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Ecological footprint of an artisanal fishing cooperative in a lagoon body.

Huella ecológica de una cooperativa de pesca artesanal en un cuerpo lagunar.

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ABSTRACT

Fishing is an important economic activity in the world that produces food and generates employment. Although cooperatives have been strengthened as a successful business model, in Mexico they face diverse problems. The use of sustainability indicators is useful to identify areas of opportunity. One of these is the ecological footprint from which the corporate ecological footprint was derived, which measures the environmental impact in surface units. The objective of this work is to identify areas of opportunity for environmental improvement of a fishing cooperative through the evaluation and analysis of the footprint, to generate strategies. The calculation was made through the Composite Method in Financial Accounts. A gross ecological footprint of 299.24 gha was found, as well as 688.96 t of CO_2. Opportunity areas are the consumption reduction in the categories of materials, land use of forest resources, and the forest ecosystem, the latter two with greater impact on the footprint. It is recommended that annual monitoring of the footprint be implemented in the future to evaluate its reduction over time.

PALABRAS CLAVE: Fishing cooperative, Ecological footprint, Corporate ecological footprint, Carbon footprint, Artisanal fishing.

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ABSTRACT

La importancia económica y social de la pesca a nivel mundial está basada en la producción de alimento y en la generación de empleo. A pesar de que las cooperativas se han fortalecido como modelo de negocio exitoso, en México las cooperativas pesqueras enfrentan problemas diversos. El uso de indicadores de sustentabilidad es útil para identificar áreas de oportunidad. Uno de estos es la huella ecológica de donde derivó el de huella ecológica corporativa que mide el impacto ambiental global en unidades de superficie. El objetivo de este trabajo es identificar las áreas de oportunidad en la mejora ambiental de una cooperativa pesquera y generar estrategias, mediante la evaluación y análisis de la huella. El cálculo se hizo a través del Método Compuesto en Cuentas Contables. Se encontró una huella ecológica bruta de 299.24 gha, así como 688.96 t de CO_2. Las áreas de oportunidad son la reducción de consumos en las categorías de materiales, suelo de recursos forestales y ecosistema bosque, éstos dos últimos con el mayor influjo en la huella. Se recomienda la implementación del monitoreo de la huella con el fin de estimar las reducciones anuales.

PALABRAS CLAVE: Cooperativa pesquera, Huella ecológica, Huella ecológica corporativa, Huella de Carbono, Pesca artesanal.

Introduction

Fishing has been an activity developed by mankind for a long time and, since 1950, it has had a vertiginous growth from 18 to 100 million tons per year, which represents a 555 % increase (Arenas, 2014). According to the Food and Agriculture Organization of the United Nations (FAO, 2020), overfishing has affected different fishing areas with poor catches, shortages, and loss of species due to several factors. Fishery production, like other activities, has had to be evaluated in the context of sustainability, to understand and reduce the environmental impacts linked to this activity, and improve fishery resources management.

The economic and social importance of fishing at a global level is based on food production and employment generation. In 2016, world production was approximately 179 million tons and generated about 59.51 million jobs (FAO, 2020). In Mexico, there are an estimated two million people who live directly or indirectly from fishing (EDF Mexico, 2015). According to the Comisión Nacional de Acuacultura y Pesca (CONAPESCA, 2012), fishing and aquaculture cooperatives have achieved a social development that has strengthened them as a successful business model, providing half of the production for human consumption of Mexicans, that it is fishing and aquaculture cooperatives that feed the world.

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Both external and internal factors affect cooperatives, limiting their progress and expansion, such as the lack of real practice of cooperative values, poor knowledge of administrative processes, lack of strict compliance with the regulatory and legal framework, low generation of added value, zero promotion and dissemination of products, predatory intermediation and little emphasis on improving marketing, among other issues, which reflect low development in fishery cooperative societies (Fishery Cooperative Societies / FCS) (Rubio-Ardanaz, 2003).

The lack of investment by the different levels of government in the fishing sector, as well as the division of the members of the fishing cooperatives and the lack of training, have led to stagnation in production and deteriorated the socioeconomic conditions of the cooperative members (Nenadovic *et al*., 2018).

Given the relevance of the fishing activity and the problems inherent to it and that faced by the FCSs as organizations, they are forced to seek strategies that can solve internal (organization) and external (context and market) problems (Nenadovic *et al*., 2018). To identify areas of opportunity, it is common to use different tools and indicators in organizations, which allow evaluating performance by contrasting it with objectives, goals, and results in a defined period.

Although there is a great tool variety to apply in cooperative organizations, the Ecological Footprint (EF) allows using a global approach from the local level. The EF concept, in its original definition, states that it is the surface area required to support a human population indefinitely and includes the resources consumed and the assimilation of waste (Wackernagel & Rees, 1996). This is an aggregate indicator and accounting tool that allows for estimating the resource consumption and waste assimilation of a given region, population, or economy, expressed in units of productive area (Wackernagle & Rees, 2001). The result is expressed in global hectares (gha), under the idea that the goods and services consumed are produced all over the world, which implies a “delocalization” of consumption. It represents a biologically productive hectare with the global average productivity (Galli, 2015), which is necessary since different types of surfaces have different productivities. The use of a common unit allows different types of land to be compared.

The EF estimation considers the total population that inhabits a given space, in a specific period, while estimating the productive surfaces dedicated to crops, grazing, forests, sea, built surface, absorption area, and conservation space, reserved for biodiversity maintenance (SEMARNAT, 2021).

The Corporate Ecological Footprint (CEF) is derived from this concept and measures the environmental impact in hectares of any company or corporation, caused by activities such as the purchase of all types of products and services that are reflected in their general economic balance, the sale of products from primary production of food and other resources that are forest or biotic, i.e. when they first enter the market chain, the occupation of space and the generation of waste reflected in their ambient impact evaluation (Domenech, 2008).

Given the fisheries importance and faced problems along with fishing cooperatives, it was proposed to use the CEF since it let to estimate the global approach, disaggregation of impacts by type of surface/ecosystem, and the possibility of integrating it with other indicators and comparing the results with other similar organizations, in the study of a fishing cooperative. In addition, the

EF allows the integration of life cycle indicators and eco-labeling in a single tool and provides a new method of political decision-making to fight climate change in a fairer way (Domenech, 2008).

This study aimed to calculate the CEF of the FCS Pescadores de San Pedro Lagunillas in Nayarit, Mexico, to identify areas of opportunity for environmental improvement by evaluating, comparing, and analyzing the footprint. This in turn will allow generating of pro-environmental strategies for this cooperative.

Background

The CEF has been applied to organizations of different types and sizes, making this indicator a dynamic and adaptable tool.

Domenech, the precursor of the conceptual and methodological framework of CEF, evaluated it in the Port of Gijon in Spain, based on electricity, water and fuel consumption, waste generation, expenditure on services, and space occupation (Domenech, 2004). Some years later, he determined that the processes of infrastructure maintenance and ship docking had the greatest impact, equivalent to 5,298 hectares of biologically productive ecosystems, using the Composite Method for Accounting Accounts (MC3), which is based on the fact that the consumption of companies is recorded through accounts and is the basis for the calculations (Domenech, 2008).

Carballo *et al*. (2008) later applied this method to two companies in the fishing sector in Galicia, Spain, and found substantial differences despite the similarities between the two organizations and identified the areas that favored the differences, finding that the greatest impacts were due to fuel consumption and the bait used (Carballo *et al*., 2008).

It has also been used in other companies, such as a canning company in Galicia, where an updated version of the method (MC3 V.2) was used. They found that the consumption categories that generate the highest CEF are seafood products, direct and indirect energy consumption, cultivated products, and forest resources (Carballo *et al*., 2008). Cagiao *et al*. (2011) applied the same method to determine the footprint of cement and demonstrate that comparability between different brands and products is fully possible, thus providing a serious alternative to methodologies with the process approach to life cycle analysis (P-LCA).

The EF in the fisheries sector has been calculated by a different method than MC3, using life cycle analysis (LCA), such as Winther *et al*. (2009) in Norway, who elaborated a very comprehensive report on the entire fishing and aquaculture industry, as well as Iribarren *et al*. (2010) in the northeastern coasts of Spain. The latter calculates the EF of a set of small artisanal fishing vessels, also under the LCA methodology. The difference between MC3 and LCA methodology is that the latter requires specialized software and technical knowledge in biology and chemistry. Therefore, MC3 is a robust and less complex option for the calculation of EF.

On the other hand, Mateo-Mantecón *et al*. (2011) measured the corporate carbon footprint of the ports of New York and New Jersey to detonate an initiative for all ports in the world to implement an action plan to fight climate change and achieve high-quality air. Thus, using the MC3 method, both ports set out to become carbon-neutral ports by the end of 2011 (Domenech & Carballo, 2009).

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A study of coastal fisheries on the coast of Jalisco analyzed the catch, specific composition, and EF of four fishing cooperatives using the MC3 V.2 method (Bravo Olivas, 2014). The FCSs studied were: Pescadores del Rosita, Cruz de Loreto, Ejidal La Fortuna, and Puerto Viejo, in which it was found that the highest expenditures made by the FCSs are in the category of direct emissions for fuel consumption for the boats (except the FCS Cruz de Loreto, they move by oars and their highest consumption was in the energy used for ice generation) and the lowest consumptions they identified were in the category of agricultural resources, fisheries and forest resources (Bravo Olivas, 2014).

Other studies using the CEF include Alvarez and Rubio (2015) where the methodologies proposed by Domenech were applied with a double objective, first to evaluate its advantages and disadvantages for the product carbon footprint and second, to evaluate the differences with the process-based analysis. Such study was carried out in a company generating the EUR-flat wood pallet (Alvarez & Rubio, 2015). They conclude with a comparison between the MC3 methodologies (Domenech, 2004), the process-based analysis, as well as the LCA of the European Union ISO 2006, and, they state that the use of MC3 drastically reduces the calculation time, compared to the LCA.

Soares and Chaves (2017) conducted a study where they analyze the CEF definition and objectives, to then apply it in a Portuguese company. They did not make any modifications to the MC3 method.

Bravo Olivas and Chávez Dagostino (2020) evaluated the CEF of the artisanal fishing FCS called La Cruz de Loreto in the state of Jalisco, Mexico, to determine its eco-efficiency and non-direct global impacts. Eco-efficiency refers to the production of goods and services at the lowest cost, in a broad sense (Domenech, 2007); also MC3 V.2 method was used which includes the categories of emissions, materials, resources, services and contracts, land use, and waste. As a result of the net CEF of 164.43 gha and a net carbon footprint of 453.37 t CO_2 per year. Reporting that the consumption category that contributed most to the footprint were indirect emissions and ecosystem fossil energy, due to the characteristics of the FCS analyzed.

Study Area

FCS is a private cooperative society, of indefinite duration, with its legal status and assets, dedicated to the capture, fishing, cultivation, processing, and commercialization of mojarra, tilapia, and black bass, among other fish species (Escobedo, 2019). The fish license is for small-boat commercial fishing, and commercial freshwater fishing (Peña, 2014). This cooperative is comprised of 86 members, 43 boats, and 43 fish nets created with 4 ½-inch one-skein gill nets, established by CONAPESCA for tilapia fishing in the lagoon body. The fishing area is located in the San Pedro Lagunillas lagoon, located in the municipality of San Pedro Lagunillas, Nayarit (Figure 1) this lagoon has 282 hectares, is fed by the San Pedro river, and is freshwater (Escobedo, 2019).

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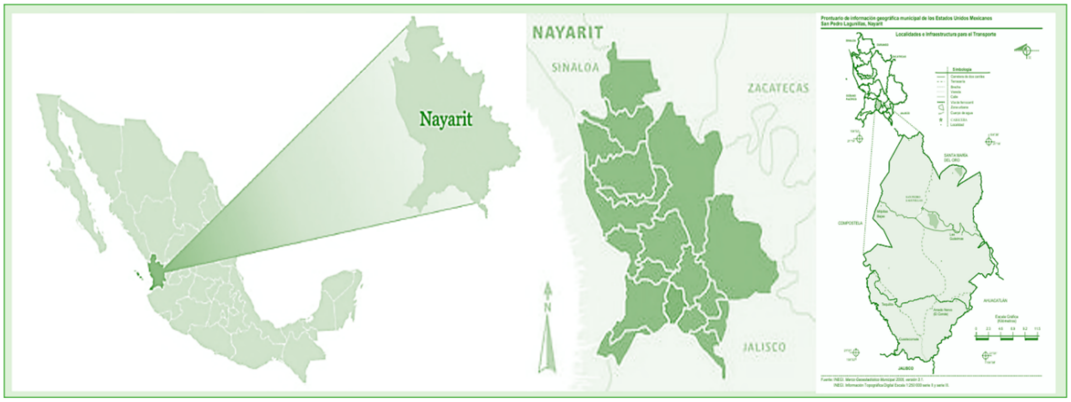

Figure 1. Location of the FCS Fishermen of San Pedro Lagunillas, Nayarit.

Source: Own elaboration based on INEGI (2017).

This cooperative only catches tilapia. For the year 2020, they registered catches of 265 tons with an approximate value of 7’950,000.00 pesos. This product is extracted from the lagoon and marketed almost entirely in the city of Guadalajara, except that which is extracted for self-consumption (Escobedo, 2019).

Material and Methods

For the CEF, Domenech proposed a calculator in which practically all the necessary data can be obtained from the organization’s accounting, based on that of Wackernagel (Domenech, 2008) and which he called MC3. Version 2 was the one applied to the FCS Pescadores de San Pedro Lagunillas for the year 2020 (Carballo *et al*., 2009a, 2009b). The main modification of this method (MC3, V.2) is the division of the spreadsheet into two, one for the carbon footprint (carbon footprint CF) and another for the EF. It also includes 18 support or complementary matrices in the CF calculation. In this version, the purchase of all types of goods and services is also considered, as well as the occupation of space and the generation of waste, making it possible to calculate the CF of any organization (Quezada *et al*., 2013).

To measure the CEF of FCS is required to identify what and how much they consume in a year for their fishing activities (description of the life cycle of the cooperative’s fishing process) such as planting, fishing, cleaning, and/or selling or self-consumption, as well as maintenance, purchase, repair of fishing gear, canoes, among other services). The initial step consisted of drawing up a list of the main categories of products consumed in a fishing cooperative, with sections for waste generated and land use (Table 1). This information was obtained through direct interviews and a review of the organization’s accounting documents regarding fuel consumption, energy, materials, services, natural and agricultural resources, forestry resources, water, land use, and waste.

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Table 1. Sources of CO_2 emissions considered in the carbon footprint (MC3. V.2).

Consumption sections	Consumption categories
1. Direct emissions	1.1 Fuels 1.2 Other direct emissions
2. Indirect emissions	2.1 Electricity 2.2 Other indirect emissions
3. Materials	3.1 Materials flows (merchandise) 3.2 Non-depreciable materials 3.3 Depreciable materials 3.4 Depreciable materials (construction) 3.5 Use of public infrastructure
4. Services	4.1 Low mobility services 4.2 High mobility services 4.3 Personnel transportation services 4.4 Goods transportation services 4.5 Use of public infrastructure
5. Agricultural and fishery resources	5.1 Clothing and manufactures 5.2 Agricultural products 5.3 Restaurant services
6. Forestry resources	
7. Water	7.1 Drinking water consumption
8. Land use	8.1 On land 8.2 On water
9. Waste, effluents, and emissions	9.1 Non-hazardous waste 9.2 Hazardous waste 9.3 Radioactive waste 9.4 Effluent discharges 9.5 Emission

Source: Own elaboration based on Carballo *et al*. (2009a).

The spreadsheet includes the counter-footprint, which is also called natural capital (natural capital NC). This concept is defined as the area available to the organization (forest, pasture, sea, etc.) that allows the footprint to be compensated or the deficit to be compensated. In an accounting analogy, the footprint is the "debit" and the NC is the "credit" (Domenech, 2007). The concept of net EF and gross EF are related in the sense that the gross EF is the net EF plus the NC or counter-footprint, in other words, the net EF does not consider the NC. In the calculation, the total EF is the gross EF.

Considering that the CF calculated by the MC3 method is also expressed in terms of the ecological footprint, the same methodology as the original method of Wackernagel & Rees (1996) was used: the application of an equivalence factor (FE) that allows aggregating all types of spaces (representing the global average productivity of a bioproductive area with the global average of all bioproductive areas), and the application of the yield factor (RF), which is the factor of local productivity against global productivity. For example, if the productivity of the forest is similar to the average productivity in the whole forest world, the yield factor will be 1, whereas, if the local

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productivity is twice as large as the world, then the yield factor will be 2. For a country, for any type of land use, it is given by

$$FR = \frac{\sum_{i \epsilon U} \quad A_{W,i}}{\sum_{i \epsilon U} \quad A_{N,i}} \qquad (1)$$

Where:

FR = Factor of the yield of an area for any given land use type.

U = Is the set of all primary products used that are produced on the land.

AW, i = Is the area needed for the overall production in a year, the available quantity of the product.

AN ,i = Is the area needed for a regional production in a year, the available quantity of product i.

These areas were calculated as shown in the following equation 2.

$$A_{N,i} = \frac{P_i}{Y_N} \; A_{W,i} = \frac{P_i}{Y_W} \qquad (2)$$

Where:

AN, i = Is the area needed for a regional production in a year, the available quantity of product i.

AW,i = Is the area needed for global production in a year, the available quantity of the product.

Pi = Is the annual growth of the production of i.

Y_N = Is the national yield.
Y_W = World yield.

The yield factors reflect the relative productivity of a country and the global average number of hectares of a given soil type. Each country, in each year, has a yield factor for each soil type. The calculation of biocapacity is reported in global hectares. Such factors were calculated for each soil type taking into account the following sources:

CF due to soil occupation and loss of bio-productive space used to absorb CO_2 is calculated by converting CO_2 hectares through the absorption factor of the occupied ecosystem (Table 2).

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Table 2. Absorption factors (tCO_2/ha) for each type of ecosystem.

Ecosystem types	Rate (2020)	References	Rate (2014)	References
Arable area	4.76	(Pomè *et al*., 2021)	1.98	(ECCP, 2004)
Pastures	1.76	(Pomè *et al*., 2021)	0.84	(Flanagan *et al*., 2002; Soussana *et al*., 2004; Suyker & Verma, 2001)
Forest	2.68	(Pomè *et al*., 2021)	3.67	(IPCC, 2001)
Built-up area	4.76	(Pomè *et al*., 2021)	1.98	(ECCP, 2004)
Sea	1.94	(Pomè *et al*., 2021)	0.24	(Sabine *et al*., 2004)
Inland waters	1.94	(Pomè *et al*., 2021)	0.24	(Sabine *et al*., 2004)

Source: Own elaboration based on on two authors (Bravo-Olivas & Chávez-Dagostino, 2020; Pomè *et al*., 2021).

Yield factors reflect the relative productivity of a country and the global average hectares of a certain type of land. Each country has an annual performance factor for each soil type. Biocapacity is reported in gha These factors were calculated for each soil type, as performed by Bravo-Olivas and Chávez-Dagostino (2020).

The equivalence factors calculated by Ewing *et al*. (2010) were used to calculate the footprints of the different soil types, converting the actual hectares to their equivalent global hectares.

It is worth mentioning that the yield and equivalence factors are applied to both biocapacity and footprint calculations to obtain results that are unitary, consistent and comparable (Table 3).

Results

In 2020 the FCS Pescadores de San Pedro Lagunillas Nayarit, Mexico produced a net EF of 296.14 gha and a net CF of 136.66 tCO_2. The most important contribution to the EF was from the forest resource consumption category due to the use of wood for the manufacture of its oars. This was followed by the category of materials consumption (non-organic), for the various materials used by FCS members to carry out their fishing work which amounted to more than 180 thousand pesos (Table 4).

Table 3. Equivalence and yield factors for each type of ecosystem.

Ecosystem types	Equivalence factors (FE) Rate (2020)	Performance factors (RF) Rate (2020)
Forest for CO_2[1]	1.26	
Arable area	2.50	0.60
Pastures	0.45	0.79
Forests	1.26	0.66
Built-up areas	2.50	0.60
Sea	0.36	1.09
Inland waters	0.36	1.00

Forests for CO_2 is the area of forest necessary to absorb the CO_2 emitted in the burning of fuels, in the manufacture of goods, in the energy expenditure of contracted services, in the energy consumed in waste treatment, etc. (Domenech, 2010).

Source: Own elaboration based on on two authors (Bravo-Olivas & Chávez-Dagostino, 2020; Global Footprint Network, 2022).

Table 4. Expenditure by FCS consumption category.

Consumption categories	Expenditure	Percentage
1.- Direct emissions	$27,912.01	7.72
2.- Indirect emissions	$74,681.23	20.66
3.- Materials (non-organics)	$180,471.54	49.93
4.- Services and contracts	$77,700.00	21.50
5.- Agricultural and fishery resources	$0.00	0.00
6.- Forestry resources	$51,600.00	0.00
7.- Water	$676.50	0.19
8.- Land use	$0.00	0.00
9.- Waste, spills, and emissions	$0.00	0.00
Total	**$413,041.28**	**100.00**

Source: Own elaboration.

The most affected ecosystem type for EF and FC was forests, while emissions from cropland and pasture were not significant (Table 5).

The consumption category with the highest expenditure is materials (non-organic) with 49 %, followed by the category of services and contracts with 21.50 %, and very close behind is the category of indirect emissions with 20.66 %. There is no expenditure in the categories of agricultural and fishing resources, land use, waste, spills, and emissions (Table 4).

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Table 5. Distribution of the ecological and carbon footprint by ecosystem of the FCS.

Ecosystem types	gha	tCO_2
Forest for CO_2	126.88	263.60
Arable area	2.63088E-07	4.96944E-07
Pastures	2.86371E-06	1.09568E-05
Forests	171.70	356.71
Built-up areas	0.66	0.40
Sea	0	68.24
Net Ecological Footprint (net EF)	**296.14**	**136.66**
Natural Capital (NC)	**3.1**	**552.3**
Gross Ecological Footprint (gross EF)	**299.24**	**688.96**

Fuente: Elaboración propia.

It can be seen that the result of the EF (expressed in gha) has a low NC that represents 1 % of the total gross EF, while the result of the CF (expressed in tCO_2) has a considerable NC since it is 80 % of the gross EF (Table 5).

The consumption of forest resources represents the largest proportion for both CF and EF. Consumption of agricultural and fishery resources is the lowest, followed by water consumption for food use (Table 6, Figures 2 and 3).

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Table 6. Distribution of EF and CF by category of consumption and ecosystem.

CONSUMPTION CATEGORY	Forests for CO_2		Arable area		Pastures		Forests		Built-up areas		Sea		Total	
	gha	tCO_2	gha	tCO_2	gha	tCO_2	gha	tCO_2	gha	tCO_2	gha	tCO_2	gha	tCO_2
1.-DIRECT EMISSIONS	1.42	2.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.42	2.94
2.-INDIRECT EMISSIONS	18.86	39.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.86	39.19
3.- MATERIAL (Non-organics)	65.95	137.01	0.00	0.00	0.00	0.00	3.38	7.01	0.00	0.00	0.00	0.00	69.32	144.02
4.- SERVICES AND CONTRATS	12.87	26.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.87	26.73
5. AGRICULTURAL AND FISHERIES RESOURCES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6. FORESTRY RESOURCES	27.63	57.39	0.00	0.00	0.00	0.00	168.28	349.60	0.00	0.00	0.00	0.00	195.90	406.99
7. WATER	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.09	0.00	0.00	0.00	0.00	0.04	0.09
8. LAND USE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.40	0.00	68.24	0.65	68.64
9. WASTE, SPILLS, AND EMISSIONS	0.00	0.34	0.18	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.18	0.36
Subtotal	126.72	263.60	0.18	0.00	0.00	0.00	171.69	356.71	0.65	0.40	0.00	68.24	299.24	688.96
Natural Capital													3.1	552.3
Total													**296.16**	**136.66**

Source: Own elaboration.

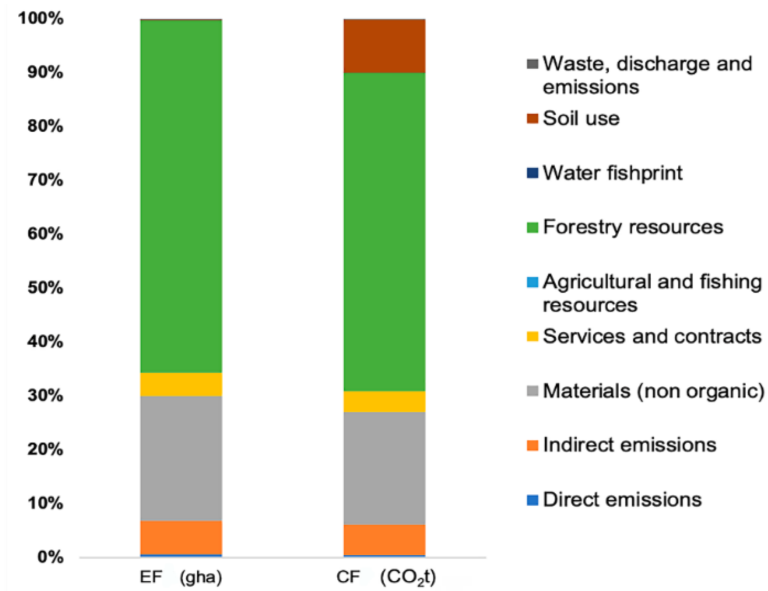

Figure 2. EF (gha) and CF (tCO_2) distribution by category of consumption in the fishing organization of the FCS Pescadores de San Pedro Lagunillas, Nayarit.

Source: Own elaboration.

For both footprints (EF and CF) the highest consumption is in the category of forest resources, followed by non-organic materials, and then for CF, it would be land use, while for EF it would be indirect emissions (Figure 2).

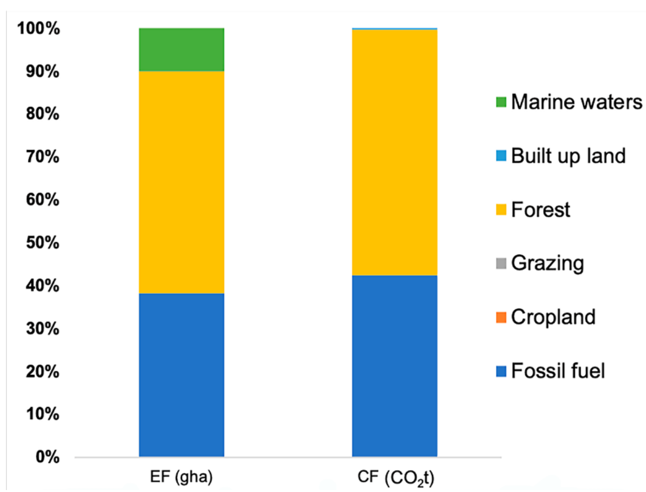

Figure 3. Ecological footprint and carbon footprint of the FCS Pescadores de San Pedro Lagunillas, Nayarit.

Source: Own elaboration.

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The impact of the footprints (EF and CF) on the ecosystem are very similar, both have a greater impact on forests, followed by forests for CO_2, and CF has a third impact on the marine ecosystem (Figure 2).

The environmental and economic eco-efficiency indicators for this cooperative are sampled in Table 7.

Table 7. FCS eco-efficiency indicators.

Eco-efficiency 1	Carbon	1.9 t/tCO_2
	Ecological	0.9 t/ha
Eco-efficiency 2	Carbon	$58,170.3 Pesos/t$CO_2$
	Ecological	$26,843.5 Pesos/ha

*Mex$. Source: Own elaboration.

It is noteworthy that these eco-efficiency indicators allow us to compare companies regardless of their size.

If FCS were to contribute to the carbon market, these emissions would cost approximately 58,170.3 pesos (2,836.19 dollars) to mitigate their impact.

Discussion

As mentioned, the EF is a sustainability indicator that currently attracts the interest of countries, organizations, and individuals worldwide. According to the official website of the ecological footprint network, it is possible to find this indicator applied by country or globally (Global Footprint Network, 2022). Despite this, this indicator has its respective limitations when making comparisons because factors such as time, available technology, the place or area where it is performed, the complexity of the place or company, as well as the formalization that these have for the reliable collection of information for the application of this indicator, enter into play, in this sense Soares and Chaves (2017) analyzed the definition and goals of the EF and applied for further study, the MC3 method. One more limitation that stands out when it is applied to the fisheries sector, is that it excludes other ecological impacts that are relevant to pollution, by only focusing on CO_2, discarding other greenhouse gases (greenhouse gases GHG). But an interesting issue in the comparison of the FSC in companies is that companies can establish strategies of their own to reduce or offset impacts within defined time frames, as well as analyze the strategies that other companies have applied to discard or adapt them. A comparison of the different companies or FCSs that have applied MC3 to find their CEF and eco-efficiency is shown below (Table 8).

The annual catch of the FCS Pescadores de San Pedro Lagunillas (265 tons of fish per year in 2020), coincides with the results of the FCS La Cruz de Loreto on the coast of Jalisco, as they are considerably more eco-efficient than the two Spanish companies (Bravo-Olivas & Chávez-

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Dagostino, 2020). One of the reasons for this efficiency is that these FCSs did not use engines in their vessels due to the characteristics of the water bodies where they fish. This considerably decreases fuel consumption and CF, which is what impacts Spanish companies the most.

The highest consumption point for FCS La Cruz de Loreto was in the category of materials (non-organic) for the use of plastics for fishing gear, and in the case of FCS Pescadores de San Pedro Lagunillas, it was obtained in the category of forest resources for the use of wood to manufacture the oars of the boats.

Bravo Olivas (2014) in his analysis of CEF from several FCSs (El Rosita, La Cruz de Loreto, La Fortuna, and Puerto Viejo) on the coast of Jalisco, found different results (See Table 8). Of these FCS, the one that comes closest in terms of tons caught per year to that of Pescadores de San Pedro Lagunillas is Puerto Viejo. For this last FCS, the category of direct emissions from fuel consumption for the boats is what represents the greatest contribution in the EF and the CF.

The results obtained by Iribarren *et al*. (2010) for artisanal fishing in northeastern Spain, was a CF of 1.49 tCO_2 /t, however, it has a catch of 18,881.47 tons per year, having a gross CF of 28,133.38 tCO_2 which, given the size of the catch, explains the high CF. A further consideration is that fuel consumption constitutes the largest contribution to CF.

In the case of Winther *et al*. (2009), they report a CF for the catch of some species much lower than the previous ones (0.00201 tCO_2 /t for cod 0.00213 tCO_2/t for saithe to mention a few). It is important to mention that this calculation excludes the transport and processing of the species caught, which would undoubtedly increase the CF considerably.

The use of fossil fuels is in many of the CEF calculations the factor that contributes most to the impact of fishing activity by capture, this is due to the use of fuels for ships or boats, and also due to the use of synthetic materials manufactured through these fuels as would be the polyethylene that is necessary for the elaboration of fishing gear (Bravo-Olivas & Chávez-Dagostino, 2020; Mateo-Mantecón *et al*., 2011; Verones *et al*., 2017). According to FAO motorized vessels represented 61 % of all fishing vessels in 2016, by 2018 it remained at 61 % and by 2020 63 % (FAO, 2018, 2020).

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. Table 8. Comparison of CEF findings in different companies or FCS.

FCS	Characteristics	Capture type	CEF	Eco-efficiency
Pesquera Galicia B1	Sea fishing, 17 members, 1 fishing gear, 98.8 tons per year, and a motorboat with 29 m. of length (Carballo *et al*., 2008).	Fish (Hake and Seabass)	1083.5 gha y 1678.2 tCO_2	10.9 gha/t
Pesquera Galicia B2	Sea fishing, 12 members, 1 fishing gear, 190.2 tons per year, and 1 motorboat with 25.7 m. of length (Carballo *et al*., 2008).	Fish (Swordfish, sharks, and Tuna)	540.2 gha y 2026.4 tCO_2	2.48 gha/t
El Rosita	Sea fishing, 7 members, 4 fishing gears, 35.5 tons per year, and 20 motorboats (Bravo Olivas, 2014).	Fish and Octopus	84 gha y 231.7 tCO_2	0.4 gha/t
Cruz de Loreto	Sea fishing, 62 members, 32 fishing gears, 91.65 tons per year, and 182 rowing boats (Bravo-Olivas & Chávez-Dagostino, 2020)	Fish, Crabs, and Shrimp	164.43 gha y 452.76 tCO_2	1.79 gha/t
La Fortuna	Sea fishing, 17 members, 17 fishing gears, 110.4 tons per year, and 200 motorboats (Bravo Olivas, 2014).	Fish, Octopus, Oysters, and Lobster	189.3 gha y 521.9 tCO_2	0.6 gha/t
Puerto Viejo	Sea fishing, 22 members, 23 fishing gears, 182.5 tons per year, and 214 motorboats (Bravo Olivas, 2014).	Fish, Octopus, and Lobster	317.9 gha, 876.5 tCO_2	0.6 gha/t
Pescadores de San Pedro Lagunillas	Inland fishing, 84 members, 42 fishing gears, 265 tons per year, and 42 rowing boats.	Fish (tilapia)	296.14 gha y 136.66 tCO_2	0.9 gha/t

Source: Own elaboration.

Calculations in different companies also vary in the use of factors, which companies do not control, for example, the type of fuel accessed in a country or how the consumed electrical energy was sourced, among others, but also different performance factors are used. This makes comparisons between companies useful, but not their absolute values for making value judgments; they should only be considered as a benchmark. Despite these limitations, what is most useful is for the company to know its impacts, monitor them, and identify areas of opportunity in relation to competitiveness. The real challenge for the company is to reduce its footprint.

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In the same sense, the EF methodology in general, allows us to elaborate an aggregate estimate of the demand that man makes on the biosphere, this is linked to the parameters used and methodological decisions, so the results allow us to see the state of the company (in this case of FCS) in terms of opportunities to promote sustainability improvement, but its use is discarded for the establishment of future scenarios.

The present study has been able to quantify the CEF, CF, and eco-efficiency indicators, which has made it possible to compare other studies that have at least calculated some of these indicators. And as mentioned (Bravo-Olivas & Chávez-Dagostino, 2020) the best contribution to the concept of EF is that it counteracts the ingrained idea that the resources for the fishing sector (fish) are infinite.

Conclusions

The CEF of the FCS Pescadores de San Pedro Lagunillas is relatively low, but the impacts (areas of opportunity) can be reduced: the use of land corresponding to forest resources, which is the largest contributor to the footprint, and the consumption of materials that impacts the forest ecosystem.

In the category of consumption of forest resources for the use and acquisition of wooden oars, the strategy for this area of opportunity would be to reuse wooden oars up to the limit of their useful life; if they are no longer functional due to use, consider acquiring other types of oars with longer-lasting material, such as plastic or aluminum oars. However, this should be evaluated before implementation.

The second area of opportunity is in the category of materials (non-organic), which has the highest expenditure, the strategy would be to reduce consumption, especially in the plastic material used for fishing gear. These could be recycled and repaired and the number of nets per boat could be reduced. Another strategy would be to recycle the various materials (buoys, life jackets, lines, and basic fishing tools) and thus reduce unnecessary consumption, which would reduce spending in this category.

For the area of opportunity of the most affected ecosystem, which is the forest, the strategy would be to recycle the product of the fish viscera for the production of fish food, as well as to separate and recycle the garbage that is concentrated near the embarkation areas. It is necessary for this FCS to also invest in the forest ecosystem type for CO_2 capture, which is the next most affected. To mitigate impacts in this area of opportunity, the strategy proposed is to carry out a cleaning program in the lagoon and afforestation of areas in the FCS.

The implementation of corporate footprint monitoring is recommended for the future to estimate annual reductions.

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Author contributions

Conceptualization of the work, authors DLJL, SCE, BOML, CDRM; methodology development, authors DLJL, BOML, CDRM; software management, authors DLJL, BOML, CDRM; experimental validation, authors 1,3,4; analysis of results, authors DLJL, SCE, BOML, CDRM; data management, authors 1,3,4; manuscript writing and preparation, authors DLJL, SCE, BOML, CDRM; drafting, revising and editing, authors DLJL, SCE, BOML, CDRM.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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