frontiers in Marine Science

ORIGINAL RESEARCH
published: 24 September 2019
doi: 10.3389/fmars.2019.00594

Monitoring the Environmental, Social and Economic Dimensions of the Landing Obligation Policy

Maria Christou[1,2,3†], Silvia de Juan[4†], Vassiliki Vassilopoulou[1], Konstantinos I. Stergiou[1,2] and Francesc Maynou[4]*

[1] Institute of Marine Biological Resources and Inland Waters, Hellenic Centre for Marine Research (HCMR), Anavyssos, Greece, [2] School of Biology, Aristotle University of Thessaloniki, Thessaloniki, Greece, [3] Marine & Environmental Research Lab, Limassol, Cyprus, [4] Institute of Marine Science (ICM-CSIC), Barcelona, Spain

OPEN ACCESS

Edited by:
Di Jin,
Woods Hole Oceanographic Institution, United States

Reviewed by:
Patricia M. Clay,
National Marine Fisheries Service (NOAA), United States
Melina Kourantidou,
Dalhousie University, Canada

***Correspondence:**
Maria Christou
maria.ch.christou@gmail.com

† These authors have contributed equally to this work

Specialty section:
This article was submitted to Marine Affairs and Policy, a section of the journal Frontiers in Marine Science

Received: *01 April 2019*
Accepted: *05 September 2019*
Published: *24 September 2019*

Citation:
Christou M, de Juan S, Vassilopoulou V, Stergiou KI and Maynou F (2019) Monitoring the Environmental, Social and Economic Dimensions of the Landing Obligation Policy. Front. Mar. Sci. 6:594. doi: 10.3389/fmars.2019.00594

Aiming to end the practice of discarding unwanted catches back to the sea within European marine waters, an obligation to land the catches of all regulated commercial species was introduced with the Common Fisheries Policy, with required implementation by the first of January 2019. The implementation of this new fisheries regulation urges the definition of standard monitoring protocols to track potential changes in the European fisheries. Importantly, this framework needs to be multi-dimensional to capture the ecological, social and economic components of the fisheries system. Aiming to address this challenge, a set of 39 candidate indicators were identified by means of literature review and expert consultation. Experts in European fisheries were gathered to discuss the selection of a restricted set of indicators and later, a remote survey was completed by the experts to assess the adequacy of the indicators against pre-defined quality criteria and to identify expected direction of change. Based on survey results, the candidate indicators were ranked according to their adequacy for monitoring of the landing obligation (LO) potential effects. This ranking was dominated by indicators related to the exploited species, rather than the social or economic dimensions of the fisheries. Because the LO is not yet fully implemented, experts expressed uncertainty in the properties of many indicators, particularly related to ecosystem properties and social system properties, and had divergent opinions on the effect of the LO on discard numbers. The feasibility to operationalize a monitoring framework with the prioritized indicators was explored with data from a Spanish demersal otter-trawl fishery. This exercise evidenced that most indicators can be routinely collected and that it would be feasible to track these variables over time in the framework of a monitoring program. However, gaps exist in the time series of the studied indicators, especially for the period after the LO implementation. This study can provide valuable baseline information for any future monitoring program, as its objective was the development of a methodological approach that contributes to science-based policy making and to indicator selection for fisheries management reforms.

Keywords: decision making, discards, landing obligation, monitoring, Mediterranean fisheries

INTRODUCTION

The landing obligation (LO) within European marine waters seeks to end the wasteful practice of discarding unwanted catches (UWC), i.e., the fraction of the catch that is not landed due to quotas, to minimum conservation reference sizes, or to market demand, and is the result of imperfect fisheries selectivity, legislation restrictions and market incentives which are specific to each type of fishery (STECF/SGMOS, 2008; Pérez-Roda, 2019). After a 4-year period of progressive implementation, the LO has fully entered into force on January 1st, 2019. During this 4-year initial phase, it has encountered serious implementation hurdles which are expected to continue in the coming years (Damalas, 2015; Stokstad, 2019). Several factors explain this situation such as lack of incentives to the industry to comply with the regulation, lack of enforcement capacity by fisheries control agencies, perceived inefficiency of the regulation to contribute to sustainable fisheries, and inadequate or ambiguous regional discards management plans (Stockhausen, 2019).

The LO in Mediterranean fisheries, concerns key species for which the use of captured individuals below the minimum conservation reference size shall be restricted to purposes other than direct human consumption[1]. Those not covered by the LO can continue to be discarded, while prohibited species [i.e., species that are protected by the national or European legislation/Common Fisheries Policy (CFP)] should be returned immediately back to the sea (EU, 2013). There is a strong regional and/or fishery variability in unwanted catch composition and its drivers within Europe (Eliasen et al., 2014), implying the need to follow a case-by-case approach to explore technically possible and cost-effective solutions agreeable to fish producers, consumers and policy makers. It is likely that the LO will have less impact on fishing practices in which discards are driven by market rather than by regulatory provisions (Catchpole et al., 2013), while a number of factors have a synergistic effect on discard patterns which are sometimes difficult to disentangle and capture (e.g., social norms and values) (Stithou et al., 2019). The introduction of the LO may cause changes at multiple scales, including the socio-economic well-being of fishers and the functioning of marine ecosystems. Some changes are expected to be negative in the short term, such as the anticipated reduction in commercial landings, which is not expected to be compensated by the sale of UWC for industrial purposes (Christou et al., 2019), but some mid to long term ecosystem benefits could be expected if the implementation of the LO leads to more selective fishing practices (Guillen et al., 2018). Where discards are in high densities (Catchpole et al., 2006) or discarding patterns exhibit high spatio-temporal heterogeneity (Maina et al., 2018), the LO regulation effects cannot be accurately estimated (Damalas et al., 2018). Therefore, while the LO is an important step for fisheries conservation in European waters, to monitor the implementation of the LO is expected to be challenging due to the diversity of issues that must be taken into account for proper monitoring, the limited control and surveillance capabilities of fisheries management agencies and the reluctance of the industry to comply with the LO (Fauconnet et al., 2019; Villasante et al., 2019).

Decisions made by fishers to address the LO may result in modifications of the fishing method to enhance post-release survival, changing fishing grounds to avoid high concentrations of UWC, or the use of more selective fishing gears to minimize the catch of undersized fish (Fauconnet et al., 2019). Also, there might be changes in the utilization of former discards, fostering their transformation in fish processing plants to meet the growing demand for aquaculture, agriculture and livestock industries (Sardà et al., 2015). Therefore, potential LO effects are multi-dimensional. Discards are food for a range of scavenging species, from avian to mesopelagic and benthic communities (Kaiser and Hiddink, 2007; Karris et al., 2018). Although ending discarding may alter the density and distribution of certain marine organisms (Bellido et al., 2011; Heath et al., 2014) conclusions drawn from different studies highlight firstly, the inherent uncertainty of effects induced by the LO on the marine ecosystems (Kopp et al., 2016), and secondly, the limited consequences of the LO on certain populations of marine species, because for specific scavenger taxa discards provide a significant food subsidy, while other taxa are less dependent on them (Depestele et al., 2019). The LO may also have positive effects on the target population structure and species length composition, because it might reduce recruitment overfishing and thus assist in rebuilding previously overexploited European stocks (Froese et al., 2018). If changes follow expectations, the LO may help to achieve values of landings at/above maximum sustainable yield (MSY), in accordance with targets for healthy stocks and accurate stock assessments (Prellezo et al., 2016; Sola and Maynou, 2018). However, an important issue to be resolved is the full reporting of catches (Condie et al., 2014) and the compliance with regulations (Maynou, 2019), which will require high levels of control and monitoring coverage (James et al., 2019), and the creation of the right incentives that will enable the support of the measure by the fishing sector (Stithou et al., 2019).

The fishing sector will face changes in activity (e.g., by the adoption of more selective fishing gears or by limiting access to problematic fishing grounds) that are expected to result in short-term income loss, with potential negative consequences for the socio-economic viability of the sector. However, if these changes result in improved stock status then fishing communities will also benefit from higher income and better living standards (Guillen et al., 2018) assuming the fishing fleets are able to remain in business until this improvement occurs. The expected impact on production for human and non-human consumption is unknown; yet, utilization of former discards is now technically possible and, in some cases, economically viable (Lopes et al., 2015). Fishermen may be incentivized to increase investments in selective fishing gears and other technical changes to help avoid discards (Prellezo et al., 2016). Similarly, infrastructure on land to support the implementation of the LO will be required, such as fish storage and processing plants. Fishing effort may rise to catch the same amount of fish as before the LO, so fuel consumption and operational

[1]The fraction of landings under the regulation can be used for industrial purposes (for instance, reduction to fishmeal or fish oil) or other transformation, including indirect human consumption (pharmaceuticals, dietary supplements, etc.).

costs might increase (Frangoudes and Guillen, 2016). The LO might also cause changes in the remuneration system, the crew number, as well as the workload, as sorting the catch is a more labor demanding task (Maynou et al., 2018). An industry may rise to handle and process the "new landings" (former discarded fraction), therefore, the LO opens the possibility of new opportunities for by-catch utilization, especially for the processing sector and ancillary industries (Guillen et al., 2018). Overall, expected changes urge the need to identify socio-economic variables that can be integrated with indicators of the state of the ecosystem and need to be monitored under a common framework across European regional seas (Colburn et al., 2016). The identification of relevant variables for developing such indicators is not an easy task due to the multi-dimensionality of the problem, but also because these variables would probably gain significance only once the LO is fully implemented.

Consequences of discard prevention policies have been previously documented in countries such as Norway, Iceland, or Chile, but their application is not always successful and often implies changes in fisheries governance, as well as additional control/monitoring resources (Karp et al., 2019). Additionally it is not always clear how to assess the potential consequences of discard policies on the functioning of fishery system, as has been highlighted in several policy documents (e.g., EU, 2011) and in the literature (Damalas, 2015). Concerning the mitigation of indirect impacts mentioned in **Table 2** of Annex III of the Directive 2008/56/EC (EU, 2008: Marine Strategy Framework Directive, MSFD) in relation to achieving Good Environmental Status (GES), the Directive does not contain specific criteria regarding indicators on discards and by-catch, allowing the matter to be examined under relevant descriptors [Descriptor 1 (biological diversity), 3 (fisheries), 4 (food webs), and 6 (sea-floor integrity)]. With the amendment of the MSFD, additional criteria and methodological standards on GES of marine waters are introduced to address the effect of discarding, including further specifications and standardized methods for monitoring and assessment (EU, 2017a,b). The effects of discards' reduction should be evaluated based on the state of the relevant biodiversity components and food-web interactions. "Extraction of, or mortality/injury to, non-commercially exploited species (incidental by-catches) as a result of fishing activities" is addressed only under criterion D1C1 (Indicator: "Mortality rate per species"). However, the proposed indicators do not cover the whole spectrum of the fishery, nor provide information on the LO-related shifts that may be encountered in the fishery components. In particular, they do not explicitly address incidental (or unwanted) by-catches of commercial species, which are the main subject of the LO. In the same vein, a general lack of consistency appears to exist in the implementation of the MSFD and CFP objectives amongst the different member states (Raicevich et al., 2017) that restricts using Data Collection Framework (DCF) data for further assessments.

Following this complex situation and the high uncertainty in the outcomes of the recently implemented LO, we explored the potential of multi-dimensional variables to document progress toward sustainability of fisheries systems in European marine waters subjected to this new regulation framework. Hence, despite regional differences, a common methodology for assessing the state of fisheries after the full implementation of the new regime is sought. Monitoring the consequences of the elimination of discards, or alternatively the full use of fisheries catches, is however challenging due to the high number of indicators reflecting the different dimensions of the discards problem (Prellezo et al., 2016; Guillen et al., 2018; Christou et al., 2019; Maynou, 2019). Through a thorough literature review and experts' consultation, we explored the adequacy of a multi-dimensional set of variables selected from the literature that meet the demands of an operational monitoring system for the European discard ban.

In the past two decades numerous suites of indicators have been defined for fisheries management purposes (FAO, 1999; Garcia and Staples, 2000; Fletcher et al., 2005; Pelletier et al., 2008; Jepson and Colburn, 2013; Anderson et al., 2015) and rather than proposing new indicators specific to the discards ban policy, it is preferable to review the properties of existing ones and apply strict selection criteria (Queirós et al., 2016; Tam et al., 2017). The essential properties of biological and socio-economic variables to become candidate indicators are their ability to inform on the direction of change in a fishery system (Jennings, 2005). Other useful properties of the variables are that they could be relatively easy or inexpensive to measure within current fisheries data collection schemes and that they should be easily understood by fisheries managers and other stakeholders, in order to facilitate good governance and decision making (Lembo et al., 2017; de Juan et al., 2018). In this work, a candidate list of variables was identified from relevant literature (amongst others: Jennings, 2005; Rice and Rochet, 2005; FAO, 2009; Lockerbie et al., 2016) and was then assessed by LO experts with the application of quality criteria (Queirós et al., 2016). A sub-set of prioritized indicators was produced to allow for a cost-effective monitoring program by the assessment of a manageable number of robust variables. Finally, the feasibility to operationalize the selected indicators was assessed by exploring the availability and nature of data in a Mediterranean case study. In that way, a suite of easily derived indicators assured through quality control and testing can be selected for fisheries management under the LO implementation, increasing reproducibility and comparability of outcomes from study site to study site.

MATERIALS AND METHODS

The methodology adopted for the selection of candidate indicators for monitoring the ecological and socioeconomic dimensions of the LO integrates five key steps, discussed in detail in this section and visualized in **Figure 1**.

Framework Description

A methodological framework to explore candidate indicators was designed in order to examine the feasibility of monitoring the consequences of discards ban policy in a systematic way, by using evidence-based quality criteria. Different high-level policy objectives were proposed in coherence with the CFP and MSFD, allowing for a more operational interpretation at

FIGURE 1 | The methodological approach followed for the selection of indicators to operationalize a monitoring of the LO effects on fishery systems.

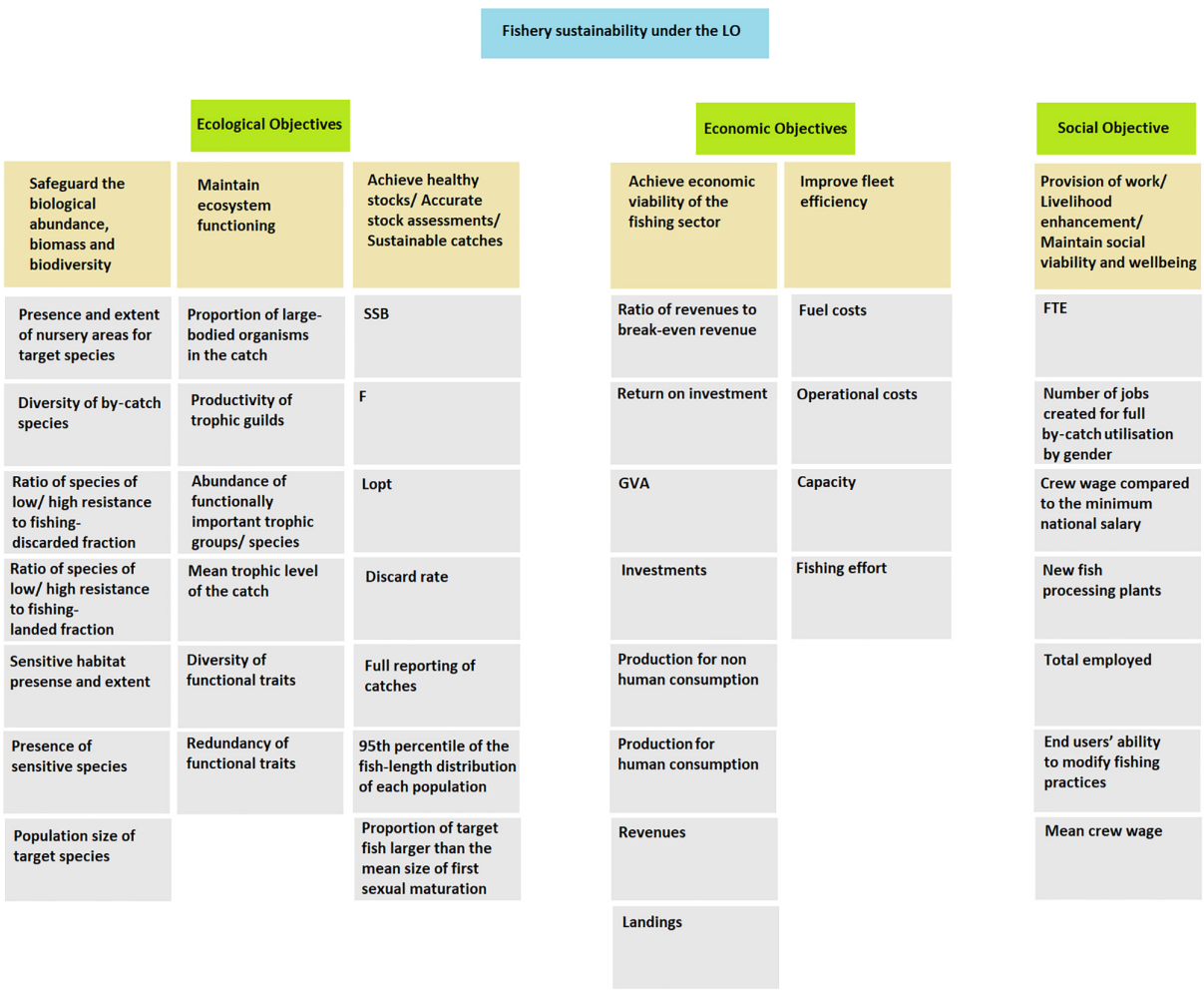

FIGURE 2 | Hierarchical tree of the goal, objectives, and indicators of the fishery sustainability under the LO. F, Fishing mortality; SSB, Spawning Stock Biomass; Lopt, Optimum length; GVA, Gross value added; FTE, Full time equivalent.

the fishery-specific levels (**Figure 2**). The principal goal (top tier) was to monitor changes to fishery sustainability, under the LO. The middle tier consisted of specific objectives nested into three dimensions (ecological, economic, social), similar to many policy documents related to the development of indicators for an ecosystem approach to fisheries (FAO, 1999, 2009), to operationalize fishery systems' monitoring under the LO. The ecological dimension was illustrated by three objectives tightly related to three Descriptors of the MSFD: (1) to safeguard biological abundance, biomass and biodiversity (Descriptor 1);

(2) the achievement of healthy stocks while improving the accuracy of stock assessments and sustainable catches (Descriptor 3); and (3) the maintenance of the ecosystem functioning (Descriptor 4). The economic dimension was represented by two objectives that are related with economic development of a sustainable fishery: (1) to improve fleet efficiency; and (2) to achieve economic viability of the fishing sector. These objectives were defined based on existing literature on fisheries sustainability targets related to the CFP (Lembo et al., 2017) and legal guidelines [e.g., Regulation (EU) No. 508/2014 (EU, 2014b), and Union Priority 1 "*Promoting environmentally sustainable, resource–efficient, innovative, competitive and knowledge–based fisheries*"]. The social dimension was represented by one objective related with the viability and wellbeing of society: the provision of work, livelihoods, and a self-defined quality of life in fishing communities. The weakness of defining social objectives in fisheries policy is discussed elsewhere (e.g., Symes and Phillipson, 2009) and, therefore, a broad objective was formulated based on the UN Sustainable development goals related to the provision of access and sustainable use of fisheries resources and sustainable patterns of production and consumption (Goals 12 and 14). This objective is also in line with Regulation (EU) No. 508/2014 (EU, 2014b) and more specifically, with Union Priority 4 "*Increasing employment and territorial cohesion by pursuing the following specific objective: the promotion of economic growth, social inclusion and job creation, and providing support to employability and labor mobility in coastal and inland communities which depend on fishing and aquaculture, including the diversification of activities within fisheries and into other sectors of maritime economy.*" The economic and social objectives are very closely related and could jointly be classified under a common dimension. However, the classification used here allows indicators related to fisheries productivity or production, i.e., economy from the point of view of the fishing industry, and economic or social indicators that represent factors that benefit society as a whole, to be represented under different categories.

A literature survey was conducted to collect and synthesize information related to the six objectives, and specifically on the potential effects of the LO on these objectives. The aim of this exercise was to include as many variables as possible in order to interconnect all available information. It included results produced by the MINOUW project, that are based on the results of structured interviews with stakeholders, scientific reports and expert knowledge. As the indicator selection was based both on literature review (e.g., FAO, 2009; Guillen et al., 2018) and deliverables from the MINOUW project (e.g., ecosystem and bioeconomic modeling outputs, mapping of by-catch areas, stakeholder interviews), not all indicators are founded on currently published data, although MINOUW outcomes are publicly available through the project's website[2]. This exercise identified 39 indicators that were classified under the six objectives (**Figure 2**). A detailed and operational specification of the indicators goes beyond the aim of the present study; as most of the indicators are commonly used in the literature (FAO, 2009; Lockerbie et al., 2016; Queirós et al., 2016; Guillen et al., 2018) some indicators are only broadly defined. However, the complete list and definition of indicators is provided in **Supplementary Material**.

[2]http://minouw-project.eu

Expert Knowledge Workshop

An *ad hoc* meeting was organized for 20 LO experts in winter 2018. The experts were selected from participants in the MINOUW project that have technical backgrounds in fisheries as well as a good knowledge of the discards ban policy. The objective of the meeting was to introduce the proposed methodological framework, based on scoring indicators through a long questionnaire, as well as to provide a detailed explanation of the questionnaire structure (see **Supplementary Material**). The introduction was followed by a group discussion to clarify any issues or concerns related to the questionnaire. During the meeting, the experts reviewed the candidate set of indicators and were encouraged to propose additional indicators and to express comments and further suggestions to improve the methodological framework. In addition, during the workshop, experts were asked to assess qualitatively the properties of the proposed indicators in terms of accuracy (how well the indicator helped inform on the objective) and sensitivity (how well the indicator helped identify the anticipated direction).

Remote Assessment of Candidate Indicators

The full survey was emailed to the project consortium as well as other experts of European fisheries that the workshop participants recommended as eligible to participate in the survey (23 individuals in total), to expand the pool of respondents, and broaden the range of disciplines covered. The recommended time dedicated to the survey was 30 min, although some experts mentioned that they devoted more than 5 h to complete the questionnaire, providing comments and suggestions, something very resourceful for acquiring a better understanding of the survey output. The deadline for submitting the questionnaire was 2 weeks after the completion of the workshop. We discussed in person or via email any points that were not clear for each respondent. Participation was on a voluntary basis and answers were anonymized in a way that there is no possible way to link the statements back to individual subjects. Twenty-three participants, covering the disciplines of ecology, marine biology, fisheries and socio-economics of fishery systems in Europe, completed the questionnaire (**Table 1**).

The first section of the survey focused on indicator quality based on 7 criteria commonly used in the literature (**Supplementary Material**; Rice and Rochet, 2005; Queirós et al., 2016; Tam et al., 2017). Suites of indicators covering the ecological, social and economic nature of fisheries are commonly used to assess the status and trends of relevant variables to help managers take informed decisions on the, often, multi-dimensional aspects of modern fisheries management (FAO, 1999; Jennings, 2005; Lockerbie et al., 2016). Following Rice and Rochet (2005), informative indicators must be significant, sensitive and measurable. In the case of monitoring the performance of the LO, the selected indicators should be

TABLE 1 | Expert's scientific background and affiliation. NGO, non-governmental organization; SME, small and medium-sized enterprise; Interdisciplinary background, expert with experience in research that involves the combining of two or more academic disciplines.

Background	Academia	Public research institute	NGO	SME
Socioeconomics	2	1		1
Marine Ecology/Fisheries Biology		11	1	
Interdisciplinary	1	5		1

The MINOUW project included 17 case studies spread across 7 European countries, examining fisheries based on trawl gears, purse seines, dredges, traps, pots, nets, and longlines.

able to significantly detect the impact of the discards ban, if properly implemented, on the ecology and socio-economy of the fisheries system, as well as be sensitive to detect changes to the system conditions. Furthermore, in order to facilitate their applicability, the indicators should be measurable with data routinely obtained during fisheries monitoring schemes or easily derived from ancillary data.

The scoring used to evaluate the indicator quality was based on the Delphi method (Okoli and Pawlowski, 2004) and in particular on an ordinal scale which takes values from 0 to 2, where 0: not met, 1: partly met, and 2: fully met (more information on the criteria and the scale applied can be found in the **Supplementary Table 5**). Besides the criteria, experts were asked to express how certain they were in their answers (in a scale from 0: 0% to 4: 100%) The experts also provided their opinions on the potential magnitude and direction of change of each indicator, assuming a full implementation of the LO (**Supplementary Table 2**).

Prioritization of Indicators

In order to produce a multi-variate but practical monitoring framework, the number of indicators to be monitored must be manageable. For this reason, the initial list of 39 indicators was ranked in a priority list. Different approaches were tested in order to select different sets of indicators based on the information contained in: (1) the score obtained through the 7 (quality) criteria, (2) the participants' certainty, and (3) the indicators' expected response direction (**Supplementary Table 1**).

An overall score was assigned to each indicator, estimated as the median of the weighted mean score (total score divided by 7) per person. Both the mean and the median of the indicators' scores were computed, but they provided a different ranking and, as the median down-weights the importance of outliers, it was used to rank the indicators in a way that is not skewed by extremely large or small values (**Supplementary Table 1**). The certainty expressed by experts was used as a weighting factor for the quality score, where a 0 implied the removal of the response, as it reflected the fact that the expert was not familiar with this particular question at all. Weighting by the certainty score avoided the inclusion of uncertain answers in the process of prioritization of indicators, in case the experts had limited knowledge on the nature of an indicator, and it provided a more valid evaluation of the indicators' suitability. As a result, the maximum score to be obtained by any indicator was 8 and the minimum 0, and the list of 39 indicators was accordingly ranked.

A subset of variables was extracted from this initial ranking by considering the additional information provided by the expected response direction (as an essential property of an indicator). Four approaches were tested and aimed to downweight the subjectivity involved in selecting cut-off points and in defining inclusion criteria. The first approach prioritizes the indicators that could eventually change due to the introduction of the LO, i.e., indicators were selected only if they were assigned either an overall positive (++/+) or negative (− −/−) expected response to the LO (i.e., to exclude indicators with a neutral effect). The second approach makes a more rigorous selection, prioritizing indicators with an expected response assigned by most respondents (≥50%), i.e., indicators were selected only if they were assigned either an overall positive (++/+) or negative (− −/−) response by the majority of experts (≥50%). The third approach was based on the selection of indicators that had obtained a minimum score of 4 (as the median of the quality score), based on the 7 criteria weighted by the certainty; this approach eliminates variables that have scored low in the quality criteria and/or those with an assigned a low certainty score (<50%) and thus retains the most robust variables. The fourth approach was a combination of the last two approaches, i.e., was based on both the expected direction of change assigned by the majority of respondents (approach 2) and the quality score (approach 3) (**Supplementary Tables 1**, **2**). To minimize subjectivity in prioritizing one approach over the other, we also produced an overall ranking of indicators by taking all approaches into account and assigning a score of 1 (for indicators that were selected by all approaches) to a score of 4 (for indicators that were not selected by any of the approaches). The properties and the number of indicators provided by each approach are further discussed in the "Results" section.

Application of the Framework in a Case Study

A case study is introduced to assess the feasibility of the methodological framework and to check for data availability to populate the list of indicators at spatial and temporal scales relevant of monitoring a fishery system. The case study is the multi-specific demersal otter-trawl fishery that targets hake (*Merluccius merluccius*) in the General Fisheries Commission for the Mediterranean (GFCM) Geographical Sub-Area (GSA) 6 (North-western Mediterranean) (see location of GSA 6 at http://www.fao.org/gfcm/data/maps/gsas/en/). A desktop review was conducted to identify sources of data for the 39 variables. Some of these variables are regularly reported in Mediterranean stock assessments by the Scientific Technical and Economic Committee for Fisheries (STECF); other variables were collected as part of a MINOUW project deliverables; while other variables needed calculations or indirect estimations. A detailed description of the data sources used in the case study is provided in the results section for those indicators included in Ranks 1-3 (Rank 4 consists of indicators that were not qualified by any of the four approaches tested). Those variables were more thoroughly

assessed, providing a discussion on the strengths and weaknesses to operationalize a monitoring framework at this early stage of the LO implementation.

RESULTS

Indicator Evaluation and Prioritization

Indicators related to the fisheries exploitation of the target species, traditionally used in stock assessments, held the highest scores based on respondents' appraisal (**Figure 3**). The economic variables held a wide range of scores, including also high scores for indicators under the "Achieve economic viability of the fishing sector" objective. Otherwise, the variables related to the social dimension of the fishery and to the ecosystem function were not well scored (median quality score was <4, i.e., quality and/or certainty on the properties of these indicators was low). This reflects a precarious opinion of respondents on the effects of the LO on social and ecosystem indicators (**Figure 3**). It could also be a potential bias of the study participants toward apportioning higher value to indicators pertaining to the natural sciences over the social sciences.

According to the experts' opinion, most indicators would not exhibit a clear response related to the LO implementation (**Supplementary Table 1**). For 15 indicators, the prevalent opinion (≥50% of responses) was of a positive effect after the implementation of the LO. For "Discard rate" experts assumed that the LO will have a large negative effect on discard numbers based on 31.6% of responses, although high variability was evident, with the second most popular answer to be a neutral effect (26.4%). On the other hand, ecosystem indicators were mostly characterized by neutral responses, although some indicators were related with a high level of uncertainty, especially for "Diversity of functional traits" and "Redundancy of functional traits" indicators. Whereas for most of the economic and social indicators, participants identified a potential response to the LO, some of the ecological indicators were not directly related to consequences of the LO, including ecosystem effects of the reduction of discards. In economic terms, according to experts' responses, the LO would likely have a positive effect on many indicators ("Investments," "GVA," "Landings," "Production for non-human consumption"), but the variance in responses was again very high. Some indicators were frequently assigned a neutral response (73.7% of responses for indicators "Capacity" and "Mean crew wage" and 79% for indicators "Fishing effort" and "Crew wage compared to the minimum national salary") suggesting a possible low additional burden of the LO on human hours and capacity.

Four approaches were adopted to select a sub-set of indicators, producing different sets of indicators that were ranked based on the frequency of selection by the approaches (**Table 2**). The first approach, that relied on experts' appraisal on the expected response, retained 20 indicators, achieving the representation of all objectives. For the second approach the same rule applied, but it was restricted to opinions given by the majority of experts (≥50%). In this case, only 15 indicators were selected, as indicators related with high variance in expert responses were excluded. The third approach excluded indicators that did not meet the quality criteria or their properties were assigned a low certainty. Fourteen indicators were retained, with a higher representation of ecological indicators, while social and economic indicators were underrepresented. The fourth approach, a combination of the second and third approaches retained 9 indicators, providing a rigorous set of indicators. Taking into account the four approaches, the indicators were ranked from 1 (i.e., retained by the 4 approaches), to 4, as the least performing indicators (i.e., that were not retained by any approach).

Case Study Application

The availability and sources of data for the 39 variables was explored in a Mediterranean case study: the demersal otter trawl targeting hake in GSA6 (**Table 3**). Only indicators in Ranks 1 to 3 were explored in depth, by retrieving data from different sources (**Table 3**). In total, 24 indicators were deployed for the operationalization of the framework. The variables estimated from catches, landings and related with data commonly included in stock assessment reports (e.g., SSB, F, fishing effort) were available for more than a decade. The economic indicators were also relatively easy to estimate from official sources of data, except for the "Production for non-human consumption," as this indicator will become relevant only with the full implementation of the LO and the availability of commercial outlets for UWCs brought to land. These limitations were also detected with social indicators, especially for three variables ("Total employed in fish processing plants," "New fish processing plants" and "Number of jobs created for full by-catch utilization by gender"), which are currently unavailable. Additionally, "End users' ability to modify fishing practices" resulted difficult to assess by participants due to its qualitative nature. None of these indicators were included in the priority list (Rank 1) (**Table 2**); however, "New fish processing plants" and "Number of jobs created for full by-catch utilization by gender" scored high (Rank 2) because most experts felt that these metrics would change due to the LO. Thus, the screening for data availability for the prioritized indicators evidenced the shortage of data to assess the possible changes related with the use of former discards. Several sources of data, particularly those for the objectives "Safeguard the biological abundance, biomass and biodiversity" and "Maintain ecosystem functioning," were identified as a product of the research project MINOUW or regular monitoring projects and protocols such as DCF, MEDITS, etc. In this case, the generalization of these variables to other case studies would be subject to data availability.

DISCUSSION

The multi-dimensionality of the potential consequences of the LO in fisheries systems implies the need to explore an extensive set of indicators that appropriately supports the gradual progress to a more complex and information rich policy framework. Our approach benefited from expert knowledge, essential for advancing on this topic as the LO implementation is in its infancy and there is high uncertainty on how the system will

TABLE 2 | Ranking of the variables according to the frequency of selection by the four approaches: 1 = the indicator is selected by all approaches, 2 = the indicator is selected by two approaches, 3 = the indicator is selected by one approach, 4 = none of the approaches selected the indicator.

Indicator	Approach 1	Approach 2	Approach 3	Approach 4	Rank
Presence and extent of nursery areas for target species	√	√	√	√	1
Presence of sensitive species			√		3
Diversity of by-catch species	√	√	√	√	1
Sensitive habitat presence and extent					4
Population size of target species	√	√	√	√	1
Ratio of species low/high resistance to fishing-discarded fraction			√		3
Ratio of species low/high resistance to fishing-landed fraction	√				3
Proportion of target species larger than the mean size at first sexual maturation	√	√	√	√	1
F			√		3
SSB	√	√	√	√	1
95th percentile of the fish length distribution of each target species	√	√	√	√	1
Full reporting of catches	√	√	√	√	1
Discard rate	√		√		2
Lopt	√	√	√	√	1
Productivity of trophic guilds					4
Proportion of large-bodied organisms (top of food webs) in the catch					4
Abundance of functionally important trophic groups/species	√				3
Diversity of functional traits					4
Redundancy of functional traits					4
Mean trophic level of the catch					4
Production for human consumption			√		3
Revenues					4
GVA	√	√			2
Return on investment					4
Landings	√	√	√	√	1
Investments	√	√			2
Ratio of revenues to break even revenue					4
Production for non-human consumption	√	√			2
Fuel costs	√				3
Operational costs	√	√			2
Capacity					4
Fishing effort					4
Mean crew wage					4
FTE					4
Crew wage compared to the minimum national salary					4
Total employed					4
New fish processing plants	√	√			2
Number of jobs created for full by-catch utilization by gender	√	√			2
End users' ability to modify fishing practices	√				3

*The same color coding is used as **Figure 3**, which denotes the indicator classification in objectives. F, Fishing mortality; SSB, Spawning Stock Biomass; Lopt, Optimum length; GVA, Gross value added; FTE, Full time equivalent.*

respond to the regulation. The experts scored the proposed variables following consolidated indicator criteria (Rice and Rochet, 2005; Queirós et al., 2016), and certainty in experts' opinion was considered for ranking the proposed indicators. Results evidenced that the indicators under the objectives "Achieve healthy stocks/Accurate stock assessments/Sustainable catches" and "Safeguard the biological abundance, biomass and biodiversity" were assigned the highest scores in respect to the quality criteria, while the indicators under the "Maintain ecosystem functioning" were assigned low scores in general. The lowest scores were assigned to the indicators under the objective "Provision of work/Livelihood enhancement/Maintain social viability and wellbeing," probably as some of the indicators under this category have a qualitative nature (e.g., "End users' ability to modify fishing practices") and were scored low in some of the criteria (e.g., "Possibility to set targets", "Quality of sampling method: measurable, accurate, precise and repeatable outputs"), but also because the experts were skeptical on the capacity of end users' to modify their practices. It is quite well-established in the literature that, socioeconomic objectives do not receive adequate attention among fisheries managers (Symes and Phillipson, 2009), who are mostly trained

TABLE 3 | Indicators under ranks 1 to 3 and application of the framework in a case study (Demersal otter trawl targeting hake in GSA6): availability of data including current sources of data, time frame available, proposed reference value, operationalization.

Indicator	Source	Time frame	Target	Operationalization
Presence and extent of nursery areas for target species	Maps produced in MINOUW D1.2 and D3.2.	Snapshot in time	Maximize current value (presence 0/1 and area)	Available script to estimate area from shapefile
Presence of sensitive species	Information compiled in MINOUW D1.1.	Snapshot in time	Maximize current value (presence 0/1)	Identification of sensitive species in the catch and/or landings
Diversity of by-catch species	Information compiled in MINOUW D1.1 and D3.9	1995–2014	Slope of temporal trend > 0	Identification of by-catch species in the catch and/or landings. Computation of Diversity indices (e.g., Kempton's Q using Ecopath with Ecosim software)
Population size of target species	DCF (DCF, 2017), MEDITS, JRC (Tables A and C)	Since 1994	Positive temporal trends	"*Ad hoc*" script for computation of number/km2 and kg/km2 (need to be prepared according to DCF/STECF)
Ratio of species low/high resistance to fishing (landed or discarded fraction)	Information compiled in MINOUW D1.1. (catch data) and D1.10 (resistance score)	1995–2014	Maximize, slope of temporal trend > 0	Available script to assign resistance score to each species
Proportion of target species larger than the mean size at first sexual maturation	DCF landings_length + discards_length + ancillary data (FishBase, SeaLifeBase, or sci. pubs.)	2010–2014	Maximize spawning potential, ref. point. 100%	"*Ad hoc*" script for estimating Froese's indicator (Froese, 2004)
F	Information compiled in STECF reports	Since 2003	Keep below reference (F_{msy})	According to STECF and GFCM stock assessments
SSB	Information compiled in STECF reports	Since 2003	Keep above reference (SSB_{msy})	According to STECF and GFCM stock assessments
95th percentile of the fish length distribution of each target species	DCF landings_length + discards_length + ancillary data (FishBase, SeaLifeBase, or sci. pubs.)	2010–2014	Safeguard mega-spawners, ref. point. 30–40%	Available script to estimate Froese's indicator (Froese, 2004)
Full reporting of catches	Current available data are only from reported catches	2012–2014	Catches reported-estimated = 0	Script needs to be written to estimate un-reported fraction based on observations
Discard rate	Information compiled in MINOUW D1.1.	2012–2014	Minimize discards, ref. point. < 5%	Available script for computation of Discards/catch rate
Lopt	DCF landings_length + discards_length + ancillary data (FishBase, SeaLifeBase, or sci. pubs.)	2010–2014	Maximize stock productivity, ref. point. 100%	Available script to estimate Froese's indicator (Froese, 2004)
Abundance of functionally important trophic groups/species	Define which species belong to each Trophic Guild and estimate abundance. Data source: MEDITS. Trophic guild data provided in MINOUW D1.10	Since 1994	Maximize; slope of temporal trend > 0	Available script for the assignation of species to trophic guilds and estimations. Available script to estimate abundance (mean CPUE could be used as an index)
Production for human consumption	Annual Economic Report; DCF data; own sampling	2008–2015	Optimize; ref. point > 0	According to Annual Economic Report (AER) estimates (e.g., STECF, 2017)
GVA	Annual Economic Report; DCF data; own sampling	2014	Maximize; ref. point > 0	According to AER estimates (e.g., STECF, 2017)
Landings	High similarity with "Production for human consumption," except when production is channeled through 'other markets'	2010–2014	Optimize; ref. point > 0	According to AER estimates (e.g., STECF, 2017)
Investments	Information compiled in STECF reports	2008–2013	Optimize; ref. point > 0	According to AER estimates (e.g., STECF, 2017)
Production for non-human consumption	No data (it could be available after LO implementation)	N/A	Optimize; ref. point > 0	N/A

(Continued)

TABLE 3 | Continued

Indicator	Source	Time frame	Target	Operationalization
Fuel costs	STECF; it can be improved with Annual Economic Report; DCF data; own sampling	2008–2013	Optimize; ref. point N/A	According to AER estimates (e.g., STECF, 2017)
Operation costs	STECF; it can be improved with Annual Economic Report; DCF data; own sampling	2008–2013	Optimize; ref. point N/A	According to AER estimates (e.g., STECF, 2017)
New fish processing plants	No data (it could be available after LO implementation)	N/A	Optimize; ref. point > 0	N/A
Number jobs created for full by-catch utilization by gender	No data (it could be available after LO implementation)	N/A	Maximize; ref. point > 0	Script needs to be written to estimate the ratio of male/female from official sources
End users' ability to modify fishing practices	A qualitative variable. Willingness to pay could be used as a 'mark up' price for fish produced in no-discard fisheries to incentivize the adoption of more selective fishing practices (Onofri et al., 2018)	N/A	Maximize; ref. point > 0	N/A

For data retrieved from MINOUW deliverables, note that these are public and are available through http://minouw-project.eu. The same color coding is used as ***Figure 3****, which denotes the indicator classification in objectives. F, Fishing mortality; SSB, Spawning Stock Biomass; Lopt, Optimum length; GVA, Gross value added.*

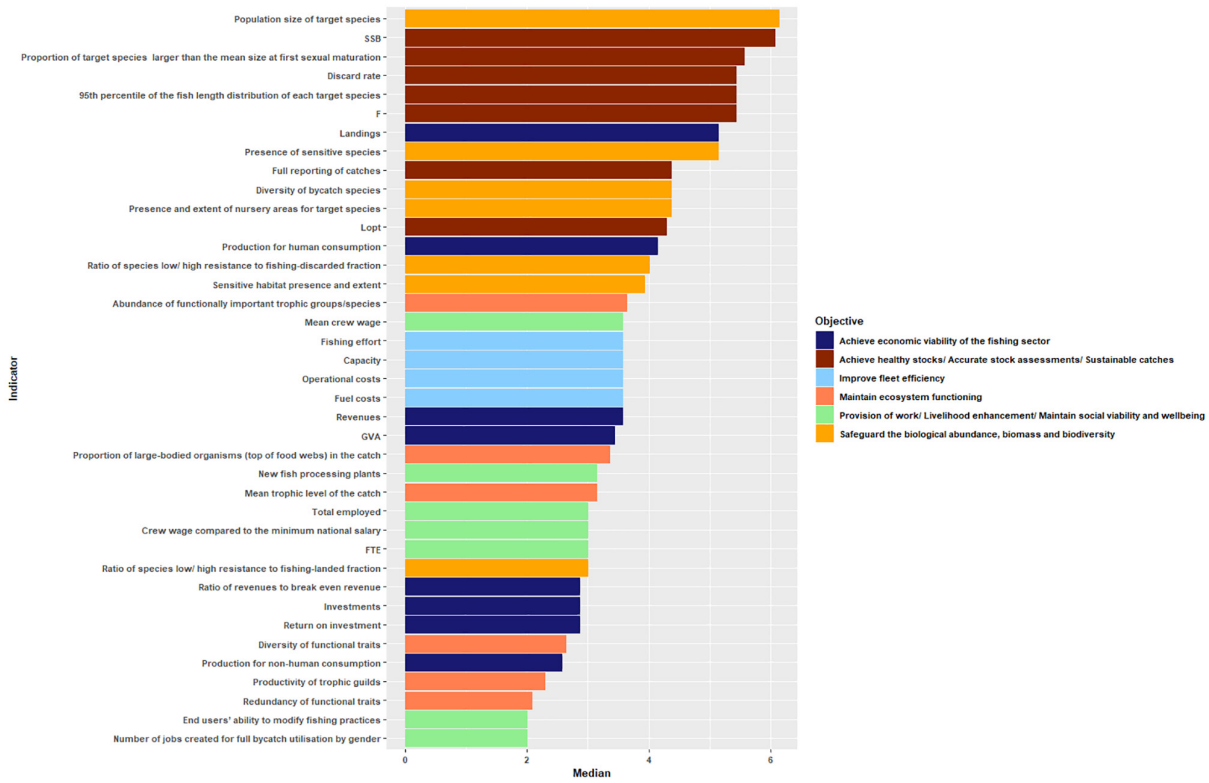

FIGURE 3 | Indicators' quality score based on experts' appraisal on 7 quality criteria and on the certainty of answers. F, Fishing mortality; SSB, Spawning Stock Biomass; Lopt, Optimum length; GVA, Gross value added; FTE, Full time equivalent. Bar color indicates framework objectives.

in biological-ecological sciences. It is not a coincidence that the policy focus of many regulations heavily relies on biological outcomes rather than other social or economic considerations (Karpoff, 1987). Tracking economic and community outputs for evaluating fisheries status was underlined by many recent studies related to the development of indicators for fisheries sustainability (Jepson and Colburn, 2013; Anderson et al., 2015). Also, the behavior of some socioeconomic indicators is not yet well understood (e.g., "New fish processing plants", "Number of jobs created for full by-catch utilization by gender"), as evidenced by the large degree of uncertainty in the experts' opinions. Currently, little information exists for estimating LO driven

changes in fishing behavior (Condie et al., 2013). The usage of social response models for the assessment of social impacts is a rapidly expanding field that can improve the analytical rigor of fisheries management (Jepson and Colburn, 2013). To trace alterations in fishery activity after the introduction of management measures may not be a simplistic task as these may vary in response to technical, environmental, and behavioral factors (Rijnsdorp et al., 2006; Kraak et al., 2008). Experts mentioned that the assessment of indicators was a challenge as the nature and link with LO for some variables was far from straightforward. That was the main reason for the low certainty expressed by experts for some indicators. Other reasons were lack of knowledge about the short-term consequences of the LO or that the indicator was not within their research expertise. Nevertheless, we emphasize the importance of including these data-poor and/or low scored indicators in a proposed monitoring approach as these might allow the launch of an early warning system to detect potential changes generated at the beginning of the full LO implementation. To our knowledge, no other study exists in the literature on the proposal of an indicator framework to assess fisheries sustainability at such an initial stage of the LO implementation; the fact that the indicators presented here were evaluated by key experts in the field is of added value, as a monitoring protocol needs to be objective, usable, and holistic, covering the environmental, social, economic and institutional aspects of sustainability (Reed et al., 2010).

A probable limitation of the study is the fact that the expert consultation was done by a relatively small group of experts from different backgrounds which were not equally represented. We also faced problems in finding experts on this topic -which is recent- and assessing variables that are not yet significant for tracing changes due to the early phase of LO implementation and this inevitability leads to high subjectivity in the survey input. And yet, the survey revealed that experts, regardless of their scientific background, perceived that the LO will result in no major changes for Mediterranean fisheries which is in accordance with the suggestion that the LO will have less impact on fishing practices for which discards are driven by market rules (Catchpole et al., 2013; Stithou et al., 2019). For less than half of the assessed indicators, experts assumed that the LO would influence their trends in a positive way. Experts assigned positive trends to indicators related to biomass extracted, such as SSB, landings, production for non-human consumption and GVA. These positive trends might reflect a belief that the LO would impact the landed portion of biomass and that it may have beneficial economic effects. On the other hand, most experts assigned a neutral response to indicators that are a function of effort. This neutral trend is in accordance to several studies that have revealed that the burden of better sorting and landing the former discards would be low, in respect to workload, due to the relatively low percentage of UWCs under the remit of the LO (Maynou et al., 2018; Sola and Maynou, 2018). A neutral response was also assigned to ecological indicators, likely because experts are still uncertain on the potential effects of the LO on the ecosystem, and only assumptions are made when assessing the indirect effects caused by changing fishing practices, i.e., changes in the integrity of ecosystems (Bellido et al., 2011; Heath et al., 2014; Moutopoulos et al., 2018). These indicators are also intended to reflect an improved ecosystem status due to changing fishing practices, e.g., the diversity of functional traits or the sensitive habitat presence and extend (Thrush and Dayton, 2002; de Juan et al., 2009, 2018). Participants assumed that only one indicator (i.e., Discard rate) would decrease, although there was a large variation in experts' opinions. The aim of the reformed CFP to reduce the impact of fisheries on the marine environment, "*including the avoidance and reduction, as far as possible, of UWCs*" (EU, 2013), could be the ultimate oxymoron as the discard ban may not result in a dramatic reduction of UWC and thus it may have a limited impact on the fishing sector or it may create additional problems to the industry (a "Crash Landing" Obligation), if it is not implemented in conjunction with additional measures and in accordance with fisher's incentives and practices (Condie et al., 2013; Christou et al., 2019; Stithou et al., 2019). Effective introduction of discard ban policies relies on high levels of surveillance or economic incentives (Condie et al., 2014). A progressive implementation of the LO started in 2015, too recent to record established patterns of change in the fishery system, especially because current evidence points to low compliance in European fisheries. Therefore, the expected changes in indicators are currently reflecting the 'fuzzy' opinion of experts. From their experience, the LO has been practically neutralized with the use and "abuse" of *de minimis* exemptions in the first two phases of its implementation, and the introduction of regional discard plans: 2015 for the small pelagic fish, 2017 for the species that define the fishery (for instance, EU, 2014a, 2018). Then, many experts can logically think that the 2019 full implementation will proceed in the same way. This thinking is probably reflected in the questionnaire, where experts may have scored some indicators relying on their personal feelings on what is likely to happen, rather than on objective knowledge on the fishery system. The general feeling of the experts (provided as "additional comments" in the survey) was that the LO implementation has certain limitations. In particular, experts commented that the implementation degree of the first two LO phases (2015, 2017) was very low and that it was not properly monitored. Fishers have also reported the partial implementation of the LO in South European countries, while they claimed that this new regime may not have a major impact on their activity (Christou et al., 2017; Maynou et al., 2018; Villasante et al., 2019).

Given the scale that LO impacts may have on the environment and on society, it is critical to promote a holistic, yet flexible framework, for monitoring fisheries systems if we aim to achieve fisheries sustainability. This framework was designed to trace changes in European fisheries but the methodology used can be of further use in other fisheries under the LO (or even other regulatory changes). Aiming to reflect the multi-dimensionality of the problem, a large set of variables was compiled. For an operational monitoring program, the indicators should be assessed against a reference value or a target. In many cases, time series of data were available, and the target could be defined as the maximization or the minimization of the indicator over time, after the LO implementation (e.g., maximization of Landings; minimization of Discards). For those variables

traditionally included in fisheries monitoring, reference values have already been proposed (e.g., F_{MSY}). For the spatial variables, like extent of nursery or sensitive habitat, it is proposed to set targets related with maintaining the *status quo* or maximization of current values (i.e., avoid the decrease of the baseline). However, to operationalize a monitoring approach, the proposed 39 indicators need to be reduced to a limited yet robust set of indicators that could be assessed efficiently to derive conclusions on the state of the fisheries systems (Borja et al., 2013). There was consistency in the prioritization of indicators by the different approaches, and the ranking performed according to frequency of selection across methods provided a list with a clear categorization of indicators. However, this ranking was dominated by ecological indicators, and specifically by variables related to the target species and fished stocks. The first approach was more inclusive and allowed the representation of indicators across all the objectives, including some variables with low quality scores. For the second and third approaches, only 15 and 14 indicators were selected respectively, with social and economic indicators under-represented. The fourth approach, including experts' appraisal on how the indicators would respond to the LO, selected only nine indicators. However, none of the approaches was completely unbiased, and not all objectives were equally represented. The selection of priority indicators implies subjectivity in defining a cut-off threshold and in deciding which information should be used for prioritization. The proposed approaches are more precise than the selection of a pre-defined set of indicators, as only the evaluation by external experts objectively determines how many indicators should be finally selected (Marletto and Mameli, 2012).

In order to test the operationalization of the ranked indicators, data was gathered for the demersal otter trawl fishery targeting hake in GSA6. We observed that the information to produce the indicators could be collected and it is feasible to track these variables over time for most indicators examined. However, the case study evidenced the data demanding nature of the approach, as we considered that to extend the exercise to a meaningful set of fisheries would take a significant amount of time. Therefore, for a cost-effective approach, the initial set definitively needs to be reduced to a manageable set of variables and the ranking of indicators might be the starting point. Another controlling factor for the selection of indicators, crucial for their consideration by monitoring authorities (i.e., European Commission or other), is the cost to obtain, including the need to develop specific research programs. For instance, deriving "Lopt" from size frequencies (Froese, 2004) is practically free, as it is a byproduct of regular monitoring programs, -e.g., MEDITS in the Mediterranean-, it has long-time records and it will be continued in the foreseeable future. Monitoring the indicator "Full documentation of catches" can be extremely expensive and/or difficult, as it relies on collaborative fishermen and on the technical and financial resources available to fisheries control agencies. Thus, the feasibility of monitoring the "Full documentation of catches" is largely questionable, although efforts for better data collection should not be dissuaded by the lack of current information; on the contrary they should be supported and strengthened. The data required for these indicators could be retrieved from multiple sources e.g., personal interviews or spatial analysis (e.g., distribution maps of recruits for target species), and both qualitative and quantitative approaches can provide critical input, although there could be regional differences. Additionally, the reference points and decision criteria could be different depending on the scale of application and management focus enabling the detailed representation of a trend/gradient rather than a binary scheme that might lead to information loss (Rice et al., 2012). To operationalize the approach, we propose the development of web-based tools that support a rapid extraction of the data (e.g., the project www.indiseas.org was developed for indicator evaluation and communication, while R scripts for calculations and applications such as "shiny app," http://shiny.rstudio.com, could be used for quick visualizations). An R-based "shiny app" provides a "friendly interface" useful for indicator applications as it is based on an open-source tool commonly used by fisheries scientists, and offers dynamic visualizations and the possibility of sharing scripts among scientist for further improvement. Another crucial factor is the definition of monitoring frequency and scale, and the temporal scale we propose is the annual scale, in accordance with regular monitoring reports, and the length of time given by whatever data are available. For GSA 6, limitations exist in the length of the time series; this lack of data exists for many fisheries in the Mediterranean (e.g., Tserpes et al., 2016). Such data limitations will compromise the monitoring of changes in fisheries systems after the introduction of the LO and should encourage regional fisheries management bodies to implement monitoring programs at this stage of early LO implementation.

Rarely there will be complete data sets for all indicators. In any case, the current identification of relevant indicators and the preliminary evaluation of gaps in knowledge provides the opportunity for developing an operational monitoring framework from an initial phase of the LO. Experts recognized the potential shift of most socio-economic indicators due to the introduction of the LO and that these should be assessed as soon as data becomes available. A delay in the implementation of the approach, so that more data are available, might imply a loss of valuable information or obtaining unexpected and undesirable outcomes. An option to overcome this issue is to model scenarios to assess trends and not static points according to the currently available data (Lockerbie et al., 2016). Although, for some variables, this would still be not possible due to uncertainty on how these might respond to direct/indirect effects of implementation. It is important to investigate the effects of the LO as a driver of change on the different components of the fishery system, because this might evidence those actions that should be highlighted to the fishing industry and policy makers, as well as any potential limitations and barriers in the implementation of the LO. One conclusion drawn from this exercise is the uncertainty on how ecological and socio-economic indicators might respond to the LO. This suggests that a monitoring framework should be receptive to feedback, while more data on LO effects is acquired. It should work in a flexible way, repeating the exercise for indicator prioritization once more data are gathered, and based on regional priorities. In fact, the adoption of a monitoring approach to each region should

be preceded by a regional experts' workshop that could help to adapt the approach to regional characteristics of the fishery socio-ecological systems and to establish a common baseline dataset, that allows comparability but also has the flexibility to include supplementary variables that would enable testing of additional hypotheses if relevant.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the manuscript/**Supplementary Files**.

ETHICS STATEMENT

The survey was prepared under the H2020 MINOUW Programme. Participation was on a voluntary basis, by filling the questionnaire it meant that consent was given to process this input and answers were anonymized in a way there is no possible way to link the statements back to individual subjects.

AUTHOR CONTRIBUTIONS

MC, SJ, VV, and FM designed the study. MC, SJ, and FM analyzed the data and wrote the first draft of the manuscript. All authors critically revised and approved the manuscript.

FUNDING

This study was developed in the framework of MINOUW EU project (Project ID: 634495). SJ was funded by H2020-Marie Skłodowska-Curie Action MSCA-IF-2016 (Project ID: 743545).

ACKNOWLEDGMENTS

This study is part of the Ph.D. thesis of the MC, conducted at Aristotle University of Thessaloniki. The authors would like to thank all participants in the survey as their contribution allows the production of this work providing a multi-disciplinary experts' perspective to the problem of LO implementation. The authors would also like to thank Maria Pantazi for her assistance in designing the questionnaire presented herein, and Ioanna and Andreas Kokkinoftas for proofreading the manuscript. Lastly, the authors are grateful to the editorial team and the reviewers for their detailed suggestions which helped us to improve the quality of the manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2019.00594/full#supplementary-material

REFERENCES

Anderson, J. L., Anderson, C. M., Chu, J., Meredith, J., Asche, F., Sylvia, G., et al. (2015). The fishery performance indicators: a management tool for triple bottom line outcomes. *PLoS One* 10:e0122809. doi: 10.1371/journal.pone.0122809

Bellido, J. M., Santos, M. B., Pennino, M. G., Valeiras, X., and Pierce, G. J. (2011). Fishery discards and bycatch: solutions for an ecosystem approach to fisheries management? *Hydrobiologia* 670, 317–333. doi: 10.1007/s10750-011-0721-5

Borja, A., Elliott, M., Andersen, J. H., Cardoso, A. C., Carstensen, J., Ferreira, J. G., et al. (2013). Good environmental status of marine ecosystems: what is it and how do we know when we have attained it? *Mar. Pollut. Bull.* 76, 16–27. doi: 10.1016/j.marpolbul.2013.08.042

Catchpole, T. L., Feekings, J. P., Madsen, N., Palialexis, A., Vassilopoulou, V., Valeiras, J., et al. (2013). Using inferred drivers of discarding behaviour to evaluate discard mitigation measures. *ICES J. Mar. Sci.* 71, 1277–1285. doi: 10.1093/icesjms/fst170

Catchpole, T. L., Frid, C. L. J., and Gray, T. S. (2006). Importance of discards from the English Nephrops norvegicus fishery in the North Sea to marine scavengers. *Mar. Ecol. Prog. Ser.* 313, 215–226. doi: 10.3354/meps313215

Christou, M., Haralabous, J., Stergiou, K. I., Damalas, D., and Maravelias, C. D. (2017). An evaluation of socioeconomic factors that influence fishers' discard behaviour in the Greek bottom trawl fishery. *Fish. Res.* 195, 105–115. doi: 10.1016/j.fishres.2017.07.003

Christou, M., Maynou, F., Tserpes, G., Stergiou, K. I., and Maravelias, C. D. (2019). "Crash Landing" obligation for Mediterranean mixed fisheries: evaluation of management strategies using bioeconomic modelling in the Aegean Sea. *Sci. Mar.* 83, 143–154. doi: 10.3989/scimar.04881.08A

Colburn, L. L., Jepson, M., Weng, C., Seara, T., Weiss, J., and Hare, J. A. (2016). Indicators of climate change and social vulnerability in fishing dependent communities along the Eastern and Gulf Coasts of the United States. *Mar. Policy* 74, 323–333. doi: 10.1016/j.marpol.2016.04.030

Condie, H. M., Grant, A., and Catchpole, T. L. (2013). Does banning discards in an otter trawler fishery create incentives for more selective fishing? *Fish. Res.* 148, 137–146. doi: 10.1016/j.fishres.2013.09.011

Condie, H. M., Grant, A., and Catchpole, T. L. (2014). Incentivising selective fishing under a policy to ban discards; lessons from European and global fisheries. *Mar. Policy* 45, 287–292. doi: 10.1016/j.marpol.2013.09.001

Damalas, D. (2015). Mission impossible: discard management plans for the EU Mediterranean fisheries under the reformed common fisheries policy. *Fish. Res.* 165, 96–99. doi: 10.1016/j.fishres.2015.01.006

Damalas, D., Ligas, A., Tsagarakis, K., Vassilopoulou, V., Stergiou, K. I., Kallianiotis, A., et al. (2018). The "discard problem" in Mediterranean fisheries, in the face of the European Union landing obligation: the case of bottom trawl fishery and implications for management. *Mediterr. Mar. Sci.* 19, 459–476.

DCF (2017). Regulation (EU) 2017/1004 of the European Parliament and of the Council of 17 May 2017 on the establishment of a Union framework for the collection, management and use of data in the fisheries sector and support for scientific advice regarding the common fisheries policy and repealing Council Regulation (EC) No. 199/2008 (recast).

de Juan, S., Demestre, M., and Thrush, S. (2009). Defining ecological indicators of trawling disturbance when everywhere that can be fished is fished: a Mediterranean case study. *Mar. Policy* 33, 472–478. doi: 10.1016/j.marpol.2008.11.005

de Juan, S., Hewitt, J., Subida, M. D., and Thrush, S. (2018). Translating ecological integrity terms into operational language to inform societies. *J. Envir. Manag.* 228, 319–327. doi: 10.1016/j.jenvman.2018.09.034

Depestele, J., Feekings, J., Reid, D. J., Cook, R., Gascuel, D., Girardin, R., et al. (2019). "The impact of fisheries discards on scavengers in the Sea," in *The European Landing Obligation: Reducing discards in complex multi-species and multi-jurisdictional fisheries*, eds S. Uhlmann, C. Ulrich, and S. Kennelly (Cambridge: Springer).

Eliasen, S. Q., Papadopoulou, K.-N., Vassilopoulou, V., and Catchpole, T. L. (2014). Socio-economic and institutional incentives influencing fishers' behaviour in

relation to fishing practices and discard. *ICES J. Mar. Sci.* 71, 1298–1307. doi: 10.1093/icesjms/fst120

EU (2008). *Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 Establishing a Framework for Community Action in the Field of Marine Environmental Policy (Marine Strategy Framework Directive)*. Brussels: European Union, 19–40.

EU (2011). *Commission Staff Working Paper Relationship Between the Initial Assessment of Marine Waters and the Criteria for Good Environmental Status*. Brussels: European Union, 95.

EU (2013). *Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC*. Brussels: European Union, 22–61.

EU (2014a). *Commission Delegated Regulation (EU) No 1392/2014 of 20 October 2014 establishing a Discard Plan for Certain Small Pelagic Fisheries in the Mediterranean Sea*. Brussels: European Union, 21–24.

EU (2014b). *Regulation (EU) No 508/2014 of the European Parliament and of the Council of 15 May 2014 on the European Maritime and Fisheries Fund and Repealing Council Regulations (EC) No 2328/2003, (EC) No 861/2006, (EC) No 1198/2006 and (EC) No 791/2007 and Regulation (EU) No 1255/2011 of the European Parliament and of the Council*. Brussels: European Union.

EU (2017a). *Commission Decision (EU) 2017/848 of 17 May 2017 Laying Down Criteria and Methodological Standards on Good Environmental Status of Marine Waters and Specifications and Standardised Methods for Monitoring and Assessment, and Repealing Decision 2010/477/EU*. Brussels: European Union, 32.

EU (2017b). *Commission Directive (EU) 2017/845 of 17 May 2017 Amending Directive 2008/56/EC of the European Parliament and of the Council as Regards the indicative Lists of Elements to be taken into Account for the Preparation of Marine Strategies*. Brussels: European Union, 7.

EU (2018). *Commission Delegated Regulation (EU) 2018/153 of 23 October 2017 Amending Delegated Regulation (EU) 2017/86 Establishing a Discard Plan for Certain Demersal Fisheries in the Mediterranean Sea*. Brussels: European Union, 1–5.

FAO (1999). *Indicators for Sustainable Development of Marine Capture Fisheries*. FAO Technical Guidelines for Responsible Fisheries. No. 8. Rome: FAO, 68.

FAO (2009). *Report of the Expert Workshop on the Development and Use of Indicators for an Ecosystem approach to fisheries*. Rome: FAO.

Fauconnet, L., Frangoudes, K., Morato, T., Afonso, P., and Pita, C. (2019). Small-scale fishers' perception of the implementation of the EU landing obligation regulation in the outermost region of the Azores. *J. Environ. Manage.* 249:109335. doi: 10.1016/j.jenvman.2019.109335

Fletcher, W. J., Chesson, J., Sainsbury, K. J., Hundloe, T. J., and Fisher, M. (2005). A flexible and practical framework for reporting on ecologically sustainable development for wild capture fisheries. *Fish. Res.* 71, 175–183. doi: 10.1016/j.fishres.2004.08.030

Frangoudes, K., and Guillen, J. (2016). *Appropriate Economic and Social Criteria to Evaluate the Discard Mitigation Strategies and the Defined Management scenarios, DiscardLess Project Deliverable Report D2.2*. Genève: Zenodo.

Froese, R. (2004). Keep it simple: three indicators to deal with overfishing. *Fish Fish.* 5, 86–91.

Froese, R., Winker, H., Coro, G., Demirele, N., Tsikliras, A. C., Dimarchopoulou, D., et al. (2018). Status and rebuilding of European fisheries. *Mar. Policy* 93, 159–170. doi: 10.1016/j.marpol.2018.04.018

Garcia, S. M., and Staples, D. J. (2000). Sustainability reference systems and indicators for responsible marine capture fisheries: a review of concepts and elements for a set of guidelines. *Mar. Freshw. Res.* 51, 385–426.

Guillen, J., Holmes, S. J., Carvalho, N., Casey, J., Dörner, H., Maurizio, G., et al. (2018). A review of the European Union landing obligation focusing on its implications for fisheries and the environment. *Sustainability* 10:900. doi: 10.3390/su10040900

Heath, M. R., Cook, R. M., Cameron, A. I., Morris, D. J., and Speirs, D. C. (2014). Cascading ecological effects of eliminating fishery discards. *Nat. Commun.* 13:3893. doi: 10.1038/ncomms4893

James, K. M., Campbell, N., Viðarsson, J. R., Vilas, C., Plet-Hansen, K. S., Borges, L., et al. (2019). "Tools and technologies for the monitoring, control and surveillance of unwanted catches," in *The European Landing Obligation: Reducing Discards in Complex Multi-Species and Multi-Jurisdictional Fisheries*, eds S. Uhlmann, C. Ulrich, and S. Kennelly (Cambridge: Springer).

Jennings, S. (2005). Indicators to support an ecosystem approach to fisheries. *Fish and Fish.* 6, 212–232. doi: 10.1111/j.1467-2979.2005.00189.x

Jepson, M., and Colburn, L. L. (2013). *Development of Social Indicators of Fishing Community Vulnerability and Resilience in the US Southeast and Northeast Regions. NOAA Technical Memorandum NMFS-F/SPO-129*. Silver Spring, MD: National Oceanic and Atmospheric Administration.

Kaiser, M. J., and Hiddink, J. G. (2007). Food subsidies from fisheries to continental shelf benthic scavengers. *Mar. Ecol. Prog. Ser.* 350, 267–276. doi: 10.3354/meps07194

Karp, W. A., Breen, M., Borges, L., Fitzpatrick, M., Kennelly, S. J., Kolding, J., et al. (2019). "Strategies used throughout the world to manage fisheries discards – Lessons for implementation of the EU landing obligation," in *The European Landing Obligation: Reducing Discards in Complex Multi-Species and Multi-Jurisdictional Fisheries*, eds S. Uhlmann, C. Ulrich, and S. Kennelly (Cambridge: Springer). doi: 10.1007/978-3-030-03308-8_1

Karpoff, J. M. (1987). Suboptimal controls in common resource management: the case of the fishery. *J. Polit. Econ.*, 95, 179–194. doi: 10.1086/261447

Karris, G., Ketsilis-Rinis, V., Kalogeropoulou, A., Xirouchakis, S., Machias, A., Maina, I., et al. (2018). The use of demersal trawling discards as a food source for two scavenging seabird species: a case study of an eastern Mediterranean oligotrophic marine ecosystem. *Avian Res.* 9:26.

Kopp, D., Marianne, R., Tiphaine, C., and Sonia, M. (2016). Some expected impacts of the common fishery policy on marine food webs. *Mar. Policy* 66, 8–14. doi: 10.1016/j.marpol.2016.01.002

Kraak, S. B. M., Buisman, F. C., Dickey-Collas, M., Poos, J. J., Pastoors, M. A., Smit, J. G. P., et al. (2008). The effect of management choices on the sustainability and economic performance of a mixed fishery: a simulation study. *ICES J Mar. Sci.* 65, 697–712. doi: 10.1093/icesjms/fsn045

Lembo, G., Bellido, J. M., Bitetto, I., Facchini, M. T., García-Jiménez, T., Stithou, M., et al. (2017). Preference modeling to support stakeholder outreach toward the common fishery policy objectives in the North Mediterranean Sea. *Front. Mar. Sci.* 4:328. doi: 10.3389/fmars.2017.00328

Lockerbie, E. M., Shannon, L. J., and Jarre, A. (2016). The use of ecological, fishing and environmental indicators in support of decision making in southern Benguela fisheries. *Ecol. Indic.* 69, 473–487. doi: 10.1016/j.ecolind.2016.04.035

Lopes, C., Antelo, L. T., Franco-Uría, A., Antonio, A. A., and Pérez-Martín, R. (2015). Valorisation of fish by-products against waste management treatments – Comparison of environmental impacts. *Waste Manag.* 46, 103–112. doi: 10.1016/j.wasman.2015.08.017

Maina, I., Kavadas, S., Machias, A., Tsagarakis, K., and Giannoulaki, M. (2018). Modelling the spatiotemporal distribution of fisheries discards: a case study on eastern Ionian Sea trawl fishery. *J Sea Res.* 139, 10–23. doi: 10.1016/j.seares.2018.06.001

Marletto, G., and Mameli, F. (2012). A participative procedure to select indicators of policies for sustainable urban mobility. Outcomes of a national test. *Eur. Transp. Res. Rev.* 4, 79–89. doi: 10.1007/s12544-012-0075-8

Maynou, F. (2019). Co-viability of a Mediterranean demersal fishery affected by the discard ban under alternative management scenarios. *Fish. Manag. Ecol.* 26, 345–353. doi: 10.1111/fme.12365

Maynou, F., Gil, M. D. M., Vitale, S., Giusto, G. B., Foutsi, A., Rangel, M., et al. (2018). Fishers' perceptions of the European Union discards ban: perspective from south European fisheries. *Mar. Policy* 89, 147–153. doi: 10.1016/j.marpol.2017.12.019

Moutopoulos, D. K., Tsagarakis, K., and Machias, A. (2018). Assessing ecological and fisheries implications of the EU landing obligation in Eastern Mediterranean. *J. Sea Res.* 141, 99–111. doi: 10.1016/j.seares.2018.08.006

Okoli, C., and Pawlowski, S. D. (2004). The Delphi method as a research tool: an example, design considerations and applications. *Inform. Manag.* 42, 15–29. doi: 10.1016/j.im.2003.11.002

Onofri, L., Accadia, P., Ubeda, P., Gutiérrez, M.-J., Sabatella, E., and Maynou, F. (2018). On the economic nature of consumers' willingness to pay for a selective and sustainable fishery: a comparative empirical study. *Sci. Mar.* 82, 91–96. doi: 10.3989/scimar.04737.10A

Pelletier, D., Claudet, J., Ferraris, J., Benedetti-Cecchi, L., and Garcìa-Charton, J. A. (2008). Models and indicators for assessing conservation and fisheries-related

effects of marine protected areas. *Can. J Fish. Aquat. Sci.* 65, 765–779. doi: 10.1139/f08-026

Pérez-Roda, A. (ed.) (2019). *A Third Assessment of Global Marine Fisheries Discards.* FAO Fisheries and Aquaculture Technical Paper, n° 633. Rome: FAO, 79.

Prellezo, R., Carmona, I., and García, D. (2016). The bad, the good and the very good of the landing obligation implementation in the Bay of Biscay: a case study of Basque trawlers. *Fish. Res.* 181, 172–185. doi: 10.1016/j.fishres.2016.04.016

Queirós, A. M., Strong, J. A., Mazik, K., Carstensen, J., and Bruun, J. (2016). An objective framework to test the quality of candidate indicators of good environmental status. *Front. Mar. Sci.* 3:73. doi: 10.3389/fmars.2016.00073

Raicevich, S., Battaglia, P., Fortibuoni, T., Romeo, T., Giovanardi, O., and Andaloro, F. (2017). Critical inconsistencies in early implementations of the marine strategy framework directive and common fisheries policy objectives hamper policy synergies in fostering the sustainable exploitation of mediterranean fisheries resources. *Front. Mar. Sci.* 4:316. doi: 10.3389/fmars.2017.00316

Reed, T. E., Waples, R. S., Schindler, D. E., Hard, J. J., and Kinnison, M. T. (2010). Phenotypic plasticity and population viability: the importance of environmental predictability. *Proc. Roy. Soc. B* 277, 3391–3400. doi: 10.1098/rspb.2010.0771

Rice, J., Arvanitidis, C., Borja, A., Frid, C., Hiddink, J. G., Krause, J., et al. (2012). Indicators for sea-floor integrity under the European marine strategy framework directive. *Ecol. Indic.* 12, 174–184. doi: 10.1016/j.ecolind.2011.03.021

Rice, J. C., and Rochet, M.-J. (2005). A framework for selecting a suite of indicators for fisheries management. *ICES J Mar. Sci* 62, 516–527. doi: 10.1016/j.icesjms.2005.01.003

Rijnsdorp, A. D., Daan, N., and Dekker, W. (2006). Partial fishing mortality per fishing trip: a useful indicator of effective fishing effort in mixed demersal fisheries. *ICES J Mar. Sci.* 63, 556–566. doi: 10.1016/j.icesjms.2005.10.003

Sardà, F., Coll, M., Heymans, J. J., and Stergiou, K. I. (2015). Overlooked impacts and challenges of the new European discard ban. *Fish Fish.* 16, 175–180. doi: 10.1111/faf.12060

Sola, I., and Maynou, F. (2018). Bioeconomic analysis of the effects of modifying the trawl extension piece with T90 netting. *Sci. Mar.* 82, 27–37.

STECF (2017). *The 2017 Annual Economic Report on the EU Fishing Fleet (STECF 17-12)*. Available at: https://stecf.jrc.ec.europa.eu/reports (assessed June 3, 2018).

STECF/SGMOS (2008). *Scientific, Technical and Economic Committee for Fisheries (STECF) Report of the SGMOS-08-01 Working Group on the Reduction of Discarding Practices*. Brussels: European Union.

Stithou, M., Vassilopoulou, V., Tsagarakis, K., Edridge, A., Machias, A., and Maniopoulou, M. (2019). Discarding in Mediterranean trawl fisheries—a review of potential measures and stakeholder insights. *Marit. Stud.* 18, 225–238. doi: 10.1007/s40152-018-00131-0

Stockhausen, B. (2019). "How the implementation of the landing obligation was weakened," in *The European Landing Obligation*, eds S. S. Uhlmann, et al. (Berlin: Springer), 438.

Stokstad, E. (2019). Ships banned from throwing unwanted fish overboard. *Science* 363, 112–113. doi: 10.1126/science.363.6423.112

Symes, D., and Phillipson, J. (2009). Whatever became of social objectives in fisheries policy? *Fish. Res.* 95, 1–5. doi: 10.1016/j.fishres.2008.08.001

Tam, J. C., Link, J. C., Rossberg, A. G., Rogers, S. I., Levin, P. S., Rochet, M.-J., et al. (2017). Towards ecosystem-based management: identifying operational food-web indicators for marine ecosystems. *ICES J. Mar. Sci.* 74, 2040–2052. doi: 10.1093/icesjms/fsw230

Thrush, S. F., and Dayton, P. K. (2002). Disturbance to marine benthic habitats by trawling and dredging: implications for marine biodiversity. *Ann. Rev. Ecol. Syst.* 33, 449–473. doi: 10.1146/annurev.ecolsys.33.010802.150515

Tserpes, G., Nikolioudakis, N., Maravelias, C., Carvalho, N., and Merino, G. (2016). Viability and management targets of mediterranean demersal fisheries: the case of the Aegean Sea. *PLoS One* 11:e0168694. doi: 10.1371/journal.pone.0168694

Villasante, S., Antelo, M., Christou, M., Facounett, L., Frangoudes, K., Maynou, F., et al. (2019). "The implementation of the landing obligation in small-scale fisheries of the Southern European Union countries," in *The European Landing Obligation: Reducing Discards in Complex Multi-Species and Multi-Jurisdictional Fisheries*, eds S. Uhlmann, C. Ulrich, and S. Kennelly (Cambridge: Springer).

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2019 Christou, de Juan, Vassilopoulou, Stergiou and Maynou. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.