UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

Colegio de Ciencias Biológicas y Ambientales (COCIBA)

Winners and Losers: an Economic Analysis of the Galápagos Sea Cucumber (*Isostichopus fuscus*) Fishery

Andrés Sebastián Pinos Sánchez

Biología

Trabajo de fin de carrera presentado como requisito
para la obtención del título de
Biólogo

Quito, 20 de diciembre de 2023

UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

Colegio de Ciencias Biológicas y Ambientales (COCIBA)

HOJA DE CALIFICACIÓN
DE TRABAJO DE FIN DE CARRERA

Winners and Losers: an Economic Analysis of the Galápagos Sea Cucumber (*Isostichopus fuscus*) Fishery

Andrés Sebastián Pinos Sánchez

Alex Hearn, Ph.D.

Quito, 20 de diciembre de 2023

© DERECHOS DE AUTOR

Por medio del presente documento certifico que he leído todas las Políticas y Manuales de la Universidad San Francisco de Quito USFQ, incluyendo la Política de Propiedad Intelectual USFQ, y estoy de acuerdo con su contenido, por lo que los derechos de propiedad intelectual del presente trabajo quedan sujetos a lo dispuesto en esas Políticas.

Asimismo, autorizo a la USFQ para que realice la digitalización y publicación de este trabajo en el repositorio virtual, de conformidad a lo dispuesto en la Ley Orgánica de Educación Superior del Ecuador.

Nombres y apellidos: Andrés Sebastián Pinos Sánchez

Código: 00211401

Cédula de identidad: 0931163588

Lugar y fecha: Quito, 20 de diciembre de 2023

ACLARACIÓN PARA PUBLICACIÓN

Nota: El presente trabajo, en su totalidad o cualquiera de sus partes, no debe ser considerado como una publicación, incluso a pesar de estar disponible sin restricciones a través de un repositorio institucional. Esta declaración se alinea con las prácticas y recomendaciones presentadas por el Committee on Publication Ethics COPE descritas por Barbour et al. (2017) Discussion document on best practice for issues around theses publishing, disponible en http://bit.ly/COPETheses.

UNPUBLISHED DOCUMENT

Note: The following capstone project is available through Universidad San Francisco de Quito USFQ institutional repository. Nonetheless, this project – in whole or in part – should not be considered a publication. This statement follows the recommendations presented by the Committee on Publication Ethics COPE described by Barbour et al. (2017) Discussion document on best practice for issues around theses publishing available on http://bit.ly/COPETheses.

RESUMEN

Este estudio analiza la pesquería del pepino de mar (*Isostichopus fuscus*) en Galápagos desde una perspectiva económica. A través de un modelo de mercado detallado, se identificaron cuatro sectores clave en la cadena comercial. Se evaluó la rentabilidad de la pesca considerando costos operativos, subsidios gubernamentales y gastos de manejo pesquero. Los resultados revelan que, si bien el sector pesquero muestra rentabilidad, los costos ocultos, como los subsidios y las inversiones en manejo, superan en ocasiones los ingresos generados. La distribución de ingresos resalta la preponderancia del mercado internacional, dejando una proporción mínima a los sectores nacionales. Esto plantea desafíos en la equidad económica interna. Además, se sugieren estrategias para mejorar la sostenibilidad económica y la conservación, como el aumento de precios y la imposición de impuestos a la exportación. Este análisis cuestiona la sostenibilidad de los subsidios a operaciones que afectan especies amenazadas, en línea con los principios de pesquerías sostenibles.

Palabras clave: Sustentable, Distribución de Ingresos, Rentabilidad Económica, Conservación de Recursos, Dinámicas del Mercado.

ABSTRACT

This study analyzes the sea cucumber fishery (*Isostichopus fuscus*) in Galápagos from an economic perspective. Through a detailed market model, four key sectors in the commercial chain were identified. The profitability of the fishery was evaluated considering operational costs, government subsidies, and fishery management expenses. The results reveal that while the fishing sector shows profitability, hidden costs such as subsidies and investments in management sometimes exceed the generated income. The income distribution highlights the predominance of the international market, leaving a minimal proportion to domestic sectors. This poses challenges to internal economic equity. Additionally, strategies are suggested to improve economic sustainability and conservation, such as increasing prices and imposing export taxes. This analysis questions the sustainability of subsidies to operations impacting threatened species, aligning with the principles of sustainable fisheries.

Key words: Sustainable Fishery, Income Distribution, Economic Profitability, Resource Conservation, Market Dynamics.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The brown sea cucumber *Isostichopus fuscus*, one of the most commercially sought-after species in the Eastern Tropical Pacific (ETP), is the sole target of the Ecuadorian sea cucumber fishery (Ramirez-González et al., 2020a, 2020b). Starting in mainland Ecuador around 1988 to meet Asian market demands, unregulated overfishing prompted a ban in 1992, driving sea cucumber fishers to the Galápagos Islands by incentives from Asian merchants. This led to uncontrolled expansion throughout the Galápagos, marked by an experimental season in 1994 that closed prematurely due to unsustainable catch rates. The fishery persisted illegally until the establishment of the Galápagos Marine Reserve in 1998, preceding the beginning of the first regulated sea cucumber fishing season in 1999 (Bucaram et al., 2012; Camhi, 1995; Castrejón et al., 2014; Hearn, 2008; Ramirez-González et al., 2020a; Shepherd et al., 2004; Toral-Granda et al., 2008).

Each of the fourteen seasons from 1999 to 2023 have been characterized by conflicts, variable quotas and landings, collapses, enforcement deficiencies, and extended moratoriums, where little progress has been made in resolving these recurrent issues (Bucaram, 2012; Camhi, 1995; Castrejón et al., 2014; Ramirez-González et al., 2020a; Shepherd et al., 2004; Toral-Granda et al., 2008). The fishery faces critical challenges, needing a novel fisheries management model in the Galápagos that accounts for economic aspects overlooked in the past. This shift aims to move from the current unsustainable "race to fish" mentality to a more sustainable "race to create value" (Bucaram, 2012; Bucaram et al., 2012).

Addressing these challenges requires going beyond the prevalent ecosystem-focused approach. While essentially this approach is of high relevance, certain gaps in this fishery understanding linger, including its economic dimensions. A comprehensive economic analysis is crucial to assess financial flows and profitability, enabling the development of sustainable management practices.

Our goal is to bridge these existing gaps in knowledge for the economic dynamics of the Galápagos sea cucumber fishery. This entails characterizing the market model encompassing all sectors and agents involved in the sea cucumber commercialization. Simultaneously, we aim to compare the income and costs of the fishing sector with and without its agents and comprehend income distribution among market sectors. The highlighted results here represent a subset of our economic model, with the complete findings to be detailed in a forthcoming peer-reviewed paper.

METHODOLOGY

The methodology presented below constitutes a partial representation of the comprehensive methods utilized in making the overarching economics model summarized in this publication.

The dataset (see: **Data availability.**) was built from various sources, including fishing reports, databases, published literature, and online repositories. While a significant amount of data was publicly accessible, additional unpublished information was acquired through direct correspondence with the Galápagos National Park Directorate (GNPD), NGOs, former sector employees, and private sector representatives. Notably, certain gaps in financial and economic information were identified within the sources. To address these gaps, assumptions were made, drawing justification from analogous markets and economic models.

The analysis centered on data encompassing 13 out of 14 fishing seasons, covering the periods from 1999 to 2005, 2007 to 2008, 2011, 2015, 2021, and 2022. The 14th season corresponds to the present year 2023 which has just finished, and no fishing report has been published yet. The missing years correspond to all the moratoriums that have been applied throughout the years.

General aspects.

Fishing Techniques.

The Galápagos sea cucumber fishery employs three main methods for capturing *I. fuscus*: shoreline harvesting (which only occurred in the initial phases of fishing, until sea cucumbers were extirpated from the intertidal zone), day fishing trips using small boats (pangas or fibras), and boat fishing trips using larger vessels that towed pangas or fibras to remote fishing sites for extended periods (Bucaram et al., 2012). For the analysis, we focused on day fishing trips and boat fishing trips as they are the only fishing methods remaining for this fishery in Galápagos, allowing a more comprehensive understanding of the different variables influenced by the specifics of these two primary fishing techniques.

Macrozones.

For the sea cucumber fishery there are eight macrozones in the Galápagos Islands: Fernandina, Isabela Norte y Este, Isabela Oeste, Santa Cruz, Floreana, Isabela Sur, San Cristobal, and Española. These macrozones are delimited sites that correspond to monitoring and extraction zones with certain characteristics that allow the presence of the resource and facilitate extraction (Conrad et al., 2006).

Understanding which fishing techniques are used across the eight macrozones in the Galápagos was essential to comprehending the variables for each scenario, as they are the combination of macrozones and fishing techniques (Unidad de Recursos Marinos Parque Nacional Galápagos, 2000). The choice of fishing techniques in each macrozone is significantly influenced by their respective distances from ports. Boat fishing trips are predominantly undertaken in macrozones that are far from ports such as: Fernandina, Isabela Norte y Este, and Isabela Oeste, while day fishing trips are more prevalent in macrozones near ports, such as: Santa Cruz, Floreana, Isabela Sur, San Cristobal, and Española.

Market Model.

The delineation of market sectors stemmed from insights extracted from literature and fishing reports. The relationships between these sectors were clarified through discussions with former members from these sectors. Additionally, stakeholders involved in bureaucratic, regulatory, and economic aspects were identified. Given the economic focus of this study, priority was given to stakeholders who directly and indirectly invest in this market model, denoted as market agents.

Cost-effectiveness.

The Galápagos sea cucumber fishery is a “business” where the profitability of the operation depends in the cost and income dynamics (cost-effectiveness). However, within the cost-effectiveness of this fishery there are certain hidden costs and investments that have a direct influence on the profitability of this fishery but are overlooked as they are covered by the market agents.

Fishing Sector.

The gross income used for the cost-effectiveness analysis was sourced from the reported data within the fishing reports issued by the GNPD (Biomar-ECCD et al., 1999; Darwin, E. C. C., 2002; Dirección del Parque Nacional Galápagos, 2016, 2022; Hearn et al., 2004; Murillo et al., 2002, 2003; Murillo & Reyes, 2008; Reyes et al., 2009; Sevilla, 2022; Toral-Granda et al., 2005; Unidad de Recursos Marinos Parque Nacional Galápagos, 2000).

The operational cost of the fishing sector is not outlined in the available data. Broadly speaking, these operational costs encompass diesel, engine oil, and food expenses, all of them linked to the fishing efforts (**ANNEX B: Fishing effort**) made during each season. Due to this lack of official information, we computed all these values for all fishing seasons, considering all available information as a reference (both qualitative and quantitative information). It is important to mention that there are other costs associated with the fishery, including fishing gear, boat maintenance, and health just to mention few; however, these costs are not taken into account, as they are not strictly related to the fishing effort, and they are covered throughout the year by the other activities made by the fishers.

Diesel Cost (DC): represents the total amount of money invested by the sea cucumber fishers per season in fuel. Essentially this value is the relation between the diesel price per gallon (subsidized price) and the fishing effort, which translates to the nautical miles sailed by season. Considering both the macrozones and the fishing technique for this calculation.

$$DC = SDGP * (SNM * NMPG)$$

Engine Oil Cost (EOC): represents the total amount of money invested by the Galápagos fishers in engine oil. This value is the relation between the engine oil price and the nautical miles sailed by all vessels that required engine oil. Considering both the macrozones and the fishing technique for this calculation.

$$EOC = EOGP * ((SNM2 * NMPG) / 62.5)$$

Food Costs (FC): represents the money invested into food by the Galápagos fishers across the fishing season. This value essentially is the relation between the daily price of a full meal in the Galápagos, and the amount of fishing days.

$$FC = ((NAF / NAB) * NTS) * 10$$

Where:

- SDGP stands for Subsidized Diesel Gallon Price, this value were obtained from Petroecuador reports (Petroecuador, 2011, 2012, 2015, 2021, 2022). We averaged the reported price for the months in which the fishing seasons took place, as the SDGP variates monthly throughout the year.

- SNM stands for Sailed Nautical Miles, this value is explained in (**ANNEX B: Fishing effort**).
- NMPG stands for Nautical Miles per Gallon, this value corresponds to the nautical miles (NM) sailed with a gallon of diesel. Fuel consumption was expressed in gallons per hour (GPH), which we obtained by dividing engine horsepower (HP) by K value of 10. The average HP = 100, which was obtained from the 2023 registry of Galapagos fishing boats. Fuel consumption per NM was determined using the nautical miles per gallon (NMPG) formula, which is essentially the boat's speed in knots divided by GPH (Sea Grant, 2012). The common average vessel speed was 17 knots, as reported by boat engine dealers. Giving a value of 1.70 NMPG which was used for all seasons.
- EOGP stands for Engine Oil Gallon Price, which was sources by averaging the reported engine oil price per gallon of different mainland dealerships, as the Galápagos engine oil price is supposed to be the same price as in mainland Ecuador.
- SNM2 is essentially the same value as SNM, however not all vessels register for the fishery have engines that require oil (only 4 stroke engines require engine oil). Hence only a fraction of the NM sailed by season correspond to four stroke engines. To obtain SNM2 first we divided the number of total vessels per season by 0.5378, as in the 2023 registry of Galapagos fishing boats, only 0.5378 of the registered boats had four stroke engines. Once we had the number of four stroke engine boats, we divided this value by the total number of active boats per season and then multiplied by the SNM.

- The value of 62.5 corresponds to a number given by the boat engine dealers. Essentially for every 62.5 gallons of diesel, one gallon of engine oil is consumed.
- NAF is the Number of Active Fisherman registered in the fishing reports.
- NAB is the Number of Active Boats registered in the fishing reports.
- NTS is the Number of Trips per Season according to our calculations. To obtain this value we add all trips made to each macrozone. Trips per macrozone are essentially the reported landings per macrozone divided by the Catch per Unit of Effort per Boat (CPUE x Boat)
    - CPUE x Boat = CPUE x Day * ND.
    - ND is the average Number of Divers per boat, this information was given in fishing reports and/or in a shared dataset.
    - CPUE x Day = CPUE * NH.
    - CPUE stands for Catch Per Unit of Effort, this information was given in fishing reports and/or in a shared dataset.
    - NH is the average Number of Hours of active diving/fishing per boat, this information was given in fishing reports and/or in a shared dataset.
- The value of 10 corresponds to the current average price of a daily meal in the Galápagos ($10.00).

Government (stakeholder).

In Ecuador, the government subsidizes fuels nationwide, including the Galápagos sea cucumber fishery. To incorporate this economic advantage into the cost-effectiveness analysis, the value of this subsidy was factored in, considering it as part of what should typically constitute the diesel expenses covered by the fishing sector. The computation of the subsidy cost (SC) involved calculating the difference between the international diesel price (EIA, 2023; The Global Economy, 2016) and Ecuador's subsidized diesel price (Petroecuador, 2011, 2012, 2015, 2021, 2022).

SC = (SNM * NMPG) * SVG

Where:

- SNM stands for Sailed Nautical Miles, this value is explained in (**ANNEX B: Fishing effort**).
- • NMPG stands for Nautical Miles per Gallon, this value corresponds to the nautical miles (NM) sailed with a gallon of diesel. Fuel consumption was expressed in gallons per hour (GPH), which we obtained by dividing engine horsepower (HP) by K value of 10. The average HP = 100, which was obtained from the 2023 registry of Galapagos fishing boats. Fuel consumption per NM was determined using the nautical miles per gallon (NMPG) formula, which is essentially the boat's speed in knots divided by GPH (Sea Grant, 2012). The common average vessel speed was 17 knots, as reported by boat engine dealers. Giving a value of 1.70 NMPG which was used for all seasons.
- SVG is the Subsidy Value per Gallon. Essentially this value is the subtraction between the international diesel price per gallon and the subsidized diesel price per gallon in Ecuador.

GNPD and NGOs (stakeholder).

Based on interviews with GNPD staff, we identified an approximate designated budget allocation of $500,000 per season invested in monitoring this fishery. This amount goes directly towards patrolling and controlling landings and fishing sites at different stages of the sea cucumber fishery (fisheries management). However, in the 1999 report, an official figure in sucres, Ecuador’s former currency, was provided alongside its corresponding conversion to American dollars (current currency) (Biomar-ECCD et al., 1999). For the rest of the seasons, we used the $500,000 as a fix value.

NGOs money investment for this fishing operation was sourced from a series of datasets provided through direct correspondence. NGOs essentially play a role in studying this fishery from an ecological point. The money investment made by the NGO varies across the years as it depends on the scale of the studies made per season, which is influenced by the season’s length and specific variables.

Income distribution.

Determining the distribution of the maximum income (maximum value achievable in the final commercialization of the product) across the different sectors within the market chain involved analyzing how the generated income flows through the different stages of the sea cucumber market chain. This assessment allowed for an understanding of how the income was apportioned among sectors involved in the commercialization process, such as harvesting (fishing sector), processing (Galápagos merchants), distribution (exports sector), and retailing (final market). By delineating the contributions of each sector to the overall income generated from sea cucumber commercialization, a comprehensive picture emerged regarding the economic dynamics and the proportional incomes of each sector in the market chain.

The computation of the maximum income generated by the commercialization of Galápagos sea cucumber (weight exports) involved utilizing the reported final market price per kilogram (Kg) of *I. fuscus* at $1.030, obtained from retail and wholesale shops in Hong Kong for 2011 (Purcell et al., 2014). This value was then adjusted for the other seasons using the price variation of Ecuadorian shrimp exports per kilograms (Cámara Nacional de Acuacultura, 2022). This approach facilitated the estimation of the income generated across various seasons within the sea cucumber commercialization framework.

Fishing Sector.

The proportional income generated by the fishing sector aligned directly with the gross income reported within the fishing reports (Biomar-ECCD et al., 1999; Darwin, E. C. C., 2002; Dirección del Parque Nacional Galápagos, 2016, 2022; Hearn et al., 2004; Murillo et al., 2002, 2003; Murillo & Reyes, 2008; Reyes et al., 2009; Sevilla, 2022; Toral-Granda et al., 2005; Unidad de Recursos Marinos Parque Nacional Galápagos, 2000). This reported gross income essentially represented the proportion of income for the fishing sector of the maximum income generated by the final commercialization of Galápagos sea cucumbers.

Galápagos Merchants.

The gross income for the Galápagos merchants was computed by multiplying the gross income of the fishing sector by a factor of "1.20". This adjustment was established based on conversations with financiers from other companies with similar commercial dynamics. The proportional income for the Galápagos merchants' sector was derived by subtracting the proportional income of the fishing sector from the calculated gross income for Galápagos merchants. This methodology was used as no information was found regarding the income of the Galápagos merchants' sector.

Exports Sector.

The exports sector's gross income was calculated by multiplying the gross income of the Galápagos merchants by a factor of "1.50". This adjustment was established based on conversations with financiers from other companies with similar commercial dynamics. Subsequently, the proportional income for the exports sector was determined by subtracting the proportional incomes of the fishing sector and Galápagos merchants from the computed gross income of the exports sector. This methodology was used as no information was found regarding the income of the exports sector, and the requested information of the exports value of the Galápagos sea cucumbers was never given by the Subsecretaría De Recursos Pesqueros (SDRP).

Final Market.

The final market gross income corresponded to the maximum income generated by the commercialization of *I. fuscus*. The proportional income for the final market was computed by subtracting the proportional incomes of the fishing sector, Galápagos merchants, and exports sectors from the final market gross income. This methodology enabled the determination of the specific income allocation within the final market encompassing the various sectors involved in the sea cucumber commercialization process.

Data availability.

A cloud link at the end of the manuscript had been attached (**ANNEX A: Data set**), housing the spreadsheet with processed data, formulas, comments, and elucidated assumptions, thus ensuring comprehensive access to the detailed methodology and comprehensive dataset supporting the findings presented within the manuscript.

Data clarification.

The economic values here presented are expressed in nominal dollars. Although the process of deflating these values to obtain the real figures was conducted, consistency was observed across the data. As a result, the decision was made to retain the values in nominal dollars to depict the economic reality of each year with its corresponding inflation. This approach aimed to accurately represent the economic context of each specific year, rather than comparing the seasons between them.

We requested certain information regarding economic and financial values on numerous occasions from different entities such as Petroecuador, Ministerio de Ambiente, Agua y Transición Ecológica (MAATE), CITES, and the Subsecretaría De Recursos Pesqueros (SDRP). In some cases, unofficial conversations and responses were given by the people in charge, providing a better understanding of the processes behind the political, regulatory and bureaucratic aspect of this fishery and its market model, but some of the official economic requested figures were never given for unknown reasons, therefore some real economic values are still missing from this economics model, and they had to be filled with assumptions and approximations.

RESULTS

Market Model.

The market chain of the Galápagos sea cucumber fishery comprises four distinct sectors. Although the composition and constituents of each sector exhibit variability across different years, their interactions and roles within the market have remained consistent over time. This market operates in a linear fashion (**Figure 1**), with each sector engaging directly and exclusively with the subsequent level, trading *I. fuscus* in exchange for money.

The fishing sector swiftly sells fresh or cooked sea cucumbers shortly after the vessels arrive at port. At this stage, various merchants purchase the product by units, giving a fixed price per unit. However, not all harvested units are commercialized; some are retained and decommissioned due to regulatory factors, such as non-compliance with the size limit of 20 cm live length or 7 cm processed length (Biomar-ECCD et al., 1999; Darwin, E. C. C., 2002; Dirección del Parque Nacional Galápagos, 2016, 2022; Hearn et al., 2004; Murillo et al., 2002, 2003; Murillo & Reyes, 2008; Reyes et al., 2009; Sevilla, 2022; Toral-Granda et al., 2005; Unidad de Recursos Marinos Parque Nacional Galápagos, 2000).

Post-processing (drying the sea cucumbers), merchants sell the product in kilograms or pounds to specific exporting companies located in mainland Ecuador. The transaction mechanisms at this stage remain undocumented. Upon reaching mainland, these exporting companies store and vend the product in batches by weight throughout the year. The specific transaction mechanisms in this phase also lacks documentation.

Lastly, the product is exported to its final market, where it is retailed in Asian seafood markets. We acknowledge that there may potentially be one or two more links in the chain (small retailers, etc.) before the product ultimately reaches restaurants and/or consumers. However, it is impossible to track down the product or its price to those stages.

This linear progression involves distinct stages, each characterized by transactions and processes integral to the sea cucumber market chain, albeit with certain undocumented mechanisms at different stages.

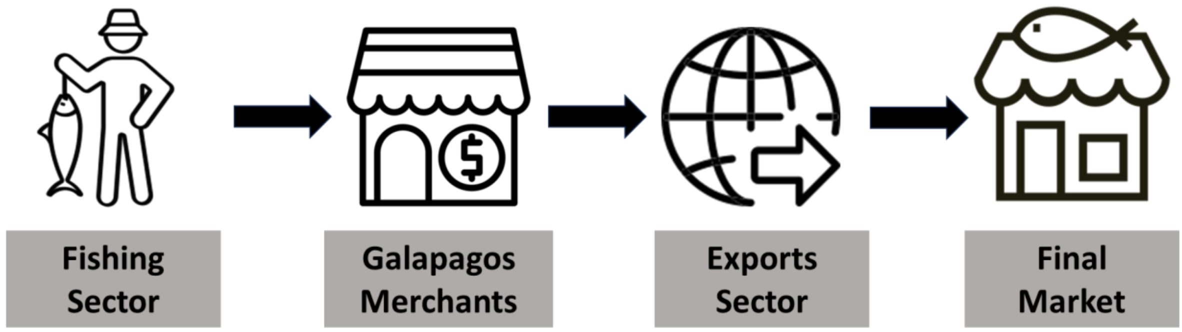

Figure 1. *Sea cucumber market chain model. Note. Icons are part of office tools.* (*icons from Microsoft Word 2023).*

Throughout the transactions conducted by the market sectors, various stakeholders influence the commercialization to some extent. Regulatory entities, such as the GNPD, issue mobilization guides, fishing permits, and necessary documentation to the fishing sector and Galápagos merchants (Biomar-ECCD et al., 1999; Darwin, E. C. C., 2002; Dirección del Parque Nacional Galápagos, 2016, 2022; Hearn et al., 2004; Murillo et al., 2002, 2003; Murillo & Reyes, 2008; Reyes et al., 2009; Toral-Granda et al., 2005; Unidad de Recursos Marinos Parque Nacional Galápagos, 2000).

The transactions made between the Galápagos merchants and exports sector, until the exportation of the product goes under scrutiny made by the MAATE, CITES, and the SDRP ensuring compliance with environmental and fishing resource regulations. Unofficial conversations with a government official of one of these three entities revealed a complex process of procedures and issuance of permits that go back-and-forth between these three entities, where regulatory gaps are left in the monitoring of exports. In economic terms, the value of each exported batch of sea cucumbers is recorded by the SDRP through invoices issued by the exporting companies. However, the same conversations reveal that from 2016 backwards there is no economic record of exports, and the economic record of exports from 2016 until the present date was never given to us.

Additionally, within this fishery, several stakeholders significantly influence the fishing sector economically (**Figure 2**). The Ecuadorian government lowers operational costs for the fishing operation through a fuel subsidy, while the GNPD and NGOs cover most, or all of the costs associated with fisheries monitoring and management. These investments directly impact the fishing sector facilitating the exploitation of *I. fuscus* by the fishers. However, these economic benefits, though impactful, are often considered hidden costs within the fishery as they contribute to operational dynamics but remain less explicit in traditional cost calculations. We have classified these stakeholders as market agents for the fishing sector.

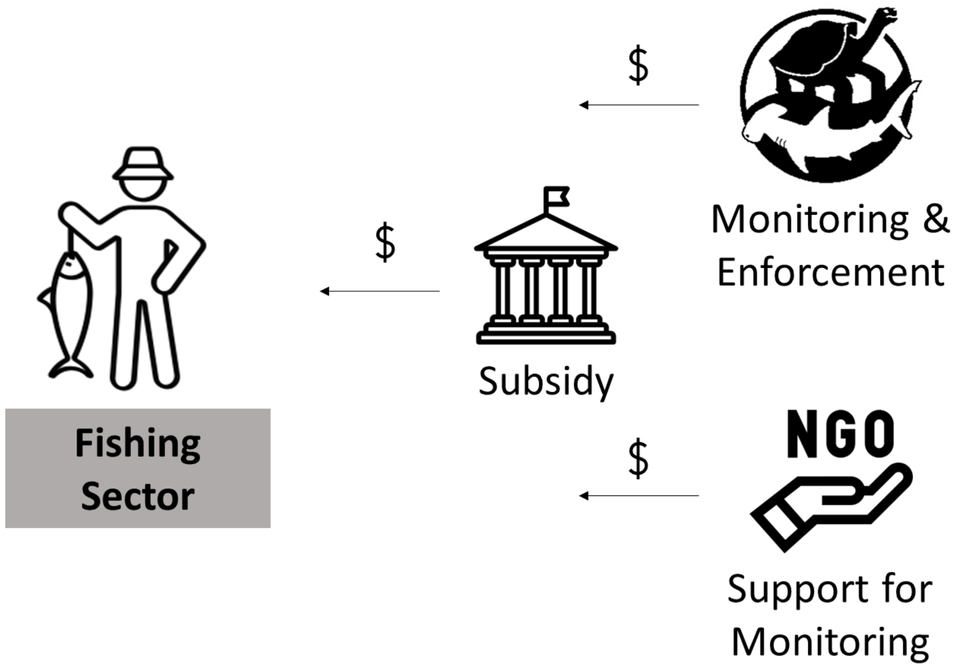

Figure 2. Fishing Sector economic market agents in Galapagos. (*icons from Microsoft Word 2023).*

Cost-effectiveness.

The assessment of the fishing sector's cost-effectiveness involved three distinct scenarios. Initially, the focus was exclusively on the fishing sector's gross income and operational costs. The second scenario included the incorporation of the diesel subsidy value, currently covered by the Ecuadorian government. Lastly, the third scenario expanded to encompass the species study, and monitoring costs of the fishing operation, financed by the GNPD and NGOs, plus the diesel subsidy value.

Table 1 reveals the comprehensive investment encompassing the fishing sector reported gross incomes, calculated operation costs, and the hidden costs covered by the government, GNPD, and NGOs, including the calculated value of diesel subsidy and the reported figures of monitoring and species studies. An essential aspect to note regarding operational costs, diesel subsidy, and fishing sector gross income values is their direct correlation with the fishing effort exerted during each season (**ANNEX B: Fishing effort &**

Sailed nautical miles x season). Analysis of seasonal characteristics reveals distinct patterns, with each season characterized by varying lengths of active fishing days (ranging from 10 to 61 days) and sea cucumber quotas (ranging from no quota to 500,000-4,700,000 units). These factors strongly influence the operational costs and diesel subsidy values, delineating the economic dynamics across different seasons (Biomar-ECCD et al., 1999; Darwin, E. C. C., 2002; Dirección del Parque Nacional Galápagos, 2016, 2022; Hearn et al., 2004; Murillo et al., 2002, 2003; Murillo & Reyes, 2008; Reyes et al., 2009; Sevilla, 2022; Toral-Granda et al., 2005; Unidad de Recursos Marinos Parque Nacional Galápagos, 2000).

Table 1. *Annual gross income to Fishing Sector and cost values for each contributing sector.*

Year	Fishing Sector (G. income)	Operational Cost	Government Subsidy	GNPD	NGOs
1999	3,400,848	408,498	445,904	37,405	21,112
2000	3,200,000	1,565,968	1,430,127	500,000	113,517
2001	1,392,223	531,064	381,297	500,000	113,517
2002	2,686,675	1,339,776	611,542	500,000	150,383
2003	3,356,840	979,604	442,101	500,000	150,383
2004	4,438,636	1,097,000	686,722	500,000	150,383
2005	1,694,445	779,805	880,924	500,000	145,383
2007	1,943,700	566,653	822,756	500,000	65,617
2008	1,816,382	610,016	1,657,692	500,000	65,617
2011	3,981,912	902,190	2,083,982	500,000	30,850
2015	1,455,600	610,133	228,638	500,000	30,850
2021	3,660,914	1,709,713	1,185,151	500,000	30,850
2022	2,168,000	1,702,387	2,444,611	500,000	30,850

Note. Fishing Sector Gross Income was sourced from fishing reports (reported) – Operational Cost represent the expenses covered by the fishing sector (calculated) – Government Subsidy indicating the total cost subsidized by the Ecuadorian central government for diesel used by this fishery (calculated) – GNPD corresponds to funds allocated by the Galápagos National Park for monitoring and conservation (reported) – NGOs reflects the investment made by non-governmental bodies toward scientific research and conservation efforts for I. fuscus *and its fishery (reported).*

First scenario – Cost-effectiveness fishing sector alone.

Across all 13 studied fishing seasons of the Galápagos sea cucumber fishery, a consistent trend of high profitability for local fishers emerges. In each case, the fishing sector's gross income exceeds the operational costs, as depicted in **Figure 3**. As mentioned earlier, no distinct pattern exists across seasons regarding both gross income and operational costs, as these values directly correlate with variables, such as fishing days and sea cucumber quotas.

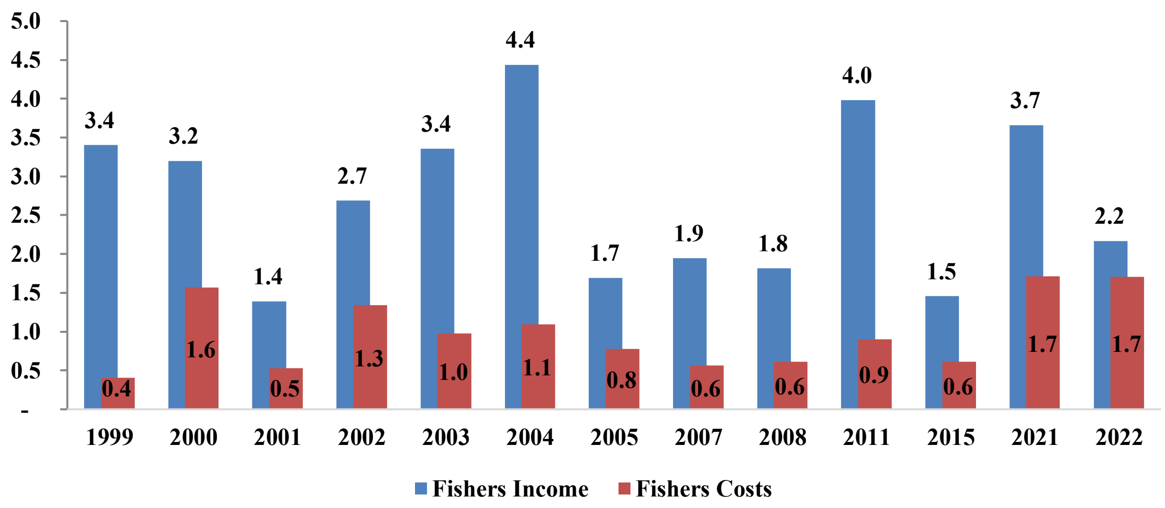

Figure 3. *Fishing sector gross income vs costs*. (*icons from Microsoft Word 2023).*

Second scenario – Cost-effectiveness fishing sector + diesel subsidy.

Factoring in the diesel subsidy provided by Ecuador's government into operational costs shows a general rise in expenses across all seasons. Notably, **Figure 4** illustrates two seasons (2008 and 2022) where the fishing sector's operational costs, along with the subsidy value, surpass the gross income, signaling a lack of profitability for those specific years. Essentially, this figure showcases the true operational cost of the fishing sector, excluding the benefit of the subsidy granted by Ecuador's government.

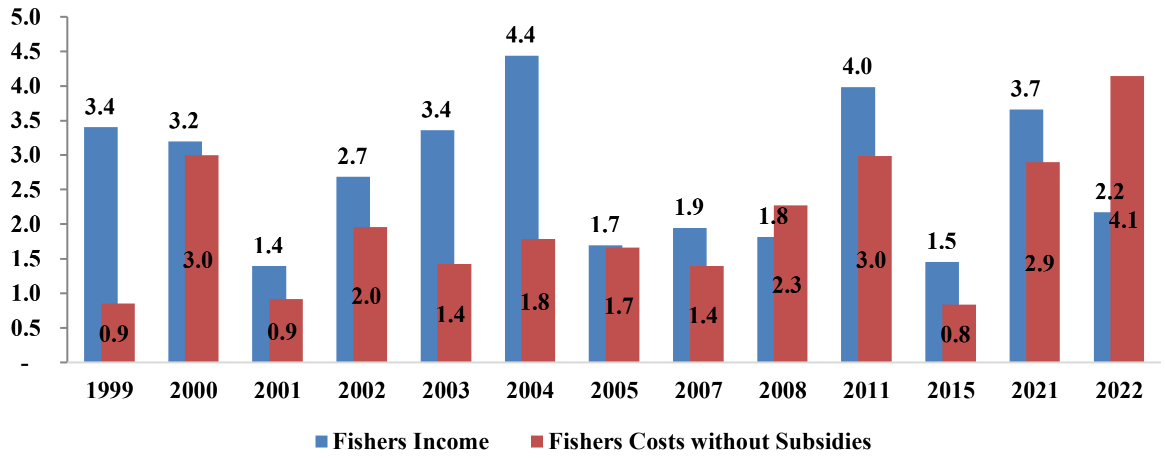

Figure 4. *Fishing sector gross income vs costs without fuel subsidy*. (*icons from Microsoft Word 2023).*

Third scenario – Cost-effectiveness fishing sector + diesel subsidy + GNPD and NGOs investment.

Considering the diesel subsidy and the contributions from the GNPD and NGOs into monitoring and *I. fuscus* studies as part of fishing sector costs, it becomes evident that they grew consistently across all seasons, as depicted in **Figure 5**. In this scenario, for six seasons (2000, 2001, 2005, 2007, 2008, and 2022), the total investment surpassed the fishing sector's gross income.

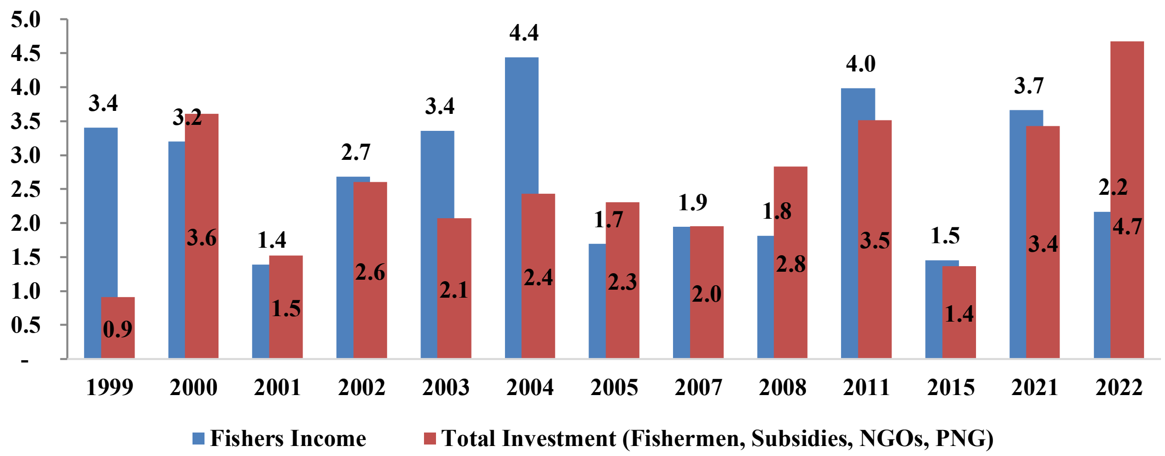

Figure 5. *Fishing sector gross income vs costs without fuel subsidy + PNG and NGOs investment*. (*icons from Microsoft Word 2023).*

Income distribution.

In **Figure 1**, four sectors within the Galápagos sea cucumber fishing industry were identified. Three of these sectors (fishing sector, Galápagos merchants, and exports sector) operate within Ecuador, integrating into the Ecuadorian sea cucumber industry. Meanwhile, the fourth sector operates in Asian countries (mostly China and Taiwan). The proportional income out of the maximum income generated by *I. fuscus* commercialization is presented in

Table 2. This insight into income distribution helps identify the destination of the income generated by this fishing operation, offering clarity on income allocation among these sectors and geographic regions.

Table 2. *Income distribution across different sectors of the sea cucumber market chain*.

Year	Fishing Sector	Galápagos Merchants	Exports Sector	Final Market
1999	3,400,848	680,170	2,040,509	118,557,946
2000	3,200,000	640,000	1,920,000	164,462,678
2001	1,392,223	278,445	835,334	64,531,980
2002	2,686,675	537,335	1,612,005	188,557,264
2003	3,356,840	671,368	2,014,104	104,533,947
2004	4,438,636	887,727	2,663,182	50,904,500
2005	1,694,445	338,889	1,016,667	24,741,673
2007	1,943,700	388,740	1,166,220	17,785,831
2008	1,816,382	363,276	1,089,829	16,464,803
2011	3,981,912	796,382	2,389,147	15,618,387
2015	1,455,600	291,120	873,360	13,413,195
2021	3,660,914	732,183	2,196,548	17,195,261
2022	2,168,000	433,600	1,300,800	11,563,628

Note. The aggregate of these values constitutes the maximum income derived from the commercialization of I. fuscus *from the Galápagos – Each value denotes the proportional income of all sectors, wherein the proportional income for a given sector is the gross income of that sector minus the proportional income of the previous sector/s – Fishing sector's proportional income equals the gross income reported in the fishing reports for the fishing sector.*

When comparing the income distribution across the market chain sectors operating in Ecuador, a consistent trend emerges: a substantial proportion of the total generated income within the Ecuadorian sea cucumber industry remains within the fishing sector, as depicted in **Figure 6**. The remainder is distributed among the other two sectors. This consistent pattern spans all 13 seasons. However, this only happens because of our assumptions, as we assigned a 1.20 and 1.50 factor increase in the gross income of the Galápagos' merchants, and exports sector respectively. While we strongly believe that these figures are close to reality, we acknowledge that this is a "forced" result because of our own assumptions.

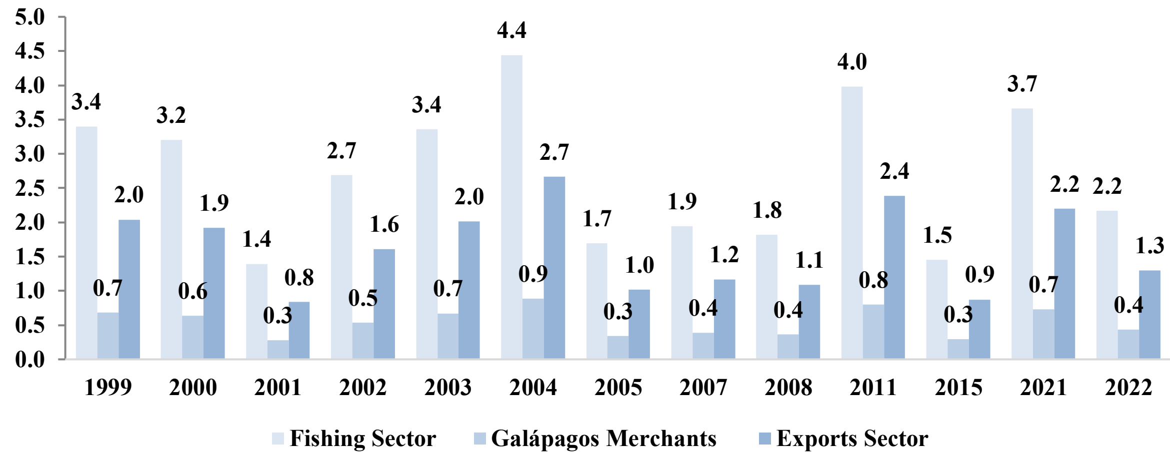

Figure 6. *Income distribution in market chain sectors of Ecuador*. (*icons from Microsoft Word 2023).*

When incorporating the final market in this income distribution analysis and comparing it with the Ecuadorian sea cucumber industry (fishing sector, Galápagos merchants, and exports sector combined), a notable disparity emerges. The final market retains the largest portion of the maximum income generated by the commercialization of *I. fuscus*, while the portion remaining within the three Ecuadorian sectors is just a fraction of it, as illustrated in **Figure 7**. While the values here presented depicted the results of our assumption, literature of other sea cucumber fisheries worldwide, have shown the same trend, in which the country extracting and commencing the species only retain a small fraction of all the money generated at the final stage of the market chain (Toral-Granda et al., 2008). Hence, we believe Galápagos sea cucumber income distribution looks similar to our results presented here.

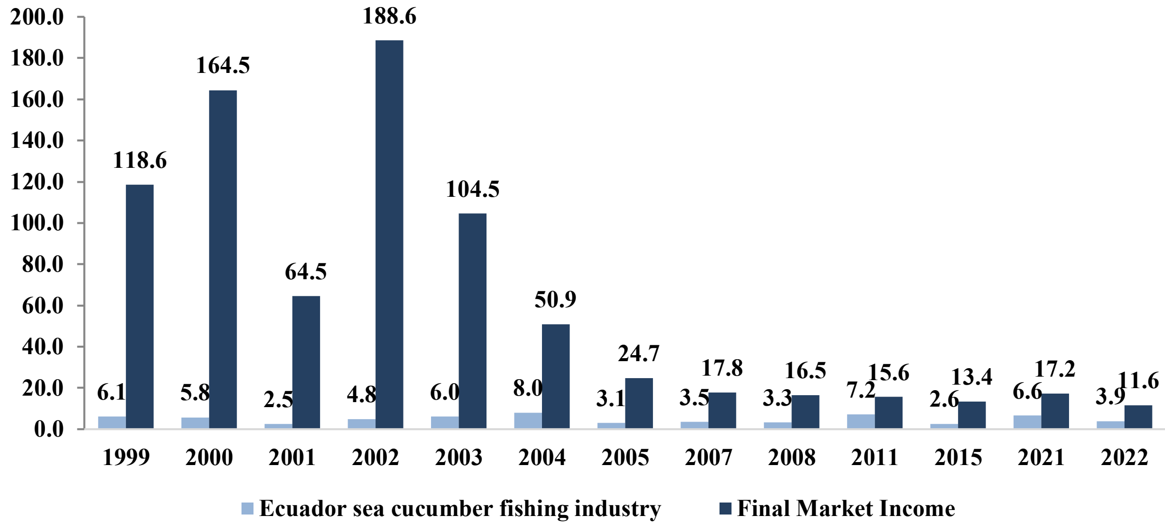

Figure 7. *Income distribution of the Ecuadorian sea cucumber industry vs the final market. (icons from Microsoft Word 2023).*

DISCUSSION

Market Model.

The Galápagos sea cucumber market model presents an intricate network involving distinct sectors and market agents, shaping the economic terrain (**Figure 1**). Operating within Ecuador are three primary sectors: the fishing sector, Galápagos traders, and the export sector. In a broader context, there exists a fourth sector, the final market, which operates internationally.

Throughout this market model, various stakeholders such as the National Government subsidizing fuels, the Galápagos National Park Directorate (GNPD) covering enforcement costs and contributing to monitoring efforts, and Non-Governmental Organizations supporting both fishers and GNPD in monitoring costs (**Figure 2**) influence the economics of the sea cucumber fishing operation. These agents play an important role in the cost-effectiveness dynamics as they cover hidden costs within this fishery, essentially investing in the extraction of *I. fuscus*.

Cost-effectiveness.

Understanding the correlation between incomes and costs holds substantial significance, akin to any business framework. This relationship stands as a critical indicator of performance, notably for the key player within a market model.

Our findings across the 13 fishing seasons revealed that the gross income within the fishing sector consistently outstripped the operational costs (**Figure *3***). This observation portrays a positive trajectory in terms of profitability, affirming the sector's capacity to generate revenue that exceeds its operational expenses. Hence, the sea cucumber fishery is profitable at least for the fishing sector itself.

Yet, delving deeper into the economic reality uncovers concealed factors pivotal for a comprehensive assessment. Notably, factors beyond the overt operational costs contribute significantly to the holistic economic picture (

Table 1).

A prime example lies in the evaluation of fuel subsidies, a significant component funded by the Government for this fishery. Upon inclusion of these subsidies, a noteworthy trend emerges. In contrast to the initial assessment, the incorporation of fuel subsidies escalates the overall costs across all seasons (**Figure 4**). Intriguingly, this adjustment even presents two years (2008 and 2022) where costs surpassed generated incomes.

Another concealed yet crucial cost pertains to enforcement and monitoring of the fishery, an activity carried out and paid for largely by the Galápagos National Park and Non-Governmental Organizations. These fisheries management aspects are important for the fishing sector as they facilitate the extraction of the sea cucumbers, giving economic advantages for the fishing sector that otherwise would have to be covered by the fishers or factored into the final price of the product.

What emerges from this analysis is a thought-provoking revelation: the incremental costs associated with fisheries management and subsidies do not correspond proportionally to the proceeds garnered from the fishery's exploitation of this endangered resource (**Figure *5***). In essence, the revenue derived from the exploitation falls short of justifying the entire investments made by all stakeholders economically involved with the fishing sector.

Income distribution.

Within this market model, three distinct sectors operate in Ecuador’s domain: the fishing sector, the Galápagos merchants, and the export sector. These three sectors essentially portray Ecuador’s sea cucumber industry. Initial observations within this national-level market model reveal a positive trend in economic terms. The strongest share of generated income resides within the fishing sector (**Figure *6***). This inclination is notably positive from an economic standpoint, signifying a robust domestic market system. Yet, this result was expected as our assumptions incline to always show the same trend in terms of Ecuador’s sea cucumber industry income distribution across market sectors.

However, a startling revelation emerges upon the incorporation of the final market sector into this analytical framework. This addition unravels an expected disproportionality in income distribution (**Figure** *7*). Between 69% and 97% of the maximum incomes generated through Galápagos sea cucumbers commercialization find their place in international markets. While this was expected due to literature, its magnitude is still worrying. The disproportionate outbound flow of income is not an optimal scenario for fostering the growth and sustainability of the sea cucumber industry sectors within Ecuador. This disproportion raises questions regarding the undervaluation of this luxury item in terms of economics and its ecological importance.

Winners and Losers.

From 1999 to 2022, about 34´906.225 sea cucumbers have been reported captured legally in the Galápagos Marine Reserve, ultimately all these animals have generated a gross income of $35.196.175 for the fishing sector (Biomar-ECCD et al., 1999; Darwin, E. C. C., 2002; Dirección del Parque Nacional Galápagos, 2016, 2022; Hearn et al., 2004; Murillo et al., 2002, 2003; Murillo & Reyes, 2008; Reyes et al., 2009; Sevilla, 2022; Toral-Granda et al., 2005; Unidad de Recursos Marinos Parque Nacional Galápagos, 2000), which is about $1 per sea cucumber. More than 34 million sea cucumbers have been harvested generating ecological disasters by collapsing entire populations all over what it is supposed to be the best-preserved marine ecosystem in the world for its historical, scientific, and ecological importance. But ultimately we have failed in keeping the balance between human interests and sustainability, pushing an already threatened species listed under CITES Appendix III (CITES, 2023; IUCN, 2013) to its extinction, making the Galápagos sea cucumber species *I. fuscus* the ultimately looser of this entire fishing operation. At the same time, many other species have been affected by taking away the ecosystem function of *I. fuscus*, and by all the illegal fishing done not only to the sea cucumbers, but to other luxury species such as sharks that have been illegally harvest during the sea cucumber fishing seasons across the years (Castrejón et al., 2014; Hearn, 2008).

From an economic perspective, the final market emerges as the ultimate beneficiary (winner), retaining between 69% and 97% of the maximum gross income from Galápagos sea cucumber commercialization, and investing nothing towards its sustainable management. In short, foreign businesses are making large sums of money while depleting Ecuador's natural heritage inside a marine reserve, and this is subsidized by Ecuador's government through taxpayers' money and through national and international NGOs. Local fishers are also beneficiaries, although the fraction of their income is just a tiny part all being generated by this luxurious item.

Recommendations.

Keeping in mind that this fishery is already profitable for the fishers (without the market agents) we should aim for economic measures that keep the profitability while enhancing conservation. I propose two additional measures, alongside with already implemented strategies like quotas, minimum size, and moratoriums, thereby exerting a positive influence on the species' ecology.

1. Price Increase for Conservation: Encouraging a rise in sea cucumber unit prices serves as an ecological measure. A rise in the sea cucumber price means less units captured to achieve economic satisfaction, so long as access to the resource is limited. This measure has to be applied alongside others to prevent a gold rush for a more valuable resource. If well-applied, this price increase should keep the profitability of the fishery, while fishing less sea cucumbers which should contribute to recovering populations back to healthy numbers.

2. Export Tax for fisheries Management: currently the GNPD and NGOs are financing this fishery by covering costs related to monitoring, management and species studies. As shown in the results, these values when included in the cost-effectiveness show fishing sector gross income to be insufficient, hence, money is being lost while exploiting a threatened species. If this fishery is to keep operating those who benefit the most (final market sector) should be the ones financing the management of this fishery, in order to justify the extraction of sea cucumbers from the Galápagos.

Fuel subsidies.

In 2022, the World Trade Organization (WTO) introduced the "Agreement on Fisheries Subsidies," prohibiting subsidies support to fisheries deemed ecologically unsustainable (WTO, 2022). While Ecuador is not a signatory to this agreement, there is a critical need for evaluation of fuel subsidies for the Galápagos sea cucumber (*I. fuscus*) fishery. This practice contradicts sustainable fisheries principles outlined by the WTO agreement and prompts a reconsideration of Ecuador's support for fuel subsidies that may heighten the extinction risk for endangered species.

CONCLUSIONS

The Galápagos sea cucumber fishery has been a subject of persistent challenges, originating from unregulated overfishing to subsequent establishment of regulations, yet plagued by conflicts, varying quotas, and extended moratoriums. These issues underscore the critical need for a novel fisheries management model in the Galápagos that acknowledges the economic facets overlooked in the past. Our study aimed to fill these voids by comprehensively characterizing the market model, assessing cost-effectiveness, understanding income distribution, and identifying the winners and losers within this fishery.

The market model analysis revealed a complex interplay among distinct sectors and agents (stakeholders), shaping the economic landscape. The fishing sector consistently portrayed high profitability across 13 seasons, although concealed factors, notably fuel subsidies and fisheries management costs, unveiled hidden economic dynamics. The incorporation of subsidies escalated costs across seasons, raising concerns about the money allocation for an unsustainable fishery.

Income distribution highlighted a disproportionate allocation, with a substantial share of incomes from sea cucumber commercialization flowing to international markets. Portraying the high valuation of this luxurious item, while it is being push to extinction by sectors that are retaining a small fraction of the maximum income generated by this market.

The proposed strategies, ranging from price increments to export taxes aim to reconcile economic gains with conservation, enhancing both the species' ecology and the fishery's profitability. Furthermore, the issue of fuel subsidies, especially concerning an endangered species like *I. fuscus*, warrants reconsideration in alignment with sustainable fisheries practices advocated by the WTO agreement on fisheries subsidies.

In conclusion, our study underscores the imperative for a comprehensive economic understanding in devising sustainable management practices for the Galápagos sea cucumber fishery. Addressing these economic dimensions in tandem with ecological considerations will be pivotal in steering this fishery towards a more sustainable and equitable future.

REFERENCES

Biomar-ECCD, (Recmar-PNG, & INP. (1999). *La pesca del pepino de mar en Galápagos: Período abril-mayo*.

Bucaram, S. (2012). *Analysis of the Fishing Behavior among Fishing Units of Production (FUPs) from the Galapagos Islands: The Case of the Red Spiny Lobster Fishery* (Vol. 74, Issue 4, pp. 185–185).

Bucaram, S., Sanchirico, J., & Wilen, J. (2012). *Modeling the Fishing Behavior for the Galapagos Lobster Fishery*.

Cámara Nacional de Acuacultura. (2022). *Estadísticas—Cámara Nacional de Acuacultura*. https://www.cna-ecuador.com/estadisticas/

Camhi, M. (1995). Industrial Fisheries Threaten Ecological Integrity of the Galapagos Islands. *Conservation Biology*, *9*(4), 715–719.

Castrejón, M., Defeo, O., Reck, G., & Charles, A. (2014). Fishery Science in Galapagos: From a Resource-Focused to a Social–Ecological Systems Approach. In J. Denkinger & L. Vinueza (Eds.), *The Galapagos Marine Reserve: A Dynamic Social-Ecological System* (pp. 159–185). Springer International Publishing. https://doi.org/10.1007/978-3-319-02769-2_8

CITES. (2023). *Isostichopus fuscus | CITES*. https://cites.org/eng/taxonomy/term/5201

Conrad, J., Franklin, H., Nøstbakken, L., Stone, S., & Viteri, C. (2006). *Fisheries Management in the Galapagos Marine Reserve: A Bioeconomic Perspective*.

Darwin, E. C. C. (2002). *Análisis de la Densidad Poblacional y Estructura de Tallas del Pepino de Mar Stichopus fuscus en la Reserva Marina de Galápagos, Monitoreo de marzo, 2002*.

Dirección del Parque Nacional Galápagos. (2016). *Evaluación de la pesquería 2016 de pepino de mar Isostichopus fuscus en la Reserva Marina de Galápagos*. Informe Técnico. Puerto Ayora, Santa Cruz, Galápagos.

Dirección del Parque Nacional Galápagos. (2022). *Evaluación de la Pesqueria de Pepino de Mar (Isostichopus fuscus) 2021 en la Reserva Marina de Galápagos*.

EIA. (2023). *U.S. No 2 Diesel Retail Prices (Dollars per Gallon)*. https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=emd_epd2d_pte_nus_dpg&f=m

Hearn, A. (2008). The rocky path to sustainable fisheries management and conservation in the Galápagos Marine Reserve. *Ocean & Coastal Management*, *51*(8), 567–574. https://doi.org/10.1016/j.ocecoaman.2008.06.009

Hearn, A., Toral-Granda, V., Castrejón, M., Nicolaides, F., Moreno, J., Reyes, H., Altamirano, M., & Vega, S. (2004). *Evaluación de la pesquería de pepino de mar (Isostichopus fuscus) en Galapagos, 2004*. Fundación Charles Darwin, Santa Cruz, Galápagos, Ecuador.

IUCN. (2013). *The IUCN Red List of Threatened Species*. IUCN Red List of Threatened Species. https://www.iucnredlist.org/en

Murillo, J. C., Chasiluisa, C., Bautil, B., Vizcaino, J., Nicolaides, F., Moreno, J., & Molina, L. (2003). *Monitoreo de la pesquería del Pepino de mar (Stichopus fuscus) en las islas Galápagos, 2003*. Estación Cientıfica Charles Darwin.

Murillo, J. C., & Reyes, H. (2008). *Evaluación de la pesquería 2007 de pepino de mar Isostichopus fuscus en la Reserva Marina de Galápagos*. Parque Nacional Galápagos, Santa Cruz, Galápagos, Ecuador.

Murillo, J. C., Vizcaino, J., Nicolaides, F., Moreno, J., Espinoza, E., Chasiluisa, C., Andrade, R., Born, B., Villalta, M., Yépez, M., & Molina, L. (2002). *Informe Técnico Final de la Pesquería del Pepino de Mar (Stichopus fuscus) en las Islas Galápagos 2001*. Parque Nacional Galápagos.

Petroecuador. (2011). *INFORME ESTADÍSTICO 2011*.

Petroecuador. (2012). *40 años Construyendo el desarrollo del país 1972- 2012*. https://www.eppetroecuador.ec/wp-content/uploads/downloads/2015/03/40-A%C3%B1os-Construyendo-el-Desarrollo-del-Pa%C3%ADs.pdf

Petroecuador. (2015). *INFORME ESTADÍSTICO 2015*.

Petroecuador. (2021). *INFORME ESTADÍSTICO ENERO - DICIEMBRE 2021*.

Petroecuador. (2022). *INFORME ESTADÍSTICO ENERO – DICIEMBRE 2022*.

Purcell, S. W., Polidoro, B. A., Hamel, J.-F., Gamboa, R. U., & Mercier, A. (2014). The cost of being valuable: Predictors of extinction risk in marine invertebrates exploited as luxury seafood. *Proceedings of the Royal Society B: Biological Sciences*, *281*(1781), 20133296. https://doi.org/10.1098/rspb.2013.3296

Ramirez-González, J., Moity, N., Andrade Vera, S., & Reyes, H. (2020a). Estimation of age and growth and mortality parameters of the sea cucumber Isostichopus fuscus (Ludwig, 1875) and implications for the management of its fishery in the Galapagos Marine Reserve. *Aquaculture and Fisheries*, *5*. https://doi.org/10.1016/j.aaf.2020.01.002

Ramirez-González, J., Moity, N., Andrade Vera, S., & Reyes, H. (2020b). Overexploitation and More Than a Decade of Failed Management Leads to No Recovery of the Galápagos Sea Cucumber Fishery. *Frontiers in Marine Science*, *7*. https://doi.org/10.3389/fmars.2020.554314

Reyes, H., Murillo, J. C., & Wolff, M. (2009). *Informe técnico de las pesquerías de pepino de mar (Isostichopus fuscus) y langosta espinosa (Panulirus penicillatus y P. gracilis) en la Reserva Marina de Galápagos*. Parque Nacional Galápagos.

Sea Grant. (2012). *Alaska Vessel Fuel Efficiency Resources | Marine Advisory Program | Alaska Sea Grant*. https://seagrant.uaf.edu/map/recreation/fuel-efficiency/

Sevilla, G. (2022). *Resumen de la pesquería de pepino de mar (Isostichopus fuscus) en la Reserva Marina de Galápagos, temporada 2022*.

Shepherd, S. A., Martinez, P., Toral-Granda, M. V., & Edgar, G. J. (2004). The Galápagos sea cucumber fishery: Management improves as stocks decline. *Environmental Conservation*, *31*(2), 102–110. https://doi.org/10.1017/S0376892903001188

The Global Economy. (2016). *Diesel prices by country, around the world*. TheGlobalEconomy.Com. https://www.theglobaleconomy.com/rankings/diesel_prices/

Toral-Granda, V., Lovatelli, A., Vasconcellos, M., & Food and Agriculture Organization of the United Nations (Eds.). (2008). *Sea cucumbers: A global review of fisheries and trade*. Food and Agriculture Organization of the United Unations.

Toral-Granda, V., Murillo, J. C., Piu, M., Nicolaides, F., Moreno, J., Reyes, Harry, Castrejón, M., & Hearn, A. (2005). *La pesquería de pepino de mar (Isostichopus fuscus) en la Reserva Marina de Galápagos en el año 2005*. Fundación Charles Darwin/Parque Nacional Galápagos. Puerto Ayora, Santa Cruz.

Unidad de Recursos Marinos Parque Nacional Galápagos. (2000). *Informe Final de la Pesquería del Pepino de Mar (Stichopus fuscus) en las Islas Galápagos período 22 de mayo – 17 julio del 2000*. Área de Investigación y Conservación Marina Estación Científica Charles Darwin.

WTO. (2022). *Agreement on Fisheries Subsidies*. https://www.wto.org/english/tratop_e/rulesneg_e/fish_e/fish_e.htm

ANNEX A: DATA SET

- Dropbox cloud link to our data set: Data set _12-19-2023.

ANNEX B: FISHING EFFORT & SAILED NAUTICAL MILES X SEASON

- For the purpose of this study, we defined the fishing effort as the number of nautical miles (NM) sailed by season. Two determine the amount sailed NM we have to keep in mind two key factors of the fishery fishing techniques (**Fishing Techniques.)** and the macrozones (**Macrozones.)**.

- We divided the sailed NM by macrozone first, keeping in mind that each macrozone had a more likely fishing technique to happen. Boat fishing trips are predominantly undertaken in macrozones that are far from ports such as: Fernandina, Isabela Norte y Este, and Isabela Oeste. While day fishing trips are more prevalent in macrozones near ports, such as: Santa Cruz, Floreana, Isabela Sur, San Cristobal, and Española.

- NM for Boat fishing trips (SNM (Boat fishing trips) – Macrozones: Fernandina, Isabela Norte y Este, and Isabela Oeste:

- SNM (Boat fishing trips) = (NDT * RDDT) + (NBT * RDBT)

- Where:

- NDT = RLP/CPUE x Boat

- NDT stands for Number of Day Trips.

- RLP stands for Reported Landings per Macrozone.

- CPUE x Boat = CPUE x Day * ND.
- ND is the average Number of Divers per boat.
- CPUE x Day = CPUE * NH.
- CPUE stands for Catch Per Unit of Effort, this information was given in fishing reports and/or in a shared dataset.
- NH is the average Number of Hours of active diving/fishing per boat given in one of the share datasets.
- RDDT = 4

- RDDT stands for Roundtrip Distance (NM) per Day Trip.

- After talking with some fisherman, we discovered that during a boat fishing trips, the smaller boats that were towed will not sail more than 2 NM on average back and forth from the bigger boat in a day.

- NBT = NDT/4

- On average, a big boat will not tow more than four small vessels. Hence, by knowing the number of boat trips (NDT) we could know the required number of boat trips to towed four of this day trips. Of course, this is an approximation.

- RDBT stands for Roundtrip Distance (NM) per Boat trip. This value was calculated by averaging the roundtrip distance from all three main ports to the macrozone experiencing boat fishing trips.

- NM for Day fishing trips (SNM (Day fishing trips) – Macrozones: Santa Cruz, Floreana, Isabela Sur, San Cristobal, and Española:

- SNM (Day fishing trips) = (NDT * RDDT)

- Where:
- NDT = RLP/CPUE x Boat
- NDT stands for Number of Day Trips
- RLP stands for Reported Landings per Macrozone.
- CPUE x Boat = CPUE x Day * ND.
- ND is the average Number of Divers per boat.
- CPUE x Day = CPUE * NH.
- CPUE stands for Catch Per Unit of Effort, this information was given in fishing reports and/or in a shared dataset.
- NH is the average Number of Hours of active diving/fishing per boat given in one of the share datasets.
- RDDT stands for Roundtrip Distance (NM) per Day Trip. This value was calculated by taking the roundtrip distance from the closest port to the macrozone experiencing the day fishing trips.

Finally, we add all eight NM sailed per season on each macrozone to obtain the Sailed Nautical Miles (SNM) in total during a sea cucumber fishing season.