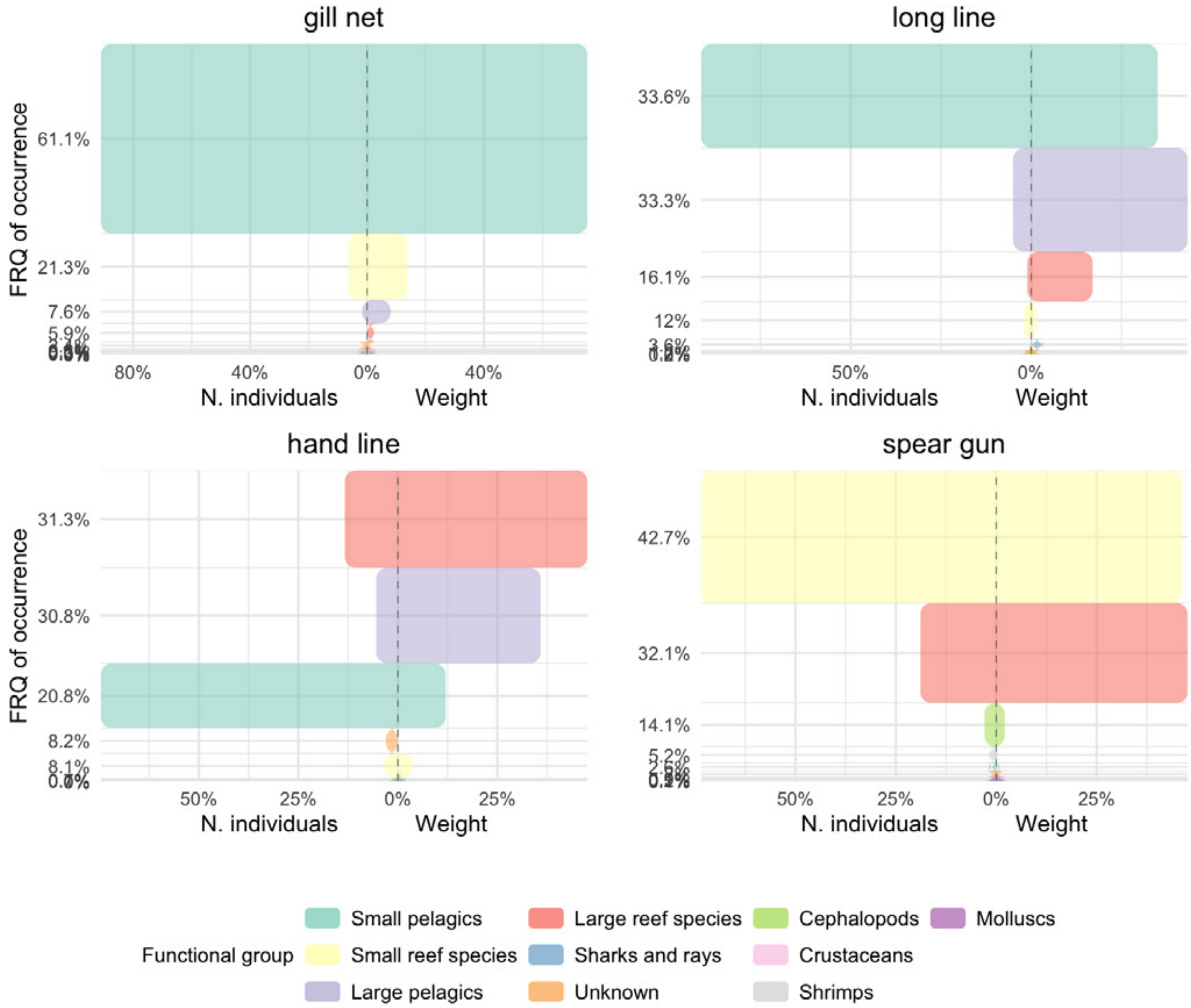


Note: A total of 24,064 fishing trips for Atauro, 27,574 for the north coast and 12,166 for the south coast. The IRI considers the weight, the number and the frequency of occurrence (%FRQ) of a functional group.

Figure 11. Catch composition using the %IRI of the landings (January 2018 to December 2021).

4.5.2. Catch composition by gear type

This section presents information on the composition of catches according to each gear type.

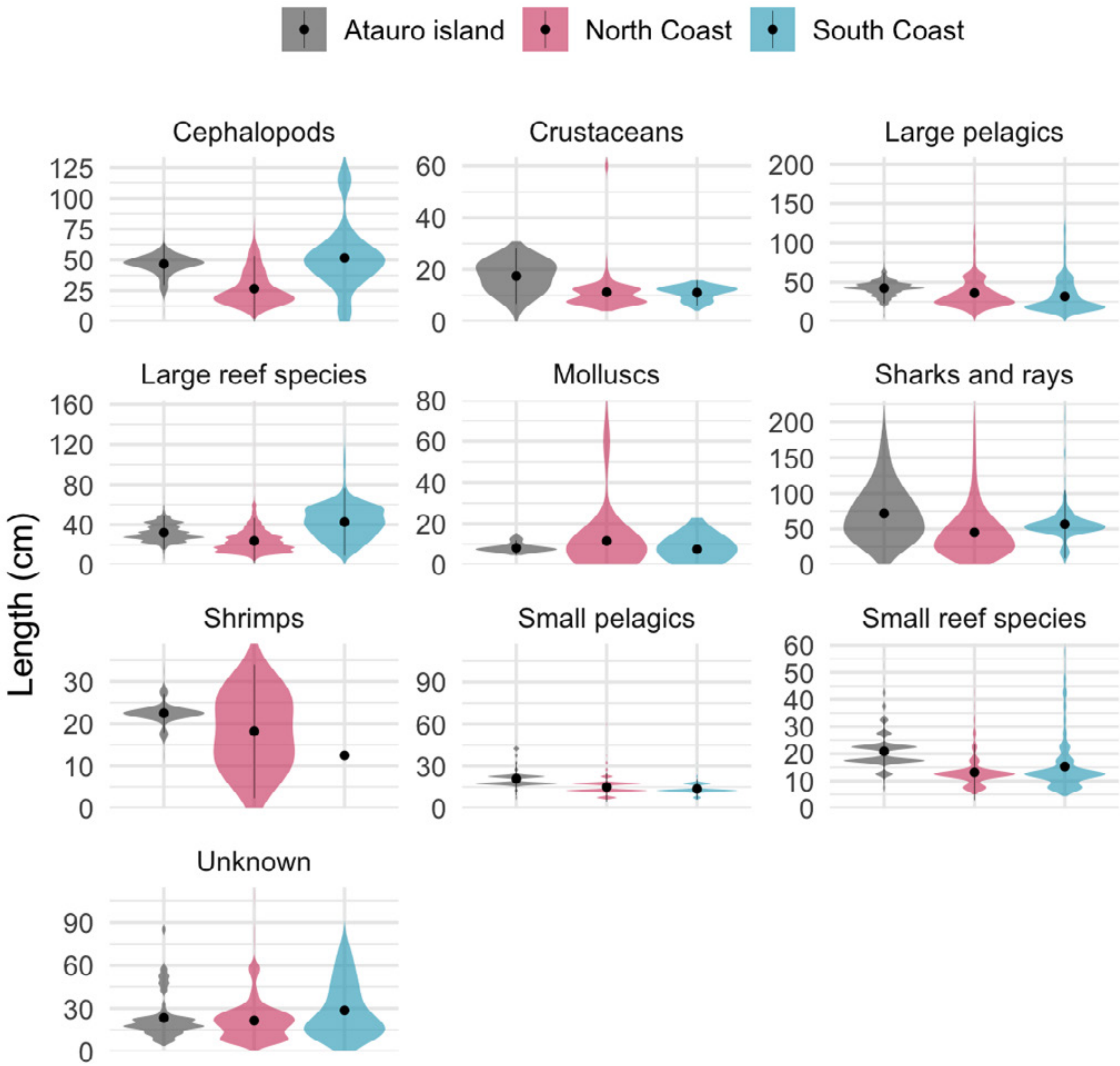


Note: The IRI considers the weight, the number and the frequency of occurrence (%FRQ) of a functional group.

Figure 12. Catch composition using the %IRI of the landings by gear type (January 2018 to December 2021).

4.5.3. Length composition of functional groups

The small pelagics, reef species, and the cephalopods caught on Atauro appear to be marginally bigger than on the north and south coasts, whereas the large reef species caught on the south coast seem slightly bigger than on Atauro and the north coast (Figure 13).



Note: Violin plots of the length (cm) of the catch for every functional group. The y-axis has free scaling for every functional group. The dot represents the median and the variance bars the first and third quartile.

Figure 13. Length composition of the functional groups.

4.6. Total monthly landings

The monthly total catch was estimated by multiplying the average catch per trip by the average number of trips per boat and by the number of boats registered in each municipality. There is no data available on the number of registered vessels per year, so estimates are based on an assumption that the total number of boats remains constant within each area throughout the sampling period.

The estimated total monthly landings (t) on the north coast are generally higher and with more peaks than on Atauro and the south coast (Figure 14a). These peaks can also be seen in north coast CPUE trends and could illustrate windfall catches of sardines, which are seasonal and the primary species of small pelagics caught on the north coast. These fish often migrate in large schools, which can result in big catch rates if one comes across such a school (Hunnam et al. 2021). This assumption is strengthened by high catches occurring during the wet season, when sardines are mostly present (Hunnam et al. 2021). The use of fish aggregating devices could also play a role in the fluctuations, as fishing near one increases the chances of encountering big schools of pelagic fishes (Tilley et al. 2019).

Landings appear to increase over time on Atauro up until the COVID-19 lockdown, which reflects the trend seen in the CPUE also (Figure 14b).

Note: The regions are plotted (a) together in one plot and (b) separately, where the y axis has free scaling. Bold lines and shaded areas represent the local polynomial regression with 95% confidence interval. The gray shaded area defines the COVID-19 pandemic period, starting from the lockdown on March 28, 2020.

Figure 14. Estimate of the total monthly catch (January 2018 to December 2021).

4.7. Seasonality

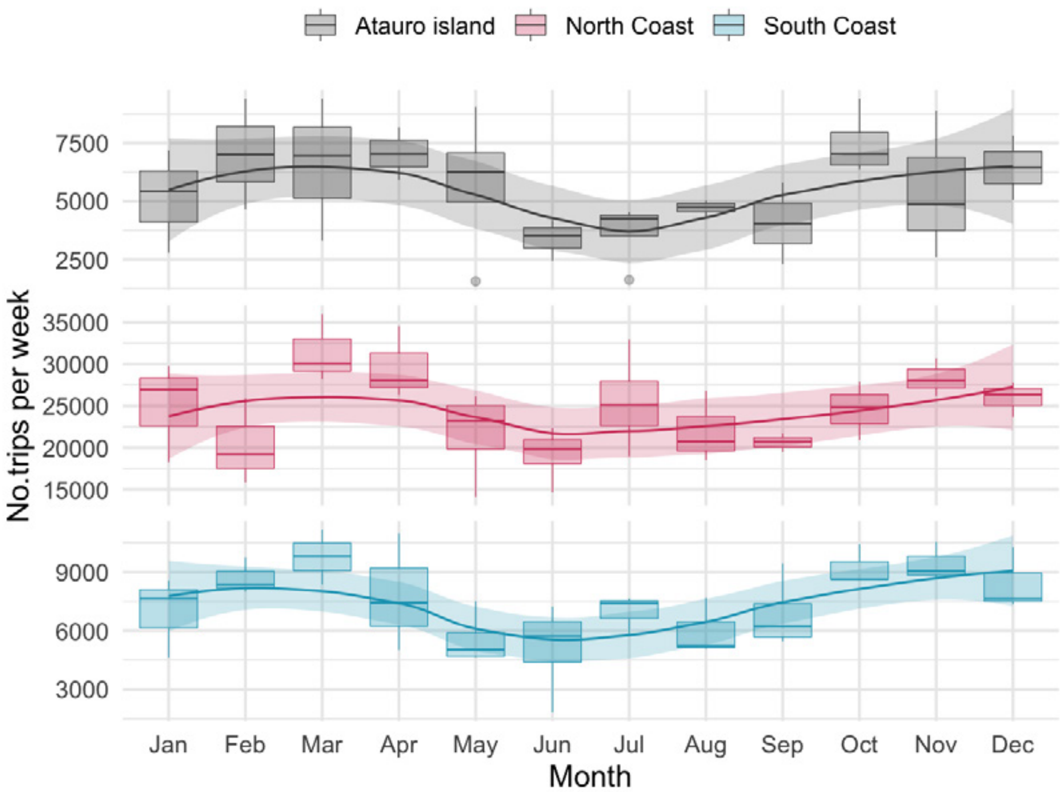
A pattern of seasonality is observed for the total number of trips taken per month as well as for the total monthly landings in all three regions (Figures 15 and 16). The fishing activity decreases around April and increases again in August, reaching a peak in December to February.

This pattern of seasonality is likely a result of the weather conditions, as well as the diverse livelihoods of most Timorese households. The fishers on the south coast make fewer trips when the seas are at their roughest, from April to August/September (Tomascik 1997). The seasonality in fishing activity seen on Atauro is in line with the findings of Mills et al. (2017), who found that there was reduced fishing activity in July and the months around August because of the rough seas caused by the southeasterly monsoon.

Fishing is for many households not their only or even primary source of income (Mills et al. 2013). Instead, the vast majority stated that crops and livestock were their main economic activity (Mills et al. 2013). It would therefore be reasonable to assume that the seasonality of agricultural activities has an influence on fishing activity. The harvests for the two primary crops, maize and rice, happens from February to April and April to July (FAO 2021). The period with the highest food insecurity is in the months before the harvests, which is also when we see the highest fishing activity on the mainland (Gorton 2018). On Atauro, however, the fishing culture is stronger, and up to half of fishers consider fishing to be their main livelihood (Mills et al. 2017).

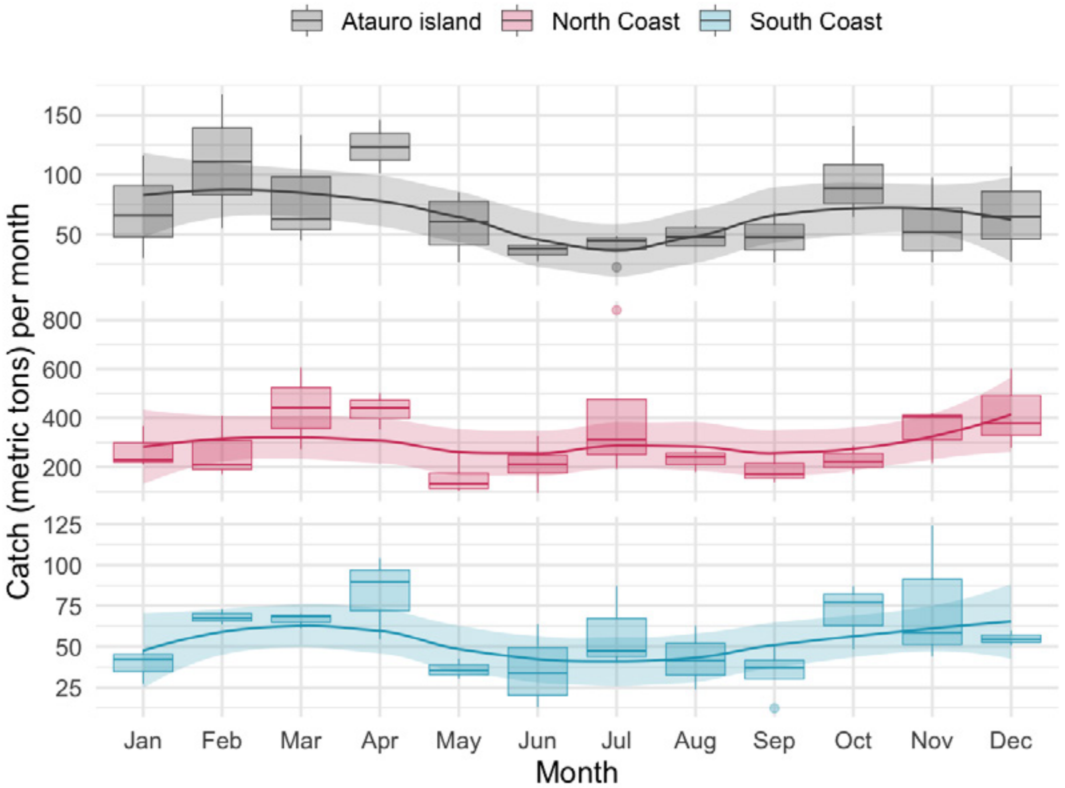
4.8. Total monthly landings by municipality

The municipalities with relatively high fish production are Atauro, Baucau, Lautém, Bobonaro and Manatuto (Figure 17). The municipalities with relatively low fish production are Ainaro, Covalima, Dili (without Atauro) and Manufahi.



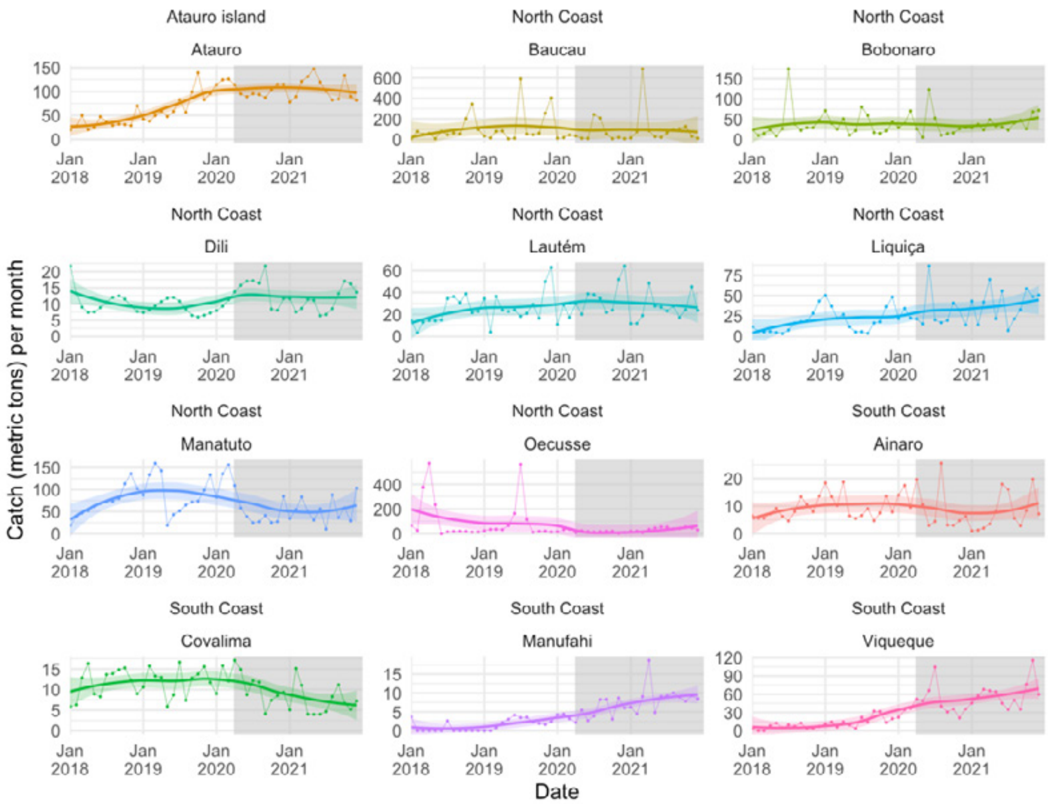
Note: Box plots of the estimated number of trips per month (2018–2021). The y-axis has a free scale for each region. The shaded areas represent the 95% confidence interval, the lines local polynomial regression fitted to the data.

Figure 15. Seasonality of trips per month.



Note: Box plots of the estimated total catch (t) for every month (2018–2021). The y-axis has a free scale for each region. The shaded areas represent the 95% confidence interval, the lines local polynomial regression fitted to the data.

Figure 16. Seasonality of total monthly catch.



Note: Bold lines and shaded areas represent the local polynomial regression with 95% confidence interval. The gray shaded area defines the COVID-19 pandemic period, starting from the lockdown on March 28, 2020.

Figure 17. Estimate of the total monthly catch for the 12 municipalities (January 2018 to December 2021).

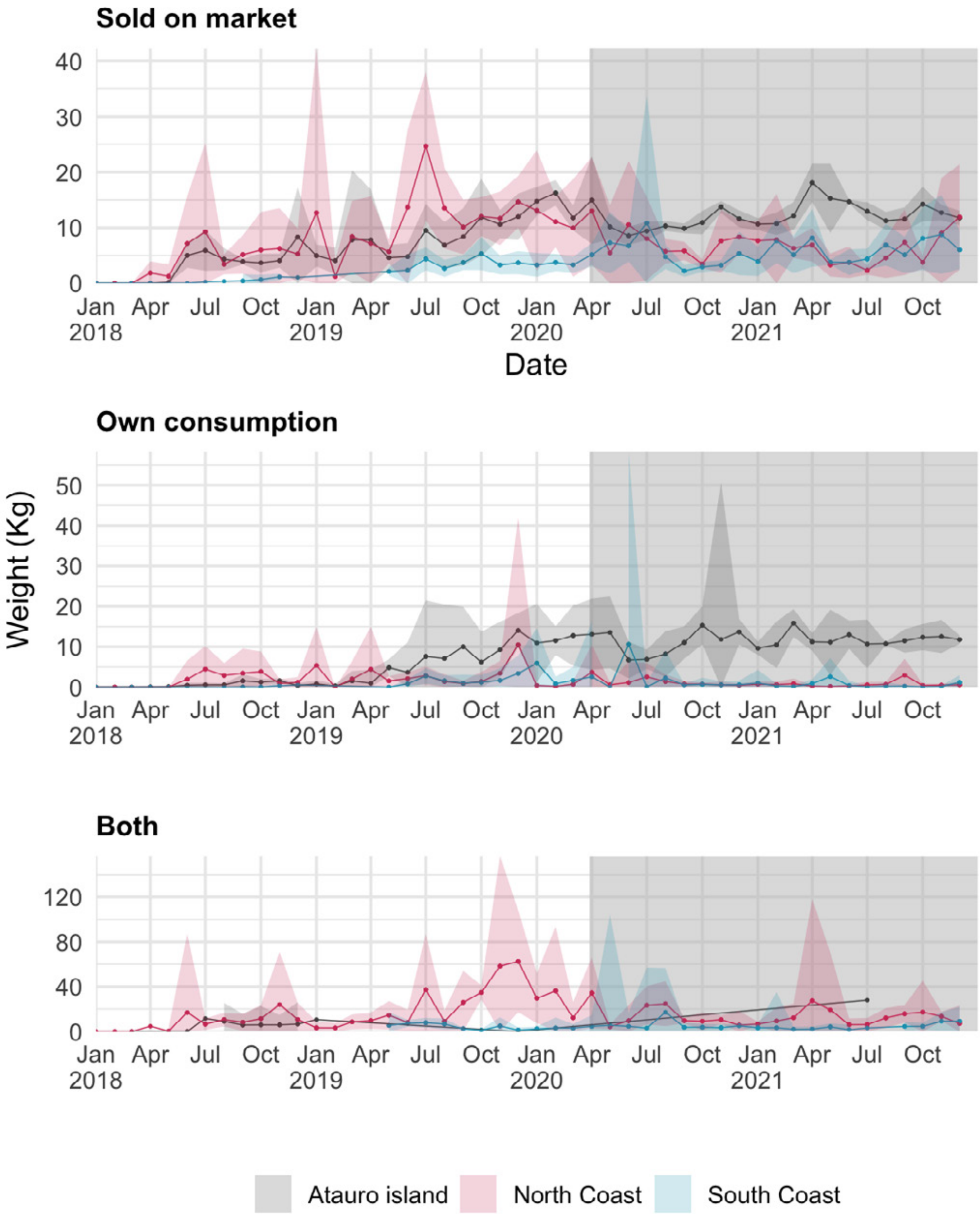
5. Market

5.1. Fisheries catch usage

When interpreting the data of the catch and the anticipated market value, it is important to keep in mind that the information is acquired before the first point of sale. This means the fisher is stating the price that they intend to sell it for based on experience and current (informal) market price information. It is a prediction made by the fisher and does not necessarily align with actual values received. An assumption we make is that a fisher will gradually adjust their price prediction based on recent sales, and it will not be purely aspirational. Fish catch is usually sold on the nearest main road to the landing site, on the water (e.g. to Indonesian fishers/traders) or to a local trader, who then transports and sells the fish at the market (Plate 9) (Población 2013). Selling catch to traders is the safest option, though it is less profitable than if sold directly to consumers. Fishers will try to sell as much of their catch as they can and keep what is left for household consumption or for sharing and bartering.

According to statements from fishers, on average 94.2% of the sampled catch on Atauro is sold at the market, 5.5% is kept for own consumption and 0.3% is deemed to be partially sold and partially kept. On the north coast, 53% goes to the market, 2.7% is used for own consumption and 44.3% is both. On the south coast, 90.6% is sold on the market, 1.9% is kept for own consumption and 7.5% is both. In the long term, market sales have shown a slight increase in all the regions, especially Atauro, whereas own consumption trends were quite stable in all the regions (Figure 18).

Plate 9. Fishers and traders selling their fish directly from the boat (a), on the road (b), at the market (c), on the beach (d) and by motorbike (e).

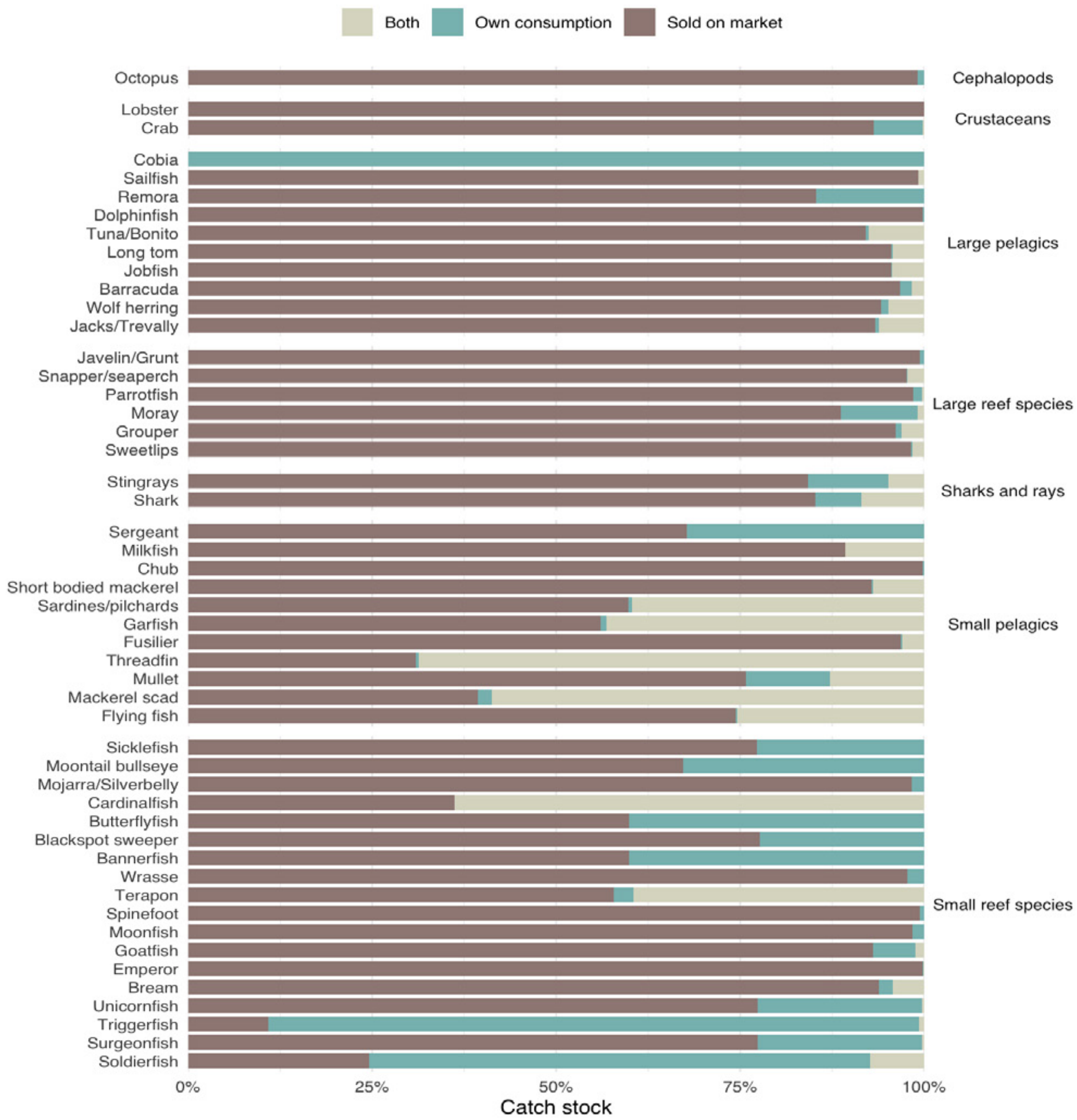


Note: The shaded areas around the time series represent the 95% confidence interval. The lines are the local polynomial regression. The gray shaded area defines the COVID-19 pandemic period, starting from the lockdown on March 28, 2020. The y-axis has free scaling.

Figure 18. Destination of catch over time in mean weight per week of the sampled catch (January 2018 to December 2021).

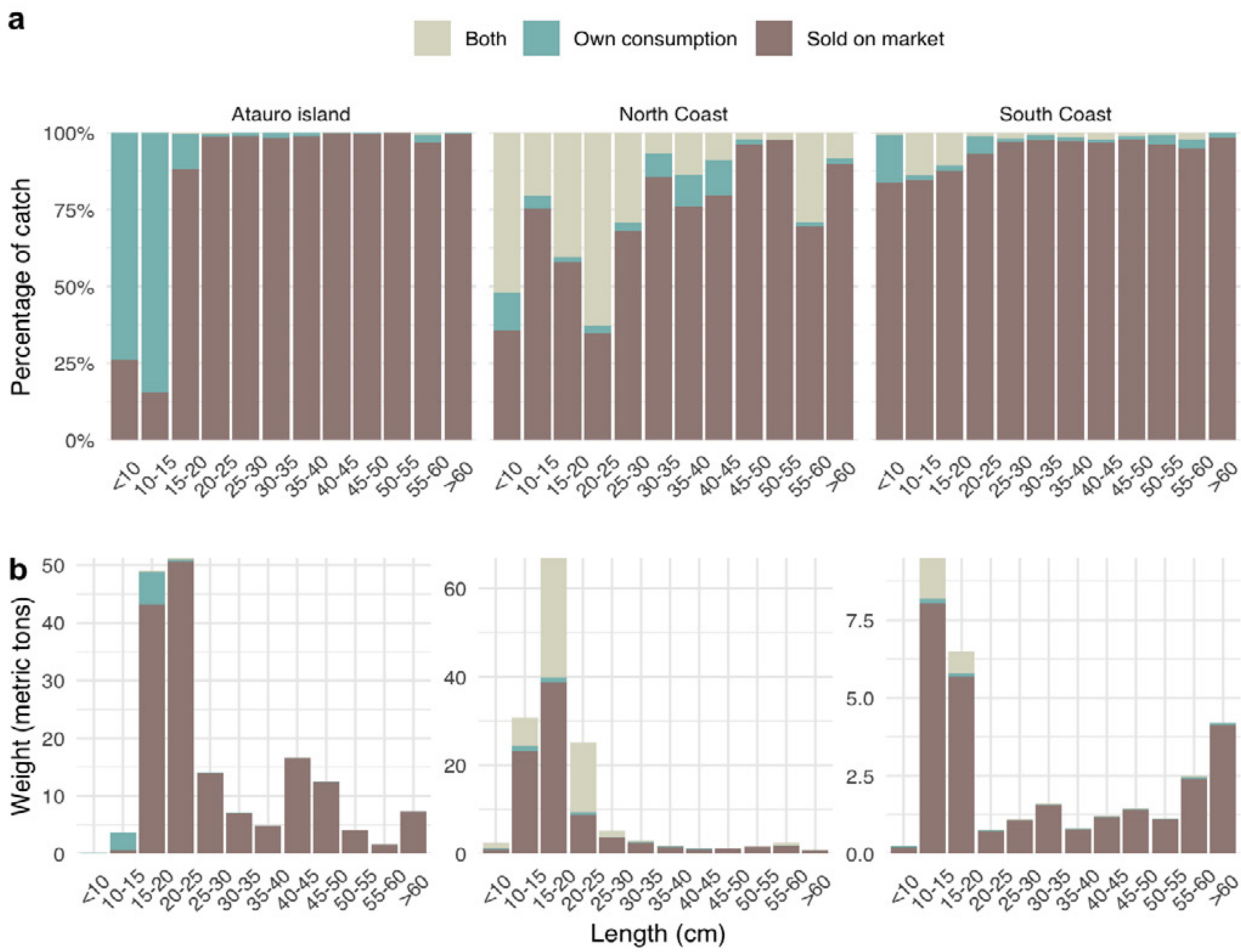
An interesting difference between the regions is that a large part of the catch on the north coast is documented as being partially used for own consumption as well as partially being sold. Although this is likely also the case on Atauro and the south coast, it is not being documented in the same manner. Why there is this difference in documenting between the regions is not clear. It could be that fishers on the north coast are more realistic with the outcome of their sales, or that fishers from Atauro and the south coast have a better understanding of which fish will sell and which will not and therefore can be more precise in their answers. It could also be because of a difference in the nuance of the question asked by the enumerators.

Most of the fish being kept for own consumption are smaller fish of large species and small fish species, with some exceptions, such as the cobia (*Rachycentron canadum*) and the moray eel (*Gymnothorax* spp.) (Figures 19 and 20). Large fish and fish species are often easier to sell, as they are in demand by the restaurants and the urban population (Venugopa and Shahidi 1995).



Note: The y-axis shows individual species grouped by functional group, and the x-axis shows the percentage of the catch in weight (kg).

Figure 19. Bar plot of the destination of the catch per species.



Note: (a) Percentage of the catch and (b) weight (kg) of the catch versus the size (cm) of the fish caught. The catch is divided into 12 length groups.

Figure 20. Bar plot of the destination of the catch per length groups.

5.2. Market value of catch

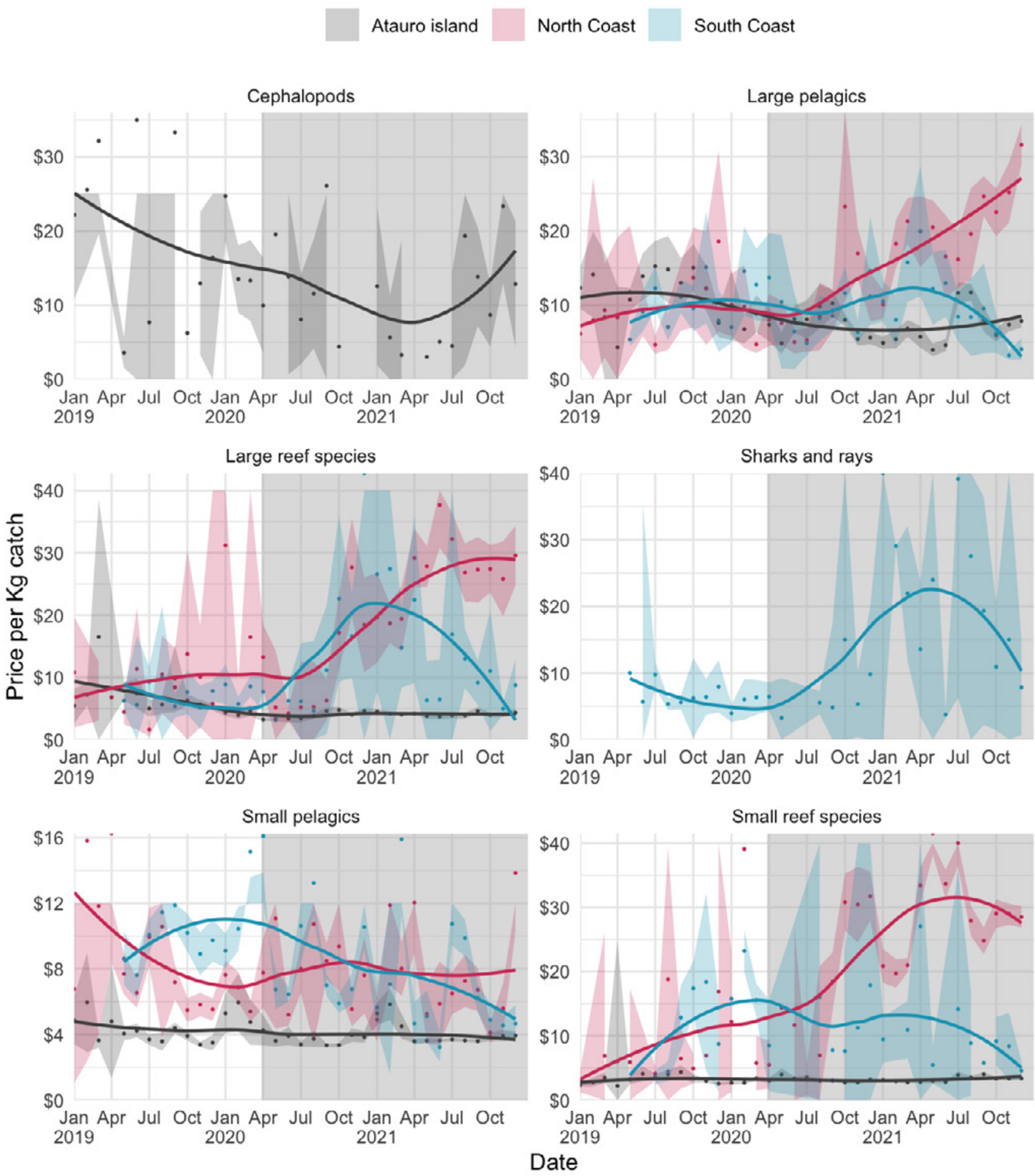
To analyze the market value of the catch, we looked at the subset of catches that were stated by the fisher as being "for sale."

In the PeskAAS dataset, the market value of the total catch is estimated by fishers, not the value per species. So to be able to estimate the market value per functional group, the data was filtered to only include trips where the catch consisted of a single fish species (77.23% of total trips).

Size appeared to drive price to a certain extent, as large pelagic and reef species yielded the highest price (USD) per kilogram of the different functional groups (Figure 21), followed by small pelagics and reef species. The lowest priced items were sharks and cephalopods. A consistent positive trend in price per kilogram is evident in the north coast, for both the reef species and the large pelagics.

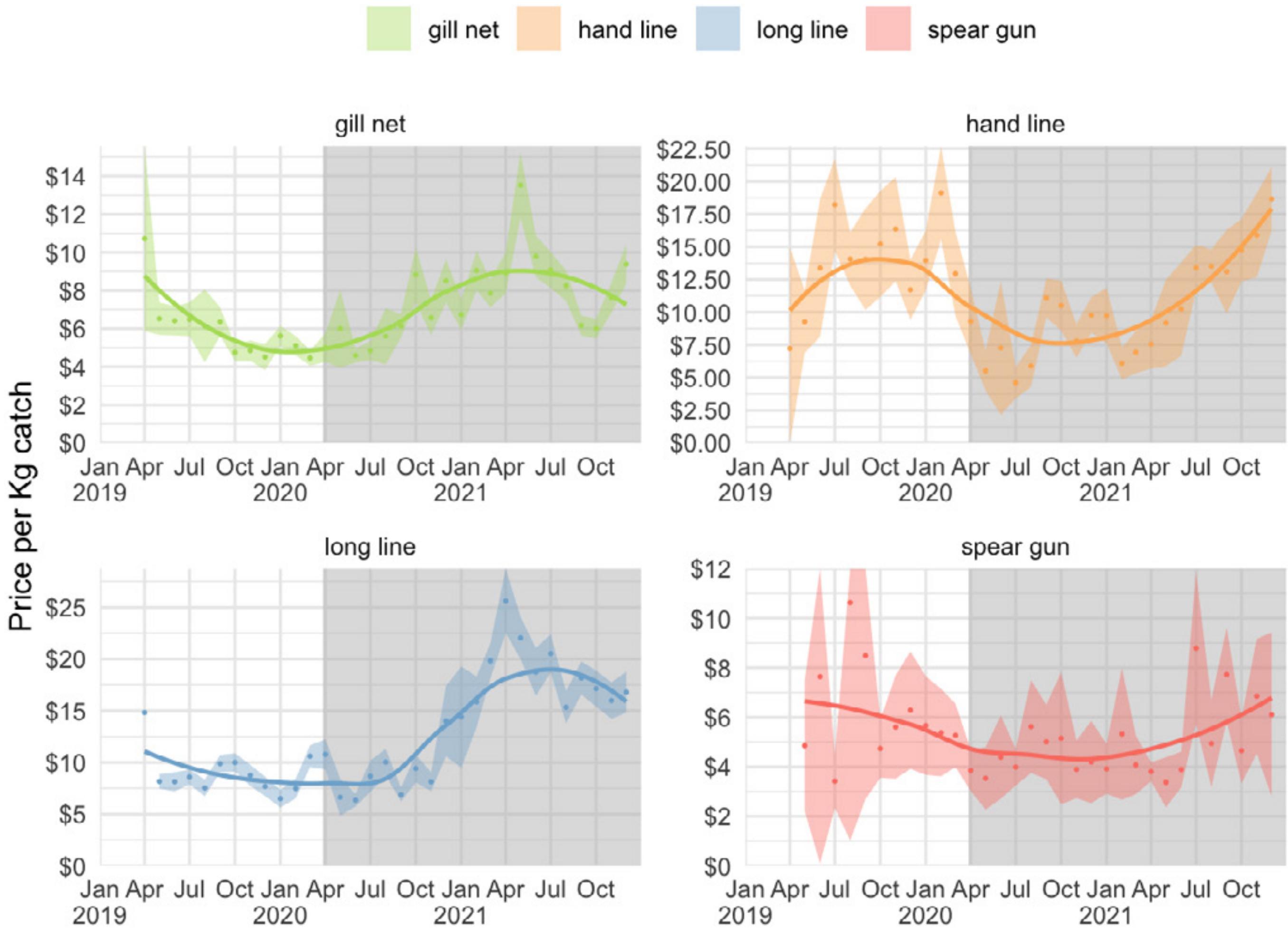
The catch from hand line fishing appears to yield the highest price (USD) per kilogram of the different gear types, followed by long lines (Figure 22). Gill nets and spear guns generate the lowest price per kilogram. This corroborates the price-size relationship, given that most large pelagic and reef species will be caught on hooks.

The high value of large fish is interesting, because in poor, rural areas smaller fish are often more sought-after for various reasons, but predominantly because they can be bought for less money and are less wasteful when cold storage is limited or unavailable. When very large fish are landed, the fisher or trader might cut up the fish into smaller pieces to increase the chance of selling it. The high value of large fish stated by fishers could be a reflection of this, and not necessarily imply that large fish are purchased whole, in single transactions.



Note: The shaded areas around the time series represent the 95% confidence interval. The lines are the local polynomial regression. The gray shaded area defines the COVID-19 pandemic period, starting from the lockdown on March 28, 2020. The y-axis has free scaling for every functional group.

Figure 21. Mean market value (USD) per kilogram of the catch of the most frequently caught functional groups (January 2019 to December 2021).



Note: The shaded areas around the time series represent the 95% confidence interval. The lines are the local polynomial regression. The gray shaded area defines the COVID-19 pandemic period, starting from the lockdown on March 28, 2020. The y-axis has free scaling for every gear type. No available data prior to April 2019.

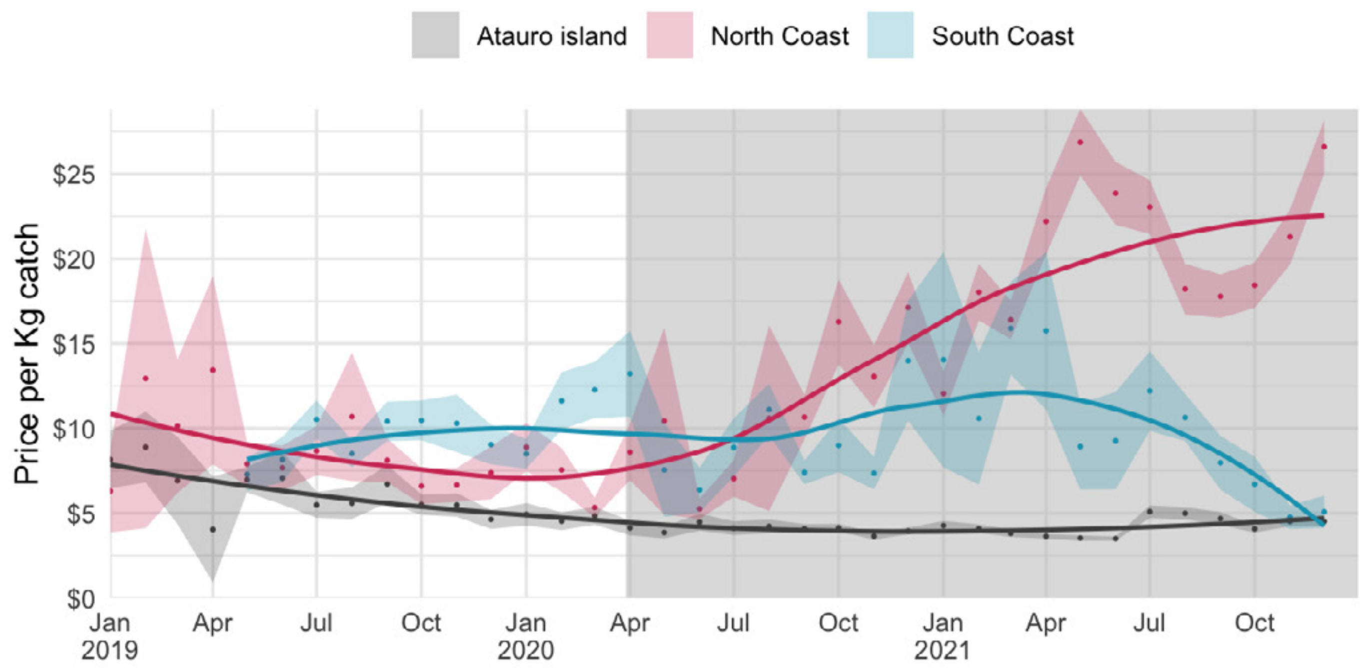
Figure 22. Mean market value (USD) per kilogram of the catch by gear type (April 2019 to December 2021).

The low and steady price structure of the Atauro market (Figure 24) likely reflects one of three possibilities: (1) the lack of market information available to fishers, meaning they do not know how much their fish are worth elsewhere, (2) higher relative competition between fishers on Atauro compared to mainland coastal communities because of the higher density of fishers and fewer markets, and (3) lower purchasing power by local consumers, as people on Atauro are generally more isolated from paid employment opportunities and so have a lower cash flow relative to the mainland.

On the north coast, a consistent positive trend in price per kilogram is evident (Figure 24), involving both reef fish and large pelagic fish. This is consistent with the growing population and relative wealth in Dili, the increased availability of fish, and potentially an increased awareness of the health benefits of eating fish through externally funded behavior change campaigns (Tilley et al. 2022).

Before COVID-19, the price per kilogram of catch was slightly higher on the south coast, followed by the north coast and lastly Atauro (Figure 24). This could possibly be because the south coast is home to larger fish species, which yield a higher price per kilogram. However, this is still somewhat counterintuitive. The south coast has poorer infrastructure and is located farther from the places with high demand, such as Dili, so the traders likely pay less as they need to compensate for the costs of transporting and storing the produce (Población 2013). This is also the case for Atauro. While fish from the island have a higher standing among the Dili-based middle class (Mills et al. 2017), the fish still need to be transported and sold through traders, resulting in a lower value for fishers. Dili-based fishers appear to sell their fish for the highest price compared to other municipalities, which strengthens the theory that value is lost in transportation and trading (Figure 24). However, the regions might not be easily comparable, as there have been differences in how the PeskAAS enumerators record the pricing between the areas, and over time. Lastly, there is additional uncertainty in asking fishers the value of their fish, as their responses could be aspirational and optimistic rather than based on recent market prices.

During COVID-19, both the north and south coasts had a consistent increase in the price per kilogram of catch. However, although the trend kept increasing in the north coast, the south coast showed a quick drop in the average price (Figure 24).



Note: The shaded areas around the time series represent the 95% confidence interval. The lines are the local polynomial regression. The gray shaded area defines the COVID-19 pandemic period, starting from the lockdown on March 28, 2020.

Figure 23. Mean market value (USD) per kilogram of the catch (January 2019 to December 2021).

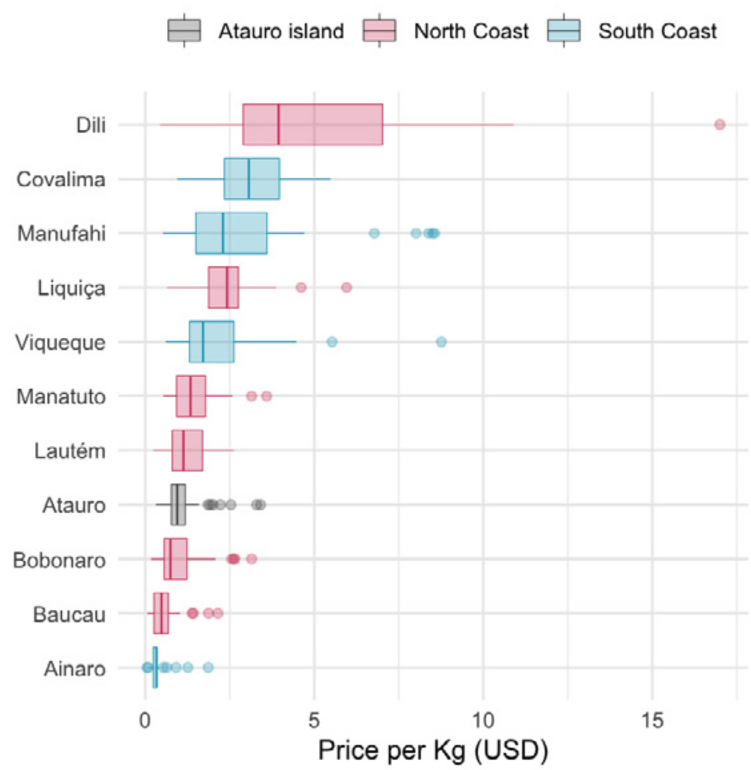


Figure 24. Mean market value (USD) per kilogram of the catch by municipality (January 2019 to December 2021).

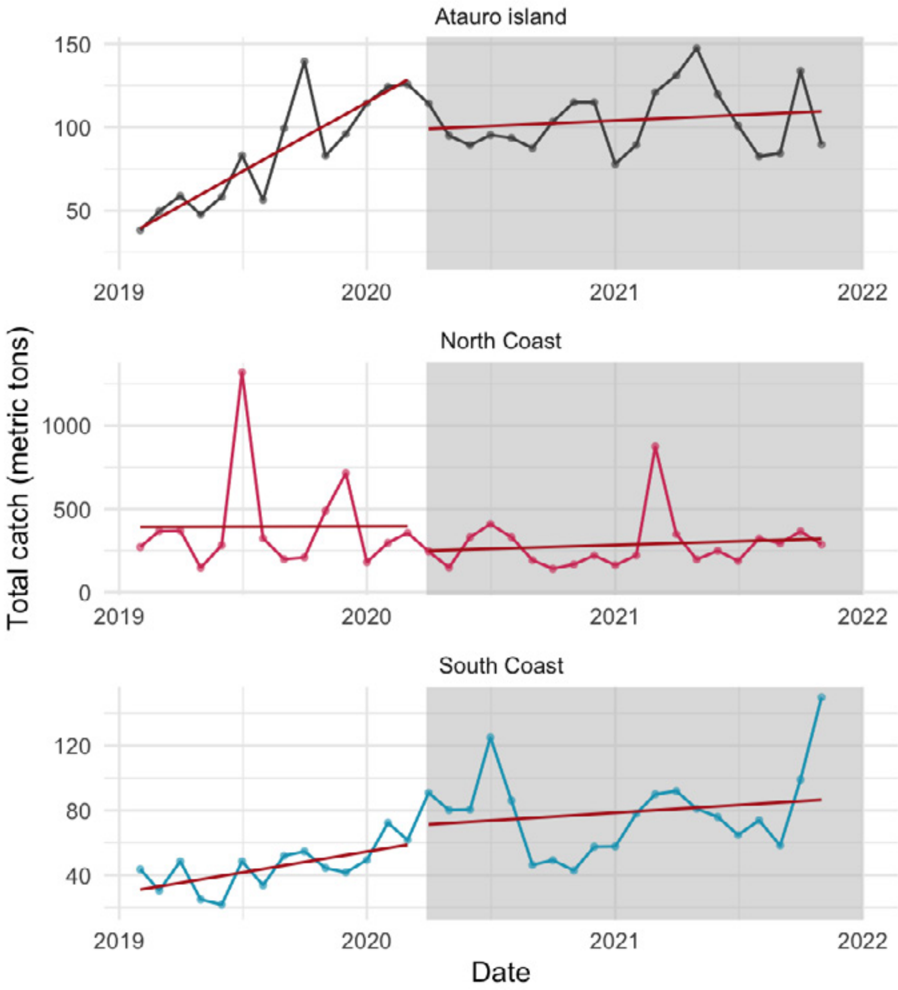
6. COVID-19

The global COVID-19 pandemic has had substantial economic, social and health impacts on the entire world (World Bank 2020a; WTO 2020). While most SIDS benefit from a remote location, which can delay and limit the spread of COVID-19, this also implies that foreign assistance during the crisis will be more problematic (Filho et al. 2020). Furthermore, foreign aid and tourism, which can be a vital part for the economy and well-being of SIDS, have dwindled because of international travel and trade restrictions (Feeny and McGillivray 2010; Pratt 2015; Filho et al. 2020). Considering the crucial role of SSF as a source of food and income in SIDS (Kelleher 2012), it is imperative to know how the pandemic and associated domestic and international movement restrictions have impacted these fishing communities and their activities.

In Timor-Leste, we observed a significant reduction of the total catch in Atauro (Figure 25 and Table 3), with COVID restrictions being responsible for a decrease of 30.26 t of fish immediately after the lockdown, and a month-by-month reduction of 6.33 t relative to pre-COVID-19 conditions.

Area	Term	Estimate	Pvalue
Atauro island	Trend before lockdown	6.891	>0.001 ***
	Lockdown effect	-30.26	0.026 *
	Trend after lockdown	-6.33	>0.001 ***
North coast	Trend before lockdown	0.3996	0.98
	Lockdown effect	-152.1	0.356
	Trend after lockdown	3.375	0.853
South coast	Trend before lockdown	2.128	0.146
	Lockdown effect	11.86	0.429
	Trend after lockdown	-1.328	0.428

Table 3. Interrupted time series analysis (ITS) of the total catch per month (January 2019 and December 2021).



Note: The gray shaded area defines the COVID-19 pandemic period, starting from the lockdown on March 28, 2020. The red lines represent linear regressions split by the beginning COVID-19 restrictions.

Figure 25. Monthly time series of the total catch (January 2019 to December 2021).

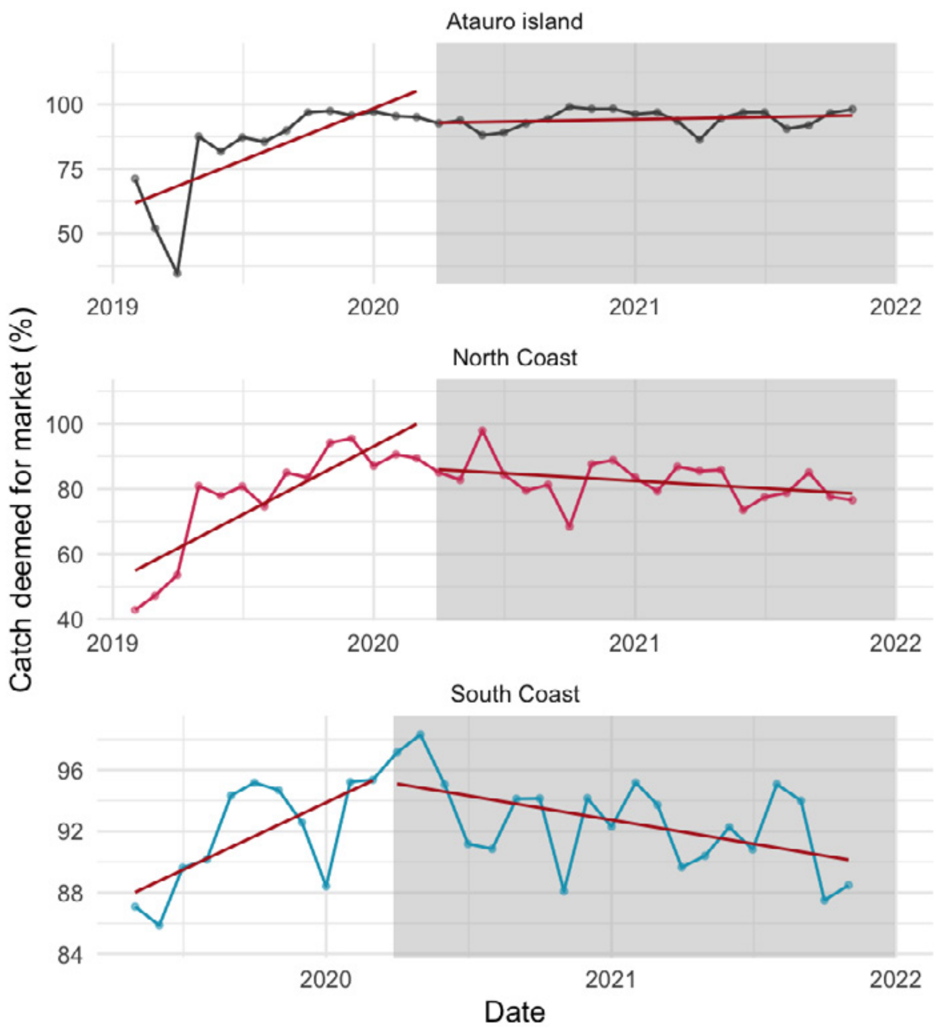
Overall, the proportion of catches deemed for sale by fishers decreased after the COVID-19 restrictions (Figure 26 and Table 4). On the north coast, from April 2020, there was an immediate drop of 13.7% of fish deemed to market. In Atauro, this was 11.8%. In contrast, the restrictions did not seem to affect south coast fish sales, perhaps because of poor road infrastructure and the traditional reliance on more localized market networks. When comparing pre- and post-COVID periods up until December 2021, all three areas experienced a decrease in the catch deemed for the market over the longer term, about 3.5% for the north coast and Atauro and 1% for the south coast.

The most apparent impact of the COVID-19 pandemic in the PeskAAS dataset appears to be on the market value of the fish. As an immediate effect, COVID-19 restrictions led to decreases in all areas, though not significant (Figure 27 and Table 5). Comparing pre- and post-COVID periods, across the entire data timeline, there was a significant decrease in fish value in the north coast and Atauro, but the south coast remained level. The north coast recorded a per month decrease of USD 0.96 and Atauro a USD 0.25 drop. The combined effect of social distancing rules, working from home and movement restrictions between districts resulted in far fewer people at markets and roadside stalls. Furthermore, the tourism sector experienced a 95% decline in revenue because COVID-19, so many businesses depending on international travelers had to partially or completely close (Rajalingam et al. 2021). The fish favored by restaurants are often the larger species, and a collapse of the tourism sector is likely to affect the demand and thus the value of these fish. As such, Timor-Leste experienced an overall economic shock because of the pandemic and earlier political uncertainty. As a result, the country's gross domestic product (GDP) is expected to decrease 6.8%, leaving the local people with less money to spend (World Bank 2020b).

Area	Term	Estimate	Pvalue
	Trend before lockdown	3.188	>0.001 ***
Atauro island	Lockdown effect	-11.76	0.054 .
	Trend after lockdown	-3.042	>0.001 ***
	Trend before lockdown	3.487	>0.001 ***
North coast	Lockdown effect	-13.71	0.01 *
	Trend after lockdown	-3.869	>0.001 ***
	Trend before lockdown	0.7309	0.008 **
South coast	Lockdown effect	0.02715	0.989
	Trend after lockdown	-0.992	0.001 **

Note: Trend before lockdown refers to the indicator trend before the lockdown. Lockdown effect refers to the mean increase or decrease of the indicator immediately after the lockdown. Trend after lockdown refers to changes in the slope of the time series after the lockdown.

Table 4. ITS of the catch stated for sale (January 2019 to December 2021).



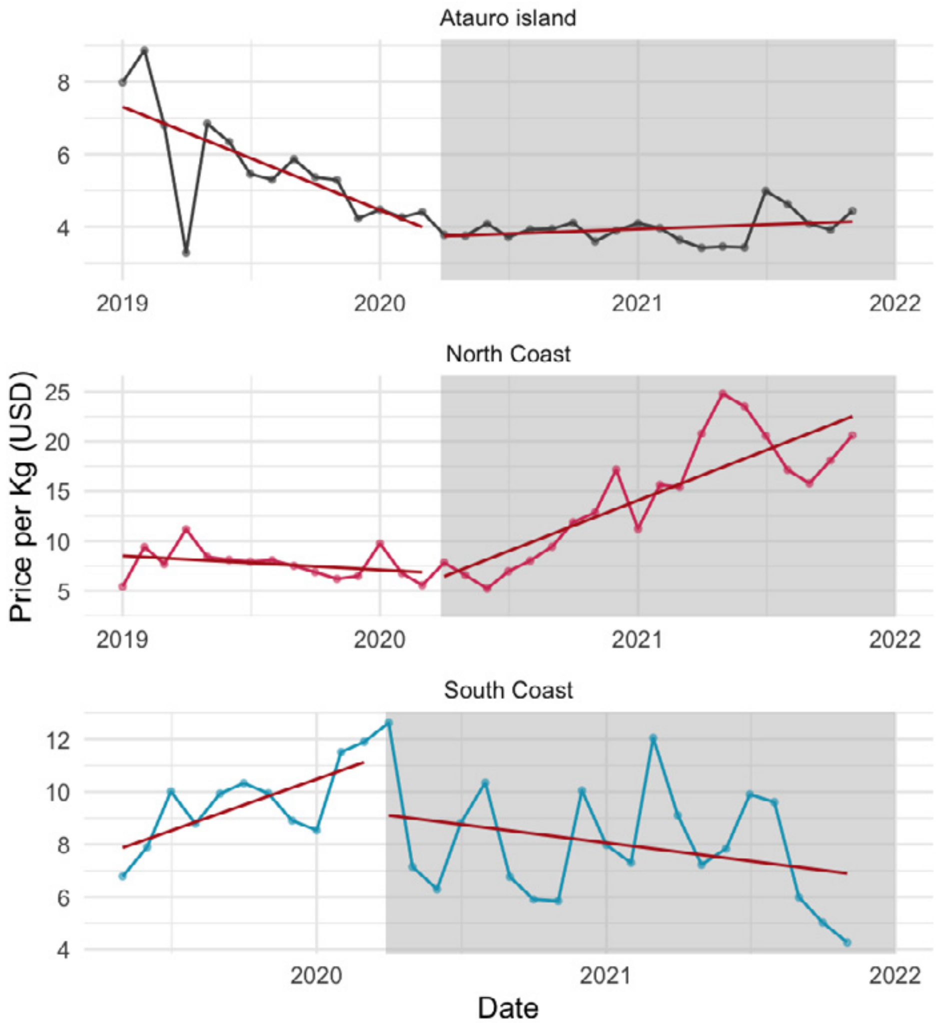
Note: The gray shaded area defines the COVID-19 pandemic period, starting from the lockdown on March 28, 2020. The red lines represent linear regressions split by the beginning of COVID-19 restrictions.

Figure 26. Monthly time series of the catch deemed for market (January 2019 to December 2021).

Area	Term	Estimate	Pvalue
	Trend before lockdown	-0.2381	>0.001 ***
Atauro Island	Lockdown effect	-0.2606	0.623
	Trend after lockdown	0.2591	>0.001 ***
	Trend before lockdown	-0.1167	0.476
North coast	Lockdown effect	-1.27	0.493
	Trend after lockdown	0.9621	>0.001 ***
	Trend before lockdown	0.3264	0.087 .
South coast	Lockdown effect	-1.92	0.184
	Trend after lockdown	-0.4418	0.034 *

Note: Trend before lockdown refers to the indicator trend before the lockdown. Lockdown effect refers to the mean increase or decrease of the indicator immediately after the lockdown. Trend after lockdown refers to changes in the slope of the time series after the lockdown.

Table 5. ITS of the catch price (January 2019 and December 2021).



Note: The gray shaded area defines the COVID-19 pandemic period, starting from the lockdown on March 28, 2020. The red lines represent linear regressions split by the beginning of COVID-19 restrictions. No available data prior to April 2019.

Figure 27. Monthly time series of the fish market value (January 2019 to December 2021).

The pandemic and the resulting lockdown do not appear to have had as large an impact on the fisheries of Timor-Leste as they had on other SSF according to some studies, where the loss of revenue and decline in fishing activity has been substantial (Bennett et al. 2020; Knight et al. 2020; Belton et al. 2021; Campbell et al. 2021; Ferrer et al. 2021; Fiorella et al. 2021; Mangubhai et al. 2021; Plagányi et al. 2021). This seems to suggest that fisheries are more resilient in Timor-Leste, which could be the result of the wholly domestic consumption of national capture fisheries and the continued reliance on traditional systems and largely informal transactions. Other SSF around the world lost a large part of their revenue because of the disruption of the international export market and the global supply chains (Knight et al. 2020; Belton et al. 2021; Plagányi 2021). This will not have affected the fisheries of Timor-Leste in a similar manner, as fish are almost entirely consumed domestically, with only minimal export of seaweed and some informal trade with Indonesia (Barbosa and Booth 2009). Furthermore, while COVID-19 had substantial impacts on the tourism in the country, the sector itself accounts only for 0.5% of the GDP, whereas in 40% of SIDS it accounts for more than 20% (UNWTO 2013; Rajalingam et al. 2020).

In most literature cases reported, the decline in fisher incomes because of COVID-19 resulted in a decrease in their fishing effort, as the costs of continuing to fish (fuel, bait, ice) started to outweigh the diminishing revenue. This does not appear to be the case in Timor-Leste (Ferrer et al. 2021; Mangubhai et al. 2021). Another, more direct impact of the pandemic and the restrictions on the fishing activity of most small-scale fishers is the required social distancing and the fear of catching the virus (Okyere et al. 2020; Mangubhai et al. 2021). Many fishers had to restrict the size of their crew to be able to maintain the necessary distance on the boat, resulting in a decrease in overall effort (Mangubhai et al. 2021). Landing sites are often crowded, and it is difficult to keep 2 m apart from one another during the landing of the fish (Okyere et al. 2020). The fear of getting sick, which is a genuine concern for many in developing countries where healthcare is poor, causes some fishers to stop fishing altogether (Lau et al. 2020). However, the Timor-Leste fishing fleet is predominantly one- or two-person canoes or small motorboats (López-Angarita 2019), and crews are often from the same household or family, so these restrictions are unlikely to have affected them as much.

SSF are often considered to be a buffer or a safety net against income shocks, in their role as supplier of high-nutrient low-cost food for lower-income consumers and as a labor buffer (Béné et al. 2010). Most SSF, especially those in low-income countries, have low entry costs, and result in limited assets being tied up in fishing (Allison and Ellis 2001), which gives individuals more opportunity to move in and out of fishing activity at various periods in their lives (Jul Larsen et al. 2003). During the pandemic, Timor-Leste experienced greater food insecurity than during other years, partially because of the associated restrictions and partially from droughts and crop pests (MAF et al. 2020). So it could be expected that households engaging in both fishing and agriculture would turn more to fishing when the crops are poor. This is reinforced by the fact that people felt that agricultural activities were more affected by the restrictions than fishing activities (MAF et al. 2020).

Conclusions

6.1. Limitations

This report is the first detailed analysis of the data collected by the PeskAAS monitoring system in Timor-Leste. There are various automatic and manual validation and data flagging steps incorporated as part of the PeskAAS workflow (Longobardi et al. 2021), and additional statistical and manual checking for specific analyses undertaken. However, because of the nature of the collection system (field based enumerators and fisher reporting), some errors might still be present. Furthermore, as a result of the continued development of the PeskAAS system over time with government partners, there were fewer enumerators and vessel trackers initially. As such, the number of records in the first year is low relative to later years, making outliers more prevalent and trends harder to determine.

Some of the trends seen in the results could also be caused by sampling bias. All the recorded information, except for what comes from the PDS trackers, is based on choices and estimations made by the fishers and the enumerators. If there is not a clear protocol and uniform routine on how to sample the data, then this will likely result in biases between the stations. The choice on which fishing trips are sampled is also likely to include inherent bias, as enumerators will prefer to work with fishers that they know are reliable and cooperative. The accuracy of the records should, however, have increased over time because of training and experience.

6.2. Further research

Over the past decade there has been a substantial rise in interest in SSF, with research and conservation efforts focused on protecting or restoring the critical nutritional and livelihood role they have in rural coastal and inland communities. As the International Year of Artisanal Fisheries, 2022 is in some ways the culmination of this growth, and the emerging work on Illuminating Hidden Harvests (FAO et al. 2022) aims to visualize the currently undervalued and invisible effects and benefits of SSF. The informal nature of SSF, their geographical and economic isolation, and the sheer diversity of fisheries, contexts and cultures involved has historically made it a very data-poor sector (Kolding et al. 2014). However, cheaper and smaller and more environmentally rugged technologies have enabled real-time sampling of SSF even in hostile and corrosive marine environments. Furthermore, the development of open-source software allows for the rapid scaling and adaptation of tools and methods from one context to another. This data obtained from PeskAAS creates crucial environmental and social benchmarks for the Timor-Leste fisheries sector, and provides decision-makers with information to support accountable management policies in the fisheries sector.

This report only describes and analyzes a part of the fishery in Timor-Leste. PeskAAS includes large amounts of information that were not included in the analysis for this report. Recently, a new nutritional dashboard was included into PeskAAS that visualizes the potential contribution of fisheries catches to recommended daily intakes of six important micronutrients and fatty acids (Iron, Zinc, Calcium, Selenium Omega-3 fatty acids and vitamin A) based on models developed by Hicks et al. (2019). Further research is underway to explore management mechanisms to incorporate nutrition information into fisheries decision-making, such as developing stock assessment models from length-frequency information for key species identified as important in Timor-Leste fisheries, and for local nutrient yield.

6.3. Conclusion

This study is the first to provide a detailed description of the SSF of Timor-Leste. There are variations in the characteristics of the fisheries within the country, caused by social, cultural, economic, geographic and climate differences. The north coast is the wealthiest and most densely populated area. As such, fisheries there invest in more expensive fishing equipment and are responsible for most of the landed fish, primarily small pelagic species. The south coast presents a more rudimentary fishing fleet dominated by paddle canoes. It also experiences harsher and more variable weather conditions at sea without being well equipped against it, resulting in a discernible seasonal pattern of the fishing activity.

Fishing is usually not the main economic activity of households on the mainland, as a diversified economy with agriculture and livestock farming are the preferred occupations. Atauro has a stronger fishing culture, as more actors identify themselves primarily as fishers. Timorese fishers sell their catch locally, and what they cannot manage to trade they will keep for their own consumption or local distribution.

Compared to other comparable SIDS and their SSF, Timor-Leste appears to have been less affected by the impact of the COVID-19 pandemic. Fishing activities do not seem to have significantly changed, and the impact is mostly observed in the decline of the market value of the catches. However, the country does not rely on tourism and export as much as many other SSFs, which could explain the lesser impact. As the fisheries of Timor-Leste are being developed and promoted, attention should be given to preserving the resilience of the fisheries and creating safety nets for possible future crises so that food security will not be put in danger.

Although the PeskAAS software and monitoring program are still developing and improving, they contain a lot of information that has enabled a description and analysis of a previously little-known fishery. Timor-Leste is a pilot study area for a wider implementation of PeskAAS. Hopefully, this study can be used to further develop and improve the monitoring system so that it can be deployed in other countries to increase our knowledge of SSF around the world.

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