FOODNECTED PROJECT
Ecological Footprint of fish products from Small Scale Fisheries in Catalunya (Spain), Sicily (Italy) and Ibiza (Spain)

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Advancing the Science of Sustainability

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NOTE: *This report has been prepared by Global Footprint Network for LIFE (Low Impact Fishers of Europe) within the Foodnected Project. The report has been authored by Maria Serena Mancini and Alessandro Galli.*

Contents

1. Introduction

This report – produced within the context of the Foodnected project – assesses the Ecological Footprint of the fish products caught by Small-Scale Fisheries in 3 pilot sites located in Catalunya (Spain), Sicily (Italy) and Ibiza (Spain), and affiliated with the Foodnected project. The standard Ecological Footprint methodology is specifically adapted to a bottom-up approach, which is informed by the Life Cycle Assessment (LCA) concept, and which required the collection of data from a total of 17 boats in the 3 sites (7 in Catalunya, 5 in Sicily, and 5 in Ibiza). Such data covers the inputs necessary for these boats to operate and make their outputs (the landed fish) available to consumers, and is ultimately used to allocate the Ecological Footprint results to the production – and subsequent consumption – of 1 kg of fish product.

This document first provides an overview of the standard Ecological Footprint methodology and how it is implemented at national level to track the consumption of natural resources due to human activities (including fishing practices). Then, a detailed explanation of the Ecological Footprint methodology applied to the specific case studies of the Small-Scale Fisheries involved in the Foodnected project is provided, followed by a section explaining the limitations of the study. Finally, the Ecological Footprint results of consuming 1 kg of fish caught by the 17 boats are analyzed and the main Footprint drivers discussed.

The overall aim of this Ecological Footprint study is to assess and compare the pressures Small Scale Fisheries (SSF) systems in three pilot sites across the Mediterranean region place on the environment, to then provide actionable insights on how fishers can reduce their impact on the Earth's ecosystems and decarbonize their activities.

2. Overall description of the Ecological Footprint's standard methodology

The Ecological Footprint is an environmental accounting tool conceived in the early 1990s by Mathis Wackernagel and William Rees at the University of British Columbia, to account for the human appropriation of the biological regenerative capacity of the biosphere[1] - its capacity to provide life-supporting and regulatory ecosystem products and services.

The standard Ecological Footprint methodology aims at quantifying the demand for (**Ecological Footprint – EF**) and the annual supply of (**Biocapacity – BC**) key provisioning and regulating ecosystem services associated with six main land types (i.e., cropland, grazing land, fishing grounds, forests, carbon Footprint, and built-up land)[2]. It can be applied at scales ranging from individuals to activities and sectors, to cities and regions, and up to countries and the world as a whole, although national-level assessments are often regarded as the most complete.

For a given country, the Ecological Footprint measures the ecological assets (i.e., the biologically productive land and sea areas) required by the population of that country to produce the natural resources and services it consumes. This includes plant-based food and fiber products, livestock and fish products, timber and other forest products, sequestration of waste (CO_2 from fossil fuel burning), and space for urban infrastructure. On the supply side, biocapacity tracks the ecological assets (including

[1] See Wackernagel, M. and Rees, W.E. 1996.
[2] See Mancini et al., 2018a.

forest lands, grazing lands, cropland, fishing grounds and built-up land) available in that country and their productivity[3].

Ecological Footprint and biocapacity thus represent two sides of an ecological balance sheet: if a country's consumption of natural resources and services (i.e., its Footprint) is greater than the capacity of its natural assets to supply them (i.e., its biocapacity), a situation of *ecological deficit* is created. Conversely, if a country's Ecological Footprint is smaller than its biocapacity, this country runs an *ecological reserve.*

Since average biological productivity differs between various land use types, as well as between countries for any given land use type, Ecological Footprint and biocapacity are expressed in mutually exclusive units of world-average bioproductive area calculated through two key coefficients: yield factors (YF) and equivalence factors (EQF). This unit of measure is referred to as a global hectare (gha) and allows for comparability across land use types and countries[4].

The most widely used application of Ecological Footprint accounting is the National Footprint Accounts (NFAs), a framework annually published by Global Footprint Network, which provides annual accounts of biocapacity and Ecological Footprint for the world and nearly 200 countries, with historical data reaching back to 1961[5]; each NFAs edition provides updated results for the entire accounting timeline[6].

Within the NFAs, Footprint results do not usually show which economic activities are posing a demand on resources but rather the consequences, in terms of land appropriation, of demanding the outputs of economic activities[2]. Still, attributing the overall demand on nature to particular human activities is essential to then be able to understand our behavior and act for a more sustainable lifestyle. This requires an additional analytical step beyond basic Ecological Footprint accounting[7], and such step is primarily represented by Environmentally Extended Multi Regional Input-Output Analyses (EE-MRIO)[8].

Multi Regional Input-Output (MRIO) tables from the Global Trade Analysis Project (GTAP) database[9] are thus used to translate land-based Ecological Footprint results (meaning results broken down by the land type upon which the Footprint is placed, such as crops, grazing land, etc) into activity-based Ecological Footprint results (meaning results broken down by the human activities responsible for such Footprint, such as food consumption, housing, transportation, etc), thus shifting the debate from where human pressure is being placed to the human activities responsible for such pressures[8]. The outcome of this additional calculation step is called the Consumption Land-Use Matrix (CLUM)[10].

3. <u>The EF methodology applied to the small-scale fisheries of the 3 pilot sites of Foodnected project</u>

Depending on the scale of application, Ecological Footprint Accounting can adopt either a top-down (compound) or a bottom-up (component) approach. The first approach is most commonly used for

[3] See Galli, A., et al., 2014.
[4] See Borucke et al., 2013 and Galli, 2015. (See Reference section for the complete citations).
[5] National Footprint Accounts (NFA) data for all countries of the world is freely available at: http://data.footprintnetwork.org/#/. This continuously updated framework is based on United Nations (UN) data sets of over 15,000 data points per country and year.
[6] See Lin, et al., 2018.
[7] Galli, et al. 2017.
[8] See Wiedmann, et al., 2006.
[9] Global Trade Analysis Project (GTAP 9 Data Base) consists of 57 sectors – 12 of which are agricultural – and includes 140 countries and regions (Narayanan and McDougall, 2015).
[10] See https://www.footprintnetwork.org/resources/mrio/

Footprint assessments at global and national scale, while the latter is preferred for product- or company-level assessments.

In order to assess the Ecological Footprint of fish products caught by the 17 boats participating in the project (pertaining to small scale fisheries), a bottom-up component approach to Ecological Footprint accounting is here adopted. This requires the definition of system boundaries and the use of surveys to collect boat-specific data. Since the ultimate basket of fishes that are being sold to the consumers depends on the fishing boats catching them, as well as on the activities happening on land for the selling phase, the Footprint analysis took into consideration each single boat participating in this assessment as the system of reference; we define this a bottom-up, boat-centric approach (see Figure 1).

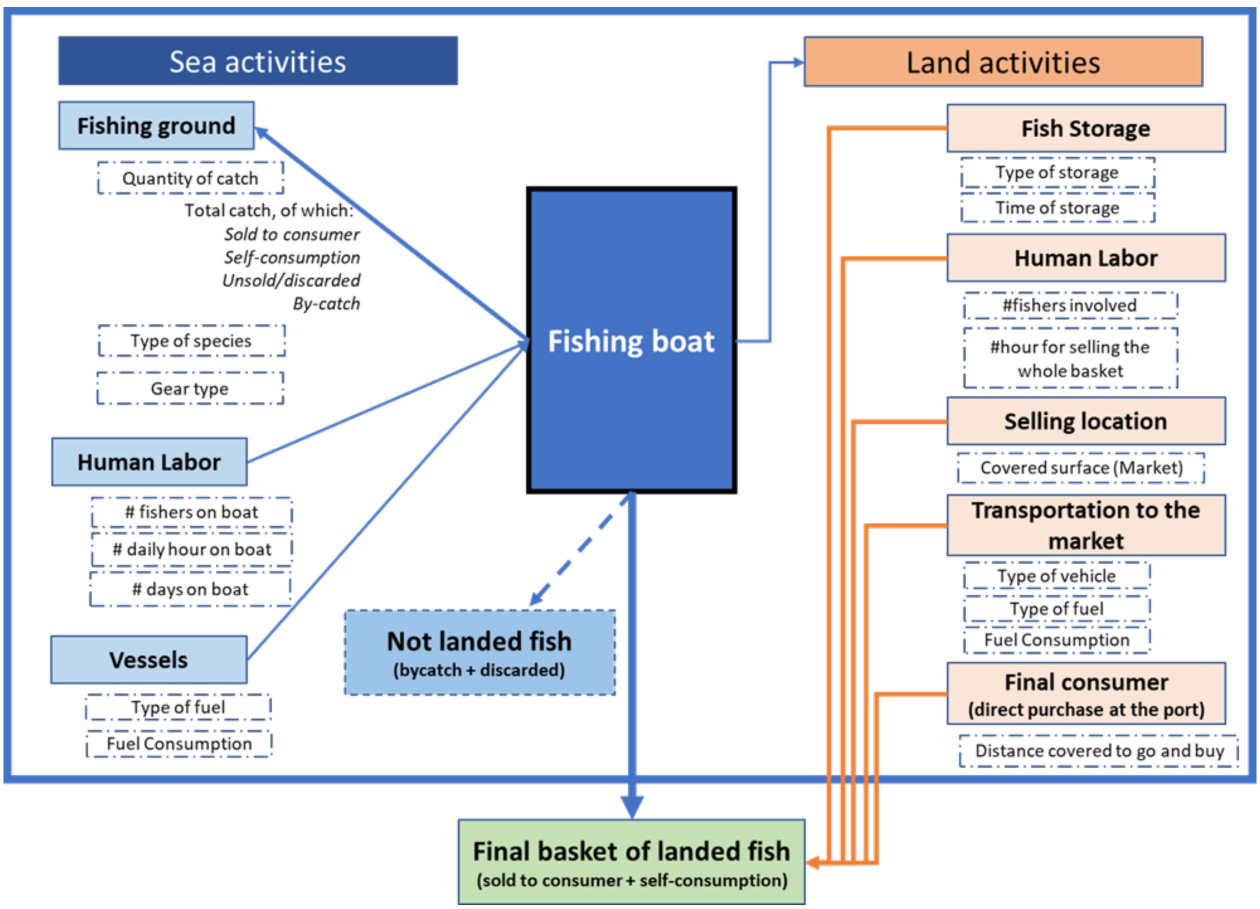

Figure 1. Diagram of the boat-centric approach for the Ecological Footprint assessment of small-scale fisheries. All boxes represent the quantifiable inputs (blue and orange) and the one output (green box) that this report focuses on. The blue elements refer to the activities happening offshore, while the light orange boxes represent the activities happening on land during the selling phase.

Once the reference system is set, activities happening offshore were distinguished from those happening on land, once each boat arrives at its port. Per each group of activities, all inputs necessary to run the boat (i.e. fuel used, number of people working on the boat) as well as the parameters depending on the fishing activity (i.e. total catch, fish storage, people needed to sell the fish, eventual selling location, any transportation from the port, final consumers) are first assessed – each of them placing a pressure on different land types (i.e., ecosystems). Once the Ecological Footprint of the whole system is calculated, the total value is allocated to the output of landing 1 kg of fish.

3.1. Rationale of each component in the Footprint assessment of small-scale fisheries

A detailed explanation of each Footprint component considered in Figure 1 is provided here below, alongside its rationale.

For the activities at sea, Footprint components are as follows:

- *Fishing Grounds Footprint Component (EF_{FG})* consists of the planet's regenerative capacity (or biocapacity) required to generate the marine primary productivity (i.e., phytoplankton) that each fish consumed by humans has, in turn, consumed over its life span. Such "embedded" marine primary production is dependent on the species' trophic level and bycatch rate (Pauly & Christensen, 1995). We first calculated the fishing ground area (in hectares) by dividing the amount of primary production embedded in an aquatic species over its lifetime by an estimate of the harvestable primary production available per hectare of continental shelf (Gulland, 1971). This was then converted into the EF_{FG} (expressed in global hectares) by applying yield and equivalence factors taken from Borucke et al., (2013). Trophic levels[11] of fish species were retrieved from the FAO Fishbase Database, while bycatch rates[12] are determined on the basis of the fishers own responses to the survey (see section 3.4.1).
- *Human Labor Footprint (EF_{HL})* consists of the biocapacity needed to support the man hours required to land a catch and, subsequently, sell it. Following the methodology proposed by Tyedmers (2000) and Mancini et al (2018b), this was calculated by multiplying the hourly national Ecological Footprint value of an average individual living in Spain or Italy (Global Footprint Network, 2019) by the actual number of hours fishers in our pilot sites spent at sea and, later on, for onshore activities.
- *Vessels Footprint (EF_V)* is the biocapacity needed to sequester CO_2 emissions from energy and fuels used during the fishing and landing phases. Following Mancini et al., (2016), this was calculated by dividing the amount of CO_2 emitted during these phases that is not sequestered by oceans, by the average carbon sequestration capacity of forests (i.e., 0.73 t C ha^{-1} yr^{-1}), and then converting the resulting areas into global hectares.

For the activities on land, Footprint components are as follows:

- *Fish Storage Footprint (EF_S)* is the biocapacity required to sequester CO_2 emissions from the electricity used by refrigerated containers to store fishes when boats arrive on land before the landed catch is sold. Electricity consumption of fish refrigerator per ton of product was found in Terehovics et al., 2018, which provide a literature range of 70-130 kWh per ton of product. Since the range refers to industrial freezers while our analysis deals with small-scale fisheries, the lower-end value is used here to account for the refrigerated containers used by the fishers (if any). Then the national electricity carbon intensity is used to convert the electricity into CO_2 emissions, and

[11] Available at: www.fishbase.org. For both LSF and SSF, the bycatch was assumed to be representative of the FAO fish category "Marine fishes nei".

[12] Here we use the NOAA definition - "*Fishermen sometimes catch and discard animals they do not want, cannot sell, or are not allowed to keep. This is collectively known as 'bycatch.' Bycatch can be fish, but also includes other animals such as dolphins, whales, sea turtles, and seabirds that become hooked or entangled in fishing gear*" – available at: https://www.fisheries.noaa.gov/node/251.

finally the carbon Footprint intensity is used to get the area in global hectare needed to sequester those emissions.

- *Selling location (EF_{LOC})* consist of the biocapacity appropriated for the physical occupation of the selling location (i.e., a market place) and its energy consumption, which translates into the built-up component and the carbon Footprint component, respectively, of the Ecological Footprint analysis. The built-up component was calculated by multiplying the reported surface of the building by the Yield and Equivalence factors of paved surfaces (Borucke et al., 2013). In the case of the carbon Footprint component, conversion factors in kg CO_2 $(hour)^{-1}$ $(m^2)^{-1}$ were derived from Resource Efficient Scotland (2016) (see section 3.4.5).
- *Transportation to the market (EF_T)* refers to the biocapacity needed to sequester the carbon dioxide emissions of any movement associated with the first sale of fish after it is landed to the port. Depending on the reported type of fuel and the distance covered, conversion factors in kg CO_2 km^{-1} derived from the IPCC (2006).
- *Market to home (EF_{MH})* this is the biocapacity needed to sequester the carbon dioxide emissions due to the transport of fish from the market to the place of final consumption by the consumers. However, the market to home Footprint was calculated only in the pilot site of **Sicily**, where final consumers go directly to the port to purchase the fish and since this transportation corresponds to the first sale of the fish; its calculation is identical to that of the Footprint of transportation (EF_T) (also see Section 3.4.6). In the case of **Catalunya** and **Ibiza**, final consumers could not be tracked down as each intermediary has its own system of fish re-distribution and delivering to the final consumers, who can be local, national or international. For these pilot sites, the analysis could be tracked until the first sale to the intermediaries, EF_T (see Section 3.4.6).

Ultimately, the Ecological Footprint of fish indicates the amount of biocapacity needed to "produce" the seafood (trophic level and bycatch) and make it available for consumers (the effort via fuel and human labor). To ease comparison among boats and pilot sites, the Ecological Footprint of seafood was divided by the quantities of fish landed, including the quantity being sold to consumers and the quantity for personal consumption by the fishers: this ratio represents the Footprint intensity of each boat and is expressed in global hectares of biocapacity used per unit of fish (gha kg^{-1}).

3.2. Steps of the boat-centric analysis

Each of the 17 boats involved in the project was analysed separately, and data collection was thus conducted for each one of them for the year 2021.

In the first step of the analysis, fishers were asked to fill an ad-hoc survey, which was developed by Global Footprint Network's researchers in consultation with experts from LIFE (Low Impact Fishers of Europe) during the February-March 2022 period, and distributed to the 17 boat owners in May-June 2022. Surveys were filled by the owners of each boat with the support of LIFE's on-the-ground partners. Data was received at Global Footprint Network from the three Pilot sites in July 2022, thus allowing the Footprint analysis to start. While performing the analysis, input data in each survey was scrutinized for quality and reliability and, whenever needed, double checked with the on-the-ground partners and eventually revised with the fishers directly. An overview of how the small-scale fisheries work in each pilot site is described in Section 3.3; more specific information on the key characteristics of the 17 boats is also provided in Table 1. The full list of survey questions is reported in Annex 1.

A Footprint calculation Excel workbook was created to assess the Ecological Footprints associated with each boat's input, sum them, and finally allocate them to the final functional unit of the Footprint analysis, which is 1 kg of landed fish made available to consumers. As final results, the analysis provides an overview of the Footprint results of all the 17 boats participating in the analysis (i.e. Catalunya, Sicily and Ibiza) – along with the weighted average across all – showing the variation among them and a discussion of their main Footprint drivers.

3.3. Description of the small-scale fisheries in each pilot site

This section provides a general description of the fishing boats interviewed and how the small-scale fisheries system works in each pilot site. Table 1 then provides a detailed description of the main characteristics of each boat.

- **Catalunya**: 7 small-scale boats were interviewed, 4 of which are located in the harbour of l'Escala and 3 in the harbour of l'Estartit. All 7 boats are affiliated – along with a few others – with the local cooperative (i.e., Cofradia), which helps them distribute and sell the daily catch. Each day, the Cofradia collects the entire catch of all the affiliated boats arriving to the harbours, and takes it to the market in the nearest town with an auction (e.g., Palamós) for the actual fish first sale. This is done with 2 refrigerated collective vans, one departing from l'Escala and the other from l'Estartit.
- **Sicily**: 5 small-scale boats were interviewed, all located in the Gulf of Catania. The 5 boats manage directly their catches as each fisher sells most of its catch to consumers directly at the port (in a few instances fishes are pre-ordered and thus sold prior to arriving at the port). Fishes eventually left unsold are brought to the nearest selling point by each fisher with its own vehicle. It may also happen that a little quantity of catch is kept for personal consumption.
- **Ibiza,** 5 small-scale boats were interviewed, 4 of them located in the harbour of Ibiza and 1 in the harbour of Sant Antoni de Portmany. All 5 boats are affiliated – along with a few others – with the local cooperative (i.e., Cofradia), which helps them to distribute and sell the daily catch. All fishers land their catch to the port and leave it in the Cofradia offices where big, shared refrigerators are located. Each of the 5 fishers has its own usual customers with whom they are in daily contact about the products caught. The fish of no interest to their usual customers is left to the Cofradia, which sells it to other clients. Clients are primarily fish markets and in few cases restaurants acting as intermediaries to the very final consumers of fish products. These clients pick-up the purchased fishes directly at the port (where the Cofradia offices are).

Table 1: Description of the 17 boats analyzed in the project.

Region	Boat number	Total catch in a year (kg)	Top 5 species sold to consumers	% of fish sold to consumers	% of fish for self-consumption	Number of Fishers	Daily hours spent on boat and # working	Area navigated	Type of refrigerator	Description of the selling phase
Catalunya	1	867	1. *Sparus aurata* 2. *Sepia officinalis* 3. *Diplodus sargus* 4. *Dicentrarchus labrax* 5. *Pagellus erythrinus*	**98%**	**2%**	1	**6**	**6**	Refrigerated container	**Selling phase for all boats in Catalunya**: Once the fishers arrive to the port, they unload their daily catch and a single van (one in each port) brings it to the auction market where it is sold to intermediaries, who in turn sell to final consumers
Catalunya	2	408	1. *Sparus aurata* 2. *Sepia officinalis* 3. *Diplodus sargus* 4. *Dicentrarchus labrax* 5. *Pagellus erythrinus*	95%	5%	1	6	6	Refrigerated container	
Catalunya	3	1387	1. *Sepia officinalis* 2. *Trachurus trachurus* 3. *Mugil cephalus* 4. *Lithognathus mormyrus* 5. *Pagellus erythrinus*	96%	4%	1	5	6	Refrigerated container	
Catalunya	4	2584	1. *Sparus aurata* 2. *Sepia officinalis* 3. *Mugil cephalus* 4. *Pagellus erythrinus* 5. *Torpedo spp*	98%	2%	1	6	25	Refrigerated container	
Catalunya	5	3075	1. *Gymnammodytes cicerelus*[13]	100%	0%	1	2.5	15	Refrigerated container	
Catalunya	6	3780	1. *Mugil cephalus* 2. *Sparus aurata* 3. *Sepia officinalis* 4. *Mullus surmuletus* 5. *Pagellus erythrinus*	93%	6%	1	6	35	Refrigerated container	
Catalunya	7	1630	1. *Octopus vulgaris* 2. *Sepia officinalis* 3. *Mugil cephalus* 4. *Raja asterias* 5. *Sparus aurata*	98%	2%	1	6	27	Refrigerated container	
Ibiza	1	1664	1. *Sepia officinalis* 2. *Scorpaena scrofa* 3. *Scorpaena porcus* 4. *Trachurus trachurus* 5. *Seriola dumerili*	94%	4%	1	10	10	Refrigerated container	**Selling phase for all boats in Ibiza:** Once the fishers arrive to the port, they unload their daily catch and bring it to the Cofradia offices (based at the port). Then fish market representative
Ibiza	2	3120	1. *Sepia officinalis* 2. *Trachurus trachurus* 3. *Scorpaena porcus* 4. *Thunnus thynnus* 5. *Dentex dentex*	94%	4%	2	12	22	Refrigerated container	
Ibiza	3	1248	1. *Sepia officinalis* 2. *Mullus barbatus* 3. *Scorpaena scrofa* 4. *Scorpaena porcus* 5. *Palinurus elephas*	94%	4%	1	5	10	Refrigerated container	
Ibiza	4	1248	1. *Octopus vulgaris*	96%	4%	1	8	6	Refrigerated container	

[13] As constants and Footprint intensities for *Gymnammodytes cicerelus* are missing in the NFA database, the EF calculation for this species relied on the use of constants and intensities for *Ammodytes spp*, the closest species available in the NFA database.

Ibiza	5	1664	1. *Spicara smaris* 2. *Scorpaena scrofa* 3. *Scorpaena porcus* 4. *Seriola dumerili* 5. *Palinurus elephas*	94%	4%	1	5	6	Refrigerated container	s go to the Cofradia to pick up the share of fishes they already have reserved. There might be few cases in which the fishers themselves go to sell their catch to the market places or to restaurants
Sicily	1	300	1. *Pagellus erythrinus* 2. *Mugilidae* 3. *Sepia officinalis* 4. *Merluccius merluccius* 5. *Uranoscopus scaber*	83%	17%	1	5	3	Box with seawater or ice	**Selling phase for all boats in Sicily:** the fishers sell their catch at the port directly at the consumers. If something is left, the fishers bring the remaining quantiy to the fishmarkets.
Sicily	2	2510	1. *Engraulis encrasicolus* 2. *Sardina pilchardus*	83%	0	1	10	3	Box with seawater or ice	
Sicily	3	5000	1. *Engraulis encrasicolus*	79%	21%	4	6	3	Box with seawater or ice	
Sicily	4	1000	1. *Merluccius merluccius* 2. *Trachurus mediterraneus* 3. *Octopus vulgaris* 4. *Sepia officinalis* 5. *Mugilidae*	98%	2%	1	9	3	Box with seawater or ice	
Sicily	5	2000	1. *Engraulis encrasicolus* 2. *Xiphias gladius* 3. *Merluccius merluccius* 4. *Sardina pilchardus* 5. *Thunnus alalunga*	99%	1%	2	6	6	Box with seawater or ice	

3.4. Input data and conversion factors used in the Footprint Assessment

3.4.1. Fishing ground Footprint component analysis

For each boat, the top 5 fish species annually caught were asked per typology of catch, distinguishing among species sold to consumers, species kept for self-consumption, species unsold or discarded, as well as species eventually turned up as by-catch. Also, each respective quantity was asked.

Such data was used to calculate the fishing ground component of the Ecological Footprint, that is the appropriation of the marine fishing area calculated based on annual primary production (PPR) embodied in each specific fish species (see section 3.1). Yield and Equivalence factors were then used to convert input data into the Footprint of fishing ground of each species.

Table 2 provides the list of all fish species collected from the 17 boats and the respective conversion factors, which were then used to calculate the Fishing ground Footprint of each species.

Table 2. List of all fish species caught from the 17 boats participating in the analysis. Species are ordered from the highest Trophic Level to the lowest. The trophic level, fish yield and the EQF values come from the NFA 2021 edition, World data 2017.

English name (Common name)	Scientific name	FishSTAT Code	Trophic Level	Fish Yield	EQF Fishing ground
[-]	[-]	[-]	[-]	[t wha^{-1}]	[gha wha^{-1}]
Common dentex	*Dentex dentex*	3182	4.50	0.012	0.37
Bluefish	*Pomatomus saltatrix*	3102	4.50	0.012	0.37
Atlantic bonito	*Sarda sarda*	2471	4.50	0.012	0.37
Greater amberjack	*Seriola dumerili*	3119	4.50	0.012	0.37
Swordfish	*Xiphias gladius*	2503	4.49	0.012	0.37
Angler(=Monk)	*Lophius piscatorius*	3379	4.45	0.014	0.37
Atlantic bluefin tuna	*Thunnus thynnus*	3296	4.43	0.014	0.37
European hake	*Merluccius merluccius*	2238	4.42	0.015	0.37
Stargazer	*Uranoscopus scaber*	15903	4.38	0.016	0.37
Torpedo rays	*Torpedo spp*	2065	4.31	0.019	0.37
Albacore	*Thunnus alalunga*	2496	4.31	0.019	0.37
European conger	*Conger conger*	2994	4.29	0.020	0.37
Red scorpionfish	*Scorpaena scrofa*	2527	4.27	0.021	0.37
Forkbeard	*Phycis phycis*	2224	4.26	0.021	0.37
[Muraena spp]	*Muraena spp*	6338	4.20	0.024	0.37
Greater weever	*Trachinus draco*	2433	4.18	0.025	0.37
Common stingray	*Dasyatis pastinaca*	11806	4.05	0.034	0.37
Turbot	*Psetta maxima*	2563	3.96	0.042	0.37
Atlantic chub mackerel	*Scomber Colias*	20480	3.90	0.048	0.37
Black scorpionfish	*Scorpaena porcus*	3331	3.90	0.048	0.37
Turbots nei	*Scophthalmidae*	2558	3.89	0.049	0.37
European seabass	*Dicentrarchus labrax*	2291	3.79	0.062	0.37
Scorpionfishes nei	*Scorpaenidae*	2521	3.77	0.065	0.37
Thornback ray	*Raja clavata*	2851	3.76	0.066	0.37
Pompano	*Trachinotus ovatus*	3117	3.73	0.071	0.37

Brown meagre	*Sciaena umbra*	3149	3.70	0.076	0.37
Atlantic horse mackerel	*Trachurus trachurus*	2306	3.64	0.088	0.37
Common eagle ray	*Myliobatis aquila*	13590	3.61	0.094	0.37
Lefteye flounders nei	*Bothidae*	3348	3.61	0.094	0.37
Mediterranean horse mackerel	*Trachurus mediterraneus*	2311	3.59	0.098	0.37
Common cuttlefish	*Sepia officinalis*	2711	3.55	0.108	0.37
Grey triggerfish	*Balistes carolinensis*	3373	3.55	0.108	0.37
Common octopus	*Octopus vulgaris*	3571	3.55	0.108	0.37
European eel	*Anguilla anguilla*	2203	3.53	0.113	0.37
Axillary seabream	*Pagellus acarne*	3174	3.48	0.127	0.37
Sand steenbras	*Lithognathus mormyrus*	2392	3.42	0.145	0.37
Surmullet	*Mullus surmuletus*	3207	3.42	0.145	0.37
Common pandora	*Pagellus erythrinus*	2368	3.40	0.152	0.37
Round sardinella	*Sardinella aurita*	2088	3.40	0.152	0.37
Gilthead seabream	*Sparus aurata*	2384	3.26	0.210	0.37
Thickback soles nei	*Microchirus spp*	2556	3.21	0.236	0.37
Corkwing wrasse	*Symphodus melops*	15520	3.20	0.241	0.37
Red mullet	*Mullus barbatus*	3208	3.15	0.271	0.37
Common sole	*Solea solea*	3367	3.13	0.284	0.37
European anchovy	*Engraulis encrasicolus*	2106	3.11	0.297	0.37
Marine fishes nei	*Osteichthyes*	3385	3.10	0.304	0.37
Sandeels(=Sandlances) nei	*Ammodytes spp*	3260	3.10	0.304	0.37
European pilchard(=Sardine)	*Sardina pilchardus*	2910	3.05	0.341	0.37
White seabream	*Diplodus sargus*	2370	3.04	0.349	0.37
Sargo breams nei	*Diplodus spp*	3175	3.02	0.365	0.37
Picarel	*Spicara smaris*	3652	3.00	0.383	0.37
Common spiny lobster	*Palinurus elephas*	3452	2.60	0.961	0.37
Mullets nei	*Mugilidae*	2256	2.43	1.421	0.37
Flathead grey mullet	*Mugil cephalus*	3050	2.13	2.836	0.37
Mediterranean starry ray	*Raja asterias*	14800	2.00	3.825	0.37
Sea urchins, etc. nei	*Echinoidea*	2767	2.00	3.825	0.37
Salema	*Sarpa salpa*	2397	2.00	3.825	0.37

3.4.2. Labor/Manpower

Data on the number of hours worked by each fisher as well as data on numbers of fishers employed in each activity was collected through surveys, for both the activities at sea and on land. Such data was multiplied by the hourly national Ecological Footprint values of an average individual in the respective countries, as explained in Section 3.1.

3.4.3. Fuel for vessels

Input data was collected through field interviews with each fisher about vessel size and the amount and type of fuel used in a year. This was coupled with data on the CO_2 emitted per liter of fuel used (Mancini et al., 2018b) to account for the carbon component of the Ecological Footprint (see Table 3).

Table 3. Summary of fuel constants

Constant	Unit	Value	Source
Footprint Intensity of Carbon	[gha_{carbon} (t CO_2)$^{-1}$]	3.42E-01	GFN NFA 2021 World Workbook
Carbon Emissions of marine fuel - Diesel	[kg CO_2 liter^{-1}]	2.65	IPCC 2000. Jun, P., Gillenwater, M., & Barbour, W. (2000). https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/2_4_Water-borne_Navigation.pdf
Carbon Emissions of marine fuel - Gasoline	[kg CO_2 liter^{-1}]	2.36	

3.4.4. Fish Storage

Information was asked to each boat about the fish storage modalities, distinguishing among simple boxes with seawater and ice, refrigerated containers or any other type. While the box with water and ice was assumed to have no Ecological Footprint, the case of refrigerated containers require a certain amount of energy to be ran and thus its Footprint was calculated (see section 3.1). The constants listed in Table 4 were used to convert the reported quantity of stored fish in refrigerated containers into the correspondent carbon Footprint component.

Table 4. Summary of constants for the fish storage in refrigerated containers (using electricity)

Constants	Unit	Value	Source
Electricity consumption for fish refrigerated containers (literature range)	[kWh t^{-1}]	**70** - 130	Terehovics et al., 2018. Analysis of fish refrigeration electricity consumption.
National Electricity Carbon Intensity - Italy	[t CO_2 (kWh)$^{-1}$]	3.08E-04	NFA 2021 Italy Workbook
National Electricity Carbon Intensity - Spain	[t CO_2 (kWh)$^{-1}$]	2.98E-04	NFA 2021 Spain Workbook

3.4.5. Selling location

The constant listed in Table 5 were used to convert the physical occupation of the selling location and its energy consumption, into the built-up component and the carbon Footprint component, respectively, of the Footprint analysis. Such calculation was done only for the boats in **Catalunya** and **Ibiza** as they indicated that the selling phase happens under a covered market. In the case of **Sicily**, the selling phase happens directly at the port in open air.

Table 5. Summary of constants for the selling location, including physical occupation and energy consumption

Constants	Unit	Value	Source
Yield factor Built-up land Spain	[wha ha^{-1}]	0.59	NFA 2021 World workbook
Yield factor Built-up land Italy	[wha ha^{-1}]	0.68	NFA 2021 World workbook
EQF built-up land	[gha wha^{-1}]	2.49	NFA 2021 World workbook
Carbon emissions of an open space without air-conditioning Spain	[kg CO_2 $(hour)^{-1}$ $(m^2)^{-1}$]	2.89E-03	Adapted from Resource Efficient Scotland, 2016. "The Green Office Guide How to run a more cost-effective and environmentally sustainable office".
Carbon emissions of an open space without air-conditioning Italy	[kg CO_2 $(hour)^{-1}$ $(m^2)^{-1}$]	2.99E-03	

3.4.6. Transportation

The distance and the fuel type were the main input data tracked to calculate the carbon Footprint associated with transportation.

In the case of **Catalunya**, the transportation is that of two vans (one for l'Estartit harbor and one for l'Escala harbor) collecting the daily catch of all boats in the specific harbor and delivering it to the market place. As these vans transport the total quantity of catch arriving from all the boats in the harbor, carbon emissions are allocated to the share representing the daily catch of each boat surveyed in Catalunya over the maximum daily load of the van.

In the case of **Ibiza**, transportation consists of the trips made daily by fish market representatives (the intermediaries) going to the port (at the Cofradia offices) to pick-up the fish they singularly purchase from the individual boats. Per each boat, carbon emissions are allocated entirely to the vehicle making the roundtrip travel to go and collect the fish products. According to the surveyor, there might be the case of special occasions in which fishers go themselves to sell their own catch to the market (or in few instances to the restaurants). However, since this is happening quite rarely, we assume here that 100% of each boat's daily catch is sold at the Cofradia.

In the case of **Sicily**, transportation is that of the final consumers going to the port to purchase the fish directly from the fishers. Per each boat, carbon emissions are allocated entirely to the vehicle making the roundtrip travel to go and collect the fish products. According to the surveyor, there might be cases in which little quantities of fish are left unsold; in these cases, the fisher of each boat takes it to the closest selling point (i.e., fish markets or road markets). When this happens (4 boats out of 5), an additional calculation was made to calculate the carbon emission of the roundtrip travel made by each fisher with its own vehicle. Given the lack of detailed data on how frequently this happens, we assumed here this additional trip to take place in 5% of the fisher's work days.

Table 6 provides the constants for the assessment of transportation Footprint.

Table 6. Constants used for assessment of transportation footprint

Constant	Unit	Value	Source
CO_2 Emissions per km travelled with a diesel vehicle	[kg CO_2 km^{-1}]	0.2117	IPCC, 2006. Guidelines for National Greenhouse Gases Inventories. Vol2. Ch.3. Values are calculated as the average across a set of fuel efficiencies leaving out the lower and upper ends.
CO_2 Emissions per km travelled with a gasoline vehicle	[kg CO_2 km^{-1}]	0.1790	

4. <u>Limitations of the study</u>

The Ecological Footprint assessment applied to Small Scale Fisheries presents few limitations that may affect the overall analysis and its final results. Limitations are listed as follows:

- The Ecological Footprint is an anthropocentric indicator able to quantify a specific sub-set of natural resources and ecosystem services that are being demanded by humans to fuel and sustain their socio-economic systems. Such human demand is measured in terms of the underlying physical surface of ecosystem types (i.e. the bio-productive surface, or ecological asset) required to produce the annual flow of resources and services that humans find useful (Mancini et al., 2018a). In the case of fisheries, this annual flow is represented by the fishes caught in a given year and the underlying ecological assets include – among others – the marine fishing area calculated as the marine primary productivity embodied in each specific fish species or the land needed to sequester the CO_2 emissions released by the fishing activities. As such, the Ecological Footprint methodology tracks the drivers of pressures on ecosystems – i.e., the fact that fishes are being taken from the ecosystem – rather than the status of ecosystems or the impacts such pressures are causing – e.g., size and dimension of fishes, vulnerability and composition of fishes, the status of stocks or their depletion. The Ecological Footprint thus does not track the consequences of fishing activities on the quality of marine ecosystems and the specific habitat of each species because that is not the research question it is aimed to respond to (Lin et. Al., 2015).

- The Ecological Footprint analysis at the 3 pilot sites was structured in a way to track all activities related – directly or indirectly – to the fishing boat, which is taken as the reference system for the analysis. Thus, both activities taking place on the boat as well as the activities on land for the selling phase were considered (see Figure 1). As concern the final consumers, the analysis was limited to the information that could be collected at the first selling point in each pilot site: the harbor in the case of Sicily where fishers directly sell their catch to the actual final consumers, and the local cooperative markets in the case of Catalunya and Ibiza, which sell the catch to fishmongers acting as intermediaries before the final consumers. In this latter case, the Footprint analysis might be underestimated as the actual final consumers could not be traced down. See also section 3.3 and 3.4.6 for further details.

- The Ecological Footprint assessment of the Small Scale Fisheries aims at analyzing each boat surveyed in the 3 pilot sites for a total of 17 boats and comparing the results across boats. Such results could not be compared with the Footprint placed by Large Scale Fisheries (LSFs) due to the lack of detailed, reliable national level data on LSFs.

5. Results

5.1. Ecological Footprint Analysis: overview

Figures 2 presents the overall results of the Ecological Footprint analysis for the 17 boats of the 3 pilot sites, each measured per 1 kg of fish landed and made available to consumers in 2021. The analysis also includes the weighted average Ecological Footprint value of all boats.

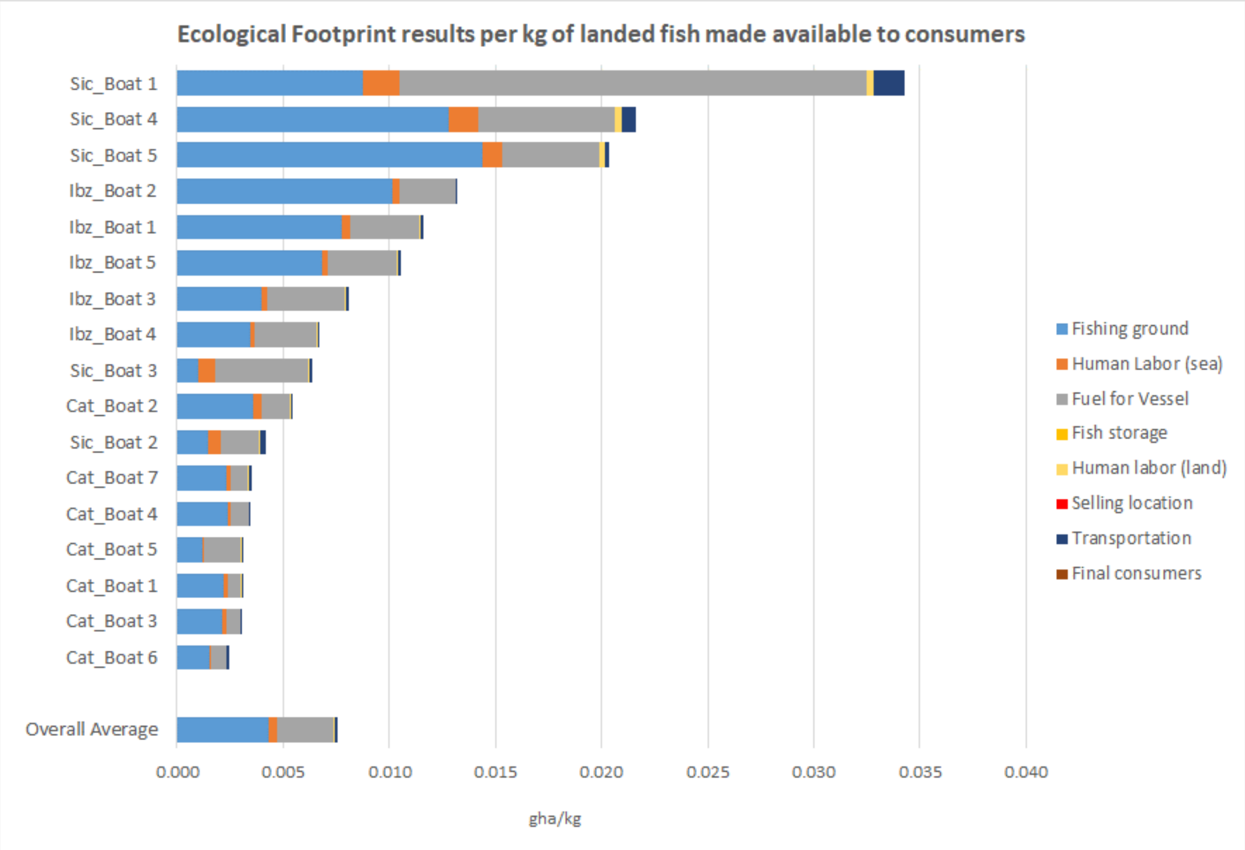

Figure 2. Ecological Footprint per 1 kg of fish landed and made available to consumers by each boat, broken down by source. Cat indicates boats from Catalunya, Sic boats from Sicily and Ibz are the boats from Ibiza. Boats are ordered from the highest to the lowest total Ecological Footprint.

The average Footprint of 1 kg of fish landed at the harbor to be sold to consumers was found to be 0.0076 gha kg^{-1}, which is equivalent to about 76 global square meters (gm^2). This means that it takes about 76 gm^2 of bioproductive land and sea surfaces to provide the renewable resources and ecological services needed to produce and make available 1 kg of fish for consumers' use.

Values from specific boats range from 24 gm^2 for Boat #6 in Catalunya to 343 gm^2 for boat #1 in Sicily. In the specific case of boat #1 in Sicily, such high Ecological Footprint is likely due to the fact that this boat lands to the harbor the lowest quantity of fish among all boats (300 kg), meaning that the boat exerts a high fishing pressure per unit of fish catch. Such info is confirmed when looking at the ratios "manhours per kg of fish landed" and "fuel use per unit of fish landed" for which Sic_Boat 1 has a value of 0.0167 (almost 1.6 time higher than the average from all boats of 0.0064) and 24.5 (4.5 time higher than the average of 4.3), respectively.

When looking at the drivers making up the total Ecological Footprint of a kg of fish, results show that on average the greatest impact is due to the appropriation of marine primary productivity via the fishing activity (corresponding to the fishing ground land type), representing 57% of the total. The second driver is the fuel used on the boat during the sea activities (on average 35% of the total), and entirely corresponding to the carbon uptake land needed to sequester the CO_2 emissions generated by the boats. Nevertheless, few boats show different shares in which the fuel used in vessel is the primary cause of the Ecological Footprint (see Table 7).

Footprint results by the main drivers are discussed in details in the following subsections.

Table 7. Overview of the Footprint results and the percentage contribution of each driver

			Footprint components						
Region	Boat	Total EF per fish landed	Fishing Grounds	Human labor (Sea)	Vessel Fuel	Fish Storage	Human labor (Land)	Selling location	Transportation
		gha/kg	%	%	%	%	%	%	%
Catalunya	#1	0.003113	71%	6%	20%	0.22%	1%	0%	2%
Catalunya	#2	0.005433	66%	7%	25%	0.12%	1%	0%	1%
Catalunya	#3	0.003071	70%	6%	22%	0.22%	1%	0%	2%
Catalunya	#4	0.003451	69%	4%	24%	0.20%	1%	0%	2%
Catalunya	#5	0.003150	39%	1%	56%	0.23%	0%	0%	4%
Catalunya	#6	0.002444	62%	4%	29%	0.28%	1%	0%	4%
Catalunya	#7	0.003496	67%	5%	24%	0.20%	1%	0%	3%
Sicily	#1	0.034294	26%	5%	64%	0%	1%	0%	4%
Sicily	#2	0.004163	35%	14%	43%	0%	1%	0%	6%
Sicily	#3	0.006399	16%	12%	68%	0%	1%	0%	2%
Sicily	#4	0.021594	59%	6%	30%	0%	1%	0%	3%
Sicily	#5	0.020361	71%	4%	22%	0%	1%	0%	1%
Ibiza	#1	0.011604	67%	4%	28%	0.06%	0.4%	0%	1%
Ibiza	#2	0.013180	77%	3%	20%	0.05%	0.1%	0%	0%
Ibiza	#3	0.008131	49%	4%	45%	0.08%	0.7%	0%	2%
Ibiza	#4	0.006700	51%	4%	43%	0.10%	0.4%	0%	1%
Ibiza	#5	0.010527	65%	2%	31%	0.07%	0.4%	0%	1%
Overall average		**0.007592**	**57%**	**5%**	**35%**	**0%**	**1%**	**0%**	**2%**

Table 8 provides the database collecting all the main results and key information of each specific boat that have been discussed in this report.

Table 8. Database summarizing main results and input data of each boat.

Region	Boat number	EF per kg fish landed	Carbon Footprint per kg of fish	kg of fish landed in a year	Type of fuel (Boat)	Fuel efficiency per fish landed	Area navigated per kg of landed fish	Manhour per fish landed	Scientific name	Quantity over the total sold	Gear 1 associated (original name as provided in the surveys)	Total gears	By-catch
		gha/kg	kgCO2/kg	kg	[-]	l/kg	$miles^2$ / kg	man*hour/kg	[spp]	%	[Type 1]	[1/1 - 1/2 ...]	%
Catalunya	Cat_Boat 1	0.0031	4.80	867	Diesel	0.7	0.007	0.007	*Sparus aurata*	53%	NANSA SEPIA	1/2	0%
Catalunya	Cat_Boat 1	0.0031	4.80	867	Diesel	0.7	0.007	0.007	*Sepia officinalis*	24%	NANSA SEPIA	1/1	0%
Catalunya	Cat_Boat 1	0.0031	4.80	867	Diesel	0.7	0.007	0.007	*Diplodus sargus*	4%	N/A		0%
Catalunya	Cat_Boat 1	0.0031	4.80	867	Diesel	0.7	0.007	0.007	*Dicentrarchus labrax*	4%	SOLTA	1/1	0%
Catalunya	Cat_Boat 1	0.0031	4.80	867	Diesel	0.7	0.007	0.007	*Pagellus erythrinus*	3%	SOLTA	1/1	0%
Catalunya	Cat_Boat 2	0.0054	9.78	408	Diesel	1.5	0.015	0.015	*Diplodus sargus*	33%	PALANGRILLO	1/1	0%
Catalunya	Cat_Boat 2	0.0054	9.78	408	Diesel	1.5	0.015	0.015	*Sparus aurata*	30%	PALANGRILLO	1/1	0%
Catalunya	Cat_Boat 2	0.0054	9.78	408	Diesel	1.5	0.015	0.015	*Trachurus trachurus*	18%	N/A		0%
Catalunya	Cat_Boat 2	0.0054	9.78	408	Diesel	1.5	0.015	0.015	*Pomatomus saltatrix*	4%	PALANGRILLO	1/1	0%
Catalunya	Cat_Boat 2	0.0054	9.78	408	Diesel	1.5	0.015	0.015	*Conger conger*	3%	PALANGRILLO	1/1	0%
Catalunya	Cat_Boat 3	0.0031	4.95	1387	Diesel	0.7	0.004	0.004	*Sepia officinalis*	24%	TRESMALL SEPIA	1/2	0%
Catalunya	Cat_Boat 3	0.0031	4.95	1387	Diesel	0.7	0.004	0.004	*Trachurus trachurus*	12%	POTERA	1/1	0%
Catalunya	Cat_Boat 3	0.0031	4.95	1387	Diesel	0.7	0.004	0.004	*Mugil cephalus*	8%	N/A		0%
Catalunya	Cat_Boat 3	0.0031	4.95	1387	Diesel	0.7	0.004	0.004	*Lithognathus mormyrus*	8%	TRESMALL SEPIA	1/2	0%
Catalunya	Cat_Boat 3	0.0031	4.95	1387	Diesel	0.7	0.004	0.004	*Pagellus erythrinus*	7%	TRESMALL LLENGUADO	1/1	0%
Catalunya	Cat_Boat 4	0.0035	5.80	2584	Diesel	0.9	0.010	0.002	*Sparus aurata*	14%	soltes	1/1	0%
Catalunya	Cat_Boat 4	0.0035	5.80	2584	Diesel	0.9	0.010	0.002	*Sepia officinalis*	10%	tresmall de sepia	1/1	0%
Catalunya	Cat_Boat 4	0.0035	5.80	2584	Diesel	0.9	0.010	0.002	*Mugil cephalus*	8%	soltes	1/1	0%

Region	Boat number	EF per kg fish landed	Carbon Footprint per kg of fish	kg of fish landed in a year	Type of fuel (Boat)	Fuel efficiency per fish landed	Area navigated per kg of landed fish	Manhour per fish landed	Scientific name	Quantity over the total sold	Gear 1 associated	Total gears	By-catch
Catalunya	Cat_Boat 4	0.0035	5.80	2584	Diesel	0.9	0.010	0.002	*Pagellus erythrinus*	8%	soltes	1/1	0%
Catalunya	Cat_Boat 4	0.0035	5.80	2584	Diesel	0.9	0.010	0.002	*Torpedo spp*	5%	N/A		0%
Catalunya	Cat_Boat 5	0.0031	11.20	3075	Diesel	2.0	0.005	0.001	*Ammodytes spp*	100%	SONSERA	1/1	0%
Catalunya	Cat_Boat 6	0.0024	5.23	3780	Diesel	0.8	0.009	0.002	*Mugil cephalus*	19%	TRESMALL DE ROGER	1/1	0%
Catalunya	Cat_Boat 6	0.0024	5.23	3780	Diesel	0.8	0.009	0.002	*Sparus aurata*	8%	palangrillo	1/2	0%
Catalunya	Cat_Boat 6	0.0024	5.23	3780	Diesel	0.8	0.009	0.002	*Sepia officinalis*	7%	tresmall per sepia	1/1	0%
Catalunya	Cat_Boat 6	0.0024	5.23	3780	Diesel	0.8	0.009	0.002	*Mullus surmuletus*	6%	Tresmall roger	1/2	0%
Catalunya	Cat_Boat 6	0.0024	5.23	3780	Diesel	0.8	0.009	0.002	*Pagellus erythrinus*	6%	solta	1/3	0%
Catalunya	Cat_Boat 7	0.0035	6.25	1630	Diesel	0.9	0.017	0.004	*Octopus vulgaris*	30%	CADUP	1/2	0%
Catalunya	Cat_Boat 7	0.0035	6.25	1630	Diesel	0.9	0.017	0.004	*Sepia officinalis*	27%	NANSES	1/2	0%
Catalunya	Cat_Boat 7	0.0035	6.25	1630	Diesel	0.9	0.017	0.004	*Mugil cephalus*	9%	TRESMALL SEPIA	1/1	0%
Catalunya	Cat_Boat 7	0.0035	6.25	1630	Diesel	0.9	0.017	0.004	*Raja asterias*	6%	N/A		0%
Catalunya	Cat_Boat 7	0.0035	6.25	1630	Diesel	0.9	0.017	0.004	*Sparus aurata*	6%	PALANGRILLO	1/2	0%
Ibiza	Ibz_Boat 1	0.0116	21.48	1664	Diesel	3.6	0.006	0.006	*Sepia officinalis*	27%	TRESMALL SEPIA	1/1	0%
Ibiza	Ibz_Boat 1	0.0116	21.48	1664	Diesel	3.6	0.006	0.006	*Scorpaena scrofa*	15%	TRESMALL SEPIA	1/3	0%
Ibiza	Ibz_Boat 1	0.0116	21.48	1664	Diesel	3.6	0.006	0.006	*Scorpaena porcus*	15%	TRESMALL SEPIA	1/3	0%
Ibiza	Ibz_Boat 1	0.0116	21.48	1664	Diesel	3.6	0.006	0.006	*Trachurus trachurus*	10%	TRESMALL SEPIA	1/1	0%
Ibiza	Ibz_Boat 1	0.0116	21.48	1664	Diesel	3.6	0.006	0.006	*Seriola dumerili*	8%	SOLTA	1/1	0%
Ibiza	Ibz_Boat 2	0.0132	16.91	3120	Diesel	2.9	0.007	0.008	*Sepia officinalis*	30%	TRESMALL MALLA FINA 5-6 pasadas	1/1	0%

Region	Boat number	EF per kg fish landed	Carbon Footprint per kg of fish	kg of fish landed in a year	Type of fuel (Boat)	Fuel efficiency per fish landed	Area navigated per kg of landed fish	Manhour per fish landed	Scientific name	Quantity over the total sold	Gear 1 associated	Total gears	By-catch
Ibiza	Ibz_Boat 2	0.0132	16.91	3120	Diesel	2.9	0.007	0.008	*Trachurus trachurus*	20%	TRESMALL MALLA FINA 5-6 pasadas	1/2	0%
Ibiza	Ibz_Boat 2	0.0132	16.91	3120	Diesel	2.9	0.007	0.008	*Scorpaena porcus*	0.2	TRESMALL LLAGOSTA	1/3	0
Ibiza	Ibz_Boat 2	0.0132	16.91	3120	Diesel	2.9	0.007	0.008	*Thunnus thynnus*	15%	LINEA DE MANO	1/1	0%
Ibiza	Ibz_Boat 2	0.0132	16.91	3120	Diesel	2.9	0.007	0.008	*Dentex dentex*	10%	PALANGRILLO	1/3	0%
Ibiza	Ibz_Boat 3	0.0081	23.46	1248	Diesel	4.0	0.008	0.004	*Sepia officinalis*	30%	TRESMALL SEPIA	1/1	0%
Ibiza	Ibz_Boat 3	0.0081	23.46	1248	Diesel	4.0	0.008	0.004	*Mullus barbatus*	20%	Trasmallo para surmuletus	1/1	0%
Ibiza	Ibz_Boat 3	0.0081	23.46	1248	Diesel	4.0	0.008	0.004	*Scorpaena scrofa*	20%	TRESMALL PESCADO	1/2	0%
Ibiza	Ibz_Boat 3	0.0081	23.46	1248	Diesel	4.0	0.008	0.004	*Scorpaena porcus*	20%	TRESMALL SEPIA	1/3	0%
Ibiza	Ibz_Boat 3	0.0081	23.46	1248	Diesel	4.0	0.008	0.004	*Palinurus elephas*	10%	TRESMALL LANGOSTA	1/1	0%
Ibiza	Ibz_Boat 4	0.0067	18.48	1248	Diesel	3.2	0.005	0.006	*Octopus vulgaris*	100%	NANSES	1/1	0%
Ibiza	Ibz_Boat 5	0.0105	20.78	1664	Diesel	3.6	0.004	0.003	*Spicara smaris*	25%	ARTET	1/1	0%
Ibiza	Ibz_Boat 5	0.0105	20.78	1664	Diesel	3.6	0.004	0.003	*Scorpaena scrofa*	13%	TRESMALL PESCADO	1/2	0%
Ibiza	Ibz_Boat 5	0.0105	20.78	1664	Diesel	3.6	0.004	0.003	*Scorpaena porcus*	13%	TRESMALL PESCADO	1/2	0%
Ibiza	Ibz_Boat 5	0.0105	20.78	1664	Diesel	3.6	0.004	0.003	*Seriola dumerili*	10%	Trasmallo para sepias	1/1	0%
Ibiza	Ibz_Boat 5	0.0105	20.78	1664	Diesel	3.6	0.004	0.003	*Palinurus elephas*	8%	TRESMALL LLAGOSTA	1/1	0%
Sicily	Sic_Boat 1	0.0343	144.57	300	Diesel	24.3	0.010	0.017	*Pagellus erythrinus*	25%	tremaglio (Trammel net)	1/1	0%
Sicily	Sic_Boat 1	0.0343	144.57	300	Diesel	24.3	0.010	0.017	*Mugilidae*	20%	tremaglio (Trammel net)	1/1	0%
Sicily	Sic_Boat 1	0.0343	144.57	300	Diesel	24.3	0.010	0.017	*Sepia officinalis*	20%	tremaglio (Trammel net)	1/1	0%
Sicily	Sic_Boat 1	0.0343	144.57	300	Diesel	24.3	0.010	0.017	*Merluccius merluccius*	20%	imbrocco (gill nets)	1/1	0%

Region	Boat number	EF per kg fish landed	Carbon Footprint per kg of fish	kg of fish landed in a year	Type of fuel (Boat)	Fuel efficiency per fish landed	Area navigated per kg of landed fish	Manhour per fish landed	Scientific name	Quantity over the total sold	Gear 1 associated	Total gears	By-catch
Sicily	Sic_Boat 1	0.0343	144.57	300	Diesel	24.3	0.010	0.017	*Uranoscopus scaber*	10%	tremaglio (Trammel net)	1/1	0%
Sicily	Sic_Boat 2	0.0042	14.39	2510	Diesel	2.0	0.001	0.004	*Engraulis encrasicolus*	90%	menaide (a small rowing fishing boat)	1/1	0%
Sicily	Sic_Boat 2	0.0042	14.39	2510	Diesel	2.0	0.001	0.004	*Sardina pilchardus*	10%	verricello (winch)	1/1	0%
Sicily	Sic_Boat 3	0.0064	29.41	5000	Diesel	4.8	0.001	0.005	*Engraulis encrasicolus*	100%	menaide	1/1	0%
Sicily	Sic_Boat 4	0.0216	47.62	1000	Gasoline	8.0	0.003	0.009	*Merluccius merluccius*	40%	monofilo	1/1	0%
Sicily	Sic_Boat 4	0.0216	47.62	1000	Gasoline	8.0	0.003	0.009	*Trachurus mediterraneus*	5%	monofilo	1/1	0%
Sicily	Sic_Boat 4	0.0216	47.62	1000	Gasoline	8.0	0.003	0.009	*Octopus vulgaris*	5%	tramaglio (trammel)	1/1	0%
Sicily	Sic_Boat 4	0.0216	47.62	1000	Gasoline	8.0	0.003	0.009	*Sepia officinalis*	5%	tramaglio (trammel)	1/1	0%
Sicily	Sic_Boat 4	0.0216	47.62	1000	Gasoline	8.0	0.003	0.009	*Mugilidae*	45%	monofilo	1/1	0%
Sicily	Sic_Boat 5	0.0204	32.16	2000	Diesel	5.0	0.003	0.006	*Engraulis encrasicolus*	35%	menaide	1/1	10%
Sicily	Sic_Boat 5	0.0204	32.16	2000	Diesel	5.0	0.003	0.006	*Xiphias gladius*	25%	palangaro	1/1	10%
Sicily	Sic_Boat 5	0.0204	32.16	2000	Diesel	5.0	0.003	0.006	*Merluccius merluccius*	15%	palangaro	1/1	10%
Sicily	Sic_Boat 5	0.0204	32.16	2000	Diesel	5.0	0.003	0.006	*Sardina pilchardus*	15%	menaide	1/1	10%
Sicily	Sic_Boat 5	0.0204	32.16	2000	Diesel	5.0	0.003	0.006	*Thunnus alalunga*	10%	palangaro	1/1	10%

5.1.1. The Fishing Ground Footprint Component

When looking at the sole fishing ground Footprint component, it can be observed that there is a high variability among the boats, with values ranging from 0.0010 gha kg^{-1} (about 10 gm^2) for boat #3 in Sicily to 0.0144 gha kg^{-1} (about 144 gm^2) for boat #5, again in Sicily.

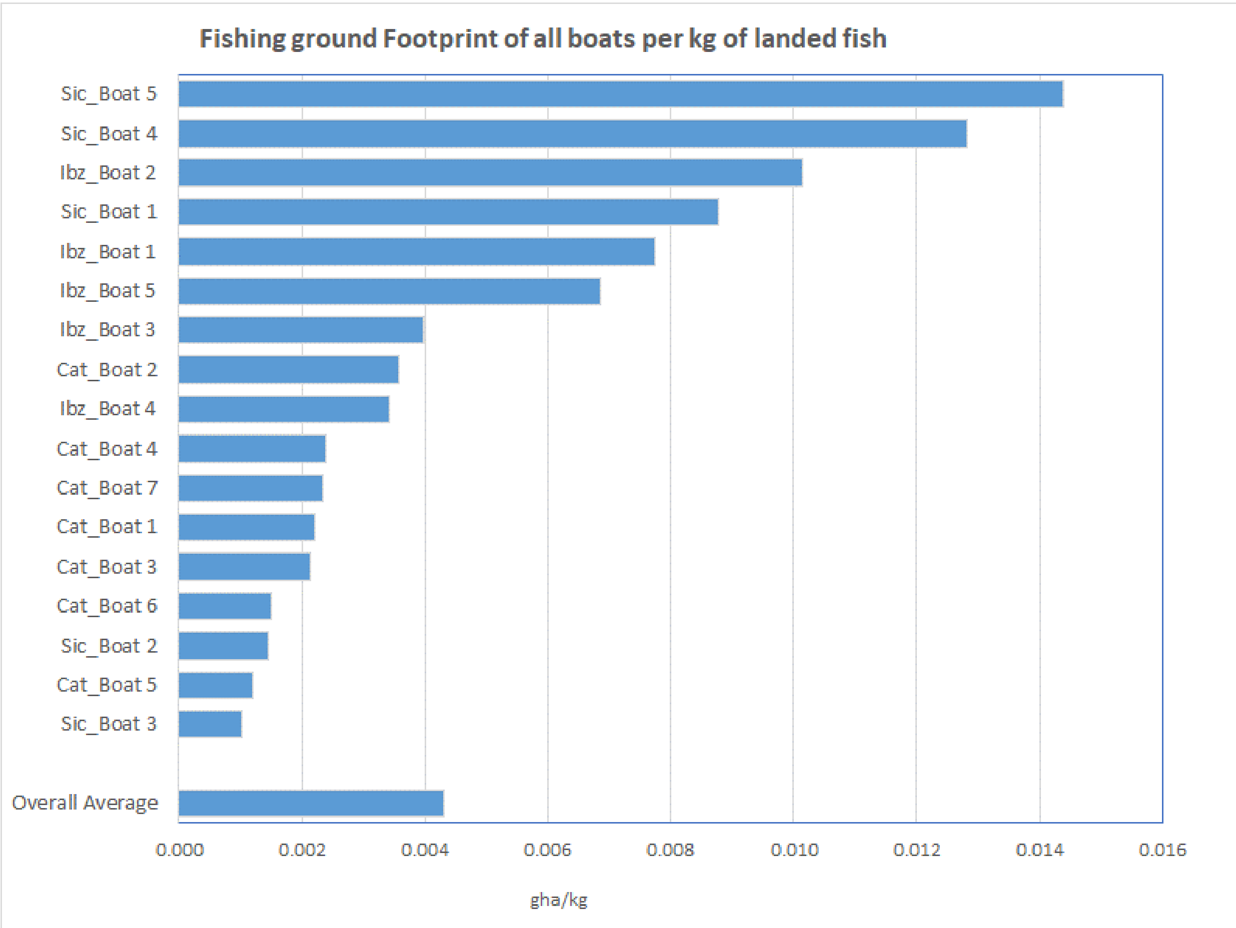

Figure 3. Fish Footprint component of all the boats. Results are visualized from the highest fish Footprint to the lowest value, and the order of boats is different from Figure 3.

This Footprint component mostly depends on the species of fish that are caught and their trophic level (TL), as well as any eventual presence of by-catch.

Boats with the highest fishing ground Footprint are found in Sicily and Ibiza. In **Sicily,** the fishing ground Footprint of all boats range from 0.0010 to 0.0144 gha per kg of fish. Boat #5 shows the highest value across all boats as it reported to catch the highest trophic level fishes, including swordfish (*Xiphias gladius*, TL 4.5), European hake (*Merluccius merluccius*, TL 4.4 – also fished by boat #4) and albacore (*Thunnus alalunga*, TL 4.3), which altogether make up 50% of the total catch of the boat. In addition, boat #5 reported a 10% by-catch over the total quantity of fish, although indication on the specific species was not reported. Boat #1 reported to fish stargazer (*Uranoscopus scaber*, TL 4.4) and European hake (*Merluccius merluccius,* TL 4.4), together representing 30% of the total catch of the boat. On the contrary, boat #3 and boat #2 in Sicily have the lowest and third lowest, fishing ground Footprint per kg of landed fish across all 17 boats, respectively as they mainly fish anchovies (*Engraulidae spp*) and pilchards (*Sardina pilchardus*), both with a low trophic level (TL 3.1). Yet, boat #3 reported a 16% by-catch rate, but no species were specified. For Sicily, it's important to note that the fishing ground Footprint in Boat #1, #2 and #3 is not the primary driver of their total Ecological Footprint per kg of fish, as it represents 26%, 35% and 16% respectively, while the fuel used for vessel is their primary Footprint driver (see Section 3.1 and 3.4.3); conversely, in boat #4 and #5 the fishing ground Footprint contributes to 59% and 71%, respectively, of their total Footprint value.

In **Ibiza**, the fishing ground Footprint of all boats range between 0.0034 and 0.0101 gha per kg of fish. Boat #2 is the third boat among all with the highest value for this Footprint component as it fishes bluefin tuna (*Thunnus thynnus*, TL 4.4), dentex (*Dentex dentex*, TL 4.5) and black scorpionfish (*Scorpaena porcus*, TL 3.9), which together make up 45% of the total catch of the boat. This boat also reported one species of by-catch (the red mullet, that is *Mullus barbatus*), although no quantitative data was communicated. Boat #1 fishes the greater amberjack (*Seriola dumerili,* TL 4.5) and the red scorpionfish (*Scorpaena scrofa*, TL 4.3), making up 23% of the total catch; it also reported by-catch of the common stingray (*Dasyatis Pastinaca,* TL 4.1), but with no specific data on by-catch amount. Finally, boat #5 fishes red scorpionfish (*Scorpaena scrofa*, TL 4.3) and greater amberjack (*Seriola dumerili,* TL 4.5), contributing to 23% of the total catch of the boat. In addition, despite the lack of data, boat #5 reported 2 species of by-catch, including stingray (*Seriola dumerili,* TL 4.1) and thornback ray (*Raja clavata*, TL 3.8).

In **Catalunya**, the fishing ground Footprint of all boats ranges from 0.0012 to 0.0035 gha per kg of fish, positioning these boats in the lower end of the Footprint's range of all 17 boats provided in Figure 3. It should be noted that boats in Catalunya reported a great variety of species caught by each boat, but – given the structure of the survey - actual quantities could be solely communicated for the top 5 species sold to consumers, for self-consumption, unsold/discarded or included in the unwanted by-catch. Consequently, the Footprint analysis uses species-specific data and Footprint intensities for the top 5 species, while for all other species - whose quantity was reported under a general "other species" category - the average Footprint intensity of fishes generally classified as *Osteichthyes* with a TL 3.1 was used. This also means that, in the case of species with a high trophic level reported in the various boats but not listed among the top 5 species, the Fishing ground Footprint is likely to be underestimated. Some examples are: the common dentex (*Dentex dentex,* TL 4.5) is caught in all boats except #3 and #5; atlantic bonito (*Sarda sarda*, TL 4.5), greater amberjack (*Seriola dumerili,* TL 4.5) and bluefin tuna (*Thunnus thynnus*, TL 4.4) are caught by boat #6; forkbeard (*Phycis phycis*, TL 4.3) is caught by boat #4, and the greater weever (*Trachinus draco*) by boat #2. Boat #2 has the highest fishing ground Footprint across the other boats of the region as it fishes bluefish (*Pomatomus saltatrix*, TL 4.5) and European conger (*Conger conger*, TL 4.3), although they make up just 7% of the reported catch. This boat also reported by-catch of the common eagle ray (*Myliobatis aquila*, TL 3.6), but no quantity nor shares are provided. Boat #5 has the lowest fishing ground Footprint value among the other boats in Catalunya, as it solely fishes the low trophic level (TL3.1) Mediterranean sand eel (*Gymnammodytes cicerelus*).

5.1.2. Fuel use and the carbon Footprint component

On average, the second Footprint driver is the fuel used by vessels, contributing to 35% of the total Ecological Footprint value. Values range from 6.3 $gm^2\ kg^{-1}$ (boat #1 in Catalunya) to 220.5 $gm^2\ kg^{-1}$ (boat

#1 in Sicily) (see Figure 4) and pressure is entirely placed on the carbon Footprint component, which represents the land needed to sequester the CO_2 emissions due to fuel use by the vessels.

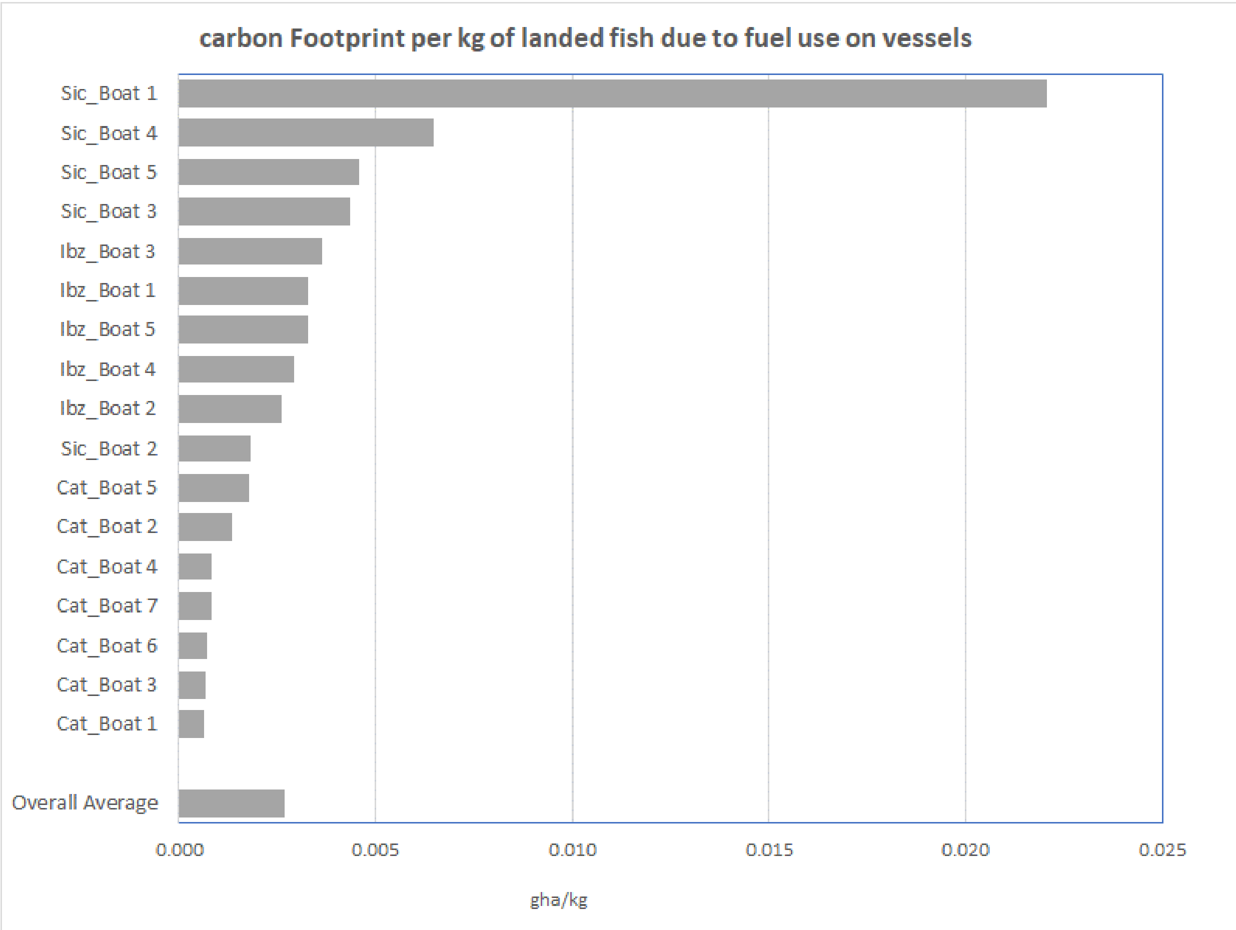

Figure 4. the carbon Footprint component of all the boats due to the use of fuel to run the vessels. Results are visualized from the highest value to the lowest.

Except for boat #2, boats in **Sicily** were found to have the highest carbon Footprint value due to the fuel use; among these boats, boat #1 seems to be an outlier as its fuel-related carbon Footprint is more than 8 times greater than the average Footprint of fuel for vessel. As a matter of fact, this boat uses about 24 liters of fuel per kg of fish landed, meaning that to fish 1 kg of fish boat #1 requires more fuel than all the other boats, as they range from 0.6 to 8 liters per kg of fish. This might depend on multiple factors, including the small amount of total catch in the entire year (300 kg), which is the smallest across all 17 boats, and also to the fish technique and the gears used by the boat (i.e. trammel and gill nets). Boat #3 has the fourth highest Footprint due to fuel use, and fuel use is the primary driver of the total Footprint of this boat, corresponding to about 68% of the total Footprint. Such high share is also partially due to the fact that Sic_Boat 3 has low Footprint values for the other activities as it fishes one single species over the entire year, of a relative low trophic level (i.e. anchovies) and thus has the lowest fishing ground Footprint. The same reason holds true for boat #2, which fishes anchovies and pilchards and for which vessel fuel represents 43% of the total Footprint. Finally, Sic_Boat #4 is the boat with the second largest carbon Footprint due to fuel consumption (8 liter kg^{-1}), although it represents the second driver of the boat's total Ecological Footprint (30% of the total value). It should be noted that this is the only one of the 17 boats that is using gasoline as type of fuel, which has slight lower carbon emissions per liter than diesel (see Table 3 in section 3.4.3).

In **Catalunya**, boat #5 was found to have a Footprint due to fuel use contributing to 56% of the total Footprint value (see table 7); its fuel efficiency is almost 2 liter kg^{-1} of fish, and this boat solely catches sand eels (a species with the lowest fish Footprint) by means of boat seines (i.e. Catalan "sonsera") as fishing gear. Nevertheless, all boats in Catalunya fall in the lower end of the overall range of the Footprint values due to fuel use, with a fuel efficiency ranging from 0.6 to 2 liter per kg of fish.

In **Ibiza**, Footprint due to the fuel use is the second driver for all boats and their fuel efficiencies range from 2.8 to 4 liter per kg of fish, positioning in the middle of the overall ranking.

5.1.3. The human labor driver

The third driver of the total Ecological Footprint of all boats is the working time of fishers for the activities at the sea. It represents on average 5% of the total Footprint value, with a contribution ranging from 1% (boat #5 in Catalunya) to 14% (boat #2 in Sicily). The Footprint of labor represents the natural resources necessary to sustain the fishers while working (see section 3.1).

Looking at the results, two main information can be seen: 1) most of the labor Footprint is due to the time spent at sea (87% on average), with a minor contribution for the working time onshore (13%); 2) once again, the highest values for this Footprint component are found in Sicily, particularly in boat 1, and 4 as these boats have a manhour per kg of fish caught much higher (0.0167 and 0.009 respectively) than the average value for all boats (0.006), which is likely due to the very low amount of catch reported at survey time. Together with boat 5, these boats are also characterized by a high Footprint value for the labor onshore (i.e., on land), possibly due to the fact that the fishers personally sell their daily catch at the port and, in a few cases, also deliver fish unsold at the port to their customers (see section 3.4.6). On the other side of the spectrum, the lowest labor Footprint – both at sea and inland – was found for boat 5 in Catalunya: in this case, fishing Mediterranean sand eels (*Gymnammodytes cicerelus*) seems to be very efficient from a labor viewpoint (0.008 manhour per kg of fish, compared to an average of 0.006), as it is efficient and time saving the practice to mandate the whole process of fish selling to the local cofradia. Still, it is worth stressing that this Footprint component plays just a small contribution to the overall Footprint of making fish available to consumers.

Figure 5 shows the Footprint of the labor components (both at the sea and on land) for all boats.

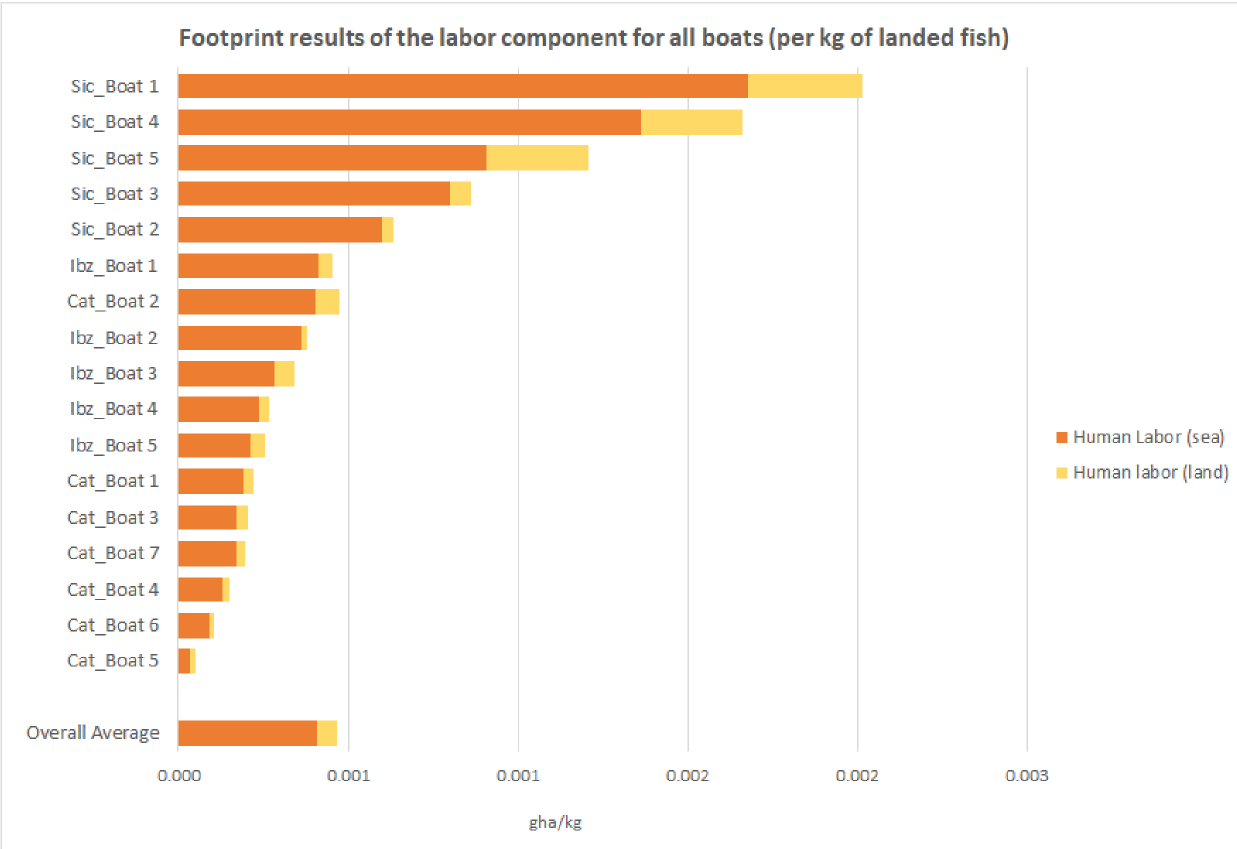

Figure 5. Ecological Footprint results of the labor component, both for the activities at the sea (fishing phase – orange color) and the activities on land (selling phase – yellow color). Results are ordered from the highest value to the lowest value of the fishing phase.

5.2. Carbon Footprint Analysis

This section presents a secondary analysis focusing exclusively on the Carbon Footprint indicator, intended as the total amount of CO_2 emissions coming from each boat's activities, both offshore and onshore, to make the catch available to consumers. This carbon analysis ignores the non-carbon impact of fisheries, as well as any connections to earth's regenerative capacity made possible by measurement in global hectares[14].

The Carbon Footprint is thus measured in kg of CO_2 released for 1 kg of fish landed and stems from the analysis of all input data representing direct and indirect carbon dioxide emissions. It is worth noting that only CO_2 emissions of carbon dioxide (CO_2) are accounted in this analysis, while Carbon Footprint accountings usually take into consideration also other type of greenhouse gases (e.g., methane, nitrous oxide, sulfur hexafluoride) that are thus measured in CO_{2eq}.

Following the GHG Protocol[15] for corporate accountings, carbon emissions can be categorized under Scope 1 (direct emissions) and Scope 2 or 3 (indirect emissions). In the analysis of the small scale fisheries, Scope 1 includes the emissions due to fuel consumption for running the boat and for transporting the catch on land through the fishers' own vehicles (in the case of Sicily only); Scope 2 includes indirect emissions due to the use of electricity for refrigerated containers for the fish storage as well as the electricity consumed in the selling location; Scope 3 emissions include indirect emissions related to the human labor and the fuel consumption of intermediaries' (in the case of Catalunya and Ibiza) or final consumers' vehicles (in the case of Sicily), thus not owned by the fishers.

It is worth noting that, in the pilot sites of Catalunya and Ibiza, the very final consumers of fish products could not identified as the first purchasers are intermediaries (i.e. fishmongers), who then distribute the fishes to third-party clients, whose location could not be tracked. Therefore, the Carbon Footprint of the boats located in these two pilot sites (as well as their Ecological Footprint) might be underestimated compared to that of the Sicilian boats.

Nonetheless, a direct marketing scheme is now being implemented in the pilot sites of Catalunya and Ibiza, which aims at selling the fishes directly to the final consumers at the cooperative markets. This new approach might contribute to reduce the carbon emissions due to fish transportation on land, but a further study would be needed to quantify the associated Footprint savings.

[14] Please refer to Galli et al., 2012 (see https://www.sciencedirect.com/science/article/abs/pii/ S1470160X11001889) for a comprehensive definition of the differences between the carbon Footprint component of the Ecological Footprint methodology (which refers to the area needed to sequester human induced CO_2 emissions) and the "Carbon Footprint" methodology (which tracks the amount – in kg – of emitted CO_2 and other GHGs).

[15] https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf

Figure 6 shows the results of the Carbon Footprint analysis for all the 17 boats and the weighted average, broken down by Scope emissions. The weighted average Carbon Footprint across the 17 boats is 9.08 kg CO_2 kg^{-1} of fish landed, ranging from 2.40 (Boat #1 in Catalunya) to 72 (boat #1 in Sicily) kg CO_2 kg^{-1}. Scope 1 results the prominent contributor to the total Carbon Footprint, representing 86% on average; Scope 3 is the second driver contributing 14% on average, while Scope 2 emissions are negligible (≈0.2% of the total).

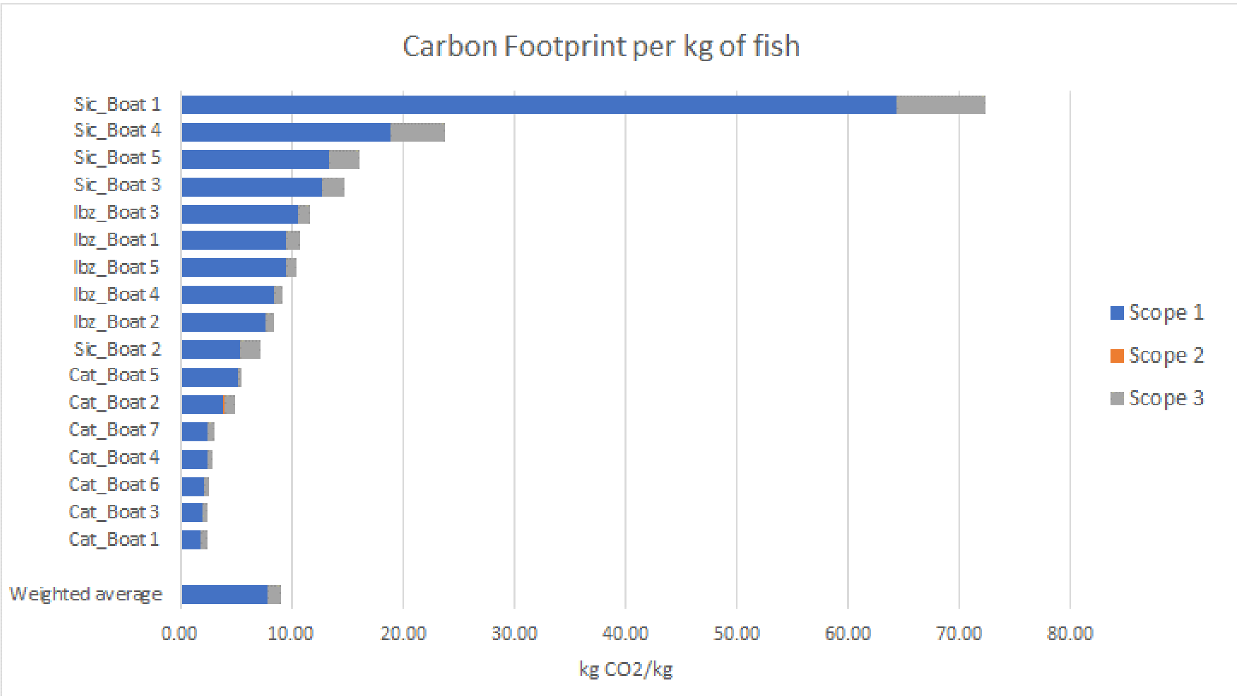

Figure 6. Carbon Footprint of the 17 small scale fisheries broken down by Scope emissions of GHG Protocol. Boats are ordered from the largest to the lowest total value of Carbon Footprint.

Since the fuel consumption of boats is the primary driver, Carbon Footprint results reflects the same pattern as the carbon Footprint component of the Ecological Footprint and the 17 boats rank in the same order (see Figure 3). Boats in Sicily position in the higher end of the overall range of Carbon Footprint results except for Boat #2, whose total result is 7.20 kg CO_2 kg^{-1}, 26% lower than the average. This might be due to one of the smallest area navigated across all boats (3 $miles^2$) to fish about 2500 kg of fish of a relative low trophic level (anchovies and pilchards only), which results in a relative low fuel consumption (2 l kg^{-1}).

Similar to the carbon Footprint component (see section 4.1.2), boats in Catalunya rank in the lower end of the Carbon Footprint results. This could be due to a combination of total fuel consumption with the total catch of the boats, which results in the lowest fuel consumption per kg of catch across all 17 boats (from 0.7 to 2.0 l kg^{-1}) despite some of the boats have the largest area navigated per kg of catch (mostly boats #7, #2, #4 and #6).

Finally, all boats in Ibiza fall in the middle-high range of the Carbon Footprint results, as they go from 8.46 to 11.43 kg CO_2 kg^{-1}, which corresponds to -7% to +30% the total average value. The fuel efficiency of boats in Ibiza goes from 2.9 to 4.0 l kg^{-1} with an area navigated from 0.007 to 0.008 $miles^2$ kg^{-1}.

It should be noted that this carbon analysis ignores the non-carbon impact of small-scale fisheries, as well as any connections to earth's regenerative capacity made possible by measurement in global hectares. However, it has been included given the recent increased use of the Carbon Footprint indicator in studies related to fishing activities, which may allow for comparisons with the results obtained in our analysis. To start, we suggest to look at 3 studies that may have relevant results for comparison (but others may be found in literature):

- Aragao et al. (2022) focuses on the fishing of hake (merluccius spp) and analyses the Carbon Footprint of its entire supply chain
- Parker and Tyedmers (2014) analyses the fuel consumption of global fishing fleets resulting in an extensive dataset that combines the fuel use intensity with species caught, gear types, and Regions of fishing activity
- Seafish brief report (2008) evaluates the GHG emissions associated with the fishing activity of various species from the point of capture to the output as seafood products from processing factories

Conclusions

The analysis of the Ecological Footprint of 17 small-scale fisheries located in 3 different pilot sites (Catalunya, Ibiza and Sicily) across the Mediterranean Basin showed that on average 92% of the total Ecological Footprint values is caused by the species of fish that boats/fishers decide to target (57%), which might also play a role in determining the fuel consumption needed to run the boats during the fishing activity (35%). Man hours needed for the activities at sea and onshore (5% and 1% respectively) and the transportation to the market (2%) were found to play a minor role in the Ecological Footprint of the boats investigated in our 3 pilot areas.

It thus appears that, in order to reduce the Ecological Footprint of Small Scale Fisheries, it is necessary to reconsider the targeted fish species (i.e. their trophic level and the level of by-catch associated) as well as the type of gear used. Also, fishers and consumers should recognize that common fishes with the highest economic value are also those with the greatest impact on the marine ecosystems, whose fishing also causes the highest CO_2 emissions.

It could be inferred that fuel consumption by each boat likely depends on the area navigated during each fishing day, which might in turn be influenced by the type of gear used on boats; while this seems a reasonable assumption, we realized that limitations in the data collection performed via the surveys we have designed do not allow us to observe a clear pattern in this sense in our database (See Table 8). As such, although fuel intensity (liter per unit of catch) in industrialized fleets is – according to Parker and Tyedmers (2014) – likely associated with the combination of fish species and gear type, the same conclusion could not be inferred for the small-scale fisheries in our study due to lack of data.

Overall, small-scale fisheries in the pilot site of Catalunya (Spain) result with the lowest Ecological Footprint values compared to the boats in the other pilot sites. These boats fish mainly species with low trophic level – although the fishing ground component might be underestimated due to the limitation of the quantitative analysis to the top 5 species – and they have a lower fuel use intensity (liter kg^{-1}) than all other boats, which results in a lower carbon Footprint component of the Ecological Footprint.

Finally, as carbon emissions are gaining more attention and in line with the overall efforts towards a decarbonization of all industries at European level (e.g., European Green Deal), the pilot sites tested for the EF analysis and the wider small-scale fisheries community could benefit from being informed on energy-efficient practices as well as existing off-the-shelf solutions to shift towards greener sources of energy to fuel their fishing activities.

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Annex 1 – survey to collect data

Survey for the Small Scale Fisheries System

Data collected on a yearly basis

Year of reference for the following data	

Small Scale Fisheries Outputs																		
Total fish landed in a year						[Species 1]		[Species 2]		[Species 3]		[Species 4]		[Species 5]		[Other Species]	
How much is the quantity of fish landed from the fishing activity?		kg	%	Euro	**Info / comment**	Species Name	% of total fish	Species Name	% of total fish	Species Name	% of total fish	Species Name	% of total fish	Species Name	% of total fish	Other species	% of total fish
Total amount in a year	Total amount of caught fish																
	Amount of fish sold to consumer (out of the total)																
	Amount of fish consumed by the fisher (own consumption) (out of the total)																
	Amount of fish unsold/discarded (out of the total)																
	Amount of unwanted by-catch thrown back in the sea (not alive) before landing (out of the total)																

Fishing boat Inputs		
Human Labor		
Indicate the number of men on boat for fishing and the hours spent on boat		
Average number of fisher on the boat		
Number of hours spent on the boat per fisher		

Vessel used			
Provide the following information regarding the boat used for fishing			
Is there any fishery that don't require a boat to be carried out?	[Yes/no]		
	Which one?		
	period of time in that fishey		
Dimension of the boat	Length (meters)		
How much of each fuel is consumed?		[liters per year]	[€ spent per year]
	Gasoline		
	Diesel		
	Other specify		
Horsepower of the motorboat	Engine horsepower (real hp)		

Fishing activity							
Provide the following information regarding the fishing activity							
Area navigated for fishing - fishing zone	Area navigated (miles^2)						
Indicate the fishing gears most frequently used on the boat		1st gear	2nd gear	3rd gear	4th gear	5th gear	Other gear
	name of the gear						
	period in which the gear is used						
Gear used per fish landed Please a X wherever a certain gear type is used to catch the listed species	Main catch	Species 1	Species 2	Species 3	Species 4	Species 5	Other Species
	[Gear 1]						
	[Gear 2]						
	[Gear 3]						
	[Gear 4]						
	[Gear 5]						
	[Other Gear]						
Gear used per by-catch fish discarded back to the sea before landing [X]	By-catch	Species 1	Species 2	Species 3	Species 4	Species 5	Other species
	[Gear 1]						
	[Gear 2]						
	[Gear 3]						

Land activities Inputs (at present date)					
Fish storage					
How is the fish stored once landed?					
Is the fish stored anyhow once landing? (yes/no)					
Type of container		[box/tank with seawater or ice]	[refrigereted container]		[other type]
	type [X]				*specify...*
Average time of storage per basket of fish	[hour]				
Human labor					
Is the landed fish directly sold by the fishers?	[yes/no]				
If yes, how many fishers take care of selling the fish?	[#]				
Average time for selling the entire basket of fish	[hours]				
If not, please explain how is the fish sold	[open question]				
Selling location and transportation					
Where does the fish selling take place?	[type X]	Covered market	Open air market	Direct selling to consumers at the port	
In the case of market place, how big is the selling location	[surface in m2]				
What is the distance between the port and the market place?	Range [x]	<10 km	10<x<60 km	>60 km	
	Known value [km]				
Is the fish transported via a motor vehicle?	[yes/no]				
Does each fisher go individually to the selling location or is there a collective system to transport the fish?	[open question]				
If a motor vehicle used, what is the fuel used to transport the fish	Type of fuel [X]	Gasoline	Diesel	Hybrid vehicle	
Consumers					
On average, what share of consumers purchasing the fish belongs to each of the following categories?	share [%]	Local (within 60 km)	National (more than 60 km)	International (exported)	
If a door-to door delivery system is in place, how much fuel is used for such delivery? What is the average distance?	[yes/no]				
	average distance of the door-to-door delivery km				
	Type of fuel [X]	Gasoline	Diesel	Hybrid vehicle	