The environmental impact of the consumption of fishery and aquaculture products in France

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Abstract

In the context of climate change, diet is a key driver of environmental impacts. Previous research has emphasized the environmental benefit of increasing consumption of fishery and aquaculture products (FAPs) in Europe. However, increasing the proportion of FAPs in consumer diets could also lead to a transfer of environmental damage from earth to sea. It is thus important to evaluate the environmental impacts of FAPs on marine ecosystems globally. For that purpose, an original database characterizing the origin of FAPs consumed in France has been constructed, and matched to indicators of environmental impact. Use of the database revealed that the FAPs in the French diets (1.7 Mt live weight) had a corresponding primary production required (PPR) worth 1,252 Mt, with an impact per ton of product live weight worth 2,622 kg CO_2 eq. for climate change, 18 kg PO_4^{3-}eq. for eutrophication, and 26,604 MJ for energy use. Some heterogeneity across species was found, implying that the species composition of the FAPS consumed had a strong influence on environmental footprint. Furthermore, production methods also substantially affect global impact. The results show that, among FAPS consumed in France, trawled crustaceans and farmed shrimps or prawns are the greatest contributors to global warming (27,800 and 13,344 kg CO_2 eq. per ton live weight, respectively), despite good performances regarding trophic level based ecosystem indicators (a PPR of 3 and 9 Mt respectively). Shellfish register the smallest footprint both globally and at ecosystem level (545 kg CO_2 eq., 1 kg PO_4^{3-} eq., 10,414 MJ, and a PPR of 5 Mt per ton live weight). Our result suggest that, to avoid a transfer of environmental burden from land to sea, policies aimed at promoting consumption of FAPs in European diets should be refined to take account of differential impacts across species, origin and production methods of those FAPs.

1. Introduction

The environmental impact of the food system is a major concern in the context of global environmental change and the biodiversity crisis (IPBES, 2019). Diet-level assessments in several countries such as Sweden (Carlsson-Kanyama and Gonzales, 2009), the U.K. (Macdiarmid et al., 2012), Europe (Westhoek et al., 2014) and France (Vieux et al., 2018) have yielded relevant recommendations to decrease the environmental impacts of food consumption. In particular, decreasing meat consumption has been found to have a positive effect on the state of the global environment, while increasing fish consumption is often considered to generate health and environmental benefits (e.g. in the UK: Scarborough et al., 2014; in Europe: Westhoek et al., 2014; in France: Vieux et al., 2018). Nevertheless, the environmental gains from the increased proportion of fishery and aquaculture products (FAPs) in the European diet raise the possibility that environmental damage will simply be transferred from earth to sea rather than being reduced, as the assessments conducted to date have important limitations.

First, most papers use aggregate indicators to compare the environmental impacts of FAPs and other foods. The most popular method used to propose environmental profiles of the agrifood sector is life cycle assessment (LCA) (Van der Werf et al., 2014). This method proposes a set of environmental objectives that are calculated through the whole product life cycle and allows the comparison of different product performances. Greenhouse gas (GHG) emissions are often low for FAPs (Poore and Nemecek, 2018), but there are important caveats. The contribution of FAPs to global warming is usually compared to that of meat products, considering aggregated categories.

However, the intra-category heterogeneity in climate impact is large for both meat products and FAPs, as documented for the latter category in the French AGRIBALYSE database[1]. Meat production varies from 2.03 kg CO_2 eq. live weight for some chicken to 21.74 for some beef. For FAPs production, the data available in the AGRIBALYSE database show variation from 2.96 kg CO_2 eq. live weight for some trout to 4.43 for some seabass and seabream. Thus, to consider the whole category masks some food-level specificities, which are relevant when seeking options to decrease the environmental impact of the diet. Hence, 74% of the FAPs consumed in the EU originate from wild fisheries (EUMOFA, 2019), and the environmental impact of the FAP production industry depends on the quantity and composition of FAPs consumed. Quantifying the total environmental impact of FAP consumption therefore requires both weighting the environmental impact of each FAP category using detailed consumption data and having detailed environmental data at the species level.

Second, even if FAPs have lower GHG emissions than some meat categories, other environmental impacts should also be considered (e.g., impact of FAPs on the marine ecosystem). Although GHG emissions, which can be evaluated for all foods, are relevant indicators of global warming, the environmental impact of fisheries and aquaculture extends beyond their effect on climate (Carlsson-Kanyama and Gonzales, 2009). The production of FAPs has an impact on the marine resources, and more generally on the whole ecosystem structure and functioning, either directly (fisheries) or indirectly (aquaculture of carnivorous species), through the catching of wild resources. The impact will differ depending on the species' level in the food web. Furthermore, fish production affects ecosystems through the choice of fishing gear, causing large bycatch or seabed damage in some cases (Jennings et al., 2001). To evaluate accurately the environmental impact of FAPs, it is therefore necessary to

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[1] https://www.ademe.fr/expertises/produire-autrement/production-agricole/passer-a-laction/dossier/levaluation-environnementale-agriculture/loutil-agribalyser

consider the specific indicators that measure the impact of FAPs production on the marine ecosystem (Abdou et al., 2019).

The aim of this paper is to fill the gap in current research regarding the real impact of FAP consumption on the environment, considering both the global impact and marine ecosystems. To this end, we need to establish an understanding of the impact of French FAP consumption. Combining several existing databases and the results of a literature review, an original database mapping the origin of FAPs was constructed and linked to consumption patterns. Furthermore, those origins were linked with ecological indicators that provide information about the ecosystem and global environmental indicators (climate change, eutrophication, and energy demand) commonly used in the literature to evaluate the environmental impact of food. Thus, our measure of environmental impact accounts for differences in species' geographical origin and production method (type of gear, wild versus farmed) through appropriate weighting.

Based on this database, combining the origin of FAPs with ecological and environmental indicators, the various impacts of FAPs are investigated when disaggregated and weighted by consumption category. The relevance of the use of specific environmental indicators for FAPs is also assessed. Finally, the analysis by species sheds light on potential heterogeneity in impact across species and, where this heterogeneity is found, allows refinement of the message communicated to consumers to improve the sustainability of the sector. Altogether, the research draws a current and accurate picture of the environmental impact of FAP consumption in France.

The paper is organized as follows: the next section lays out the data and methodology, while section 3 presents the results, which are discussed in section 4. A short conclusion follows in section 5.

2. Data and methodology

First, an original database mapping the origin of FAPs was constructed by combining trade and production data from several sources, as explained in section 2.1. The trade data describe commercial exchanges in real terms of FAPs between France and other countries. The production data describe the production of FAPs occurring in each country of origin. In a second step, this information on origin was matched with biological or ecological data extracted from FishBase, the international database on fish constructed from the scientific literature (Froese and Pauly, 2019), as explained in more detail in section 2.2.

2.1 Origin of FAPs

For the trade data, the apparent market is used to represent the overall consumption of seafood products in France. All the market data are from year 2012. The apparent market AP (tons of live weight) by species i is constructed as follows:

$$AP_i = PROD_i + IMP_i - EXP_i \qquad (1)$$

where $PROD_i$ is French production for species i, IMP_i is imports of species i in France, and EXP_i is French exports. The production data were gathered from FAO production data through the FishStat J software. These data cover all French production, covering both human and non-human consumption. For import and export data, the Eurostat database Comext (BDD COMEXT - Eurostat, 2019)[2] was used. Forty-five species across 90 partner countries were identified (see table A.1).

To obtain the products' origin, our study was extended beyond the Eurostat data. Those data only identify trading countries, which are not necessarily the countries of production, as trade flows often involve multiple countries. The partner countries listed in the BDD COMEXT

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[2] The FAO data are expressed in live weight, thus Eurostat data have been converted to live weight using the conversion ratio reported on the EUMOFA website (Metadata 2 – Annex 7).

correspond to the last origin of the flow and not to the country of origin. If the product passes through several countries before arriving in France, only the last country will be indicated. In the case of France, BDD COMEXT attributes large amounts of FAP trade to Belgium, Denmark and the Netherlands, although the products are often not produced in those countries.

The identification of transit countries is based on knowledge of the fisheries sector and validation by literature review. The study of the species produced and the composition of imports and exports by each country allows the identification of transit countries. For example, France imported 16,036 tons of shrimp and prawns (live weight) from Belgium, while for Belgian aquaculture production for all species were estimated at 300 tons. In addition, shrimp and prawn imports represent approximately 20% of the value of Belgian FAP imports (350,000 tons) and 28% of the value of FAPs exports (169,000 tons) (EUMOFA, 2020). Therefore, Belgium is identified as a transit country for shrimp and prawns.

After identifying transit countries, assumptions were made regarding the flow of products to trace back the provenance. Thus, when a country from which France imports was identified as a transit country (say country B), the compositions by country of origin of imports and exports of country B were considered as the same. As an example, Belgium imports 18% of shrimp and prawns (in tons of live weight) from Bangladesh so that 18% of shrimp and prawns exported from Belgium to France are assumed to originate from Bangladesh. This assumption is called "linearity of flows". The entire database has been constructed based on this assumption, which makes it possible to estimate the origin of FAPs consumed in France.

It is also evident that France itself is a transit country and for several species exports were higher than production. The Eurostat database does not allow the distinction between FAPs that only go through one country ("transit products") from those that are produced in this country and then exported ("real exports"). To address this issue, linearity assumption was used again. The sum of French production and imports for a given species is labelled "French supply". To evaluate the apparent market, exports are deducted in proportion to the contribution of each country, from the “French supply”. Otherwise the work would not be done on French consumption but on French supply capacity of FAPs. For example, French domestic production of cephalopods accounts for 36.6% and imports for 63.4% of “French supply”. The calculation of the apparent market therefore subtracts from French supply 36.6% of the quantity exported from French production, and the rest of exports (63.4%) from French imports. The total matches with equation (1). In a final step, given that France imports FAPs from multiple countries, imports are split among export countries proportionally to their shares in French imports.

Once the database on the origin of FAPs was constructed using the linearity assumption, the origin could be matched with production methods and production zones. The Eurostat database does not distinguish between wild and farmed products, and has no information on type of gear nor fishing zone of the fleets. To fill the gap, the Scientific, Technical and Economic Committee for Fisheries (STECF) database was used for European countries and data from the literature was used for non-European countries (Among others: htttps://www.fishsource.org/). For all wild fish products the fishing gear used is identified according to the STECF classification. The origin of FAPs database gave us coupled species and countries. For each pair, the fishing gear and the production zone were matched. The assumption of linearity was applied to connect that information with the apparent market in France. For example, Spain produces 43% of seabream through aquaculture and fishes the remaining 57%; thus, exports from Spain to France were assumed to be made up of 43% aquaculture products and 57% fisheries products. The same assumption holds for the zone of fishing and the type of gear used (see table A.2 for gear classification, and table A.3 for an example of matching for seabream).

2.2 Ecological and environmental indicators of FAPs

To evaluate the environmental impact of FAP consumption in France, the database on origin was matched with five ecological and environmental indicators. Those indicators are chosen for their relevance and feasibility of estimation given the data available, and the need for estimation at species level for all trading partners. The selected indicators are the primary production required (PPR), the mean maximum length (MML) and three indicators based on LCA analysis (climate change, eutrophication, and energy demand). The indicators based on LCA analysis are commonly used in environmental impact studies, in particular of entire diets (Masset et al, 2010), but to the best of our knowledge never at such a detailed level for FAPs. The PPR and MML are environmental indicators specific to FAPs but have never been studied in the context of consumption patterns.

The overall impact on the food web was taken into account through the PPR indicator (Pauly and Christensen, 1995):

$$PPR = \frac{Total\ consumption}{[0,1^{TL-1}]} \tag{2}$$

where the total consumption (tons of live weight) is based on the apparent market (database on origin), while the trophic level (TL) is assessed for each species (based on the literature review and Fishbase). More specifically, PPR measures the carbon used by photosynthesis to produce a kilogram of biomass in the population of a given species (Pauly and Christensen, 1995). The TL is a measure of the place occupied by the species in the food chain, starting from 1 for primary producers (seaweeds and phytoplankton), then 2 for their consumers (primary consumers), 3 for their predators (secondary consumers), and so on. Therefore, the higher the TL, the higher the species is in the food chain (ending with top predator), and the larger the primary production from the sea required to sustain FAPs consumption. Value 0.1 used in eq. 2 can be considered as a conventional measure of the ratio of production between a predator and its prey. From the TL and total consumption per species, a global PPR was calculated for the total consumption and a PPR by category of FAPs (see table A.4 for details).

The MML is calculated on average for all the species included in the consumption from the maximum length that each species would reach at the theoretical maximum age the species can live. This indicator can be calculated only for fish and does not depend on the method of production. The higher the MML is, the more the FAPs consumption is based on large and thus usually long-lived and low-turnover species. The TL and maximum length per species have been extracted from the ISSCAAP Troph software of Fishbase (FAO, 2019) and a literature review.

Furthermore, environmental impacts calculated by the LCA method were considered. LCA is a standardized method (ISO, 2006 a,b) conceived to assess the environmental impact of a service or a product all along its life duration, from the extraction of raw material up to its end of life or recycling. In our study, the boundaries of the studied system include the building of vessels and fishing gear, the use of fuel and consumables, and feeds and specific inputs for aquaculture. The fish is delivered to the dock or at the farm gate. Three impact categories were selected. Firstly, the climate change potential (kg CO_2 eq./ton) which takes into account the different GHG emissions and is widely used to compare products. Secondly, the eutrophication potential (kg PO_4^{3-} eq./ton) which takes into account the emissions of reactive nitrogen and phosphorus in the ecosystems. Thirdly, the energy demand (MJ eq./ton) as proposed by Pelletier et al. (2007) for seafood products.

The characterization methods for the calculation of the impact categories refer to the CML2 method for eutrophication and climate change (Guinée et al., 2002) and to the total cumulative energy demand (TCED) method (Frischknecht et al., 2004), which were the main methods used in the literature in LCA of fisheries and aquaculture (e.g. for fisheries: Avadi and Fréon, 2013; for aquaculture: Bohnes et al. 2018).

Several sources for the values of those indicators in FAPs were used, including research results (ICVpêche[3]) and published literature[4]. Four hundred and twenty combinations of species, fishing gear, and production zones were obtained. Some of which are unfortunately not covered by the previous evaluation of the environmental impact of FAPs. In that case, proxies were used to evaluate missing values, based on proximity of species, type of gear, and the fishing zone.

2.3 Principal component analysis of environmental indicators

To analyze further this original database, a principal component analysis (PCA) was used to highlight correlations between indicators. Some global impact indicators, i.e., nonfish-specific, and marine ecosystem indicators, mainly TL-based indicators, which are more specific to the FAPs sector, were used. Statistical individuals are the 420 identified FAPs, i.e., the combination of species, fishing gear, and production zone (see table A.4 for descriptive data). PCA allows us to draw groups of individuals inside our database to highlight some similarity between indicators, if any. Factors of the analysis use climate change, eutrophication, energy demand and TL as active variables, while quantitative and qualitative illustrative variables are the size of the apparent market, the MML (due to the null value for many individuals, as this indicator can only be used for fish), the species and the mode of production. Norwegian lobster and shrimp that are bottom trawled will be used as an illustration, meaning they are not included for calculation. Indeed, for those species, one method of production (trawling) greatly influences the indicators, and thus, the PCA was more relevant without such extreme

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[3] https://www.ademe.fr/expertises/produire-autrement/production-agricole/passer-a-laction/dossier/levaluation-environnementale-agriculture/loutil-agribalyser

[4] The key references used to construct the database on GHG, Eutrophisation and MJ in regards of the type of gear, species and production zone by species, fishing gear, and production zones are: Eyjolfdottir et al., 2003; Ziegler et al., 2003; Thrane, 2004; Hospido et Tyedmers, 2005; Schmidt and Thrane, 2006; Ziegler and Valentisson, 2008; Aubin et al., 2009; Pelletier et al., 2009; Sund et al., 2009; Iribarren et al., 2010; Bosma et al., 2011; Cao et al., 2011; Ramos et al., 2011; Vazquez-Rowe et al., 2011; ERM, 2012; Hilborn and Tellier, 2012; Tyedmers and Parker, 2012; Vazquez-Rowe et al., 2012; Chen et al., 2014; Ramos et al., 2014; Aubin et al. 2015; Driscoll et al. 2015; Pelletier et al., 2015; Santos et al., 2015; Abdou et al., 2017; Aubin et al. 2017.

observations. PCA was performed with the FactoMineR package (Le et al., 2008) of R software (R Core Team, 2018).

2.4. Limitations of the database

During the construction of the database, several issues were raised. First, the identification and traceability of some products are complicated, as a commercial name can match several scientific species. That is the case for scallop (*Pecten maximus, Pecten jacobeus, Aequipecten opercularis, Zygochlamys patagonica, Argopecten purpuratus*), tuna (*Sarda sarda, Thunnus albacares, Thunnus alalunga, Katsuwonus pelamis, Thunnus obesus*, *Thunnus thynnus*), pollock (*Theragra chalcogramma, Pollachius virens*), or rays (*Raja montagui, Leucoraja naevus, Raja clavata, Raja undulata, Raja brachyuran, Raja microocellata, Leucoraja circularis, Leucoraja fullonica*). For those species, the commercial name is identical regardless of the biological species, despite some very different origins, fishing methods, or fish stock state. In this case, the species were weighted using all available information. For the flatfish category, 49% is classified as “undetermined species” in Eurostat (flatfish unspecified); thus, the construction of indicators (origin, fishing zone and type of gear) is based on the remaining apparent market of flatfish (51%). As a result, 25,756 tons are not taken into consideration in this analysis, namely, 1.5% of the apparent market. For some other species, no information was found despite some consumption in France (e.g., for sea spider, whelk, carp, red mullet). However, as those are marginal species in terms of quantity, the closest species was considered as a proxy. Finally, it has proven impossible to identify the origin of some productions (1.8% of the apparent market), with the most important shares of unknown origin being recorded for monkfish (16%).

3. Results

3.1 Characteristics of FAPs consumed in France

The unique database that we constructed allows us to trace products from water to plate and to determine FAPs' origin, production method, and environmental impact. Our database corresponds to overall consumption, covering both consumption at home and in food service establishments (meaning private and public catering) in France. The Kantar household panels database for at-home consumption is used to allow the comparison between overall consumption and at-home consumption. There is a slight difference between at-home and food-service consumption. In particular, shellfish as well as demersal and benthic fish, are consumed relatively less frequently at home than in food service establishments, while the opposite is true for Salmonidae and pelagic fish (fig 1). If the Pelagic species represent more than 30% of at-home consumption in quantity, this amount decreases to less than 19% when taking into account food-service consumption. The FAPs consumed in France originate from 90 different countries. Almost half of the FAPs come from European countries (47% excluding Norway and Faroe Island, 61% with those countries included) including 27% of FAPs coming from France. Thus, FAP consumption in France is largely dependent on commercial trade within and outside of Europe.

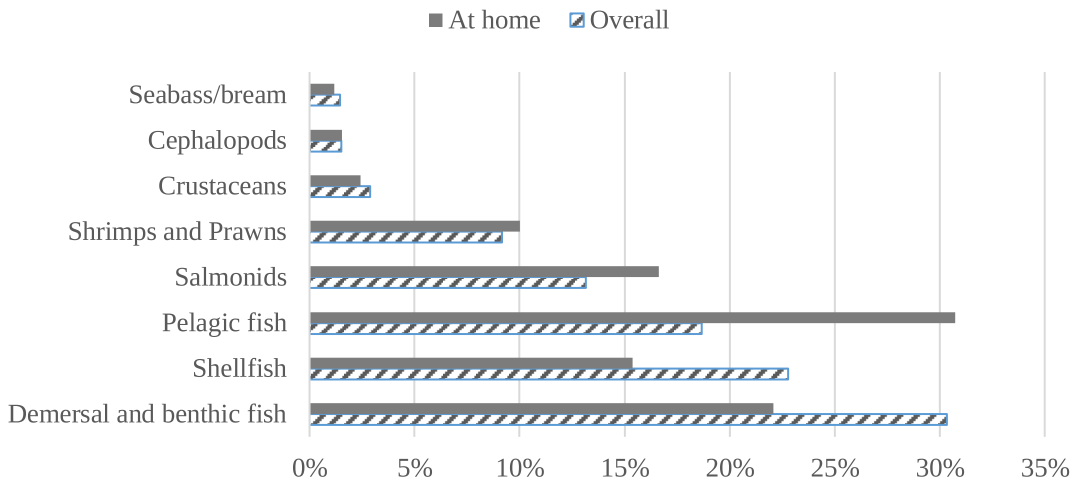

Figure 1 – Consumption shares of categories of FAPs for at-home consumption (full line) versus overall consumption (striped line) in France in 2012, % by species (distribution of quantities - tons of live weight). Own elaboration.

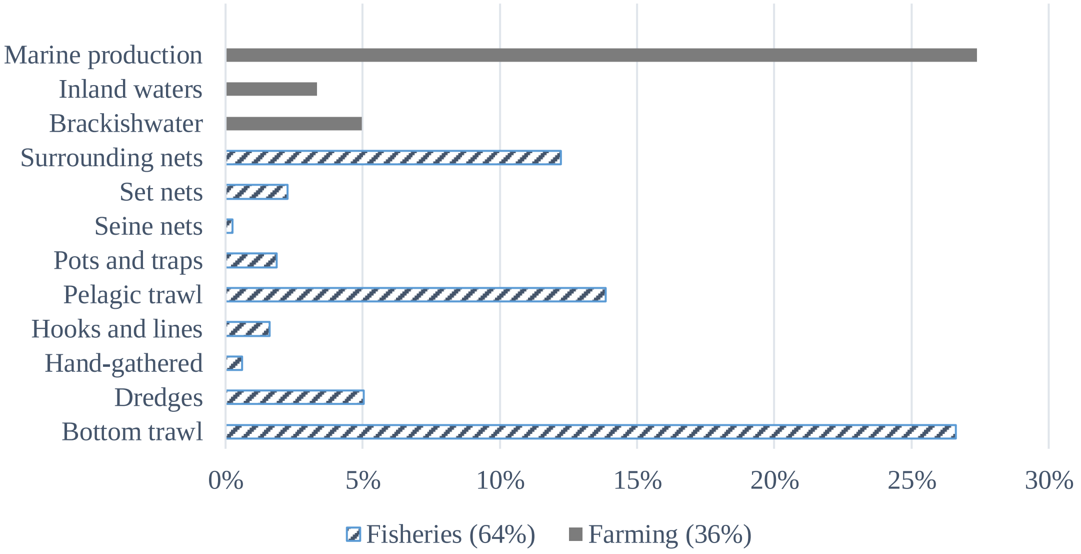

Figure 2 – Methods of production of FAPs consumed in France. Undetermined type of gear represents less than 0.04% (repartition of amount - tons of live weight). See table A.2 for gear categories. Own elaboration.

A majority of consumed FAPs comes from fisheries (64% of live weight, see fig 2), with bottom trawl being the most commonly used fishing gear, followed by pelagic trawl. Active gears[5] account for 58% of FAPs consumed in France, while passive gears account for only 6% of live

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[5] Active gears are mainly trawls and dredges, while passive gears are nets, lines and traps. See http://www.fao.org/3/y3427e/y3427e04.htm

weight. In terms of methods of production for aquaculture, 77% of farmed products consumed in France come from marine production systems (27% of FAPs).

3.2 Ecological and environmental impact of FAPs consumption

3.2.1. Overall impact

First, fish-related indicators allow us to characterize the environmental impact of FAPs consumption with regards to the aquatic ecosystem. While the total French consumption of FAPs is estimated to be approximately 1.7 Mt per year, the PPR to sustain this production is 1,252 Mt per year[6]. This result suggests that the global impact on marine food webs could be much larger than the direct impact of harvesting seafood. The MML of French consumption of fish is 118 cm, which appears to be a very high value explained by the fact that fish consumption is dominated by large species (such as tuna, cod, salmon, etc.).

With respect to a more global indicator of environmental impact, overall consumption contributes to greenhouse gas emissions by an average 2.6 tons of CO_2 eq. per ton of FAPs (live weight at the dock). It is difficult to compare this indicator between species, which do not produce the same amount of edible food. Nonetheless, this indicator gives the global impact of consumption. Based on the French AGRIBALYSE database[7], the climate change for beef systems is between 21.7 and 8.2 tons of CO_2 eq. per ton of live weight, depending on the farm system. Thus, weighted by quantity of consumption, FAPs still remain on average less damaging in terms of global warming impact. Eutrophication reaches 17.8 kg of PO_4^{3-} eq. per ton of FAPs on average, and finally, the fish consumption in France requires 26,599 MJ eq. per ton of FAPs (See table 1).

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[6] In this version of the paper: Value subjects to caution, calculation of NT still ongoing for aquaculture species.

[7] https://www.ademe.fr/expertises/produire-autrement/production-agricole/passer-a-laction/dossier/levaluation-environnementale-agriculture/loutil-agribalyser

Table 1– Characteristics and environmental impact of FAPs consumption in France, consumption data of 2012.

Apparent Market (live weight):	1,745,252 tons
Number of Country of Origin:	90 countries
Top five of country of Origin (%):	France – 27% Norway – 13% USA – 7% UK – 5% Spain – 4%
Ecosystem indicators:	
PPR (Mt/years)	1,252
Mean Maximum length (MML)	118 cm
Life cycle assessment impact categories (/ton of live weight):	
kg CO_2 eq.	2,622 (*Min*: 544; *Max*: 10,343; *s.e.*: 1,774)
kg PO_4^{3-} eq.	18 (*Min*: 0.8; *Max*: 78; *s.e.*: 20)
MJ	26,604 (*Min*: 10,414 **-** *Max*: 132,906 *s.e.*: 10,902)

Own elaboration. (Min and Max for species categories, Standard error of weighted average: s.e.)

3.2.2. Heterogeneity across species

The species categories show a large heterogeneity in terms of their environmental performance. Thus, consumers' choices with regards to species have an impact on the environmental externality generated by FAP consumption, and it is possible to decrease the environmental impact of this consumption by choosing less-impacting species.

In terms of ecosystem indicators, Salmonidae (trout and salmon) and demersal and benthic (including colin[8], cod, flatfish[9], whiting, monkfish, and others demersal and benthic fish[10]) have higher levels of PPR (see table 2), while the lowest levels are observed in crustaceans (excluding shrimp and prawns (S&P)) [11] and shellfish. The MML indicator holds only for fish, emphasizing that all categories are dominated by large long-living species (able to reach a

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[8] *Alaska Pollack, Pollock, Saithe, and Hake.*

[9] *Flounder, Halibut, Plaice, Megrim, Sole, Turbot, Rays, and skates.*

[10] *Haddock, Ling, Dogfish, Redfish, and Bleu grenadier.*

[11] *Crab, Lobster, Norway Lobster, Rock lobster, and sea crawfish*

length larger than 110 cm on average). Therefore, except for the seabass and seabream category (merging smaller species that are both fished and farmed), little difference is observed between categories, suggesting that FAPs fish production systems tend to select large predator species, rather than small prey species. However, in some categories the average may mask large intra-category variations, as is likely the case for pelagic fish where small species, such as herring or sardine, are aggregated with tunas. Consumers thus do not only eat the largest top predators of the sea.

For global environmental indicators, the species do not rank similarly. Despite good ecosystem performances linked to their low TL, the global environmental impact of crustaceans (excl. S&P) per kg consumed is among the most important in terms of climate change and energy consumption. Shrimp and prawns have bad environmental performances, in terms of both climate change and impact on marine ecosystems. Salmonidae do not affect global change more than the average FAP, even in terms of the impact on the ecosystem due to an improved efficiency in fish-meal feeding (Kaushik and Troell, 2010). On the other hand, the shellfish category has the best environmental performance, considering both global and ecosystem impacts. The pelagic category has good environmental performance compared to other categories, in addition to a relatively high PPR level.

Table 2. Environmental impact and origin of FAPs by category.

	Independence (%)			Ecosystem indicators	
	France	UE	UE + Norway and Faroe	PPR (Mt/years)	MML (cm)
Demersal and benthic	21	34	52	758	120
Shellfish	46	66	66	5	---
Pelagic	35	65	67	367	110
Salmonidae	13	28	89	68	131
Shrimps and Prawns	≈0	15	15	20	---
Crustaceans (excl. S&P)	24	65	66	3	---
Freshwater fish	1	5	5	9	118
Cephalopods	37	76	76	14	---
Seabass and seabream	43	96	96	8	72
Overall	27	47	61	1,783	118

	Global environmental indicators (/tons of live weight)			Apparent market	
	kg CO_2 eq.	kg PO_4^{3-} eq.	MJ	Thousands tons	%
Demersal and benthic	2,368	8	27,961	530	30
Shellfish	545	1	10,414	398	23
Pelagic	1,155	3	17,917	326	19
Salmonidae	2,143	48	33,283	229	13
Shrimps and Prawns	10,344	78	34,446	125	7
Crustaceans (excl. S&P)	10,315	34	132,906	50	3
Freshwater fish	5,370	33	19,731	35	2
Cephalopods	6,094	14	47,953	27	2
Seabass and seabream	2,909	65	45,147	25	1
Overall	2,622	18	26,599	1,745	100

Own elaboration.

However, despite bad environmental performances, crustaceans (excl. S&P) account for only 3% of the amount of FAPs consumed in France, while pelagic fish and shellfish account for 19% and 23%, respectively (see table 2). Thus, beyond the per unit environmental impact of consumption of a species, it is fundamental to examine the total quantity consumed. The most important categories of fish consumed in France are the demersal and benthic fish. Most of the fish from this category are caught by bottom trawls (93%), resulting in a high energy demand of 27,962 MJ per ton of product (once weighted by consumption amount). At the same time, the related greenhouse gas emissions rate is slightly lower than the overall average (see table 2). However, while a 10% decrease in CO_2 eq. from crustaceans would reduce the greenhouse gas emissions of FAPs by 1% only, the same decrease for demersal and benthic fisheries would reduce the global emission of greenhouse gases from FAPs by approximately 3%.

It is interesting to examine the link between gear type and environmental impact. The crustacean (excl. S&P) category has the highest level of energy demand (see table 2), but it is mainly due to the bottom trawls used by Norway Lobster (BT-NL) fisheries, which considerably increase climate change (27,800 kg CO_2 eq for BT-NL), eutrophication potential (17 kg PO_4^{3-} eq for BT-NL), and energy demand (325,000 MJ for BT-NL). The substitution of bottom trawls by pots and traps to catch Norway Lobster, for a given amount of crustaceans consumed, would decrease the environmental impact to 5,330 kg CO_2 eq. (- 48%), 17 kg PO_4^{3-} eq. (- 50%) and 71,840 MJ (- 46%), yet trawling accounts for the catch of only 25% of consumed crustaceans. In 2012, pots and traps were used for only 2% of Norway Lobster consumed in France. Thus, gear choice does affect the global environmental impact of fisheries while also strongly determining the impacts on the sea floor, even though it will not change the impact in terms of PPR.

The LCA coefficients used are from the sea to the dock; thus, it is interesting to look at the origin of products for two main reasons. First, transportation of FAPs after landing also has an impact. Shrimp and prawns are already among the worst species in terms of impact as measured by LCA, and this result is reinforced when taking into account transportation, as almost 85% of this consumption originates from non-European countries. In contrast, shellfish products are mostly produced in Europe and are associated with a low global environmental impact. Second, production that takes place in Europe is subject to European regulations, meaning there is more leeway to implement policy to reduce the environmental impact of FAPs.

3.3 PCA results

The PCA results reinforce previous analysis regarding the correlation between climate change and energy demand, and between TL (used to calculate PPR) and eutrophication. The first principal component (PC) (horizontal in fig 3) explains the variance due to "climate change" and "energy demand". Both indicators contribute similarly. The second PC (vertical) explains the variance due to "trophic level" and "eutrophication", both indicators being negatively linked. The composition of the first two PCs can explain 75.52% of the system variance. The points in blue (MML and Quantity (Qty)) correspond to the illustrative variables, not included in the PCA.

Four clusters have been selected by hierarchical analysis (see fig 4). The first cluster (in black on the far left in fig 5) includes 98 products and can be considered the more environmentally friendly cluster. This cluster includes productions by pelagic trawl, dredges and surround nets. The key species are mussels, anchovy, sardines, and clams; these are mainly species with, on average, low TLs (2.9) and environmental impacts lower than the average in terms of eutrophication (5.55), climate change (712), and energy demand (12,397). A convergence for this cluster was found between global impact and marine ecosystem TL-based indicators.

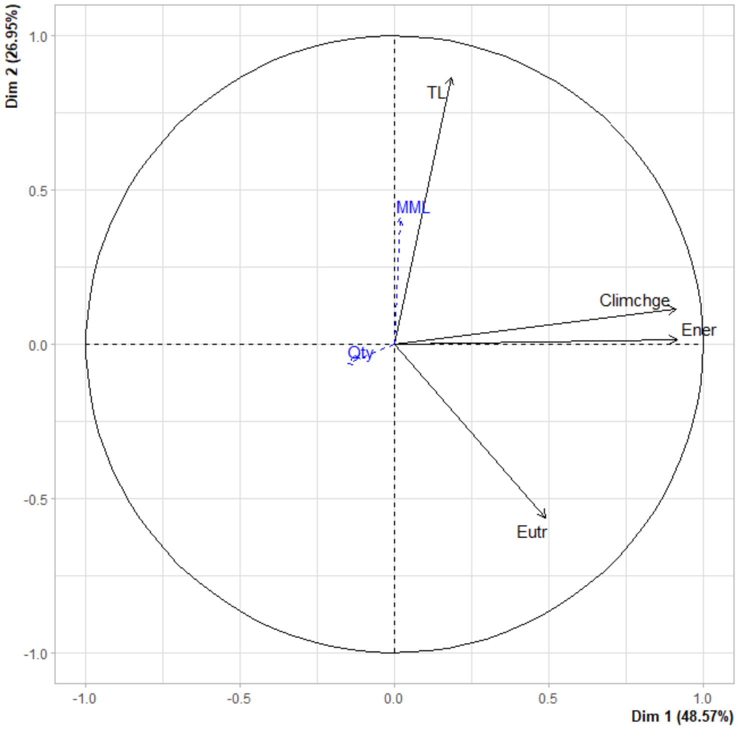

Figure 3 – Graphic representation of PCA. Dim 1 (48.57)/Dim 2 (26.95). n=404. The variables in blue are illustrative. ClimChge: Climate Change potential; Ener: Energy demand; Eutr: Eutrophication potential; MML: Men maximum length; TL: Trophic level.

The second cluster (in red on the far right in fig 4) is the most diverse group, with very heterogeneous production methods for 218 products (52% of the studied population). This cluster represents most specifically the production by bottom trawl, hook lines, and set nets. The key species are ling, rays, swordfish, sole, whiting, and tuna. The global environmental performances (climate change and energy demand) are close to average, but the marine ecosystem TL-based indicators show higher values (TL – 3.97 and MML - 85.8) while the eutrophication values are lower on average (9.46).

The third cluster (in green on the middle right in fig 4) is the aquaculture group, which is composed of 26 products. Unsurprisingly trout, shrimp, seabass, and seabream were found in this group, and these are the key species. This group is marked by a much higher than average level of eutrophication (104 versus 18) and higher than average level of energy demand (51,180). The values are also higher for marine ecosystem indicators.

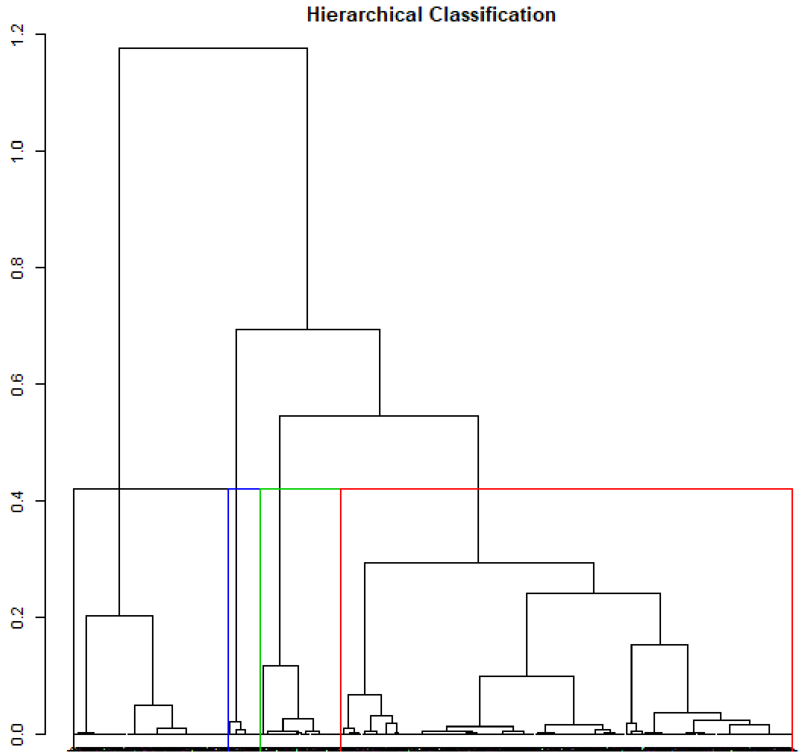

Figure 4 – Hierarchical clustering of the population. Nb of obs.= 404. 4 clusters identified (cluster 1 in black, cluster 2 in red, cluster 3 in green, and cluster 4 in blue).

Crustaceans and cephalopods mainly compose the fourth cluster (in blue on the middle left in fig 4) as it is the group including production by pots and traps. This group includes 62 individuals, with low TLs (2.94) but high impacts in climate change (5,244) and energy demand (68,430).

A fifth cluster can be considered, composed of individuals who are not used for the PCA. This cluster is the production group of shrimp and Norwegian Lobster by bottom trawl and includes 16 observations. The cluster has impacts on energy demand (170,563), climate change (27,800), and eutrophication (77) several times above the average but a TL (2.66) below the average.

While a strong correlation between climate change and energy demand is observed, not convergence is found through clusters between the LCA-based impact and TL-based indicators. If in the larger cluster (2) eutrophication is better than average, the TL-based indicators are the worst, while in other cases, the lower marine ecosystem impact can be associated with higher values for climate change and energy demand (clusters 4 and 5). The only convergence holds for cluster 1, which is mainly composed of species produced using pelagic trawl, dredges and surround nets, in which case, both types of environmental indicators suggest better-than-average performances. Only surround nets and pelagic trawl used to fish tuna do not belong to this cluster. Despite being pelagic species, tuna fisheries worsen the marine ecosystem indicators, although the global environmental indicators are better.

4. Discussion

Our results show that, all other things being equal, changing modes of production for less impacting ones can be an efficient way to reduce the environmental impact of FAP consumption without decreasing the level of consumption. To help consumers to switch to FAPs with less impacting methods of production, both in terms of global impact and ecosystems impact, information is thus fundamental.

The impact of FAP consumption on the ecosystem and at the global environmental level is examined more precisely. The construction of the database allowed us to understand French consumption in terms of the origin (country) and methods of production of the FAPs consumed, together with the related ecological and environmental impacts. Examining the distribution of consumption by species, our database matched national data on French consumption (FranceAgriMer, 2013). The FAPs consumed in France originate mainly from Europe (61% from European countries, including Norway and the Faroe Island), while only 27% are produced domestically. Regardless of the origin, 1.7 Mt (live weight) of FAPs are consumed in France, including 36% from aquaculture. The corresponding PPR was estimated at 1,252 Mt. In terms of impact, this consumption generates on average 2,622 kg CO_2 eq. (Climate change), 18 kg PO_4^{3-} eq. (Eutrophication), and 26,604 MJ (Energy use) per ton of product live weight. Results show that some species have low impact as measured by all the indicators used. It is particularly the case of shellfish. However, no species can be considered the worst performer across all indicators. The PCA results reinforce this view, as although there is strong correlation between climate change impact and energy demand, consistency is not found across clusters between LCA-based impact and TL-based indicators.

Our study only used a limited number of ecosystem indicators, but additional impacts should be considered in the future to clarify the environmental properties of some clusters of FAPs with many heterogeneous environmental impacts not considered in our analysis (e.g., impact on the seabed, or on unwanted or protected species). In addition, our analysis did not consider if fished products are coming from well-managed stocks, as no data are currently available allowing to specify from which fish stock a given product is coming from.

Furthermore, global and marine-specific impacts may differ. Good performances with regard to global warming do not necessary match good performances in terms of TL-based ecosystem indicators. In this situation, it is unfortunately very complex to implement a labeling scheme taking into account all environmental impacts while remaining easily understandable by consumers, and even if only the environmental dimension of sustainability was considered. It is thus paramount to construct the data infrastructure to provide information about environmental impact to consumers together with other management tools to decrease the negative environmental impact of FAP consumption.

5. Conclusion

If the environmental impact of the food system is a major concern in the context of global environmental change and the biodiversity crisis, the environmental gains from increasing the share of FAPs in the European diet are questionable, as the possibility exists of a transfer of impact from earth to sea.

Thus, the policies aimed at raising the sustainability of diets by advocating increases in FAP consumption must be carefully refined. In order to be efficient, rather than treating FAPs as a homogenous group of products, the message towards consumers should differentiate species and fishing/production methods in order to encourage consumption of the less impacting FAPs. This approach reinforces the current trend in the European market to extend the mandatory information on methods of production for all products with FAPs as a major ingredient (MAC, 2020). Since January 2014, the method of production has been a mandatory piece of information on unprocessed prepacked and non-prepacked FAPs. This mandatory requirement should be extended to all FAPs (not only the unprocessed version).

Two demand-side solutions should be jointly implemented to decrease the environmental footprint of FAPs without changing the total amount consumed. First, improving the environmental impact by favoring the less damaging gears and production methods. Second, favoring the consumption of product categories with relatively low environmental footprint.

In pursuit of both objectives, establishing a strong labeling or scoring policy is needed. It should provide consumers with easily understandable information on species, country of origin and method of production for all FAPs. This information is needed regardless of the degree of transformation of the final product. If indeed our objective is for consumers to make the “sustainable” choice, detailed information is required to favor the consumption of less damaging categories. Favoring the consumption of less damaging categories is also necessary to favor changes in the fisheries sector. Indeed, consumers are willing to pay more for FAPs produced with relatively less impacting production methods (Menozzi et al., 2020) and improved environmental performance (Salladarré et al., 2018).Thus, using labels or a scoring of sustainability performances to inform the consumer increases the economic incentive for industry to adopt less damaging gears and methods of production.

Nevertheless, consumers' behavior in terms of substitution between species needs to be addressed to implement efficient policy. Preferences in terms of FAP consumption may influence the effectiveness of a policy. If favored species regarding environmental impacts are not considered by the consumer as substitutes for more damaging species, substitution will not happen, and no improvement will be observed in the market. To address this issue, we are currently working to match our database with a system of demand for FAPS estimated with the Kantar Database (real purchase database). Matching our original database with demand elasticity will allow us to take into account consumer preferences and thus recommend efficient policy to improve the environmental impact of FAP consumption.

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Appendix:

Table A.1: Trade with France: Species, partner countries, and zone of fishing (own elaboration)

Countries	Angola, Argentina, Armenia, Australia, Bahamas, Bangladesh, Belgium, Belize, Brazil, Canada, Chile, China, Colombia, Costa Rica, Croatia, Cuba, Cyprus, Denmark, Ecuador, Estonia, Faroe islands, Fiji, Finland, French Polynesia, French Southern Territories, Gambia, Germany, Ghana, Greece, Greenland, Guatemala, Guyana, Honduras, Iceland, India, Indonesia, Ireland, Italy, Ivory Coast, Jamaica, Japan, Kenya, Korea (Republic of), Latvia, Lithuania, Madagascar, Malaysia, Maldives, Mauritania, Mexico, Morocco, Mozambique, Namibia, Netherland, New Caledonia, New Zealand, Nicaragua, Nigeria, Norway, Oman, Panama, Papua New Guinea, Peru, Philippines, Poland, Portugal, Russia, Senegal, Seychelles, Singapore, Slovenia, South Africa, Spain, Sri Lanka, St Pierre and Miquelon, Suriname, Sweden, Taiwan, Tanzania, Thailand, Tunisia, Turkey, Uganda, United Kingdom, United States of America, Uruguay, Venezuela, Vietnam, Yemen, Zimbabwe, Indeterminate
Species	Alaska Pollack, Anchovy, Blue grenadier, Cephalopods, Clam, Cod, Crab, Dogfish, Flounder, Freshwater crayfish, Freshwater catfish, Haddock, Hake, Halibut, Herring, Jack and horse mackerel, Ling, Lobster, Mackerel, Megrim, Monkfish, Mussel, Nile perch, Norway lobster, Oyster, Plaice, Pollack, Rays and skates, Redfish, Rock lobster and sea crawfish, Saithe, Salmon, Sardine, Scallop, Seabass, Seabream, Sea urchins, Shrimps and prawns, Sole, Swordfish, Tilapia, Trout, Tuna, Turbot, Whiting,
Zone of fishing	Atlantic Iberian waters; Barents Sea and Norwegian Sea; Bay of Biscay; Bay of Biscay and Atlantic Iberian waters; Belts and sounds; Black Sea; Bristol Channel; Cantabrian Sea and Atlantic Iberian waters; Celtic Sea; Celtic Sea and West of Ireland; Celtic Sea, West of Ireland, English Channel and Bay of Biscay; Eastern Central Atlantic; Eastern Central Pacific; Eastern Channel; Eastern English Channel; Eastern Indian Ocean; English Channel; Faroe grounds; Faroe Plateau Ecosystem; Gulf of Lions; Iceland and East Greenland; Iceland grounds; Indian Ocean; Irish Sea; Irish Sea, Celtic Sea, English Channel, southern North Sea; Lake Victoria; Mediterranean and Black sea; Mediterranean Sea; NE Atlantic/N Stock; North Pacific; North Sea; North Sea and West of Scotland; North Sea, Eastern channel and Skagerrak; North Sea, Skagerrak and Kattegat; Northeast Atlantic; Northeast Pacific; Northern Adriatic; Northern stock; Northwest Atlantic; Northwest Pacific; Norwegian Sea and Barents Sea; Pacific southeast; Porcupine Bank; Portuguese waters; Rockall; Skagerrak and Kattegat; Southeast Atlantic; Southeast Pacific; Southern Celtic Sea and the English Channel; Southern stock; Southwest Atlantic; Southwest of Ireland; Southwest Pacific; West of Ireland; West of Scotland; Western Central Atlantic; Western Channel; Western English Channel; Western Indian Ocean

Table A.2 – Gear classification (source: STECF, 2019)

Code STECF	Description STECF	Gear Paper
PS	Purse seines	SURROUNDING NETS
LA	Lampara nets	SEINE NETS
SDN	Danish seines	
SSC	Scottish seines	
SPR	Pair seines	
TBB	Beam trawl	BOTTOM TRAWL
OTB	Bottom otter trawl	
PTB	Bottom pair trawl	
OTT	Otter twin trawl	
OTM	Midwater otter trawl	PELAGIC TRAWL
PTM	Pelagic pair trawl	
DRB	Boat dredges	DREDGES
DRH	Hand dredges	
HMD	Mechanised dredges including suction dredges	
GNS	Set gillnets (anchored)	NETS
GND	Driftnets	
GNC	Encircling gillnets	
GTR	Trammel nets	
GTN	Combined gillnets-trammel nets	
LHP	Handlines and pole-lines (hand-operated)	HOOKS AND LINES
LHM	Handlines and pole-lines (mechanized)	
LLS	Set longlines	
LLD	Drifting longlines	
LTL	Troll lines	
FPO	Pots	POTS AND TRAPS
FYK	Fyke nets	
FPN	Stationary uncovered pound nets	
HAR	Harpoons	OTHER GEARS
SV	Beach and boat seine	
SB	Beach seines	
LNB	Boat-operated lift nets	
LNS	Shore-operated stationary lift nets	
NK	Gear not know or not specified	INDETERMINATE
NO	No gear	
MIS	Miscellaneous Gear	

Table A.3 – Origin of seabream matched with production methods and production zones. (Own elaboration).

Country (**Contribution to AP in %**)	French **AP** (in tons)	Source of supply†		Gear/Production source†		Stock/Area†	
Greece (43%)	6,038	Aquaculture (100%*)	6,038	Marine production (100%)		Greece	6,038
France (36%)	5,077	Aquaculture (23%)	1,183	Marine production (100%)		France	1,183
		Fisheries (77%)	3,894	Bottom trawl (33%)	1,285	North Sea (33%)	424
						Northeast Atlantic (43%)	553
						Gulf of Lions (24%)	308
				Pelagic trawl (31%)	1,207	Northeast Atlantic (84%)	1,014
						North Sea (15%)	181
						Gulf of Lions (1%)	12
				Set nets (20%)	779	Gulf of Lions (32%)	249
						Northeast Atlantic (63%)	491
						North Sea (2%)	16
						Corsica Island (3%)	23
				Surrounding nets (7%)	273	Gulf of Lions (29%)	79
						Northeast Atlantic (71%)	194
				Hooks and line (7%)	273	Gulf of Lions (24%)	65
						Corsica Island (4%)	11
						North Sea (1%)	3
						Northeast Atlantic (71%)	194
				Seine nets (2%)	78	North Sea (44%)	34
						Corsica Island (4%)	3
						Northeast Atlantic (52%)	40
Spain (18%)	2,625	Aquaculture (43%)	1,142	Marine production (100%)		Spain	1,142
		Fisheries (57%)	1,483	Bottom trawl (54%)	801	Mediterranean (10%)	80
						Northeast Atlantic (90%)	721
				Seine nets (32%)	475	Mediterranean (6%)	28
						Northeast Atlantic (94%)	446
				Set nets (10%)	148	Northeast Atlantic (50%)	74
						Mediterranean (50%)	74
				Hooks and line (4%)	59	Northeast Atlantic (70%)	42
						Mediterranean (30%)	18
Turkey (2%)	231	Aquaculture (100%)	231	Marine production (100%)		Turkey	231
Italy (1%)	207	Aquaculture (100%)	207	Marine production (100%)		Italy	207
Total (100%)	14,178		14,178				14,178

† The tons of live weight correspond to the French apparent market (AP), while the percentage corresponds to the composition of the national production for every country studied.

Reading note: France accounts for 36% on AP, and 77% of French seabream production comes from fisheries, formed at 33% of bottom trawl.

Note: 688 tons are not taken into account: either the country of origin is unknown or ~~we do not find any~~no information regarding production were found.

** There are some fisheries of seabream in Greece, but exports are based only on farmed seabream.*

Table A.4. TL, PPR and MML by species, weighted by consumption share of each species.

Species	TL	PPR (thousand tons/years)	MML (cm)
Salmonidae	**3.47**	**68,013**	**131,16**
Salmon	*3.48*	*59,425*	135
Trout	*3.42*	*8,588*	108
Pelagic	**3.73**	**366,708**	**110,10**
Tuna	*4.38*	*324,922*	212
Mackerel	*3.65*	*21,821*	51
Sardine	*3.05*	*8,000*	28
Herring	*3.19*	*6,232*	42
Others	*3.28*	*5,733*	33
Crustacean	**2.70**	**2,882**	
Crab	*2.60*	*1,100*	
Lobster	*3.00*	*521*	
Norway Lobster	*2.60*	*510*	
Rock lobster and sea crawfish	*3.20*	*750*	
Shrimps and prawns	**3.21**	**20,266**	
Freshwater species	**3.38**	**9,419**	**118,35**
Freshwater catfish	*3.15*	*2,422*	125
Others	*3.59*	*6,997*	112
Shellfish	**2.10**	**5,008**	
Mussels	*2.10*	*2,091*	
Scallop	*2.10*	*1,885*	
Oyster	*2.10*	*972*	
Others	*2.10*	*60*	
Demeral and bentic fish	**4.05**	**757,888**	**119,70**
Colin	*3.8*	*148,722*	87
Cod	*4.42*	*407,850*	186
Flatfish	*3.58*	*10,350*	76
Whiting	*4.37*	*33,672*	63
Monkfish	*4.47*	*83,522*	150
Others	*4.03*	*73,772*	99
Cephalopods	**3.73**	**14,248**	
Seabass/bream	**3.44**	**7,823**	**71,64**
Seabream	*3.26*	*2,705*	57
Seabass	*3.68*	*5,118*	92
Total		**1,252,256**	

Table A.5 – Quantitative data description for ACP (own elaboration)

Parameters	Min.	1st Quartile	Median	**Mean**	3rd Quartile	Max.
Quantity (Amount consumed in tons of live weight)	3.0	210.5	681.5	**4130.4**	2499.0	143616.0
Climate change (kg CO_2 eq.)	10	17.59	2804	**3662**	3840	27800
Eutrophication (kg PO_4^{3-} eq.)	-0.74	5.89	7.30	**17.88**	11.2	150.0
Energy demand (MJ)	2175	24078	37788	**43489**	54656	325000
Trophic level	2.10	3.05	3.60	**3.494**	4.20	4.50
Mean Maximum Length	0	0	0	**53.8**	92	455