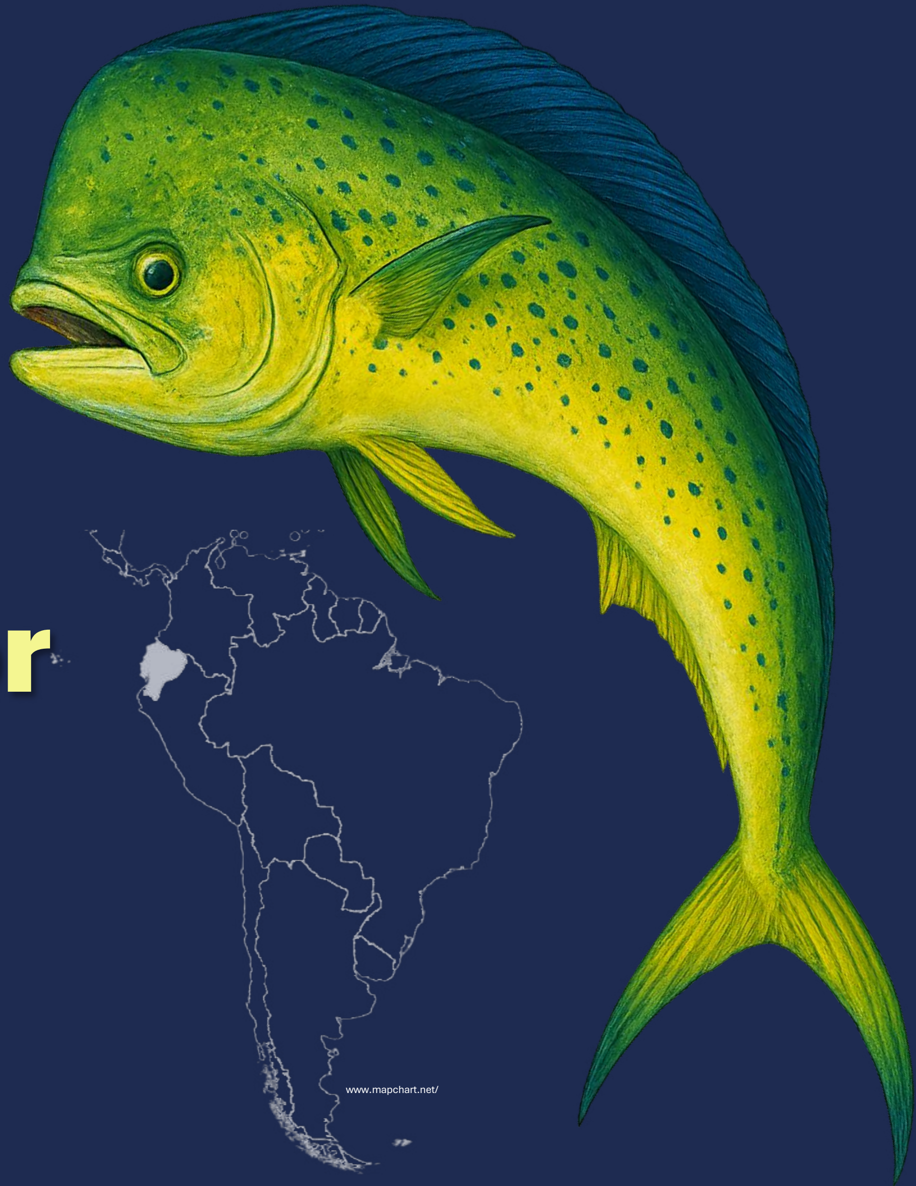
The mahi-mahi fishery in Ecuador

A socioeconomic analysis



Sustainable Fisheries Partnership • September 2025

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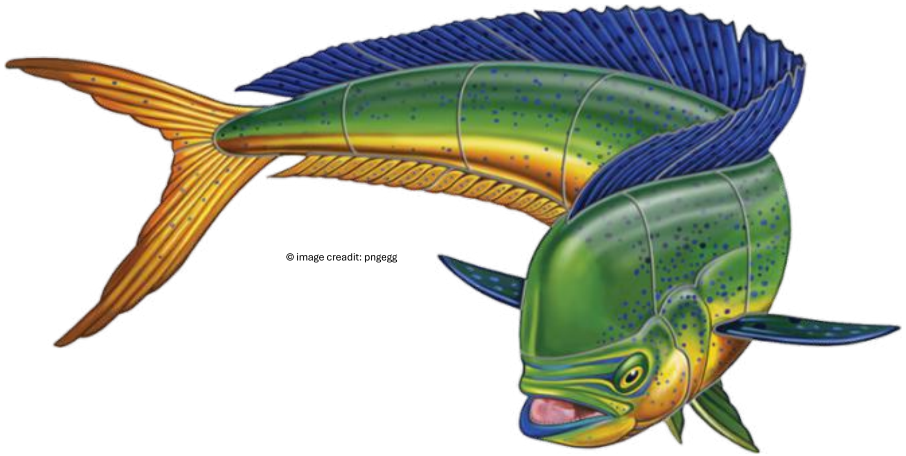

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KEYWORDS

Fishery; socioeconomic analysis; maximum sustainable yield; sustainability; Latin America; seafood trade; assessment; fisheries management; stock status

PREFERRED CITATION

SFP. 2025. The mahi-mahi (*Coryphaena hippurus*) fishery in Ecuador: a socioeconomic analysis. Sustainable Fisheries Partnership (SFP). September 2025. 47 pp.

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1 BACKGROUND

Mahi-mahi, or dolphinfish (*Coryphaena hippurus*), is a large, fast-growing pelagic species that inhabits offshore epipelagic waters worldwide. It is typically found near the surface in open ocean areas, often associated with floating objects or algae such as Sargassum. Mahi-mahi prefer warm waters between 20°C and 28°C and exhibit rapid growth and a short life span, with most individuals living no more than 4-5 years. Average adult sizes range from 5-15 kg, though specimens of up to 20 kg have been recorded. Although distributed globally, available data suggest mahi-mahi occur at higher densities in regions with strong oceanic currents, such as the Gulf of Mexico, the Caribbean Sea, the eastern tropical Pacific, and the western Indian Ocean, making it a key species in both commercial and recreational fisheries (Oxenford, 1999; Moltó et al., 2020; Merten et al., 2022; FAO, 2025a; Froese and Pauly, 2025).

In terms of its relevance as a seafood commodity, mahi-mahi represents a relatively small sector compared to major species such as tuna or whitefish. However, its importance in international markets has grown steadily in recent years. Global production and trade of mahi-mahi have increased over the past three decades, with current worldwide production estimated at approximately 120,000 tonnes and exports valued at over $70 million (FAO, 2024b; FAO, 2025b). The United States is by far the largest end market, accounting for more than 95% of the total mahi-mahi trade by value (FAO, 2024c). Given recent trends, catches are likely to stabilize at current levels or experience only modest growth.

Ecuador's mahi-mahi fishery is one of the country's most valuable seafood industries, supporting approximately 16,000 fishers and contributing significantly to both local livelihoods and the national economy (WWF-Ecuador, 2021). According to the FAO, landings over the past 15 years have ranged between 90,000 and 130,000 tonnes (FAO, 2015b), with the majority of exports destined for the United States (FAO, 2024c). Most catches originate from the small-scale fisheries fleet, which landed approximately 10,900 tonnes in 2024, compared to 1,800 tonnes from the industrial fleet. Mahi-mahi accounts for around 35% of total catches in the small-scale sector, with the remainder mostly composed of tunas (mainly skipjack and yellowfin), billfish such as swordfish and blue marlin, and various shark species (MPCEIP, 2025).

Ecuador's longline fishery, where most mahi-mahi is caught, accounts for approximately 20% of the country's fishing fleet (MPCEIP, 2022). It comprises two distinct components: the inshore and oceanic fleets, which differ in operational range and fishing methods. The inshore fleet consists of small fiberglass boats, locally known as *fibras*, typically ranging from 7.5-9.0 meters in length. These vessels operate independently in offshore waters approximately 40-200 nautical miles from the coast, with fishing trips lasting 2-3 days. The oceanic fleet with an artisanal component, by contrast, includes medium-to-large-sized mothership vessels, referred to as *botes nodriza*, *barcos nodriza*, or simply *nodrizas*, ranging from 7.6-25.9 meters in length. Each mothership tows between one and 12 small *fibras* and employs a group fishing strategy centered around the mothership. The mothership carries all essential supplies, including ice, bait, fuel, and food, and serves as a central storage unit for both its own catches and those of its associated *fibras*. Under Ecuadorian law, the mothership and its accompanying *fibras* are considered a single fishing unit (MPCEIP, 2011).

Despite its growing importance as a seafood commodity, the mahi-mahi sector faces key challenges, particularly the lack of comprehensive stock assessments. The status of most mahi-mahi stocks remains unknown (Merten et al., 2022). In the Pacific Ocean in particular, stock structure is still unclear, but studies are being conducted to reduce these uncertainties. In the Eastern Pacific, including the Ecuadorian EEZ, the Inter-American Tropical Tuna Commission (IATTC) is responsible for managing transboundary species such as tunas, billfishes, and mahi-mahi. A recent stock assessment in the Southeast Pacific, using fisheries data from Ecuador and Peru (the region's two main fleets), found that dolphinfish is currently fished within sustainable biological limits (Roa-Ureta et al., 2024). However, there is still no assessment of the fishery's economic sustainability, particularly its resilience to external factors like fluctuations in market value and shifts toward other target species such as tuna, billfish, and sharks.

The main objective of this study was to collect operational and socioeconomic data from the fishery, in order to analyze the current profitability of the activity. This assessment will serve as a baseline for measuring the economic impacts of future scenarios affecting the mahi-mahi fishery, whether driven by environmental changes, excessive fishing, specific management measures, or operational factors.

2 DATA SOURCES AND METHODOLOGY

2.1 Study scope, data collection, database cleaning, and imputation process

This study focused on the two distinct fleet types that operate in Ecuador's mahi-mahi fishery, inshore and oceanic, specifically in the ports of Manta, Esmeraldas, and Santa Rosa.

Two separate databases were developed, one for mothership vessels and another for fiberglass vessels.

The mothership vessel database includes 95 variables related to fishing location, vessel characteristics (e.g., size, tonnage), fishery operations, and economic data such as costs (e.g., maintenance, ice) and income. It contains records from 36 motherships, all registered at the port of Manta and using longline gear. Interviews to collect the information were conducted between April and June 2021. All interviewees confirmed that mahi-mahi is the target species, with no other specific targeted species during the mahi season. Of the respondents, 31 were shipowners, four were shipowners and captains, and one was a captain. Fishing location data was missing for 21 vessels; three vessels reported coordinates at 84°W and two at 86°W and at 94°W. The remaining eight vessels reported coordinates between 82°W and 93°W.

The fiberglass vessel database includes 81 variables, also covering fishing activities, vessel specifications, operational details, and economic information (both fixed and variable costs), as well as revenue. Data were collected from 68 fiberglass vessels, evenly distributed between the ports of Esmeraldas and Santa Rosa. All vessels used longline fishing gear, consisting of a mainline with baited hooks set at intervals. Interviews were conducted in April 2021 and included 22 shipowners (10 of whom also served as captains), 38 captains, and eight crew members. Fishing location data was missing for 21 vessels; the fiberglass vessels travel between 20 miles to 220 miles from the shore. As with motherships, three vessels reported 84°W and two reported 86°W.

All collected data were compiled and organized in an Excel database, and a thorough data cleaning and imputation process was carried out. Variable names were reviewed for compatibility with R, data entries were standardized, factor variables were converted into categorical variables, and missing values were coded as "NA" (not available). Maintenance costs were normalized based on the total fishing season length for both motherships and fiberglass vessels.

After completing the data cleaning and standardization processes, the database was finalized and prepared for analysis. Detailed procedures for cleaning and data imputation are provided in the Appendices. To ensure confidentiality, vessel names were replaced with identifying codes, using "NODxx" for the long-distance (motherships) fleet and "FVxx" for the fiberglass (coastal) fleet. All data analysis was conducted using R version 4.4.1.

2.2 Data analysis

The Kendall correlation coefficient was used to measure the correlation between quantitative variables. Normality was assessed using the Shapiro-Wilk test, along with skewness and kurtosis values. Levene's test was applied to test equality of variances. Because the data showed significant deviations from normality, the Mann-Whitney-Wilcoxon test was used to compare medians, specifically for the number of fiberglass boats per mothership and crew size.

Seasonal catch was estimated by multiplying the reported number of fishing trips per season by the average total catch per trip. Seasonal revenue was then calculated by multiplying the total catch by the average market price per pound of mahi-mahi over the season (Figure 2-1).

A similar approach was used to estimate seasonal costs: In addition to the operational costs such as gas, ice, and bait, seasonal maintenance costs (which weren't factored into the profit calculation for the most recent trip) were also included. Maintenance costs were normalized to reflect the full fishing season, based on the average maintenance expense. Using these estimates, seasonal profit was calculated as the difference between revenue and total costs (operational plus maintenance). This estimate does not account for depreciation, taxes, or interest. As such, it represents EBITDA (Earnings Before Interest, Taxes, Depreciation, and Amortization), which serves as an indicator of net income.

To classify both mothership and fiberglass vessels by characteristics, fishing operations, and profitability, a k-means clustering analysis was conducted. This method groups vessels with similar traits, helping to identify distinct operational patterns within the fleet. All numerical variables were first standardized (mean = 0, standard deviation = 1) to ensure comparability. The k-means algorithm then assigned each observation to a cluster based on proximity to the nearest centroid, minimizing within-cluster variance.

The optimal number of clusters was determined using the Within-Cluster Sum of Squares (WCSS) and the Davies-Bouldin Index, selecting the solution with the best balance between compactness and separation. The Hopkins statistic was used to confirm that the data was suitable for clustering, and metrics such as the Silhouette Score and Dunn Index were used to evaluate cluster quality.

To estimate asset depreciation, vessel and gear lifespan were both assumed to be 60 years, due to limited available data. Residual values after the end of the asset lifespan were not considered in this analysis.

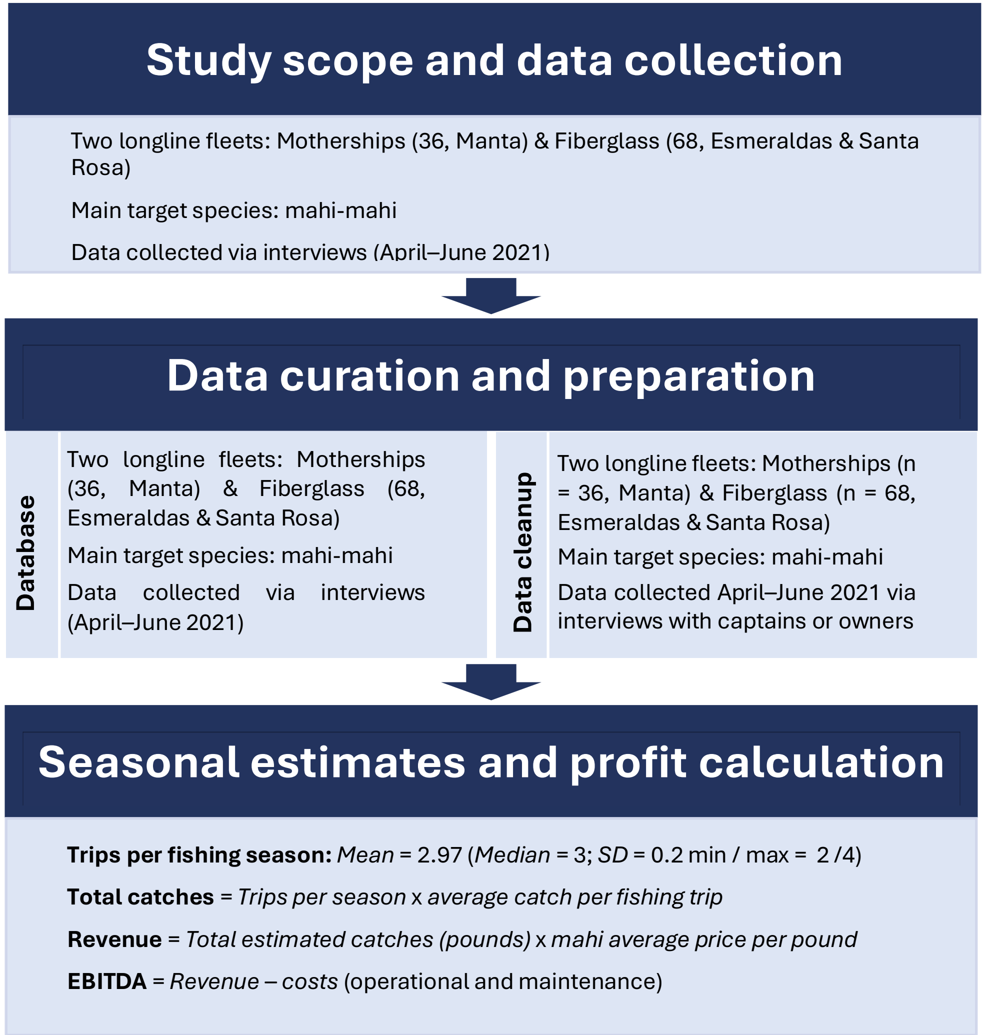

Figure 2-1 | Diagram illustrating the various steps in the data collection and analysis process for the current study of the Ecuador mahi-mahi fishery.

3 MAIN FINDINGS

A total of 104 interviews were conducted to gather information on the Ecuadorian mahi-mahi fishery, between April and June 2021. As outlined in the Methodology, the interviews focused on two main segments of the fishery: (1) 36 interviews with operators of the long-distance fishery, which involves large mothership vessels (7.6-25.9 m) that transport smaller boats, travel long distances to fishing grounds, and conduct multi-day fishing trips; and (2) 68 interviews with participants in the coastal fishery, which relies on smaller fiberglass (*fibra de vidrio*) boats (7.5-9.0 m) (Martínez-Ortiz et al., 2015).

Except for one coastal-fleet boat, for which two interviews were conducted, each interview focused on a single vessel and was typically conducted with either the boat captain or owner. Only eight were conducted with crew members (fishers).

The following sections present key findings on vessel characteristics, operational and fishing trip costs, revenue from landings, species composition and catch volumes, trip duration, and other aspects for both fishery segments.

3.1 Mothership Vessels

The database has a total of 95 different variables relative to the data and fishing location, vessel characteristics, fishery characterization, and variables related to the economic impact of the fishery – the fixed and variable costs of the fishery and the income obtained by the fishery. It has information related to 36 mothership (*nodrizas*) vessels. The vessels are all registered in Manta port and all use the same longline fishing gear.

The interviews were conducted in 2021, six of them in April and the remaining 30 in June. All interviewees answered that targeting mahi-mahi in Ecuador is their main activity, and none of them have a second activity. Of all the interviews, 31 were with the shipowner, four with the shipowner/captain, and just one with the captain. The exact location of the last fishing trip could not be used, as it was not given for most vessels. However, a heatmap of the apparent fishing activity and fishing grounds of the vessels throughout 2022 is presented in **Figure 3-1**.

3.1.1 Fishery characterization

All 36 sampled mothership vessels were equipped with a fixed engine. Nearly 60% of them (58.3%) operated with six or a maximum of ten accompanying fiberglass vessels. The average number of crew members per mothership was eight, ranging from five to ten. Additionally, the average number of crew members working directly on the fiberglass vessels was 20, with a range from 10 to 30 (**Table 3-1**).

The typical motherships (*nodrizas*) had six accompanying fiberglass vessels, eight crew members on the mothership, and generally three crew members per fiberglass vessel (**Figure 3-2**).

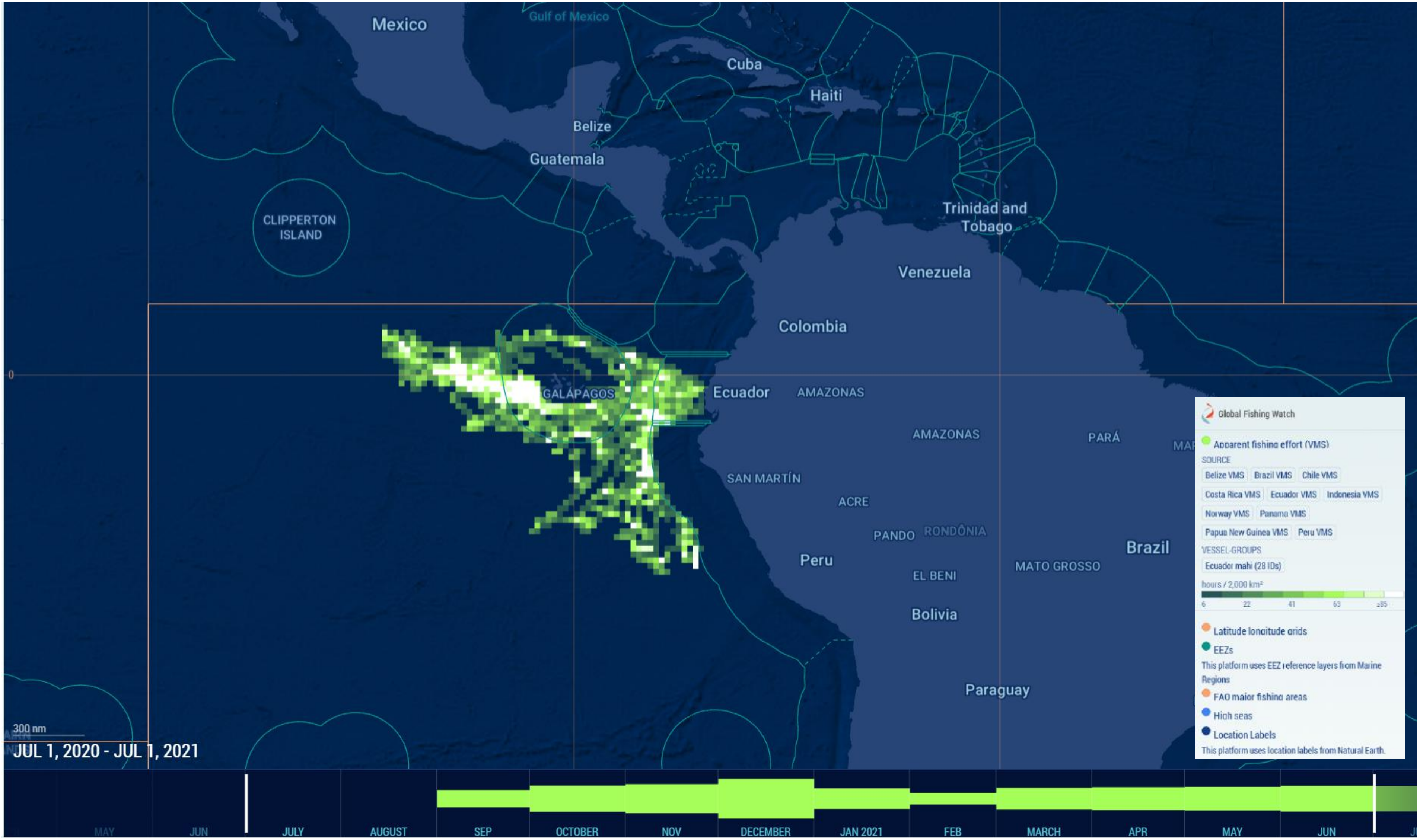

Figure 3-1 | Apparent fishing effort by 28 identified Ecuadorian mothership vessels in the Southeast Pacific, between July 2021 and July 2022. Effort is shown as total hours fished by 2,000 km^2 (heatmap, top) and monthly distribution of effort (bottom). Source: Global Fishing Watch (2025).

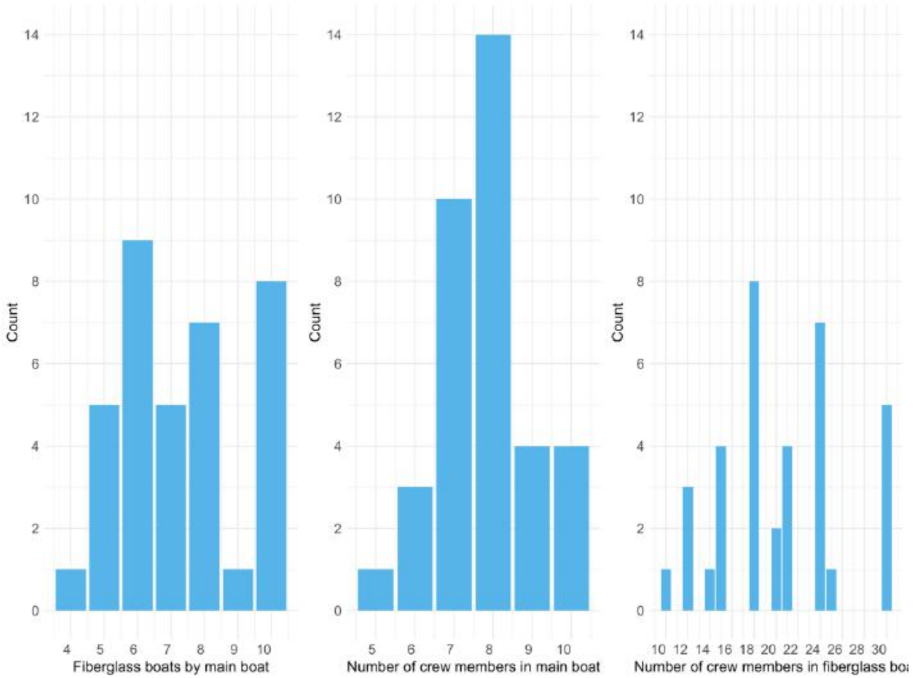

Figure 3-2 | Bar plots displaying the number of fiberglass vessels per mothership, and number of crew members on the mothership (*nodrizas*) vessels and on the fiberglass vessels, for the long-distance Ecuadorian mahi-mahi fishery.

Regarding the vessel characteristics, **Table 3-2** presents statistics for the mothership vessels' horsepower, the number of hooks per vessel, the number of hooks per fiberglass vessel, and the vessels' hold capacity. The hold capacity is not significantly related to the horsepower (τ = -0.12, p = 0.313) or to the miles travelled to the fishing spot (τ = 0.17, p = 0.165). However, there is a significant positive relationship between horsepower and the miles traveled to the fishing spot (τ = 0.25, p = 0.046), indicating that vessels with higher horsepower usually travel to farther fishing spots.

Table 3-1 | Attributes of mothership (*nodriza*) vessels and fiberglass boats documented in this study, for the long-distance Ecuadorian mahi-mahi fishery.

Variable/Attribute	Category	Valid responses (n)	% of valid responses
Vessel type	Vessel	36	100
Type of propulsion	Fixed engine	36	100
Number of engines	1	36	100
Average number of fiberglass vessels that a mother vessel tows	4	1	2.8
	5	5	13.9
	6	9	25.0
	7	5	13.9
	8	7	19.4
	9	1	2.8
	10	8	22.2
Total number of crew members working directly on the mothership	5	1	2.8
	6	3	8.3
	7	10	27.8
	8	14	38.9
	9	4	11.1
	10	4	11.1
Total number of crew members working directly on the fiberglass vessels	10	1	2.8
	12	3	8.3
	14	1	2.8
	15	4	11.1
	18	8	22.2
	20	2	5.6
	21	4	11.1
	24	7	19.4
	25	1	2.8
	30	5	13.9

Table 3-2 | Descriptive statistics of some key attributes of the mothership (*nodrizas*) vessels included in the current study, for the long-distance Ecuadorian mahi-mahi fishery.

Variable	Min	Med	Avg	Max	SD	n
Horsepower	300.0	450.0	447.7	650.0	89.3	36
Number of hooks per vessel	200.0	650.0	680.6	1200.0	305.0	36
Number of hooks per fiberglass vessel	180.0	500.0	484.2	800.0	218.0	36
Vessel hold capacity (tons)	9.0	26.2	25.9	40.9	7.3	36

Figure 3-3 shows a bubble plot illustrating the relationship between the mothership vessels' horsepower and the distance traveled to fishing grounds, with bubble size representing the hold capacity and color the number of fiberglass boats per mothership. The data indicates that there is a significant correlation between the distance (miles) to the fishing grounds and the mothership vessels' horsepower ($\tau = 0.25$, $p = 0.045$). There is no significant correlation between the fishing distance (miles) to the fishing grounds and the mothership vessels' hold capacity ($\tau = 0.17$, $p = 0.165$), or between the mothership vessels' hold capacity and horsepower ($\tau = -0.12$, $p = 0.313$). The miles traveled, the mothership vessels' hold capacity, and horsepower show no significant differences based on whether the number of fiberglass vessels carried is greater than six or not (minimum $p = 0.055$).

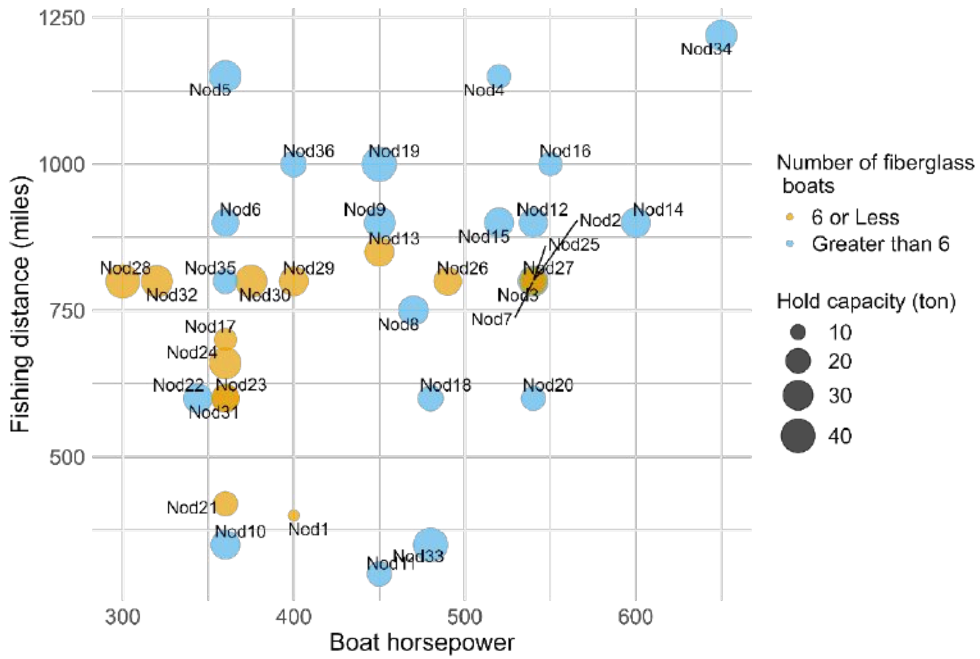

Figure 3-3 | Bubble plot showing the relationship between mothership vessel horsepower and distance traveled to fishing grounds, with bubble size representing the hold capacity and color the number of fiberglass boats per mothership, for the long-distance Ecuadorian mahi-mahi fishery.

Table 3-3 shows the main statistics of the variables related to the fishery, including the shipowner's experience fishing mahi-mahi, the distance traveled to the fishing spot, the number of days spent traveling to the spot (one way), and the number of days spent at the fishing spot. The shipowners exhibit a wide range of experience, from six to 40 years, with a mean of 20.0 years (median of 17.5 years). On their last fishing trips, the vessels traveled distances ranging from 300 miles to 1,220 miles, with a median of 800 miles. They spent a median of six days traveling to the fishing spot and 10 days actively fishing there. A fishing trip had a mean total duration of 22.2 days (median of 22.1 days).

Table 3-3 | Descriptive statistics of fishery-related variables for the mothership (nodrizas) vessels.

Variable	Minimum	Median	Mean	Maximum	Standard deviation	n
Years of experience fishing mahi-mahi	6.0	17.5	20.0	40.0	9.7	36
Distance in miles traveled for fishery	300	800	766.7	1220	223.3	36
Number of days spent travelling to the fishing zone	4.0	6.0	5.7	8.0	1.2	36
Number of days actively fishing	6.1	10.1	10.7	19.9	3.0	36
Total fishing trip duration	19.7	22.1	22.2	32.5	2.0	36

Regarding the relationship between the shipowners' years of experience and the miles traveled, the analysis indicated that more years of experience are not significantly correlated with days spent fishing ($\tau = 0.24$, $p = 0.060$) or with the miles traveled ($\tau = 0.02$, $p = 0.899$) (**Figure 3-4**). A significant negative correlation was observed between the number of days spent fishing and the distance traveled to the fishing spot ($\tau = -0.35$, $p = 0.006$), indicating that the farther the fishing spot, the fewer the total days spent actively fishing. The miles traveled, the number of days spent at the fishing spot, and the years of experience show no significant differences based on whether the number of fiberglass vessels carried is greater than six or not (minimum $p = 0.090$).

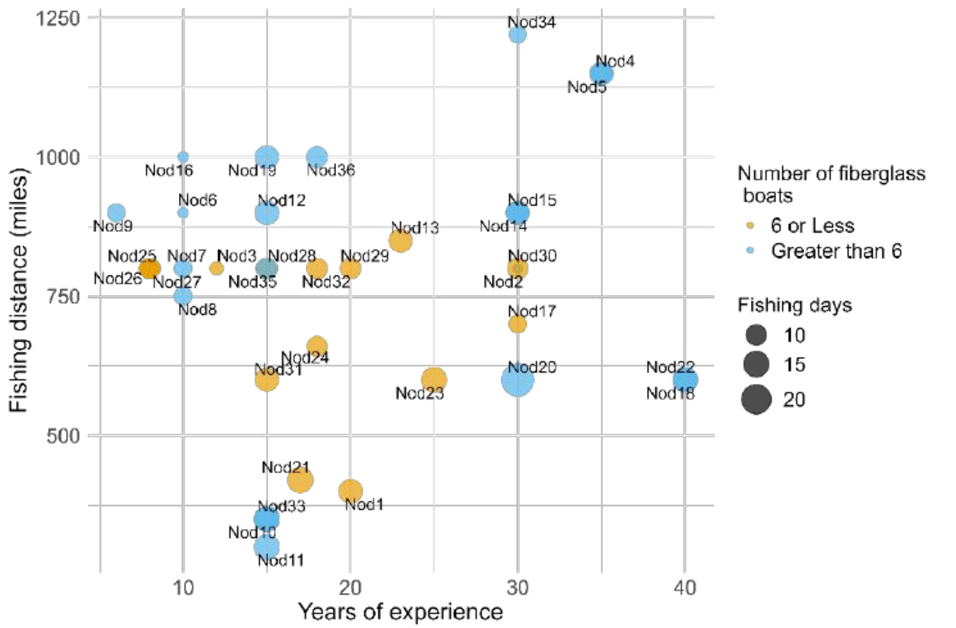

Figure 3-4 | Bubble plot of the experience (years of fishing) related to the miles travelled, with bubble size representing the number of fishing days on the fishing spot and color the number of fiberglass vessels on the main boat, for the long-distance Ecuadorian mahi-mahi fishery.

3.1.2 Fishery costs

In terms of fishing-related costs, the results show that during their last fishing trips, vessels had a mean operational cost of $21,187.1, with a median cost of $20,827.5, minimum of $8,236.0, and maximum of $34,480.0 per fishing trip. There is a significant positive correlation found between the total cost of the fishing trip and the mothership vessel's horsepower (τ = 0.34, p = 0.006) and the total number of crew members (τ = 0.32, p = 0.006).

Regarding the operational costs and income from the last fishing trip, Figure 3-5 and Table 3-4 display the statistics for the operational and fishing-related costs. Seven main cost categories were reported for the fishery: fuel, lubricant, food, bait, ice, transportation to the fishing port, and goods provision. Some descriptive statistics by category are provided below.

3.1.2.1 Food

The median food cost during the last fishing trip was $4,650, with a minimum of $2,800 and a maximum of $12,000. The median cost per crew member (including those on the main vessel and fiberglass vessels) was $161.

There was no correlation between the goods provision and the total number of crew members (τ = -0.08, p = 0.558) or the food cost by fishing trip. However, a significant positive correlation was found between food costs per trip and the total number of crew members (τ = 0.29, p = 0.022).

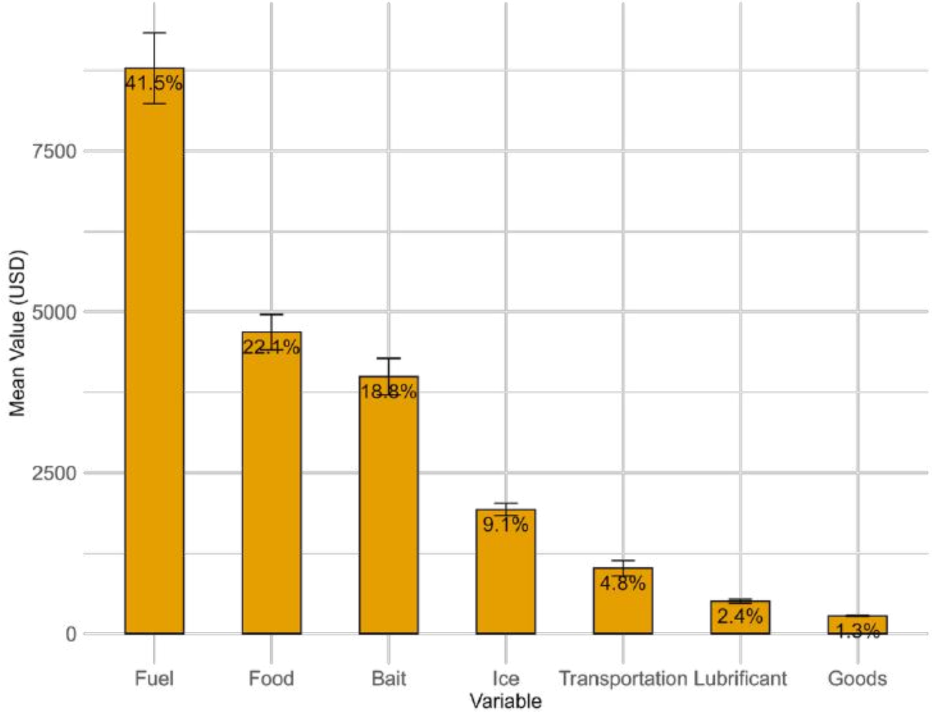

Figure 3-5 | Bar plot displaying costs per fishing trip by item and the respective percentage relative to the total cost, for the long-distance Ecuadorian mahi-mahi fishery.

3.1.2.2 Ice

The median expenditure on ice was $2,000, with a minimum of $416 and a maximum of $3,000. During the trip, a median of 800 units of ice were used, with each unit costing a median of $2.50.

There was no correlation between vessel horsepower and total ice cost per trip (τ = 0.20, p = 0.117). However, there was a significant positive correlation between vessel hold capacity and ice cost per trip (τ = 0.36, p = 0.003).

Table 3-4 | Descriptive statistics of operation and fishery costs of the last fishing trip, for the long-distance Ecuadorian mahi-mahi fishery.

Variable	Minimum	Median	Mean	Maximum	Standard deviation	Sample (n)
Fuel consumption by fishery (gallons)	1,000	7,000	6,975	10,000	2,207.2	36
Fuel price ($ per gallon)	0.92	1.29	1.25	1.49	0.16	36
Fuel cost by fishery ($)	1,290	9,065	8,786	14,800	3,287.2	36
Total lubricant consumption by fishery (gallon)	2.0	7.00	7.08	14.0	2.36	36
Lubricant price ($ per gallon)	50.0	70.0	70.61	90.00	8.28	36
Lubricant cost by fishery ($)	160.0	472.5	504.2	1,120.0	194.0	36
Total food expenditure by fishery ($)	2,800	4,650	4683	12,000	1,649.9	36
Food expenditure by total mothership vessel and fiberglass crew members ($)	90.3	161.0	170.8	400	60.8	36
Bait cost	720	3,600	3,992	10,100	1,708.21	36
Frigate tuna		3,300	3,546			24
Frigate tuna and squid		6,000	6,620			5
Frigate tuna and chub mackerel		3,500	3,500			1
Frigate tuna and herring		3,800	3,667			6
Ice units by fishery	208.0	800.0	773.6	1,100.0	189.6	36
Ice cost per unit ($)	1.3	2.5	2.47	3.2	0.3	36
Ice cost ($)	416	2,000	1,930	3,000	566.0	36
Transportation to fishing port ($)	200	900	1,015	3,500	710.4	36
Provisioning of goods ($)	150	250	277	500	54.4	36
Total cost by fishery	**8,236**	**20,827.5**	**21,187.1**	**34,480**	**5,702.7**	**36**

3.1.2.3 Bait

The median cost of bait during the trip was $3,600, with a minimum expenditure of $720 and a maximum of $10,100. The most expensive bait type was frigate tuna/squid, with a median cost of $6,000.

There is no correlation between bait cost and the total number of fiberglass vessels (τ = 0.24, p = 0.06). However, as expected, there is a significant positive correlation between bait cost per trip and the total number of crew members (τ = 0.28, p = 0.022).

3.1.2.4 Land transportation to the fishing port

Transportation expenses to the fishing port, including personnel, equipment, materials, and other related costs, had a median of $900, with a minimum expenditure of $200 and a maximum of $3,500.

3.1.2.5 Goods provision

The median cost for goods provision was $250, with a minimum of $150 and a maximum of $500.

3.1.3 Mothership vessel maintenance costs

The variables related to vessel maintenance and the frequency of maintenance were converted into seasonal maintenance costs (considering a four-month season). **Figure 3-6** portrays the vessel maintenance variables, highlighting higher variability in "other costs," hull maintenance costs, and engine maintenance costs. In contrast, maintenance costs associated with guarding, navigation systems, and electrical systems exhibit a higher proportion of vessels with values clustered around their medians.

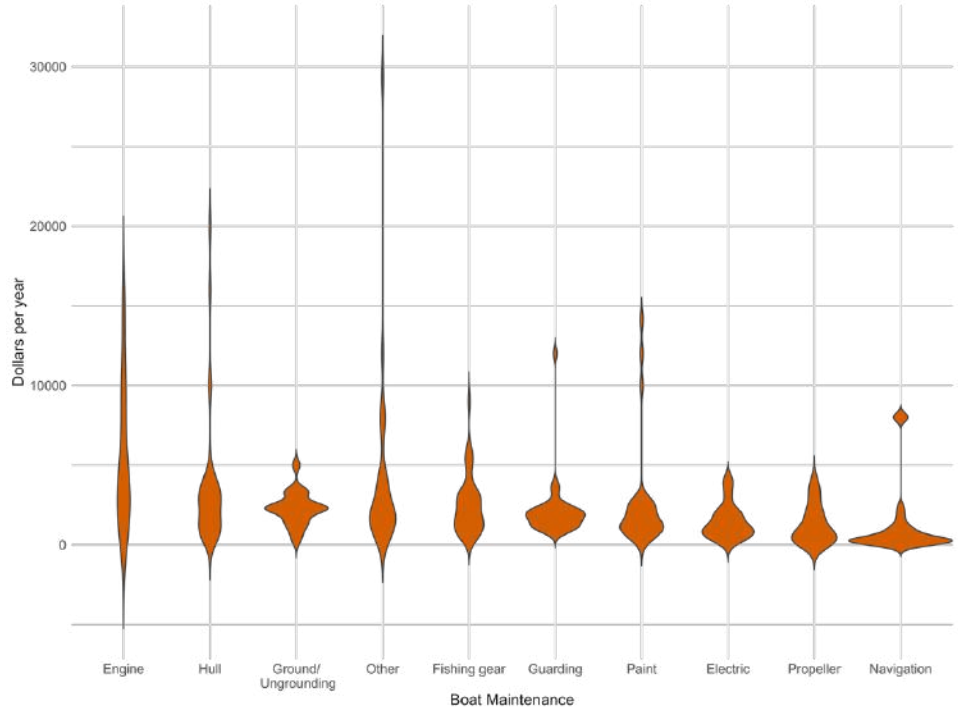

Figure 3-6 | Violin plot showing the variation in maintenance costs for different vessel components and fishing gear in the long-distance Ecuadorian mahi-mahi fishery.

Table 3-5 presents the descriptive statistics for vessel maintenance costs by season. The engine contributes the most to total maintenance costs, with a median seasonal cost of $3,800, representing 20.5% of the total maintenance costs. This is followed by costs associated with other aspects of the vessel, which have a median cost of $2,000 and account for 14.3% of the total maintenance costs.

Table 3-5 | Descriptive statistics of mothership vessel maintenance costs and percentage of the total maintenance cost per fishing season.

Variable	Min.	Median	Mean	Max.	SD.	% of total cost
Engine	333.3	3,800.0	5,293.6	15,000.0	4,323.4	20.5
Other	266.7	2,000.0	3,696.1	29,333.3	5,137.6	14.3
Hull	145.8	2,666.7	3,528.0	20,000.0	4,202.3	13.7
Fishing gear	600.0	1,950.0	2,562.5	9,000.0	1,866.4	9.9
Paint	104.2	1,333.3	2,384.9	14,117.7	3,088.0	9.3
Grounding/ Ungrounding	166.7	2,276.0	2,276.0	5,000.0	1,061.8	8.8
Guarding	800.0	1,800.0	2,116.7	12,000.0	1,838.9	8.2
Electric system	133.3	1,100.0	1,475.4	4,000.0	1,085.1	5.7
Propeller	41.7	750.0	1,272.6	4,000.0	1,206.5	4.9
Navigation system	66.7	333.3	1,172.5	8,000.0	2,157.6	4.6
Total	**9,487.1**	**23,390.0**	**25,778.2**	**66,904.1**	**11,868.0**	**100**

Hull maintenance represented 13.7% of the total maintenance costs, with a median seasonal value of $2,666.70. Maintenance costs for fishing gear accounted for almost 10% of the total maintenance costs, with a median seasonal value of $1,950.

The mothership boats present a mean of $25,778.2 for the total seasonal maintenance costs, with a median value of $23,390.0. The minimum of the total seasonal maintenance costs was $9,487.1 and the maximum was $66.904.1.

In terms of maintenance costs and vessel-specific equipment, a significant positive correlation was observed between vessel horsepower and total maintenance costs (Figure 3-7). However, hold capacity is not significantly associated with total maintenance costs or with the major components that contribute to vessel maintenance. Additionally, there is a significant positive correlation between vessel horsepower and the maintenance costs for the engine and paint.

3.1.4 Annual depreciation of fishing equipment and vessels

To evaluate the total cost of fishing activities, investment in the vessel, engine, and other equipment must also be considered. When calculating costs, we accounted for the lifespan and acquisition value of all boat components, including the vessel, hull, engine, propeller, equipment, and fishing gear. For this analysis, we disregarded any potential residual value of these assets after their lifespan. The procedures used in this section to cover some data limitations are detailed and explained in **Appendix 1**.

Regarding the acquisition cost per year, calculated as the total acquisition cost divided by the lifespan of each boat component, our analysis showed that asset acquisition results in an average annual cost of $37,017 (with a median of $27,772), ranging from a minimum of $12,717 to a maximum of $54,007 per year (Table 3-6). The investment in fishing gear contributes an average annual cost of $5,633 (median: $5,850), while investments in motherships account for an average of $31,384 per year (median: $31,279).

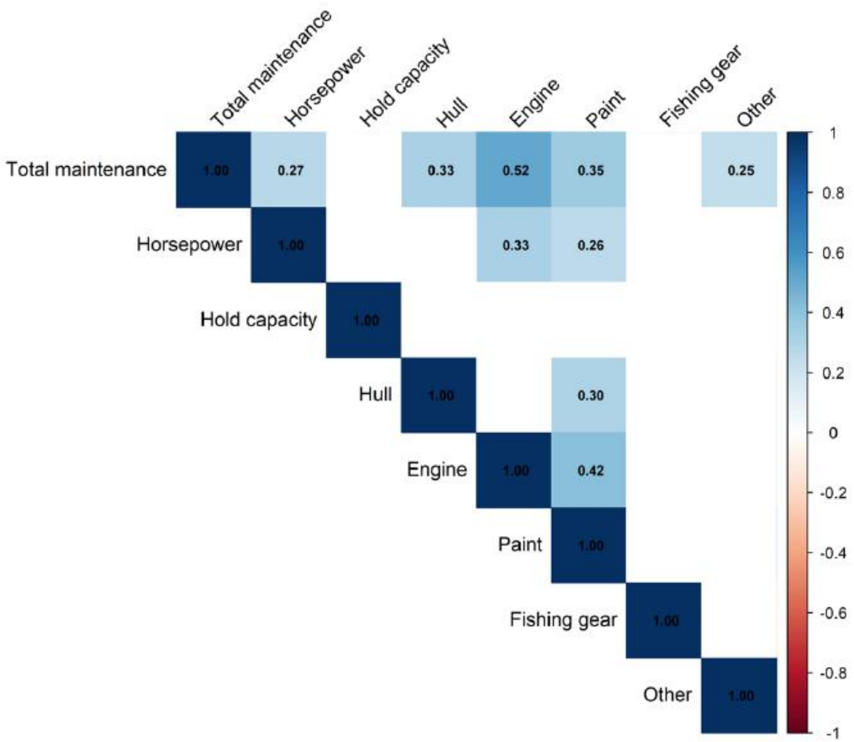

Figure 3-7 | Correlation plot displaying the relationship between the total maintenance cost and the mothership vessel variables and the specific maintenance cost, for the long-distance Ecuadorian mahi-mahi fishery.

Table 3-6 | Descriptive statistics of the acquisition costs by year of the various key components of the fishing vessels (motherships) used in the long-distance Ecuadorian mahi-mahi fishery.

Expense variable	Min.	Median	Mean	Max.	Std. Dev.	Sample (n)
Vessel cost by year ($)	4,000	13,333	13,278	23,333	5,148	36
Hull cost by year ($)	833	4,167	7,944	8,333	1,777	36
Engine value by year ($)	1,667	6,458	7,944	21,6667	4,727	36
Propeller value by year ($)	167	1,857	2,337	8,500	1,875	36
Equipment value by year ($)	500	3,000	3,881	10,000	2,623	36
Total mothership active cost by year ($)	8,867	31,279	31,384	49,657	9,532	36
Mothership fishing gear value by year ($)	255	850	829	1,700	389	36
Fishing gear value ($)	1,400	5,000	4,803	8,000	1,605	36
Total mothership fishing gear actives cost by year ($)	2,250	5,850	5,633	8,850	1,696	36
Total cost ($)	**12,717**	**37,772**	**37,017**	**54,007**	**9,967**	**36**

3.1.5 Catches, revenue, and profit

3.1.5.1 Revenue per fishing trip

Table 3-7 depicts the variables related to the revenue from the last fishing trip. The sale price of mahi-mahi varied between a minimum of $1.10 and a maximum of $2.46 per pound, with a median sale price of $1.52 per pound. The catch (in pounds) of mahi-mahi also showed a very high variability, ranging from 5,200 pounds to 70,000 pounds in a single fishing trip, with a median of 34,500 pounds. This highlights the high variability of the catch among the 34 vessels observed, as evidenced by a coefficient of variation of 47.9%.

The total revenue from each fishing trip depends on two factors: price per pound and the quantity sold. For this reason, it exhibited a very high variability (coefficient of variation = 54.7%), ranging from $7,713.30 to $124,600.00, with a median revenue of $48,528.60. Revenues from non-target species, which were also reported for some fishing trips, averaged roughly $1,550 (median = $1,550) per fishing trip. The most reported non-target species sold were sharks (reported by nine vessels) and swordfish (reported by three vessels). Other bycatch species included *picudo* (likely blue marlin, *Makaira nigricans*, but could include other billfishes), *sierra* (likely wahoo *Acanthocybium solandri*, but could include Spanish mackerels), and *wahoo*.

Figure 3-8 presents a violin plot of the revenue from mahi-mahi (in $) and the total catch (in pounds). The analysis reveals a strong variability in both the total catches and the revenue generated by each mothership vessel during their last fishing trip.

Table 3-7 | Descriptive statistics for total mahi-mahi catch, landed value of mahi-mahi, and landed value of non-target species from the most recent fishing trip in the long-distance Ecuadorian mahi-mahi fishery.

Variable	Min	Median	Mean	Max	SD	n
Mean sale price ($) per pound	1.10	1.52	1.57	2.46	0.36	36
Quantity of mahi-mahi (pounds)	5,200.0	34,500.0	35,050.0	70,000.0	16,510.1	36
Mahi-mahi sale value ($)	7,713.3	48,528.6	54,599.8	124600.0	29862.8	36
Sale of additional catch ($)	500.0	1,000.0	1,548.3	7,000.0	1,588.5	23

A correlation plot between total catch, vessel variables, cost variables, and fishing trip variables is displayed in **Figure 3-9**. Interestingly, total catch is not significantly correlated with any of the variables, including the number of active fishing days or the distance (in miles) to the fishing ground. Conversely, total vessel costs are positively correlated with vessel horsepower, the number of crew members, and the number of fiberglass vessels.

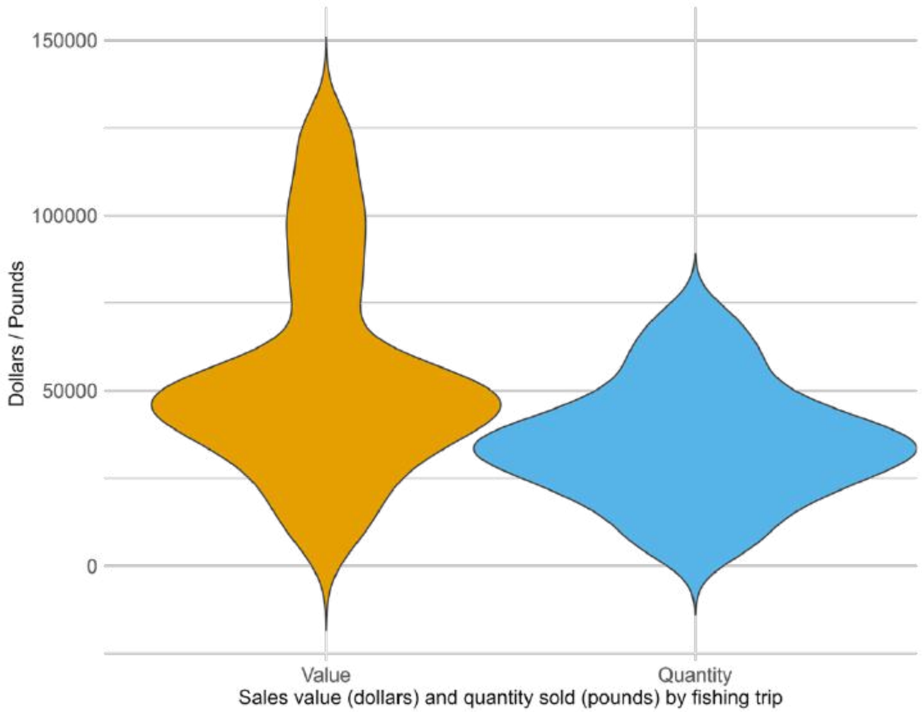

Figure 3-8 | Violin plots showing the distribution of both the quantity (in pounds) and landed value of mahi-mahi from the most recent fishing trip in the long-distance Ecuadorian mahi-mahi fishery.

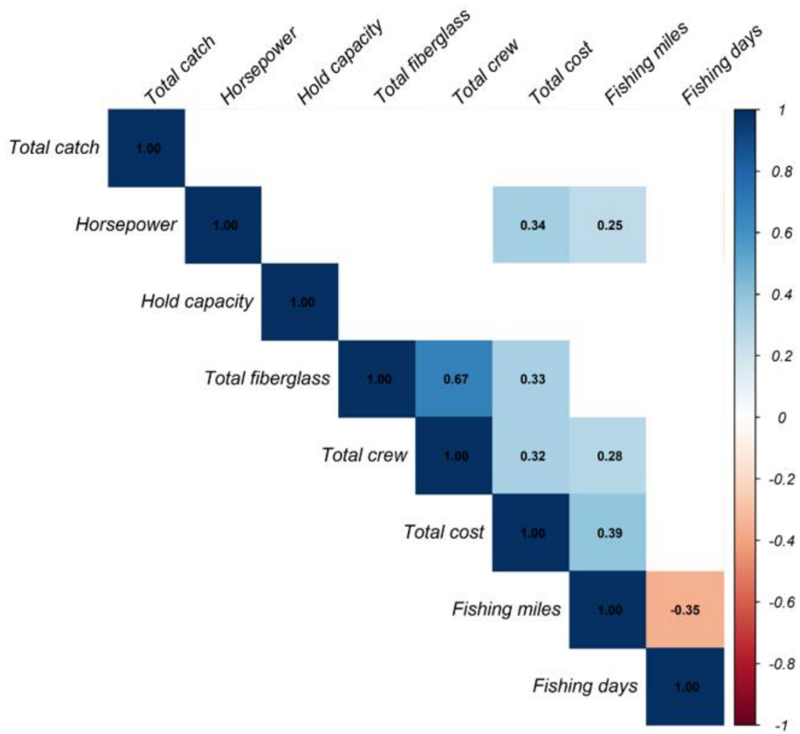

Figure 3-9 | Correlation plot between the total reported catches in the last fishing trip, some of the fishing vessels' characteristics (e.g., hold capacity), operational costs, and fishing trip characteristics, for the long-distance Ecuadorian mahi-mahi fishery.

3.1.5.2 Profit per fishing trip

For operational profit, we consider the profit derived from the direct costs of the fishing trip and the revenue generated from selling the mahi-mahi catch. This excludes maintenance costs and depreciation costs of fishing equipment and vessels. In the most recent fishing trip, only three vessels reported a loss in their fishing operations (**Figure 3-10**). There is no significant correlation between the revenue and the cost on the last fishing trip (τ=-0.01, p=0.949).

Regarding operational costs and revenues (in dollars), revenue per fishing trip presents a higher dispersion than costs (**Figure 3-11**). This supports the fact that while the costs of the fishing trip are relatively consistent across motherships, revenue is highly dependent on the total catches (which have higher variability) and the price per pound of mahi-mahi.

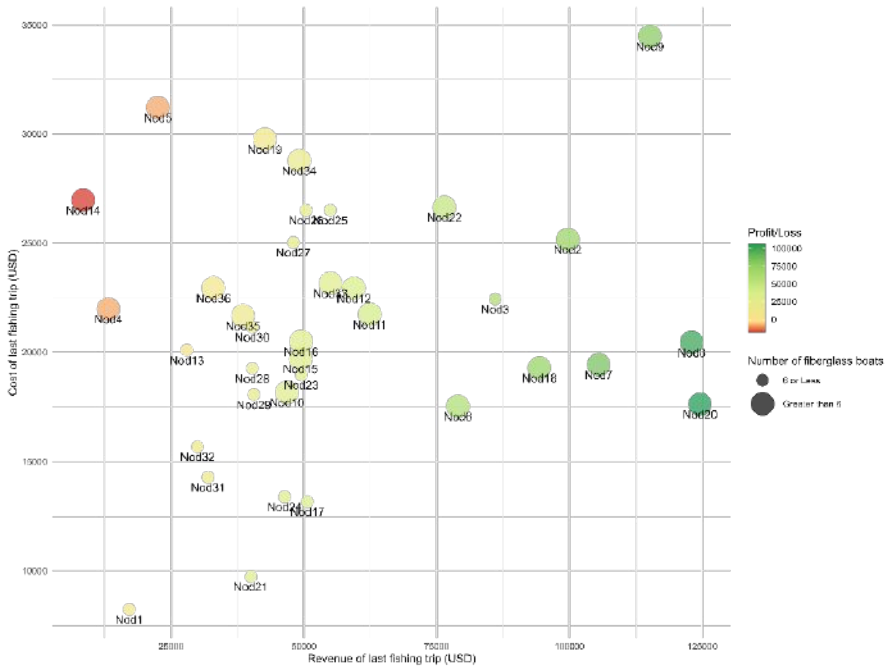

Figure 3-10 | Bubble plot showing the relationship between revenue (x-axis) and costs (y-axis, including operational costs) from the last fishing trip for the long-distance Ecuadorian mahi-mahi fishing fleet. Bubble size represents the number of fiberglass boats per mothership, and bubble color indicates estimated profit.

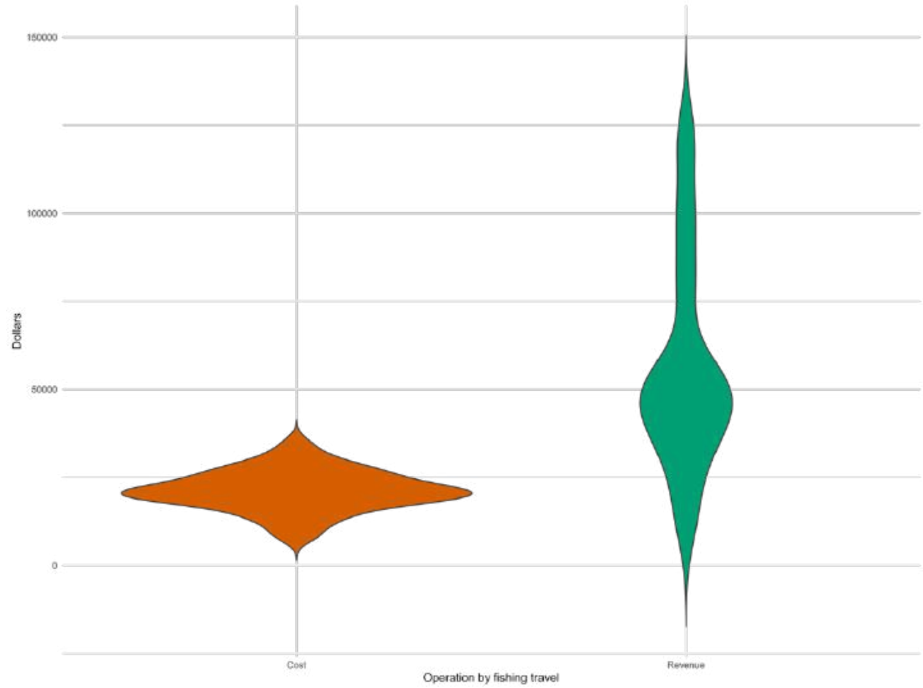

Figure 3-11 | Violin plot showing the distribution of operational costs and revenue from the last fishing trip for the long-distance fleet of the Ecuadorian mahi-mahi fishery.

3.1.5.3 Season total catch and profit estimates

This section presents estimates of seasonal revenue, operational costs, vessel maintenance costs, and annual depreciation of fishing gear and vessels. These calculations are based on the average number of fishing trips per season, estimated at three fishing trips (mean = 2.97 and median = 3).

Using these estimates, we calculated the seasonal profit for each vessel. As aforementioned, this initial profit estimate does not account for depreciation, taxes, or interest. Therefore, it reflects EBITDA (Earnings Before Interest, Taxes, Depreciation, and Amortization), a common measure of operating profitability. When annual depreciation costs are included, we obtain a profit estimate that still excludes taxes and interest.

When considering only maintenance costs, 17.6% of vessels show a negative profit. These include: *Cristhel Marhía*, *Amor y Paz*, *Dios con Nosotros*, *Leonardo*, *Siempre Michael*, *Don Solis*, *Joel y Raquel*, *Luis Armando I*, *Johnson Line II*, *Torre Fuerte II*, *Siempre Joselyn*, and *Siempre Mahanaim*. When annual depreciation is also factored in, the proportion of vessels operating at a loss increases to 30.6%.

It is important to note that these estimates assume the catch from the last fishing trip is representative of the average catch per trip for the entire season. However, data is only available for the final trip of the season, which might yield lower total catches and may also have a lower sale price per pound of mahi-mahi. As such, this assumption may be unrealistic, as it is based on a single trip that may not accurately reflect average or natural intra-seasonal changes in both catches and sale price.

The estimated total revenue per season, the total operational costs, the seasonal vessel maintenance costs, and the annual depreciation costs of the fishing gear and vessels are presented in **Figure 3-12**.

Figure 3-13 illustrates a bubble plot of the seasonal revenue versus the total seasonal costs (including operational, maintenance, and depreciation costs). The bubbles are colored to represent profit and are sized according to the number of fiberglass vessels.

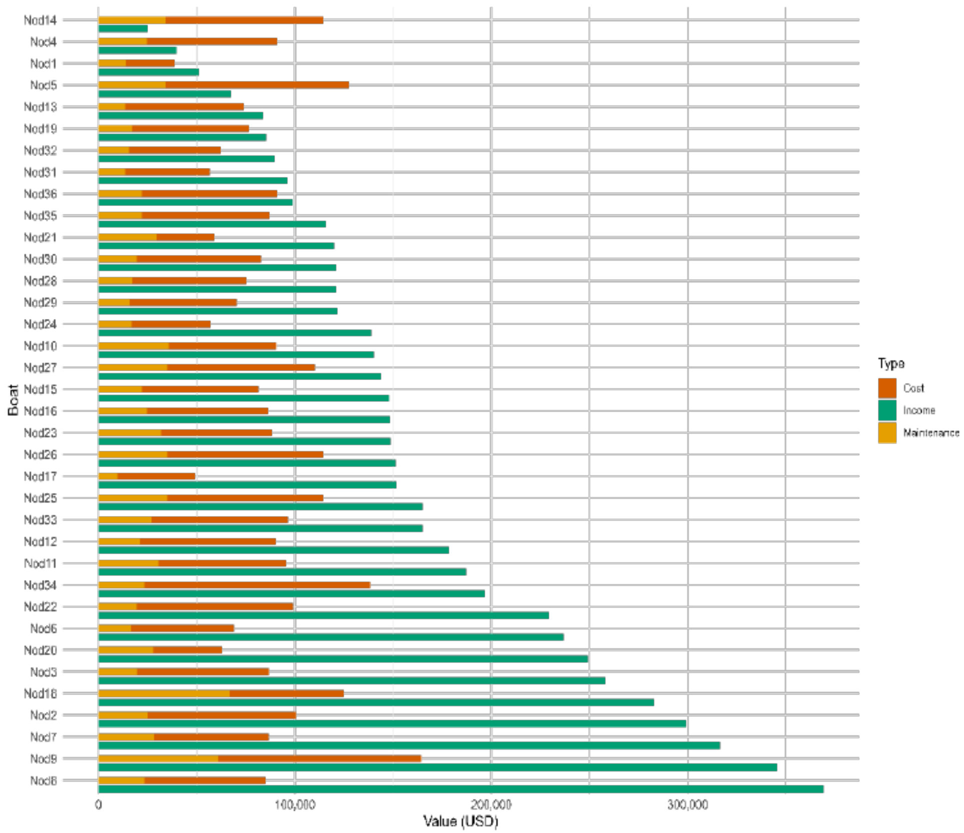

Figure 3-12 | Bar plot showing total seasonal revenue, total operational costs, total maintenance costs, and depreciation costs of mothership vessels, for the long-distance Ecuadorian mahi-mahi fishing fleet.

No significant differences were observed between profit per mothership and the number of associated fiberglass vessels (W = 119, p = 0.226). Similarly, there was no significant correlation between annual profit and vessel hold capacity (τ = -0.09, p = 0.473) or engine power (τ = 0.06, p = 0.649). However, a significant negative correlation was found between profit and the distance traveled to the fishing spot (τ = -0.26, p = 0.032), suggesting that vessels traveling farther distances tend to achieve lower profits.

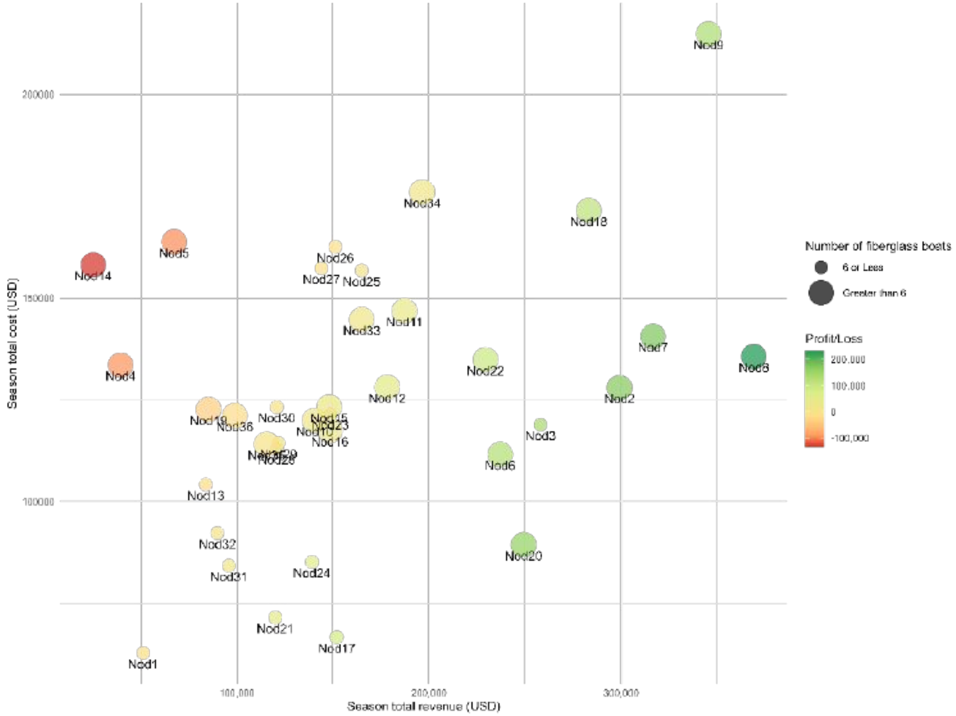

Figure 3-13 | Bubble plot illustrating the relationship between seasonal revenue (x-axis), seasonal costs (y-axis, including operational, maintenance, and depreciation costs), and the number of fiberglass boats per mothership (bubble size) for the long-distance Ecuadorian mahi-mahi fishing fleet. Bubble color represents profit levels.

3.1.6 Cluster analysis

Using the k-means clustering method, we identified two distinct clusters based on vessel characteristics, fishing operations, and estimated profitability. The variables used for clustering included: vessel horsepower, hold capacity (tons), number of hooks per vessel and per fiberglass vessel, average number of fiberglass vessels per mothership, total crew on the mothership and on the fiberglass vessels, number of trips per season, fishing distance (miles), years of experience targeting mahi-mahi, estimated seasonal revenue, operational costs, maintenance costs, and annual depreciation.

The Hopkins statistic of 0.61 indicated that the data is suitable for clustering, though the clusters are not highly compact. This is further supported by a Davies-Bouldin Index value of 2.1 and a Within-Cluster Sum of Squares (WCSS) of 402.4 for the two-cluster solution. The mean Silhouette Score of 0.15 and Dunn Index of 0.30 suggest moderate separation and low internal compactness.

Figure 3-14 presents the results of the k-means clustering on a two-dimensional plot. While the clusters are distinguishable, they remain weakly grouped. Cluster 1 includes vessels characterized by lower fishing activity (i.e., fewer fishing trips) and investment levels, while Cluster 2 comprises vessels with higher fishing activity and greater operational costs. There is of course an important correlation between fishing activity and greater operational costs.

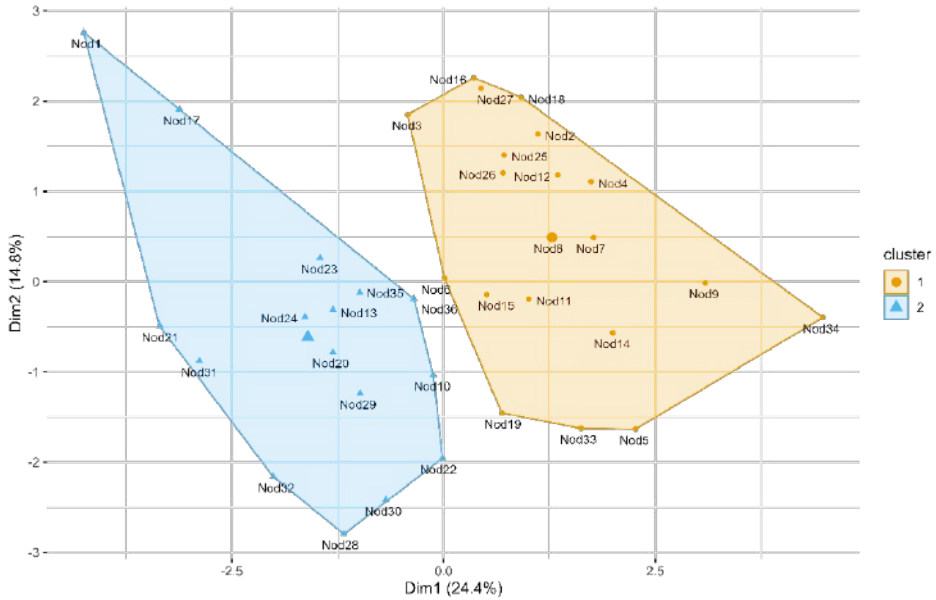

Figure 3-14 | Clusters obtained from k-means method in a two-dimensional map, using the mothership characteristics and other fishery-related data obtained in the current study, for the long-distance fishing fleet in the Ecuadorian mahi-mahi fishery.

Figure 3-15 shows two distinct vessel profiles based on cluster analysis. Cluster 1 includes vessels that follow a lower-investment, small-scale fishing strategy. These boats typically have lower horsepower engines, smaller crews, and fewer fiberglass vessels. Their operations are more localized, involving shorter travel distances. They also incur significantly lower maintenance and depreciation costs, indicating a cost-efficient approach. Interestingly, despite their smaller scale, these vessels use more hooks per vessel on average, possibly to offset their limited operational capacity.

Cluster 2, by contrast, represents larger, more capital-intensive operations. These vessels have more powerful engines, larger crews, and a higher number of fiberglass boats. They travel greater distances, conduct more frequent trips, and generally operate at a higher intensity. As a result, they have substantially higher maintenance and depreciation costs, reflecting larger investments in their fleet and equipment. While they generate higher revenues per trip, their profitability depends on maintaining frequent, high-yield operations to cover elevated operating costs.

These structural differences suggest two distinct strategies within the fleet: one prioritizing cost control and operational efficiency, and the other aiming to maximize output through greater investment and effort.

3.2 Fiberglass vessels

As previously mentioned, the fiberglass vessel database includes data from 68 vessels, evenly split between the ports of Esmeraldas and Santa Rosa. All vessels use longline fishing gear, which consists of a mainline with baited hooks spaced at regular intervals. The dataset comprises 81 variables covering fishing locations, vessel characteristics, operational details, and economic information. The economic data includes both fixed and variable costs, as well as revenue generated from fishing activities.

Interviews were conducted in April 2021. Of the respondents, 22 were shipowners (10 of whom also served as captains), 38 were captains, and eight were crew members.

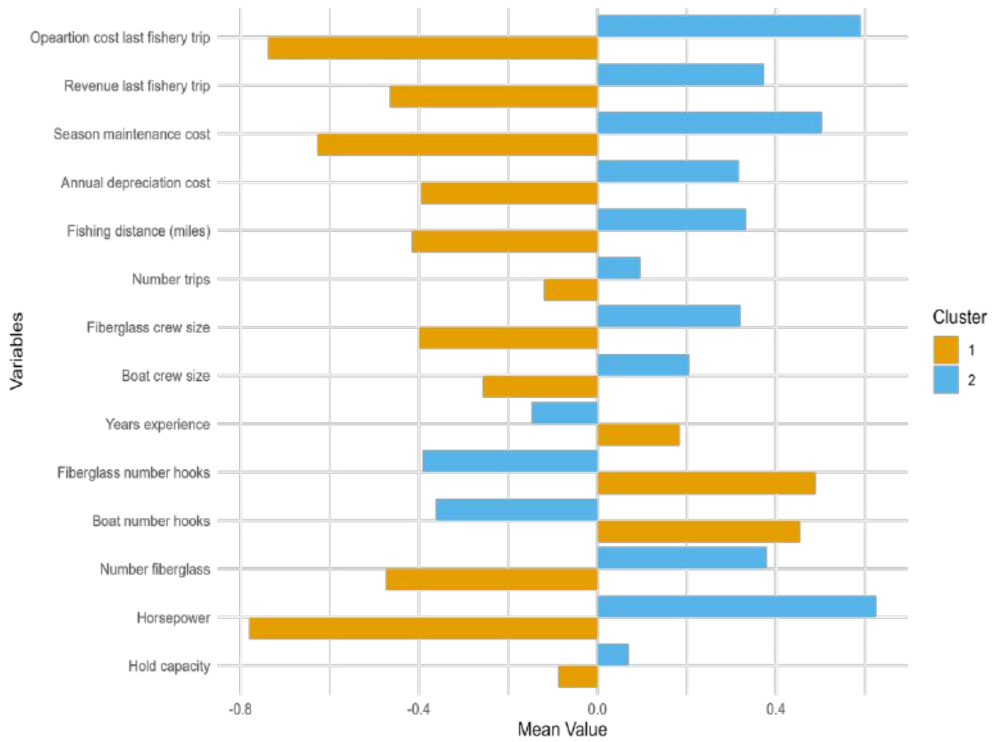

Figure 3-15 | Variable importance plot. Each bar represents the average (center) value of a given variable for vessels in a specific cluster identified by the K-means algorithm, for the mothership vessels of the Ecuadorian long-distance longline mahi fishery.

3.2.1 Fishery characterization

Table 3-8 shows the main statistics of the variables related to the fishery of the fiberglass vessels, including the shipowner's experience fishing mahi-mahi, the distance traveled to the fishing spot, and the number of hours spent traveling to the fishing spot (one way).

The interviewees reported a wide range of fishing experience, from one to 55 years, with a median of 20 years. During a typical fishing trip, fiberglass vessels traveled between 20-220 miles to reach fishing grounds, with a median distance of 70 miles. The median travel time to these locations was five hours.

Table 3-8 | Descriptive statistics of fishery-related variables for the fiberglass vessels considered in the current study.

Variable	Minimum	Median	Mean	Maximum	Standard deviation	n
Years experience fishing mahi-mahi	1.0	20.0	22.0	55.0	10.6	68
Distance to the fishing ground (miles)	20.0	70.0	83.4	220.0	50.1	68
Number of hours spent travelling to the fishing zone	1.0	5.0	5.6	12.0	2.8	68

Figure 3-16 presents a bubble plot illustrating the relationship between interviewees' years of fishing experience and the distance traveled to the fishing grounds. The data are categorized by the number of engines used in fiberglass vessels and the number of hours spent traveling to the fishing spot. The analysis shows no significant correlation between years of experience and travel time ($\tau = 0.08$, $p = 0.843$), nor between years of experience and distance traveled ($\tau = 0.01$, $p = 0.989$). As expected, a strong positive correlation is observed between travel time and distance traveled ($\tau = 0.80$, $p < 0.001$). Additionally, there are no significant differences in distance traveled, travel time, or years of experience, based on whether vessels use one or two engines (minimum $p = 0.060$).

Table 3-9 shows that all fiberglass vessels are equipped with outboard motors: 35.3% of the interviewees reported their respective vessel to have one motor, while 64.7% had two. Most vessels operate with three crew members (95.6%), while only three vessels reported working with two crew members. All vessels used surface longline gear, typically with J3, J4, or J5 hooks.

Most fiberglass vessel owners (91.2%) reported that fishing for *Dorado* (mahi-mahi) is their primary activity. Only six owners (8.8%) indicated that fishing is not their main occupation. Of these, three identified as vendors, one operated a tourist vessel, one was a municipal worker, and one also worked as a bricklayer.

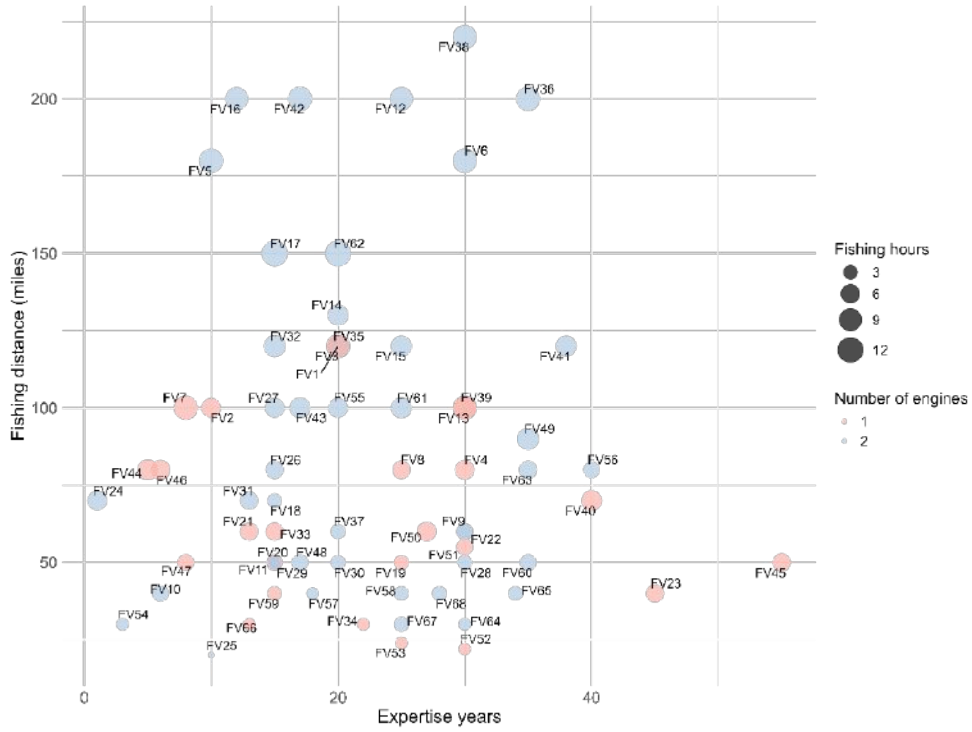

Figure 3-16 | Bubble plot showing the relationship between fishing experience of respondents and the distance traveled to fishing grounds, with bubble size representing fishing hours and color depicting the number of engines, for the inshore Ecuadorian mahi-mahi fishery.

Table 3-9 | Descriptive statistics of some key attributes of the fiberglass vessels considered in the current study, for the inshore Ecuadorian mahi-mahi fishery (part 1).

Variable	Category	N	% of total
Vessel type	Fiberglass	68	100
Port where the vessel is registered	Esmeraldas	34	50
	Santa Rosa	34	50
Type of propulsion	Outboard motor	68	100
Number of engines	1	24	35.3
	2	44	64.7
Fishing gear	Surface longline	68	100
Total number of crew members	2	3	4,4
	3	65	95,6
Dorado fishing as main activity	No	6	8.8
	Yes	62	91.2

Regarding vessel characteristics, **Table 3-10** presents descriptive statistics for of the fiberglass vessels used in the Ecuadorian inshore mahi fishery. Horsepower is not significantly related to hold capacity ($\tau = 0.03$, $p = 0.792$) or to the distance traveled to the fishing grounds ($\tau = 0.09$, $p = 0.384$). However, a significant positive relationship exists between hold capacity and distance traveled ($\tau = 0.35$, $p = 0.001$), suggesting that vessels with greater storage capacity tend to fish farther from shore.

The number of hooks per vessel differs significantly between fiberglass boats with one versus two engines ($W = 280.5$, $p = 0.001$). Vessels with two engines have a median of 355 hooks, while those with one engine have a median of 200 hooks.

Table 3-10 | Descriptive statistics of some key attributes of the fiberglass vessels considered in the current study, for the inshore Ecuadorian mahi-mahi fishery (part 2).

Variable	Min	Median	Mean	Max	SD	N
Horsepower	40	75	68.5	90	14.1	68
Number of hooks per fiberglass vessel	140	300	333.7	600	139.4	68
Vessel hold capacity (tons)	1	2	1.9	2	0.29	68

Figure 3-17 presents a bubble plot illustrating the relationship between distance traveled to fishing grounds, number of hooks, hold capacity, and crew size. The data analysis suggests that vessels with fewer crew members tend to travel shorter distances and use a smaller number of hooks.

There appears to be no clear relationship between fishing distance or the number of hooks used and vessel hold capacity. This is likely due to the relatively low variability in hold capacity across the majority of vessels.

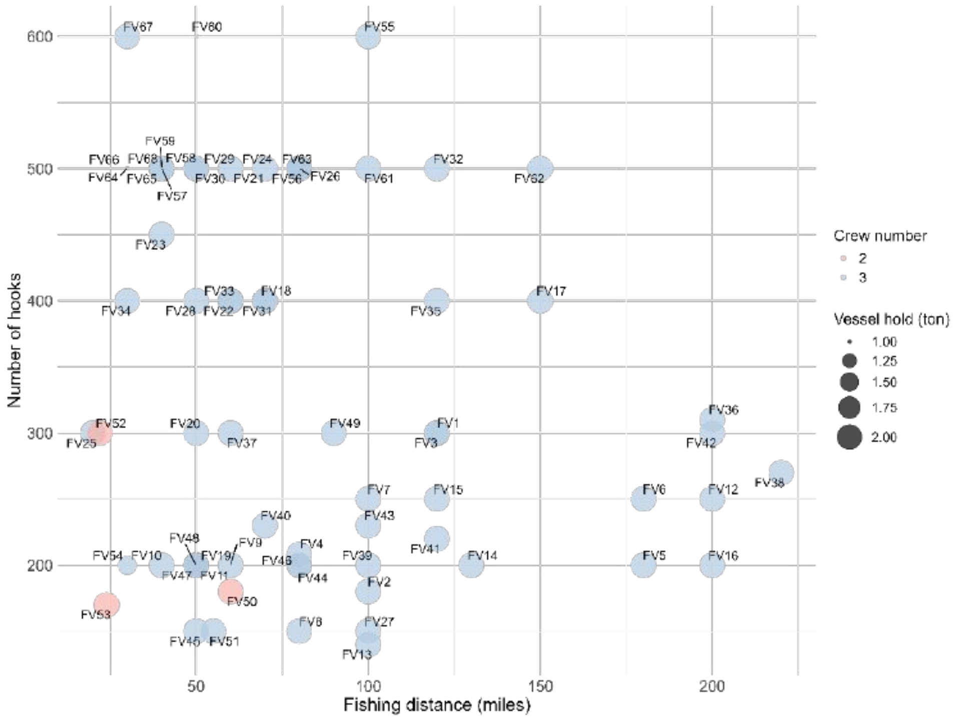

Figure 3-17 | Bubble plot showing the relationship between distance traveled to fishing grounds and number of hooks, with bubble size representing the hold capacity and color the number of fishers per vessel, for the inshore Ecuadorian mahi-mahi fishery.

3.2.2 Fishery costs

Regarding the operational costs and income from the last fishing trip, **Table 3-11** presents the statistics of the operation and fishery costs from the fiberglass vessels. Five main cost categories were identified: fuel, food, bait, ice, and transportation to the fishing port.

On average, fiberglass vessels incurred an operational cost of $366.00 per trip, with a median of $327.70. The minimum reported cost was $133.10, and the maximum was $697.00.

A significant positive correlation was found between total trip cost and the distance to the fishing grounds ($\tau = 0.70$, $p < 0.001$), indicating that longer travel distances lead to higher costs. However, there was no significant correlation between operational cost and years of fishing experience ($\tau = 0.07$, $p = 0.385$).

3.2.2.1 Fuel

During the most recent fishing trip, fiberglass vessels had a median fuel consumption of 162 gallons, with a median cost per gallon of $0.96. This resulted in a median total fuel cost of $158.80, ranging from $69.10 to $432.00.

No significant correlation was found between vessel horsepower and fuel cost per trip ($\tau = 0.03$, $p = 0.728$). However, as expected, there was a significant positive correlation between vessel hold capacity and fuel cost ($\tau = 0.33$, $p = 0.001$), suggesting that larger vessels tend to incur higher fuel expenses.

3.2.2.2 Food

The median food cost per trip was $100.00, with a range from $20.00 to $160.00. This corresponds to a median cost of $33.30 per crew member.

There was no significant correlation between the number of crew members and total food cost per trip ($\tau = 0.17$, $p = 0.100$).

3.2.2.3 Ice

Expenditure on ice in the last fishing trip had a median of $26.50, ranging from $7.00 to $80.00. Vessels used a median of six units of ice, with each unit costing approximately $4.00.

No significant correlation was found between either vessel horsepower ($\tau = 0.16$, $p = 0.126$) or hold capacity ($\tau = 0.10$, $p = 0.126$) and total ice cost.

3.2.2.4 Bait

The median bait cost was $47.50, with expenditures ranging from $20.00 to $160.00. Squid was the most expensive bait type, with a median cost of $60.00 per trip.

No significant correlation was found between bait cost and the number of crew members ($\tau = 0.26$, $p = 0.092$).

3.2.2.5 Land transportation to the fishing port

Mobilization (land transport) costs had a median value of $20.00, ranging from $3.00 to $72.00.

Table 3-11 | Descriptive statistics of operation and fishery costs of the last fishing trip, for the inshore Ecuadorian mahi-mahi fishery.

Variable	Minimum	Median	Mean	Maximum	Standard deviation	n
Fuel consumption (gallons)	72	162	202.0	450	102.6	68
Fuel price ($ per gallon)	0.95	0.96	0.98	1.2	0.06	68
Fuel cost by fishery ($)	69.1	158.8	196.3	432	96.9	68
Total food expenditure by fishery ($)	20	100	91.9	160	32.4	68
Food expenditure by crew member ($)	10	33.3	31.1	53.3	10.8	68
Bait cost (purchased, in $)	12	47.5	56.4	160	30.6	32
Frigate tuna		47.5	58.3			28
Squid		60	60			1
Small schooling fish		12	12			1
Chub mackerel		50	50			2
Ice blocks by fishing trip	2	6	7.3	20	3.5	68
Ice cost by fishing trip ($)	7	26.5	29.1	80	13.8	68
Transportation to the fishing port	3	22.1	20	72	15.8	68
Total expenditure by fishery ($)	**133.1**	**327.7**	**366.0**	**697.0**	**127.2**	**68**

Figure 3-18 illustrates the mean costs per item and their respective percentage of total operational costs during the most recent fishing trip. Fuel was the largest expense, accounting for 49.6% of total costs, followed by food (23.2%), bait (14.2%), and ice (7.3%).

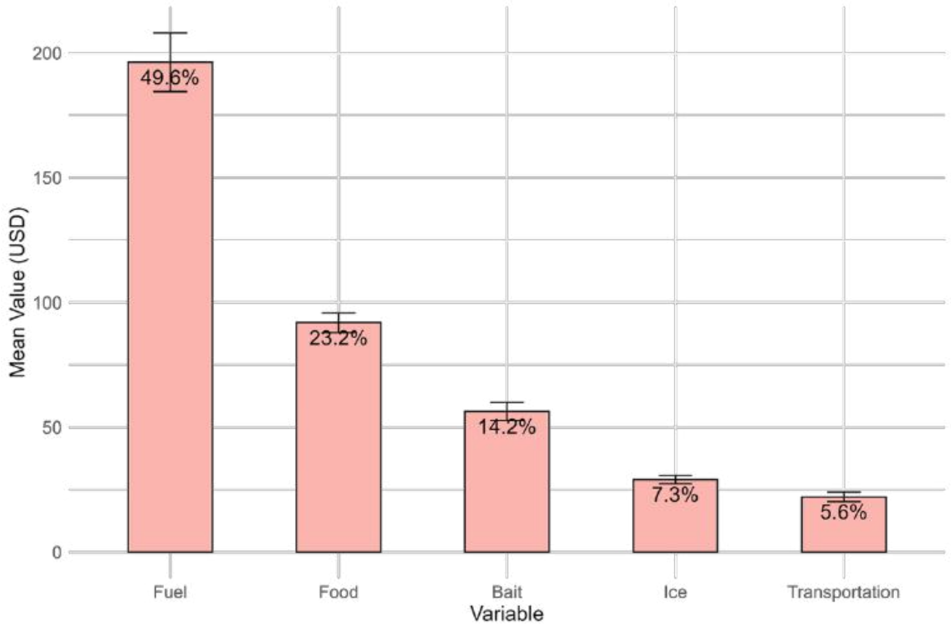

Figure 3-18 | Bar plot displaying costs per fishing trip by item and the respective percentage relative to the total cost, for the inshore Ecuadorian mahi-mahi fishery.

3.2.3 Fiberglass vessel maintenance costs

Variables related to fiberglass vessel maintenance and maintenance frequency were converted into seasonal maintenance costs, assuming a six-month fishing season. Table 3-12 presents the descriptive statistics for these costs per fishing season.

Engine maintenance accounted for the largest share, representing 26.9% of total maintenance costs, with a mean seasonal cost of $529.00. Fishing gear maintenance made up 23.2%, with an average seasonal cost of $456.60. Guarding costs accounted for 20.3%, while other costs represented 16.7%, and painting contributed the remaining 12.8% of total seasonal maintenance expenses.

Table 3-12 | Descriptive statistics for the 68 fiberglass vessels included in this study (inshore fishery), detailing maintenance costs by category.

Maintenance category	Min	Median	Mean	Max	SD	n
Engine	25.0	300.0	529.0	3,000.0	704.9	68
Paint	50.0	250.0	251.4	650.0	127.7	68
Fishing gear	20.0	300.0	456.6	3,000.0	558.3	68
Other	10.0	250.0	328.5	1,200.0	217.1	68
Guarding	120.0	360.0	399.3	1,800.0	264.8	68
Total	691.3	1,707.5	1,964.5	4,680.0	948.5	

Figure 3-19 presents violin plots of fiberglass vessel maintenance costs by category. The analysis reveals a greater variability in other costs, as well as fishing gear and engine maintenance expenses. In contrast, painting costs show a higher concentration of values around the median, indicating more consistent spending across vessels in this category.

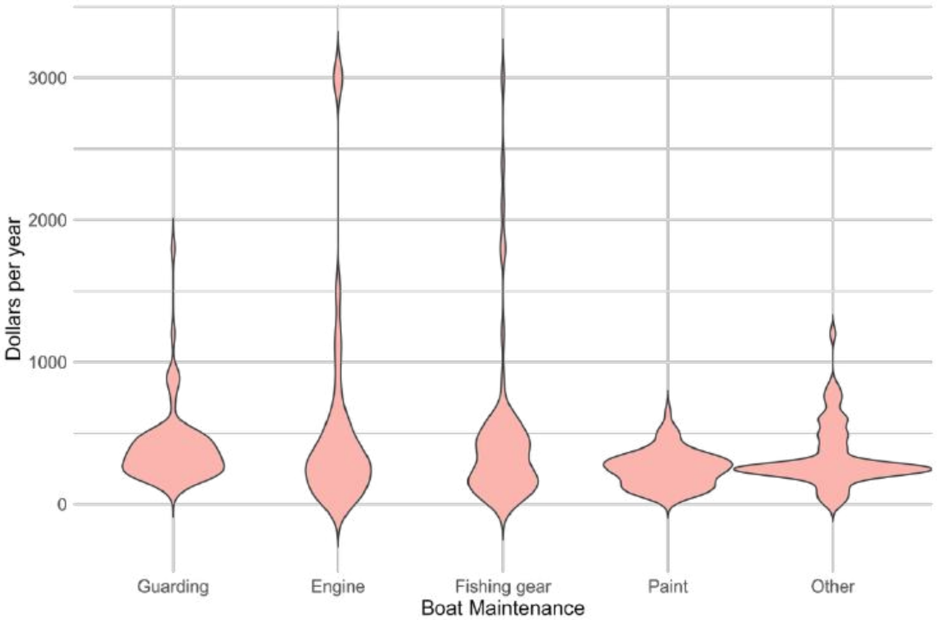

Figure 3-19 | Violin plot showing the variation in maintenance costs for different vessel components and fishing gear in the inshore Ecuadorian mahi-mahi fishery.

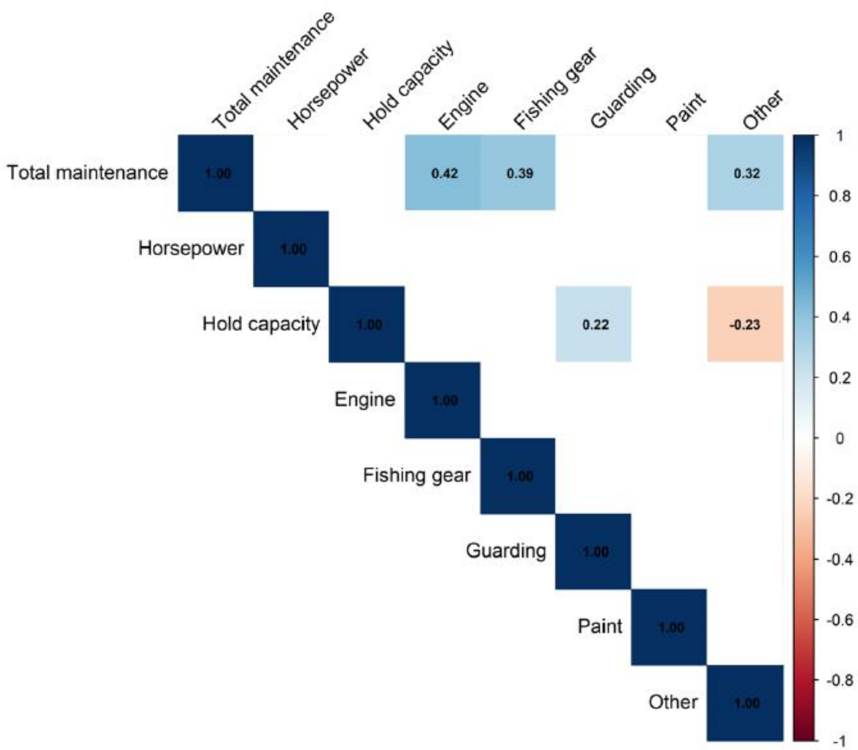

Figure 3-20 | Correlation plot displaying the relationship between the total maintenance cost and the mothership vessel variables and the specific maintenance cost, for the inshore Ecuadorian mahi-mahi fishery.

Figure 3-20 displays a correlation plot between total maintenance costs, fiberglass vessel characteristics, and specific maintenance cost categories. A significant positive correlation is observed between total maintenance costs and the costs associated with engine maintenance, fishing gear, and other expenses. However, hold capacity and engine horsepower are not significantly correlated with total maintenance costs. Additionally, hold capacity is positively correlated with guarding costs and negatively correlated with other maintenance costs. These results indicate that the engine and fishing gear have the highest influence on the total maintenance costs of a fishing vessel.

3.2.4 Annual depreciation of fishing equipment and vessels

As with the long-distance fleet, investments in vessels, engines, and equipment were considered to fully assess the total cost of fishing operations. This analysis includes the lifespan and acquisition cost of all key fiberglass vessel components: the hull, engine, onboard equipment, and fishing gear. No residual value is assumed for these assets at the end of their useful life. A detailed description of assumptions and data limitations is provided in **Appendix 1**.

Table 3-13 presents the annualized acquisition cost, calculated by dividing the total acquisition cost by the estimated lifespan of each component. The analysis indicates that capital investments result in an average annual depreciation of $3,278, with a median of $2,322, ranging from $950 to $15,400 per year. Of this, fishing gear contributes an average of $367 per year (median: $283), while the vessel itself accounts for an average of $2,911 annually (median: $1,982).

Table 3-13 | Descriptive statistics of the acquisition costs by year of the various key components of the fishing vessels (motherships) used in the inshore Ecuadorian mahi-mahi fishery.

Expense variable	Min	Median	Mean	Max	SD	Sample (n)
Vessel cost per year ($)	35	267	266	767	134	68
Engine value by year ($)	433	1,469	2,429	14,000	2,395	68
Equipment value by year ($)	67	167	217	1,500	207	68
Total vessel active cost by year ($)	780	1,982	2,911	14,400	2,406	68
Fishing gear value by year ($)	133	283	367	1,000	226	68
Total assets cost by year ($)	950	2,322	3,278	15,400	2,500	68

3.2.5 Catches, revenue, and profit

3.2.5.1 Revenue per fishing trip

Table 3-14 presents variables related to revenue from the most recent fishing trip. The sale price of mahi-mahi ranged from $1.60 to $4.00 per pound, with a median price of $2.55. The catch per trip also showed high variability, ranging from 170 to 2,500 pounds, with a median of 487.5 pounds.

Because total revenue depends on both sale price and catch volume, it also varied widely. Revenue from mahi-mahi sales ranged from $320 to $4,000, with a median of $1,410.90 and a coefficient of variation of 45.9%, indicating substantial variability across vessels.

Bycatch revenue had a median of $190, with sharks being the most reported bycatch (noted by nine vessels), followed by swordfish and *miramelindo* (likely escolar, *Lepidocybium flavobrunneum*), reported by four vessels. Other reported bycatch species included *picudo* (likely blue marlin or other billfishes), *albacora* (albacore, *Thunnus albacares*), and *cherna* (likely groupers, *Epinephelus* spp.).

The wide range in mahi-mahi catch, exhibiting a coefficient of variation of 66.8%, further emphasizes the variability in fishing success among the 68 fiberglass vessels surveyed.

Table 3-14 | Descriptive statistics for total mahi-mahi catches, landed value of mahi-mahi, and landed value of non-target species from the most recent fishing trip in the inshore Ecuadorian mahi-mahi fishery.

Variable	Min	Median	Mean	Max	SD	n
Mean sale price ($) per pound	1.6	2.6	2.7	4.0	0.8	68
Quantity of mahi-mahi (pounds)	170	487.5	558.8	2500	373.5	68
Mahi-mahi sale value ($)	320	1366	1410.9	4000	647.9	68
Sale of additional catch ($)	10	190	270.3	1400	313.5	23

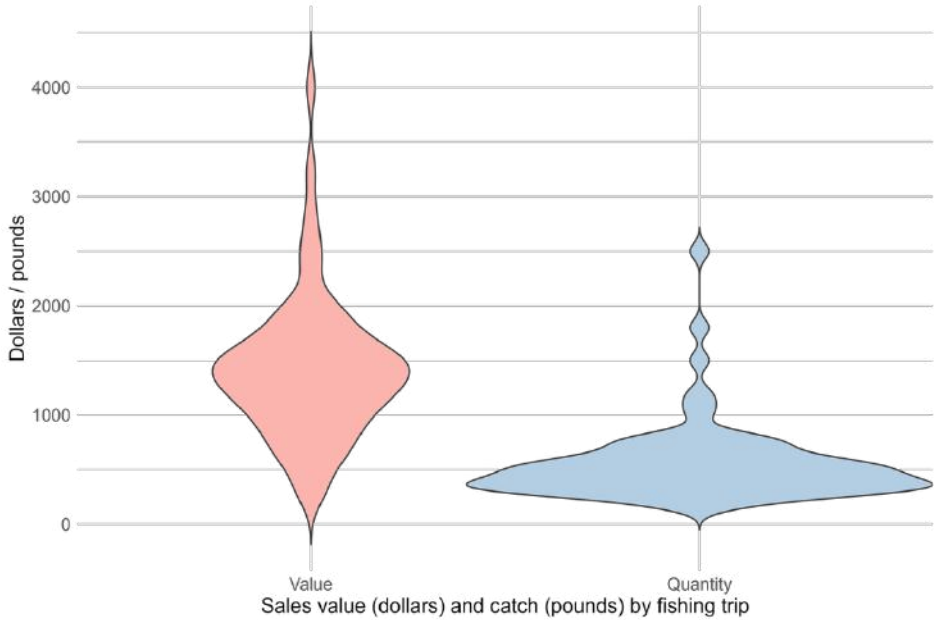

Figure 3-21 | Violin plot Income of mahi-mahi catch and the total catch (in pounds).

Figure 3-21 presents violin plots of mahi-mahi revenue (in $) and total catch (in pounds). As can be observed, both catch volume and revenue show a substantial variability among fiberglass vessels during their most recent fishing trip.

Figure 3-22 displays a correlation plot between total catch, fiberglass vessel characteristics, cost variables, and fishing trip attributes. Notably, total catch shows no significant correlation with any variable except for fishing hours to the fishing spot, which is negatively correlated. Surprisingly, these results suggest that longer travel times are associated with lower catches. In contrast, total costs are positively correlated with hold capacity, distance to the fishing grounds, and travel time, indicating that fishing crews with larger vessels, or travelling longer distances to fishing grounds, incur higher operational expenses.

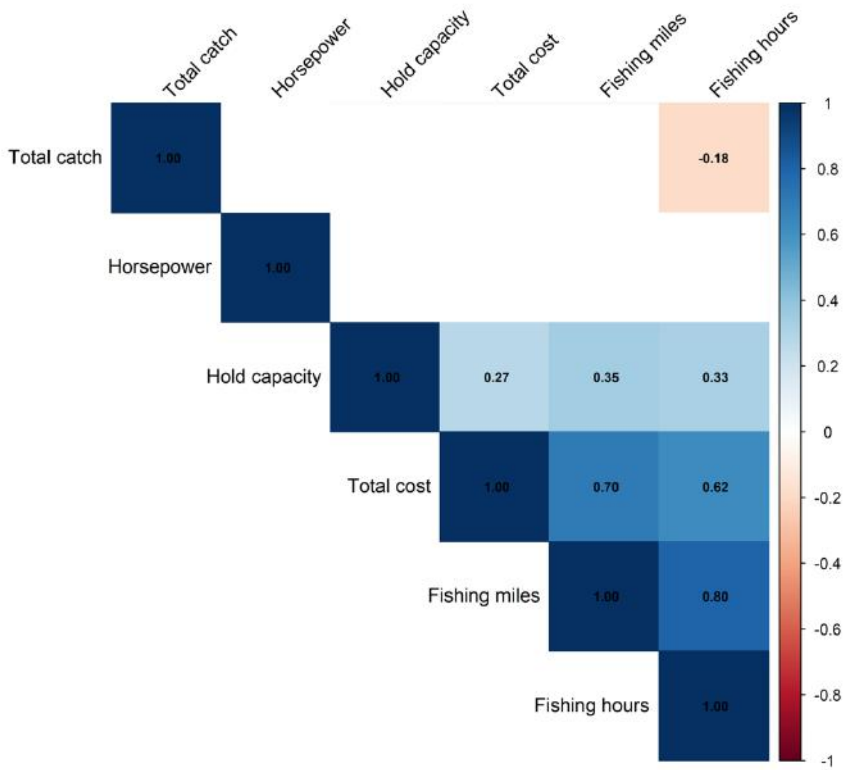

Figure 3-22 | Correlation plot between the total reported catches in the last fishing trip, some of the fishing vessels' characteristics (e.g., hold capacity), operational costs, and fishing trip characteristics, for the inshore Ecuadorian mahi-mahi fishery.

3.2.5.2 Profit per fishing trip

As noted in the previous section, operational profit was defined as the difference between the revenue from mahi-mahi sales and the direct operational costs of the fishing trip, excluding maintenance expenses.

Figure 3-23 presents a bubble plot of revenue versus trip costs for the most recent fishing trip. Each bubble is colored by profit and scaled (in size) by the number of crew members. The plot shows that none of the fiberglass vessels reported a loss during the fishing trip, indicating that all operations were at least marginally profitable when considering only direct costs.

Figure 3-23 Bubble plot illustrating the relationship between revenue (x-axis), total costs (y-axis), and crew size (bubble size) in the last fishing trip, for the inshore Ecuadorian mahi-mahi fishing fleet. Bubble color represents profit levels.

Figure 3-24 (violin plot) illustrates the costs and revenues (in $) from the most recent fishing trip for the inshore fiberglass vessels included in the study. The plot reveals greater variability in revenue compared to costs. As expected, this suggests that while operational costs remain relatively consistent across vessels, revenue is highly influenced by total catch (which varies significantly) and the price per pound of mahi-mahi, both of which are subject to higher unpredictability.

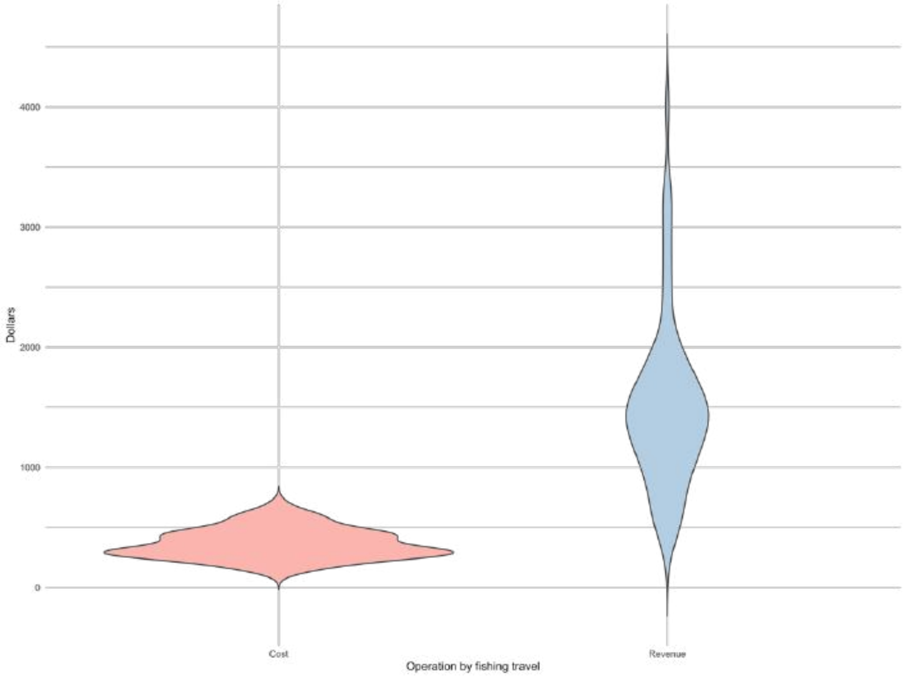

Figure 3-24 | Violin plot showing the distribution of operational costs and revenue from the last fishing trip for the inshore fleet of the Ecuadorian mahi-mahi fishery.

3.2.5.3 Seasonal total catch and profit estimates

Like the long-distance fleet, this section presents estimates of revenue, operational costs, vessel maintenance costs per season, and annual depreciation of fishing gear and vessels. These calculations are based on the average number of fishing trips during the whole season.

To estimate the total seasonal catch, the mean number of fishing trips per season (mean = 7.9; median = 6.0; SD = 6.9; range = 1–39) was calculated and then multiplied by the average catch per trip. This estimate was then used to calculate seasonal revenue and seasonal costs, following the same methodology applied to the long-distance dataset.

Using these estimates for seasonal revenue, operational costs, and maintenance costs, the seasonal profit was also calculated. As already noted, this profit estimate does not include asset depreciation, taxes, or interest, and therefore reflects EBITDA (Earnings Before Interest, Taxes, Depreciation, and Amortization) – a standard indicator of operating profitability.

Figure 3-25 presents the estimated seasonal revenue, operational costs, fiberglass vessel maintenance costs, and annual depreciation costs for fishing gear and vessels. When considering only operational costs, all fiberglass vessels had profit in the 2021 season. However, when maintenance costs are included, 19.1% of vessels operated at a loss. If depreciation costs are also factored in, the proportion of vessels showing a loss increased to 42.6%.

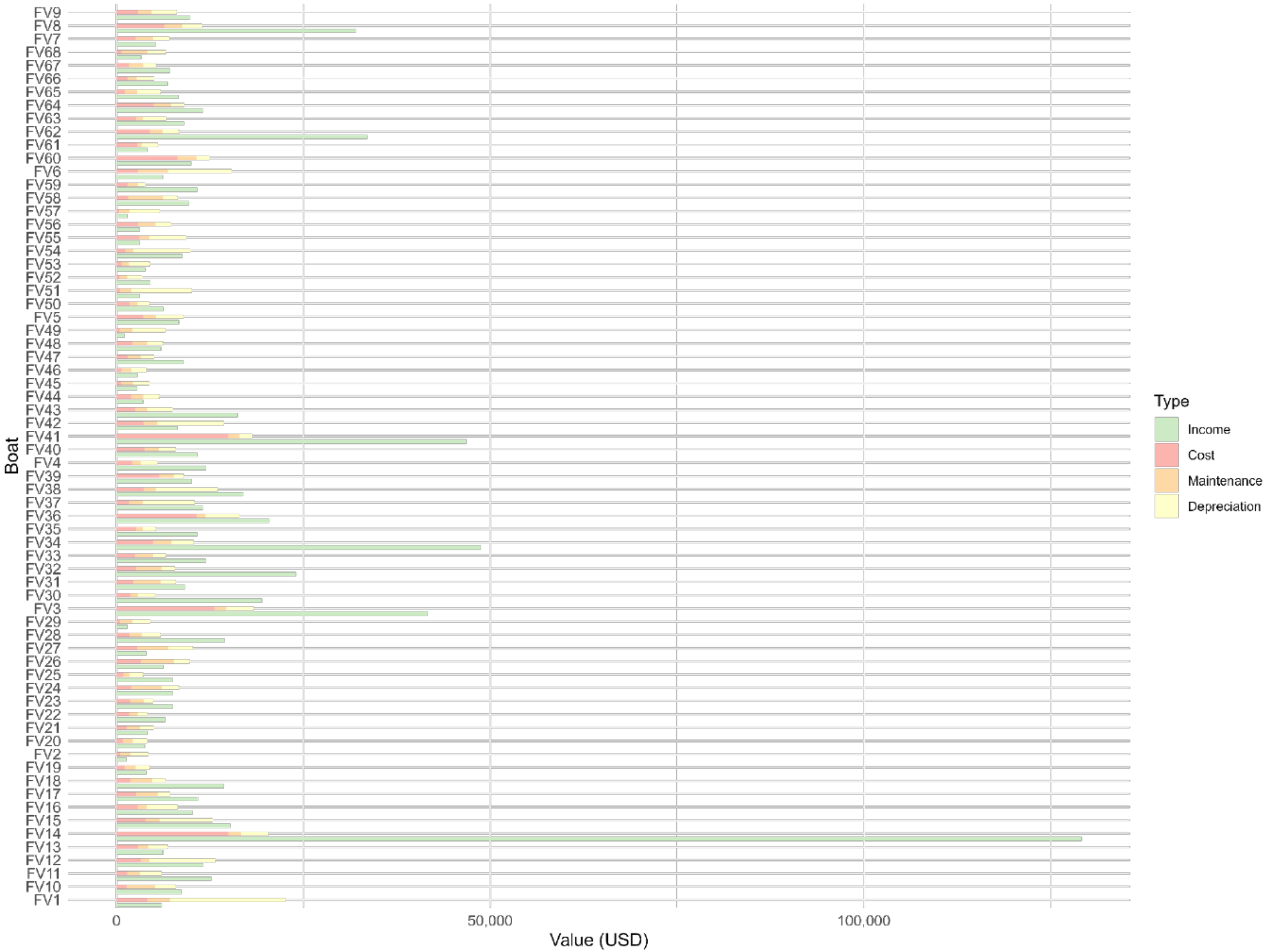

Figure 3-25 | Bar plot showing total seasonal revenue, total operational costs, total maintenance costs, and depreciation costs of mothership vessels, for the inshore Ecuadorian mahi-mahi fishing fleet.

It is important to note that these estimates assume the catch per trip remains constant, based on values observed during the most recent fishing trip. As mentioned before, this assumption is likely unrealistic, as it relies on a single data point that may not accurately reflect a typical or average fishing trip.

Figure 3-26 presents a bubble plot of seasonal revenue versus total seasonal costs (including both operational and maintenance costs). Bubbles are colored by profit and sized according to the number of crew members.

A significant positive correlation was found between seasonal revenue and total seasonal costs (τ = 0.40, $p < 0.001$), suggesting that higher revenues are generally associated with higher expenditures

3.2.6 Cluster analysis

The cluster analysis was used to try to identify possible different groups within the inshore fleet, based on their attributes and fishing-related aspects. Using the k-means clustering method, we identified two distinct clusters, based on fiberglass vessel characteristics, fishing operations, and profitability. The variables used in the clustering analysis included: engine horsepower, hold capacity (in tons), number of hooks per vessel, total crew size, number of trips per season, years of experience fishing mahi-mahi, distance traveled to fishing grounds (in miles), seasonal maintenance costs, operational costs from the last fishing trip, and revenue from the last fishing trip.

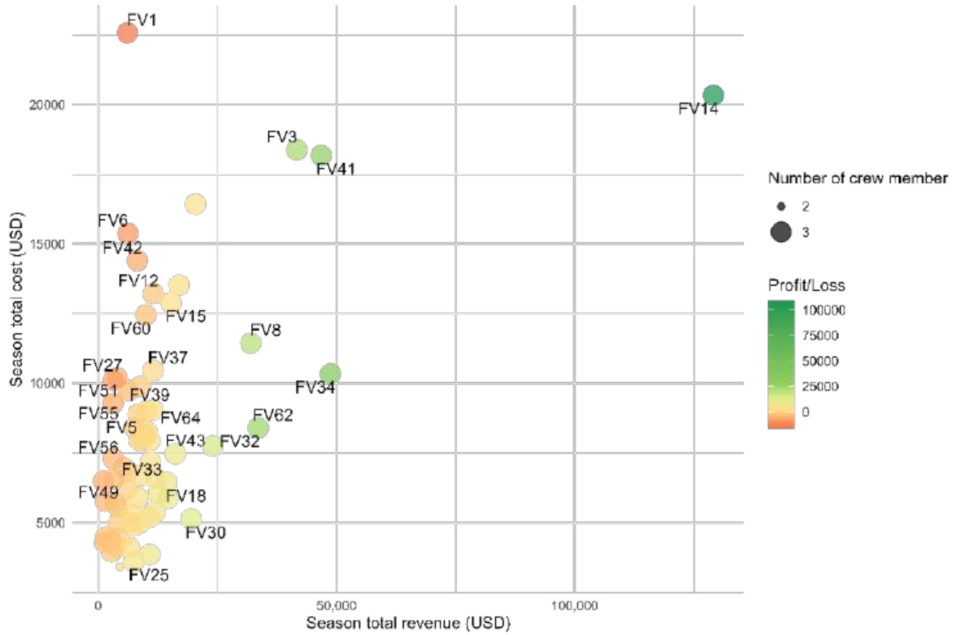

Figure 3-26 Bubble plot illustrating the relationship between seasonal revenue (x-axis), seasonal costs (y-axis, including operational, maintenance, and depreciation costs), and the number of crew members per vessel (bubble size), for the inshore Ecuadorian mahi-mahi fishing fleet. Bubble color represents profit levels.

The Hopkins statistic of 0.78 confirms that the dataset is suitable for clustering. The Davies-Bouldin Index reaches a value of 1.4, and the Within-Cluster Sum of Squares (WCSS) peaks at 603.1 when using two clusters. The mean Silhouette Score of 0.34 and Dunn Index of 0.22 suggest that while the clusters are distinguishable, they are moderately compact and separated.

Figure 3-27 shows the two clusters generated using the k-means method, visualized on a two-dimensional map. Among them, Cluster 1 represents high-activity, high-cost operations, while Cluster 2 consists of vessels with lower activity levels and investment.

Further details are provided in **Figure 3-28**, where Cluster 1 is characterized by vessels with higher fishing activity, greater operational costs, more experienced fishers, and higher horsepower engines. These vessels undertake more frequent and longer trips, and they incur significantly higher maintenance and depreciation expenses, reflecting substantial investment in equipment and upkeep.

In contrast, Cluster 2 includes vessels with lower horsepower, reduced fishing activity, and fewer trips per season. These vessels generally travel shorter distances and operate with lower maintenance and depreciation costs, indicating a more conservative and cost-conscious investment strategy.

The clusters can be summarized as follows:

- **Cluster 1:** *High-activity, high-cost fishery*
  Comprising vessels with experienced crews, higher engine power, and frequent long-distance trips. These vessels exhibit greater operational intensity and higher investment, as reflected in their maintenance and depreciation costs.

- **Cluster 2:** *Lower-cost operations fishery*
  Includes vessels with lower fishing frequency, reduced horsepower, and shorter trip distances. While their per-trip revenue and costs may be slightly higher in some cases, they follow a less intensive, more cost-efficient operational model.

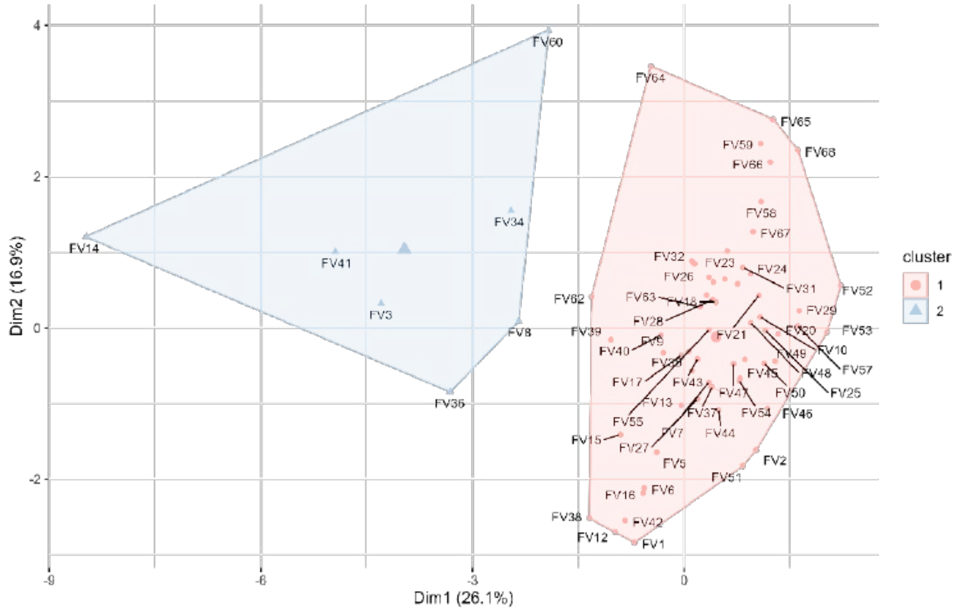

Figure 3-27 Clusters obtained from k-means method in a two-dimensional map, using the fiberglass vessels characteristics and other fishery-related data obtained in the current study, for the inshore fishing fleet in the Ecuadorian mahi-mahi fishery.

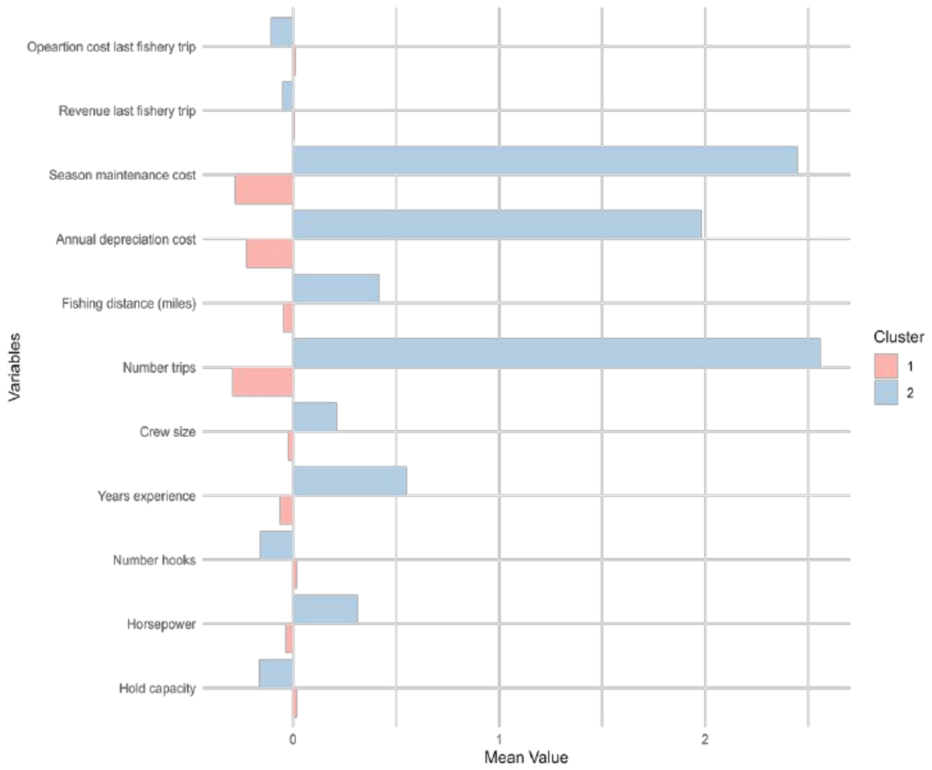

Figure 3-28 | Variable importance plot. Each bar represents the average (center) value of a given variable for vessels in a specific cluster identified by the K-means algorithm, for the fiberglass vessels of the Ecuadorian inshore longline mahi fishery.

3.3 Mahi-mahi catches and economic sustainability analysis

3.3.1 Mahi-mahi catches, fishery revenue, and costs per season

The number of registered mothership vessels in Ecuador's longline fishery is 228, with an estimated 50% targeting mahi-mahi. Based on this assumption, total seasonal catch, revenue, and cost estimates are presented in **Table 3-15**. This 50% proportion of the long-distance longline fleet was used to infer the population size for extrapolating seasonal mahi-mahi catch and associated economic indicators. The table also includes the mean and standard error of each estimate.

Table 3-15 | Estimates and standard errors for total catch per season, seasonal revenue, and seasonal operational and maintenance costs by fishery, for the long-distance fishing fleet in the Ecuadorian mahi-mahi fishery.

Estimate	Mean	Standard Error
Total catch (metric tonnes)	5,386	242
Total season revenue ($)	18,610,773	1,296,858
Total season cost ($)	7,178,886	191,787
Total maintenance cost ($)	2,938,716	126,716
Total depreciation cost ($)	4,219,940	106,420

The results indicate that the mothership-based mahi-mahi fishery in 2021 was estimated to produce a **total catch of 5,386 metric tonnes** per season (95% CI: 4,911–5,860), generating an **estimated revenue of $18,610,773** (95% CI: $16,068,931–$21,152,615). Operational costs were estimated at **$7,178,886** (95% CI: $6,802,983–$7,554,789), with

maintenance costs of $2,938,716 (95% CI: $2,690,353–$3,187,079) and **depreciation costs of $4,219,940** (95% CI: $4,199,082–$4,240,798). The resulting **net profit** for the mothership fleet was approximately **$4,273,231**, or an average of **$37,485 per vessel** per season.

For the fiberglass vessel population, Table 3-16 presents estimated total catch, seasonal revenue, and costs in 2021. These estimates assume that 50% of the 3,217 registered fiberglass vessels targeted mahi-mahi. Using this inferred population, the table reports the estimated catch and associated economic figures per fishing season, including mean values and standard errors.

Table 3-16 | Estimates and standard errors for total catch per season, seasonal revenue, and seasonal operational and maintenance costs by fishery, for the inshore fishing fleet in the Ecuadorian mahi-mahi fishery.

Estimate	Mean	Standard error
Total catch (metric tonnes)	3,202	74
Total season revenue ($)	19,344,923	463,103
Total season cost ($)	4,623,926	102,618
Total maintenance cost ($)	3,161,101	38,047
Total depreciation cost ($)	5,274,493	100,283

Based on the results, the fiberglass vessel fleet is estimated to have landed **3,202 metric tonnes** of mahi-mahi in 2021, with a 95% confidence interval, ranging from 3,056 to 3,347 tonnes. This catch generated a total estimated revenue of approximately **$19.3 million** (95% CI: $18.4 to 20.3 million).

Estimated seasonal expenses for this fleet include **operational costs** of about **$4.62 million** (95% CI: $4.42 to 4.83 million), **maintenance costs** of **$3.16 million** (95% CI: $3.09 to 3.24 million), and **depreciation costs** of approximately **$5.27 million** (95% CI: $5.08 to 5.47 million). Based on these estimates, the annual **net profit** for the fiberglass fleet is around **$6.29 million**, which corresponds to an average profit of **$3,906 per vessel per season**.

By combining the estimated catches from both the mothership and fiberglass fleets, the **total annual mahi-mahi catch in Ecuador** is estimated at **8,588 metric tonnes**, with a 95% confidence interval ranging from 7,969 to 9,207 tonnes.

3.3.2 Economic sustainability analysis

This section presents forecasts of costs and revenue to assess their impact on the economic sustainability of the mahi-mahi fishery. These estimates assume that the mean values observed in the dataset accurately represent a typical fishing trip and respective catches. However, since the data are drawn from a single fishing event, which was close to the end of the season, this assumption may limit the accuracy of the projections, and results need to be interpreted with caution.

Figure 3-29 presents a forecast of the mothership-based mahi-mahi fishery profit as a function of changes in fuel price, including a 95% confidence interval. A blue dot marks the observed mean fuel price of $1.248 per gallon for mothership vessels. The analysis indicates that if fuel prices exceed $3.11 per gallon (representing an increase of over 150%) and all other costs remain constant, the fishery would begin to operate at a financial loss.

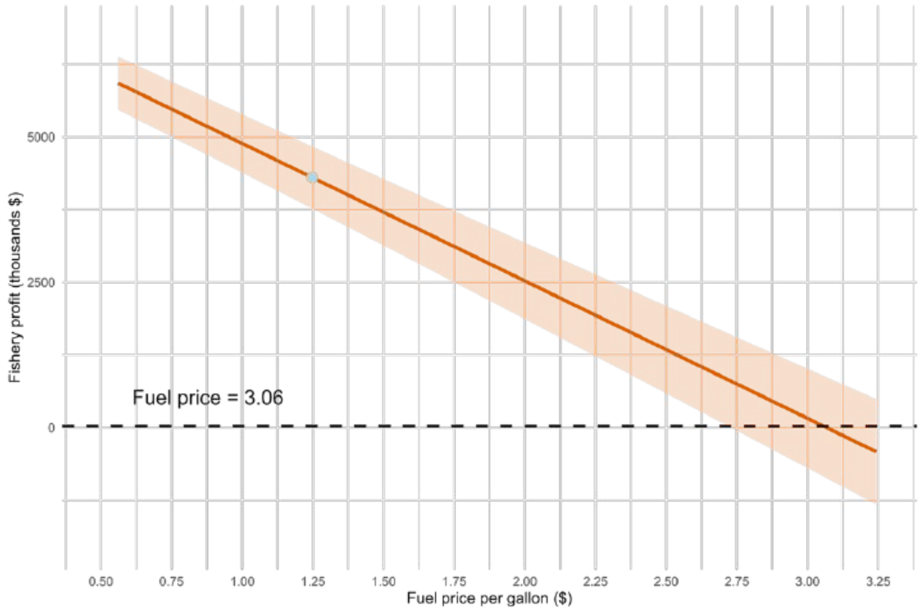

Figure 3-29 | Projected long-distance mahi-mahi fishery profit as a function of changes in fuel price. Shaded bands represent the 95% confidence interval of the estimates. The blue dot indicates the estimated profit based on the mean fuel price for mothership vessels ($1.248 per gallon)

Figure 3-30 illustrates a forecast of fiberglass vessel mahi-mahi fishery profit as a function of fuel price changes, with a 95% confidence interval. A blue dot marks the observed mean fuel price of $0.982 per gallon for fiberglass vessel. The analysis shows that if fuel prices exceed $3.81 per gallon (representing a 289% increase over the current average for the inshore fleet) and all other costs remain constant, the fishery would operate at a loss.

It is interesting to note that the mean cost per gallon of fuel for the fiberglass vessels was 79% lower than that of the mothership vessels, which significantly impacts the profit values of both fleets.

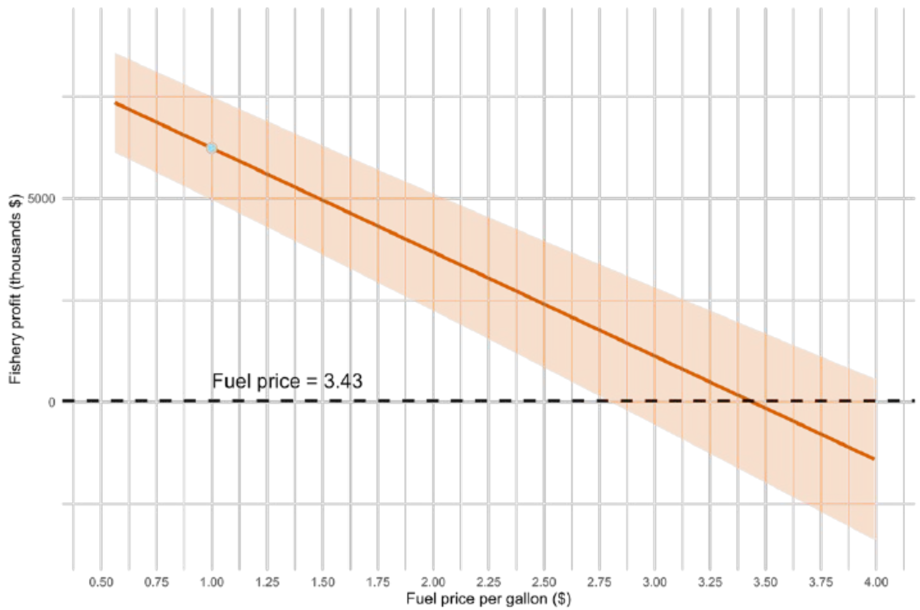

Figure 3-30 | Projected inshore mahi-mahi fishery profit as a function of changes in fuel price. Shaded bands represent the 95% confidence interval of the estimates. The blue dot indicates the estimated profit based on the mean fuel price for fiberglass vessels ($0.982 per gallon)

Figure 3-31 shows a forecast of mothership-based fishery profit as a function of changes in the mahi-mahi sale price, with a 95% confidence interval. An orange dot marks the observed mean sale price of $1.567 per pound for mothership vessels. The analysis indicates that a 75% decrease in the sale price, down to $1.18 per pound, would result in the fishery operating at a loss, assuming all other costs remain constant.

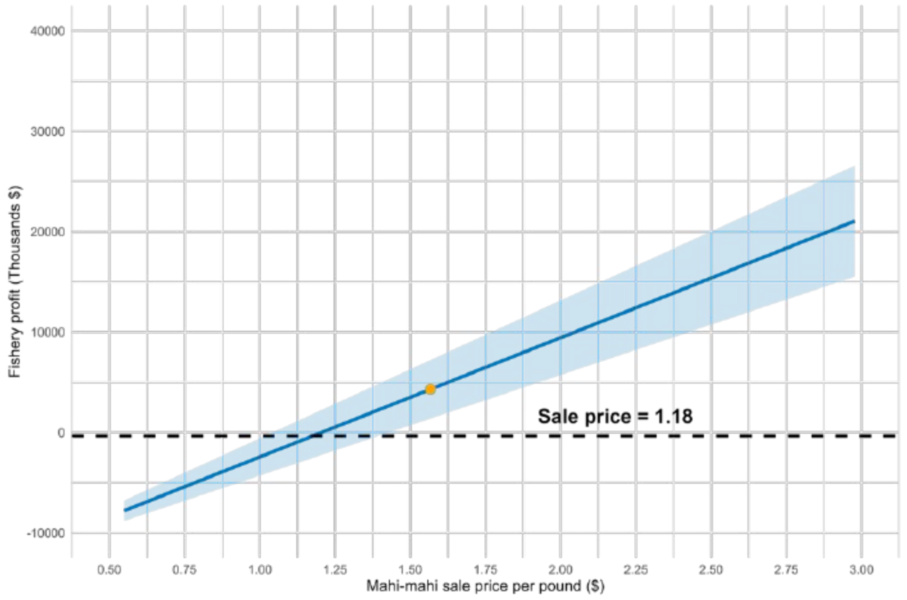

Figure 3-31 | Projected long-distance mahi-mahi fishery profit as a function of changes in mahi-mahi sale price. Shaded bands represent the 95% confidence interval of the estimates. The orange dot indicates the estimated profit based on the mean sale price for mothership vessels ($1.567 per pound). The dashed horizontal line indicates the mahi-mahi sale price needed for a 0 profit.

Figure 3-32 presents a forecast of fiberglass vessel fishery profit as a function of mahi-mahi sale price changes, with a 95% confidence interval. An orange dot marks the observed mean sale price of $2.740 per pound for fiberglass vessels. The analysis indicates that a 63% decrease in the sale price (down to $1.72 per pound) would result in the fishery operating at a loss, assuming all other costs remain constant.

Likewise, as observed in the analysis of fuel price changes, the average sale price of mahi-mahi for the fiberglass vessel fleet is significantly higher ($2,740) than that of the mothership-based fishery ($1,567). This difference in average sale price has a strong impact on the profit values of both fleets.

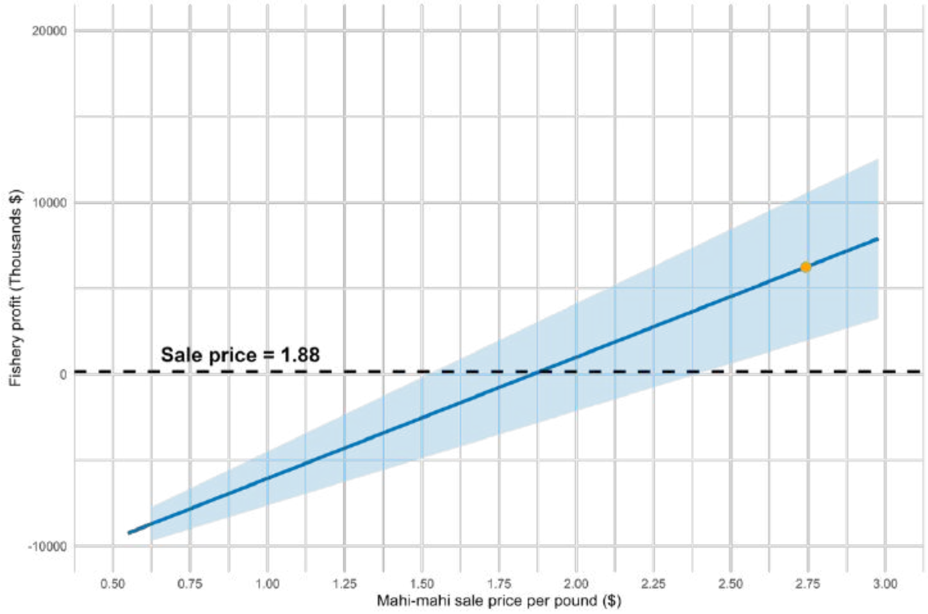

Figure 3-32 | Projected inshore mahi-mahi fishery profit as a function of changes in mahi-mahi sale price. Shaded bands represent the 95% confidence interval of the estimates. The orange dot indicates the estimated profit based on the mean sale price for mothership vessels ($2.740 per pound). The dashed horizontal line indicates the mahi-mahi sale price needed for a 0 profit.

4 CONCLUSIONS AND FINAL REMARKS

This study represents an important contribution to the knowledge of the economic dynamics and current profitability of Ecuador's mahi-mahi fishery, particularly within the long-distance and small-scale fleet segments. To the best of our knowledge, this is the first of its kind for the Ecuadorian longline mahi fishery and provides critical baseline information on operational costs, revenues, and profit margins across different vessel types and fishing strategies.

Based on our analysis, in 2021 the **long-distance longline fleet** targeting mahi-mahi caught an estimated **5,400 tonnes**, generating approximately **$19 million** in revenue. The **inshore fleet**, by comparison, was estimated to land around **3,200 tonnes** yet generated a similar revenue of about **$19 million**. This higher revenue despite lower volume is likely explained by a **considerably higher sale price per pound**, nearly double that of the long-distance fleet. The price difference is likely due to better product quality, as mahi-mahi from the inshore fleet is generally landed in fresher condition.

Our results highlight that, while many vessels appear to operate profitably when considering direct trip costs, profitability becomes much more constrained when accounting for maintenance and capital depreciation. In fact, our analysis suggests that a substantial proportion of vessels, especially from the inshore fleet, operate at a net seasonal loss once full operating and asset costs are included. However, since the data were collected from a single fishing event near the end of the season, these conclusions should be interpreted with caution and considered carefully.

We also found that economic performance is highly sensitive to two key external factors: market dynamics (such as fluctuations in mahi-mahi sale prices) and resource availability, which directly affects catch volume. This sensitivity is important, as declines in mahi-mahi abundance or price could lead fishers to shift effort toward other species, including vulnerable shark populations. Such shifts could have serious ecological consequences and pose long-term risks to the sustainability of both the ecosystem and the fishery itself.

These factors introduce considerable uncertainty into the fishery and highlight the need for economic risk management alongside traditional biological management measures. To ensure the long-term economic sustainability of the fishery, it is essential to strengthen the current governance frameworks that address not only stock conservation (for example, through science-based rules on fishing effort and stock status), but also market conditions. Efforts should thus also focus on improving price stability and enhancing transparency throughout the supply chain.

Finally, it is important to note some of the limitations and caveats of this study. Despite being based on a relatively representative sample of the fleet, the dataset was restricted to a limited number of fishing trips, primarily focusing on the last trip of the season. In addition, missing key information on fishing locations and other operational details may have introduced some level of uncertainty and potential bias in the estimations.

Future research should aim to expand the dataset to cover a greater number of fishing events across the full season and collect more granular data on costs, sources of revenue (e.g., on all the bycatch species), and fishing effort, including detailed spatial data on fishing grounds. This would not only improve the accuracy of future economic assessments but also support the design of more effective management and policy interventions for the mahi-mahi fishery.

ACKNOWLEDGEMENTS

This publication, developed within the framework of the "Por la Pesca" project, was made possible thanks to the generous support of the American people through the United States Agency for International Development (USAID).

The contents of this document are the sole responsibility of the authors and do not necessarily reflect the views of USAID or the United States government.

We would also like to extend our sincere thanks to all the fishers, vessel owners, and crew members of the Ecuadorian longline mahi-mahi fishery who generously contributed their time and shared valuable information through the questionnaires. Their participation was essential to the success of this research and is deeply appreciated.

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APPENDICES

Appendix 1: Data cleaning and imputation process

The data preparation process began with cleaning and revising the database to ensure compatibility with R for subsequent analysis. Variable names were reviewed to ensure they conformed to R's requirements, and any inconsistencies or deviations were corrected. Categorical variables were converted into factors, and discrepancies in formatting or data types were resolved. Missing values were marked as "NA" (Not Available).

During the imputation process, several steps were taken to handle missing data across both mothership and fiberglass boat datasets. These steps were applied to the following categories: operational costs, maintenance costs, depreciation costs, sale price and catch, and fishing says and fishing trips.

The assumptions and imputations made per category are described below.

Operational costs

When information regarding reported costs was missing, the missing values were imputed using the mean value from other boats or based on reasonable assumptions, such as using the average of similar boats.

Maintenance costs

Maintenance costs, including those for the engine, fishing gear, and navigation systems, were imputed when data was missing. For boats with missing maintenance frequency data (e.g., for navigation systems), mean values from similar boats were used. All maintenance costs were normalized to account for the assumed fishing season lengths: four months for mothership boats and six months for fiberglass boats.

Depreciation costs

In some cases, responses from fishers contained significant outliers. As a result, we used average values provided by experts for key components like the vessel, hull, engine, and fishing gear. Specifically, the assumed mean lifespan for vessels was 30 years, and for hulls, it was 60 years. These values were applied uniformly to all mothership boats due to the lack of detailed data. For engines, missing values and outlier cases were adjusted using a mean lifespan of 5 years.

Fishing gear values were also adjusted for outliers. The average value for fishing gear without a winch was set at $3,000, while for fishing gear with a winch, it was $7,000, resulting in an estimated total fishing gear value of around $10,000 per mothership boat. For fiberglass boats, the average fishing gear value was set at $1,500, with a 3-year average lifespan for the gear.

It is important to note that fishing gear undergoes frequent maintenance and replacement, which extends its usable life. Specifically, a mothership's winch is expected to last an average of five years, though higher-quality winches may last 10 years or more with proper maintenance.

Sale price and catch

The dataset for mothership vessels included information on the total catch of mahi-mahi during the last fishing trip, the estimated sale value of that catch, and the mean sale price for mahi-mahi per boat for each month (from October to April).

Because the reported values were highly inconsistent, the total revenue was estimated by multiplying the mean sale price of mahi-mahi (for all reported months) by the total reported catch. The total revenue reported by interviewees for mahi-mahi was not used. However, the reported value for bycatch was included, as no other information was available.

Fishing Days and Fishing Trips

The dataset for mothership vessels also reported the number of days required to reach the fishing spot, as well as the total number of days for the first, second, third, and fourth fishing trips. We used this data to estimate the number of days actively fishing and the number of days spent traveling to and from the fishing spot. To do this, we calculated the mean number of days for the first, second, third, and fourth trips, providing an indicator of the total days spent traveling.

Missing values for fishing-trip-related data were imputed using the median of available values. For boats with missing data for fishing days and trip days, imputation was done based on the mean values from boats with similar characteristics.

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