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Methods for developing and computing indicators of Good Environmental Status and economic profitability

1. Summary

The Landing Obligation (LO) is a legal requirement to land all catches of certain fish species, introduced as part of the EU's Common Fisheries Policy; it will be fully implemented starting Jan 1st 2019 (Article 15, EU regulation 1380/2013). As the LO is likely to bring social, economic and ecological impacts, a suite of indicators to inform of possible changes in the fishery system on the short, medium, and long-term is needed. This study aims to contribute towards identifying suitable indicators that capture the effects of the LO on the health of marine ecosystems, following Marine Strategy Framework Directive (MSFD) and Good Environmental Status (GES) objectives, as well as on the socio-economic viability of the fishery sector. It is conducted in the frame of the EU H2020 RIA project MINOUW that focuses on the minimization of unwanted catches in the European Fisheries. The first step was to conduct a desk review to collect and synthesize available information on indicators related to the social, economic and ecological dimensions of the LO using evidence-based quality criteria. Then, a dedicated expert-knowledge survey was developed and was completed by experts of the MINOUW consortium who, aside from reviewing the aforementioned information, were also asked to propose new indicators related with potential changes in the fishery system after the implementation of the LO, evaluating in parallel the potential magnitude and direction of change of each indicator. Furthermore, experts' opinions were gathered on the possible integration of certain socioeconomic and environmental targets affected by the LO. Results were analyzed using ranking and multivariate methods. Outcomes suggest that the identification of sensitive and informative indicators capturing LO effects is a demanding task. A methodological framework that may shed light on different properties of the discarding process, changing of fishing practices, and overall potential LO impacts has been proposed to help managers monitor key attributes of the LO implementation. The indicators that have emerged based on the framework could be a set of monitoring tools to inform of the status or sustainability of the fishery system after the LO has been fully implemented. Yet, this exercise evidenced that further research is needed to elucidate specific aspects associated to ecosystem mechanisms and behavioral interventions related to the minimization of unwanted catches.

2. Glossary

Here in,

- Target species= species, of commercial value, for which the fisher has specifically designed the fishing method and gear.
- Catch =Organisms brought on-board the fishing vessel
- Fished assemblage - all organisms that are fished and later on will be brought on board and selected to be sold, discarded, etc.
- By-catch= all organisms that are not targeted; it may consist of a commercial and a non commercial fraction that is traditionally discarded (Unwanted catch)
- Unwanted catch = catches that are either prohibited to land due to quotas, minimum conservation reference sizes (undersized individuals), or due to market demand or for other reasons (e.g. damaged commercial species)

Discards= the part of the catch that is returned back to the sea

3. Introduction

The landing obligation (herein LO, Art. of EU Reg. 1380/2103) legislation is seeking to end the practice of discarding unwanted catches back to the sea (these include catches that are either prohibited to land due to quotas, minimum conservation reference sizes, or due to market demand or other reasons impose this) by the first of January 2019 within European marine waters, as a potential fisheries management contribution to achieve healthy fish stocks (Descriptor 3 of the Marine Strategy Framework Directive). Discarding unwanted catch, dead or alive, is caused by imperfect fisheries selectivity, legislation restrictions and market incentives which are specific to each type of fishery. For the species subjected to the LO, the use of catches of species below the minimum conservation reference size shall be restricted to purposes other than direct human consumption; those not covered by the LO can continue to be discarded, while prohibited species should be returned immediately back to the sea. This makes imperative to follow a case-by-case approach that proposes technically feasible and cost-effective solutions agreeable to fish producers, consumers and policy makers. While the LO is a huge step for fisheries conservation in European waters, it will be a challenge have fishermen comply with the obligations to record, land and account for all fish that are taken aboard their vessels (“full documentation of catches”, Art. 15.5.d). Additionally, a difficult task will be to monitor changes resulting from the LO, as well as to increase traceability of landings that will be brought to land either for human or non-human consumption.

Decisions made by fishers to address the LO may result in a more selective fishery, as well as other changes in the usage of former discards, and may initiate direct or indirect effects that affect different parts of the fishery, on land or at sea. These may include changes in the ecosystem functioning, fishing communities and national economies. Therefore, to assess the impact of the new regulation, it is essential to understand the underlying mechanisms and examine the complexity of the discard problem and provide tools, such as the set of practical indicators developed here to help managers monitor progress. The selection of suitable indicators to monitor progress towards the gradual elimination of discards, or alternatively, the full use of fisheries catches is challenging because of the potentially high number of indicators available and also because of the different dimensions (social, economic, ecological) of the problem. By means of literature research and expert consultation we propose a manageable, restricted set of indicators whose properties are known and can inform on the impact and direction of changes in the fishery system resulting from the implementation of the LO in the near future. In this way, it might be possible to reduce discards effectively and to achieve Good Environmental Status (GES) within European marine waters, following Marine Strategy Framework Directive (MSFD) and the Common Fisheries Policy (CFP) aims.

Changes in the biological abundance, biomass and biodiversity have been reported to be affected by discard prevention policies, since discarded fish are food for a range of scavenging species; so, ending discarding may have consequences on the density and distribution of these organisms and, consequently, broader ecosystem effects (Heath et al., 2014). The LO may also impact on the distribution of nursery grounds of target fish species, as well as catch composition, due to changes in the behaviour of fishers to avoid areas with undersized individuals assemblages. Moreover, the LO may result in changes in target population structure and species length composition of the fishery, and may help to achieve a value at/above maximum sustainable yield, in accordance with targets for healthy stocks and accurate stock assessments. Full reporting of catches is also a necessary condition for accurate stock assessments. These effects might have indirect consequences for the ecosystem functioning, therefore it is crucial to monitor variables related with the trophic network structure and possible indicators of the functioning and stability of ecosystems.

From an economic point of view, the LO may also have an impact on the economic activity and fleet performance of the EU fisheries sector. The expected impact on production for human and non-human consumption, in the short- and long-term profitability of the fishing sector, is unknown; yet utilization of former discards is now possible. Fishers may increase investments in selective fishing gears to help avoid discards. Other technical changes and infrastructure development may arise. The fishing sector will face changes in activity; fishing effort may rise to catch the same amount of fish as before the LO and so fuel consumption and operational costs might increase as well (Frangoudes and Guillen, 2016).

Monitoring the social aspect of the fishery is also critical, as sustaining social viability and wellbeing of affected communities is vital. Changes in the remuneration system may result due to the implementation of LO. The crew workload may change, as sorting the catch may become more demanding as fishers are required to distinguish the parts of the catch that maybe landed. Alternatively, more selective fishing practices may reduce the workload for the crew, as less unwanted catch is brought aboard the fishing vessel in the first place. The number of people employed by the fishing sector may also change due to the LO. An industry may rise to handle the “new landings” caused by the LO and the requirement for processing them. This creates the need for newly developed indicators, especially in terms of economic status of the fishery and ancillary industries, because of the possible creation of new industries for bycatch utilization. This includes the contribution of each gender in the emerging industry, as an indicator of gender equity, social inclusion and fair living standards. It is also important to monitor fishers' behavioural changes to adapt due to the LO, for example: in modifications to the fishing method to enhance survival (e.g. slipping in purse seine); switching fishing grounds; or using more selective fishing gears.

The gap of knowledge on indicators related to direct or indirect impacts that the destiny of the biomass of the fished assemblage, and in particular to the fraction of the catch that is not targeted (bycatch), might have on the functioning of the fishery system has been highlighted in several policy documents (e.g. European Commission, 2011). Concerning the indirect impacts mentioned in Table 2 of Annex III of the Directive 2008/56/EC, the Commission Decision on GES criteria does not contain specific criteria and indicators on discards and by-catch, allowing the matter to be examined under relevant descriptors (Descriptor 1 (biodiversity), 3 (fishery stocks), 4 (food-webs) and 6 (sea-floor integrity). By the amendment of the previous MSFD policy, additional criteria and methodological standards on GES of marine waters are introduced and further specifications and standardised methods for monitoring and assessment (COMMISSION DECISION EU 2017/845; COMMISSION DECISION EU 2017/848) are proposed to present the effect of discarding, which is 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 are not covering the whole spectrum of the fishery, nor provide information on the LO-related shifts that may be encountered in the fishery components.

Under the LO, management plans are going to be established independently by each member state (or co-ordinately by a few number of member states, as in the "PESCA" group: Spain, France, Italy) by taking into account the particularities of each fishery or region. Thus, a common methodology for assessing the state of fisheries after the full implementation of the new regime is sought. Herein, we present a framework that includes three standard components of the fishery system and related indicators to inform of the GES and socioeconomic sustainability of the fisheries systems within European marine waters. It is important to investigate the effect of the LO as a driver of change on the different components of the fishery system, because this might show priority components for the adoption of measures and actions, and highlight potential limitations in the implementation of the LO. Moreover, by applying the framework, member states could identify besides from changes in the ecosystem integrity (state of the stock, ecosystem status, maintenance of biomass, biodiversity, and abundance), possible socioeconomic challenges that the EU members will confront: the alteration of catch main channels, societal adaptability, levels of compliance and monitoring deficiencies.

The research presented is a first effort to compile a proposed methodology to evaluate indicators capturing the effects of the LO. Relevant indicators were also desired to be evaluated by MINOUW experts. Their appraisal on indicator quality, uncertainty, and direction and magnitude of the LO impact, and their opinion on the hierarchy of objectives that the LO is called to fulfil were sought. Indicator selection was based on a set of quality criteria commonly used for the assessment of ecological indicators (see Rice and Rochet, 2005) while for the assessment of objectives multi-criteria methods commonly used in policy decision making (Marletto and Mameli, 2012) supported their organisation into a proper structure. Although a set of indicators may be formulated, this does not imply that by reporting the changes or constructing informative indicators of the system status could diminish unwanted catches alone. The need of developing more selective gears or supporting fishing communities by incentivising the avoidance of bycatch hotspots is highlighted, in combination with updated info on the fishery components in order to mitigate the expected implementation implications and increase the success of the aims of management sustainability.

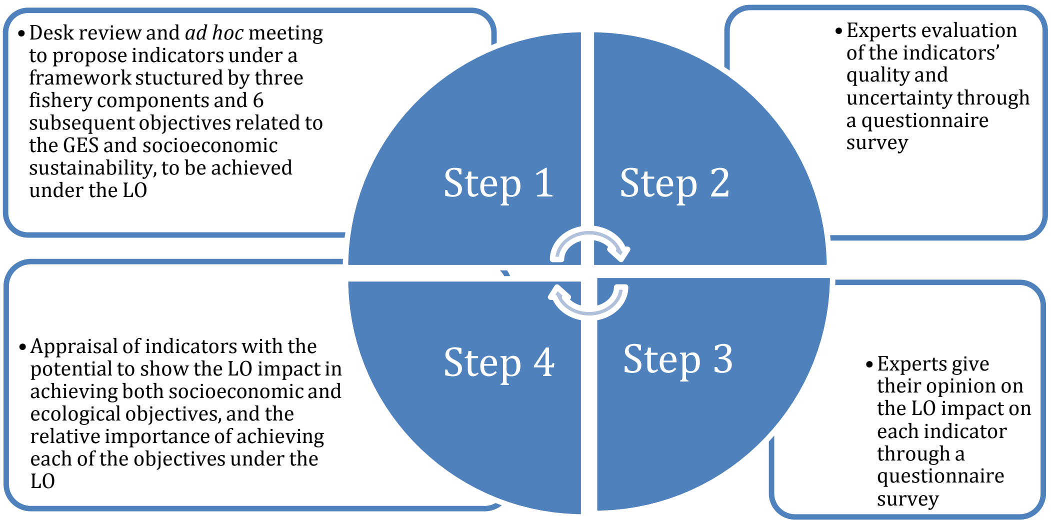

Figure 1. Steps for formulating the framework of indicators of Good Environmental Status and socioeconomic sustainability

4. Materials and Methods

The procedure adopted for the identification of indicators of Good Environmental Status and socioeconomic sustainability is summarized in Figure 1 and integrates different steps that helped to define the final selection of indicators. Firstly, a framework that incorporates three dimensions of environmental, economic and social sustainability using evidence-based quality criteria was designed. The conceptual framework formulated is of the Thematic Indicator Development logic (Marletto and Mameli, 2012), which is explicitly designed to manage sustainability policy issues, contrary to the more complex and informative—but less policy oriented—Driving forces-Pressure-States-Impacts-Response (DPSIR) approach (UNCSD, 2001, Elliot et al., 2017).

As a starting point, different high-level policy objectives have been proposed and grouped by topics allowing for more operational interpretations at the fishery specific levels (Figure 2). The overall goal was to identify the impact of the LO on the fishery sustainability (top tier). The middle tier consisted of the objectives which were grouped into three dimensions (ecological, economic, social). The first objective refers to the Descriptor 1 of the MSFD and aims to safeguard biological abundance, biomass and biodiversity. The second objective refers to the achievement of healthy stocks while improving the accuracy of stock assessment and sustainable catches (Descriptor 3). The third objective targets the maintenance of the ecosystem functioning (Descriptor 4). These three objectives describe the ecological component of the fishery system. The economic component of the framework is expressed by the aim of improving fleet efficiency (fourth objective) and economic viability (fifth objective) of the fishing sector, which are important components of economic development of a sustainable fishery. Positive mechanisms that will be developed and applied through the implementation of the LO, taking into account the socio-economic conditions of the EU members, may lead to the conservation and sustainable use of the fishery system that is a precondition to economic sustainability of the fishing communities. Last, the social objective set (objective sixth) was formulated as the provision of work and livelihood enhancement of fishing communities that the fishery supports under the LO (Social viability and wellbeing of the society). Both social and economic state of the fishery system is an imperative to be assessed and monitored under the CFP and MSFD legislation.

These six objectives were articulated into 39 indicators, with some indicators affecting multiple objectives and having implications for multiple dimensions. A literature survey on indicators was conducted to collect and synthesize information related to the social, economic and ecological dimensions of the LO. Moreover, the aim of this exercise was to include as many indicators as possible developed through the MINOUW project in order to interconnect all available information and reflect the outcomes of the project. The MINOUW indicators are based on the results of interactions with stakeholders, scientific reports and expert knowledge. A list of the indicators proposed, with their definitions, are summarised in the Appendix. It must be pointed out that the 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; this is why some indicators are only broadly defined. In addition, the indicator linkage to the LO is also specified in each indicator definition (Figure 3). So, in this way, each of the indicators informs on the properties of the area that needs to be assessed to evaluate whether a fishery system is achieving each of the objectives of the framework under the LO

An *ad hoc* meeting was organized for MINOUW experts, focused on the collection and synthesis of available information on indicators related to the social, economic and ecological dimensions of the LO. A dedicated session was set so that experts were familiarized with the framework in order to establish a common understanding of the framework components. During the meeting experts reviewed the first set of indicators and where also encouraged to propose additional indicators and to express comments and further suggestions to improve the framework. The full survey, that encompassed the quality criteria, expected response direction of indicators and priority of the framework objectives, was emailed to the MINOUW Consortium members. Participation was on a voluntary basis and consent was provided after receiving the questionnaire.

The first section of the survey focused on the assessment of the indicator quality based on 7 criteria commonly used for ecological indicators (Tam et al., 2017; Queirós et al., 2016; Rice and Rochet, 2005). The scoring used to evaluate the indicator quality was based on a 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 can be found in the Appendix). Overall scores were estimated as the median of the weighted mean score (total score divided by 7) per person. Apart from the criteria, experts were asked to express how certain they were when providing their answers (in a scale from 0: 0% to 4: 100%). The certainty expressed by experts was used as a weighting factor and allowed more detailed evaluation of the indicators' suitability. This way, the quality score was weighted by the certainty score. As a result, the maximum score to be obtained by an indicator was 8 and the minimum 0. Moreover, the experts were given the chance to evaluate the potential magnitude and direction of change of each indicator, assuming a full implementation of the LO (a large positive ++, a small positive +, zero 0, a small negative - and a large negative effect - -).

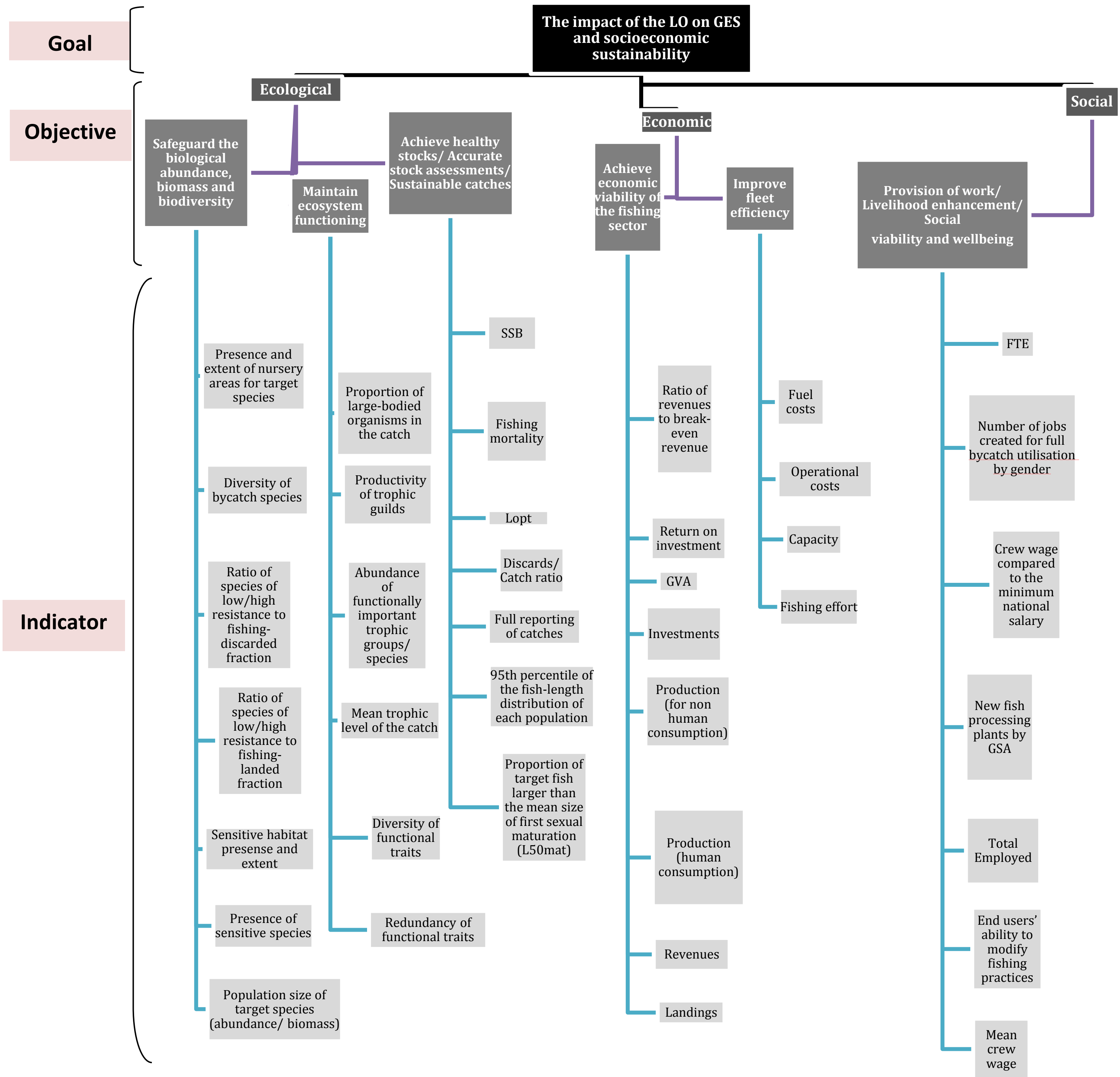

Figure 2. Hierarchical tree of the goal, objectives and indicators of the impact of the LO on GES and socio-economic sustainability.

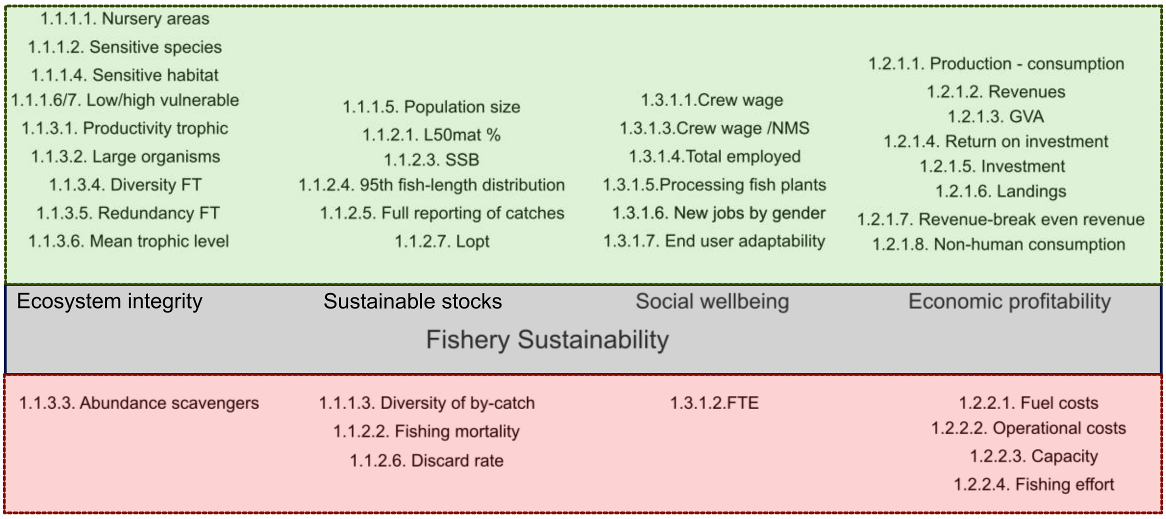

Figure 3. Relationship between the variables and the Good Environmental Status and Socio-economic sustainability (here referred as "Fishery Sustainability") of the fishery systems. Some variables will be positively related to the Fishery Sustainability (in the green box), whereas some variable represent sustainability in negative terms (in the red box). The monitoring of these variables will help the assessment of the "Fishery Sustainability" from a multidisciplinary perspective**.**

In a second section of the survey, experts' opinions were gathered on the possible integration of certain socioeconomic and environmental targets affected by the LO. Results were analyzed using ranking and multivariate methods in order to illustrate the effect of the LO on the multiple dimensions of sustainability. Specifically, experts evaluated the potential of the LO in achieving both socioeconomic and ecological objectives, and the relative importance of achieving each of the objectives under the LO through a questionnaire survey using Multi Criteria Decision Analysis (MCDA). This is an area of growing interest in fisheries management, and there are several applications (e.g., Kavadas et al., 2015; Rossetto et al., 2015; Lembo et al., 2017) that confirm the MCDA is a powerful tool for addressing specific problems that exhibit a variation in expert's opinions. However, MCDA assessments can be affected by a range of uncertainties due to the inadequate understanding of the specific system to be assessed and the subjectivity of expert judgments (e.g., Rossetto et al., 2015).

5. Results

The survey was completed by 16 MINOUW experts that reflected a diversity of research backgrounds related with the study of fishery systems, encompassing the disciplines of ecology, economics and social sciences. However, it should be pointed out that 75% were fishery biologists, broadly reflecting the experts' composition of the Consortium. Results from the survey showed 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 and certainty, as seen in Figure 4. The lowest scores were given to the indicators under the objective “Provision of work/Livelihood enhancement/Social viability and wellbeing”, probably as some of the indicators under this category have a qualitative form (End users’ ability to modify fishing practices) and, therefore, were scored low in some of the criteria. Also, other indicators proposed under this objective have not been currently investigated as the LO has not been fully implemented and, thus, the behaviour of these indicators is not yet well understood (New fish processing plants, Number of jobs created for full bycatch utilisation by gender), showing a large degree of uncertainty in the experts’ opinions. In table 1 the mean and median of each indicator are shown. As observed, the mean and the median of the indicators’ score provide a different ranking, but the median was used to select a subset of indicators that is not skewed by extremely large or small values (it down-weights the importance of outliers), and so it may give a better idea of the most frequent values. Also, a certainty threshold was applied, retaining only those responses equal or above 75% of certainly, so the respondent is confident on the score assigned to the indicator (Figure 4). As a result, figure 4 shows the indicators in an ascending order based on experts’ appraisal. Eight indicators came out to have a score of higher than 5 (Figure 4), but none of them refers to the economic and social dimension of the LO which is partly due to the scientific background of the majority of the experts.

Table 1. The quality score assigned to the 39 Indicators, clustered by objective: mean, S.E. and median of the 16 responses are shown.

Objective	Indicator	Mean	S.E.	Median
Safeguard the biological abundance, biomass and biodiversity	*Presence and extent of nursery areas for target species*	4.74	0.24	5.14
	Presence of sensitive species	4.65	0.31	5.14
	Diversity of bycatch species	4.63	0.40	4.29
	Sensitive habitat presence and extent	4.04	0.44	3.86
	Population size of target species	5.55	0.43	6.14
	Ratio of species low/high resistance to fishing-discarded fraction	4.05	0.29	4.29
	Ratio of species low/high resistance to fishing-landed fraction	3.78	0.45	3.43
Achieve healthy stocks/ Accurate stock assessments/ Sustainable catches	*Proportion of target species larger than the mean size at first sexual maturation*	4.93	0.51	5.57
	F (fishing mortality)	5.66	0.39	6.57
	SSB (spawning stock biomass)	5.78	0.37	6.29
	*95^th^* percentile of the fish length distribution of each target species	5.35	0.48	5.43
	Full reporting of catches	4.83	0.47	4.36
	Discard rate	4.84	0.63	5.14
	Lopt[1]	4.36	0.52	4.14
Maintain ecosystem functioning	*Productivity of trophic guilds*	2.56	0.32	2.43
	Proportion of large-bodied organisms (top of food webs) in the catch	3.17	0.38	2.71
	Abundance of functionally important trophic groups/species	2.79	0.34	2.64
	Diversity of functional traits	2.59	0.32	2.64
	Redundancy of functional traits	2.25	0.33	2.07
	Mean trophic level of the catch	3.13	0.46	3.14
Achieve economic viability of the fishing sector	*Production for human consumption*	4.04	0.46	3.57
	Revenues	3.89	0.50	3.57
	GVA (gross value added)	3.47	0.51	2.57
	Return on investment	3.26	0.52	2.57
	Landings	4.13	0.46	4.00
	Investments	3.37	0.54	2.71
	Ratio of revenues to break even revenue	3.38	0.53	2.71
	Production for non-human consumption	2.55	0.44	2.43
Improve fleet efficiency	*Fuel costs*	3.86	0.55	3.36
	Operational costs	3.90	0.49	3.14
	Capacity	3.58	0.50	3.21
	Fishing effort	4.09	0.53	3.50
Provision of work/Livelihood enhancement/ Social viability and wellbeing	*Mean crew wage*	3.80	0.60	2.93
	FTE (Employment, full time equivalent)	3.21	0.61	2.29
	Crew wage compared to the minimum national salary	3.17	0.61	2.57
	Total employed	3.24	0.57	2.57
	New fish processing plants	3.06	0.52	2.71
	Number of jobs created for full bycatch utilization, by gender	2.55	0.56	2.00
	End users' ability to modify fishing practices	1.92	0.43	1.86

[1] *Optimum* length, Froese (2004, Fish and Fisheries 5: 86-91)

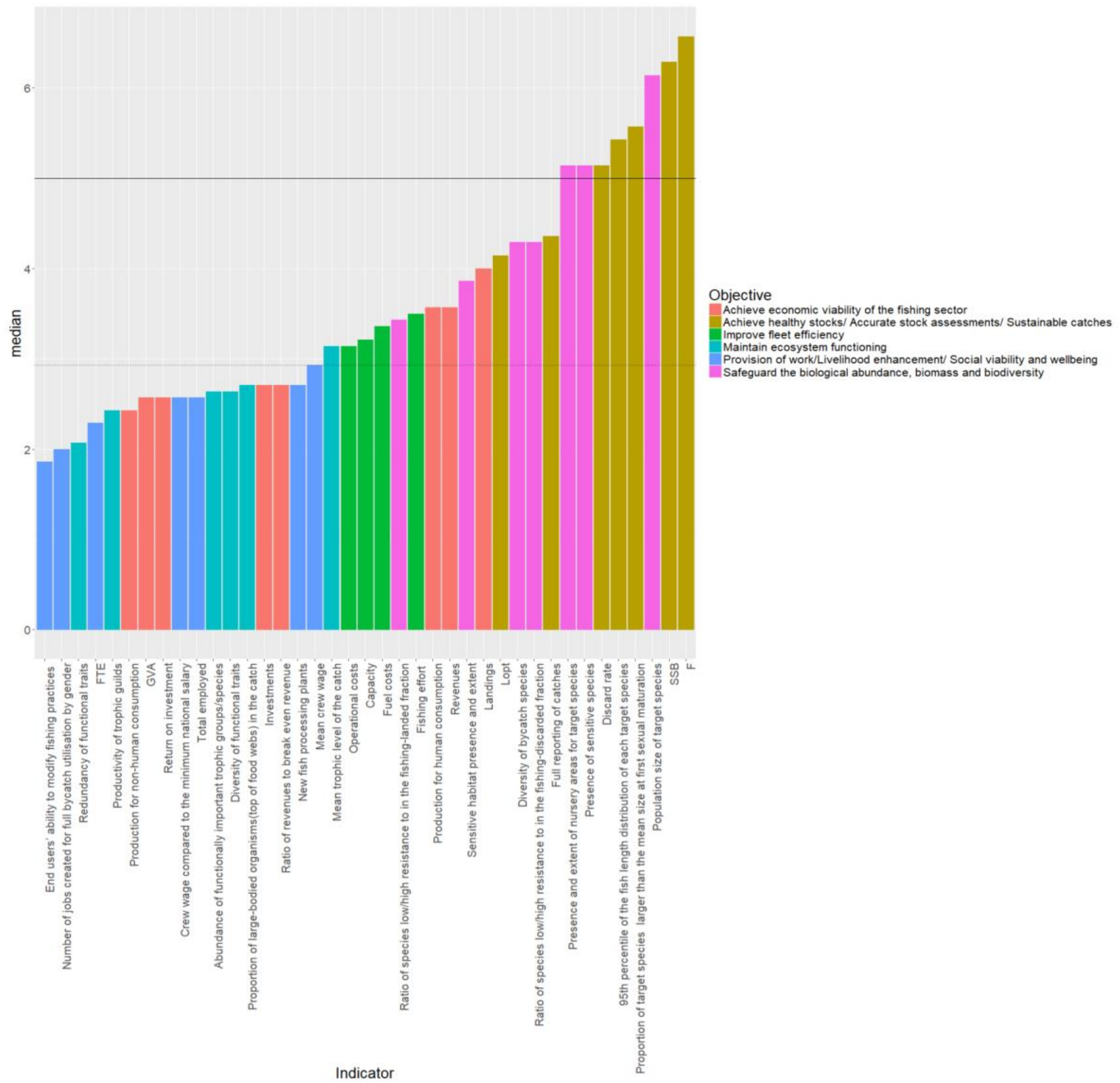

Figure 4. Indicators'quality scorebased on experts' appraisal on 7 quality criteria and the certainty of answers in an ascending order. The solid line denotes the cutoff point of 5 and the dashed line a cutoff point of 2.93 (F=Fishing mortality, SSB=Spawning Stock Biomass, Lopt=Optimum length, GVA=Gross value added, FTE= Full time equivalent).

The selected eight indicators with a score of 5 or higher are: F, SSB, Population size of target species, Discard rate, 95th percentile of the fish length distribution of each target species, Presence and extent of nursery areas for target species, Presence of sensitive species, Proportion of target species larger than the mean size at first sexual maturation. A lower threshold may have allowed a higher number of indicators to be selected. Therefore, in order to include indicators from all dimensions, a threshold of 2.93 should have been set (this is the minimum threshold to retain a minimum of one indicator per objective). This new threshold is translated into a selection of 23 indicators (Figure 4). Note that this new threshold still leaves the indicators from the objective "maintain ecosystem functioning" and "provision of work" poorly represented, with only one indicator per objective retained. It must be stressed that setting a cut-off threshold is more precise than selecting a pre-defined set of indicators, because only the evaluations of external experts objectively determine which and how many indicators should be finally selected (Marletto and Mameli, 2012).

Table 2. Experts opinion (expressed as percentages of responses) on how the indicator would change after an effective implementation of the LO. In bold the main selected response. If the LO will have mostly a positive effect on the indicator (+ or ++) then the row is highlighted in green, mostly a zero effect (0) then the row is highlighted in blue and mostly negative effect (- or –) then the row is highlighted in red, based on experts appraisal(F=Fishing mortality, SSB=Spawning Stock Biomass, Lopt=Optimum length, GVA=Gross value added, FTE= Full time equivalent).

Indicator	+ +	+	0	-	- -	other	NA
Presence and extent of nursery areas for target species	6.25	**62.50**	31.25	0.00	0.00	0.00	0.00
Presence of sensitive species	0.00	25.00	**50.00**	6.25	0.00	18.75	0.00
Diversity of bycatch species	7.14	**42.86**	25.00	18.75	0.00	0.00	0.00
Sensitive habitat presence and extent	6.67	26.67	**43.75**	6.25	0.00	12.50	0.00
Population size of target species	26.67	26.67	**37.50**	0.00	0.00	0.00	6.25
Ratio of species low/high resistance to fishing-discarded fraction	0.00	31.25	**43.75**	18.75	6.25	0.00	0.00
Ratio of species low/high resistance to fishing-landed fraction	6.25	37.50	**43.75**	6.25	0.00	0.00	6.25
Proportion of target species larger than the mean size at first	**12.50**	**43.75**	43.75	0.00	0.00	0.00	0.00
F	5.56	16.67	**50.00**	12.50	0.00	18.75	6.25
SSB	5.88	**47.06**	37.50	0.00	0.00	0.00	12.50
95th percentile of the fish length distribution of each target	18.75	**43.75**	37.50	0.00	0.00	0.00	0.00
Full reporting of catches	12.50	**62.50**	12.50	0.00	0.00	12.50	0.00
Discard rate	13.33	20.00	25.00	0.00	**37.50**	0.00	0.00
Lopt	18.75	**43.75**	37.50	0.00	0.00	0.00	0.00
Productivity of trophic guilds	0.00	12.50	**68.75**	6.25	6.25	6.25	0.00
Proportion of large-bodied organisms (top of food webs) in the	0.00	26.67	**56.25**	6.25	6.25	0.00	0.00
Abundance of functionally important trophic groups/species	13.33	13.33	**37.50**	18.75	12.50	0.00	0.00
Diversity of functional traits	0.00	20.00	**43.75**	6.25	6.25	18.75	0.00
Redundancy of functional traits	0.00	20.00	**43.75**	6.25	6.25	18.75	0.00
Mean trophic level of the catch	0.00	25.00	**50.00**	6.25	6.25	12.50	0.00
Production for human consumption	0.00	25.00	**56.25**	6.25	6.25	6.25	0.00
Revenues	0.00	38.89	**43.75**	18.75	0.00	6.25	0.00
GVA	0.00	**58.82**	18.75	25.00	0.00	0.00	0.00
Return on investment	0.00	35.29	**37.50**	25.00	0.00	0.00	6.25
Landings	0.00	**56.25**	31.25	6.25	0.00	0.00	6.25
Investments	6.25	**43.75**	31.25	18.75	0.00	0.00	0.00
Ratio of revenues to break even revenue	0.00	18.75	**50.00**	18.75	0.00	6.25	6.25
Production for non-human consumption	12.50	**75.00**	12.50	0.00	0.00	0.00	0.00
Fuel costs	5.88	29.41	**43.75**	12.50	0.00	6.25	6.25
Operational costs	6.25	**56.25**	12.50	25.00	0.00	0.00	0.00
Capacity	0.00	11.76	**68.75**	12.50	0.00	6.25	6.25
Fishing effort	5.88	5.88	**81.25**	0.00	0.00	6.25	6.25
Mean crew wage	0.00	0.00	**68.75**	25.00	0.00	0.00	6.25
FTE	0.00	18.75	**62.50**	12.50	0.00	0.00	6.25
Crew wage compared to the minimum national salary	0.00	6.25	**75.00**	12.50	0.00	0.00	6.25
Total employed	6.25	37.50	**50.00**	0.00	0.00	0.00	6.25
New fish processing plants	12.50	**56.25**	31.25	0.00	0.00	0.00	0.00
Number of jobs created for full bycatch utilisation by gender	0.00	**56.25**	31.25	0.00	0.00	6.25	6.25
End users' ability to modify fishing practices	0.00	**46.67**	31.25	0.00	0.00	6.25	12.50

Table 3. Experts have expressed their opinion on the LO impact in allowing the achievement of both socioeconomic and ecological objectives (Other=not sure, not relevant, blanks). Results expressed as percentages of responses. In bold the main selected response.

***If* the LO achieves the following ecological objective:**	***Then* which of the following socioeconomic objectives will also be achieved?**								
	Achieve economic viability of the fishing sector			Improve fleet efficiency			Provision of work/Livelihood enhancement/ Social viability and wellbeing		
	Yes	No	Other	Yes	No	Other	Yes	No	Other
Safeguard the biological abundance, biomass and biodiversity	**87.5**	12.5	0	37.5	18.75	**43.75**	**56.25**	25	18.75
Achieve healthy stocks/ Accurate stock assessments/ Sustainable catches	**93.75**	6.25	0	**75**	6.25	18.75	**87.5**	12.5	18.75
Maintain ecosystem functioning	**87.5**	6.25	6.25	25	25	**50**	**62.5**	18.75	18.75
***If* the LO achieves the following socioeconomic objective:**	***Then* which of the following ecological objectives will also be achieved?**								
	Safeguard the biological abundance, biomass and biodiversity			Achieve healthy stocks/ Accurate stock assessments/ Sustainable catches			Maintain ecosystem functioning		
	Yes	No	Other	Yes	No	Other	Yes	No	Other
Achieve economic viability of the fishing sector	**68.75**	18.75	12.75	**68.75**	12.75	18.75	**56.25**	18.75	25
Improve fleet efficiency	**62.5**	12.5	25	**68.75**	12.75	18.75	**68.75**	12.75	18.75
Provision of work/Livelihood enhancement/ Social viability and wellbeing	**62.5**	6.25	31.25	**50**	18.75	31.25	**56.25**	12.5	31.25

In Table 2, experts have expressed their opinion on the indicators that might respond to the implementation of the LO. According to experts' opinion, most indicators would not be affected by the LO; experts assume that one indicator (Discard rate) will decrease, while experts estimate that the LO will have a positive impact on 15 indicators (see Table 2).

The relative importance of the different ecological, economic and social targets was evaluated in Tables 3 and 4. The general support of ecological objectives over socio-economic is highlighted. This is because experts acknowledge that the fishery viability is based on ecosystem integrity and healthy stocks, but also possibly because of their scientific background. This is reflected also in table 4 in how the objectives were ranked based on their contribution to achieve GES and socio-economic sustainability under the LO. The ecological objectives had the highest weights based on pair comparison of the 6 objectives. In any case, through this process, the most informative indicators are capturing certain ecological properties of the LO.

Table 4. Ranking of the objectives which contribute more to the goal (achieve GES and socio-economic sustainability) using MCDA.

Objective	Weight	Rank
Safeguard the biological abundance, biomass and biodiversity	26.30%	2
Achieve healthy stocks/ Accurate stock assessments/ Sustainable catches	23.10%	3
Maintain ecosystem functioning	29.00%	1
Achieve economic viability of the fishing sector	8.60%	4
Improve fleet efficiency	5.20%	6
Provision of work/Livelihood enhancement/ Social viability and wellbeing	7.80%	5
geometric consistency index= 0.01 consistency ratio=0.4%		

6. Discussion

As far as we know, no other study exists in the literature on the application of such an integration of indicators on the effect of the LO on the fishery sustainability (taking into account ecological, economic and social objective). Many studies explicitly consider the dimensions of environmental, social and economic sustainability separately and have not elaborated a multi-disciplinary perspective of the challenges that the European fisheries will have to confront. However, recently, efforts have been made to elucidate stakeholders' perceptions on the implementation of the LO in European waters (Villasante et al., 2016; Maynou et al., 2018; Christou et al.,2017). In this context, we addressed the challenge to identify and select multi-dimensional indicators as tools for the monitoring of potential direct and indirect effects of the full implementation of the LO on the fishery system.

Indicators are synthetic tools that facilitate the communication between policy makers and scientists. Under this assertion, we identified a suite of variables that meet the basic criteria to be effective indicators and illustrate potential changes in a fishery system. Each of the selected indicators was linked to a specific objective, all of which seek the accomplishment of the main goal (the attainment of GES and socioeconomic sustainability). The final aim of our approach is to select a subset, and manageable, set of indicators that are founded on expert knowledge, but were selected according to pre-defined quality criteria that ensures sound scientific basis, cost-effectiveness, predictive power and realistic monitoring implementations. As a result, we expect this indicator set could be used as an effective tool to monitor real-world fishery systems that will soon be subjected to a full implementation of the LO. Therefore, the information presented herein will be valuable to the European Commission or other monitoring authorities that will be in charge to observe possible changes due to the implementation of the LO.

The CFP commitments are characterised by multiple objectives (e.g., GES-related), including the selection of indicators associated with such specific objectives. Most of them aim to track a reversal in the overexploitation status of stocks, and simultaneously identify the minimization of economic and social impacts. However, designing a framework that will enable the monitoring of changes towards this aim is a complex task that requires reliable data, specific expertise, and the involvement of multiple actors that could help to upgrade the knowledge on the LO effects and give feedback on management measures for a smooth implementation of the CFP.

The outcomes of our expert-based approach suggest that the identification of sensitive and informative indicators that capture the effects of the LO is a demanding task. And yet, a preliminary suite of indicators that shed light on different properties of the discarding process and LO impacts have been proposed to enlighten managers about key attributes of the LO implementation. The first set of indicators selected based on a literature review process (n= 39) is considered too large to become part of an operational monitoring program. However, the selection of a subset of indicators is rather arbitrary, as there is no scientific-based recommendation for an optimal indicator number. Consequently, we conducted different trials, following different assumptions, to select a subset considered manageable by the authors of this work. When a strict threshold is set (median= 5, arbitrarily selected as those scores provided by experts with a certainty of 75% or higher) then 8 indicators are selected (F, SSB, Population size of target species, Discard rate, 95th percentile of the fish length distribution of each target species, Presence and extent of nursery areas for target species, Presence of sensitive species, Proportion of target species larger than the mean size at first sexual maturation). However, these indicators do not include any variable from the social and economic components and, thus, we observed that a more flexible threshold of 2.93 would allow indicators from all objectives to be monitored. Still, indicators under the objectives of “ecosystem functioning” and “social viability” were poorly represented. As “ecosystem functioning” belongs to the Ecological objective, already well represented in the subset by indicators under “healthy stocks” and “biological abundance, biomass and biodiversity”, the under-representation of this component could be neglected; moreover, responses suggest variables under this component are too complex to provide easy-to-interpret indicators. However, “social viability” is the only component representing the Social objective, and this suggests the selection of indicators under each objective should be subjectively balanced. Also, experts’ responses suggest the low scores assigned to the social objectives might be linked to the qualitative nature of social variables (scored low in criteria like “possibility to set targets” or “quality of sampling method”) and to the lack of evidence on variable trends in fishery systems. Thus, we claim the necessity to improve scientific knowledge and monitoring efforts of these components of the fishery system. Further effort to run the study on a truly representative sub-sample of experts from different scientific backgrounds is desired.

Qualitative comments were also included in the text to enable the selection of the final set of indicators. For instance, deriving Lopt indicator from size frequencies with data from the DCF is practically free (it is a by-product of the regular monitoring), has a long history and will be continued in the future. Instead, monitoring the 'full reporting of catches' can be extremely expensive and/or difficult, and depends on the collaboration of fishers, the means available to fishers' controllers, etc. Furthermore, the identification of indicators that will describe possible future economic activities and an emerging production channel for non-human consumption for former bycatch have scored low but, experts agree on the important of monitoring this indicator, as it would provide evidence on how the LO works in each community and increase the traceability of biomass extracted from the marine environment. This opens a different discussion arena, on how to represent these experts’ opinions while trying to maintain a systematic selection of indicators.

Overall, the indicators that have emerged contribute to the clarification of possible LO impacts on multiple objectives (environmental, social, economic). We observed that responses assigned to the “expected indicator trend after the full implementation of the LO” were highly influenced by experts’ opinions on how the LO will be implemented and its effectiveness in changing fishing and fishermen practices. In general, experts have noticed that the LO would not affect the fishery to a big extent because the degree of implementation is likely to be very low. Also, it is important to note how the 'traditional' fisheries indicators (e.g. F, SSB, Lopt) tend to score higher. This has the advantage of facilitating future monitoring, but also stresses the fact that there is a lack of knowledge on how the LO will affect economic or social aspects of the fishery. Perhaps the impact on these components will be really low, especially in a "soft implementation" scenario. Other respondents have pointed out that, in the Mediterranean, the implementation of the LO would not result in serious changes regarding the composition of the catch, given the multispecies nature of the Mediterranean fisheries, which does not allow the avoidance of non-commercial species, without important changes to fishing technology. Besides, several non-selective gears are already prohibited, through existing regulations, in coastal areas that usually serve as nurseries for numerous species. The LO is not directed to protect target species per se. Where there is a high component of juveniles/undersized target species in the catch, the LO may directly benefit by encouraging more selective practices, thus reducing pressure on this component of the population. This, in turn, could benefit SSB, through improvement in recruitment. Conversely, the new regime may reduce revenues because of more selective practices, may increase fishing pressure on target species, and may stimulate misreporting / non-reporting of catches. Experts have stressed that there are two scenarios: either fishers will be incentivised by the LO to avoid hotspots of bycatch or the commercialization of former bycatch which will lead to different results in fishery sustainability.

The study has also investigated not only experts’ appraisal on the LO effects but also the relative importance of 6 objectives under the three main dimensions of fishery sustainability. Experts ranked the different objectives, so the Ecological objective was given priority to the Economic and the Social objectives. This ranking results are pertinent to the discussion on the importance of providing weights to the different indicators according to component importance. However, first, the survey should target a balance in the participants’ area of expertise, as already mentioned above, a bias towards fishery biologists, and a poor representation of economists and social scientists, may have conditioned this ranking. This balance could only be achieved by extending the survey to MINOUW external participants, targeted by area of expertise, which is per se a demanding task but would definitely provide a set of indicators capturing also the socioeconomic properties of the LO.

In any case, the achievement of ecological objectives is a precondition for the achievement of socioeconomic targets. Several studies confirm that stock recovery will result in economic gains because biological sustainability will lead to higher incomes and lower operational costs (Frangoudes and Guillen, 2016). Profits will increase due to higher income from greater yields and lower costs arising through increased catch per unit of effort because of increased stock biomasses. Indeed, the economic performance of certain EU fleets in the Mediterranean continues to stagnate, alongside the state of several stocks that are overfished in this region have contributed to constraining economic performance of the fishing fleet (DGMARE, 2017). The LO may contribute towards a healthier ecosystem, an increase of adoption of selective practices and a reduction of the impact on nursery areas and sensitive habitats. Then, healthier biological communities will better sustain fisheries and increase productivity, landings and income. The economic viability of the fishing sector though does not necessarily imply maximum sustainability of the resources. Experts claim that the ecological sustainability targets are a prerequisite for the achievement of socioeconomic viability of the fishery and the need for the adoption of Ecosystem approach to Fisheries is underlined. Further research is required to clarify the different ecosystem mechanisms and behavioural interventions related to the minimization of unwanted catches. The need for further expansion of the present study and the application of the proposed methodological framework to test the indicators at a regional fishery scale is needed to further consider context-specific objectives, indicators and data; while the communication of indicators among experts, citizens and stakeholders will help to avoid the generation of ambiguous conclusions. The latter will result to the comprehensive dashboard comprising a multidimensional suite of indicators that will be informative to the effects of the LO.

7. Appendix

A1. The definitions of the indicators that reflect the Good Environmental Status and Socio-economic sustainability of the fishery system are presented. These indicators might respond to changing fishing practices due to the LO. The indicators have been developed within MINOUW project following three main objectives:

1.1. Ecological objectives

1.1.1. Safeguard the biological abundance, biomass and biodiversity

1.1.1.1. Presence and extent of nursery areas for target species (source: EU 2017, MINOUW D1.2)

Nursery grounds are known as essential habitats for target species, as these are crucial for the population replenishment. Therefore, it is vital to ensure that there is a sufficiently large habitat to maintain target species' populations, taking into consideration any threat of deterioration or loss of such habitats by changing fishing practices.

1.1.1.2. Presence of sensitive species (source: EU 2017, MINOUW D1.3)

Sensitive species are those highly vulnerable to fishing activities (e.g. elasmobranchs, sessile benthic species such as soft corals and sponges) and that might hold key roles in the ecosystem. But sensitive species can be a by-catch of fisheries, therefore, information on sensitive species presence in fishing areas is important to assess the ecological effect of changing fishing practices.

1.1.1.3. Diversity of by-catch species (source: EU 2017, MINOUW D 3.9, DCF 2017)

An indirect effect of fishing activities is the retention of non-target species in the fishing nets, known as by-catch that can be either landed and sold or discarded. The by-catch species number and abundance are relevant to estimate the impact of the LO on the fisheries assemblage composition.

1.1.1.4. Sensitive habitat presence and extent (source: EU 2017 MINOUW D 3.2)

Sensitive habitats are highly vulnerable to fishing practices due to dominance of sensitive organisms or to existence of organisms that are of interest because of their rarity, e.g. seagrass meadows, maërl beds, sponge covers. The distribution, range and pattern of sensitive habitats is important to assess potential consequences of changes in fishing effort and practices due to LO on these habitats.

1.1.1.5. Population size of target species (abundance/ biomass) (source: STECF 2017; EU 2017)

Each target species has a minimum population size necessary to ensure the long-term resilience of the species. Knowledge of population size is important to assess the effect of the LO on target species long-term resilience.

1.1.1.6. Ratio of species low/high resistance to fishing -discarded fraction (source: EU 2017, MINOUW D1.4, D1.10)

“Resistance” to fishing is defined by a set of biological traits of the species that potentially increase or decrease the vulnerability of the organisms and their populations to fishing practices (Resistance has three components: susceptibility to being catch, survival under discard practices and population resilience). The composition of the fished assemblage that is discarded in terms of “resistance” is an indicator of the effects on fishing practices on marine communities and the shift in the harvest pattern that may be caused by the LO.

1.1.1.7. Ratio of species low/high resistance to fishing -landed fraction (source: EU 2017, MINOUW D1.4, D1.10)

“Resistance” to fishing is defined by a set of biological traits of the species that potentially increase or decrease the vulnerability of the organisms and their populations to fishing practices (Resistance has three components: susceptibility to being catch, survival under discard practices and population resilience). The composition of the fished assemblage that is landed (both bycatch and target species) in terms of “resistance” is an indicator of the effects on fishing practices on marine communities and the shift in the harvest pattern that may be caused by the LO.

1.1.2. Achieve healthy stocks/ Accurate stock assessments/ Sustainable catches

1.1.2.1. Proportion of target fish larger than the mean size at first sexual maturation (>L50mat %) (source: EU 2017, DCF 2017)

Fish larger than the mean size of first sexual maturation are considered to be the spawning population that will replenish the current population. The proportion of large fish is crucial to assess if fishing practices are compatible with healthy stocks.

1.1.2.2. Fishing mortality (source: EU 2017, STECF 2017)

Fishing mortality is an indicator of the harvest pressure on the stock. The most common target in fisheries management is achieving F_{MSY}, and it is important to achieve a value at/above maximum sustainable yield.

1.1.2.3. Spawning Stock Biomass (source: EU 2017, STECF 2017)

Spawning Stock Biomass is an indicator of stock viability and represents the fraction of the population that is able to spawn. The most common target in fisheries management is achieving SSB_{MSY}, and it is important to pursue that this value is at/above maximum sustainable yield.

1.1.2.4. 95th percentile of the fish-length distribution of each target species (source: EU 2017, DCF 2017)

95th percentile of the fish-length distribution is an indicator of population structure and species length composition. Therefore, this indicator is relevant to assess the effect of fishing activities on the health of the stocks, including the impact of the LO.

1.1.2.5. Full reporting of catches (Newly developed indicator)

The full reporting of catches is necessary to ensure an accurate stock assessment. The compliance (recorded in various forms dependent on the authority e.g. by monitoring) with the LO regulation and the luck of discards and “new landings” under the LO will be evaluated with this indicator.

1.1.2.6. Discard rate (Discards/Catch ratio) (source: DCF)

The proportion of the catch that is discarded is linked to the selectivity of the fishery and to technical management measures, such as the minimum conservation size. Low discard rates are desirable to achieve sustainable catches. This variable will evidence any changes in discard practices due to the LO.

1.1.2.7. Optimum exploitation length (Lopt) (source: DCF 2017)

Another indicator of population condition/age class structure of target and commonly discarded species is Lopt, i.e., the size when fish grow and reproduce; the mean length at first capture equals the length where the biomass of an unexploited cohort would be maximum. Therefore, this variable is important to assess the sustainability of catches under LO.

1.1.3. Maintain ecosystem functioning

1.1.3.1. Productivity of trophic guilds (production per unit biomass in each fishery) (source: EU 2017, MINOUW D3.9)

Productivity of trophic guilds can be defined as the percentage of energy entering the ecosystem incorporated into biomass in a particular trophic guild (primary producers, primary consumers, etc.). It is commonly measured in grams per meter squared.

1.1.3.2. Proportion of large-bodied organisms (top of food webs) in the catch (source: EU 2017, MINOUW D3.9)

To maintain a well-structured food web, including optimal size and abundance of components, there is a need to assess the proportion of species caught at the top of food webs. This proportion is a key variable due to the susceptibility of these species to fishing.

1.1.3.3. Abundance of functionally important trophic groups/species (source: EU 2017, MINOUW D3.9, Frangoudes and Guillen, 2016)

Functionally important groups or species are those organisms performing key roles in the ecosystem function (e.g., scavengers). Variability in the abundance of these groups in the fished assemblage is relevant to assess the effect of changes in fishing practices, for example, changes in the discard numbers due to LO may affect the abundance of scavengers.

1.1.3.4. Diversity of functional traits (number of biological traits) (source: EU 2017, MINOUW D3.9)

The functional traits of the organisms and their interactions determine the functioning and stability of ecosystems. The number of functional traits that contribute to safeguard the integrity of ecosystems; however, fishing practices might impact on the diversity of traits of the fished assemblage.

1.1.3.5. Redundancy of functional traits (number of species per trait) (source: EU 2017, MINOUW D3.9)

The functional traits of the organisms and their interactions determine the functioning and stability of ecosystems and the higher the numbers of species that are characterized by each trait (redundancy) indicate an ecosystem of higher functional integrity. As fishing practices might impact on the number of species with similar traits, redundancy of traits in the fished assemblage is an indicator of the maintenance of ecosystem function.

1.1.3.6. Mean trophic level of the catch (source: DCF)

The trophic level of an organism is the position it occupies in a food chain and denotes its nutritional relationship to the primary sources of energy. The LO may reduce food supply at various trophic levels so is important to monitor possible changes in the average trophic level of organisms brought on board (catch).

1.2. Economic objectives

1.2.1. Achieve economic viability of the fishing sector

1.2.1.1. Production – human consumption (€) (source: Carvalho et al., 2017)

Production refers to the value from landings (sale of seafood products for human consumption).

1.2.1.2. Revenues (€) (source: Carvalho et al., 2017)

The value of production and income generated from the use of the vessel in other non-commercial fishing activities (e.g. recreational fishing, transport, tourism, etc.), may also include insurance payment for gear damage/loss /vessel. Income from direct subsidies and fishing rights are excluded. This is an indicator of economic profitability of the fleet and may change due to the LO.

1.2.1.3. Gross Value Added (GVA) (€) (source: Carvalho et al., 2017)

The net output of the fishing sector after deducting intermediate inputs from all outputs. It is a measure of the contribution to GDP made by an individual fisher, fleet or fishing sector. It can be an indicator of the long-term profitability of the fishing sector.

1.2.1.4. Return on investment (%) (source: Carvalho et al., 2017)

This indicator is deducted from the ratio between the net profit and cost of investment, as an indicator of efficiency of the investment that may change due to the LO.

1.2.1.5. Investments (€) (source: Carvalho et al., 2017)

This indicator could be a representative of the changes in investments due to the LO implementation and technical changes that may arise.

1.2.1.6. Landings (kg) (source: Carvalho et al., 2017)

In here, it refers to the amount of harvested fish (catches minus discards) for traditional markets (human consumption).

1.2.1.7. Ratio of revenues to break-even revenue (source: source: Carvalho et al., 2017; Rosetto et al., 2015)

The ratio of revenues to break-even revenue gives an indication of the economic sustainability of the fishing fleet and the short-term profitability of the fleet.

1.2.1.8. Production – non-human consumption (€) (source: Newly developed indicator)

It refers to the value of landings of former discards destined to uses other than human consumption under the LO.

1.2.2. Improve fleet efficiency

1.2.2.1. Fuel costs (€) (source: Carvalho et al., 2017)

Fuel costs is an indicator of effort changes and fuel consumption.

1.2.2.2. Operational costs (€) (source: Carvalho et al., 2017)

This indicator reflects operational costs and it is related to days at sea and it may change due to the LO.

1.2.2.3. Capacity (source: Carvalho et al., 2017)

The capacity of the fleet, in terms of numbers of vessels

1.2.2.4. Fishing effort (source: Carvalho et al., 2017)

Fishing hours, fishing days per year dedicated to fishing activity or any other form expressing fishing effort may change due to the LO

1.3. Social objective

1.3.1. Provision of work/ Livelihood enhancement/Social viability and wellbeing

1.3.1.1. Mean crew wage (€) (source: Carvalho et al., 2017)

This is an important factor for wellbeing and changes in the remuneration system may be encountered due to the LO.

1.3.1.2. Full Time Equivalent (FTE) (#) (source: Carvalho et al., 2017)

The crew workload involved in the fishing sector is described by this indicator which facilitates comparison with other economy sectors and may change due to the LO.

1.3.1.3. Crew wage compared to the minimum national salary (%) (source: Carvalho et al., 2017

This indicator compares economic status of the fishing sector in respect to the national economy.

1.3.1.4. Total Employed (person) (source: Carvalho et al., 2017)

The number of people employed by the fishing sector may change due to the LO.

1.3.1.5. New fish processing plants by GSA (#) (Newly developed indicator)

An industry may rise due to the LO and the need for processing bycatch in different units.

1.3.1.6. Number of jobs created for full bycatch utilization by gender (#) (Newly developed indicator)

New jobs will be created due to the LO and it is important to monitor this indicator including the contribution of each gender in this possible industry and by examining gender equity and social inclusion

1.3.1.7. End users' ability to modify fishing practices (source: MINOUW D1.5)

Fishers may adapt and change their practices due to the LO and their ability to change practices and modify the fishing method to enhance survival (i.e. slipping in purse seine) or switching fishing grounds or using more selective gears) is important to be studied in order to investigate possible adjustments in both behaviour and technologies (fishing practices).

A2. Criteria and quality evaluation scale explanation

Table 1. Example of the criteria and quality evaluation scale for each indicator (adjusted from Queirós et al., 2016)

Criteria	**Criteria Quality Evaluation Scale**			
	0	**1**		**2**
	Explanation: The characteristics of the criterion are **not met** for the indicator (e.g. very costly to obtain indicator)	Explanation: The criterion is **partially met** if its characteristics are not met at a satisfactory level (e.g. high cost to obtain the indicator but it gives a signal of ecosystem change and its cost-efficiency can be optimized through survey design)		Explanation: If all the characteristics of the criterion describe the indicator at a high level then the criterion is **fully met** (e.g. the indicator is cost efficient as it is based on a precise and accurate method that is not costly to implement)
	The criterion is not met:	**The criterion is met under the following characteristics:**		
Scientific basis	The indicator has **no scientific basis**	**Expert judgment/ qualitative approach** are adequate	**Peer-reviewed publications** evidencing the conceptual basis for using the indicator are preferred, stressing the existence of a **general causal link** (effect) between the indicator and a given pressure	The indicator must be reproducible, i.e., the conceptual basis and causality relationship have been published using **multiple data sets** (wide acceptance within the scientific community)
Responsiveness to pressure	The indicator **does not respond** in a consistent and significant manner to pressures in the system	A **quantitative approach** is adequate	The data should include some information about the **natural baseline of the system** (or comparable ecosystems), including information about its **natural variability** (which is known and understood) because this may confound the ability to detect a pressure driven effect	The **method** of analysis must consider the impact/ influence of natural variability (if any) on the response of the indicator (identify, estimate, and diagnose). The analysis must be appropriate for the complexity of the data to hand
Possibility to set targets	A **clear and unambiguous** target cannot be defined for the indicator	Both **expert judgment/ qualitative approach and a quantitative approach** can be adequate	Information about the **range of natural variability** of the system is required, against which **the target level is defined**.	The **method** of analysis must consider the impact/ influence of natural variability (if any) on the response of the indicator (identify, estimate, and diagnose). The analysis must be appropriate for the type of data at hand
Precautionary capacity/early warning/ anticipatory capability	There is **no immediate and measurable change** in the indicator associated with a change in the pressure that anticipates fishery-level change in the system	A **quantitative approach** is adequate	**Data** that enables a quantification of the time lag between pressure level and indicator response, and between pressure change and fishery-level relevant change. The indicator must be responsive to pressure and the existence of data is particularly important in instances where system collapse may occur. **The rate of change** in the indicator during impact and recovery phases may be distinct	Any **quantitative and reproducible method** of analysis that measures the lag time between pressure and indicator response, and the lag between pressure change and fishery- level change
Quality of sampling method: measurable, accurate, precise and repeatable outputs	The indicator **is not concrete/measurable, accurate, precise or repeatable**	A **quantitative approach** is adequate	Identification of whether an indicator is suitable requires availability of well-defined quantitative **data**	Any **method** that enables well-defined quantitative information on the indicator can be used that can be supplemented with power analysis and species area curves to evaluate the necessary sampling effort
Cost effective implementation	The indicator is **not cost effective**	A **quantitative approach** is adequate	Information about the **levels of precision and accuracy** required against which the costs of the necessary method of implementation of the indicator are calculated	Any **analysis** that enables the establishment of the change in cost associated with an improvement in the criteria of accuracy and precision of the indicator
Part of existing or ongoing data	The indicator is **not currently used in ongoing monitoring program(s)**	A **quantitative approach** is adequate	Information about the **length of time** during which the indicator has been in use within a monitoring program, and of the **redundancy** of the indicator in relation to others (if any) also in use within the scale of analysis of interest	Any **method** that quantifies all the aforementioned requirements

A3. Questionnaire for developing indicators to assess the impact of the Landing Obligation on The Good Environmental Status and Socioeconomic Sustainability of the fishery system

Dear Participant,

We are currently undertaking, as part of MINOUW project, a research into the indicators that could facilitate the assessment of the effect of the Landing Obligation (LO) on the Good Environmental Status (GES) and socioeconomic sustainability of fishery systems. The overall MINOUW aim is to assess the consequences of the gradual elimination of discards in European marine fisheries. Possible effects will be encountered in the marine ecosystems, economic activity and social welfare and, therefore, a toolbox of indicators is needed to assess potential changes in the system.

As part of this research, we would like to obtain your perception on the above as an expert in discard management through a survey questionnaire. We are asking you to provide your opinion on the proposed indicators and contribute to define a final sub-set of indicators of the effect of the LO on ecological and socioeconomic sustainability of the fishery system. In order to evaluate their suitability for our target, we ask you to rate the indicators against a preselected list of quality criteria, to then express your opinion on the potential magnitude and direction of change of each indicator under an effective implementation of the LO.

In the following pages there are instructions for the completion of the questionnaire. The information you provide will be of great value for this research, and accordingly, your participation is anticipated and very much appreciated.

We sincerely hope you are willing to participate in this exercise.

Thank you in advance for your time.

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A. Instructions for completion

For the identification of indicators of the Good Environmental Status (GES) and socio-economic sustainability of fishery systems, a framework is being developed. The framework includes ecological, economic and social objectives, and pertinent six sub-objectives to be achieved (1.1.1: Safeguard the biological abundance, biomass and biodiversity, 1.1.2: Achieve healthy stocks, 1.1.3: Maintain ecosystem functioning, 1.2.1: Achieve economic viability of the fishing sector, 1.2.2: Improve fleet efficiency, 1.3.1: Livelihood enhancement), all structured in a hierarchic classification. We propose a list of indicators classified within these objectives that may be sensitive to the LO and that are currently developed within MINOUW deliverables. We also take into account commonly used indicators in the literature (e.g. Tam et al., 2017; Rosetto et al., 2015; Lembo et al., 2017) and in the CFP, the Annual Economic report (AER) (Carvalho et al., 2017) and the Marine Strategy Framework (MSFD) (EU, 2017) and other H2020 programs, i.e. DiscardLess (see Frangoudes and Guillen, 2016).

The present survey involves **three steps** that ultimately aim to 1) identify appropriate indicators that may be sensitive to changes in a fishery system due to the gradual minimization of discards in European marine fisheries, and 2) organize the framework objectives into a proper hierarchy.

More specifically, experts will have the opportunity:

STEP 1. To evaluate the indicators' quality (Table 1) based on a list of criteria commonly used for the assessment of ecosystem indicators (Tam et al., 2017; Queirós et al., 2016; Rice and Rochet, 2005). The quality criteria are being described as follows:

1. ***Scientific basis***

The indicator is based on scientific, peer-reviewed outcomes that could provide a true representation of the impact of the LO on ecological and socioeconomic sustainability.

2. ***Responsiveness to pressure***

The indicator reflects change in the fishery system's state that is caused by a consistent and specific significant pressure(s).

3. ***Possibility to set targets***

Clear and unambiguous targets - that meet appropriate target criteria (absolute values/ trend directions) for the indicator - can be specified to reflect ecological and socioeconomic objectives.

4. ***Precautionary capacity/early warning/anticipatory capability***

The indicator should have an early warning nature, described by a well-defined time lag between pressure change and the detection of a measurable change in the indicator level that is suitable enough to enable mitigation actions.

5. ***Quality of sampling method: measurable, accurate, precise and repeatable outputs***

Indicators should be technically rigorous. Indicators should ideally be easily and accurately determined by using technically feasible and quality assured methods that have repeatability.

6. ***Cost effectiveness***

Sampling, measuring, processing, analyzing indicator data and reporting assessment outcomes should make effective use of limited financial resources.

7. *Part of existing and ongoing data collection programs*

Indicators are supported by existing or ongoing monitoring programs that provide the necessary data to derive the indicator. Ideal monitoring programs should have a time series capable of supporting baselines and reference point setting. Data should be collected on multiple sequential occasions using consistent protocols.

STEP 2. To express their opinion on the direction of change (negative/positive impact) of each indicator due to an effective implementation of the LO (Table 2).

STEP 3. To evaluate the potential of the LO in achieving **both socioeconomic and ecological objectives,** and the relative importance of achieving each of the ecological and socioeconomic objectives (Tables 3, 4).

B. Personal profile (Confidential)

Name: Field of research:

Position: Affiliation/organization:

You work in a public research institute, NGO, Other (specify): Email:

Development of indicators of the Good Environmental Status and Socio-economic Sustainability of the fishery system

Target	Indicator	Evaluation criteria											
		Scientific basis	Certainty	Responsiveness to pressure	Certainty	Possibility to set targets	Certainty	Precautionary capacity/early warning/ anticipatory capability	Certainty	Quality of sampling method: measurable, accurate, precise and repeatable outputs	Certainty	Cost effective implementation	Certainty	Part of existing or ongoing data	Certainty
Safeguard the biological abundance, biomass and biodiversity	*Presence and extent of nursery areas for target species*														
	Presence of sensitive species														
	Diversity of bycatch species														
	Sensitive habitat presence and extent														
	Population size of target species														
	Ratio of species low/high resistance to fishing-discarded fraction														
	Ratio of species low/high resistance to fishing-landed fraction														
Achieve healthy stocks/ Accurate stock assessments/ Sustainable catches	*Proportion of target fish larger than the mean size at first sexual maturation*														
	F														
	SSB														
	95th percentile of the fish length distribution of each target species														
	Full reporting of catches														
	Discard rate														
	Lopt														

Objective	Indicator	Evaluation criteria													
		Scientific basis	Certainty	Responsiveness to pressure	Certainty	Possibility to set targets	Certainty	Precautionary capacity/early warning/ anticipatory capability	Certainty	Quality of sampling method: measurable, accurate, precise and repeatable outputs	Certainty	Cost effective implementation	Certainty	Part of existing or ongoing data	Certainty
Maintain ecosystem functioning	*Productivity of trophic guilds*														
	Proportion of large-bodied organisms(top of food webs) in the catch														
	Abundance of functionally important trophic groups/species														
	Diversity of functional traits														
	Redundancy of functional traits														
	Mean trophic level of the catch														
Achieve economic viability of the fishing sector	*Production for human consumption*														
	Revenues														
	GVA														
	Return on investment														
	Landings														
	Investments														
	Ratio of revenues to break even revenue														
	Production for non-human consumption														
Improve fleet efficiency	*Fuel costs*														
	Operational costs														
	Capacity														
	Fishing effort														
Provision of work/Livelihood enhancement/ Social viability and wellbeing	*Mean crew wage*														
	FTE														
	Crew wage compared to the minimum national salary														
	Total employed														
	New fish processing plants														
	Number of jobs created for full bycatch utilisation by gender														
	End users' ability to modify fishing practices														

Table 2. Express your opinion on how the indicator would change after an effective implementation of the LO (direct effect: a large positive ++, a small positive effect +, zero 0, a small negative -, a large negative - -). If no direct effects can be established, then select the column "Other" (if the indicator illustrates the GES of the fishery).

Indicator	Experts' perception on the effect of the LO on the indicator					
	Direct effect					Other
	+ +	+	0	-	- -	The indicator is informative of the GES of the fishery system
Presence and extent of nursery areas for target species						
Presence of sensitive species						
Diversity of bycatch species						
Sensitive habitat presence and extent						
Population size of target species						
Ratio of species low/high resistance to fishing-discarded fraction						
Ratio of species low/high resistance to fishing-landed fraction						
Proportion of target fish larger than the mean size at first sexual maturation						
F						
SSB						
95^{th} percentile of the fish length distribution of each target species						
Full reporting of catches						
Discard rate						
Lopt						
Productivity of trophic guilds						
Proportion of large-bodied organisms (top of food webs) in the catch						
Abundance of functionally important trophic groups/species						
Diversity of functional traits						
Redundancy of functional traits						
Mean trophic level of the catch						
Production for human consumption						
Revenues						
GVA						
Return on investment						
Landings						
Investments						
Ratio of revenues to break even revenue						
Production for non-human consumption						
Fuel costs						
Operational costs						
Capacity						
Fishing effort						
Mean crew wage						
FTE						
Crew wage compared to the minimum national salary						
Total employed						
New fish processing plants						
Number of jobs created for full bycatch utilisation by gender						
End users' ability to modify fishing practices						

Assess the relative importance of the different ecological, economic and social targets:

a. Assuming objectives have equal weight

Table 3. Will the LO allow the achievement of both socioeconomic and ecological objectives? Please express your opinion (yes/no).

If the LO achieves the following ecological objective:	**Then which of the following socioeconomic objectives will also be achieved?**		
	Achieve economic viability of the fishing sector	Improve fleet efficiency	Provision of work/Livelihood enhancement/ Social viability and wellbeing
Safeguard the biological abundance, biomass and biodiversity			
Achieve healthy stocks/ Accurate stock assessments/ Sustainable catches			
Maintain ecosystem functioning			
If the LO achieves the following socioeconomic objective:	**Then which of the following ecological objectives will also be achieved?**		
	Safeguard the biological abundance, biomass and biodiversity	Achieve healthy stocks/ Accurate stock assessments/ Sustainable catches	Maintain ecosystem functioning
Achieve economic viability of the fishing sector			
Improve fleet efficiency			
Provision of work/Livelihood enhancement/ Social viability and wellbeing			

b. Assuming objectives have different weight

Table 4. The expert should express the degree of preference between the two alternatives: which objective contributes more to the goal (achieve GES and socio-economic sustainability)? Select the alternative on the left if this is more important while on the right otherwise (Opinion A and B; first and third column respectively). The following scale has been adopted to evaluate the relative importance of each objective over the others: 9 extremely more important, 7 much more important, 5 more important, 3 moderately more important, 1 equally important. Please highlight the most important objective and explain why.

Option A	**Scale**	**Option B**
Safeguard the biological abundance, biomass and biodiversity	9 7 5 3 1 3 5 7 9	Achieve healthy stocks/ Accurate stock assessments/ Sustainable catches
	9 7 5 3 1 3 5 7 9	Maintain ecosystem functioning
	9 7 5 3 1 3 5 7 9	Achieve economic viability of the fishing sector
	9 7 5 3 1 3 5 7 9	Improve fleet efficiency
	9 7 5 3 1 3 5 7 9	Provision of work/ Livelihood enhancement/Social viability and wellbeing
Achieve healthy stocks/ Accurate stock assessments/ Sustainable catches	9 7 5 3 1 3 5 7 9	Maintain ecosystem functioning
	9 7 5 3 1 3 5 7 9	Achieve economic viability of the fishing sector
	9 7 5 3 1 3 5 7 9	Improve fleet efficiency
	9 7 5 3 1 3 5 7 9	Provision of work/ Livelihood enhancement/Social viability and wellbeing
Maintain ecosystem functioning	9 7 5 3 1 3 5 7 9	Achieve economic viability of the fishing sector
	9 7 5 3 1 3 5 7 9	Improve fleet efficiency
	9 7 5 3 1 3 5 7 9	Provision of work/ Livelihood enhancement/Social
Achieve economic viability of the fishing sector		Improve fleet efficiency
	9 7 5 3 1 3 5 7 9	Provision of work/Livelihood enhancement/ Social viability and wellbeing
Improve fleet efficiency	9 7 5 3 1 3 5 7 9	Provision of work/Livelihood enhancement/ Social viability and wellbeing

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