Colegio de Postgraduados

Economic performance of the hake (*Merluccius productus* Aires) fishery in the Gulf of California

Mendoza-Portillo, Francisco, J.[1*]; **Ramírez-Rodríguez, Mauricio**[2]; **Hernández-Trejo, Victor**[1,3]

[1] Universidad Autónoma de Baja California Sur. Departamento Académico de Economía. Carretera al Sur, km. 5.5, C.P. 23085, La Paz, B.C.S. México.
[2] Instituto Politécnico Nacional. Centro Interdisciplinario de Ciencias Marinas. Av. Instituto, Politécnico Nacional s/n, Playa Palo de Sta. Rita, 23096 La Paz, B.C.S.México.
[3] Red de investigación socioeconómica para la conservación y manejo del Corredor Marino del Pacífico Tropical Oriental (Red-MOPTO). Francisco Andrade Marín, E6-122 y Av. Eloy Alfaro, Quito, Ecuador.
* Correspondence: fjmendozaportillo@gmail.com

Abstract

Objective: Analyze the Pacific hake (*Merluccius productus*) fishery in the northern Gulf of California from 2010 to 2021 to evaluate fleet performance, profitability, and implications for a quota system.

Design/methodology/approach: Information on fleet composition, fishing effort, catch efficiency, and economic indicators was analyzed for small and large vessels. Net cash flow, cost-benefit ratio, and return on investment were calculated. A break-even analysis was conducted to estimate the minimum harvest required to sustain fleet operations.

Results: Small vessels were more numerous and active, while large vessels showed 1.5 times higher efficiency. Average catch per vessel rose from 30 t in 2010 to 108 t in 2021, and CPUE in large vessels increased from 2 t/d to 6 t/d. In 2021, small vessels recorded negative returns (net cash flow: −MX$176,604; C/B=0.90; ROI=−10%), while large vessels achieved positive outcomes (MX$337,735; C/B=1.13; ROI=12%). Break-even analysis indicated that sustaining half the fleet required 7,798 t, equal to 75% of the proposed TAC.

Limitations/Implications: Market price variability and environmental fluctuations may affect results beyond the study period.

Findings/Conclusions: Quota systems must consider efficiency disparities. Implementing quotas, monitoring, and stakeholder participation is essential to prevent overfishing and ensure sustainability.

Keywords: Economic performance, cost-benefit ratio, return of investment, Gulf of California, fisheries management.

Citation: Mendoza-Portillo, F. J., Ramírez-Rodríguez, M., & Hernández-Trejo, V. (2026). Economic performance of the hake (Merluccius productus Aires) fishery in the Gulf of California. *Agro Productividad*. https://doi.org/10.32854/k7kd5272

Academic Editor: Jorge Cadena Iñiguez
Associate Editor: Dra. Lucero del Mar Ruiz Posadas
Guest Editor: Juan Francisco Aguirre Medina

Received: September 24, 2025.
Accepted: December 27, 2025.
Published on-line: March XX, 2026.

Agro Productividad, 19(1). January. 2026. pp: 183-199.

INTRODUCTION

Excess fishing capacity, generated by increased fishing effort or technological improvements in fleets, has been recognized as one of the factors threatening fishery sustainability, with ecological, economic, and social consequences (FAO, 2022; Zhang *et al.*, 2018; Pascoe *et al.*, 2012; Coll *et al.*, 2008). Economically, excess fishing capacity within a

fishery increases production costs, affects the prices of landed products, and reduces fishing economic benefits (Pascoe *et al.*, 2012; Arnason, 2005; Hatcher *et al.*, 2005), as fishers increase fishing effort or adopt technological improvements (*e.g.*, number of trips, fishing days, number and size of fishing gears, effective fishing hours) to achieve economically profitable extraction levels (Zhang *et al.*, 2018; Sumaila *et al.*, 2012; Whitmarsh *et al.*, 2000).

To achieve biologically sustainable and economically efficient fisheries, it is necessary to regulate excess fishing capacity (FAO, 2022). For this purpose, different countries have implemented management systems based on catch quotas (Q), which can be total (TAC) or individual vessel quotas (IVQ), with or without transferability (Zhang *et al.*, 2018; Pascoe *et al.*, 2012; Hatcher *et al.*, 2005; Arnason, 2005). Although quota systems have the potential to generate economic rent, eliminate the "race to fish," and improve fishery management, their implementation and effectiveness depend on the capacities of governmental fishery managers, fisher participation, and the availability of data monitoring and enforce quota compliance, as well as to estimate biological and economic indicators regarding the status of the target resource and the fishing fleet involved (Arnason, 2005, 2007; Hatcher *et al.*, 2005; Whitmarsh *et al.*, 2000).

In principle, the total allowable catch (TAC) establishes limits on the amount of a given species that can be harvested, aiming to prevent overexploitation. However, suppose the fleet grows excessively or becomes technologically more efficient. In that case, technological and eco-technological externalities could rise, potentially increasing the pressure on the resource, and leading to effects such as the "race to fish," where vessels aim to catch the maximum number of fish in the shortest time before the TAC is exhausted (Pascoe *et al.*, 2012). This primarily occurs in systems where quotas are allocated to the entire fleet rather than to individual vessels (Arnason, 2007; Hatcher *et al.*, 2005). Beyond its impact on the resource, this modification affects potential vessel revenues and profitability (Birkenbach *et al.*, 2017; Grimm *et al.*, 2012; Asche *et al.*, 2009).

The profitability of fishing vessels is influenced by catch quotas, operational efficiency, and conservation policies (Zhang *et al.*, 2018; Pascoe *et al.*, 2012). Fishery management that balances resource sustainability with the economic viability of fleets is essential to secure the future of the fishing sector in emerging economies. This requires analyzing the economic performance of fleets or individual vessels to evaluate whether they can operate profitably and sustainably over time, considering revenues, costs, investments, and regulatory policies in accordance with vessel characteristics, fishing systems, and the spatial-temporal distribution of the fishing effort applied (Anderson & Seijo, 2010).

This is the case for the Pacific hake fishery (*Merluccius productus*), which is conducted in the northern Gulf of California, Mexico (Figure 1). The National Fisheries Charter (CNP) indicates that this fishery is still developing and requires management actions to maintain the resource at biologically sustainable and economically profitable levels for fishers (SADER, 2022).

Therefore, some researchers (Zamora-García *et al.*, 2013; Zamora-García & Stavrinaky Suárez, 2018) have proposed establishing a TAC based on a percentage of the total estimated biomass for each season in the Pacific hake fishery (SADER, 2022), with the

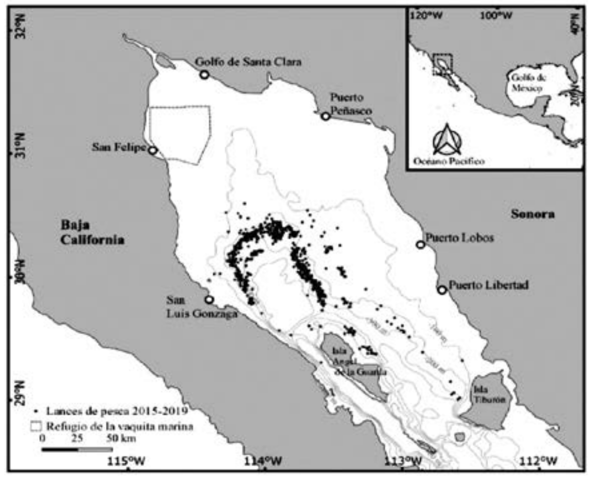

Figure 1. Distribution of the PHF operations in the Gulf of California. (Adapted from Parra-Alaniz & Ramírez-Rodríguez, 2022).

possibility of implementing individual vessel quotas (IVQs) as a means of respecting the TAC. This could ensure profitable vessel operations; however, the information required for a more in-depth analysis is currently insufficient (Ramírez-Rodríguez, 2017).

The CNP provides a summary of information on the status of fishery resources in Mexico, including species-specific data and management recommendations. This document reports that from 2006 to 2014, Pacific hake catches followed a positive trend, reaching 10,800 tonnes in 2014, and remained steady until 2016. Subsequently, and up to 2020, the trend reversed, reaching a minimum of 2,700 tonnes (SADER, 2022).

This study examines the economic performance of the Pacific hake fleet (PHF) in the northern Gulf of California to estimate economic indicators by vessel type and assess possible changes in fleet/vessel profitability. The analysis also aims to estimate the minimum catch required to generate economic benefits and its implications for managing policies, such as implementing an individual vessel quota system.

MATERIALES Y MÉTODOS

The methodology employed to analyze the PHF was conducted as follows: 1) technical and productive elements of the fleet through analysis of catch trends, 2) costs and revenues structures updating by vessel type according to the Representative Production Unit (URP) method, and 3) application of break-even analysis to determine the minimum catch level required to cover operational and management costs for a URP for small and large vessels. To characterize the performance of the PHF, data from vessel landing notices reporting Pacific hake catches from 2010 to 2021 were analyzed at the offices of the National Commission of Aquaculture and Fisheries (CONAPESCA). These data include departure and arrival dates, landing port, vessel name, national registry code, number of fishing days, and landed weight (in kilograms).

Additionally, based on vessel characteristics, a classification label was assigned to categorize vessels as small or large. This classification followed the proposal by Parra-

Alaniz and Ramírez-Rodríguez (2022), considering attributes related to vessel size and cargo capacity.

The characterization of production trends by season and vessel type included the number of vessels, the average number of trips per vessel, the average duration of a fishing trip (in days), the total catch (in tons), the average catch per vessel (in tons), and the catch per day per vessel (in tons). The average catch by vessel type was estimated as follows:

$$Cavg = CTvt / NTv \quad (1)$$

Where *CTvt* is the total catch by vessel type per season, and *NTv* is the total number of vessels per type per season.

To evaluate whether the performance of small and large vessels differed significantly across fishing seasons, a Kruskal-Wallis test was applied to eight vessel performance indicators: total number of vessels, number of trips, fishing days per trip, number of trips per vessel, total catch by vessel type, catch per vessel, catch per trip, and catch per day. The analysis was conducted using version 8.9.1 of the Real Statistics Resource Pack software (Zaiontz, 2023).

Cost structure and prices of landed products

For the profitability analysis, data for the cost structure were obtained based on the characterization and evaluation of a Representative Production Unit (URP) (Richardson & Nixon, 1985) during the 2013 fishing season (Ramírez-Rodríguez & Almendarez-Hernández, 2014). Cost structure data were updated for vessels operating in the 2021 season, considering two URPs: one representing a small vessel and another representing a large vessel. All values are expressed in Mexican pesos (MXN).

Following the recommendations of Georgianna *et al.* (2001) and Tietze *et al.* (2005), the cost structure was divided into two sections: 1) Fixed costs (do not vary with production level), associated with vessel maintenance and URP administration, *e.g.*, office expenses and fishery services. 2) Variable costs (vary with production level), generally recognized as operating costs, such as fuel, deck supplies, and crew wages.

Fixed costs were divided into administrative and maintenance expenses. Administrative costs of the URPs include those related to office operations and fishing services. Office expenses include salaries and social security contributions for employees, vehicle ownership taxes, insurance, maintenance and fuel for cars, telephone and internet services, water, electricity, and office supplies. Fishing services include third-party vessel insurance, membership fees to the National Chamber of Fisheries and Aquaculture Industries, fishing permits, dispatch fees, maritime safety training, fire extinguishers, fumigation services, and waste management.

The administrative structure is the same for both URPs. Each has an office staffed by the owner, a secretary, a driver, and an assistant. For mobility and product transport, they operate two vehicles. Administrative expenses include salaries, permits, insurance, and accounting services. Fishing permits are paid annually and renewed every four years

(Ramirez-Rodriguez & Almendarez-Hernandez, 2014). Vessel insurance only covers third-party damages; vessels are not insured against partial or total loss. Although the vessels remain operational, due to their age (over 24 years), they were considered fully depreciated. Fishing activity in Mexico is not eligible for credit from commercial or development banks.

The maintenance cost of a vessel participating in the hake fishery (Ramírez-Rodríguez & Almendarez-Hernández, 2014) was calculated proportionally to the Pacific hake fishing season. Maintenance items included payments to shipyards, hull repairs, propellers, zinc plates, engines, winches, hake nets, boards, refrigeration systems, navigation equipment, welding, and vessel fumigation. Vessel and fishing gear maintenance costs were considered equal for both types of vessels.

Variable costs include those associated with vessel operations, such as fuel, crew wages, deck and engine supplies, and landing services. Since 90% of hake fishing trips are carried out mainly between January and March of each season, the fixed costs defined in the 2013 URP (Ramírez-Rodríguez & Almendarez-Hernández, 2014) were proportionally adjusted to the hake fishery, considering only three months of activity.

Total costs were calculated by considering the differences in average catch, the number of trips, and the duration of fishing days. Administrative and maintenance costs for the 2021 season were then added. Total costs (TC) per vessel type were estimated as follows:

$$TC = ACk + Sk + MCk + TPCk + Dk \quad (2)$$

Where *ACk* is the administrative cost (*k*=1 office costs; *k*=2 fishing services), *Sk* is the fishermen's and captains' wages (*k*=1, fishermen's salary; *k*=2, captain's salary), *MCk* is the maintenance and fishing gear costs (*k*=1, shipyard; *k*=2, repairs; *k*=3, fishing gear; *k*=4, refrigeration; *k*=5, navigation equipment; *k*=6, fumigation), *TPCk* is the trip provisioning costs (*k*=1, fishing materials; *k*=2, food; *k*=3, oil; *k*=4, spare parts; *k*=5, tools; *k*=6, landing and ice costs), and *Dk* is the diesel cost per trip.

Cost Structure Updating

To update the values of the production cost structure and prices per kilogram of hake, the Producer Price Index (PPI) and the Consumer Price Index (CPI) for the fisheries sector were used as adjustment factors. These indices measure the variation in prices for a fixed basket of goods and services, which is representative of a Mexican fishery production unit over time, using the second semester of 2019 as the basis for the index for calculation (INEGI, 2024).

The values for each cost structure component were updated to 2021 by adding the annual inflationary increase from its 2013 reference value, as follows:

$$VE_{cost} = VO_{cost} * \left(1 + Vi\ INPP\ of\ the\ year\ t\right) \quad (3)$$

$$VE_{price} = VO_{price} * \left(1 + Vi\ INPC\ of\ the\ year\ t\right) \quad (4)$$

Where, VE_{cost} is the updated cost value, VE_{price} is the updated price value.

Where, VO_{cost} is the observed value for the cost structure, VO_{price} is the observed value of the price, Vi_{price} and Vi_{cost} is the inflationary value of the index.

$$Vi_{price} = \left(INPP_{year\,i} - INPP_{base\ year}\right) / \, INPP_{base\ year} \tag{5}$$

$$Vi_{cost} = \left(INPC_{year\,i} - INPC_{base\ year}\right) / \, INPC_{base\ year} \tag{6}$$

Revenues

The value of landed catch (VLC) by vessel type is used as a proxy for income (I). This indicator was estimated by multiplying the average catch by vessel type by the market price per ton of hake as follows:

$$I = VLC = Cavg * Pi \tag{7}$$

Where *Cavg* is the average catch by vessel type in year *i*, and *Pi* is the price of hake per kilogram in Mexican pesos in year *i*.

Economic profitability and break-even point

To evaluate the profitability of the URPs for small and large vessels, three economic indicators were used, based on their income and cost. The first indicator was the Net Cash Benefit before Taxes (NCB), which measures the URP's capacity to generate profits during a fishing season. This indicator is obtained by subtracting total costs (TC) from total income (TI). The greater the positive difference between income and costs, the greater the URP's capacity to generate economic benefits from catches. The formula used was:

$$NCB = Total\ Revenue - Total\ costs\left(IT - CT\right) \tag{8}$$

The second indicator was the Return on Investment (ROI), which assesses the URP's capacity to generate profits from the investment made during a fishing season (Tietze *et al.*, 2005). The higher the ROI, the more profitable the fishery. For this calculation, investment was considered as the total expenditure required to ensure vessel functioning, fishing operations, and URP administration. The formula used was:

$$ROI = \left(Net\ Profit - Investment\ Made\ /\ Investment\ Made\right) \times 100 \tag{9}$$

Where *ROI* is the return on investment, and the *Investment Made* is assumed to be the total Costs (TC).

The third indicator used was the Benefit-Cost Ratio (BCR). This indicator compares the total net benefits generated by the URP with the total costs incurred during a fishing season (Hernández-Trejo *et al.*, 2014). If BCR>1, it indicates that the net benefits obtained from catches exceed total costs, making the project economically viable. A BCR equal to 1 indicates that benefits equal costs, meaning there is no net gain, but the project covers its own expenses. Conversely, if BCR<1, it indicates that total costs exceed the economic benefits, making hake fishing unprofitable. The formula used was:

$$BCR = \left(TR / TC\right) \tag{10}$$

Break-Even Analysis

The break-even analysis was used to project the minimum catch level of small and large vessels, at the expected price, required to cover both variable costs and fixed costs during the 2021 hake fishing season. This method has been applied for demersal fisheries to assess the effect of changes in fishing operations on equilibrium catch levels (Georgianna *et al.*, 2011).

Based on the identified cost structure, the average catch per vessel type (*Cavg*) and the unit price (*Pi*, price per ton) were considered. The individual variable cost $\left(UVC = TVC / Cavg\right)$ and the individual fixed cost $\left(UFC = TFC / Cavg\right)$ per ton of hake were calculated as indicators to estimate the equilibrium catch for both small and large vessels URP, as follows:

$$Q = TFC / \left(Pi - UVC\right)$$

Where Q is the break-even catch (in tons), *TFC* is the Total fixed costs (in MXN), *Pi* is the price per ton of hake (MXN), and UVC is the variable cost per ton (MXN). This calculation enables the determination of the minimum catch required for a vessel (or URP) to cover both variable and fixed costs, thereby ensuring the economic sustainability of the fishery.

Finally, based on the latest estimate of Pacific hake biomass in the northern Gulf of California (INAPESCA, 2014), the catch identified to maintain the operation of small boats in economic equilibrium and assuming differences in the number of vessels participating in the same season, we calculate whether the break-even point defined as IVQ does not exceed the TAC and would allow an increase in economic benefits (ROI) for both types of vessels if they maintained their cost and price structure.

RESULTADOS AND DISCUSSION

Fleet performance

During the analyzed period, fleet landings and catch per vessel have exhibited marked variations across fishing seasons. Initially, from 2010 to 2012, catches increased from 903 t to 2,373 t. Between 2013 and 2016, catches rose further, averaging 5,463 t per season, reaching their maximum in 2014 with 6,582 t. From 2017 onwards, landings declined by 43% compared to the average of the previous period. By the first year of the millennium, the trend had shifted to a positive, reaching 4,973 tons (Figure 2a). Regarding catch per vessel, Figure 2b displays the same pattern as landings for the 2010-2021 period. An increase from 2010 to 2012. Five years later, catch per vessel remains almost steady, averaging 86 tons/vessel, with a peak in 2014. By 2020, there is a marked decrease, followed by a sudden rise in 2021.

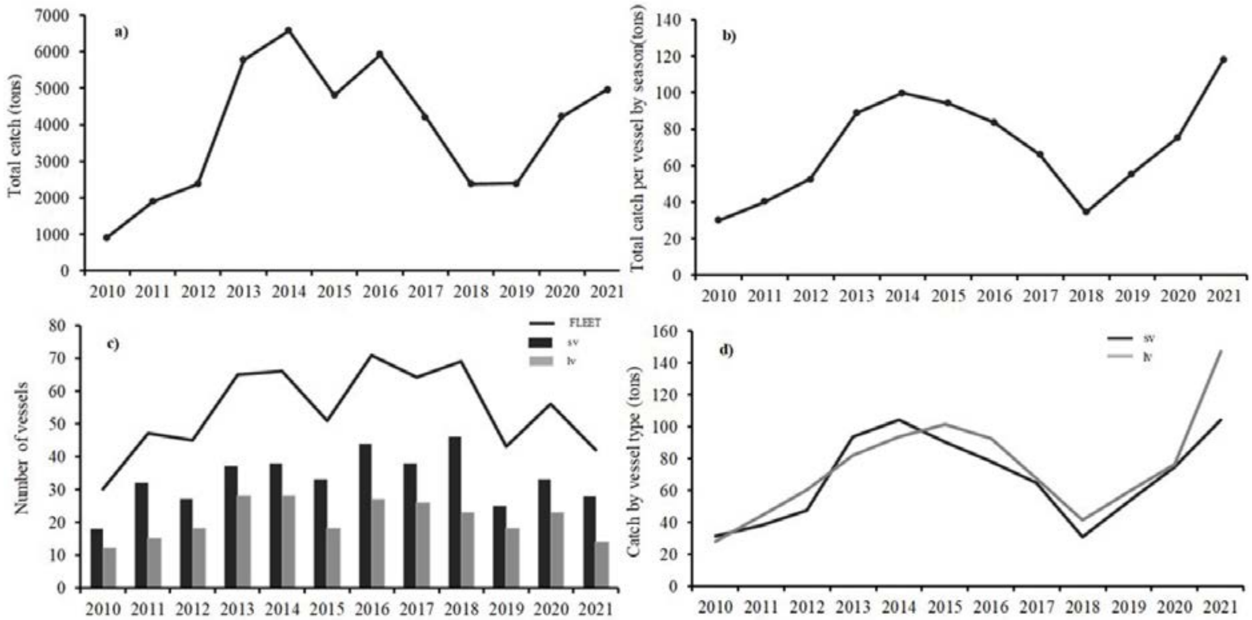

Figure 2. Gulf of California FPM production indicators. a) Total catch by season; b) Total catch per vessel by season; c) Number of vessels per season; d) Catch by vessel type. *sv=small vessel; lv=large vessel.

The fleet is made up of small and large boats. Small vessels are relatively old (average age of 48 years), with an average net tonnage of 45 tons and a storage capacity of 17 tons, an average length of 20.8 meters, and an average engine power of 400 HP. In contrast, large vessels are not so old (average age of 42 years), with higher net tonnage (64 t) and an average storage capacity of 32 tons, greater length (22.3 m), and more powerful engines (508 HP).

A total of 150 different vessels participated in the PHF; however, the total number of vessels varied per season. From 2010 to 2016, the fleet size expanded from 30 to 71 vessels. Furthermore, the fleet has gradually decreased in the number of vessels, from 65 in 2017 to 42 in 2021 (Figure 2c). Although large vessels generally performed better than small vessels, the Kruskal-Wallis test revealed no significant differences in catch per vessel per season ($p<0.39$) (Figure 2d). However, from 2018 to 2021, catches increased to 104 tonnes for small vessels and 144 tonnes for large vessels. The average monthly catch per season of small boats (643 t) was significantly higher ($p>0.026$) compared to large boats (408 t) across all seasons (Figure 2d).

The number of fishing trips during the analyzed period for small vessels and large vessels did not show significant differences ($p>0.057$). Meanwhile, the trend in the number of trips per month per season from 2010 to 2017 for small boats and large boats increased significantly ($p>0.017$). Both URPs reached their maximum records in 2016 with 61 and 31 trips, respectively. From 2018 to 2019, the number of trips decreased significantly in both cases. However, from 2020 to 2021, the trend reversed, with 41 trips per month for small boats and 24 for large ones (Figure 3a).

Regarding the number of vessels per month in the PHF, an average of eight small and five large vessels has been incurred in the PHF from 2010 to 2021. From 2013 to 2017, the monthly increase in vessels was significant (p>0.00). In 2018, the number decreased to 14 small and seven large vessels; the number of small vessels remained unchanged until the end of the period, while the number of large vessels increased by 2 (Figure 3b).

Small vessels carry out more trips and are more numerous than large vessels. The average number of trips per season per vessel showed no significant differences for the 2010-2021 period (p<0.150), despite changes in the average number of fishing trips per season per vessel (Figure 3c).

The average catches per vessel show no significant difference (p=0.474). However, from 2010 to 2017, catches per vessel increased significantly (p=0.022). For the period from 2018 to 2019, catches per vessel for both types decreased, and in 2021, average catches by vessel type increased (Figure 4a). Catches per trip (t/v) for vessels improved significantly (p=0.022) in line with the increase in fleet size and trip length (Figure 4b). The catch per day of fishing (*CPUE=t/d*) between small and large vessels is not significantly different (p=0.052) (small vessels 3.2 t/d; large vessels 3.5 t/d). However, CPUE varied significantly across seasons (p>0.002) (Figure 4c). Finally, the fishing trip length decreased from 7 to 5 days for small vessels and from 6 to 5 days for large vessels. Between 2018 and 2019, in both cases, trip duration increased to 7 days, and catches to 10 and 12 t/v, respectively.

Economic Benefit of the URP

The estimated average price per kilogram of hake landed for the 2021 season was MX$13.84, reflecting a 54% increase compared to the MX$10.00 observed in 2013. Over the last decade, the average annual inflation rate associated with the INPP was 4.3%. During the 2021 season (January to March), small vessels made six fishing trips and large

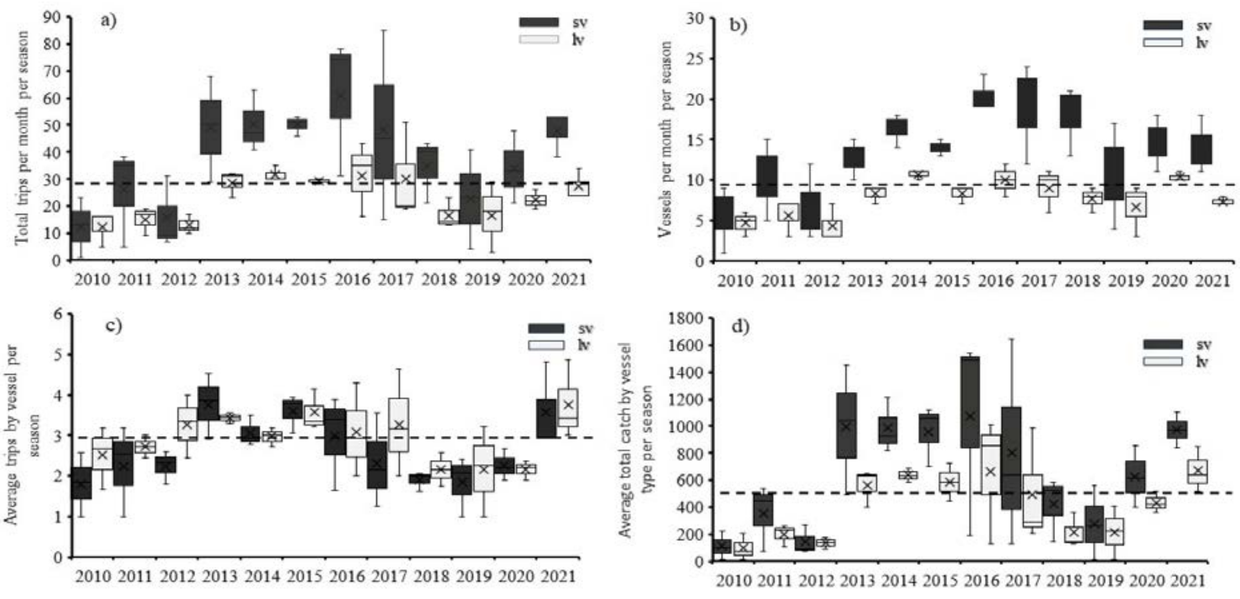

Figure 3. Gulf of California FPM activity indicators by vessel type. a) Total trips per month per season; b) Number of vessels per month per season; c) Average trips per vessel per season; d) Average total catch by vessel type per season *sv: small vessels; lv: large vessels.

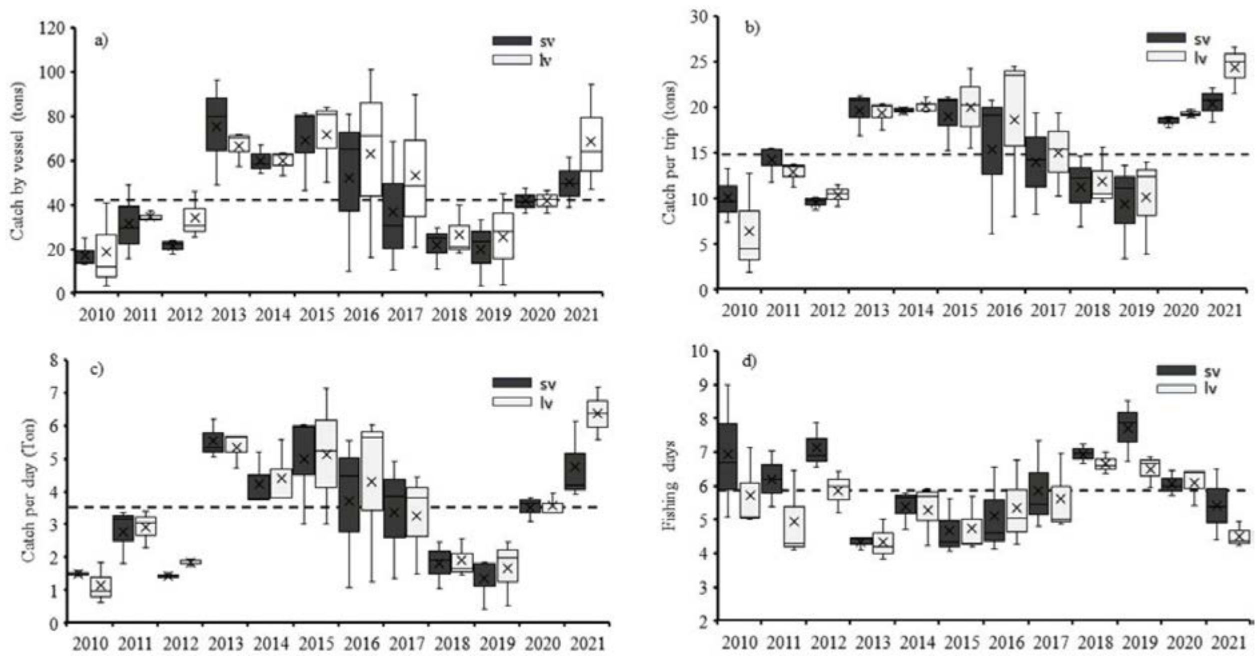

Figure 4. Gulf of California PHF performance indicators by vessel type: a) Catch per vessel per month per season; b) Catch per trip per month per season; c) Catch per day (CPUE) per vessel per season; d) Fishing trip length per season. *sv=small vessels; lv=large vessels.

vessels made nine. It involved six crew members and lasted an average of six days for both small and large vessels. Small vessels caught an average of 20 tons per trip, totaling 120 tons over the three months, which represented a revenue of MX$1,660,800. Meanwhile, large vessels averaged 24 tons per trip and a total catch of 216 tons, representing a revenue of MX$2,989,440.

The fixed costs of the URP were estimated at MX$390,987. These include payments for fishing services (6%), vessel maintenance (24%), office expenses (29%), and salaries (41%). In 2021, the total estimated variable costs of fishing were MX$1,446,418 for small vessels and MX$2,244,751 for large vessels. The proportional distribution of variable costs was similar for both vessel types. About 43% corresponded to fuel (diesel), 37% to crew wages, and the remaining was allocated to deck supplies (11%), landing services (5%), and engine provisions (4%). Highlighting that the fuel cost for small vessels was 30% lower than that of large vessels. Crew payments and landing service costs for small vessels were 56% lower than those of large vessels (Table 2).

The updated total cost showed an upward trend from 2010 to 2021, but there was no corresponding increase in revenue. This is associated mainly with an unchanged price (Figure 7b) and seasonal fluctuations in catch. Although the nominal price of hake increased by 38%, its real price showed a slight decrease (Figure 5b). Diesel is the primary input for the vessel's operation; this input increased by 137%, going from MX$9.12 in 2010 to MX$21.70 in 2021 (Figure 5c). The total maintenance cost of a vessel that fishes for hake from January to March 2021 was estimated at MX$99,015.21. Hull, engine, and hake nets maintenance represented 75% of this total.

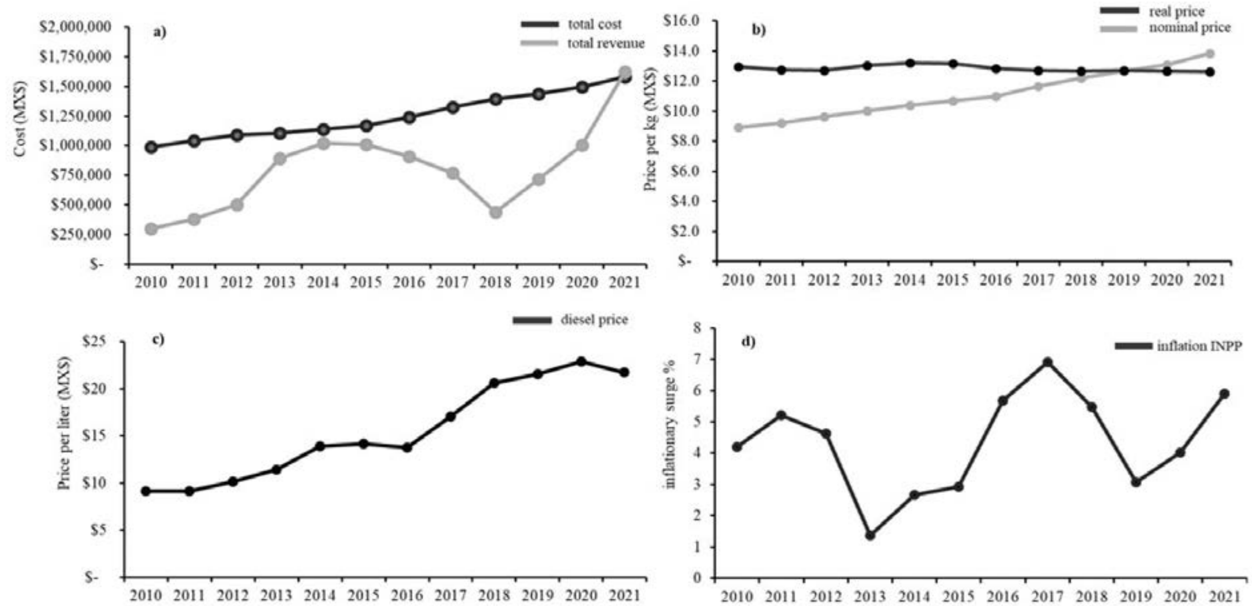

Figure 5. Trends in economic indicators related to the operation of the URP for small and large vessels: a) revenue and total cost; b) nominal and real price of hake; c) diesel price (liter); d) INPP (National Producer Price Index).

Economic Indicators

The total operating costs for a small vessel are considerably lower than those of a large vessel. However, the relationship between total costs and catch efficiency per vessel indicates that the catch cost per ton for small vessels (MX$12,053) is 15% higher than for large vessels (MX$10,392) (Table 1). The difference between total revenue and total costs in 2021 generated a gross margin of 12% and 24% for small vessels and 24% for large vessels, representing MX$214,382 and $744,689, respectively.

After deducting operating costs from gross profit, the results indicate that in 2021, small vessels experienced a cash flow deficit before taxes of MX$176,604, with a total cost-income ratio (C/B) of 0.90 and an ROI of −10%. In contrast, large vessels achieved a net revenue of MX$337,735, with a C/B ratio of 1.13 and an ROI of 12% during the 2021 season.

The overall balance for the 2021 season shows that small vessels did not obtain economic benefits from hake fishing (C/B=0.90). Their costs exceeded total revenues by 10%. Their total cost per ton was MX$15,312, while the market price was MX$13,840. Conversely, large vessels generated positive economic returns (C/B=1.13), with a total cost per ton of MX$12,276, at the same market price.

Break-even

The break-even analysis, considering the selling price per ton of hake and the cost structure, identified that in the 2021 season, small vessels required a catch of 219 tons to reach economic equilibrium. However, their observed catch was only 120 tons, *i.e.*, 99 tons below the threshold, indicating that they failed to cover their total costs and operated at a

Table 1. Revenue and cost figures (MX$) of the representative production unit of the Pacific hake fishery for small and large vessels.

Concept	Total landed catch		Selling price per ton		small vessels	large vessels
Landing Income	120	216	$ 13,840	$ 13,840	$ 1,660,800	$ 2,989,440
Total Capture costs			$ 12,053	$ 10,392	$ 1,446,418	$ 2,244,751
Mechanic supplies					$ 51,000	$ 76,500
Deck supplies					$ 169,920	$ 254,880
Fuels					$ 688,474	$ 946,728
Landing services					$ 72,000	$ 129,600
Crew wages					$ 465,024	$ 837,043
Gross Profit			$ 1,787	$ 3,448	$ 214,382	$ 744,689
Total Operating costs			$ 3,258	$ 1,884	$ 390,987	$ 406,953
Fishing services					$ 23,615	$ 23,615
Office expenses					$ 103,103	$ 119,070
Maintenance					$ 99,015	$ 99,015
Administrative salaries					$ 165,253	$ 165,253
Total costs					$ 1,837,404	$ 2,651,705
Economic benefit					−$ 176,604	$ 337,735
VAT refund					$ 120,713	$ 164,941
Net Income					−$ 55,892	$ 502,676
Rentabilidad (ROI)					−10%	12.7%
Cost/Benefit					0.90	1.13

Note: RPU=representative production unit. The total catch landed is expressed in tons.

loss (Figure 6a). In contrast, large vessels reached break-even with approximately 119 tons, and their observed catch of 216 tons far exceeded this level, reflecting a more efficient operation, with revenues exceeding costs and, therefore, favorable economic performance (Figure 6b).

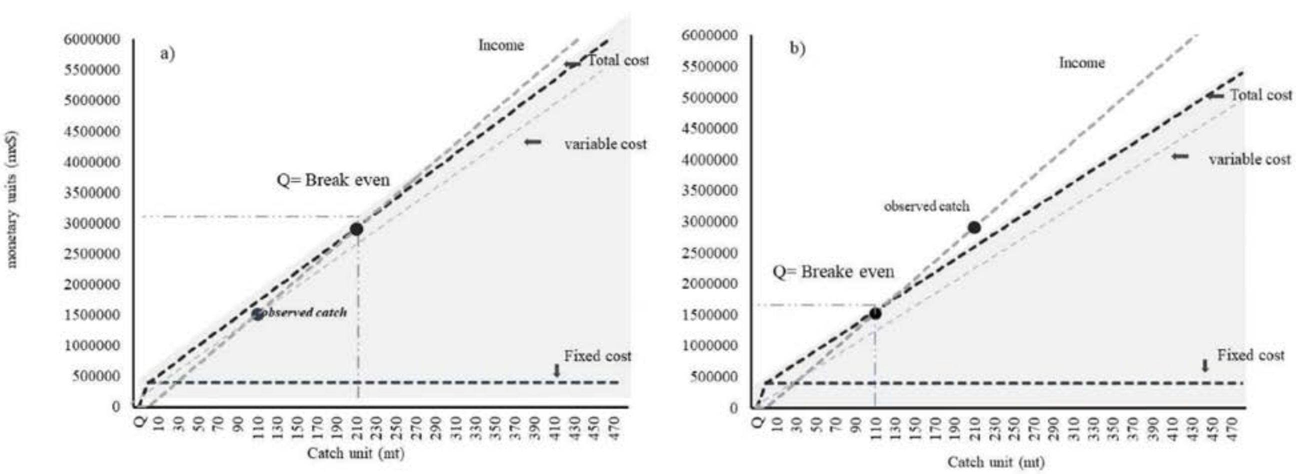

Figure 6. Break-even point in tons of hake for small (a) and large (b) vessels of the FPM in the Gulf of California, Mexico.

Assuming that the TAC corresponds to 25% of the available biomass, that the IVQ is defined at the break-even point for small vessels (219 tons), and that the size and proportion of the fleet remains the same (28 small vessels and 14 large vessels), 9,198 tons would be required, representing 54% of the available TAC, to maintain the fleet in economic equilibrium, with the possibility of generating an ROI of 6.4 and 12.7% for small and large vessels, respectively. If the entire authorized fleet participated with the same IVQ, the entire TAC (17,520 tons) would be required to generate the same cost-benefit values and maintain the fleet in equilibrium (Table 2).

The results indicate that the Pacific hake fleet (FPM) in the Gulf of California experienced a significant increase in the number of trips, fishing days, and vessels per season from 2010 to 2021, with small vessels being more active and numerous. Catch per vessel, per trip, and per day changed significantly across seasons, primarily for large vessels. This is attributed to their higher efficiency, estimated to be 1.5 times greater than that of small vessels, resulting in higher catches in fewer days (Parra-Alaniz & Ramírez-Rodríguez, 2022).

Differences in catch efficiency between small and large vessels must be considered when defining a quota system (total or per vessel), as they differentially affect vessel profitability (Arnason, 2005, 2007; Hatcher *et al.*, 2005; Whitmarsh *et al.*, 2000). Quota allocations should be adjusted to ensure that economic benefits from fishing are achieved while maintaining resource sustainability. Constructing the data required to estimate economic benefits for both vessel types in 2021, based on the 2013 representative production unit (URP) analysis, assumes that the operational cost structure was similar in both periods.

In the 2013 season, it was estimated that the hake URP, without distinguishing vessel types, could generate a 6.98% ROI with 100 t per season, with a CBR equal to 1.07. However, the operational conditions of the hake URP will differ, as all vessels have higher participation in shrimp fishing, and until 2020, fuel for fishing vessels was subsidized (Ramírez-Rodríguez, 2017). According to Sumaila *et al.* (2010), subsidies are considered a "financial transfer created by public entities to benefit a sector, allowing firms to earn more profits than they would otherwise." Although the FPM generated a positive ROI (6.98%) in 2013, this benefit may have masked the fleet's real capacity to generate economic returns and maintain its own operations.

Table 2. Unit cost values, return on investment, and benefit-cost ratio under a scenario with two fleet sizes and catch quota per vessel.

Scenario	**Vessel type**	**Q observed (mt)**	**Number of vessels**	**TAC estimated (mt)**	**TAC % (mt)**	**Total catch (mt)**	**Total unit cost ($/mt)**	**ROI**	**Q BE (mt)**
no-quota	Small vessel	120	28	17,065	20%	3,360	$ 15,311	−10.0%	219
	Large vessel	216	14		18%	3,024	$ 12,276	12.7%	119
	Vessel type	**BE=IVQ (mt)**	**Number of vesselss**	**TAC estimated (mt)**	**TAC % (mt)**	**Total catch (mt)**	**Total unit cost ($/mt)**	**ROI**	**Q break-even point (mt)**
with quota	Small vessel	219	40	17,065	51%	8,760	$ 15,311	0%	219
	Large vessel	219	40		51%	8,760	$ 12,276	12%	219

Subsidies for fuel, equipment, or bait are particularly prone to increasing fishing capacity and contributing to stock depletion, as they reduce production costs and incentivize fishing intensity (Cisneros-Montemayor *et al.*, 2016). Our results indicate that in the 2021 season, during the fleet's three peak months, catch values for both vessel types (120 t for small vessels and 216 t for large vessels) were higher than the 2013 estimates, despite production costs per kilogram of hake being 10% higher than the market price and the absence of fuel subsidies, which were eliminated by the Mexican government starting in 2020 (DOF, 2025), limiting economic benefits, particularly for small vessels.

Some authors suggest that economic losses resulting from the removal of a subsidy can be offset by gains in catches as the harvested population recovers (Cisneros-Montemayor *et al.*, 2016). However, in the case of the FPM, a lack of effort control and strict enforcement of fisheries regulations prevents these gains from being retained, as vessels increase their effort and investment to compensate for lost economic benefits (Hernández-Trejo, 2011).

In 2013, 54 vessels recorded a catch of 4,450 t, with an average of 82 t per vessel (Ramírez-Rodríguez, 2017). In 2021, a total of 48 vessels operated —28 small and 14 large— with a recorded catch of 4,973 t, averaging 118 t per vessel, 104 t for small vessels, and 141 t for large vessels. Our results suggest that nearly half the fleet could be close to exceeding the total catch proportion estimated for 59 vessels, as proposed by Ramírez-Rodríguez (2017), based on the latest biomass estimate (INAPESCA, 2014).

In 2021, the cost-benefit ratio for a small vessel with an average catch of 120 t per season was RCB=0.9, with a negative ROI (−10%), requiring an additional 99 t per season to reach the break-even point. The cost-benefit ratio for a large vessel was RCB=1.3, with an average seasonal catch of 216 t, achieving an ROI of 12.7%, although its break-even point would be 119 t. These figures indicate that, to maintain the operation of half the authorized fleet (42 vessels) at or slightly above break-even for 14 large and 28 small vessels, a total catch of 7,798 t would be required. This catch represents 75% of the TAC level (11,905 t) estimated by Ramírez-Rodríguez (2017) for 119 vessels.

Álvarez-Trasviña *et al.* (2022) estimated an available biomass of 68,260 t for 2014, which would result in a total allowable quota of 17,065 t. Assuming that the fishery were managed with IVQ considering the break-even point for small vessels, the evidence indicates that the catch would be 4% above the TAC (17,520 t), small vessels would have an RCB=1.06 (income=cost) and large vessels would maintain their RCB=1.13, which implies that, despite having the entire quota (TAC), the fleet would continue without obtaining considerable economic benefits. This highlights the need to structure a management plan that considers not only biological and vessel efficiency indicators, but also economic indicators to establish catch limits that generate economic benefits and maintain the sustainability of the fishery.

In the Pacific hake fishery in the Gulf of California, labor and fuel costs account for the highest proportion, representing 63% of total costs. Trends in rising inflation and government fiscal and economic policies limit options related to fishing system efficiency, diversity, and the quality of landed products, as well as their prices (Ponce-Díaz *et al.*, 2021; Hernández-Trejo, 2012). The goal is to establish individual vessel quotas that support resource sustainability and vessel profitability, avoiding a "race to fish." This requires optimal management with participation from fishery sector stakeholders, focusing on strengthening the value chain (Knútsson *et al.*, 2016).

The fleet's economic results confirm that profitability differs markedly between small and large vessels. While large vessels achieved a positive ROI of 12%, small vessels recorded losses (−10%). This pattern is consistent with findings in other fisheries where scale and efficiency determine the ability to cover costs and generate surpluses (Olukunle, 2017).

Our results indicate that sustaining the operation of at least half of the fleet would require catching approximately 75% of the proposed TAC. This level of exploitation underscores the need to design differentiated quotas by vessel type, so that smaller vessels have access to minimum catch levels that allow them to cover costs without compromising the sustainability of the resource. When quotas are allocated equitably but without considering relative efficiency, this creates economic inequalities and disincentives for the less profitable fleet (Pascoe *et al.*, 2012; Whitmarsh *et al.*, 2000).

A complementary strategy would be to link quotas to strengthening the value chain, improving the quality and value of the landed product. As Knútsson *et al.* (2016) showed in Iceland, effective fisheries management has a positive impact not only on biological sustainability but also on competitiveness in high-value markets. For the FPM, this would involve accompanying quota allocation with technological innovation programs, market diversification, and access to financing.

In short, the evidence confirms that without quota-based management that integrates economic and biological criteria, the hake fishery will hardly achieve a sustainable balance. An IVQ scheme adapted to local conditions could generate incentives for efficiency and ensure the long-term sustainability of economic benefits, avoiding overexploitation and the marginalization of small vessels.

Overall, the results support the need for information that enables fishery managers to assess the current economic benefits of fishing and its potential under individual quota management schemes.

An economic analysis of the hake fishing fleet in the Gulf of California reveals a marked difference in profitability between small and large vessels, with the former operating below the break-even point and with a negative ROI, while the latter achieves positive margins. This asymmetry reflects the fact that scale and catch efficiency are determining factors for the financial viability of production units, which is consistent with what has been observed in other small- and large-scale fisheries (Olukunle, 2017).

The elimination of fuel subsidies and the increase in operating costs have limited the capacity of small vessels to sustain their activities, highlighting the need to rethink fisheries management beyond strictly biological criteria. In this sense, the evidence suggests that an individual catch quota (IVQ) system designed with differentiated criteria by vessel type could help balance profitability between fleet segments and, at the same time, promote the sustainability of the resource. International experiences, such as the Icelandic ITQ model, demonstrate that well-designed use rights schemes are capable of enhancing efficiency, reducing overcapacity, and generating sustainable economic benefits (Arnason, 2006).

However, the allocation of quotas alone does not guarantee benefits. They will need to be complemented with policies that strengthen the value chain, promote technological innovation, and improve access to higher value-added markets, as has been observed in successful fishery management cases (Knútsson *et al.*, 2016).

CONCLUSIONS

The economic viability and sustainability of the hake fishery depend on the implementation of a comprehensive management scheme that considers both biological and economic indicators. Only under a system that combines fair catch quotas, efficiency incentives, and market strategies will it be possible to guarantee the permanence of the fleet and the long-term conservation of the resource.

ACKNOWLEDGMENTS

The authors express their gratitude to the fishermen and shipowners of the hake fishery. To the Instituto Politécnico Nacional, Centro de Estudios Interdisciplinarios en Ciencias Marinas, at the Fisheries Department, for the initiative of this research topic. To the Autonomous University of Baja California Sur, the Academic Department of Economics, and the Laboratory for Environmental and Resource Economics (LEARN) for hosting the lead author's postdoctoral project. They would like to thank the Environmental Defense Fund Mexico and the Secretaría de Ciencia, Humanidades, Tecnología e Innovación for the facilities and support provided to this research.

REFERENCES

Álvarez-Trasviña, E., Arizmendi-Rodríguez, D. J., Marín-Enríquez, E., Salcido-Guevara, L. A., Sánchez-Cárdenas, R., & Rodríguez-Domínguez, G. (2022). Distribution and abundance of the Pacific hake, *Merluccius productus*, and relationship with the environment in the Gulf of California, México. *Ciencias Marinas*, 48, e3256. https://doi.org/10.7773/cm.y2022.3256

Anderson, L. G., & Seijo, J. C. (2010). Bioeconomics of fisheries management. John Wiley and Sons.

Asche, F., Bjørndal, T., & Gordon, D. V. (2009). Resource rent in individual quota fisheries. *Land Economics, 85*(2), 279-291. https://doi.org/10.3368/le.85.2.279

Arnason, R. (2005). Property rights in fisheries: Iceland's experience with ITQs. *Reviews in Fish Biology and Fisheries, 15*(3), 243-264. https://doi.org/10.1007/s11160-005-5139-6

Arnason, R. (2007). Fisheries self-management under ITQs. *Marine Resource Economics*, 22. https://doi.org/10.1086/mre.22.4.42629568

Birkenbach, A. M., Kaczan, D. J., & Smith, M. D. (2017). Catch shares slow the race to fish. *Nature*, 544, 223-226. https://doi.org/10.1038/nature21728

Cisneros-Montemayor, A. M., Sanjurjo, E., Munro, G. R., Hernández-Trejo, V., & Sumaila, U. R. (2016). Strategies and rationale for fishery subsidy reform. *Marine Policy*, 68, 229-236. https://doi.org/10.1016/j.marpol.2015.10.001

Coll, M., Libralato, S., Tudela, S., Palomera, I., & Pranovi, F. (2008). Ecosystem overfishing in the ocean. *PLoS One*, 3, e3881.

Food and Agriculture Organization of the United Nations. (2022). The State of World Fisheries and Aquaculture 2022: Towards Blue Transformation. Rome: FAO. https://doi.org/10.4060/cc0461en

Georgianna, D., Thunberg, E., Keiley, E., McAfee, B., & Reed, S. (2011). Break-even analysis of the New England groundfish fishery for FY2009 and FY2010. Massachusetts Division of Marine Fisheries.

Grimm, D., Barkhorn, I., Festa, D., Bonzon, K., Boomhower, J., Hovland, V., & Blau, J. (2012). Assessing catch shares' effects: Evidence from federal United States and associated British Columbian fisheries. *Marine Policy*, 36, 644-657. https://doi.org/10.1016/j.marpol.2011.10.014

Hatcher, A. (2005). On the microeconomics of quota management in fisheries. *Marine Resource Economics, 20*(1), 77-99. https://doi.org/10.1086/mre.20.1.42629415

Hernández-Trejo, V. (2012). Subsidios al sector pesquero en México. Un panorama general. La Paz: WWF México.

Hernández-Trejo, V., Ramírez-Rodríguez, M., Ponce-Díaz, G., & Almendarez-Hernández, L. (2014). Rentabilidad de Unidades Representativas de Producción Pesquera del calamar gigante *Dosidicus gigas* en el Golfo de California. *Hidrobiológica, 24*(1), 78-80.

INAPESCA (Instituto Nacional de Pesca). (2014). Prospección de merluza (*Merluccius* spp.) en aguas marinas del centro y norte del Golfo de California. Instituto Nacional de Pesca, Centro Regional de Investigación Pesquera en Guaymas.

INEGI (Instituto Nacional de Estadística y Geografía). (2024). Índice Nacional de Precios Productor: documento metodológico: base julio 2019=100. México: Instituto Nacional de Estadística y Geografía.

Knútsson, Ö., Kristófersson, D. M., & Gestsson, H. (2016). The effects of fisheries management on the Icelandic demersal fish value chain. *Marine Policy*, 63, 172-179. https://doi.org/10.1016/j.marpol.2015.03.015

Olukunle, O. T. (2017). Profitability analysis of small-scale fisheries and value chain in Lagos State, Nigeria. Ocean & Coastal Management, 141, 106-113. https://doi.org/10.1016/j.ocecoaman.2017.03.011

Parra-Alaniz, J. C., & Ramírez-Rodríguez, M. (2022). Fleet efficiency in the Pacific hake (*Merluccius productus*) fishery in the Gulf of California, Mexico. *Latin American Journal of Aquatic Research, 50*(1), 99-109.

Pascoe, S., Coglan, L., Punt, A. E., & Dichmont, C. M. (2012). Impacts of vessel capacity reduction programmes on efficiency in fisheries: The case of Australia's multispecies northern prawn fishery. *Journal of Agricultural Economics, 63*(2), 425-443.

Ponce-Díaz, G., Vergara-Solana, F. J., & Aranceta-Garza, F. (2021). Análisis bioeconómico de los objetivos de manejo pesquero ante cambios en los precios de venta. *Economía: teoría y práctica* (55), 149-170. https://doi.org/10.24275/etypuam/ne/552021/ponce

Ramírez-Rodríguez, M. (2017). A profitability analysis of catch quotas for the Pacific hake fishery in the Gulf of California. *North American Journal of Fisheries Management*, 37, 23-29.

Ramírez-Rodríguez, M., & Almendarez-Hernández, L. C. (2014). Unidad Representativa de Producción de camarón-merluza-escama de Puerto Peñasco, Sonora. Environmental Defense Fund de México.

Richardson, J. W., & Nixon, C. J. (1985). Description of FLIPSIM V: A general firm model policy simulation model. Texas A&M University, Department of Agricultural Economics, Agricultural and Food Policy Center, Bulletin B1528.

SADER (Secretaría de Agricultura y Desarrollo Rural). (2022). Acuerdo mediante el cual se da a conocer la actualización de la Carta Nacional Pesquera. Diario Oficial de la Federación, 26/07/2022.

Sumaila, U. R., Rashid, A. S., Khan, A. J., Dyck, R. W., Munro, G., Tydemers, P., & Pauly, D. (2010). A bottom-up re-estimation of global fisheries subsidies. *Journal of Bioeconomics, 12*(3), 201-225. https://doi.org/10.1007/s10818-010-9091-8

Tietze, U., Thiele, W., Lach, R., Thomsen, B., & Rihan, D. (2005). Economic performance and fishing efficiency of marine capture fisheries. FAO Fisheries Technical Paper, 482, 68 pp.

Whitmarsh, D., James, C., Pickering, H., & Neiland, A. (2000). The profitability of marine commercial fisheries: A review of economic information needs with particular reference to the UK. *Marine Policy*, 63, 257-263.

Zamora-García, O. G., & Stavrinaky-Suárez, A. (2018). Ficha técnica de merluza del Pacífico norte. Environmental Defense Fund de México.

Zamora-García, O. G., Díaz-Avalos, C., & Stavrinaky-Suárez, A. (2020). Catch rate, length, and sex ratio of Pacific hake (*Merluccius productus*) in the northern Gulf of California. *Fishery Bulletin*, 118, 365-379.

Zhang, D., Sokveland, M., & Hermansen, O. (2018). Fishing fleet capacity and profitability. *Marine Policy*, 88, 116-121.

Zaiontz, C. (2023). Real Statistics Using Excel. www.real-statistics.com

AGRO PRODUCTIVIDAD