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Fishing Eco-Efficiency of Ports in Northwest Spain

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Abstract: Fishing is an essential economic activity and source of livelihood for millions of people worldwide. However, overfishing and unsustainable practices have led to a decline in fish populations and the degradation of marine ecosystems. Moreover, fishing activities can contribute to climate change through the emission of greenhouse gases (e.g., carbon dioxide and methane) from fishing vessels and seafood transportation. To mitigate the environmental impacts of fishing activities, sustainable fishing practices must be implemented to minimize the negative impacts of fishing on the environment while maintaining the productivity and diversity of fish populations and ecosystems. These practices include using selective fishing gear, avoiding fishing in vulnerable habitats, implementing fishery management plans, and reducing the carbon footprint of the fishing industry. To this end, and as a first step in defining efficient and effective measures towards the sustainability of capture fishing activity, an analysis of the environmental sustainability of the Galician fishing sector, one of the main European regions in this field, is presented in this work. An ecosystem-based indicator (ecological footprint, calculated by adding the so-called fishing ground footprint and the carbon footprint) was employed to quantify the main impacts of capture fishing during extractive activity. The catch composition and fuel consumption of the fleet based on the vessels' power, and economic benefits, were the parameters used in this analysis. The results showed that ports with larger vessels and fleets seem to be more eco-efficient than those concentrating smaller vessels in targeting lower trophic level species.

Keywords: eco-efficiency; environmental impact; fishing; marine resources; sustainability

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1. Introduction

Fisheries are essential for ensuring food security and nutrition as suppliers of rich sources of protein and nutrients, along with creating employment opportunities for many individuals globally [1,2]. In numerous countries, the fisheries sector is considered a key driver of economic growth, with over 12% of the global population relying on fisheries for their livelihood [3]. In recent decades, factors such as increased supply, evolving consumer preferences, technological advancements, income growth, and the rise of aquaculture have significantly influenced the per capita consumption of aquatic foods [4,5]. Blue food, derived from aquatic sources, is recognized for being high in protein and low in fat, offering numerous health benefits, including essential vitamins and nutrients [6–9]. As a result, it offers reasonably priced and easily available supplies of micronutrients and animal proteins, which are vital for the food and nutritional security of coastal communities. This has led to a significant increase in the demand for marine products over the last 20 years. Between 1961 and 2019, the apparent global consumption of blue foods increased at an average yearly rate of 3%, which was almost twice as fast as the 1.6% annual global population growth rate during the same time frame [10]. During the same timeframe, the average per capita consumption of aquatic animal foods increased by around 1.4% annually, from 9.0 kg to 20.5 kg. The production of aquatic animals was projected to reach 178 million tons worldwide in 2020, with 90 million tons (51%) coming from catch fisheries, which also brought about USD 141 billion in sales [10].

With the rising nutritional demands of the growing human population and strain on terrestrial resources, the ocean is anticipated to assume a more critical role in the future. Global food production systems depend heavily on aquaculture and fisheries [2,4], and the sustainable management of these industries is critical to maintaining food security, income, human dignity and equality, and the conservation of natural resources. Therefore, maintaining marine biomass stocks for present and future generations has become imperative, as the net productivity and resilience of marine ecosystems to fishing activities have declined in various regions worldwide [11,12]. Unsustainable fishing practices, such as overfishing and habitat destruction, have caused significant declines in fish populations and the degradation of marine habitats, jeopardizing the long-term viability of fish stocks and communities reliant on them [13]. Current data [10] indicate that fewer fish stocks worldwide are being harvested within biologically sustainable limits, with 35.4% of stocks being overexploited. Sustainable fisheries management involves adopting practices that maintain fish populations at healthy levels, minimize environmental impacts, and promote economic and social well-being [14]. This strategy not only enhances the resilience of marine ecosystems but also ensures the availability of marine resources for future generations. In Europe, the Common Fisheries Policy [15] aims to ensure the sustainability of European fisheries by optimizing the use of marine resources and reducing fish discards.

With this aim, the sustainable use of marine resources and healthy ecosystems can be guaranteed by constantly monitoring marine ecosystems, maintaining them in healthy and productive conditions, and maintaining the abundance of fish stocks at or above the level associated with maximum sustainable yield [16]. Moreover, the integration of ecological, economic, and social dimensions in fisheries management is essential for achieving sustainability and addressing the complex challenges facing global fisheries today [17,18]. These objectives can only be achieved through efficient fishing measures that consider the three pillars of sustainability (environmental, economic, and social). However, current fishing practices challenge this objective, and sometimes miss one or more of these core concepts.

However, the concept of sustainable fishing activity is also currently associated with other concepts related to the environmental impacts of this primary activity and how they affect the ecosystems in which it takes place [19–21] and, in general, planet and climate change. The impacts of fishing activity on climate change have garnered increasing attention in scientific research owing to the sector's substantial contribution to global food security and its environmental footprint. In this context, wild-caught fish generally have a lower carbon footprint than many other food production sources [22–24]. This is because fishing does not require the same energy-intensive processes as other types of food production, such as land cultivation, fertilization, and irrigation. Additionally, many fishing methods have a relatively low environmental impact compared with other forms of agriculture. However, the carbon footprint of wild fish can vary depending on several factors, including the type of fish, fishing method used (such as trawling, which can result in large amounts of fuel consumption and emissions, contributing significantly to greenhouse gas emissions and, thereby exacerbating climate change [25,26]), and the distance the fish must travel to reach consumers.

Compared to farmed fish, wild-caught fish generally have a lower carbon footprint, as farmed fish require energy-intensive inputs, such as feed, water, and energy for light and temperature control. Compared with meat, wild-caught fish tend to have a lower carbon footprint, as meat production involves significant energy inputs from feed production, animal breeding, and transportation [27,28]. However, it is worth noting that the carbon footprint of wild fish can still be significant if the fish are transported long distances or if fishing methods are particularly energy intensive [25,29]. Overfishing and unsustainable fishing practices can have significant environmental impacts beyond carbon emissions because the disruption of marine ecosystems through overfishing and habitat destruction can alter carbon sequestration processes, further influencing climate dynamics [30–32]. Therefore, addressing these issues is critical, as sustainable fishing practices not only support the conservation of marine biodiversity, but also play a role in mitigating climate change.

In light of this, and to face the increasing awareness of environmental sustainability of the fishing industry, the application of carbon and ecological footprint methodologies to assess the environmental impacts has gained relevance in the last years. Carbon footprint analysis focuses on quantifying greenhouse gas emissions associated with fishing activities, from fuel consumption to the entire supply chain, highlighting the importance of reducing carbon emissions to mitigate climate change [26,33]. Ecological footprint, on the other hand, measures the demand placed on ecosystems by fishing activities, including resource use and waste generation, and provides a comprehensive view of environmental impacts [34]. Together, these methodologies offer a robust framework for evaluating the sustainability of fishing practices and guiding policy decisions aimed at reducing environmental degradation [35,36]. Some examples of the application of these methodologies to fisheries worldwide, providing critical insights into the environmental impacts of diverse fishing practices, are as follows: According to a study conducted in New Zealand, which used carbon footprint analysis, one of the least amounts of animal-based protein comes from wild-caught fish that are gathered and processed at sea by deep-water fishermen in the country [37]. Similarly, in Sweden, the ecological footprint of a Baltic Sea cod fishery was assessed, revealing significant environmental impacts due to overfishing and habitat degradation, prompting the development of more sustainable management practices [38,39]. In the Mediterranean, carbon footprint assessments of small-scale fisheries in Spain identified the high carbon costs of certain gear types, such as trawling, compared to less intensive methods, such us longlining, leading to policy recommendations for gear modifications to minimize emissions [40]. Additionally, a life cycle assessment of the Peruvian anchoveta fishery integrated both carbon and ecological footprints, demonstrating the importance of sustainable catch limits and eco-friendly processing methods to reduce the overall environmental burden [41].

To go a step further in the related literature on different approaches and methodologies mentioned above dealing with the topic of environmental implications of fishing, this work aims to be the first to quantify and discuss the environmental sustainability and eco-efficiency (that combines environmental and economic aspects) of the capture fishing sector in Galicia (northwest of Spain) at a port level. Consequently, future fishing measurements can be performed with a data-based tool using an ecosystem-based indicator, the ecological footprint (EF). These assessments can be applied to the most important fish species in terms of commercial revenue, fishing métiers (as defined in [42,43]), and main landing ports. The catch composition and fuel consumption of the fleets, based on the vessels' power, and economic benefits, were the parameters used to perform this analysis, relying on official data from the regional government to avoid the bias of personal surveys. The obtained results can be used to assess the sustainability of fishing activities in this European region through efficient technical measures, contributing to global efforts to mitigate environmental impacts and promote marine conservation.

2. Materials and Methods

2.1. Area of Study

In this case study, we analyzed capture fisheries in Galicia (NW Spain) operating in ICES areas 6, 7, 8, and 9, which account for approximately 50% of the total volume of captures in Spain, one of the major marine fisheries countries on a worldwide scale [10,44]. More precisely, the Galician fishing sector unloaded 146,595 tons of fresh fish in 2021 [44]. So, it can be concluded that fishing is one of the most important economic activities in this region in the NW of Spain, assuming 1.8% of its gross domestic product (GDP) in 2021 [44]. Fishing, shell fishing, marine aquaculture, and the seafood processing sector employ more than 50,000 people in Galicia, which represents more than 50% of maritime fishing employment in Spain and 10% in the EU. In fact, 91% of Galician economic activity is related to the maritime fishing sector.

Data were compiled from the Technological Platform of Fishing (Galician Government, https://www.pescadegalicia.gal/, accessed on 22 November 2023). The 2021 Fishing Annuary was selected for the study, and data on the main captured species by economic value, main ports, fishing gear for each species and port, and fleet composition (number of vessels by fishing gear and average power of each vessel) were extracted. The selected species represent 48.1% of unloaded fish species and 82.4% of the economic value of landed marine species in Galician auctions in 2021. These species include the European hake (*Merluccius merluccius*), black-bellied angler (*Lophius budegassa*), angler (*Lophius piscatorius*), Atlantic horse mackerel (*Trachurus trachurus*), megrim (*Lepidorhombus whiffiagonis*), blue whiting (*Micromesistius poutassou*), and Atlantic mackerel (*Scomber scombrus*). The selected species were primarily captured by bottom trawlers, bottom longliners, and purse seiners.

The number of landing days for each species, considering all ports analyzed, ranged from 304 to 310. The total landed mass, economic benefits, and fishing gear of each species are listed in Table 1. The port locations are shown in Figure 1. Crustaceans, mollusks, bivalves, cephalopods, large fish, frozen fish, and aquaculture were excluded from the sustainability assessment because these activities involve very different fishing techniques and require separate and more specific analysis.

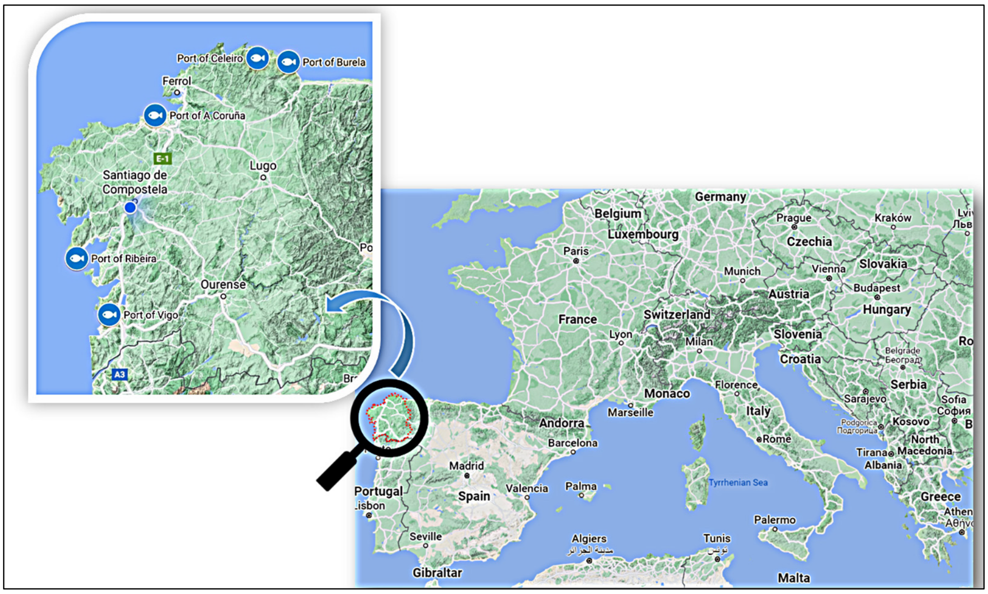

Figure 1. Location of the different ports studied in this work: Burela (43°39′42″ N/7°21′24″ W); Celeiro (43°40′43″ N/7°35′40″ W); A Coruña (43°21′52″ N/8°23′38″ W); Ribeira (2°33′39″ N/8°59′24″ W); and Vigo (42°14′13″ N/8°43′59″ W).

Table 1. Total biomass (t), economic benefit (EUR), and fishing gear for selected Galician fresh fish species.

Common Name	Biomass (t)	Benefit (EUR)	Fishing Gear
European hake	25,095.89	102,303,804	Bottom trawl, bottom longline
Black-bellied angler	5229.08	28,753,630	Bottom trawl, bottom longline
Megrim	5197.39	19,461,303	Bottom trawl
Atlantic horse mackerel	16,938.47	18,750,299	Purse seine
Blue whiting	20,449.17	16,076,443	Bottom trawl
Atlantic mackerel	8040.67	9,785,470	Bottom trawl, purse seine
Angler	1637.86	9,468,752	Bottom trawl
Total	82,588.53	204,599,701	-

2.2. Environmental Assessment

The environmental impact of fishing on these species was estimated using an ecosystem-based indicator, the ecological footprint (EF) [45]. This indicator was selected because it accounts for the effect of natural productivity associated with delicate, naturally overexploited resources such as marine ecosystems. Only the main impacts of the activity being evaluated are considered, that is, the consumption (and associated discard) of marine biomass (fresh fish) through the fishing ground footprint (FGF) and emissions generated from the use of fuel by the carbon footprint (CF).

The calculation methodology is based on that of [46–48]. The fishing ground footprint value indicates the area in global hectares (gha) of marine ground required to (re)generate the biomass extracted by fishing. FGF estimation involves calculating the required primary productivity (PPR) to guarantee sustainable capture, according to Equation (1) [46,49].

$$\mathrm{PPR} = \mathrm{B} \cdot \mathrm{CC} \cdot \left(\frac{1}{\mathrm{TE}}\right)^{(\mathrm{TL}-1)} \tag{1}$$

where B is the quantity of biomass of each species in tons (t) and CC is the carbon content on a wet-weight basis, with a value of 1/9. Transfer efficiency (TE) is the carbon transfer efficiency between species, which is highly dependent on the ecosystem type. In this study, a value of 14%, specific for temperate shelves [50] was selected considering the area of study. TL is the trophic level of each species, which also depends on the ecosystem type. The higher the TL, the higher the relative FGF associated with a specific species. The TL for each species was retrieved from the Sea Around Us platform (www.seaaroundus.org, accessed on 21 May 2024). A total PPR was obtained by adding the individual PPR of each species and then dividing by the world average available primary productivity ($4.25\ \mathrm{t\,C \cdot wha^{-1} \cdot y^{-1}}$) to obtain the FGF [47].

The carbon footprint (CF) accounts for the carbon dioxide emissions from the fuel consumption of the associated fleet and was calculated using Equation (2):

$$\mathrm{CF} = \frac{\mathrm{CO}}{\mathrm{Y_c}} \tag{2}$$

where CO represents the carbon dioxide emissions produced by fuel combustion (measured in tons of CO_2), and Yc indicates the yearly carbon dioxide sequestration rate per hectare for the global average of forested land, which has a value of $2.7\ \mathrm{t\,CO_2 \cdot wha^{-1} \cdot y^{-1}}$ [48]. In this study, the fraction of CO_2 emissions sequestered by the oceans (0.28) was not included to provide a worst-case estimation of the CF. Other impacts derived from the use of other utilities and vessel construction were not included, because they were not considered relevant to the objectives of this case study. Moreover, these impacts have been proven to be of minor importance in other related studies [25].

To estimate fuel consumption, which depends on both the fishing gear employed and the number and power of vessels in each port, an equation (Equation (3)) adapted from [51] was employed.

$$\mathrm{C} = \frac{\mathrm{A} \cdot \mathrm{P_{max}} \cdot \mathrm{S} \cdot \mathrm{t}}{\mathrm{d}} \tag{3}$$

where C is the consumed fuel (in L), Pmax is the maximum power of the engine (hp), S is the specific consumption of fuel ($0.15\ \mathrm{kg \cdot hp^{-1} \cdot h^{-1}}$), and d is the density of the fuel ($0.86\ \mathrm{kg \cdot L^{-1}}$). A is an activity factor that varies between 0.6 (fishing) and 0.9 (steaming). The activities of a vessel during a fishing trip are highly variable [52] and depend on several factors, such as weather or fish bank positions. Therefore, an average factor of 0.75 was estimated in Equation (3). Finally, t denotes the engine usage time (hours). Table 2 shows the number of fishing trips and their durations, depending on fishing gear and location/fishing grounds [53]. Using these data, the number of days allowed to fish, and the working time limits at sea set by RD 502/2022 for Spanish fishing grounds and by

IMO/ILO [54] for EU waters, the engine usage time during fishing trips was calculated for each fleet in each port as the mean of their recommended duration.

Table 2. Average value of fishing trips (in hours) depending on the location of the fishing ground.

Fishing Gear	Fishing Trip Duration (h)	Number of Fishing Trips/Year	Recommended Duration
Small-scale fleets	8	261	Less than 1 day
Purse seine	8	261	Between 4 and 12 h
Pair and bottom trawling (coastal)	48	131	From 1 to 3 days
Bottom and surface longline (coastal)	60	112	From 2 to 3 days
Bottom trawling (Great Sole Bank)	360	14	Between 10 and 15 days + 2–3 days of navigation
Bottom longline (Great Sole Bank)	360	14	Between 10 and 15 days + 2–3 days of navigation

Although these species landed in more than 10 ports in the study area (Galicia), only five were considered in detail to discuss the obtained results because of their much higher capture rates. These ports are A Coruña, Vigo, Celeiro, Burela, and Ribeira (Figure 1). The fleet composition of these ports is listed in Table 3. When a species is captured by different fishing gears (or métiers) in the same port, emissions allocation is based on the average power of the corresponding fleet segment. An emission factor of 3160 kg CO_2 per ton of consumed fuel was employed in the CF calculation [55]. Therefore, CO in Equation (2) is as follows:

$$CO = 3176 \cdot C \tag{4}$$

Given the scope of this work, which focuses on the fishing activity of an entire region instead of that of a particular fleet, an average discard percentage was selected for each fishing gear, according to [56]. These values were 30.9%, 23.9%, and 4.70% for bottom trawling, bottom longline, and purse seine, respectively.

Total EF was calculated by adding FGF and CF, which were previously converted into global hectares of average bioproductivity by using the equivalence factors of 0.37 $\text{gha}\cdot\text{ha}^{-1}$ and 1.29 $\text{gha}\cdot\text{ha}^{-1}$ for fishing grounds and forest, respectively [57].

Table 3. Fleet composition in selected ports.

Fishing Gear	Number of Vessels	Max Average Power (HP)
A Coruña		
Bottom trawling (community ground)	3	859.8
Bottom trawling (Spanish ground)	5	733.0
Bottom longline (community ground)	1	595.0
Surface longline (deep sea)	5	842.3
Purse seine	5	167.6
Minor gears	72	32.9
Burela		
Bottom trawling (community ground)	2	838.3
Bottom trawling (Spanish ground)	5	473.0
Bottom longline (community ground)	20	554.5
Surface longline (deep sea)	6	707.5
Surface longline (Spanish ground)	15	409.3
Purse seine	3	244.8
Minor gears	26	63.6

Table 3. *Cont.*

Fishing Gear	Number of Vessels	Max Average Power (HP)
Celeiro		
Bottom trawling (community ground)	1	700.0
Bottom trawling (Spanish ground)	5	728.3
Bottom longline (community ground)	22	570.2
Bottom longline (Spanish ground)	2	175.5
Surface longline (deep sea)	5	1222.6
Surface longline (Spanish ground)	2	475.8
Purse seine	2	244.0
Minor gears	18	51.21
Ribeira		
Bottom trawling (Spanish ground)	26	497.2
Bottom longline (community ground)	2	499.4
Surface longline (Spanish ground)	1	266.2
Surface longline (deep sea)	7	731.3
Purse seine	4	258.8
Minor gears	202	27.4
Vigo		
Bottom trawling (community ground)	11	760.0
Bottom longline (community ground)	2	566.8
Surface longline (Spanish ground)	13	461.3
Surface longline (deep sea)	28	744.7
Purse seine	17	250.5
Minor gears	28	35.0

3. Results

3.1. Total EF

The total footprints of the ports analyzed for each species are shown in Figure 2. Only five main ports were included because the gha of land requested by the remaining ports was negligible. The values ranged from 142,018 gha in Vigo to 107,059 gha in Ribeira, indicating that Coruña and Celeiro had similar EFs to Vigo. Burela had an intermediate value (126,946 gha). Regarding the species contribution, Celeiro and Burela presented a very similar profile, although EF was higher in the former because of the higher capture of hake, the main target species in both ports (although in Celeiro hake accounted for 75% of the total capture, while in Burela it accounted for close to 50%). However, Coruña and Vigo showed more distributed profiles among captures. In A Coruña, the species contributing the most to EF were blue whiting and hake, followed by Atlantic horse mackerel, and megrim. Vigo EF was mainly caused by two species, black-bellied anglers, and megrims, with lesser contributions from hakes, anglers, and Atlantic horse mackerel. Vigo and A Coruña, together with Burela, are the most important ports in terms of economic value (20.7%, 15.2%, and 15.8% respectively) and landed volume of fresh fish; thus, it is logical that they have such high values. Burela extracts part of its economically important albacore, which was not considered in this study (since landings of this species are mainly restricted to this port), and the EF of this port is lower than that of the other two for this reason. The high EF values reflect, on one hand, the high trophic levels of the species captured, that is, species that require a much higher area of marine ground to grow, and on the other hand, the fishing gears employed to catch these species, involved in most cases bottom trawling, which has an associated high percentage of discards. Finally, the lower EF in Ribeira was in accordance with the landings of fresh fish and the targeted species (blue whiting, Atlantic horse mackerel, and Atlantic mackerel). EF was mostly caused by blue whiting (almost 54% of the total capture). This species has a TL > 4 and was captured via bottom trawling. The environmental impact of the Galician fleet for fresh fishing was concentrated in five of the 13 ports analyzed. These other ports showed low values of total EF, approximately 8000 gha per year for one port (Camariñas), and even lower than 1000 gha/y in the remaining cases. The high EF values (>100,000 gha/y) in the main ports were only due to the capture of four species: hake, blue whiting, black-bellied angler, and megrim. This result indicates that centering catches among predators in marine ecosystems may be a non-sustainable practice in the long term. Overfishing of top predators leads to a phenomenon known as fishing down marine food webs, where the depletion of high trophic level species results in the targeting of increasingly lower trophic levels, thereby disrupting the balance of marine ecosystems [58]. Therefore, the removal of top predators can cause trophic cascades, leading to the loss of ecosystem functions and services [59,60]. Additionally, biodiversity loss due to overfishing undermines the resilience of ocean ecosystems and their ability to provide essential services. Consequently, the nutritional value of more abundant and less bioproductive species should be considered in addition to consumer preferences [61] to reduce the massive presence of only a few species in the total capture. Furthermore, targeted fishing favors the generation of discards, a serious environmental problem already addressed by the Common Fisheries Policy [15].

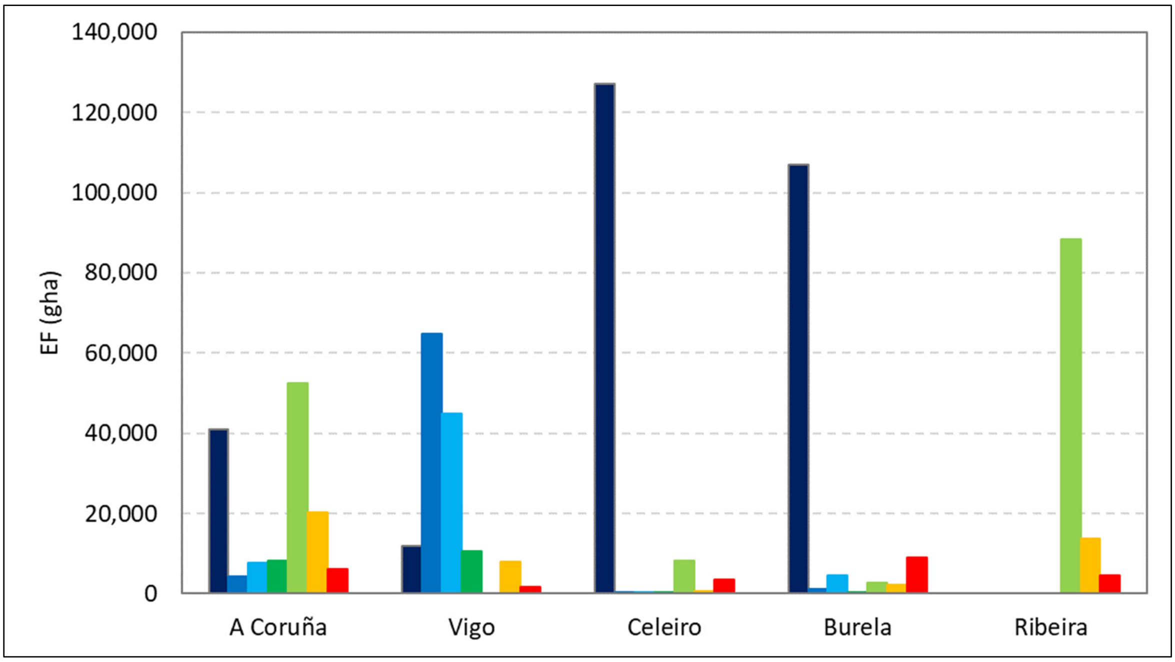

Figure 2. Total ecological footprint (EF) of the analyzed ports by species (hake ■, black-bellied angler 🟦, megrim 🟦, angler 🟩, blue whiting 🟩, Atlantic horse mackerel 🟨, Atlantic mackerel 🟥).

If the relative EF (per ton of catch) is analyzed in each port, A Coruña, Burela, and Celeiro presented values of 7.7, 7.8, and 7.2 gha/t, respectively. However, Vigo has an EF of 6.2 gha/t, while Ribeira presented the lowest value (4.0 gha/t), very far from the other ports. The higher values of EF per ton of fish in the first three ports are related to both the capture composition and the power of bottom trawlers (i.e., higher fuel consumption), in line with results presented in [26,33,62,63]. In Vigo, despite having similar total captures of fresh fish with that of A Coruña and higher captures than that of Burela and Celeiro, the fleet has in general lower average engine powers for its trawlers (Table 3). Finally, in Ribeira, the species that were captured also resulted in a reduced relative footprint.

To further investigate the environmental implications of not only the capture but also the fleet, it is interesting to analyze the influence of the carbon footprint on total EF. Contributions ranged from 10% in Celeiro to 20% in Ribeira. In A Coruña, Burela, and Vigo, it represented 17%, 15%, and 12%, respectively. The cause of these differences is found in fleet composition and fishing gear, as above-mentioned. Figure 3 shows the total CF in gha for each port and fishing gear, calculated by using Equations (2)–(4) and data from Table 3. The CF of Celeiro and Burela is mainly due to the bottom longline, as their main target species (hake) is caught using this fishing gear. Although longliners have less power than trawlers [26], the number of longliners in the fleets of Burela and Celeiro was rather high (26 and 24, respectively). Something similar happens in Ribeira with bottom trawling, being 75% of its CF due to this fishing gear. Although the average engine power of trawlers is lower than that of other ports, the number of vessels is very high (26 in Ribeira versus 11 in Vigo or 3 in A Coruña). In A Coruña, the high contribution of purse seines reflects the high capture of Atlantic horse mackerel using this gear (more than 7000 gha of CF). Nonetheless, Vigo presented a lower CF than A Coruña and Ribeira despite the large quantity of fish, the high trophic level of the main species, and the high percentage of bottom trawling of the total catch per year, indicating a more balanced fleet composition. The reduction in CF is imperative in the fishing sector and involves more environmentally friendly fuels and/or improvements in the energy efficiency of engines [64–66]. Although new engines have appeared in recent years, the use of new fuels with lower emissions than conventional heavy oils is expensive, especially for trawlers [66], and is currently not an interesting option for ship owners.

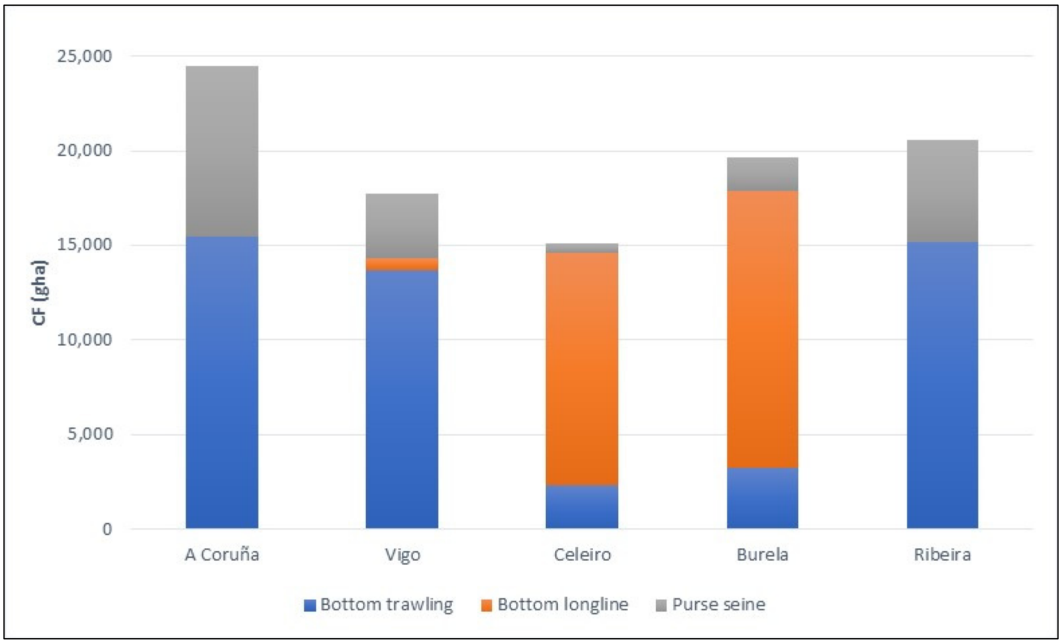

Figure 3. Carbon footprint (CF) of the analyzed ports by employed fishing gear.

To improve the presented results and as part of future research, the installation onboard analyzed fisheries of sensors to precisely measure fuel consumption (now estimated here, [67]) together with the already collected geo-referenced positions, speed of each haul [68,69], and how the devices should be fit should be carried out as key steps to develop a first energy audit of the Galician fishing sector as an effective way to obtain a clearer idea about effective ways of reducing energy consumption levels (and, therefore, environmental impacts) and associated costs. Implementing an energy audit can be considered a strategy to enhance the performance of a fishery managed under an Ecosystem Approach to Fisheries (EAF) framework [25].

3.2. *Eco-Efficiency of the Fishing Sector in Galicia*

Figure 4 shows the catch of the main species in the different ports studied as a function of their EF intensity (gha/t of fish) and the economic benefit in millions of euros [44]. It can be seen that hake is the most profitable species in terms of earnings for Celeiro and Burela, which have an income of approximately EUR 40 million, considerably higher than the larger ports of A Coruña and Vigo, with profits of EUR 20 and 4 million, respectively.

Even in A Coruña, this species represents almost 50% of total income. Celeiro presented the highest EF per ton of hake (10.6 gha/t), towing to the CF caused by emissions from bottom longliners. However, other species such as black-bellied anglers, megrims, or anglers show, in general, higher EF intensities, reaching a value of approximately 12 to 13 gha/t for black-bellied anglers in Celeiro, Burela, and A Coruña, and close to 16 gha/t for megrims in Burela. However, the profits of these species are low when compared to other species (e.g., mackerels), leading to the same benefit and a much lower footprint. In the port of A Coruña, for example, benefits from the catch of Atlantic horse mackerel are 2.5 times higher than catches of black-bellied anglers. Only in the case of Vigo can captures of black-bellied anglers and megrims be considered eco-efficient, as they present moderate EF intensities and net benefits of EUR 14.7 and EUR 26 million, respectively.

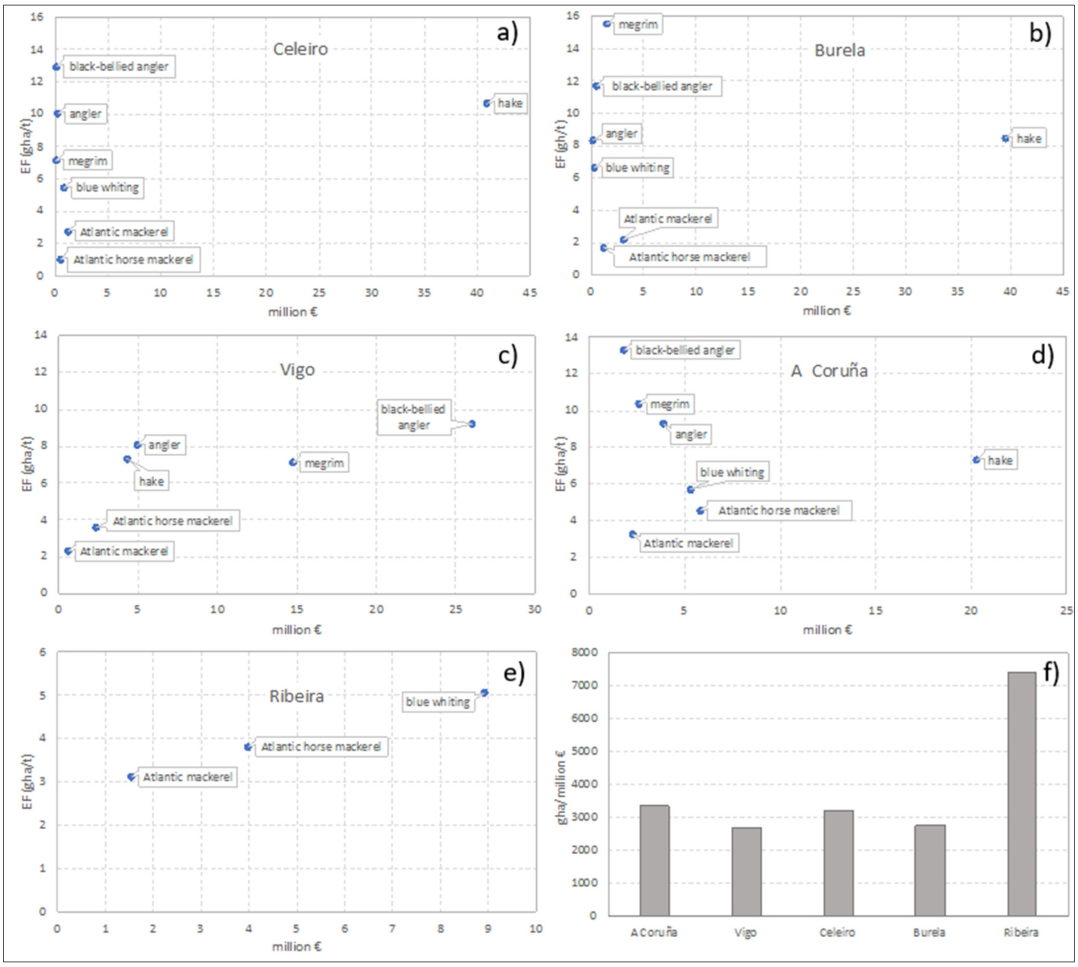

Figure 4. Catch of main species as a function of their EF intensity (gha/t of fish) and economic benefit (millions of euros) in the analyzed ports: (**a**) Celeiro; (**b**) Burela; (**c**) Vigo; (**d**) A Coruña; (**e**) Ribeira. Graph (**f**) shows a comparison of the calculated *eco-efficiency* of the different ports.

Although landed fish in the port of Ribeira consist only of low trophic level species (i.e., with low footprint intensities), the economic benefit obtained is also much smaller (EUR 14 million vs. EUR 40 million). This makes the eco-efficiency of this port very low in comparison with larger ports, demanding 7407 gha/EUR million with respect to the 2682 gha/EUR million required by Vigo (Figure 4).

Finally, a sustainability assessment should take into account other qualitative/intangible aspects of considered species like the volume of discards, mainly due to high grading practices (i.e., the choice made by fishers to throw back low-value fish to increase their catch of higher-value fish, [70]); the conservation problems on board of some species, like the blue whiting, which deteriorates very easily; or their nutritional values, tightly related to health benefits and consumer preferences. Overall, mackerel has the highest nutritional value. It is particularly high in omega-3 fatty acids, which can provide numerous health benefits (like improving heart health and brain function), and it provides a good source of vitamin D (which helps maintain strong bones and teeth) and B12 (which is essential for red blood cell formation and nerve function), as well as selenium content (which supports a healthy immune system). Other important species in terms of captured volumes, like blue whiting and hake, are both good sources of protein but do not offer as many other nutritional benefits as mackerel. This could be considered a competitive advantage for those ports with high landings of this species if nutritional awareness was improved, thus increasing monetary benefits.

4. Conclusions

Fishing sustainability is an evident necessity that deeply relies on efficient catch management. Therefore, studies evaluating not only fisheries stocks but also subsequent steps (i.e., fish landing) need to be developed. A widely employed ecosystem indicator (EF) in fisheries was combined with economic income to provide a first example of how to evaluate fishing ports on their eco-efficiencies towards developing more sustainable fisheries or can be used to contribute to healthy ecosystem-based fisheries to support improved, effective fisheries management capabilities. The results indicate that large vessels, fleets, and ports are more efficient per ton of catch in terms of more discrete environmental and economic impacts, causing approximately 50% of the impact per economic unit. This outcome is logical if the concept of a scaled-up economy is considered. However, additional negative aspects should be considered if we consider large vessels and ports, such as large enterprises. In this particular case, targeting only a few species causes an imbalance in marine ecosystems by decreasing the populations of these species and generating a high quantity of discards. However, for smaller ports targeting lower trophic species, other positive aspects should be considered in global sustainability assessments to highlight the benefits of smaller, artisanal fleets that contribute to local economies and food security. Medium fleets, like, for example, Ribeira (with a very low eco-efficiency of 7407 gha/EUR million in comparison with larger ports like Vigo, with a value for this indicator of 2682 gha/EUR million), and small artesian fleets supply a wide variety of fresher fish to local markets, providing nutritional welfare as well as important incomes to their local communities. In this study, the results regarding fleet eco-efficiency were provided as information to describe part of the complex relationships among all aspects of fishing sustainability that should be developed more in depth in future research, including an analysis of social aspects such as community well-being, labor conditions, equitable access to resources, and community engagement and participation.

A more thorough study that includes the economic, environmental, and social aspects as the backbone of a thorough environmental assessment combined with current research on Galician fleet dynamics should be used to guide improved, effective, and efficient marine sustainability goals and policies. More detailed guidance on how to implement findings in practical, policy-making contexts would enhance the utility of the research. Finally, to overcome the specificity of the Galician fleet dynamics and enable a detailed comparison between case studies, we should develop a proper methodology for the generalizability of the findings to other regions or contexts with different ecological, economic, and social conditions.

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