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THE CONCEPT OF ECO-EFFICIENCY IN FISHERIES. A LITERATURE REVIEW

Key words: sustainable development, sustainability, eco-efficiency, sustainable fisheries, marine resources, data envelopment analysis

ABSTRACT. In light of the decreasing level of biodiversity in the seas and oceans, humanity has to take action to simultaneously maintain a socio-ecological balance and a satisfactory level of fish catches. The degree to which these priorities are achieved can be analyzed using measures of eco-efficiency. The aim of this paper is to present the concept of eco-efficiency in fisheries in literature. In other words, to find out and compare which definitions and measurement methods are most often used by researchers in this area. For this purpose, manual content analysis has been used to research documents available in the SCOPUS database. The review found that, while literature on eco-efficiency in agriculture is abundant, there is still a deficit of research strictly on the fisheries sector. Among 980 articles, only 8 dealt accurately with the selected issue. The most common definition of eco-efficiency is the one proposed by the WBCSD, and the dominant method for measuring eco-efficiency in fisheries is DEA+LCA; however, social aspects are often omitted in these studies, and the studies themselves have a short time span. It is also mentioned that the results obtained in fisheries have lower reliability than in the agricultural sector, mainly due to the phenomenon of bycatch and poorer control of activity at sea.

INTRODUCTION

Efficiency is one of the basic categories used to describe the state, functioning, and growth potential of various types of organizations, especially economic entities, such as businesses or companies. Vilfredo Pareto proposed the following definition in his Course in Political Economy and the Manual of Political Economy: an allocation of resources in an economy is optimal if there is no other productively feasible allocation making all units in the economy at least as well off, and at least one strictly better off than at the beginning [Lockwood 2018]. Despite the use of the word "optimal", there is consensus that this is actually the definition of efficiency [Lockwood 2018]. Tjalling C. Koopmans and Gerard Debreu reduced efficiency analysis to the level of interacting production units [Modzelewski 2011]. The issue of efficiency has a prominent place in modern economic thought. Paul Samuelson and William Nordhaus argue that efficiency can be the main object of the study of economics [Samuelson, Nordhaus 1995]. A special type of efficiency is eco-efficiency, which can be presented as a quantitative approach for business enterprises interested in practical ways of achieving sustainable development goals. Nowadays, research on eco-efficiency is also increasingly approved in relation to economic sectors, especially in agriculture, and developing the idea of increasing its level to achieve economic, environmental and social goals [Rutkowska 2013]. The question arises, how is the issue of eco-efficiency presented in the particular sub-sector of agriculture – fisheries? If the need to raise the level of eco-efficiency in other agricultural sectors is current, is it a popular topic in literature related to fisheries? Therefore, the purpose of this paper is to assess the state of research on the concept of eco-efficiency in the fisheries sector, its definitions and measurement methods. To achieve the aim, a literature review has been conducted with reference to articles indexed in the SCOPUS database. The following parts of the paper present the definition of eco-efficiency in literature, the methodology of the review regarding eco-efficiency in fisheries and the results of the review. In the last part of the paper, basic conclusions are formulated.

THE CONCEPT OF ECO-EFFICIENCY IN LITERATURE

Eco-efficiency is the most analytical and quantitative approach for companies interested in practical ways of implementing the sustainability theory [Willison, Côté 2009, Matuszczak et al. 2020]. On the theoretical side, this concept can be associated with Veblen's institutional economics and social welfare theory. As early as 1970, the term eco-efficiency was defined as the concept of "environmental efficiency" [Freeman 1973]. Subsequently, Stefan Schaltegger and Andreas Sturm [1990] introduced eco-efficiency as "the link between business and sustainable development". Rodrigo Caiado et al. [2017] provided its definition as an objective measurement of achieving economic goals in an environmentally responsible manner. However, the main definition comes from Livio DeSimone and Frank Popoff [1997] and the World Business Council for Sustainable Development (WBCSD). The description of eco-efficiency presented there reads as follows: "Eco-efficiency is achieved by providing competitively priced goods and services that meet human needs and enhance the quality of life, while progressively reducing environmental impacts and resource intensity over the life cycle to a level at least consistent with the estimated carrying capacity of the earth". WBCSD defines eco-efficiency quantitatively as the quotient of "the value of a product or service" and "its environmental impact".

Eco-efficiency is the achievement of high environmental performance, which indicates the low environmental impact of a company's or sector›s activities [Repar et al. 2017]. Measuring the level of eco-efficiency is common in other agricultural industries, such as the dairy industry [Basset-Mens et al. 2009] or wineries [Vázquez-Rowe et al. 2012]. Eco-efficiency analyses can provide new insight into the process of wealth generation [Hoffren 2006] and even provide answers to the question of how the impact of long-term policy preferences affects environmental outcomes [Matuszczak et al. 2020]. Currently, one of the most widely used methods for measuring eco-efficiency in agriculture is Data Envelopment Analysis (DEA) [Papież et al. 2019, Matuszczak et al. 2020]. In this approach, a linear programming problem is solved, and the level of eco-efficiency is calculated for a given decision-making unit (DMU) with respect to a designated efficiency frontier. In contrast to the standard DEA efficiency model, the eco-efficiency framework uses environmental variables. These can be treated as additional inputs, or more commonly as undesirable (bad) outcomes. Eco-efficiency can be calculated using DEA-based radial models or non-radial models, including directional distance functions or slack-based measure (SBM) models [Halkos, Petrou 2019]. The level of eco-efficiency is then often regressed on several factors, including the socio-economic characteristics of the producer or the policy and institutional environment. Life Cycle Assessment (LCA), which is often an enrichment of DEA analysis, is a method to identify the environmental impacts associated with all stages of production of a commodity (the so-called cradle-to-grave environmental damage identification of a product) [Stępień et al. 2020].

RESEARCH MATERIAL AND METHODS

Following the FAO, fisheries, as a branch of agriculture, can be divided into four sections: land aquaculture, marine aquaculture, land fisheries and marine fisheries (including, for example, coastal or deep-sea fisheries). The latter section, marine fisheries, accounted for 58 million tons of the 178 million tons of total fish caught in 2018 and was the largest (47%) part of fisheries [FAO 2020]. In this paper, the focus is on literature regarding marine fisheries, hence, further in this article, marine fisheries will be understood under the term “fisheries”. In addition, it should be noted that the literature on fisheries typically excludes the catch volumes of marine mammals, as well as crocodiles, alligators, caimans and seaweed from fishery studies [FAO 2020].

Manual content analysis was used to survey available sources in the SCOPUS database. The first part of the study was the creation of a database. This database was created from searching article titles, abstracts and keywords related either to “fisheries” or “fishery”or “fishing” and “environmental efficiency” or “eco-efficiency” or “ecoefficiency”. The following code has been used: (TITLE-ABS-KEY (fishing) OR TITLE-ABS-KEY (fishery)

OR TITLE-ABS-KEY (fisheries) AND TITLE-ABS-KEY (environmental AND efficiency) OR (TITLE-ABS-KEY (eco-efficiency) OR TITLE-ABS-KEY (eco AND efficiency) OR TITLE-ABS-KEY (ecoefficiency))). This resulted in 980 records. The second part of the study consisted of filtering out articles that were relevant to the definition and measurement of eco-efficiency in fisheries (marine fisheries) from this group and did not simply situate their research in the marine environment, refer to the fishing industry or mention the impact of the phenomenon on marine organisms.

Fifty-seven articles (5.82% of the total) were not accessed. The largest group of articles (198) that did not meet targets were articles from scientific disciplines addressing issues related to the cultivation/maintenance/use of land as well as the cultivation of plants, fungi or bacteria, of which 3 dominant groups can be distinguished: 67 articles dealing with biological issues (for example, attempting to capture a functional measure of vulnerability in marine ecosystems [Arreguín-Sánchez, Ruiz-Barreiro 2014]), 58 chemical processes (for example, the uptake of dioxins (PCDDs/PCDFs) and dioxin-like PCBs in Spanish turbot (*Psetta maxima*) [Blanco et al. 2007]) and 24 articles on animal development and behaviour (for example, differential behavioural responses to novel conditions and food types in hybrids of first-generation farmed and wild juvenile Chinook salmon [Janisse et al. 2019]). The second, slightly smaller group of non-compliant articles were those related to modelling, technology, and electronics (187), of which 42 articles dealt with synthetic models and hypothesis implementation (for example, an integrated mathematical model of a large marine ecosystem in the Barent Sea and White Sea as a tool for natural hazard assessment and the efficient use of biological resources [Berdnikov et al. 2019]), 84 were related to the application of technology and new solutions (for example, near real-time, open-source monitoring and an analysis system for small-scale fisheries [Tilley et al. 2020]), and 10 more articles dealt with increasing the level of eco-efficiency after applying solutions related to the Internet of Things (for example, GPS relative positioning strategies for the fishery Internet of Things [Cao et al. 2020]). Another 87 articles dealt with waste management, biodegradation and pollution, but again, none of them referred to the study of eco-efficiency levels in fisheries (for example, a comparative analysis of wastewater treatment plants in an eco-efficiency perspective [Lorenzo-Toja et al. 2016]). Another group of articles (73) addressed efficiency in issues related to society and tourism (for example, declared tourist preferences for eco-efficient distillation planning options [Kelly et al. 2007]), consumption or decision-making (for example, the management of fish conservation zones based on public perceptions and the willingness to pay for ecosystem services [Chen et al. 2018]). Another group of articles (72) that did not meet the objectives were those related to urbanization, development and urban planning processes (for example: what type of industrial agglomeration is beneficial for eco-efficiency in Northwest China? [Gao 2021]), natural resource management, environmental impacts of agricultural activities (for example, assessing the eco-efficiency of agricultural production in the EU-28 [Rybaczewska-Blazejowska, Gierulski 2018]), and regional differences (for example, regional differences in industrial eco-efficiency and the antigradient development strategy under the gradient development model in China [Yang et al. 2013]). Another 61 articles not meeting objectives can be categorized under the group related to legislation, policy and certification (for example, Fishery Systems Assessment: A Comprehensive Analytical Framework and its Application to the EU Common Fisheries Policy [Belschner et al. 2019]). Another group (49) consisted of articles that addressed the topic of measuring eco-efficiency in different approaches (e.g., technological), however, all of them were related to aquaculture (for example, assessing the eco-efficiency of shrimp aquaculture production in Mexico [Cortés et al. 2021]). Another 50 were rejected for similar reasons – their studies were related to fisheries in freshwater reservoirs (for example, the effects of climate and land-use change on global lake fishery [Kao et al. 2020]). Another group of articles (37) not meeting objectives were those measuring eco-efficiency, but not specifically in the fisheries sector (and, for example, the eco-efficiency of wineries, farms and seaports, like the eco-efficiency of a marine biorefinery for the valorisation of cartilaginous fish biomass [García-Santiago et al. 2021]). 40 articles dealt with eco-efficiency related to energy in a broad sense, from biodiesel production to greenhouse gas emissions [Rebolledo-Leiva et al. 2017] and energy storage methods. The last group (45) that did not meet objectives were related to implemented technologies in the food production process and food management (the eco-efficiency of applied food chain scenarios or the canning of processed fish [Laso et al. 2018b]).

One article dealt with marine fisheries but did not mention eco-efficiency [Cook et al. 2013], while another was a literature review concerning how to measure eco-efficiency [Vásquez-Ibarra et al. 2020]. 14 articles addressed fishery issues and mentioned efficiency or eco-efficiency, however, they either did not strictly concern how to measure eco-efficiency in fisheries, did not provide any definition related to eco-efficiency or cited such studies only as an example or benchmark (for example, is employment size an appropriate factor in LCA+DEA studies? Observations on the combined use of economic, environmental and social parameters [Iribarren, Vázquez-Rowe 2013]). Finally, out of 980 articles, only 8 articles were fully in line with assumptions and dealt with eco-efficiency in the fisheries sector. In conclusion, it can be said that the concept of eco-efficiency in fisheries is, thus far, under-researched.

RESULTS

As previously mentioned, in the group analyzed, only 8 papers were identified that addressed the issue of eco-efficiency in the fisheries sector in the assumptions made – to know the definitions of eco-efficiency used in marine fisheries. As can be seen in Table 1, three of them dealt with studies conducted in Spain [Vázquez-Rowe et al. 2010, Laso et al. 2018a, Vázquez-Rowe et al. 2011], others in Peru [Avadí et al. 2014], Mexico [Bravo-Olivas et al. 2020], Portugal [González-García et al. 2015] and Gambia and Mali [Avadí, Acosta-Alba 2021]. The last work treats both countries, and while Mali is landlocked and the fisheries studied mainly take place on the Niger River, Gambia has access to the Atlantic Ocean, so the focus is only on the part of the paper treating the measurement of eco-efficiency in Gambia›s fisheries. The papers by Martin Willison and Raymond Côté [2009] and Ángel Avadí et al. [2014] were published in the journal with the highest Impact Factor for 2020 in the collection at 9.297 (Journal of Cleaner Production), while the paper by Myrna Bravo-Olivas et al. [2020] was published in the journal with the lowest IF for 2020 at 0.893 (Open Ecology Journal). The most recent paper is written by Ángel Avadí and Ivonne Acosta-Alba [2021] and the oldest by Martin Willison and Raymond Côté [2009]. All papers except Sara González-García et al. [2015] and Jara Laso et al. [2018a] cite the definition of eco-efficiency from The World Business Council Sustainable Development (WBCSD) [Willison, Côté 2009, Bravo-Olivas, Chávez-Dagostino 2020, Vázquez-Rowe et al. 2010, 2011, González-García et al. 2015, Avadí et al. 2014, Avadí, Acosta-Alba 2021].

The most commonly used method among these articles to measure the level of eco-efficiency is DEA+LCA [Vázquez-Rowe et al. 2010, González-García et al. 2015, Avadí et al. 2014, Laso et al. 2018a, Vázquez-Rowe et al. 2011]. As shown in Table 1, in this method, the most frequently mentioned inputs were fuel consumption, the consumption of specific materials (such as copper, epoxy resin, fiberglass, lead, nylon, steel and wood) and also units of electricity, litres of tap water, ice and other materials related to the maintenance of the fishing vessel (paints, coolants and lubricating oils) – these are included either in the construction phase or in the maintenance phase of the vessel. The quantity of fish caught (expressed in kg) or in the value of the catch (usually in Euros) and, in the work of Ian Vázquez-Rowe et al. [2010], the volume of discards from the catch, were most often indicated as outputs. This is the only use of so-called "bad output" in this method in the examined literature. The inclusion of greenhouse gas emissions as negative environmental effects is currently common in research on the level of eco-efficiency in other branches of agriculture, so its absence in the study of the fisheries sector may be surprising. In the work of Ángel Avadí and Ivonne Acosta-Alba [2021], the authors use LCA and in the work of Martin Willison and Rayond Côté [2009] a literature review. As the authors state, the use of the Life Cycle Assessment combined with the

Data Envelopment Analysis (LCA+DEA) method, which is a tool to assess the relative efficiency of multiple entities used, is reliable for specific use when production systems, such as fishing fleets are analysed [González-García et al. 2015]. Additionally, the use of a combined LCA+DEA method allows researchers to gain a number of advantages. In this way, it is possible to simultaneously obtain calculations of technical inefficiencies as well as environmental savings that could have been made if the units (fishing vessels in the given studies) had operated in an efficient manner [Vázquez-Rowe et al. 2011]. In 5 works, possible determinants of fishery eco-efficiency were directly indicated (Table 2). The work of Sara González-García et al. [2015] pointed to the skills of fishermen (the level of education, experience but, above all, the so-called "skipper effect"), the type of boat (its purpose, adaptation to different types of fishing, as well as the state of maintenance) was considered an important differentiating factor in the articles of Ángel Avadí et al. [2014] and Ian Vázquez-Rowe et al. [2011], while the articles of Ángel Avadí et al. [2014] and Ángel Avadí and Ivonne Acosta-Alba [2021] pointed to the influence of a country's fisheries policy and the way the sector is managed. The paper by Jara Laso et al. [2018a] indicates the relevance of the influence of the way individuals approach the problems of environmental degradation. The article by Ian Vázquez-Rowe et al. [2010] suggests a possible influence of the types of boats studied and the skills of the fishermen, citing sources on the "skipper effect" but without explicitly mentioning it. The article by Martin Willison and Raymond Côté [2009] and Myrna Bravo-Olivas et al. [2020] do not identify any possible determinants.

What then is the "skipper effect"? Following Ian Vázquez-Rowe and Peter Tyedmers [2013], the skipper effect, or the skill of the skipper combined with his experience, is considered by some researchers to be the primary factor affecting fishing efficiency. The fact of the relevance of this factor seems to be confirmed by the aforementioned study, which found that, in a relatively homogeneous fleet, the best performing vessels repeatedly achieved similar high-efficiency rates throughout the period, while lower performing vessels had higher standard deviations, regardless of the time or place of landing. The efficient operation of inefficient vessels could provide significant environmental benefits, especially in relation to optimizing the consumption of fuel resources.

The results of the work of Ian Vázquez-Rowe et al. [2010] highlighted that the link between operational efficiency and environmental impacts is possible through the optimization of resource use (a reduction of waste, unproductive inputs or process misuse) to reduce potential environmental impacts in different impact categories. In the results of the work of Sara González-García et al. [2015], it was confirmed that fishing for small pelagic fish shows lower energy intensity compared to other fisheries and that changes in the level of eco-efficiency of a given boat do not change much with time. In contrast, the results of the work of Ángel Avadí et al. [2014] showed that fleets from the SME sector show slightly lower levels of eco-efficiency than vessels defined for industrial fleets or

Table 1. Comparison of the surveyed articles in terms of the place of publication, the definitions of eco-efficiency used and the methods of measuring it

Authors	The Title	Year	Journal	IF'20	The eco-efficiency def.	Details	Method	Output	Input
Vázquez-Rowe et al.	Combined application of life cycle assessment and data envelopment analysis as a methodological approach for the assessment of fisheries	2010	International Journal of Life Cycle Assessment, 15(3), 272-283	4.141	The WBCSD definition	decision-making units (24 Spanish vessels), functional unit (1 kg of landed fish)	DEA +LCA	catch value [€/year], bad discards [kg/year]	diesel [l/year], lubricating oil [l/year], paint [l/year], trawl net [kg/year], steel for boat construction [kg/year], ice [kg/year]
González-García et al.	Cross-vessel eco-efficiency analysis. A case study for purse seining fishing from north Portugal targeting European pilchard	2015	International Journal of Life Cycle Assessment, 20(7), 1019-1032	4.141	no definition included	decision-making units (20 Portuguese vessels), functional unit (1kg of landed fish), period: 2011-2012	DEA +LCA	landed pilchard [t/year]	fuel consumption [l/year], construction phase [point units/year], maintenance phase [point units/year]
Willison and Côté	Counting biodiversity waste in industrial eco-efficiency: Fisheries case study	2009	Journal of Cleaner Production, 17(3), 348-353	9.297	The WBCSD definition	-	literature review	-	-
Avadí et al.	Eco-efficiency assessment of the Peruvian anchoveta steel and wooden fleets using the LCA+DEA framework	2014	Journal of Cleaner Production, 70, 118-131	9.297	The WBCSD definition	decision-making units (160 Peruvian vessels divided into 13 different segments), functional unit (tonne of landed fish), period: 2005- 2010	DEA +LCA	landed anchoveta [t/year]	fuel consumption [kg/year], construction phase [point units/year], use phase [point units/year], maintenance phase [point units/year]
Laso et al.	Revisiting the LCA+DEA method in fishing fleets. how should we be measuring efficiency?	2018	Marine Policy, 91, 34-40	4.173	no definition included	decision-making units (32 Spanish vessels), functional unit (tonne of landed fish), period: unknown one year	DEA +LCA	catches [kg/year], energy [MJ/year], biomass [kC/kg fish]	fuel consumption [kg/year], construction phase [point units/year], use phase [point units/year], maintenance phase [point units/year]

Table 1. Cont.

Authors	The Title	Year	Journal	IF'20	The eco-efficiency def.	Details	Method	Output	Input
Vázquez-Rowe et al.	Computation of operational and environmental benchmarks within selected Galician fishing fleets	2011	Journal of Industrial Ecology, 15(5), 776-795	6.946	The WBCSD definition	decision-making units (76 Spanish vessels divided into 6 different segments), functional unit (tonne of landed fish], period: 2008	DEA +LCA	catch value [€/year]	diesel consumption [litre/year], steel for hull construction [kg/year], antifouling paint consumption [litre/year] or net usage [kg/year]
Bravo-Olivas et al.	Sustainable fishing? ecological footprint analysis of an artisanal fishing organization	2020	Open Ecology Journal, 13(1), 1-10	0.893	The WBCSD definition	data for 32 vessels included fuel consumption, energy, materials, services, natural and agricultural resources, forest resources, water, land use, and waste	ecological footprint	-	-
Avadí and Acosta-Alba	Eco-efficiency of the fisheries value chains in the Gambia and mali.	2021	Foods, 10(7)	4.121	The WBCSD definition	indices: fuel use intensity (FUI) the ratio between landed fish and fuel consumed to catch and land the fish, energy return on investment (EROI), protein-per-impact (PPI)	LCA	-	-

Source: own study

Table 2. Presentation of determinants, results, recommendations and limitations of studied articles

Authors	Determinants	Results	Recommendations	Limitations
Vázquez-Rowe et al. [2010]	Mentioned: the migratory nature of most species, the lack of a standard operation of the different vessels, the variable characteristics of these vessels, and the skipper skill ”skipper effect”	The link between operational efficiency and environmental impacts is possible by optimizing resource usage (waste reduction, unproductive inputs, or incorrect use of processes)	LCA+DEA approach for fisheries is recommended for its regular use. The potential inclusion of “bad outputs” in DEA models makes the proposed method suitable for quantifying potential improvements in currently underrepresented issue areas such as discarding by-catch	Lack of social issues in the LCA method
González-García et al. [2015]	fishermen skills ”skipper effect”	Vessels tend to maintain similar levels of efficiency from a temporal perspective. The results in this study confirm that fishing small-pelagic fish shows low energy intensity as compared to other fisheries	The results tend to suggest that the ”skipper effect” could have an influence on observed inefficiencies. A wider window of analysis would be desirable to confirm the tendencies	Only two years as a time period. Improvements in efficiency are linked to a wide range of issues, which are difficult to identify. The possible ”skipper effect” might have influenced other factors
Willison and Côté [2009]	not given	It is proposed that an eco-efficient metric for the value per unit mass of discarded fish (by-catch) can be set to be equivalent to that of the market value of the utilized catch	To develop eco-efficiency metrics which may have negative values. If all negative eco-efficiencies in fisheries were eliminated, considerable progress in the sustainable development of fisheries would be made	The eldest article among the researched set of articles
Avadí et al. [2014]	maintenance of the vessel, the policy, environmental regulations of fisheries in Peru	Fleet segments from the small- and medium-scale fleet showed in general terms slightly lower efficiencies than those identified for the industrial fleets	The use of the LCA+DEA method has proven in past studies to be a useful tool in determining the eco-efficiency of fishing vessels, as well as their potential to improve their environmental profile when increasing their efficiency	Scarce in the amount of available data. Longer time of the research would be appreciated

Table 2. Cont.

Authors	Determinants	Results	Recommendations	Limitations
Laso et al. [2018]	the cultural perspective on environmental problems (given 5 different points of view: individualist, the hierarchist, the egalitarian, the hermit and the fatalist)	Results suggest that the optimization of environmental impacts is strongly influenced by the cultural perspective selected. To avoid biased interpretations, there is a need to define more flexible and holistic frameworks in LCA+DEA	It is recommended that future LCA+DEA studies that aim at computing environmental impact benchmark targets through resource use minimization should enhance the relevance of their results by providing deeper sensitivity analysis	A shift from a deterministic to a stochastic approach when combining LCA and DEA is a current need in order to be able to assess the robustness and significance of the results obtained with this method
Vázquez-Rowe et al. [2011]	the type of vessels	Strong dependence of environmental impacts on one major operational input: fuel consumption. The most intensive fuel-consuming fleets, such as deep-sea trawling, were found to entail the diesel consumption levels nearest to the efficiency values	Galicia is one of the major fishing regions in the European Union, many of the conclusions and perspectives obtained in this study may be extrapolated to other fishing fleets at a European or international level	Current eco-efficiency indicators disregard relevant biodiversity parameters, so future efforts are needed to include biological aspects in fishery related ecoefficiency studies
Bravo-Olivas and Chávez-Dagostino [2020]	not given	Eco-efficiency, determined by the organization´s ecological footprint, was 0.6 t/ha and its carbon footprint was 0.2 t/tCO2 per year, a low one when compared to other	These results can help to see the actual state of the cooperative in terms of opportunities to advance in sustainability but should not be used to establish future scenarios	The comparison is impossible since it depends on time and available technology and this research should not be used as a predictive tool
Avadí and Acosta-Alba [2021]	policy, the type of fishery organisation and governance prevailing in these countries, „skipper effect”	Industrial Gambian fleets' fuel use efficiency is rather low compared with global mean fuel use intensity. Impacts of average fish captures from industrial fleets are higher than those of demersal artisanal fleets	Suggestions of improvements in the landing infrastructure and fishing units' engines, coupled with technical and business training and improved processing methods	The availability of data is rather limited, and the activities are poorly monitored

Source: own study

even coastal fleets – this is due to differences in the way fuel consumption is managed. On the one hand, small and medium-sized enterprise vessels do not tend to minimize fuel consumption as much as poorer small coastal fleets usually do and, on the other hand, they do not benefit from the economies of scale of operations to the same extent as industrial fleets operating on the high seas. Ultimately, it is the fleets composed of the smallest and largest vessels that have proven to be the most eco-efficient. Given that Peru is one of the countries with the largest marine fisheries, this is valuable information for other countries in terms of managing cutters and trawlers by size. In addition, the work of Ian Vázquez-Rowe et al. [2011] showed a strong relationship of environmental impact by one operational factor, which is the level of fuel consumption. The results of this work, therefore, seem to confirm the results of the work of Ángel Avadí et al. [2014], as it found that the most fuel-consuming fleets (the largest-industrial ships) have the level of diesel consumption closest to the values considered efficient. The work of Ángel Avadí and Ivonne Acosta-Alba [2021] shows that the fuel efficiency of Gambian industrial fleets is rather low compared to global average fuel intensity (fish landed/fuel consumed) for both small pelagic and groundfish species. Interestingly, in contrast to the aforementioned results of Ángel Avadí et al. [2014] and Ian Vázquez-Rowe et al. [2011], a study by Ángel Avadí and Ivonne Acosta-Alba [2021] found, to the surprise of the authors, that, in the Gambia, the effects of the average fish catch of industrial fleets are higher than those of artisanal fleets. The authors point to the unusual shape of the Gambia›s exclusive economic zone (EEZ) and the respective fishing zones for artisanal and industrial fleets, the condition of the target stocks limiting economies of scale, and even the "skipper effect" limiting the productivity of industrial vessels as possible reasons for this deviation from the norm.

As a result of their study, the authors of the paper Martin Willison and Raymond Côté [2009] found that the values per unit weight of fish discarded can be set as equivalent to the market value of the catch used. The authors of the paper Jara Laso et al. [2018a] indicate that the optimization of the environmental impact is strongly dependent on the cultural perspective chosen (5 were chosen: individualist, hierarchist, egalitarian, hermit and fatalist). In contrast, in the work of Myrna Bravo-Olivas et al. [2020], eco-efficiency was calculated using an organization›s ecological footprint. Ecological footprint (EF) is an integrated indicator that estimates resource consumption and the waste assimilation demand of any human population or economic system relative to its productive land area [Wackernagel, Rees 1996]. Finally, this study produced low values compared to other countries.

In the recommendations in the surveyed articles, it was mentioned, several times, that the use of the combination of LCA+DEA methods proved to be a useful tool in determining the eco-efficiency of fishing vessels, as well as their potential to improve their environmental profile while increasing their efficiency. However, a more holistic approach in the creation of impact benchmarking based on anthropocentric views is encouraged by the work of Jara Laso et al. [2018a], as the current approach may ignore the health of organisms and the complexity of the ecosystem. According to the authors, there is a need to define a more flexible framework in LCA+DEA modelling to enrich the set of preconceived assumptions to avoid biased interpretations.

In addition, the article by Martin Willison and Raymond Côté [2009] highlights that current eco-efficiency indicators do not consider important biodiversity parameters, so future efforts are needed to include biological aspects in fisheries-related eco-efficiency studies. If all negative effects in fisheries could be eliminated, there would be considerable progress in the sustainability of fisheries. One of the negative effects of fisheries is bycatch, which is the portion of the catch that includes marine organisms not targeted by default. By-catch, in its living and, more often, dead state, ends up back at sea, which is both economically and ecologically wasteful. In relation to the existence of the bycatch phenomenon, the considerations of Martin Willison and Raymond Côté [2009] are somehow joined by Ian Vázquez-Rowe et al. [2010] claiming that the potential inclusion of „bad results" in DEA models will make the proposed method able to more accurately assess the effectiveness of actions taken to eliminate problems such as bycatch, among others. As the authors state, many of the conclusions and perspectives obtained in the study by Ian Vázquez-Rowe et al. [2011] can be extrapolated to other fishing fleets at a European or international level. This conclusion may encourage further research in this area.

Regarding limitations – in the work of Ian Vázquez-Rowe et al. [2010], no social factors were included in the study at an LCA level. Moreover, a static state was studied, without considering the passage of time. In the work of Sara González-García et al. [2015], a period of two years has already been studied, which, on the one hand, seems a short period to carry out the study; on the other hand, the authors refer to the work of Ian Vázquez-Rowe and Peter Tyedmers [2013], which confirmed that the mentioned „skipper effect" is characterized by certain stability over time. The paper by Ian Vázquez-Rowe et al [2011] does not include factors related to biodiversity. The work by Ángel Avadí et al. [2014], due to incomplete data, pointed out the low robustness of results, similar to the study of Jara Laso et al. [2018a]. The study of Sara Bravo-Olivas et al. [2020] highlighted the impossibility of directly comparing the results obtained with other similar studies and the fact that the method used cannot be used as a tool to predict trends. The study by Ángel Avadí and Ivonne Acosta-Alba [2021] again highlighted the inaccuracy of data and the poor monitoring of obtaining them, which can negatively affect results. Most of the reviewed works [Vázquez-Rowe et al. 2010, 2011, González-García et al. 2015, Avadí et al. 2014, Laso et al. 2018a] cited the need to repeat the study, but over a longer period or in different fisheries, as the main gap for future research. In addition, a comparison at a level of the entire fishery or an examination of differences between countries would be an interesting topic to address in future research.

CONCLUSIONS

To achieve the article›s objective of presenting the concept of eco-efficiency in fisheries, manual content analysis was used to examine existing literature. The review revealed that the concept of eco-efficiency in fisheries is not widely developed. Out of 980 articles, only 8 thoroughly addressed the selected issue within the accepted framework, thus, as the main conclusion, it can be drawn that the concept of eco-efficiency in fisheries is niche and there is a significant research gap to be filled. The main limitation of this study is, primarily, the imposed framework of (I) fisheries as marine fisheries and (II) the need to include definitions and methods related to measuring the level of eco-efficiency in the articles under study. As previously mentioned, aims – to find out and compare which definitions and measurement methods are most often used, it may be concluded that the main definition of eco-efficiency cited by the authors of the surveyed papers is the one proposed by the WBCSD in 1992. Moreover, there are significant similarities in the manner of measuring the level of eco-efficiency in the agricultural sector – the most frequently used method is DEA, while in its sub-sector, fisheries, the DEA+LCA method dominates. In agriculture, the accepted unit is one farm, while in fisheries, the farm-unit role is played by one vessel. However, there is a significant difference – measuring harmful inputs is much easier and more reliable in the agricultural sector, in general, than in fisheries alone, especially in the open sea. Nonetheless, given that it is the norm to include bad output as a variable representing the negative effects of a sector in the DEA method in agriculture, it may be surprising that only one paper included bycatch as bad output. Furthermore, as long as bycatch practices exist, research in this area will not fully be accurate. In the future, it would be good practice to include at least the level of greenhouse gas emissions in similar studies. Most studies emphasize the uncertainty of the data collected for the research, the need to repeat the research in a broader time frame or with more information related to biodiversity factors (due to bycatch phenomena) or social aspects of the sector, especially when the skill and experience of the captain (the ”skipper effect”) is cited as one of the main determinants of the level of eco-efficiency of an individual fishing unit. As shown in Ángel Avadí and Ivonne Acosta-Alba [2021], it is also worth noting the possible strength of the influence of government regulations and international agreements on the general rule in which the largest vessels in the industrial fleet/trawlers have relatively eco-efficient fuel consumption. Given the research to date in this area, it would be interesting to replicate the study of eco-efficiency in the fishing industry using the most common method used (DEA+LCA), but include social factors and, perhaps, those related to biodiversity. Without them, a study of the level of eco-efficiency, a measure closely related to the implementation of the idea of sustainable development, will never be complete, in the author›s opinion. Moreover, such an analysis should have a broader research period in order to better estimate the direction and strength of influence of potential determinants of the level of eco-efficiency in fisheries.

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KONCEPCJA EKOEFEKTYWNOŚCI W RYBOŁÓWSTWIE. PRZEGLĄD LITERATURY

Słowa kluczowe: zrównoważony rozwój, ekoefektywność, zrównoważone rybołówstwo, zasoby morskie, obwiedniowa analiza danych

ABSTRAKT

W obliczu zmniejszającego się poziomu bioróżnorodności mórz i oceanów, ludzkość zmuszona jest do podejmowania działań, mających na celu jednoczesne utrzymanie równowagi społeczno-ekologicznej oraz podtrzymanie zadowalającego poziomu połowów ryb. Stopień osiągnięcia tych priorytetów może być analizowany za pomocą miar ekoefektywności. Celem artykułu jest przedstawienie koncepcji ekoefektywności w rybołówstwie w literaturze przedmiotu. Innymi słowy, poznanie i porównanie, jakimi definicjami i metodami pomiaru najczęściej posługują się badacze tego obszaru. W tym celu do badania artykułów naukowych dostępnych w bazie SCOPUS wykorzystano manualną analizę treści. W wyniku przeglądu stwierdzono, że choć literatura dotycząca ekoefektywności w rolnictwie jest bogata, to nadal istnieje deficyt badań dotyczących ściśle sektora rybołówstwa. Spośród 980 wstępnie wyselekcjonowanych artykułów, tylko w 8 zajmowano się zagadnieniem ekoefektywności w kontekście badanego w artykule sektora. Najczęściej występującą definicją ekoefektywności jest ta zaproponowana przez WBCSD, a dominującą metodą w pomiarze poziomu ekoefektywności w rybołówstwie jest DEA+LCA. Jednak często pomija się w tych badaniach aspekty społeczne, a same badania cechują się krótkim przedziałem czasowym. Wspomina się również, że uzyskane wyniki w rybołówstwie charakteryzują się niższą wiarygodnością niż sektorze rolniczym, głównie przez zjawisko przyłowu i uboższy sposób kontroli aktywności na morzu.

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