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Is the Ecological Footprint Enough Science for Algerian Fisheries Management?

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Abstract: There is an urgent need to understand the fishing sector, given the uncertainties and the importance it has gained due to the potential of Algerian waters. The main objective of this paper is to establish a diagnosis of the demand for fishery resources at Algiers fishing ports and provide additional information regarding energy use at a reduced scale. According to the estimated ecological footprint (EF) of fishery production (EFf), Algiers fishing is in the status of ecological surplus, as the demand for fisheries production averages 15,338.49 gha compared to more than 108 thousand gha of biologically productive fishing area. In addition to this overall output, this metric indicates each species' primary production requirement (PPR), which could help to restructure the fishing effort based on the stock's condition. For the energy component, the fuel consumption and greenhouse gas (GHG) emissions expressed in metric tons of CO_2 were used to estimate the required area for carbon sequestration, valued roughly at 500 gha. The latter is a reference state and remains approximate because it was derived from unofficial data provided by the fishers. This study demonstrated that EF is informative and could be used for resources management. However, it must be built on precise data and supported by further analysis.

Keywords: ecological footprint; sustainable fisheries; Algiers port; Algerian coast

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1. Introduction

Fisheries resources are considered heritage that must be preserved to achieve self-sufficiency [1]. Algeria benefits from a marine frontage of more than 1200 km, a continental shelf of approximately 13,700 km^2, and roughly 9.5 million hectares dedicated to fishing [2–6], demonstrating the country's potential for fisheries production. Indeed, Algeria considers the fishing sector a vital component of the country's economic growth.

It is essential to emphasize that coastal fishing, which generally targets small pelagic fishes, accounts for the bulk of fishing in Algerian waters and the Mediterranean [2,6–9]. However, this production hardly exceeds 100 thousand tons per year. Algeria's yearly consumption of fish per capita does not exceed 5 kg, remaining relatively low compared to the Mediterranean average, estimated at 20.5 kg [10]. Moreover, numerous Algerian researchers indicate that a number of the fish stock, including target species such as *Boops* (Bogue), *Trachurus trachurus* (Atlantic horse mackerel), *Pagellus acarne* (Axillary seabream), *Mullus barbatus* (Red mullet), are in good [1,3], or stable [11] condition, excluding a stat of overexploitation. On the other hand, others attest that specific Algerian regions are suffering from overfishing, related either to fish populations such as the Common Pandora [12] or to space, especially the narrow continental shelf [5].

To these uncertainties is added the country's location in the Mediterranean Sea, where 78% of the stocks assessed, including stocks composed of priority species are considered overexploited [13]. Other studies, such as the global network of the ecological footprint (EF), classify Algeria as a nation in ecological deficit [14]. The EF measures the human demands on natural resources, expressed as the amount of land required to sustain their use, and allows for the assessment of the human impact on the ecosystems [14–16]. In particular, the EF approach was also applied to estimate the primary production necessary (PPR) to sustain the fisheries' catches [17]. Many studies considered the impact of this activity on the marine environment, namely: quantification of the resources associated with aquaculture feed, revealing that 989 ha is expected for 100 GJ of blue whiting products (meal and oil) [18]; the estimation of the capacity in terms of surface area necessary to sustain shrimp culture [19]; the evaluation of the interaction between natural ecosystem and fishing activity, highlighting that, during 2012, Italian fisheries catch required about 7 million tons of carbon in terms of PPR [20]. Unlike the original model built on the final consumption [15,21], this work applies a component approach [22–25] to consider all the possible impacts generated by fishing at a reduced scale. For instance, the EF of marine products and energy use during fishing trips. The inclusion of energy usage to the component approach is advantageous since it involves developing net energy flows by activity type and the associated emissions, especially since the government is compelled to implement this form of inventories as a member of the Paris Agreement [26]. The main objective of this study to draw an overview of fishing in the study area and determine whether the ecological deficit in this sector should be asserted or rejected. Secondly, the study evaluates the contribution of this tool as a policy driver.

2. Methodology

The study area comprises mainly the four fishing ports of Algiers, which is the capital of Algeria. The main port is the national port to fishing and trade (Alger), two other ports are dedicated for fishing (El Djamila, Rais Hamidou), and the fourth is a safe harbor for fishing vessels (El Marsa). The study considers data from 2015, during which about 274 vessels were distributed over Algiers ports [27], accounting for only 5% of the country's fleet, and provided about 1777 direct and indirect jobs in the fishing sector.

This study follows a bottom-up model based on the component ecological footprint (EF) approach [22,23] considering both fish biomass removal from the natural environment and energy use associated with fishing at a reduced scale. The EF calculations are based on data collected locally by the entities in charge of fishing management, namely, the Ministry of Fishing and Fisheries Production (MPRH), The Regional Directory of Fishing and Fisheries Production (DPRH), and the National Company for Ports Management (SGPP).

Information such as fishing grounds extent, fishing fleet types, and fuel consumption have been collected. In addition, exchanges with fishers in the three fishing ports provided supplementary information for the duration of fishing trips, fishing trips number, and fuel consumption. The data collected for each component of the system and their description are resumed in Table 1.

Table 1. Data collection for the assessment of the ecological footprint of fishing in Algiers ports in 2015.

	Component	Data	Units	Source
Material	***Total Fisheries landing***	**15,338.49**	tons	DPRH
	Demersal Fishes	1198.09		
	Small Pelagic Fishes	13,467.2		
	Large pelagic Fishes	172.58		
	Crustacean	413.32		
	Molluscs	87.27		
Energy	***Total Trips per year***	**1080**		Fishers DPRH, SGPP
	Total Vessels	**275**		
	Trawlers	51		
	Sardine Vessels	143		
	Small-scale Vessels	81		
	Total Fuel Consumption	$\mathbf{1.14 \times 10^4}$	Cubic Meters	Fishers

Note: The bold indicates the toal amount.

2.1. EF Calculation

This study assesses two types of land that support fishing activity and fisheries. The first land considers fisheries production and is called EF of fishing (EFf). The second land focuses on the amount of CO_2 emission generated from fishing vessels and is addressed as the EF of Carbon sequestration (EFc).

The EFf reflects the marine and inland waters required to generate the primary production needed to support aquatic species (fish and seafood) catches [15–17,28–30]. The assessment of the EF of fishing grounds is based on the estimate of the annual primary production required (PPR) to maintain a harvested aquatic species present in the fishing catch (Equation (1)), considering the species' average trophic level [16,17].

$$PPR = CC \times DR \times (1/TE)^{(TL-1)} \quad (1)$$

where: CC: carbon content of wet-weight fish biomass; DR: discard rate for bycatch; TE: transfer efficiency of biomass between trophic levels; TL: trophic level of the fish species in question.

The EFc reflects the capacity of forest ecosystems to absorb the fraction of anthropogenic CO_2 emissions generated by a product or an activity, and which has not been absorbed by oceans [28,30,31]. This waste form is assumed to be absorbed mainly by forests due to a lack of data regarding alternative ecosystems that may absorb CO_2 emissions [17]. The EFc uses the annual carbon uptake of a hectare of average world forest [17,28], to convert CO_2 emissions into the required land to absorb it, following Equation (2).

$$EF_C = P_{CO_2} \times (1 - Socean) \times Y_c \times EQF \quad (2)$$

where: Y_c: Carbon Sequestration Yield calculated using C to CO_2 Ratio; P_c: Emissions of Carbon in $MtCO_2$/Year; S_{ocean}: Ocean Sequestration Rate; EQF: Equivalence Factor given by Global Footprint Network (GFN) in gha/wha.

EF is expressed in global hectares (gha), a standardized unit that captures the average productivity of the world's biologically productive lands and water areas in a particular year [17,32]. This measurement unit describes hypothetical hectares derived from physical national (nha) or world hectares (wha).

2.2. Fishing Zones Mapping

This paper additionally describes the biocapacity (BC) of the study area. The Global Footprint Network (GFN) defines this metric as "*The capacity of ecosystems to produce or regenerate biological resources consumed and to absorb waste material produced by a given population, under present management schemes and extraction technologies*" [33]. It should be recognized that, at the national level, the national area accessible for fishing is estimated at 9.5 million hectares. However, it is difficult to define a similar area locally, especially considering that neither fishers nor marine species are limited by the administrative borders of the research area. Furthermore, in Algeria, there are no "fishing grounds," but rather "fishing waters", which makes fishing zones diverse and extensive, and fisheries production primarily governed by the fishing gears [5]. Consequently, it was necessary to map the different zones used by fishers to estimate, roughly, the available fishing area (Figure 1).

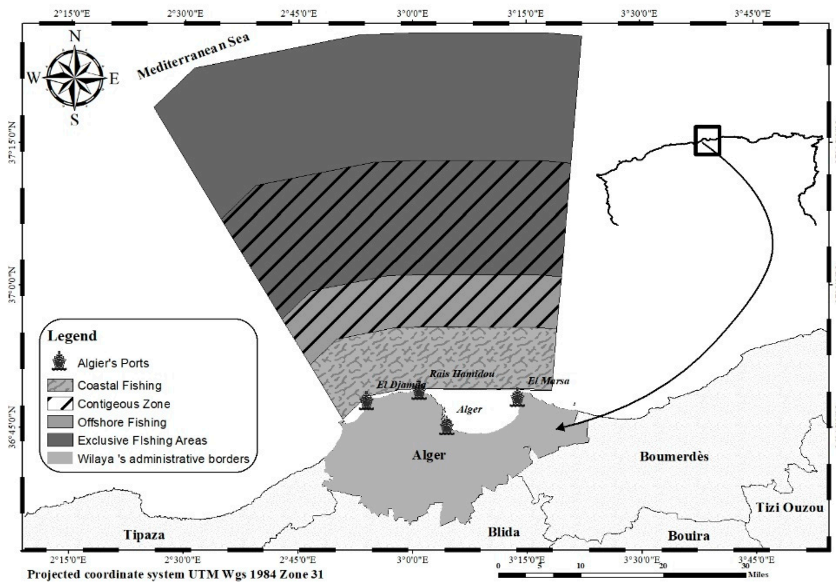

Figure 1. Fishing zones delimitation in the study area.

The first line that defines the different zones represents the baselines of bay closure. Its coordinates are described in Decree N° 84-181 (*Decree No. 84-181 defining the baselines from which the width of the maritime zones under national jurisdiction is measured*). Similarly, the length and distribution of the different zones was defined according to the national legal texts: The article 30 of law 01-11 (*Law N° 01-11 on Fisheries and Aquaculture*), the decree N° 18-96 (*Presidential Decree N° 18-96 of 2 Rajab 1439 corresponding to 20 March 2018, establishing an exclusive economic zone off the Algerian coast*), the Executive Decree N° 96-121 (*Executive Decree N° 96-121 of 6 April 1996, setting the conditions and modalities of Fishing*), and the Convention on the territorial waters and the contiguous zone. Thus, the study considers the following two fishing areas:

- Coastal fishing, which covers an area that does not exceed 6 miles.
- Offshore fishing, which occurs beyond the coastal fishing zone and does not exceed 12 miles.

3. Results

3.1. Ecological Footprint of Fishing (EFf)

The study considered port fishing landings of 70 species from different groups ranging from small to large pelagic fishes, demersal fishes, crustaceans, and mollusks. Results are defined based on species-specific primary production requirements (Table S1). The total EFf of the study area reached a total of 15,338.49 gha for more than four thousand tons of fisheries production in 2015.

Based on descending order of yield, *Sardinella aurita* (Round sardinella), *Sarda* (Atlantic bonito), *Sardina pilchardus* (Sardine), *Trachurus* (Atlantic horse mackerel), *Xiphias gladius* (Swordfish), *Sphyraena spp* (Barracudas), and *Engraulis encrasicolus* (European anchovy) represent 91% of Algiers' landings. Round sardinella production yield equals 0.27 tC/ha/year, accounting for 37% of the total EFf of marine production in Algiers, dominating the fisheries landings. Despite their small proportion in the fisheries production, large pelagic fish such as bonito, swordfish, and little tunny are associated with larger EFf, due to their higher trophic level, and thus the primary production required for their harvest.

3.2. Ecological Footprint of Carbon (EFc)

According to the DPRH data, Algiers ports hosted around 275 boats in 2015. Small scale vessels represent over half of the region's fleet. The EFc calculation is built on CO_2 emissions generated from gasoline consumption during fishing trips. However, the management bodies do not take this information into account and do not provide it. Therefore, CO_2 emissions estimates are based on information provided by fishers, such as fishing trips number per month for each type of métier and gasoline consumption during fishing trips. The total amount of fuel was converted in the equivalent energy using 38.68 MJ as a converting figure and introduced in a life cycle assessment software, named Global Emission Model for Integrated Systems (GEMIS) to determine the resulting emissions in terms of metric tons of CO_2 equivalent. Thus, the overall emissions from fishing in Algiers ports in 2015 were estimated at 1542.51 $MtCO_2eq$. According to the EFc equation, this amount of GHGs requires an extent of 521.41 gha of bioproductive area (forest) to absorb it.

3.3. Fishing Grounds Biocapacity (BCf)

This research considered coastal and offshore fishing zones to estimate the fishing grounds biocapacity (BCf), since the bulk of fish landings in Algeria are from this area, especially from the coastal zone. Consequently, this metric has been generated from the physical extent of coastal and offshore fishing zones obtained from ArcGIS (Table 2).

Table 2. Physical surface and estimated biocapacity of the coastal and offshore fishing areas in Algiers.

Zone	Extent from the Coast Miles	Physical Surface Ha	Biocapacity gha
Coastal fishing	6	55,877.26	19,640.9
Offshore fishing	12	253,618.24	89,146.8
Total Area	12	309,495.5	108,787.7

Algiers' fishing area represents about 8% of the total Algerian area dedicated to fishing. Using the specific conversion factors provided by the GFN, the total extent of fishing grounds was estimated at 108,787.7 gha. Compared to the demand on fisheries production, i.e., EFf, the BCf is seven times higher, which implies that the considered area is in a state of ecological "reserve" (surplus). This finding could be interpreted as potential grounds accessible for fishing, and available primary production to be exploited.

4. Discussion

This study addressed the three key elements below to describe the ecological state of the area and assess the relevance of the EF as a tool to support fishing and fisheries management:

4.1. EF to Restructure Fishing

Algerian fishing is mainly coastal, dominated by pelagic fishes. The EFf analysis indicates that the demand for fisheries resources is substantially lower than the biological capacity of the available fishing grounds in the region of interest (BCf). According to the EF concept rationale, the fishing area would be in a state of an "ecological reserve". This assumption can neither confirm nor reject the ecological deficit state attributed to Algeria [14] because this study was carried out on a small scale (ports of Algiers) and only considered local production statistics. Moreover, the GFN calculation uses international, synthetic data on fisheries and aqua farming production and trade. The EF of production based on PPR is even more interesting, as it serves as a lens to estimate the biomass demand of each species. For example, Crustaceans and Mollusks have the lowest PPR records due to their trophic levels, implying that increasing their catches would have negligible effects on the overall EFf. However, such a strategy should consider the species' stock status.

Furthermore, it is worth noting that in Algeria, both overfishing and sustainable fishing have been reported for different locations and species. Indeed, the stocks of horse mackerel, bogues, red mullet, and axillary seabream do not appear to suffer from overexploitation in the port of Algiers [34], or round sardinella in Ghazaouet [1]. In other locations, the status of these populations' stock has been described as unsustainable, particularly, the horse mackerel stock at the port of Bou Ismail [10], or overexploited for the red mullet, the Axillary seabream, and the Common sardine at the ports of Beni-Saf [35] and Ghazaouet [1]. However, the same authors recommend that these findings be investigated cautiously due to the sampling strategy and data collection system, which is regarded as weak and possibly biased [3,10]. In this case, the EF model could be an effective organizational tool for data collection. However, with regard to the uncertainties and the complexity of the component assessed, it is evident that EF results should be supplemented by other studies, such as biological and stock dynamics analyses [34,36,37], as well as environmental parameters and climate monitoring, which is assumed to be lacking at the level of fisheries management structures [3].

4.2. Energy Use Inventory

According to this research, the catch of one ton of fisheries products requires an average of 22 L of diesel each year. More than a thousand metric tons of CO_2 are released from this combustion, requiring about five hundred global hectares of sequestration land. This metric has been derived from data supplied by fishers and serves as a baseline, since no previous research has been undertaken in this sector. However, detailed data on the number of days at sea, departure and arrival times, distance traveled, and actual fuel consumption would improve the quality of the results.

The effectiveness of the component-based EF remains in its standardized structure, which might support entities attempting to track their energy use and contribute to the establishment of greenhouse gases (GHG) inventories by activity type. Furthermore, the simple EF design makes it straightforward and facilitates its usage by fishers and allows them to engage in the management of fishing in a participatory framework. Indeed, according to national experts, multidisciplinarity is a crucial prerequisite for the fishing sector's long-term growth [38]. In the context of the present study, the estimate of the CO_2 sequestration land is approximate and probably not representative of the activity. A more detailed approach based on an accurate number of trips per type of métier conducted in the fishing ports of Tipaza (Algeria) has provided representative results, outlining the correlation between production and fuel consumption by vessel types [39]. The latter highlighted that sardine vessels use the least fuel quantity per estimated production, compared to trawlers and small-scale vessels representing 67% and 23%, respectively, of the CO_2 emissions associated with fishing [39].

4.3. Available Fishing Grounds

This situation of "ecological reserve" available and potentially exploitable meets the hypothesis of other authors in Algeria who stipulate the possibility of investigating further areas, notably zones of more than 500 m of depth [2,5]. Nonetheless, managers and decision-makers should not arbitrarily expand fishing efforts based on this conclusion. Indeed, prior initiatives to increase the national production resulted in a temporary growth that faded due to intense competition for the same marketed resource and the same space explored by all users [40].

5. Conclusions

The present work is based on the estimate of the component EF related to the fishing activity considering both fisheries production and energy use during fishing trips. The study's main finding is an estimate of ecological impact of local fisheries production, which was assessed using fisheries landings statistics of four ports in Algiers. The total EFf in the area was estimated at 15,338.49 gha. The latter was compared to the available fishing grounds biocapacity of the region. The comparison highlighted that the region could be in state of an "ecological reserve", which means that Algiers' BCf is higher than the impact of the exploitation of available fisheries resources. The EFf analysis provide additional information regarding the requirement of each species in terms of primary production

(PPR). However, this diagnosis should be reviewed cautiously and supplemented by further analysis especially the targeted species' exploitation state in the Algerian market. It is also important to note that not every boat lands at Algiers' ports, and that boats from other wilayas accost and offload in Algiers. Consequently, this study should be initiated for all Algerian ports for data integrity purposes.

In 2015, more than a thousand metric tons of CO_2eq were released from the activity of local fishing fleet. This output is to be regarded as a reference state of fishing activity in Algiers, which could be improved using relevant data. Based on the EF calculation, these emissions require a total extent of 521.41 gha of sequestration land. Nonetheless, this impact could only be valued through a comparison with Algiers coastal forest area available for CO_2 sequestration, to determine whether the fishing activity in this region outgrown the natural ecosystem's capacity for carbon uptake.

In conclusion, the EF indicator represents a useful tool to provide a rough estimate of human reliance on natural ecosystems [20]. At a reduced scale, the EF serves as a lens that allows us to target where the impact occurs. However, it is evident that such a tool should be part of an extensive analysis especially for a complex component such as the marine environment, which require accurate data [41] and combined knowledge of the aquatic species dynamics and biology, the stock exploitation, as well as the physical-chemical conditions.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/su14031418/s1, Table S1: Ecological footprint of Algiers fisheries production of 2015.

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