Marine Policy 177 (2025) 106661

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Full length article

A practical framework to evaluate the feasibility of incentive-based approaches to reduce bycatch of marine mammals and other protected species

Manuel Bellanger [a,*,1], Benjamin Dudouet [a,b,1], Sophie Gourguet [a,1], Olivier Thébaud [a,1], Lisa T. Ballance [c,2], Nicolas Becu [d,2], Kathryn D. Bisack [e,2], Annie Cudennec [f,2], Fabienne Daurès [a,2], Sigrid Lehuta [g,2], Rebecca Lent [h,2], C. Tara Marshall [i,2], David Reid [j,k,2], Vincent Ridoux [l,2], Dale Squires [m,2], Clara Ulrich [g,2]

[a] Ifremer, Univ Brest, CNRS, IRD, UMR AMURE, Unité d'Économie Maritime, IUEM, Plouzané, France
[b] EqualSea Lab – CRETUS, Universidade de Santiago de Compostela, Spain
[c] Marine Mammal Institute, Oregon State University, Newport, OR, USA
[d] CNRS, UMR LIENSs, La Rochelle, France
[e] Northeast Fisheries Science Center, NOAA Fisheries, Woods Hole, MA, USA
[f] Université de Bretagne Occidentale, Brest, France
[g] Ifremer, Nantes, France
[h] Marine Policy Consultant, San Diego, CA, USA
[i] University of Aberdeen, Scotland, United Kingdom
[j] Marine Institute, Galway, Ireland
[k] International Council for the Exploration of the Sea, Copenhagen, Denmark
[l] La Rochelle University/CNRS, Observatoire Pelagis, La Rochelle, France
[m] University of California, San Diego, CA, USA

ARTICLE INFO

JEL Classifications:
Q22
Q27
Q28
D01
D02

Keywords:
Incentive-based management
Bycatch
Marine mammals
Marine conservation
Fisheries management
Economic and social incentives

ABSTRACT

Fisheries bycatch is one of the biggest threats to marine mammal populations and an important conservation and management problem worldwide. Conventional marine mammal bycatch mitigation approaches typically rely on top-down, command-and-control regulations that often fail to create desired incentives for fishers to avoid bycatch. There is growing recognition of the need to explore alternative approaches that encourage behavioral change through the creation of an appropriate set of incentives – both economic and social – towards bycatch reduction. This study introduces a practical framework that aims to evaluate a range of dimensions related to the feasibility and durability of incentive-based approaches to mitigate marine mammal bycatch. We use this framework to examine seven case studies where incentive-based measures have been implemented or proposed, demonstrating both its applicability in a variety of contexts and usefulness in *ex-ante* assessment of alternative bycatch mitigation options. Our analysis underscores important operational aspects to consider in implementing such approaches, including the need for fine-scale data collection, the importance of a credible threat such as a fishery closure or loss of market access, the involvement of fishers in solution development, and the pivotal role of collective organizations in addressing marine mammal bycatch issues which almost always are complex and multi-faceted.

* Corresponding author.
E-mail address: manuel.bellanger@ifremer.fr (M. Bellanger).
[1] Authorship equal for these lead authors
[2] Authorship equal for these authors

https://doi.org/10.1016/j.marpol.2025.106661
Received 30 September 2024; Received in revised form 20 February 2025; Accepted 27 February 2025
Available online 12 March 2025

1. Introduction

Fisheries bycatch – the incidental capture or entanglement of non-target species in fishing gears – is widely considered as the most prevalent and widespread threat to marine mammals [54,55]. Bycatch is the primary anthropic driver of marine mammal population declines and the principal obstacle hindering the recovery of depleted populations [55]. Bycatch of marine mammals occurs worldwide in most types of fishing gear and in all kinds of fisheries, ranging from artisanal to large industrial fisheries [54]. Moreover, bycatch is not limited to marine mammals; it affects many other species including sea turtles, sea birds, sharks, non-target species, undersized target species, and commercial fish species for which quotas are limiting and discards banned [36].

Conventional marine mammal bycatch mitigation approaches include the adoption of a range of technical and process standards such modifications to gear and gear deployment, the use of deterrent devices, spatial-temporal closures and other changes to fishing operations [19]. The effectiveness of these measures varies depending on the species involved, the type of fishery, and the local ecological, socio-economic, and regulatory conditions [19]. Their implementation is generally based on top-down, command-and-control approaches. However, command-and-control approaches often fail to create desired incentives towards the adoption of cost-effective bycatch reduction measures [61]. In addition, these approaches often fail to address the implications for bycatch reduction efforts of changes in the market, environmental, technological and resource circumstances of fishing. There is growing recognition of the need to explore alternative approaches that encourage behavioral change through the creation of an appropriate set of incentives towards bycatch reduction [21,25,34,50,61,66].

Incentive-based bycatch-reduction measures create incentives to modify decision-making of producers towards optimal bycatch reduction [61]. An incentive is an economic or extrinsic motivation (see [23]) that modifies the behavior of an economic agent by altering the benefits and costs of alternative courses of action without forbidding any options. In a fisheries context, incentives may relate to business and operational decisions such as: choice of fishing areas, times and/or fishing practices; choice of target species and fishing gear; choice of investments in different types of vessels; strategies for observing interactions with marine mammals; and information-sharing regarding observed interactions.

Incentive-based approaches seek to avoid command-and-control regulations such as strict fishery closures, or the prohibition of certain fishing gears, and promote self-decided changes in fishing practices [50]. Relative to command-and-control approaches, incentive-based bycatch reduction measures (see typology below) aim to provide economic actors with greater flexibility in designing solutions to reduce bycatch, in creative and cost-effective ways [34]. They can allow operators to respond flexibly to changing market, environmental, technological and resource conditions, using decentralized, private information that is not available to the management authority [61]. In contrast, command-and-control regulations are generally not envisaged and designed based on the incentives they create [67]. While analyzing the incentives created by command-and-control measures is potentially interesting (see e.g. [32]), this paper focuses on strategies that specifically target the creation or modification of incentives leading to behavioral changes, whose potential in addressing bycatch issues remains largely underexplored [58].

In practice, the goal of incentive-based measures can be twofold: (1) encourage adoption of practices that limit bycatch; and (2) encourage information sharing and participation in knowledge acquisition programs, which are critical given the data-poor context of marine mammal bycatch [53]. Furthermore, incentive-based measures are often combined with top-down measures to provide comprehensive management strategies.[3] Incentive-based approaches have been applied in a variety of fisheries [50], including with the aim of mitigating marine mammal bycatch [34]. However, their application to marine mammal and other protected species bycatch issues remains rare compared to traditional command-and-control management approaches, and research is still needed to better understand the determinants of their applicability according to context.

Building on previous research regarding the evaluation of policy measures aimed at resolving conflicts between human activities and biodiversity conservation [7,5], we propose a practical framework to evaluate the applicability of a variety of incentive-based approaches to reduce marine mammal bycatch. The framework identifies six dimensions related to the feasibility and durability of new institutional arrangements that can be assessed through a semi-quantitative approach. We focus on practical aspects related to transaction costs [41] which are often overlooked in policy design, despite having demonstrated effects on the feasibility of management measures [44]. Our framework thus complements traditional ecosystem-based management assessment approaches relying on a wide range of biological and socio-economic indicators [22,35], by bringing in transaction cost considerations relating to the feasibility of management measures [39,65]. We use this framework to examine seven case studies from around the world where incentive-based approaches to reduce bycatch have been implemented or are being proposed. While these case studies provide an example of operationalization of the framework for a diverse set of measures, the evaluations that we present are primarily illustrative examples that demonstrate how the framework can be applied to leverage expert knowledge and help stakeholders think practically about which incentive-based management strategies may be appropriate and feasible to address a specific bycatch issue. Thus, the results presented are not directly generalizable to provide a definite evaluation of the general merits of specific measures - in the context of this paper, they merely illustrate how the framework can be applied in a variety of settings. Drawing on expert knowledge, we also outline a range of important operational aspects to consider in implementing incentive-based approaches, relating in particular to the existence of a “credible threat” to fishing activity deriving from either regulatory decisions or from market response to the bycatch problem, as well as fine-scale information on the level and determinants of the bycatch problem.

The article is structured as follows. Section 2 presents our practical evaluation framework and the approach taken to apply it to a variety of incentive-based measures to mitigate fisheries bycatch. Section 3 presents a typology of incentive-based measures, the selection of case studies and the scores derived from their evaluation. Section 4 discusses practical considerations in applying the proposed framework and potential for future application as well as the lessons learned from the case studies.

2. Methods

2.1. A practical evaluation framework for assessing bycatch management options

First, we propose a practical evaluation framework to examine the determinants of the feasibility and durability of incentive-based bycatch management measures. Here the term ’durability’ refers to the ability of institutional arrangements to maintain their core functions (i.e. mitigate the problems they are intended to solve) over the long term, including resilience to external change. We build on previous work regarding the determinants of such feasibility and durability [7,5], considering bycatch management as a special case of the broader challenges

[3] See e.g. the Scottish conservation credit scheme that combines penalty-and-reward system of days at sea with mandatory technological standards [60].

Table 1
Structure of the practical evaluation framework.

Dimension	Rationale for assessment	Score assigned
(A) Stakeholder number and homogeneity	Small number of homogeneous stakeholders involved in the solution	5 – very favorable
	Large number of heterogeneous stakeholder groups involved in the solution	1 – very unfavorable
(B) Coordination and cooperation	Existing institutions can adequately support implementation of the solution	5 – very favorable
	Lack of existing coordination mechanisms and no cooperation among stakeholders	1 – very unfavorable
(C) Costs and benefits uncertainty	Solution costs and benefits can be anticipated and are considered adequately distributed by stakeholders	5 – very favorable
	Very large uncertainty about the costs and benefits associated with implementing the solution, and their distribution	1 – very unfavorable
(D) Ecological uncertainty	Very low uncertainty about the bycatch mitigation effectiveness of the solution and its possible side effects	5 – very favorable
	Very high uncertainty about the bycatch mitigation effectiveness of the solution and its possible side effects	1 – very unfavorable
(E) Anticipation of non-compliance	Stakeholders consider that conditions to ensure a high level of compliance are fulfilled	5 – very favorable
	Stakeholders anticipate a high level of non-compliance in the implementation of the solution	1 – very unfavorable
(F) Stakeholder values	The solution strongly aligns with stakeholder values	5 – very favorable
	The solution conflicts with stakeholder objectives and worldviews	1 – very unfavorable

associated with managing social-ecological systems for sustainability [49] and understanding institutional change [70]. A core concept in addressing these challenges is the consideration of the transaction costs in policy design [44]. Marshall [41] defines transaction costs as "the resources used to: define, establish, maintain, use and change institutions and organizations; and define the problems that these institutions and organizations are intended to solve". Transaction costs include costs related to: research and information; enactment or litigation; design and implementation; support and administration; contracting; monitoring; and enforcement [15]. Building on the investigation of determinants of these transaction costs, Bellanger et al. [7,5] proposed a conceptual framework to assess conflicts between human activities and biodiversity conservation at the interface of multiple jurisdictions. The conceptual framework considers that the transaction costs associated with resolving these conflicts are largely determined by the heterogeneity of stakeholder groups involved, in terms of value systems, views of the management problem, objectives or priorities, knowledge bases, and perceptions of acceptable allocation of costs and benefits associated with proposed solutions. This conceptual framework considers the following dimensions:

A. **Number and homogeneity of stakeholders**: limited entry, well-delineated, small, and homogeneous groups facilitate collective action to address resource use externalities [2];
B. **Existing coordination mechanisms and level of stakeholder cooperation in the definition of solutions**: governance institutions that allow for coordinated action, support from authorities, and stakeholder involvement can favor the emergence of solutions [63];
C. **Level of uncertainty about the distribution of costs and benefits associated with implementing the solution**: low uncertainty about the benefits of coordination and a proportionate distribution of costs and benefits among stakeholders are key to the feasibility of a solution [37];
D. **Level of scientific uncertainty about the mitigation potential of a proposed solution and possible side effects**: the lower the scientific uncertainty about a solution's mitigation potential, the more likely it is that this solution will be widely accepted and durable [30];
E. **Anticipation of non-compliance**: anticipation of agreement violations may undermine the feasibility and durability of a solution [38] and depends on monitoring and enforcement mechanisms [48];
F. **Alignment with stakeholder values**: solutions that align with stakeholders' intrinsic motivations [23] facilitate behavioral change and increase the likelihood of long-term commitments [71].

In this paper, we apply this framework to the question of evaluating alternative solutions for marine mammal and protected species bycatch, with a particular focus on incentive-based management measures. Indeed, the articulation of these six dimensions (A-F) provides a simple and adaptable framework to evaluate the feasibility and durability of such measures, which is, in principle, applicable in a variety of bycatch situations. We illustrate the application of the framework using semi-quantitative expert evaluation. Our proposed approach is based on a scoring process to assess each of the six dimensions (A-F), with scores ranging from 1 (= very unfavorable with respect to the feasibility and durability of a solution) to 5 (= very favorable). Table 1 synthesizes this practical evaluation framework and describes the rationale for maximum and minimum scores for each dimension. Notably, we evaluate each dimension separately and we do not combine the scores. In interpreting the results, we consider that a single dimension that is not adequately satisfied can be sufficient to undermine the feasibility of a solution. The purpose of this approach is thus to characterize each of these dimensions for a given management strategy to guide reflections on its practicality as a policy option. Experts are also asked to provide a rationale for their individual scores, which helps communicate these reflections within and beyond the expert group involved in the assessment.

2.2. *Applying the framework*

A two-day workshop was convened in March 2023 in Brest, France, bringing together 16 experts from different disciplines (economics, biology, fishery science, bio-economic modeling, and law), with international experience on incentive-based approaches to reduce bycatch and on marine mammal bycatch. Notably, the group of experts comprised 13 senior scientists, including eight who were selected for their extensive experience and long-term involvement in studying and helping to manage bycatch problems, particularly in the case studies that were eventually selected. The group's collective experience conferred the legitimacy to provide an evaluative perspective and apply the framework to case studies. The 16 experts who participated in the workshop are all co-authors of the current paper.

The workshop used a multi-step approach to test our evaluation framework. We first aimed at validating a typology of incentive-based measures to address marine mammal and protected species bycatch. We built on Pascoe et al. [50] who proposed a typology of market-based approaches to limit fisheries bycatch. During the workshop, experts discussed the relevance of this typology for marine mammal and protected species bycatch and debated the appropriateness of completing this typology with categories related to social-based incentive measures that are increasingly found in the literature but were not detailed in the initial typology by Pascoe et al. [50]. Building on participant comments, we produced a revised typology which includes this type of measures. The typology is presented in the results of this article.

Next, we selected seven case studies (Table 2) illustrative of a diversity of types of bycatch issues and incentive-based measures across this typology, of which at least one of the senior scientists had an in-

Table 2
General characteristics of the seven case studies.

Case study	Region	Bycatch species of concern	Fisheries involved, target species	Management goals and targets	Type of incentive-based measures
(1) BATmap: bycatch avoidance mapping tool	West coast of Scotland	Choke species (cod, whiting) and spurdog	Demersal trawl	Reduce catch of potential choke species to comply with the Landing Obligation	Dynamic spatial management, capacity building
(2) The endangered North Atlantic right whale	US Northwest Atlantic coast	North Atlantic right whale (*Eubalena glacialis*)	Lobster fishery (pots and traps)	Reduce the incidental take of North Atlantic right whales to the Potential Biological Removal (PBR = 1 or below) level	Dynamic spatial management
(3) US Import Regulations under MMPA	US import market for seafood	Marine mammals	Fisheries whose product is destined for sale in the US market	Ensure that marine mammal bycatch standards for importing country are comparable in effectiveness to US standards	Trade barriers
(4) Marine Stewardship Council Eco-Label – new standards	Global	Endangered and Threatened Species	Case-specific	Reduce impacts of fisheries on Endangered and Threatened Species	Labeling
(5) The dolphin-set tuna purse seine fishery	Eastern Tropical Pacific	Dolphins (*Stenella* spp. and *Delphinus delphis*)	Yellowfin tuna purse-seine fishery	Reduce dolphin mortality to "insignificant levels approaching zero"	Bycatch limits, labeling, trade barriers, private buyers' strategies, good practice promotion
(6) Cooperative-based Salmon savings incentive plan agreements	Eastern Bering Sea, Alaska USA	Chinook and chum salmon (*Oncorhynchus tshawytscha* and *Oncorhynchus keta*)	Pollock midwater trawl fishery	Reduce bycatch of chinook and chum salmon	Tax/levies, rewards, insurance, bycatch limits
(7) Dolphin bycatch in the Bay of Biscay	Bay of Biscay, France	Common dolphin (*Delphinus delphis*)	Gillnet, trawl, and purse seine fisheries	Minimize and where possible eliminate dolphin bycatch	Dynamic spatial management (7a), bycatch limits (7b)

depth understanding. The primary purpose of our study was not to compare case studies, but to demonstrate the applicability of our approach in a variety of contexts. It was therefore important to test the approach on a range of cases and types of measures. The group of experts reviewed each of the case studies collectively. Individual experts with specific expertise on a particular case study were then asked to apply our scoring approach to assess each of the six dimensions (A-F) following the evaluation criteria provided in Table 1. Case study experts were also invited to write a brief justification for the scores provided. The assessment proceeded iteratively between case study experts and the lead authors who ensured that each dimension was evaluated consistently across all cases. The iterative process allowed experts to discuss the scores, revisit their evaluation, develop a shared understanding of each dimension, and resolve conflicting assessments through consensus. Radar plots were generated based on the resulting scores, to allow for an intuitive visualization highlighting strengths and weaknesses in each case study (greatest area of polygon in a radar plot corresponding to most favorable situation). Justification text was consolidated in the course of the iterative scoring process, and forms an integral part of the results, providing the rationale for the final scores.

3. Results

3.1. Typology of incentive-based bycatch management measures

The proposed typology distinguishes between market-based incentive measures and social-based incentive measures (Fig. 1). Market-based incentive measures affect the costs and benefits to fishery operators associated with different options, and act as extrinsic motivators to reducing bycatch [34]. They include financial incentives that directly affect the returns from different fishing activities; interventions on fishing opportunities such as bycatch limits or variations of target species quotas according to bycatch rates, as well as market access restrictions. Social-based incentive measures can target intrinsic motivations of individual agents [23], encouraging them to behave in a socially valued and approved manner.[4] This includes the use of personalized nudges and the showcasing of committed fishers. They can also more indirectly target the collective level, aiming to strengthen information sharing, stimulate social learning [46] and reduce transactions costs [2,5]. Social-based incentives measures targeting the collective level include the promotion of good practices as well as supporting capacity building initiatives.

A detailed description of these different types of incentive-based measures is presented in Supplementary Appendix A. As stressed by Gneezy et al. [23], the effects of these different categories of measures may depend on their design, as well as on how they interact with both intrinsic and extrinsic motivations.[5] It is therefore important to better understand this design as well as implementation contexts to be able to predict their potential impacts.

3.2. Selected case studies

Based on the above typology, we selected a limited number of case studies from around the world, illustrating a diversity of approaches relying on one or several types of measures (Table 2). The *ex-post* evaluation of these case studies was carried out using our practical evaluation framework, with the help of knowledgeable experts in the group (case studies 1–6). Since we also aimed to show the potential for using the framework in *ex-ante* evaluation of alternative management options, we also selected a case study where incentive-based management measures are currently being proposed, but have not been adopted (case study 7). We focused on the illustrative case of common dolphin (*Delphinus delphis*) bycatch in the Bay of Biscay, which is currently among the most high-profile challenges of marine mammal bycatch in European fisheries [29,51]. Table 1 synthesizes the characteristics of our seven case studies, of which a short description is provided hereafter.[6]

3.2.1. Case study 1: BATmap – bycatch avoidance mapping tool

On the west coast of Scotland, the bottom trawl fishery aims to

[4] See [64] and [28] for illustrations of the importance of social norms in determining compliance behavior in commercial fisheries.

[5] For example, Gneezy et al. [23] underscore that extrinsic (relative price) effects and intrinsic (psychological) effects can crowd each other in (reinforce) or out.

[6] One additional case study on the Cooperative-based halibut bycatch credit systems is included in Supplementary Appendix A

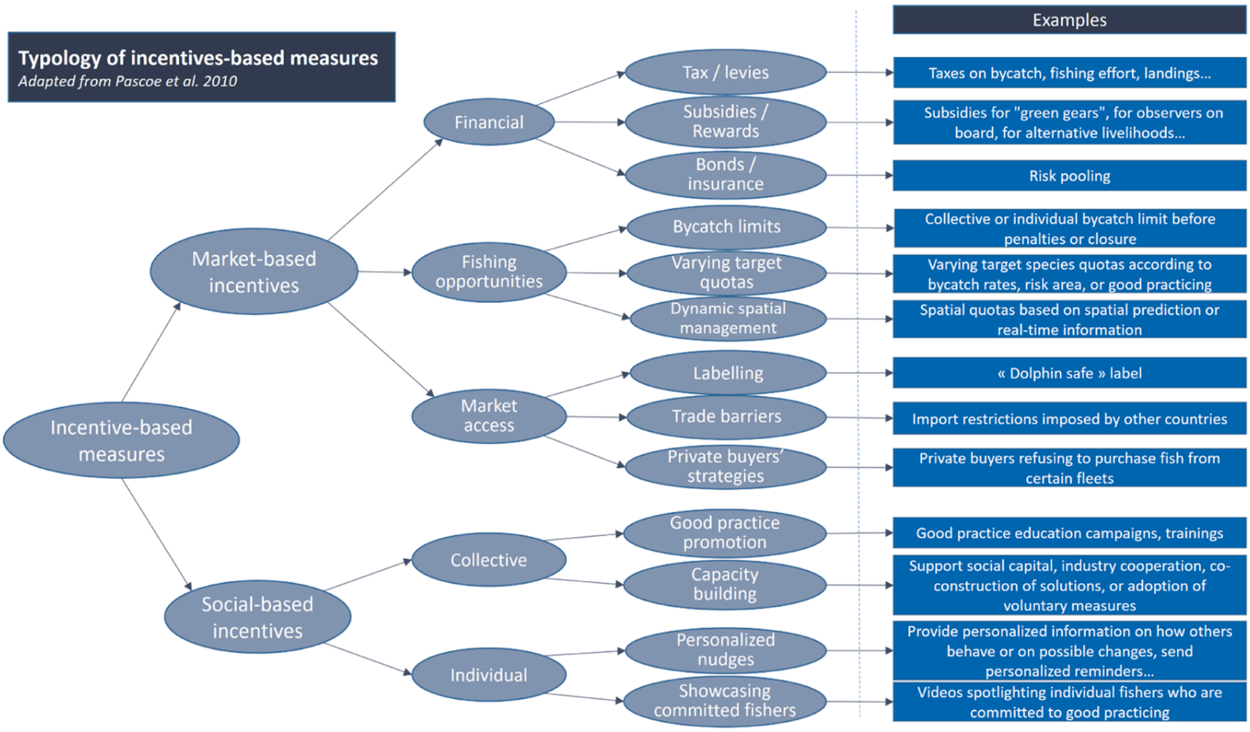

Fig. 1. Typology of incentive-based measures to limit fisheries bycatch. Adapted from Pascoe et al. [50]. See Supplementary Appendix A for more details on the different types of measures and references to illustrative examples from the literature.

reduce bycatch of commercial species having low quotas to protect depleted local stocks, e.g. cod and whiting. Spurdog sharks are a species of specific conservation concern that cause damage to fishing gear. To reduce bycatch of these species and comply with the landing obligation (i.e., the discard ban implemented under the EU's Common Fisheries Policy), the fishery has developed a system for sharing both catch and vessel position information in real time [42]. This is done via the software platform BATmap (https://info.batmap.co.uk/), an application financed, developed and managed by industry including several participating producer organizations (POs). Uniquely, the data storage and processing are managed by industry and independently of the government. High bycatch values automatically generate alerts that are disseminated in real time to inform fishers of areas where high bycatch has been recently reported and that they may choose to avoid. Routine use of the application has been in place since 2020. Currently, BATmap is being trialed in the inshore *Nephrops* fleet on the west coast of Scotland and uptake in a proportion of that fleet is expected by the end of 2024.

3.2.2. Case study 2: the endangered North Atlantic right whale

In the Northwest Atlantic, entanglement in lobster fishing gear is one of the leading known causes of mortality for endangered North Atlantic right whales (NARW). Between 2003 and 2009, the National Oceanic and Atmospheric Administration (NOAA) introduced a Dynamic Area Management (DAM) system, which included an aerial survey program that provided real-time data to fisheries managers to determine if and where to trigger a DAM [11]. After each flight, the sightings data were used to determine whether the density of right whales was above the threshold to trigger a DAM. Fishing activity within these zones was restricted to a list of gear (whale-modified-gear) established by NOAA, thereby creating an indirect economic incentive for some fishers to adopt the whale-modified-gear [11]. The *ex-ante* regulatory analysis of mandatory gear removal in DAM zones estimated foregone lobster revenues of $3.2 M (US$2002). However, to continue fishing in DAMs, fishers modified their gear voluntarily before it became mandatory throughout the region when DAMs were phased out in 2009.

3.2.3. Case study 3: US import regulations under the Marine Mammal Protection Act

The U.S. Marine Mammal Protection Act (MMPA) requires measures for monitoring and mitigation of marine mammal bycatch in domestic fishing operations. The US legislation also requires that fishery products imported into the US are from fishing fleets that are subject to marine mammal bycatch standards equivalent in effectiveness to the US fishery [8]. The implementing regulations provide requirements for this effectiveness, including monitoring (such as observer coverage), bycatch estimation methods, reporting requirements, a stock assessment to understand potential population-level impacts, and conservation and management measures aimed at reducing bycatch. The exporting country must obtain a comparability finding before January 1, 2026 in order to continue selling on the US market [20]. The credible threat of lack of US market access has been an effective incentive for countries to take voluntary action in terms of monitoring and mitigating marine mammal bycatch [8].

3.2.4. Case study 4: Marine Stewardship Council eco-label – new standards

Market access may be an incentive to seek Marine Stewardship Council (MSC) eco-certification and agree to submit to the Chain of Custody requirements. In 2023, MSC introduced new standards that more specifically address interactions with endangered, threatened, and protected species [24]. One key change from the status quo is that MSC's new Fishery Standard directly addresses fisheries in which the endangered, threatened, or protected species is a marine mammal and intentional harassment or killing of that species is an integral part of the fishing operation. The marine mammal species 'must be at or above favorable conservation status with a high degree of certainty'. Fisheries seeking MSC certification for the first time will need to follow the new Standard starting 1 February 2026, while currently-certified fisheries have until 1 November 2030 to transition to the new standard.

3.2.5. Case study 5: the dolphin-set tuna purse seine fishery

Bycatch mortality of cetaceans in the eastern tropical Pacific yellowfin tuna purse-seine fishery dates to the inception of "dolphin sets" in the late 1950s, where fishers set nets on schools of spotted and spinner dolphins to catch associated yellowfin tunas ([3], and references therein). More than 6 million dolphins have been killed in this fishery, most in the first 15 years of the fishery, reducing the two most impacted species to an estimated 44 % and 19 % of pre-fishery abundance. Since that time, direct mortality has fallen by more than 99 %, due largely to modifications of fishing gear and fishing practices developed and implemented by the fishers themselves. With the exception of establishing dolphin mortality limits on a vessel-specific basis, verified by 100 % observer coverage, US legislation and international agreements have been much less successful in decreasing bycatch mortality[7] [3].

3.2.6. Case study 6: cooperative-based salmon savings incentive plan agreements

The pollock midwater trawl fishery in Alaska's eastern Bering Sea is affected by problematic bycatch of Chinook and Chum salmon. To deal with this, the cooperatives, together with the government and a private company that manages and collects data for real-time spatial management, have signed an inter-cooperative agreement to jointly harvest and allow the transfer of pollock quota between fishing cooperative members [34,6]. This cooperation allows coordination in achieving standards. Three different solutions have been put in place: voluntary rolling hotspots, which are temporary closures that can be fished depending on the cooperative's bycatch performance; a penalty system (a cooperative's chinook salmon bycatch limit is lowered if it does not meet the performance standards); and a reward system (current savings can be set aside for future use). Additionally, each vessel must contribute bycatch units (credits) to a bycatch risk pool as insurance against the risk of closure [34].

3.2.7. Case study 7: dolphin bycatch in the Bay of Biscay

It is estimated that between 4000 and 9000 common dolphins are captured by fisheries each year along the French Atlantic coast,[8] mainly in the Bay of Biscay, potentially threatening the common dolphin population of the Northeast Atlantic in the long term [29]. Dolphin bycatch occurs in both active (trawls, seines) and passive (nets) fishing gears and across a variety of fisheries across the Bay of Biscay [51]. Characteristics that make implementation of solutions challenging include: little to no reporting of bycatch and resulting uncertainties about circumstances under which bycatch occurs; numerous small boats unmonitored by VMS and lacking onboard observers; reluctance towards the adoption of cameras; limited control and enforcement capacity; and an ongoing sectoral crisis linked to a perception among certain fishers of regulatory overload and of a lack of legitimacy of fisheries representative bodies [14]. The European Commission issued a formal notice in 2020, and a reasoned opinion in 2022, to urge France to take measures to reduce common dolphin bycatch in the Bay of Biscay. The government's action plan included non-incentivized trials such as voluntary on-board camera programs and at-sea observers, as well as trials of different types of acoustic repellents developed within research projects and intended to be specifically adapted to the situation in the Bay of Biscay. The only remediation scenarios considered so far – including the 30-day closure imposed for over 400 vessels between 22 January and 20 February 2024 – have been based on conventional top-down regulations (e.g. time-area fishery closures, use of acoustic repellents). Thus, there appears to be scope for exploring the potential benefits of introducing incentive-based measures to support efforts to address the issue.

In our analysis of the possibilities of applying incentive-based measures to address potential ways forward for the Bay of Biscay dolphin bycatch issue, we identified the need to obtain reliable data, therefore measures related to data collection and information sharing are essential elements of the proposals. We further noted the relevance of collecting fine-scale information on a wide range of protected species to be able to evaluate potential unintended side effects of a management intervention as well as anticipate future needs for management of other protected species. Other key considerations included the opportunity to favor solutions coming from the fishers themselves and the key role that could be played by collective organizations in implementing incentive-based measures. Below we examine two proposals selected to illustrate how our framework can help identify the opportunities and barriers to implementing alternative options.

Proposal 1 – "BATmap"-like app: The development and use of an application for sharing information in real time such as BATmap would enable industry actors to obtain detailed data on bycatch in the Bay of Biscay fisheries, in which there is currently a real deficit of information available to managers on how much, where, why, and how dolphin bycatch occurs. Improving this information, and the ability of stakeholders to act upon the information gained (e.g. in avoiding high risk areas as they are identified, or in better targeting the fishery closures spatially and temporally, to optimize the costs of these closures) is expected to help significantly improve the situation as compared to having no data on the interactions. We hypothesize that this information sharing system could be financed, developed and managed by POs – as was done for the original BATmap application. The collected information could then be used by professional organizations for real-time management: risk maps, alerts, dynamic spatial management, etc.

Proposal 2 – annual individual limits managed by POs with full observation: Provided that appropriate information is available on the levels and origins of bycatch, a system of bycatch limits would make it possible to cap bycatch to a threshold that would not endanger the common dolphin population. The annual total bycatch limit could be based on the Potential Biological Removal (PBR) management framework, which is the limit threshold considered by the US MMPA for annual mortality from anthropogenic sources [69]. Allocation of this total limit to individual fishers could be implemented as for quotas of commercial species, through POs. Similar to the French fishing quota management system, we thus assume a PO-based bycatch limit approach in which POs would use individual allocations to their members to avoid overruns of their collective allocation. We further assume that limits could be transferable only through the POs. The implementation of such a system would require 100 % observed fishing activity (e.g. through on-board cameras) and improved data processing techniques for near real-time management.

3.3. Evaluation results

The radar plots in Fig. 2 synthesize the scores related to feasibility and durability dimensions A-F outlined in Section 2.1 for the seven case studies. The rationale for the scores is presented below.

3.3.1. Evaluation of case study 1: BATmap – bycatch avoidance mapping tool

The participation rate is high in the west of Scotland bottom trawl fishery (vessels holding >80 % of the total cod quota for the area) and the participants are culturally homogeneous in that they are all UK-based. Participating vessels are comparable in the type of fishing gear used and the size of vessels. This high homogeneity results in a "very favorable" rating for (A) (Fig. 2). Because participation in BATmap is

[7] The bycatch problem in this case included four types of externalities: the public good bycatch externality, the information externality, the transnational/transboundary externality, as well as a public good externality associated with adopting bycatch reducing technological change. This explains the fact that multiple policy instruments had to be developed to adequately address the problem.

[8] For years 2019–2021, average bycatch estimates were 9040 [95 % CI 6640–13300] based on strandings and 5938 [95 % CI 3081–9700] based on at-sea sampling data; for years 2016–2018, average bycatch estimates were 6620 [4411–10827] based on strandings and 3973 [1998–6598] based on at-sea sampling data [29].

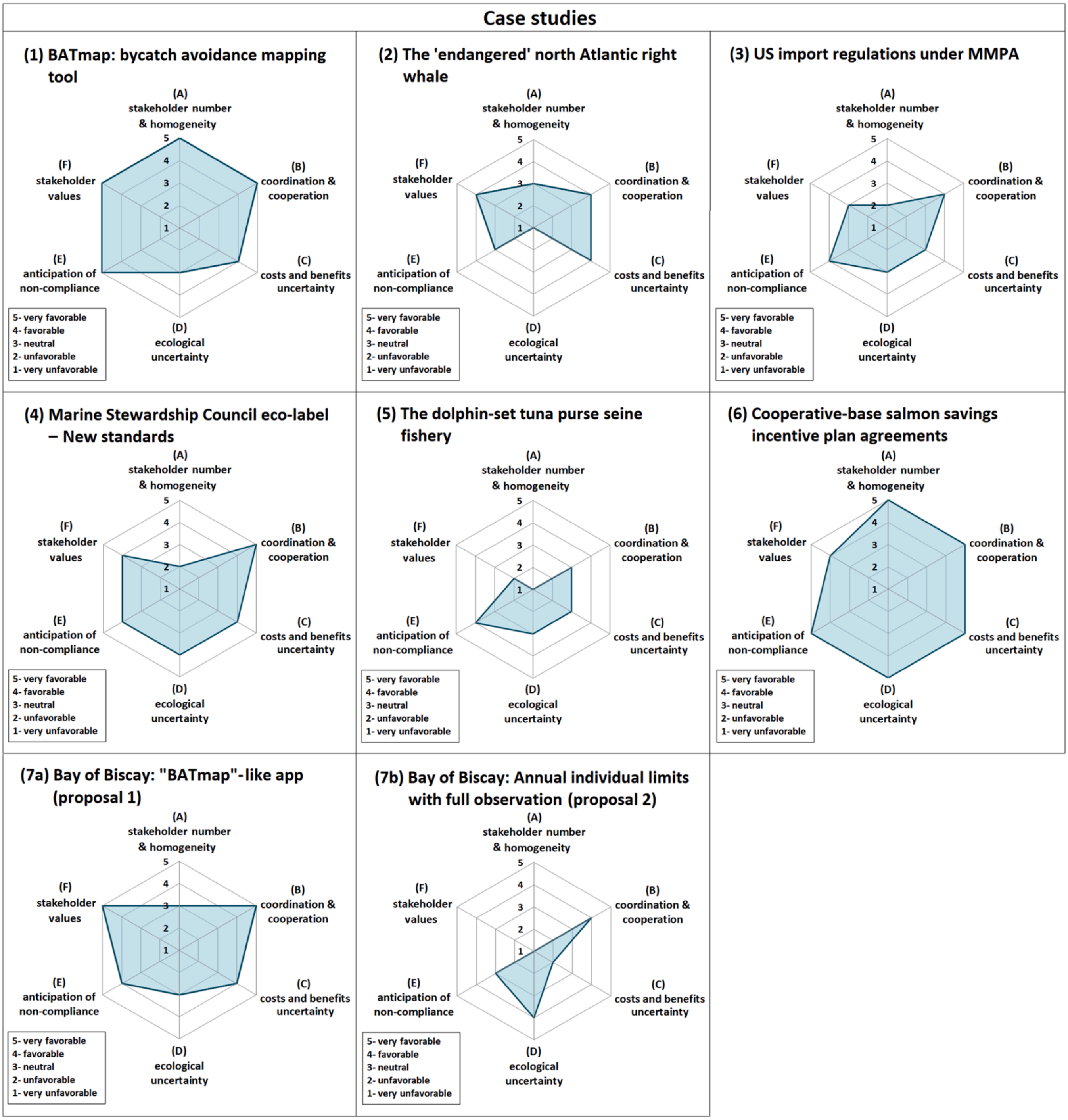

Fig. 2. Feasibility and durability characteristics of case studies. Dimensions evaluated: (A) Number and homogeneity of stakeholders; (B) Existing coordination mechanisms and level of stakeholder cooperation in the definition of the solution; (C) Level of uncertainty about the distribution of costs and benefits associated with implementing the solution; (D) Level of scientific uncertainty about bycatch mitigation potential of the solution and possible side effects; (E) Anticipation of non-compliance; (F) Alignment with stakeholder values.

voluntary and industry-based coordination is an inherent aspect of information sharing, the rating of (B) is "very favorable". Costs are relatively low after the initial investment in development of the software, effectively a sunk cost. The new roll-out in the Nephrops fishery requires only modifying the current software. Benefits include providing tangible evidence of adhering to policies aimed at reducing bycatch. The rating of (C) is therefore "favorable". Ecological uncertainty pertains to uncertainty regarding the effectiveness of spatial avoidance in reducing bycatch. As it is difficult to quantitatively assess the amount of bycatch that go uncaught by not fishing in an area, the ecological uncertainty (D) was rated as "neutral". Anticipation of non-compliance (E) was rated as "very favorable" given that BATmap is self-regulating by the fishing industry and participation is voluntary. Alignment with stakeholder values (F) was rated as "very favorable" given the widespread public interest in reducing bycatch of fish and other species and the generally favorable perception of BATmap across different stakeholder groups, as evidenced by being adopted in a second fishery.

3.3.2. Evaluation of case study 2: the endangered North Atlantic right whale

The impact of stakeholders (A) is "neutral" (Fig. 2) since there are a large number of participants, physically dispersed across the lobster fishery, yet in part, offset by the high level of homogeneity within the fishery. The Take Reduction Team (TRT) under the Marine Mammal Protection Act requires an equitable balance of representation between resource users and non-users, and representation is needed from every fishery and geographic region affected; (B) was thus rated as "favorable". The NARW program was "favorable" for the level of uncertainty about the distribution of costs and benefits associated with implementing solutions (C). Indeed, costs associated with the DAM solution were < 1 % of dock-side lobster revenues, yet the benefit may have reduced entanglement risk by 6.5 % on average [11]. Given right whales' ability to carry gear for long distances, in instances where gear is recovered, there is significant uncertainty in assigning the location, type and configuration of the gear involved in an entanglement. It is thus nearly impossible to assess the biological success of a particular policy instrument within the Plan. (D) was thus considered "very unfavorable". Anticipation of non-compliance (E) was unknown and considered "neutral" since data were not collected to determine if fishers followed gear modification requirements, and the level of observation was too low to calculate compliance statistics. Management proved flexible in responding to a potential safety problem for fishers [56] and therefore alignment with stakeholder values (F) were considered "favorable".

3.3.3. Evaluation of case study 3: US import regulations under the Marine Mammal Protection Act

The variety of stakeholders, including the national government of the USA and that of more than 130 exporting nations representing more than 2500 exempt[9] and export fisheries, processors, and firms in the chain of custody, drives the low score for (A) (Fig. 2). Coordination and cooperation (B) is considered "favorable" as there have been extensive consultations with the responsible agencies in exporting countries to ensure that they provide all available information on their fisheries and there has been capacity building for exporting countries. While the distribution of costs and benefits across stakeholders (C) is difficult to anticipate, there is a sense that developing countries may face a greater challenge in meeting the US bycatch standard, and in fact the product could end up in another market with less scrutiny over marine mammal bycatch. The overall ecological effect is relatively uncertain as the possibility of diverting product to another market (production leakage) means that the overall level of marine mammal bycatch may actually increase (conservation leakage) – hence the "neutral" score for (D). As the US system will have checks and balances, expected compliance levels are considered "favorable" (E). Alignment with stakeholder values (F) are considered "neutral": while these regulations are imposed top-down, there seems to be relatively balanced agreement and disagreement with the process and outcome.

3.3.4. Evaluation of case study 4: Marine Stewardship Council eco-label – new standards

Revision of the standard involves many stakeholders from the industry and conservation sectors worldwide, both at the fishery and overarching levels, which gives a low score ("unfavorable") for (A) (Fig. 2). However, in this case, the existing structures in place to gather technical and stakeholder views (associated with a high score for B) such as the Technical Advisory Board and a Stakeholder Advisory Council addressed difficulties that could have arisen from the large number of stakeholders. The uncertainties about the distribution of costs and benefits (C) are considered low as labeling is a voluntary choice made by a group of private operators who tend to remain under the program. The level of ecological uncertainty (D) is considered "favorable" as the revised Fishery Standard includes new elements that address uncertainty. The chain of custody and annual review process of MSC ensuring compliance drive the high score ("favorable") for (E). Finally, alignment with stakeholder values (F) is also rated as "favorable" as eco-labeling certifications demonstrate commitment to sustainable fishing practices and reputation is key to the viability of the MSC, thus addressing the information externality.

3.3.5. Evaluation of case study 5: the dolphin-set tuna purse seine fishery

Adoption of modifications in fishing gear and fishing practices was, to a large extent, voluntary, based on the benefits associated with lower numbers of dolphins entangled in nets. It also resulted from changes in social norms towards conservation, along with the credible threat of market restrictions by processors, in a context of increased information on the bycatch problem being made available. Ineffectiveness of, or reluctance to comply with, US legislation and international agreements was driven in the early years of the fishery by transfer effects as the composition of the fleet changed from the heavily regulated US to the less regulated non-US fleet. In later years of the fishery, differences in culture and institutions led to ineffective communication and lack of coordination and trust across the many layers of stakeholders (associated with "neutral" scores for B, C, and D, and a low score for F) (Fig. 2). 100 % observer coverage under the International Dolphin Conservation Program Act (IDCPA) dramatically reduced reported bycatch mortality (associated with high score for E). Finally, the large number and heterogeneity of stakeholders drives the low score for A ("very unfavorable").

3.3.6. Evaluation of case study 6: cooperative-based salmon savings incentive plan agreements

The limited number of multi-vessel companies through their inter-cooperative agreement and homogenous vessels and production processes, give very high scores for (A) and (B) (Fig. 2). This co-managed bycatch reduction program is voluntarily and cooperatively organized. (A) and (B), along with the flexibility brought by the transferability of quotas, allow for an effective allocation of bycatch among vessels and thus reduce uncertainties related to the distribution of costs and benefits (C, rated "very favorable"). Co-management with the North Pacific Fishery Management Council and a strong NOAA scientific program reduce the level of scientific uncertainty about bycatch mitigation (D, rated "very favorable"). The 'salmon savings credits' incentives, co-management, and credible threat all contribute to compliance. Therefore the rating of (E) is "very favorable". (A), (B), co-management, and voluntary programs all facilitate good practice promotion and alignment with stakeholders' values (F, rated "favorable").

3.3.7. Evaluation of case study 7: dolphin bycatch in the Bay of Biscay

3.3.7.1. Proposal 1: "BATmap"-like app. The high scores for criteria related to coordination and cooperation (B), costs and benefits uncertainty (C), compliance (E) and stakeholder values (F) indicate the potential feasibility and relevance of this proposal (Fig. 2). French POs are well established institutions with existing structures to implement coordinated action and foster cooperation across fishers. As shown in the BATmap case study, developing the App can be relatively low cost and data storage and processing can be done independently of the government to favor adoption and compliance. Despite high heterogeneity of fishing practices across numerous vessels, the fact the only type of stakeholders involved would be from the fishing industry gives a "neutral" score for (A). Implementation may also be impeded by ecological uncertainty (D): even if the data sharing App is widely used, it is unclear whether it would lead to a reduction in bycatch, and fishers or professional organizations may thus be reluctant to implement this solution. To overcome this barrier, it could be beneficial to identify

[9] Exempt fisheries are fisheries that have no known or a remote likelihood of marine mammal bycatch and are exempt from instituting a regulatory program.

complementary bycatch reducing management interventions (based on real-time information) to make the mitigation potential of the solution more tangible. In any case, even if bycatch reduction is difficult to quantify, standardized collection of bycatch data will become an asset over time to inform fine-tuned management.

3.3.7.2. Proposal 2: annual individual limits managed by POs with full observation. The possibility of making use of established institutions such as POs with strong coordination mechanisms (B) and the relatively low scientific uncertainty about its mitigation potential (D) are considered "favorable" (Fig. 2). However, the implementation of such a system would involve many stakeholders from the industry, regulator, scientific, and conservation sectors, both at the fishery and overarching levels, with highly differing worldviews and value systems, hence a low score for (A). The distribution of costs and benefits (C) would be highly uncertain because of the current lack of knowledge about the extent to which different fisheries are affected by dolphin bycatch, and fleet ability to avoid bycatch and at what cost. In addition, the strong opposition of fishers to mandatory on-board cameras raises questions about compliance (E). Finally, the conflicting views of the management problem across stakeholders, and reluctance of conservationists to see dolphin bycatch effectively allowed, result in a low score for (F). Overall, such an option currently appears hardly feasible given the current circumstances of the Bay of Biscay dolphin bycatch issue.

4. Discussion

4.1. Lessons learned from case studies

We developed a practical evaluation framework aimed at evaluating the feasibility and durability of alternative fisheries management options, with special emphasis on incentive-based bycatch management. We tested the implementation of this framework using an iterative, expert-based assessment of selected case studies, reflecting a diversity of management options, in a wide range of contexts. Our results demonstrate the applicability of the approach, and its usefulness in thinking about the transaction costs associated with adopting these management measures, both *ex-post* and *ex-ante*.

Designing and implementing incentive-based measures to reduce marine mammal bycatch often involves multiple stakeholder groups, including fishers, POs, firms in the value chain, fishery managers, government agencies, conservation organizations, and scientists (dimension A of our practical framework). The fact that stakeholders with similar interests are more likely to reach consensus on a solution to mitigate bycatch is generally verified in the case studies presented above (e.g. the BATmap case study, the cooperative-based salmon savings incentive plan agreements). In cases involving a larger number of diverse stakeholders with conflicting interests, coordination mechanisms and stakeholder cooperation (B) are crucial for the feasibility of a potential solution [7]. As illustrated by the case on the revision of the MSC standard, existing institutions bringing these diverse groups together to work towards a common goal can be the key to deal with the complexity of the issue and overcome conflicts [63].

Stakeholders who expect to benefit from a solution are more likely to cooperate and actively contribute to its success, whereas an imbalanced distribution of costs and benefits can lead to resistance and potential legal challenges [37]. The case studies show that industry-led interventions are typically characterized by low levels of uncertainty about the distribution of costs and benefits (C). When the policy intervention is imposed top-down by the regulator, an *ex-ante* analysis can also reduce this type of uncertainty, as illustrated by North Atlantic right whale case study [11].

Scientific uncertainty about the ecological benefits and the long-term sustainability of mitigation efforts (D) is an important determinant of stakeholders' support for a chosen approach [30]. High scientific uncertainty about the bycatch mitigation effect can undermine the durability of the solution, as shown in the North Atlantic right whale case study [11]. The US import regulation case also underscores the importance of taking possible unintended effects into account, e.g. if new regulations induce a shift of production towards countries with higher bycatch rates. Information on conditions in which bycatch occurs at relevant spatial and temporal scales and across supply chains for a wide range of protected species is thus critical to ensure that the solution appropriately considers interactions across ecosystems, fleets and markets, both at the fishery and overarching levels [19].

Many of the cases stress the role of a credible threat, such as fishery closure or loss of market access, as an incentive to drive changes in fishing practice and foster compliance (E). Industry-led solutions, well-established chain of custody, and high observation coverage are also identified as beneficial to compliance [10,6]. When 100 % observer coverage is not feasible, it is essential to work on identifying and eliminating factors that can discourage voluntary information sharing and undermine compliance, such as reputational risks, administrative burden, uncertainty about data use, perceived inequities, and economic impacts [19,34]. Furthermore, the definition by public authorities of standards including guidelines for monitoring and enforcement can also be useful so that private initiatives such as labels can be based on these standards [26].

Alignment with stakeholder values (F) as well as support towards collective capacity building and information sharing can contribute to the feasibility and long-term sustainability of solutions by fostering trust among stakeholders, cooperation, compliance, and a shared commitment to conservation goals [71]. As illustrated by the BATmap case and the cooperative-based salmon savings incentive plan agreements, co-construction with industry, voluntary programs, and the role played by POs can all facilitate harnessing social motivations and make new arrangements more durable [52].

Regarding the application of the framework to the Bay of Biscay case study in a prospective analysis, our findings suggest that initial steps such as the BATmap-like app can lay the groundwork for real-time management measures in the future [33]. Another approach to improve bycatch data, adopted in tuna fisheries to deal with problems of seabird bycatch, is based on an electronic observation system (cameras), coupled with an obligation to declare bycatch [17]. The implementation of a system of verification by sampling of the similarities between cameras and declarations, and penalties if a bycatch event is recorded by the cameras but not declared, has proved effective in incentivizing real-time bycatch reporting by creating the conditions for more stringent reporting obligations [18]. This system opens up interesting prospects for real-time management in contexts like the Bay of Biscay as there is no need to wait for the video data to be processed to get information on bycatch to fishery operators as well as managers.

4.2. Potential of incentive-based measures and operational elements related to policy design and implementation

As illustrated by the typology presented in this paper, incentive-based measures may provide a wide range of opportunities for cost-effective marine mammal bycatch mitigation. Workshop discussions highlighted a number of potential advantages of these measures.

Economic incentives play a crucial role in encouraging compliance with regulations aimed at reducing marine mammal bycatch [64]. First, non-compliance with marine mammal bycatch regulations can result in fines, fishery closures, loss of preferred markets, or even trade sanctions. In addition, regulations aimed at reducing marine mammal bycatch often require changes in fishing practices, gear modifications, or the adoption of new technologies. These changes can be associated with initial costs or operational adjustments. Economic incentives can offset these costs, making it economically viable for fishers to comply with the regulations [50].

Normative and social influences are also important for compliance with marine mammal bycatch regulations [10,28,6,64,68]. Social motivations can help generate support for regulations within the fishing community by ensuring that their voices are heard and their concerns addressed. Fishers are more likely to comply voluntarily when regulations are seen as fair and just [68]. Social networks within fishing communities can also exert significant influence [10,68]. When regulations are supported by influential community members or leaders, they can shape social norms and encourage compliance through peer pressure [27].

Initiatives aimed at collective capacity building and information sharing may also foster collaboration among stakeholders, including fishers, fishery managers, scientists, and conservation organizations [16]. When regulations are developed in collaboration with fishing communities, e.g. through co-management arrangements, fishers are more likely to comply because they perceive the rules as legitimate and reflecting their interests [27,68]. In addition, social learning [46] can facilitate the sharing of information and best practices within fishing communities [31].

Discussions among workshop participants on the application of measures leveraging economic and social-based incentives highlighted that policy design and implementation processes are critically important for their feasibility and long-term success. In particular, stakeholder engagement was seen to be highly beneficial to ensure that policy design takes the various needs, concerns, and insights of different groups into account [4]. Conducting focus groups with stakeholders can contribute to inclusive and participatory policy design. By facilitating open and respectful dialogue on potentially sensitive topics, focus groups can be instrumental in addressing disagreements among stakeholders and can help identify issues not known to the regulator [9]. Policymakers can then use this input to refine policy and implementation procedures to ensure they align with the needs and constraints of stakeholders. This can also help identify and prevent the risks of economic incentives undermining ('crowding out') intrinsic motivations and leading to counterproductive outcomes [61].

Small-scale pilot programs were also seen as useful to test the effectiveness of incentive-based measures in real-world conditions [16]. Pilots provide an opportunity for adjustments and learning before full-scale implementation [13]. Learning by doing, leading to revisions of a bycatch reduction program, can be a valuable way to minimize risks and uncertainties [38], in relation to dimensions C and D of the framework. Successful pilot programs can also generate interest and support among stakeholders by demonstrating positive outcomes [59]. It is also important that pilot program designs consider the possibility that the test may not be successful and provide for a plan to stop quickly and safely should the need arise.

4.3. *Considerations in applying the evaluation framework and perspectives for future applications and further research*

Our proposed framework provides a structured method for evaluating the feasibility of different bycatch mitigation measures. The expert-based application we proposed and tested is explicitly designed to leverage the experience of experts, allowing the inclusion of context-specific knowledge that may be difficult to obtain through other means [43]. Such an expert-based approach offers a pragmatic way to address complex, multi-dimensional issues where empirical data may be limited or unavailable [12]. The application of the framework relies on expert-based assessment of the six dimensions (A-F). The framework can be applied by bringing together a group of experts who collectively have the capacity to analyze the various dimensions of the framework. In particular, this necessitates the participation of experts who have the capacity to analyze the institutional context and the differences of opinion between stakeholders (e.g., social scientists and governance experts). The quality of the assessment is thus highly dependent on the availability of such knowledge in the expert group [65]. While expert-based assessments are valuable tools for decision-making, they may be subjective and biased [45]. Therefore, we recommend documenting the rationale for each score to increase transparency and facilitate interpretation of the results. In fact, this information can be just as interesting as the score itself for understanding the opportunities and barriers to implementation.

Perspectives for further developments of the approach include collaborating with fishery managers to develop protocols to facilitate their uptake of the framework [40]. This could be done through explicitly reviewing the different dimensions for a particular management approach in a given context, with the key stakeholders involved in seeking solutions. An alternative approach to implementing the framework could rely on more extensive surveys of fishery participants and other concerned parties, with a questionnaire capturing the different dimensions of the evaluation framework [1], to elicit the perceptions of stakeholders regarding alternative courses of action. While this might help gain a more in-depth understanding of the diversity of perceptions regarding management measures under consideration, it would also likely require significant resources to implement.

Establishing and testing standardized scoring criteria for each dimension could facilitate their appropriation of the framework while ensuring consistency and repeatability in assessments. In addition, exploring ways to integrate more quantitative data into the semi-quantitative framework, e.g. by developing specific indicators that can be consistently applied across case studies, could facilitate and enhance the precision of evaluations [47]. Furthermore, expanding the application of the framework to other case studies could bring insights on how to mainstream the use of incentive-based measures to reduce marine mammal bycatch.

Whatever evaluation method is chosen, we suggest the framework could be used by fishery managers to enable discussion among the diverse stakeholders engaged in consultations on a specific bycatch issue, encouraging the exploration of innovative strategies that go beyond traditional management instruments. The typology we presented in the results, which offers a comprehensive reference for all the incentive-based management strategies involving the encouragement of certain types of behavior or the discouragement of others, can facilitate the identification of such strategies. By focusing on incentive-based approaches, our intention in this work is to shift the conversation from command-and-control measures to solutions designed to align stakeholder incentives with conservation goals [57]. Nevertheless, given the broad applicability of its evaluative dimensions, our proposed framework could also be used to assess the feasibility of command-and-control regulations aimed at addressing bycatch problems, making it broadly relevant across various policy tools. In fact, applying the framework to compare across command-and-control and incentive-based strategies on a particular case study would likely represent a valuable avenue for further investigation.

5. Conclusion

This study presents a practical framework to assess the applicability of incentive-based approaches to address marine mammal bycatch in a variety of contexts. Building on existing governance and institutional approaches, the framework consists of an expert-based evaluation of six dimensions related to the feasibility and durability of new institutional arrangements. This framework, we contend, provides a pragmatic tool for both investigating the elements that have inhibited incentive-based approaches in the past and for evaluating options in a prospective manner when a particular marine mammal bycatch situation emerges.

We demonstrated how this can be done with the application of the framework to seven case studies from around the world and representing a wide range of contexts. Our analysis underscores a range of important operational aspects to consider in implementation, such as the need for fine-scale data collection, the involvement of fishers in solution development, and the pivotal role of collective organizations. With regard to the Bay of Biscay case study specifically, our *ex-ante* analysis resulted in the identification of a potentially feasible option to improve data sharing and inform more targeted management, in contrast with another option that appears unlikely to be a solution in the current context of the fishery. Looking ahead to further development of this work, the generalization of the evaluation outcomes will require the examination of additional case studies, and the development of tools for the systematic consultation of large numbers of stakeholders, e.g. through a survey approach.

While marine mammal bycatch mitigation is often based on conventional top-down regulation, we argue that considering incentive-based measures can be beneficial to broaden the perspective on how to tackle such complex issues. The adoption of such measures is likely to be easier in the presence of credible threats of regulatory or market responses to the bycatch problem. In addition, multiple complementary approaches may be required when there are multiple facets of the problem (i.e., multiple externalities) that a single policy instrument cannot address [62]. Often some combination of top-down pressure, traditional regulation, and incentive-based policy instruments may be needed to resolve complex bycatch situations.

CRediT authorship contribution statement

Bellanger Manuel: Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Dudouet Benjamin:** Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Gourguet Sophie:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Thébaud Olivier:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Ballance Lisa:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **Bécu Nicolas:** Writing – review & editing, Investigation, Formal analysis. **Bisack Kathryn:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **Cudennec Annie:** Writing – review & editing, Investigation, Formal analysis. **Daurès Fabienne:** Writing – review & editing, Investigation, Formal analysis. **Lehuta Sigrid:** Writing – review & editing, Investigation, Formal analysis. **Lent Rebecca:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **Marshall Tara:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **Reid David:** Writing – review & editing, Investigation, Formal analysis. **Ridoux Vincent:** Writing – review & editing, Investigation, Formal analysis. **Squires Dale:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **Ulrich Clara:** Writing – review & editing, Investigation, Formal analysis.

Declaration of Competing Interest

None.

Acknowledgments

This work was supported by the Delmoges project, co-funded by the Ministry of Ecology Directorates DGAMPA (Fisheries and Aquaculture) and DEB (Aquatic Biodiversity), and the Fisheries Sector Association (FFP – France Filière Pêche).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2025.106661.

Data availability

Data will be made available on request.

References

[1] L. Amigo-Dobaño, M.D. Garza-Gil, M. Varela-Lafuente, The perceptions of fisheries management options by Spain's Atlantic fishermen, Mar. Policy 36 (5) (2012) 1105–1111.
[2] J.M. Baland, J.P. Platteau, Economics of common property management regimes, in: K.G. Mäler, J.R. Vincent (Eds.), Handbook of Environmental Economics 1, 2003, pp. 129–190.
[3] L.T. Ballance, T. Gerrodette, C.E. Lennert-Cody, D. Squires, « A history of the tuna-dolphin problem: successes, failures, and lessons learned », Front. Mar. Sci. 8 (2021) 754755.
[4] M. Ballesteros, M. Dickey-Collas, Managing participation across boundaries: a typology for stakeholder engagement in the international council for the exploration of the sea, Mar. Policy 147 (2023) 105389.
[5] M. Bellanger, R. Fonner, D.S. Holland, O. Thébaud, Cross-sectoral externalities related to natural resources and ecosystem services, Ecol. Econ. 184 (2021) 106990.
[6] M. Bellanger, D.S. Holland, C.M. Anderson, O. Guyader, Incentive effect of joint and several liability in fishery cooperatives on regulatory compliance, Fish Fish. 20 (4) (2019) 715–728.
[7] M. Bellanger, C. Speir, F. Blanchard, J.C. Young, Addressing marine and coastal governance conflicts at the interface of multiple sectors and jurisdictions, Front. Mar. Sci. 7 (2020) 544440.
[8] J. Bering, H. Gargan, J. Kuesel, A. Rowe, Will unilateral action improve the global conservation status of marine mammals? A first analysis of the US Marine Mammal Protection Act's Import Provisions Rule, Mar. Policy 135 (2022) 104832.
[9] K. Bisack, P.M. Clay, Compliance with marine mammal protection: focus groups reveal factors in commercial fishermen's decisions, Mar. Policy 115 (2020) 103789.
[10] K. Bisack, P.M. Clay, Behavioral responses to competing incentives and disincentives: compliance with marine mammal protection, Mar. Policy 132 (2021) 104674.
[11] K.D. Bisack, G.M. Magnusson, Spatial management to reduce entanglement risk to north atlantic right whales in fishing gear: a case study of U.S. Northeast Lobster Fishery 2002–2009, Front. Mar. Sci. 8 (2021) 540966.
[12] M.A. Burgman, M. McBride, R. Ashton, A. Speirs-Bridge, C. Twardy, Expert status and performance, PLOS One 6 (7) (2011) e22998.
[13] T.L. Catchpole, T.S. Gray, Reducing discards of fish at sea: a review of European pilot projects, J. Environ. Manag. 91 (3) (2010) 717–723.
[14] C. Cazé, J. Réveillas, A. Danto, C. Mazé, Integrating fishers' knowledge contributions in marine science to tackle bycatch in the Bay of Biscay, Front. Mar. Sci. 9 (2022) 1071163.
[15] A. Coggan, S.M. Whitten, J. Bennett, Influences of transaction costs in environmental policy, Ecol. Econ. 69 (9) (2010) 1777–1784.
[16] T.M. Cox, R.L. Lewison, R. Žydelis, A.J. Read, Comparing effectiveness of experimental and implemented bycatch reduction measures: the ideal and the real, Conserv. Biol. 21 (5) (2007) 1155–1164.
[17] T.J. Emery, R. Noriega, A.J. Williams, T. Peatman, The use of electronic monitoring within tuna longline fisheries: implications for international data collection, analysis and reporting, Rev. Fish. Biol. Fish. 28 (2018) 887–907.
[18] T.J. Emery, R. Noriega, A.J. Williams, J. Larcombe, Changes in logbook reporting by commercial fishers following the implementation of electronic monitoring in Australian Commonwealth fisheries, Mar. Policy 104 (2019) 135–145.
[19] FAO. 2021. Fishing operations. Guidelines to prevent and reduce bycatch of marine mammals in capture fisheries. FAO Technical Guidelines for Responsible Fisheries No.1. Rome.
[20] Federal Register. (2023). 50 CFR Part 216 [Docket No. 231109–0265] RIN 0648–BK06. Modification of Deadlines Under the Fish and Fish Product Import Provisions of the Marine Mammal Protection Act. ⟨https://www.govinfo.gov/content/pkg/FR-2023-11-17/pdf/2023-25399.pdf⟩.
[21] R. Fonner, M. Bellanger, A. Warlick, Economic analysis for marine protected resources management: challenges, tools, and opportunities, Ocean Coast. Manag. 194 (2020) 105222.
[22] E.A. Fulton, A.D. Smith, D.C. Smith, P. Johnson, An integrated approach is needed for ecosystem based fisheries management: insights from ecosystem-level management strategy evaluation, PLOS One 9 (1) (2014) e84242.
[23] U. Gneezy, S. Meier, P. Rey-Biel, When and why incentives (don't) work to modify behavior, J. Econ. Perspect. 25 (4) (2011) 191–210.
[24] S.D. Good, S. McLennan, M. Gummery, R.J. Currey, Updating requirements for endangered, threatened and protected species MSC fisheries standard v3. 0 to operationalise best practices, Mar. Policy 163 (2024) 106117.
[25] R.Q. Grafton, R. Arnason, T. Bjørndal, Q. Weninger, Incentive-based approaches to sustainable fisheries, Can. J. Fish. Aquat. Sci. 63 (3) (2006) 699–710.
[26] N.L. Gutiérrez, O. Defeo, S.R. Bush, A.E. Punt, The current situation and prospects of fisheries certification and ecolabelling, Fish. Res. 182 (2016) 1–6.
[27] N.L. Gutiérrez, R. Hilborn, O. Defeo, Leadership, social capital and incentives promote successful fisheries, Nature 470 (7334) (2011) 386–389.
[28] A. Hatcher, S. Jaffry, O. Thébaud, E. Bennett, Normative and social influences affecting compliance with fishery regulations, Land Econ. 76 (3) (2000) 448–461.
[29] ICES 2023. Workshop on mitigation measures to reduce bycatch of short-beaked common dolphins in the Bay of Biscay (WKEMBYC2). ICES Scientific Reports.
[30] F. Jensen, H. Frost, J. Abildtrup, Fisheries regulation: a survey of the literature on uncertainty, compliance behavior and asymmetric information, Mar. Policy 81 (2017) 167–178.
[31] S. Jentoft, B.J. McCay, D.C. Wilson, Social theory and fisheries co-management, Mar. Policy 22 (4–5) (1998) 423–436.

[32] T. Kompas, P. Gooday, The failure of 'command and control' approaches to fisheries management: lessons from Australia, Int. J. Glob. Environ. Issues 7 (2/3) (2007) 174–190.
[33] S.B.M. Kraak, D.G. Reid, E.A. Codling, Exploring the RTI (real-time incentive) tariff-based approach to single-species fisheries management, Fish. Res. 155 (2014) 90–102.
[34] R. Lent, D. Squires, Reducing marine mammal bycatch in global fisheries: an economics approach, Deep Sea Res. Part II: Top. Stud. Oceanogr. 140 (2017) 268–277.
[35] P.S. Levin, M.J. Fogarty, S.A. Murawski, D. Fluharty, Integrated ecosystem assessments: developing the scientific basis for ecosystem-based management of the ocean, PLOS Biol. 7 (1) (2009) e1000014.
[36] R.L. Lewison, L.B. Crowder, A.J. Read, S.A. Freeman, Understanding impacts of fisheries bycatch on marine megafauna, Trends Ecol. Evol. 19 (11) (2004) 598–604.
[37] G.D. Libecap, The conditions for successful collective action, J. Theor. Polit. 6 (1994) 563–592.
[38] G.D. Libecap, Addressing global environmental externalities: transaction costs considerations, J. Econ. Lit. 52 (2014) 424–479.
[39] J.S. Link, M. Dickey-Collas, M. Rudd, M. Rae, Clarifying mandates for marine ecosystem-based management, ICES J. Mar. Sci. 76 (1) (2019) 41–44.
[40] C. Macher, N.A. Steins, M. Ballesteros, C. Ulrich, Towards transdisciplinary decision-support processes in fisheries: experiences and recommendations from a multidisciplinary collective of researchers, Aquat. Living Resour. 34 (2021) 13.
[41] G.R. Marshall, Transaction costs, collective action and adaptation in managing complex social–ecological systems, Ecol. Econ. 88 (2013) 185–194.
[42] C.T. Marshall, P. Macdonald, E. Torgerson, J. Asare, R. Turner, Design, development and deployment of a software platform for real-time reporting in the west of Scotland demersal fleet, Fish. Innov. Scotl. (2021) 39.
[43] T.G. Martin, M.A. Burgman, F. Fidler, P.M. Kuhnert, S. Low-Choy, M. McBride, K. Mengersen, Eliciting expert knowledge in conservation science, Conserv. Biol. 26 (1) (2012) 29–38.
[44] L. McCann, Transaction costs and environmental policy design, Ecol. Econ. 88 (2013) 253–262.
[45] A. Mehdic, T. Gunton, M. Rutherford, Assessing the role of subjective judgment and science in environmental impact assessment: implications and options for reform, J. Environ. Plan. Manag. 63 (10) (2020) 1771–1790.
[46] M. Mobius, T. Rosenblat, Social learning in economics, Annu. Rev. Econ. 6 (2014) 827–847, 2014.
[47] G. Murray, L. D'Anna, P. MacDonald, Measuring what we value: The utility of mixed methods approaches for incorporating values into marine social-ecological system management, Mar. Policy 73 (2016) 61–68.
[48] J.R. Nielsen, An analytical framework for studying: compliance and legitimacy in fisheries management, Mar. Policy 27 (5) (2003) 425–432.
[49] E. Ostrom, A general framework for analyzing sustainability of social-ecological systems, Science 325 (5939) (2009) 419–422.
[50] S. Pascoe, J. Innes, D. Holland, T. Hutton, Use of incentive-based management systems to limit bycatch and discarding, Int. Rev. Environ. Resour. Econ. 4 (2) (2010) 123–161.
[51] H. Peltier, M. Authier, F. Caurant, V. Ridoux, In the wrong place at the wrong time: identifying spatiotemporal co-occurrence of bycaught common dolphins and fisheries in the Bay of Biscay (NE Atlantic) from 2010 to 2019, Front. Mar. Sci. 8 (2021) 617342.
[52] R. Plummer, J. FitzGibbon. People matter: the importance of social capital in the co-management of natural resources, Natural Resources Forum, Vol. 30, No. 1, Blackwell Publishing Ltd., Oxford, UK, 2006, pp. 51–62.
[53] A.E. Punt, M.C. Siple, T.B. Francis, A.N. Zerbini, Can we manage marine mammal bycatch effectively in low-data environments? J. Appl. Ecol. 58 (3) (2021) 596–607.
[54] A.J. Read, P. Drinker, S. Northridge, Bycatch of marine mammals in U.S. and global fisheries, Conserv. Biol. 20 (1) (2006) 163–169.
[55] R.R. Reeves, K. McClellan, T.B. Werner, Marine mammal bycatch in gillnet and other entangling net fisheries, 1990 to 2011, Endanger. Species Res. 20 (2013) 71–97.
[56] R.R. Reeves, A.J. Read, L. Lowry, S.K. Katona, D.J. Boness. Report of the North Atlantic right whale program review, Marine Mammal Commission, Bethesda, Maryland, 2007.
[57] L.A. Roberson, C.J. Brown, C.J. Klein, E.T. Game, C. Wilcox, Opportunity to leverage tactics used by skilled fishers to address persistent bycatch challenges, Fish Fish. (2024).
[58] L.A. Roberson, C. Wilcox, Bycatch rates in fisheries largely driven by variation in individual vessel behaviour, Nat. Sustain. (2022) 1–9.
[59] A.M. Scheld, C.M. Anderson, H. Uchida, The economic effects of catch share management: The Rhode Island fluke sector pilot program, Mar. Resour. Econ. 27 (3) (2012) 203–228.
[60] Scottish Government 2013. Scottish Government Conservation Credits Scheme: Scheme Rules. Versions 4.2 (25 September 2013). Available online at: ⟨https://studylib.net/doc/7874209/scottish-governmentconservation-credits-scheme⟩ (accessed Aug 14, 2024).
[61] D. Squires, L.T. Ballance, L. Dagorn, R. Lent, Mitigating bycatch: novel insights to multidisciplinary approaches, Front. Mar. Sci. 8 (2021) 613285.
[62] D. Squires, R. Lent, P.H. Dutton, L. Dagorn, L.T. Ballance, Credit systems for bycatch and biodiversity conservation, Front. Mar. Sci. 8 (2021) 613279.
[63] R.L. Stephenson, A.J. Hobday, C. Cvitanovic, et al., A practical framework for implementing and evaluating integrated management of marine activities, Ocean Coast. Manag. 177 (2019) 127–138.
[64] J.G. Sutinen, K. Kuperan, A socio-economic theory of regulatory compliance, Int. J. Soc. Econ. 26 (1999) 174–193.
[65] J.C. Tam, C.E. Parlee, J. Campbell-Miller, M. Bellanger, J. Bentley, V. Pourfaraj, G. Beaulieu, Expanding the scope and roles of social sciences and humanities to support integrated ecosystem assessments and ecosystem-based management, ICES J. Mar. Sci. 81 (1) (2024) 22–42.
[66] O. Thébaud, J.R. Nielsen, Motova, B.M.J. Vastenhoud, Integrating economics into fisheries science and advice: progress, needs, and future opportunities, ICES J. Mar. Sci. (2023) fsad005.
[67] T. Tietenberg, L. Lewis. Environmental and Natural Resource Economics, twelveth ed., Routledge, New York, 2023.
[68] L. Van Hoof, Co-management: An alternative to enforcement? ICES J. Mar. Sci. 67 (2) (2010) 395–401.
[69] P.R. Wade, Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds, Mar. Mammal. Sci. 14 (1) (1998) 1–37.
[70] O.E. Williamson, The new institutional economics: taking stock, looking ahead, J. Econ. Lit. 38 (3) (2000) 595–613.
[71] J.C. Young, K. Searle, A. Butler, A. Jordan, The role of trust in the resolution of conservation conflicts, Biol. Conserv. 195 (2016) 196–202.