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EDITED BY
Steven Mackinson,
Scottish Pelagic Fishermen's Association, United Kingdom

REVIEWED BY
Anne-Marie Svoboda,
Ministry of Agriculture Nature and Food Quality, Netherlands
Marije Siemensma,
Marine Science &Communication, Netherlands

*CORRESPONDENCE
Justine Réveillas
justine.reveillas@gmail.com

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Integrating fishers' knowledge contributions in Marine Science to tackle bycatch in the Bay of Biscay

Cosma Cazé[1,2], Justine Réveillas[1,2]*, Anatole Danto[1,2] and Camille Mazé[1,2]

[1]UMR 7266 LIENSs, Littoral Environnement et Sociétés, Centre National de la Recherche Scientifique, Université de La Rochelle, La Rochelle, France, [2]Apolimer international research network, Institut des sciences humaines et sociales, Centre National de la Recherche Scientifique, La Rochelle, France

The issue of bycatch is raising considerable political, mediatic and scientific attention. Bycatch is one of the main causes of at-sea mortality for small cetacean species and for seabirds. Scientists are raising alerts regarding the potential effects on the structure of the ecosystem, increasingly aiming for research-action. Decision-makers are facing a political trade-off, with increasing pressure from the European Commission and international nongovernmental organizations to implement mitigation measures such as space-time closure of the fisheries, which could present a risk of altering the well-being of the fishing industry in the short-term. The process of co-creation of knowledge on bycatch is key to understand better the fishers-species interactions and to develop regulations that are adapted to local specificities, towards an adaptive and inclusive socio-ecosystem-based management of the fisheries. But the knowledge co-creation process is hindered by tensions between the interests of stakeholders, the climate of mistrust, dense media coverage and power asymmetries between actors. In parallel, the fast rate of biodiversity degradation is calling for the rapid development of regulations. Understanding the complex system dynamics highlighted by these conflicts requires an analysis of the socio-political dimension of the interactions between fisheries and marine biodiversity. Based on a series of ethnographic interviews with the different stakeholders involved in the bycatch mitigation projects in the Bay of Biscay, this paper explores how co-creating knowledge through conflict and collaboration between researchers and fishers can generate collective learning for bycatch mitigation policies. We adopt an epistemological approach, with the objective to promote transparency in the exchange between researchers and fishers and to inform decision-making at various scales of governance. We argue that co-creation of knowledge on bycatch should not aim for consensus. We conclude that acknowledging the presence of conflicts between the stakeholders, and understanding their roots and their impact on the co-design process can allow identifying factors of path-dependency hindering the adaptive capacity of institutions. Moreover, we

highlight the key role of the fishers' representative bodies in knowledge co-creation, and the importance to improve our understanding of fishers' perception of their political representation.

KEYWORDS

cetacean bycatch, seabird bycatch, knowledge co-creation, local ecological knowledge, co-design, conservation conflicts, controversy analysis, collective learning

Introduction

The impact of bycatch, or the incidental capture of non-targeted species in commercial and recreational fisheries (Rouby et al., 2022) raises concerns regarding biodiversity conservation (Hall et al., 2000). Bycatch is one of the main causes of at-sea mortality for small cetacean species, such as the common dolphin (*Delphinus delphis*) and the harbour porpoise (*Phocoena phocoena*), but also for seabird species (Dias et al., 2019; Rouby et al., 2022). The socio-genesis of bycatch as a political issue in France can be traced back to the emergence of whistleblowers in the 1970s, as scientific concerns grew on marine biodiversity degradation. Prior to this, the interactions between fishers and the marine megafauna were only considered by most actors as competition for the same food resources, and cetaceans were sometimes hunted and consumed (Fichou and Levasseur, 2004). The cetacean strandings have started to be recorded as statistical data by the *Réseau National Échouage* (RNE), a participatory science program created in 1972, forming a network of 350 correspondents, which documents the spatio-temporal trends in stranding numbers. The RNE is steered by a committee of scientists, managers and correspondents elected within the network, and it is coordinated by the Pelagis observatory, a research unit whose main missions are to support research in marine megafauna ecology and public conservation policies (Dars et al., 2020). From 1970 to 1993, 4,627 cetacean strandings were reported on the French Atlantic and Mediterranean coast (Collet and Mison, 1995). It was not until 1989 that researchers, noticing a significant increase in the number of cetacean strandings, became interested in the correlation with accidental captures (idem). This correlation was later confirmed by the Pelagis observatory, which concluded that 60% and, during peaks of strandings, up to 90% of the animals autopsied have traces of fishing gear (Peltier et al., 2019). In the Bay of Biscay, dolphin stranding increased significantly from 2016 onward, most of them with evidence of having been bycaught. The size of the bodies, the contemporary western cultural significance of the species, and the communication work of marine conservation organizations such as Sea Shepherd contributed to make the strandings a visible impact of fisheries on marine biodiversity.

The scientific concerns regarding the bycatch of seabird in France emerged in the French Southern and Antarctic Territories (TAAF) with the shift from bottom trawls to longlines for the fishing of the Patagonian toothfish in the 1990s, which led to a significant increase in the bycatch of three species of albatrosses and four species of petrels (Cherel et al., 1996; Tuck et al., 2003). The strong presence of scientists on the territories since the 1960s contributed, among other factors, to the estimation of the long and short-term trends in the species populations and to the identification of the vessels responsible for bycatch (Rolland et al., 2010; Weimerskirch et al., 2018). In the Atlantic coast, the first scientific projects to study the interactions between fishing activities and protected seabird species only started around 2010, thus little is known yet about the bycatch of seabirds in the area.

A normative framework aimed at mitigating bycatch was established at the European level and then at the national level in French law (Figure 1). In 1992, when concerns arose regarding the impact of driftnets on dolphin and seabird populations, the Commission of the European Communities decided to prohibit "any vessel from carrying on board or engaging in fishing activities with one or more driftnets whose individual or cumulative length exceeds 2.5 kilometers" (OJEC, 1992). This ban met a lot of resistance from the fishers and led to unintended consequences. Once driftnets were banned, fishing activity was shifted offshore by long-lining, where other species such as albatrosses and petrels started to be affected by bycatch (Euzen et al., 2017). Another European regulation was implemented in 1997 to ban the use of driftnets for the capture of certain migratory fishes such as albacore (*Thunnus alalunga*) and bluefin tuna (*Thunnus thynnus*) starting from 2002 (OJEC, 1997). It was not until 2011 that French law transposed the European driftnet regulations (JORF, 2011a). Another ministerial order was issued in 2011, to determine the list of marine mammals protected on the national territory and the modalities of their protection (JORF, 2011b). In 2019, a bycatch reporting requirement for fishers was introduced, requiring ship captains to report protected

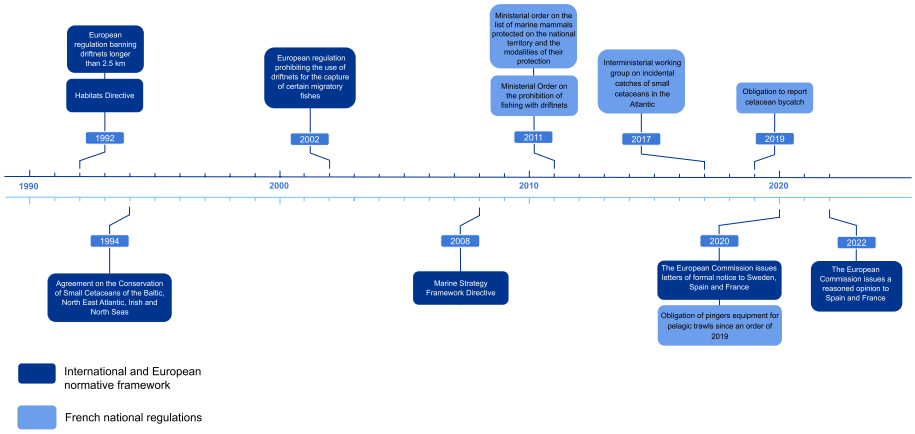

FIGURE 1
Evolution of European and national policies regarding the incidental capture of seabirds and cetaceans.

marine mammal specimens caught accidentally in fishing gear (JORF, 2018). The information provided by fishers is intended to advance research into the understanding and characterization of incidental catches, with the aim of preventing them. This declaration can be made through a digital declaration for vessels of more than 12 meters equipped with an electronic fishing logbook, while smaller vessels can use fishing paper's sheets (Ministry of Agriculture, 2022). Finally, from 26 December 2019, fishers have the obligation to equip pelagic trawls with acoustic deterrent devices, also called pingers, in the Bay of Biscay (JORF, 2019).

Despite the measures taken, the bodies of small cetaceans are regularly washed ashore, most of them with evidence of having been bycaught, and decision-making authorities are pressured by the European Commission to accelerate the mitigation of bycatch through the regulation of fishing practices. On 2 July 2020, the European Commission issued letters of formal notice to Sweden, Spain and France for failing to correctly transpose the obligations related to the Habitats Directive regarding the establishment of a coherent monitoring scheme of cetacean bycatch and the subsequent taking of conservation measures (Autier et al., 2021). On 15 July 2022, considering that France and Spain had not taken the necessary measures since their letter of formal notice, the European Commission sent them a reasoned opinion requesting that the two countries take the necessary measures to "prevent the incidental catch of dolphins and other protected species" within two months (European Commission, 2022). If France is still considered to fail to comply with its obligations after this date, the Commission may decide to refer the matter to the Court of Justice, a process which may entail financial sanctions, which can be a lump sum and/or a penalty payment, in case of sustained failure to comply with the European regulations.

The bycatch of seabirds in the Bay of Biscay are subject to significantly less legislative and political attention. Since the Bird Directive was established in 1979, there are no hard laws intended to reduce seabird bycatch in France, except the regulations regarding the use of driftnets. Fishers are not required to declare the catches of marine bird species nor to equip their vessels with repellent devices.

The main policy options to improve the selectivity of the fisheries operations are the implementation of technical measures, and the adjustment of when and where the fishing effort takes place (Calderwood et al., 2021), such as through space-time closure of fisheries, or through the closure of an area in a fishery to one or more gears for a temporary period when a bycatch threshold is reached (Dunn et al., 2010). Technical measures entail the deployment of repellents on other vessels than the pelagic trawls and the change of fishing practices. The measures are evaluated according to numerous factors such as estimated impact, management complexity, socio-economic impact, and financial investment.

The technical devices tested showed mitigated results. The effectiveness of the pingers was demonstrated for pelagic trawls (Morizur et al., 2012). The Necessity project showed a decrease in yearly common dolphin bycatches of about 70%, but the number of observations had to be doubled to hope to show a significant difference in the confidence intervals (Morizur et al., 2008). The PIC project showed a significant reduction in common dolphins bycatch of around 65% (Le Gall, 2020). The devices were first set up voluntarily and then made mandatory. Numerous projects were implemented by the fishers' representatives in partnership with scientists to test pingers on nets, but the repellents tested did not yet demonstrate their effectiveness (Morizur et al., 2009). In some cases, pingers on gillnets even present the risk to attract marine mammals such as the gray seal, who learn to associate the pinger sound with the

fishing gear and easily accessible food resource, an unintended consequence that is called the "dinner bell effect" (Carretta and Barlow, 2011). Pingers can also increase the risk of excluding harbor porpoise from their feeding areas (Olesiuk et al., 2002). The effectiveness of techniques for birds, such as the weighting of lines was proven but is difficult to quantify (Jiménez et al., 2018; Santos et al., 2019).

Time-area closures are recommended by the International Council for the Exploration of the Sea (ICES) to limit cetacean bycatch, and they are considered to be the only effective measure according to the Pelagis observatory (Peltier et al., 2019). Environmental protection NGOs also advocate for time-area closures to achieve biodiversity conservation objectives. However, there is a risk that the measure triggers a shift of the fishing effort in the surrounding areas. Moreover, the closures are considered neither actionable nor acceptable by professional actors and their representatives because the large range of gears associated with bycatch makes its socio-economic application difficult. Time-area closures would entail a restriction of fishers' activities, who would be financially compensated by the State (by temporary cessation for example). This measure can require short-term losses, induced by the lost economic opportunity (Smith et al., 2020), but they have the potential to produce long-term net economic gains, depending on the distribution of benefits and costs among the fishing communities (Armsworth et al., 2010).

The economic condition of the fisheries in the European Atlantic coast is tense. The significant decrease in the size of coastal fishing fleets (Leaute, 2008) in a general context of depletion of the fishery resource, symbolized in particular by the first European Fleet Exit Plans, has left its mark on the communities of single-species oriented fishers. If public authorities already have enacted regulations constraining fishing activities in the past, the issue of bycatch is particularly controversial, and decision-makers are aiming to maintain the economic and social stability in the ports and to sustain national production. It is worth highlighting that the fishing sector in France represents only a small part of the economic activity of the country but it is an historical structuring activity of the French coastal areas (Meunier et al., 2013). Moreover, there is a political trend to enhance sovereignty on food production considering the increase in the trade balance deficit of fish and seafood products (FranceAgriMer, 2021).

Decision-makers are supporting the bloom of scientific projects to improve our understanding of bycatch, which is still the source of scientific uncertainties regarding populations of small cetaceans and seabirds (abundance, distribution) and incidental catches (rates, conditions) (Darrieu, 2018; Peltier et al., 2021). Research institutions and scientists are progressively building knowledge, in partnership with fisher representative bodies, to evaluate the circumstances, the magnitude and the impact of bycatch (target species, areas, periods), and to test escape and repellent devices.

In this paper, we present a diagnosis of the interactions between fishers and scientists with regards to bycatch mitigation projects in the Bay of Biscay. More specifically, we analyze the political and scientific approaches of integrating fishers in knowledge production and in decision-making processes on bycatch reduction. How do decision-makers, fishers and researchers interact to evaluate the options to reduce bycatch? How do they analyze and compare the sets of policies, techno-economic and behavioral options to reduce bycatch? We also explore the evolution of the cooperation dynamics between the different stakeholders, and the main sources of tension arising from collaborating on bycatch mitigation projects.

We analyze the co-construction of knowledge on bycatch for both cetaceans and seabirds. If the impact of bycatch on seabird populations receive less political and scientific attention in France, it is not less significant, with several species vulnerable to bycatch, such as the balearic shearwater, being severely endangered (Genovart et al., 2016). We do not mention projects to improve the selectivity of fisheries with regards to bycatch of fish species and discards.

We argue that the process of co-creation of knowledge on bycatch through conflict and collaboration is key to improve our understanding of the complex system dynamics at play, and to develop regulations adapted to local specificities, towards an adaptive socio-ecosystem based management of the issue. Conflict analysis contributes to highlighting the levers and blockages in the decision-making process regarding fishing policies and biodiversity conservation regulations. We assess the potential of knowledge co-creation to improve fishers' ability to find solutions to tackle the issue of bycatch. We conclude by presenting the lessons learned through conflicts between fishers and researchers to inform bycatch mitigation policies.

Method

This article is the result of a research project which aims to analyze controversies on seabirds and cetaceans bycatch in the Gulf of Biscay. The fieldwork combines several types of materials: archives, ethnographic interviews with a diverse set of stakeholders, observations in professional gatherings, participation in scientific conferences, and social science analyses (actor mapping, epistolary analysis, etc.).The interviews were conducted along the French Atlantic coast to collect qualitative data, favoring face-to-face meetings, and following a flexible course of discussion in order to adapt to the specificities of each actor. Data collection entailed the experiences of bycatch, the interactions between actors within and without the stakeholder group, the roles in the decision-making processes, and the perception of the different measures for bycatch reduction. Participation in scientific conferences and professional gatherings was used as an opportunity to collect additional feedback and to consider the actors' discourses and

strategies in debates on bycatch. Although the choice of actors intended to include a diversity of expertises, the majority of fishers interviewed in this study are operating in small-scale fisheries. This ethnographic approach aims at understanding complex maritime and coastal socio-ecosystems (Danto et al., 2018), and exploring the relationships between knowledge and power (Mazé et al., 2017).

We acknowledge the limits associated with the categorization of stakeholders used for this publication, namely the social groups designed as "fishers", "researchers", "government" and "NGOs". There is porosity between research institutions and decision-making bodies for example. The AGLIA, a fishers' representative entity, has a hybrid governance structure composed of both public actors and professionals from the fishing sector. Likewise, within the same stakeholder group, important differences exist, such as between administrative bodies acting at the national and at the regional scale. There are also differences between scientific institutions: the two main institutions working on bycatch in the Bay, IFREMER and the Pelagis observatory, have different roles and are distinctively perceived by the other stakeholders. Fishers also can not be considered to be a united social group. The profession is heterogeneous, and there are power asymmetries between fishers. Different types of vessels, from France but also from other countries such as Spain and Belgium, are operating in the Bay of Biscay, fishing specific species, with various practices and interactions with marine biodiversity (Peltier et al., 2021).

Process of integrating fishers' contributions

Tackling bycatch in the Bay of Biscay requires experimenting with technical solutions and regulating fishing practices in a way that is adapted to the specificities of the socio-ecosystem. The co-design of research projects is key to develop the knowledge necessary to implement efficient measures and to learn from experimentation at the "boat scale". The notion of "co-design" is used here to refer to the co-creation of credible and legitimate ocean knowledge solutions (IOC-UNESCO, 2021) to reduce bycatch. In theory, fishers' empirical knowledge can be leveraged to inform Western science and policy making in order to create applicable mitigation measures which would be adapted to local specificities. For example, fishers' Local Ecological Knowledge could be used to determine which areas are to be managed, and when, to develop dynamic adaptive ecosystem management (Mazé, 2020). We use the notion of Local Ecological Knowledge to refer to the set of knowledge derived from daily interactions with the ecosystems, as opposed to Conventional Scientific Knowledge (Berkström et al., 2019), or expert knowledge (Lascoumes, 2001; Barthelemy, 2005), which is built from collecting data according to a scientifically designed methodology, and theoretically interpreted.

The fishers are mostly mobilized to contribute to the scientific measures of the magnitude of bycatch and to the test of technical devices. Yet, there are variations in the process of integrating their contributions and in the strategy of each actor in the knowledge co-creation process.

Evolution of cooperation dynamics

The collaboration dynamics between the actors evolved since the first projects, partly due to the sharp increase in cetacean strandings and the change of scope regarding the vessels responsible for bycatch. Numerous European and national projects on the bycatch of cetaceans were implemented between 2000s and 2010s in the Bay of Biscay, involving a diverse but small set of scientists, fishers representatives, and administrative bodies (Northridge et al., 2006; Morizur et al., 2008). These research projects were focused on pelagic trawlers, as they were the main fleet held responsible for the bycatch of small cetaceans in the area (Morizur et al., 2012). The OPs, fishers representative bodies also called *Organisations de Producteurs*, were involved in the monitoring of the fleet, and due to the relatively limited number of vessels compared to the gillnet fleet (Peltier et al., 2020b), they were able to monitor the fishing effort. The fishers' representatives interviewed describe the collaboration in the first projects as pragmatic and focused on finding technical solutions. Long-term cooperation dynamics were not achieved but stakeholders were interacting with mutual respect. In 2019, communication between actors started to be altered by a lack of trust. While the projects had focused on pelagic trawls, the observation efforts showed that the gillnets also contributed to the risk of bycatch (Peltier et al., 2019).

Moreover, during winter 2016, a peak in cetacean strandings was observed, with 1,342 cetacean strandings recorded on the French coastline, of which 53.3% were common dolphins (Dars et al., 2017). During the following years, the level of bycatch stayed significantly higher than what had been observed before 2016. Preferring the approach of managing through science rather than managing through use (Barthelemy, 2005), the political focus in reaction to this peak of strandings was to support the production of new scientific knowledge on bycatch. As a result, there was an increase in the funding of research projects to further explore the ecological and social issues raised by bycatch, and the potential solutions to reduce its occurrence. Along with the increasing number of research projects on bycatch, the number of actors involved in the research process also significantly increased, creating a dense social environment with diverse collaboration dynamics and scientific approaches, as illustrated in Figure 2, which does

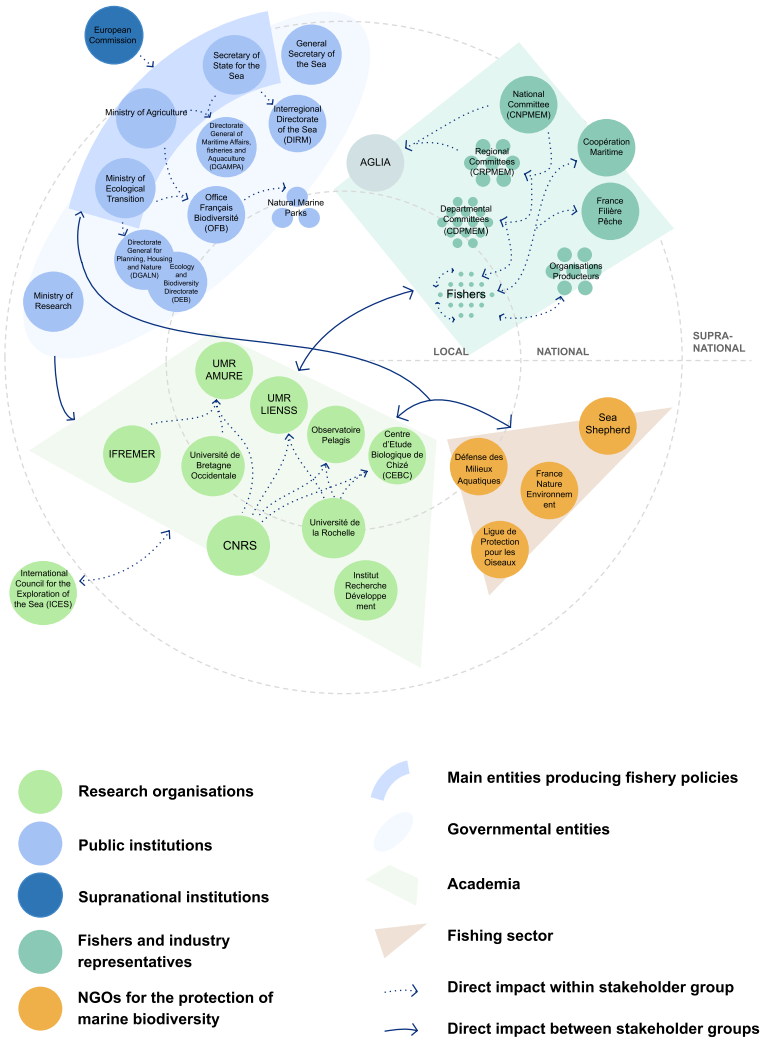

FIGURE 2
Sociogram of the actors' system involved in bycatch mitigation in the Bay of Biscay.

not intend to be exhaustive but represents the complexity of the actors' network (Figure 2).

The research projects on the bycatch of seabirds in the Bay of Biscay started significantly later than the projects on cetaceans, the first being the transnational program FAME in 2010, led in France by different organizations including the League of Protection for Birds (LPO). The project aimed at improving our knowledge of seabirds, mainly the Balearic Shearwater (*Puffinus mauretanicus*) and the Northern Gannet (*Morus bassanus*), and at raising awareness of the users of the sea, and it did not involve onboard observations. The research work on seabird bycatch in the area, and the related collaboration with fishers, then paused until a new set of projects started around 2020. Projects such as ARPEGI and CARI3P include fishers' representative bodies as partners and consider fishers' observations and proposals. The CARI3P project, for example, aims to characterize the incidental catch of Balearic shearwaters by longliners, gillnetters and purse seiner. The project collects fishers' observations regarding their knowledge of the species and on their experimentation of bird-scaring techniques, and the solutions that they envision. The program also aims to foster exchange between French fishers and Portuguese longline fishers who have worked on the fisheries-bird interaction programs.

Platform for discussion

Deliberative processes for remediation have also been implemented, such as the Interministerial national working group on incidental catches of small cetaceans in the Atlantic, created in 2017. This working group, led by the State Secretary for Sea (through the General Directorate of Maritime Affairs,

Fisheries and Aquaculture) and the Ministry of Ecological Transition (through the Ecology and Biodiversity Directorate), is composed of a diverse set of stakeholders (administrations, scientists, NGOs, fishing professionals). The group meets regularly to discuss the latest results of the research projects on the interactions between fishing activities and small cetaceans, and the measures to limit bycatch in a sustainable manner. The initiative is nationally held, but it also aims to serve as a platform to organize collaboration with foreign counterparts operating in the Bay of Biscay, with the frequent participation of actors from border countries such as Spain and with the participation of the European Commission as an observer. The national group started with a limited number of members who previously collaborated in bycatch mitigation projects. The members interviewed mentioned that, as the number of people around the table increased, the dialogue dynamics progressively shifted to a sequence of presentations with limited opportunities for discussions. The degradation of the dialogue dynamics was taken into account by the organizing institutions, who decided to structure the national group into subgroups discussing specific dimensions of bycatch.

Data collection with and without the fishers

The current data collection on bycatch in France entails the estimation of bycatch rate (with observers deployed on vessels, number of stranding recorded, fishers' reporting), bycatch risk assessment (population distribution, areas of mortality, fishing effort, interactions with fishing gear), estimation of the impact of bycatch (threshold, abundance, cascade effects), and the measurement of the effectiveness of technical devices, such as pingers. Many scientific studies are mobilizing observers to collect data. In that case, fishers' participation is limited to accepting, or not, the observer on board. For example, the sea observation program Obsmer, led by the General Directorate of Maritime Affairs, Fisheries and Aquaculture, and co-funded by the European Union, collects data on the vessels, the catches, and the tidal environment from annual sampling realized with on-board observation since 2009, in partnership with IFREMER and fishers' representatives (IFREMER, 2022). Fishers' knowledge has also been integrated through surveys and voluntary statements in order to create a diagnosis of the fleets and to characterize the interactions on pilot sites (Pelagis observatory, 2022). Some research projects, such as the program Obsenpeche, are studying participatory science tools, with the aim to deploy a network of "sentinel fishers", using an application to report knowledge on bycatch, and to initiate a reflection on the evolution of fishing strategies. Other data collection methods bypass the fishers' and observers' onboard perspective regarding the interaction with cetaceans and seabirds, and the biases associated with it. The Pelagis Observatory organizes aerial observation campaigns of marine megafauna under the SAMM (Aerial Monitoring of the Marine Megafauna) program. This program is intended to produce an inventory of the spatial distribution of certain species in metropolitan waters, to estimate their abundance and to identify the preferential habitats of cetaceans and seabirds according to the seasons. The two SAMM campaigns in 2011 and 2012 allowed the observation of nearly 3,000 marine mammals and 35,000 seabirds (Laran et al., 2017). Another program aiming to estimate the rate of bycatch is using electronic observation devices to better understand the interactions between dolphins and gillnetters. The test of onboard cameras on vessels and the development of an automated algorithm for image processing by artificial intelligence to consider the extension of the system to 400 gillnetters was launched at the request of the ministry, in partnership with a diverse set of stakeholders (Ascobans, 2021).

Control over knowledge co-production

The control over the process of knowledge co-production is held by research institutions, but also by fishers' representative bodies. On one hand, scientists have the social capital and the legitimacy to have control over the methodology adopted (Bourdieu, 1976). On the other hand, fishers' representatives (national, regional and departmental committees, and fisher organizations, also called *Organisations de Producteurs*, OP) are almost systematically involved as partners. Communicating and collaborating with fishers on the numerous projects require logistics, hence the professional representative bodies (the regional and departmental committees and the OP, depending on the area) manage the different requests, distributing the corresponding surveys and requests among fishers. They play a decisive role, organizing data collection with the fishers, hence the research projects depend on their approval.

Incentives for knowledge co-creation

Researchers and fishers are drawn into knowledge co-production by different incentives. Careful analysis of incentives is crucial since the interactions of the stakeholders are unlikely to be socially or politically neutral (Armitage et al., 2007). For scientists, the approval of fishers to participate is decisive, as they need a representative sample to be able to draw conclusions. The significant statistical sample has been set by the European Commission at a minimum of 5% of the fishing effort for cetaceans (Peltier et al., 2016), and 10 to 20% for the bycatch of seabirds, since the bycatch of birds are rare events but when they occur, they can impact a significant number of individuals (Babcock et al., 2003). Engaging in knowledge co-production is also the opportunity to have more acceptable and objective

results of the research projects, when the scientific experts finalize their diagnosis.

Fishers are contributing to scientific studies with the aim for transparency, and to contribute to rapidly finding technical solutions to reduce bycatch. Yet, the participation in research projects is not a core aspect of their work, and it is perceived as an additional constraint on their activities. Sometimes, a relationship of trust is already established if the fisher and the researcher have already interacted at other occasions. If this is not the case, for a research project to be accepted among the fishing communities, scientists need to highlight fishers' interests to participate. They are promoting the integration of fishers' feedback, of their expertise and knowledge of the marine ecosystems, in order to create more specific regulations, rather than applying regulations to all gears and fishing practices. Participating in a research project on bycatch would give them the opportunity to refute the data with which they do not relate.

Cooperation with researchers is not always voluntary, especially since the 2019 regulation requiring ship captains to report any occurrence of cetacean bycatch. The Ministry of Ecological Transition and Solidarity, with the help of researchers from the Pelagis observatory, have provided fishers with a guide on the declaration procedure (the species concerned, the steps to report the occurrence of bycatch in the fishing paper's sheets and in electronic fishing logbook) (Tachoires et al., 2018). However, the obligation of bycatch reporting is partially deficient, and the data collected are not very usable, as they suffer from numerous biases.

Regulations are adding legitimacy to scientists' approach. The regulatory framework in place becomes an argument for scientists to incentivize fishers to collaborate. Even if the rules put in place are not always legally binding, they can serve as an argument for scientists to convince fishers to take part in the projects. Researchers interviewed have given the example of Biodiversity Law of 2016 (JORF, 2016), stating that risk assessment must be realized in fisheries, or soft laws such as the National Action Plan 2021-2025 for the Balearic Shearwater.

Conflicts hindering co-creation

The knowledge co-creation process for bycatch reduction in the Bay of Biscay is hindered by several, interrelated factors of tension constraining collective learning and limiting the capacity of actors to come up with shared solutions.

Different interests and narratives for the sustainability of the fishing sector

Fishers and researchers collaborate with the common objective to improve knowledge on the species vulnerable to bycatch and to implement effective solutions to limit the occurrence of accidental captures. Indeed, for fishers, cetaceans and seabirds arouse respect and consideration, and bycatch induces significant costs related to the degradation of fishing gears. Pursuing this common objective, numerous disagreements arise from the interactions between the different actors involved in bycatch mitigation projects.

The definition of the problem and the set of solutions perceived as acceptable vary not only according to the state of the resource but also according to the interest perceived by the actors (Lapijover, 2018). Indeed, the actors involved in the process have different perspectives regarding the impact of bycatch on marine biodiversity depending on their interests. The research projects have not yet established a commonly agreed upon knowledge basis, resulting in divergence regarding the perceived importance of the issue. For fishers, cetaceans and seabirds are the signal for the presence of fish, but they are also competitors. The fishers are perceiving that the phenomenon of depredation is increasing, and depredation, especially when using gears such as straight nets to fish red mullet, is considered to have a significant negative effect on fishers' catch. The conflicting perceptions of the impact of fishing on cetacean and seabird populations create friction in the process of co-creation. Fishers tend to consider their individual experiences on a single vessel rather than the impact of the fishing sector as a whole, thus if they perceive that their activity does not have a significant impact on cetaceans and seabirds, they tend to disagree with the use of the notion of emergency with regards to bycatch in the Bay of Biscay, and with the hierarchy of concerns for fisheries management resulting from it.

The stakeholders also disagree on the solutions envisioned by fisheries scientists and managers to reduce bycatch, such as time/area closure, change of vessel, and economic compensation. Fishers have economic incentives to invest in acoustic repellents, but they perceive limited interests in interrupting fishing in specific areas. Different data are mobilized by each actor in order to defend their respective vision regarding policy priorities. Most professional actors consider that since there were 467,673 common dolphins counted in the European waters of the Atlantic in 2016 (Hammond et al., 2017), the population is not in danger of extinction in the short-term, thus implementing measures such as time-area closures now would be a political demonstration of excessive environmentalism. On the other hand, some researchers consider that waiting until a species is declared endangered to implement conservation measures significantly reduces the probabilities of successfully preserving this species, and thus they highlight the need to adopt a long-term vision in today's policies. Each actor refers to a specific part of the knowledge on bycatch, according to which he develops an interpretation of the sector's history, a vision for its evolution, and a strategy to defend this vision (Catanzano and Rey, 1997).

Actors' views and values are polarized resulting in different narratives for the "sustainability" of the fishing

industry. The beached dolphin bodies become a symbol of the impact of fishing on marine ecosystems, and call into question the interrelationships between humans and nature, and more specifically the industrial exploitation of the ocean (Clouette, 2022). Faced with this question, fishers argue that, in order to satisfy the current national demand for seafood, the corresponding fishing techniques must be maintained, giving the example of fish sole and scampi that cannot be caught with fishing traps. The actors have different perceptions of the socio-ecosystem, and of the behaviors of actors perceived as at risk (Lapijover, 2018). The knowledge exchange deteriorates, as the actors are entrenched in their position regarding the transformations necessary to reach sustainability, resulting in path-dependency. The notion of path-dependency refers to the observation that, even if a more "efficient" solution is known than the solution currently chosen by an individual (in terms of technology or practices for example), this solution is not necessarily adopted (Palier, 2014) due to the presence of "lock-ins" (Goldstein et al., 2023). Steins, Mattens and Kraan observe that the uptake of more selective gears in the Netherlands, even if the innovation is fisher-led, depends on a complex interplay of social, policy and science-related factors, among which the fishers' intrinsic motivation and beliefs about sustainable fishing, and perceptions about the motivations and behaviors of other fishers (Steins et al., 2022).

Dichotomy between two worlds

The disagreements are reinforced by the perceived dichotomy between the worlds of academia and fisheries, as the measures envisioned do not always meet the reality faced by fishers (Suuronen, 2022). For the fisher, the environmental manager, the decision maker and the natural scientist belong to the sphere of technocratic power (Barthelemy, 2005), which is considered too far removed from the realities on the sea. The fishers are pointing to a lack of knowledge of the field, and of their working conditions, and often invite decision-makers, scientists and journalists to get on board to see for themselves. Indeed, fishers are generally aware of the basic requirements for the sustainability of fishing, but due to the harsh circumstances of their work, it is challenging for them to undertake these transformations (Suuronen, 2022). Fishers and their representatives highlight a gap between what is required from them, and the core mission of their profession. This feeling of distance between bureaucratic professions and sea labor can lead to doubt about the relevance of the different scientific approaches, and to the rejection of the entire knowledge co-creation process.

Climate of mistrust

If co-creation of knowledge requires building trust between the different parties (Hakkarainen et al., 2021), trust can be eroded very quickly, as a result of the failure to meet a commitment or because of an unexpected regulation for example (Armitage et al., 2007). Although the researchers and fishers' representatives are realizing an important work of communication to improve the collaboration dynamics, researchers and fishers are in a defensive position, sharing doubts about each other's intentions.

The change in scope of the responsible vessels altered the relationship of trust between fishers and researchers: the finding that pelagic trawls were not the only vessels responsible for cetacean bycatch induced suspicion from scientists regarding the willingness of fishers to collaborate.

Researchers' doubts regarding fishers' motivations are also based on the significant difference between the number of accidental catches declared by fishers and the number of strandings recorded on the Atlantic coast. Indeed, qualitative surveys in the human and social sciences reveal, within small fishing communities, a tendency (unquantifiable for the moment), to under-report, for fear of administrative reprisals, of NGOs, or even of neo-rural and neo-coastal inhabitants. As soon as the fishers do not comply with the regulation to disclose bycatch, they are associated with "reluctant" partners whose refusal to report is a convincing sign of its unwillingness to collaborate. Researchers assume that the fisheries feel threatened by the possibility that research projects contribute to the development of new regulations and do not disclose all the information that they hold. The question of data reliability becomes more acute as restrictions on fishing effort are tightened and, consequently, tensions between fishers and scientists increase (Deldreve, 2010).

The fishers' defensive position is due to the assumption that sharing data could lead to more regulations. While the fishing profession is traditionally associated with freedom, the inflation of rules and requirements are perceived by some fishers as an infringement of freedom. The fishers interviewed also mentioned their apprehension of the socio-economic impact of regulations such as the reduction of sole quotas in the Bay of Biscay, sole being one of the main targets of the gillnetters. Hence the fishers are facing a conflict of interest, acknowledging the value of their integration in bycatch mitigation projects, but having limited incentives to share catch information, fearing that their participation may play against them (Calderwood et al., 2021). The research on change management models for fisheries has highlighted the impact of intrinsic motivation factors concerns on the resistance to change fishing practices, the most impactful factors being the concerns that change will be costly and painful, perceived lack of incentives to offset any catch loss, perceived

loss of cover over the fishing operations and uncertainty about the future, including how fishers may be affected by change.

Controversies around the conventional scientific approach to data production and interpretation

If the limits of integrating fishers' knowledge considering the existing conflict of interest are highlighted by scientific institutions, conventional scientific knowledge production is also at the heart of controversies, for being accused of normativity with political ends. The role of researchers in the development of bycatch mitigation policies is generating debate over the acceptable level of normativity in sciences. Indeed, scientific experts who contribute to the establishment of norms take ethical and political positions (Roy, 2001), which have direct implications for the cooperative relationships between fishers and researchers (Deldreve, 2010). Scientific objectivity is questioned in the discourses of the fishers: on the one hand, IFREMER researchers are accused by small-scale sustainable fisheries of being too dependent on the fishing industry. On the other hand, the Pelagis observatory is considered by other professional actors to have an ecological bias. The rationality so specifically attributed to natural, "hard" sciences (Naim-Gesbert, 1999; Darrieu, 2018) is questioned, since the professional actors perceive that scientists are tailoring their methodologies to the results they are aiming to get, pointing at a lack of coherence in the scientific approach.

Moreover, fishers and their representative bodies report the lack of tangible results from their involvement in the research projects on bycatch, except for the test of technological devices. Fishers perceive that their contributions did not translate into the identification of concrete solutions: the outcomes of the research projects were for the most part scientific publications, and the possibility to apply time-area closures is still considered an option.

Finally, there are important research gaps regarding fishers' Local Ecological Knowledge (LEK), and few projects explicitly mention the intent to pair LEK with Conventional Scientific Knowledge. Fishers are generally rather considered by researchers as "cooperating users" (Barthelemy, 2005), representing a potential source of scientific data useful for bycatch management, although scientific projects sometimes organize discussions such as seminars of cross sensibilization in order to integrate fishers' feedback and expectations on scientific studies. It is assumed that fishers hold knowledge regarding the techniques which are the least and the most likely to cause bycatch. Yet academic methodologies tend to disregard fishers as holders of empirical knowledge. Since the main opportunity to share their experience is through participating in researchers' data collection, their refusal to cooperate as participants to conventional scientific methods also leads to their non-participation as holders of this empirical knowledge.

Persistent uncertainties

Numerous uncertainties remain regarding the occurrence of bycatch which wears out the motivation of the different actors to engage in knowledge co-creation. The cause of the sharp increase in cetacean strandings is yet to be scientifically explained. A possible explanation would be a change in distribution of the population relative to the fishing grounds where fisheries posing the greatest risk of bycatch operate (Peltier et al., 2021), since the results of several observation campaigns suggest that the abundance of the common dolphin's population has recently increased in the Bay of Biscay (Van Canneyt et al., 2020). However, the abundance estimates have a high margin of uncertainty which makes the statistical detection of change (Murphy et al., 2019) and the estimation of long-term trends challenging (Lapijover, 2018). The ICES raised that for any particular European Union Member State, it is nearly impossible to establish whether the observed trend in the local abundance of common dolphins represents a shift in distribution (ICES, 2019). Likewise, little is known yet about the rate of occurrence and the types of practices and the vessels responsible for cetacean and seabird bycatch in the Bay of Biscay.

The data collection in research projects on bycatch has limits. Biases have been identified in observer programs, such as "the deployment effect", stemming from the lack of a sampling strategy, as the presence of observers depends on the willingness of the fishers; and "the observer effect", i.e., the change in fishing practices when an observer is present (Benoît and Allard, 2009; Faunce and Barbeaux, 2011; Amandè et al., 2012; Murphy et al., 2019; Peltier et al., 2020a). Moreover, the models to estimate bycatch from stranding data and from observer programs provide "ranges" with a large amplitude. For example, the work by the ICES Working Group on Bycatch (WGBYC), which collates and assesses information on bycatch monitoring and assessment for protected species, estimated in 2016 from observer programs the bycatch of common dolphins to be between 1,607 and 4,355 in ICES zone VIII, and between 1,400 and 4,800 from stranding data along the French Atlantic coastline (ICES, 2018).

There are different ideological positions regarding the process of data interpretation with regards to scientific uncertainties to conclude on the best measures for bycatch reduction. At the level of the strategic actor, uncertainty is a fundamental resource for negotiation between different interests (Lapijover, 2018). Some stakeholders argue that there are still too many uncertainties about the magnitude of the problem, and thus about the urgency of the situation, to apply constraining regulations on fishing activities, while others argue that the data

available is sufficient to justify these measures. The negotiation process is well illustrated by the debates around space-time closures, and the use of a threshold to determine when and where the closures should take place.

Media, science communication and activism

The media coverage of these strandings is significant and can be compared to that of news items. Marine mammals arouse emotions in the public, due to their cultural significance, being perceived as "iconic" animals (Lorimer, 2007; Danto et al., 2020; Mathur, 2021). The conflicts, the blood, the bodies of sea mammals are all visually powerful and tend to trigger public reactions (Geistdoerfer, 1984). The organizations dedicated to marine biodiversity conservation are leveraging these emotions through the media to raise awareness of civil society and to call the attention of the decision makers, in order to move the issue of bycatch further up in the political agenda. The choice of words such as "killing" or "slaughter" to describe fishers' work plays on the emotional relationship with the marine mammal, stronger than the one shared with the fish or the seabird and is questioning the responsibility of the fishers (Clouette, 2022). The NGOs also use statistical surveys from research projects on bycatch in their communication, since data plays a key role in engaging an audience (Desrosières, 2014; Clouette, 2022).

Fisher representatives are pleading that the discourses of the NGOs in the media fail to present all the elements to grasp the complexity of the issue, and the uncertainties about the nature of the interaction. This tension is leading to numerous, sometimes violent altercations between some fishers and Sea Shepherd. This resentment was already present in 1994, when the media picked up on a conflict between French and Spanish fishers over the ban of driftnets, which they dubbed the "tuna war" (Lequesne, 2002). This new regulation was not well received among French fishers, who perceived that they were condemned "in the face of the fantastic media hype" (Antoine, 1995).

Both researchers and fishers perceive that collaboration dynamics are hindered by the media coverage and by the conflicts with the NGOs. Fisher representatives consider that researchers' science communication strategy contributes to fuel the NGOs' anti-fisheries discourse and to the oversimplification of the issue. Direct conflicts between fisher representatives and scientific institutions arose regarding the content of posts on social media for example, where representative bodies plead that the publications are not reflecting the work done and draw hasty conclusions on the stranding figures by failing to specify the context in which the data is elaborated and the attenuation factors to be taken into account when interpreting the numbers.

Discussion

Socio-ecological conflicts tend to be seen as negative phenomena to be avoided and "resolved" as quickly as possible by finding win–win solutions, through cooperation, negotiation and consensus seeking (Fisher and Ury, 1981; Ury et al., 1988; Temper et al., 2018). In the case of bycatch mitigation, the conflicts hindering knowledge co-production have complex and profound roots, with important political, historical, social, environmental and cultural components. The conflicts highlight two key underlying identity issues: the establishment of the unquestionable legitimacy of scientific expertise and the image of fishing, either perceived as a diversified and legitimate activity or as a destructive harvesting activity, and of fishers, either considered as responsible producers or as unconscious predators (Deldreve, 2010).

Temper et al. argue that conventional conflict resolution approaches have limited potential to successfully deal with such socio-ecological frictions, and that they can lead environmental conflicts to become recurrent as they offer little opportunities for developing robust democratic and sustainable agreements for the use and management of the environment and territories (Temper et al., 2018). They suggest that conflicts are rooted in situations that are perceived as unjust, and that, by expressing a questioning of the status quo, conflicts can have constructive potential (Lederach, 1995; Dukes, 1996; Temper et al., 2018). Analyzing the points of friction related to bycatch mitigation, and identifying power asymmetries and institutional failures, can help understanding the transformations necessary to take into account the social and environmental issues in the decision-making process regarding the management of a marine socio-ecosystem faced with anthropogenic pressures.

Actions taken to shift social–ecological systems through transformation towards more sustainable trajectories can have negative social impacts and exclude people from decision-making processes (Bennett et al., 2019). Co-creating knowledge with fishers requires understanding the governance structures for fishers, considering power asymmetries in the governance and management of the ocean (Caze et al., 2022), and the economic domination that some fishers undergo (Clouette, 2021). The literature on transformation research calls for a greater integration of politics and power, by considering the decision-making process behind the measures leading to the transformations of the system and of the practices, and by tracking winners and losers in the transformations, with the aim for societal justice. For example, if the measures taken by the government are mobilizing economic incentives, such as penalties or subsidies, the difference of impact on small-scale and industrial fisheries should be considered. The impact on small-scale fisheries has already been used as an argument from fishers' representatives to protest against a new regulation. In 2014, when the European Commission formulated a proposal to

ban all driftnets with the aim of reducing bycatch, among other objectives, considering the circumvention of the regulation of 2002, fishers' representatives in France protested, arguing that the use of driftnets was used by small-scale, sustainable fisheries. If the conflicts in co-designed bycatch mitigation projects reveal a perceived injustice and gaps in the current governance system, can it also be a tool to start a process of transformation to reach a more equitable and inclusive management process? Can knowledge co-creation be a way for fishers, as agents of transformation, to improve their ability to find solutions to reduce bycatch and to adapt to future regulations? In other words, beyond a greater understanding of the issue at hand, what is the political impact of the knowledge co-creation process in this particular case?

In order to assess whether conflicts in co-designed bycatch mitigation projects in the Bay of Biscay can foster the empowerment of fishers to tackle the issue of bycatch, it is necessary to understand the decision-making processes and the science-policy interactions at play.

The decision-making process shaping the pathway of the fishing industry is cross-sectoral and multi-scalar, thus the policies result from a process of mutual adjustment between different actors. The three distinctive entities currently responsible for producing national policies on fishing are the Secretary of State for the Sea, the Ministry of Agriculture and Food Sovereignty, and the Ministry of Ecological Transition and Territorial Cohesion. In the French government, a Secretary of State has almost the same functions as a Ministry, with the exception that the Secretary of State only attends the Council of Ministers when the agenda includes a question concerning their ministerial department. The management of the resource was for a long time carried out by the Ministry of Agriculture, and the management of fishers and vessels has long been disconnected from the management of fishery resources and from biodiversity conservation. The inherent scientific work was partly carried out by a higher education and research institution under the supervision of this same ministry, since fisheries constitutes in the history and epistemology of French sciences a branch of agronomy. This distinction has led to difficulties in the implementation of public policies that are not necessarily always coordinated on the field.

Various successive reforms, marked by the spirit of the New Public Management (Barone et al., 2018), led to the closure of a large number of administrative maritime services. The concept of New Public Management emerged in the early 1980s in the United Kingdom and New Zealand, and then gradually spread to many countries, including France. It is based on the main idea that the public sector, organized according to bureaucratic structures and principles, is inefficient and that it would be desirable to draw inspiration from private sector principles (Pollitt and Bouckaert, 2011). In the maritime administration, the service that originally constituted the first territorial level of Maritime Affairs, called the "Syndic des gens de mer", which was considered as a referent for fishers, was closed, as well as the Maritime Affairs Quarters, with the subsequent disappearance of the Chief Administrator of the Quarter, the second point of contact with fishers for more political or serious matters (Danto, 2021). The increasing centralization of institutional bodies could negatively impact the implementation of the policies to mitigate bycatch, policies to which the fishers often do not lend any legitimacy. Moreover, fishers' access to speech in the social and political system is variable, depending on their social position and of their network, which accentuate the power asymmetries within the fishing communities in a context of administrative centralization. The fishers' representative bodies play a crucial role to bridge the communication gap, connecting fishers with policymakers and researchers, yet little is known so far about their actual role in the decision-making process, and fishers' positions with regards to this representation. Improving our knowledge of the "invisible" professional fishers who are not members of OPs and refuse contacts with the Committees, as well as of the level of satisfaction of fishers with regards to the representative democracy within the maritime political sphere, could contribute to a better apprehension of fishers' reception with regards to new fishing policies and biodiversity conservation regulations.

The balancing of ecological concerns within the social, economic, cultural and democratic spheres of the decision-making process is shaped and constrained by different factors that can be distinguished in three categories: values, rules and knowledge (Colloff et al., 2017). First, the choice of bycatch mitigation policies is impacted by the preferences, and thus by the values of decision-makers: fear of social unrest in the Atlantic ports, incentives to maintain the fishing industry, duty of protecting marine biodiversity … Then, the institutional context in which the decision-makers operate determines the prescribed and proscribed actions and the associated bodies of laws and social norms for how rules are applied (Colloff et al., 2018). In France, the European Union has an exclusive competence over "the conservation of the biological resources of the sea within the framework of the Common Fisheries Policy". This strategic competence gives the European institutions a central and widely discussed role (Khalilian et al., 2010; Lapijover, 2018), and it is exercised by the use of different instruments, such as European Directives. The Habitat Directive, the Birds Directive, and the Marine Strategy Framework Directive (MSFD) are all impacting the science-policy approach to bycatch mitigation in the Bay of Biscay. The MSFD, for example, aims to set a European strategy for the marine environment that intertwines acquisition of scientific data and implementation of management measures, while taking into account the local specificities. The Directive demonstrates the intertwining of scientific knowledge and decision-making processes, giving a central place to scientists and decision-makers, but it does not mention the integration of other representations of the marine environment (Lapijover, 2018).

If the government is not complying with the European norms, the European agencies can directly exercise pressure through an infringement procedure. The interactions between the different scales of governance which shape the institutional context of bycatch mitigation policies are taking place in arenas that are highly distant to fishers' reality. This mechanism does not prevent a State from following a strategy that is divergent from the European norms, as it has often been the case with regards to French political decisions.

Finally, decision-makers formulate policies according to their understanding of the world, which is defined by the political use of scientific expertise (Latour, 2018), but also by their experiential knowledge and world views. Knowledge production on bycatch emerges as a key step to the management of an issue that remains the subject of uncertainties, hence participating in knowledge production through the academic system could theoretically be a lever for empowering stakeholders to take an active role in shaping the policies for sustainability (Caze et al., 2022). Power is linked to deliberation, learning (and who defines what type of learning), the choice of indicators for measuring outcomes, and the sharing of risk (Lascoumes, 1994; Armitage et al., 2007). However, in this situation, the scientific approach to integrate fishers' knowledge is often limited to data production, and fishers' representatives are not systematically integrated at the step of interpretation of the projects' results to inform policy making and develop bycatch mitigation tools such as thresholds. In some cases, research projects are concluded by negotiation on measures to take based on the project results, and fisher representatives are given the opportunity to be represented in the different operating committees to discuss and express their disapproval. Consultation, as an operation to collect the opinions of the actors concerned, does not lead to the sharing of decision-making power, nor does it guarantee that the opinions expressed will be taken into account. The government, which is responsible for implementing the European directives from which most of the research work stems, has the final word on the measures to be applied.

The empowerment of fishers to mitigate bycatch through the participation in research projects is also questionable due to the controversies regarding the impact of science on decision-making. When scientists present their assessments of the bycatch impact analysis with plausible ranges of values, recognizing the uncertainties in their conclusions, policymakers must choose a single value, knowing that the subtleties of a variance or confidence interval are generally beyond their grasp. Political arbitrage is not only determined by political will, since the research projects did not result in the identification of a silver bullet solution for bycatch. Scientists argue that uncertainty should not justify inaction, especially since for many of them the reality of the impact, in view of the state of knowledge and data available, is largely underestimated (Deldreve, 2010; Peltier et al., 2020b). However, the interpretation of scientific results by policymakers has most often led them to choose the least constraining option for fishers in the immediate term, even if this option has negative consequences in the medium and long term (Deldreve, 2010). Only a few binding regulations exist, such as the ban on driftnets. Moreover, researchers highlight that the current governmental incentives to pursue research can be interpreted as a political strategy to postpone political arbitrage. Indeed, research projects on bycatch are criticized for being instrumentalized in order to validate either conservation or exploitation policies, depending on the research institutions and on the political directives.

The decision-makers' approach to learn from the conflicts could suggest that controversies and alternative practices have had little impact on the genesis of knowledge and management methods. But it is difficult to evaluate the influence of the different sources of knowledge in the negotiation process informing the political arbitrage, due to the opacity of the process of construction of the political strategy. It is understood that scientific knowledge, although indispensable, could not be sufficient in view of the uncertainties that weigh on the data, the variables to be considered, and more broadly on the complex and uncertain realities of the marine and associated social environments. Recognizing the limits of the scientific approach when managing situations of crisis and high uncertainty is part of a more general reflection on the limits of representative, delegative democracy, where political actions are produced by central authority bodies which define both the objectives and the means to achieve them (Deldreve, 2010; Latour, 2018). This raises an interesting question about the extent of power-sharing that is required to find solutions for bycatch mitigation. The different manifestations of power in the conflicts, and the way power emerges and evolves through control, resistance, and solidarity, influence collaboration and learning (Armitage et al., 2007). The issue of the debates regarding whether the power gap is a factor blocking or facilitating transformation is critical for determining what "knowledge co-production" means for the future of fisheries science in settings where research is mobilized to foster innovation.

Recommendations

There are contradictions in the needs of the actors involved in the process of knowledge co-creation that does not lead to a holistic, silver bullet solution for bycatch. The complexities associated with the issue of bycatch requires to reject ready-made solutions, and instead compose a "situated knowledge", emphasizing the local and contingent connections. Collective commitment in bycatch mitigation projects, through conflict and collaboration, can be an opportunity to engage in collective learning (Cundill and Fabricius, 2010) and to inform decision-making processes to create inclusive and just biodiversity conservation policies.

The limits of the scientific approach highlighted by the conflicts with the fishers suggest that reform cannot be driven only by providing evidence that the current status quo has to change. Acknowledging the presence of conflicts between the stakeholders and understanding their roots and their impact on the co-design process can allow the identification of factors of

path-dependency hindering the adaptive capacity of institutions. Conflicts can also prepare the system for change, and disagreements can become catalysts for social change and generate positive friction, if the necessary negotiating processes are in place to allow discussion among different narratives for the sustainability of the fishing sector.

The process of knowledge co-production on bycatch should be pursued, with the aim to foster a change in perspective of the actors involved, and a greater understanding of the other, creating incentives to think beyond dogmatic positions. Ensuring that the process will generate collective learning requires acknowledging the perceived dichotomy between academia and the fishing activities and to continue the effort of acculturating scientific and administrative structures to the working conditions of fishers. The collaboration between scientists and fishers has a very strong vocation to convey concepts produced in science to societal actors, but it requires to create the appropriate framework to be in capacity to share a common vocabulary (Fabricius and Cundill, 2014). Social science scientists can play a key role when shaping such a framework (Geistdoerfer, 2007), as well as a supranational organization dedicated to the issue, inspired by existing organizations, integrating the issue of ecological knowledge in their management processes (Danto, 2022).

Transformation of the fishing sector cannot be achieved without the fishers. As the research projects on bycatch progressively improve our understanding of the human-species interactions, national policies should be designed to empower fishers to foster the emergence of alternative practices through experimentation and through the sharing of good practices.

When negotiations fail to move further, and the actors are entrenched in their position, activating other levers in parallel of the political debate can help to recreate dialogue between the stakeholders. The current national strategies to reduce bycatch of small cetaceans and seabirds should be regularly updated with concrete actions to support the experimentation of alternative practices in order to rapidly find applicable solutions. For example, creating economic incentives for fishers to change practices.

The actors are placing a lot emphasis on the test of technological innovations to reduce bycatch. Market-based approaches or technological innovations are, in many instances, insufficient to produce sustainability transformations (Scoones et al., 2015). Accelerating long-term structural transitions also requires leveraging change of the social groups' standards, by contesting dominant social and political structures, and to reconsider the macro-economic dynamics of food production, as well as the deep cultural patterns interrelated with these dynamics (Geels and Schot, 2007).

Improving the quantitative and qualitative data and the sharing of other forms of knowledge provided by the fishers requires creating incentives for the different fishers to further contribute to the research projects, but also overcoming the resistance to non-scientific knowledge sources. Continuing to assess the potential of a hybridization of knowledges, with scientists, naturalists, and fishing professionals experimenting practices to reduce bycatch, is key to eventually creating the foundations for an inclusive decision-making framework.

Knowledge co-creation is a lengthy process which presents the risk of slowing down the transformation of the fishing sector. Yet, enough time needs to be dedicated to consult all stakeholders when conceptualizing the project, as well as to present them the methods of data analysis, and to give feedback on how the consultation has been integrated, or not, in the project. Particular attention should be given to the process of data interpretation and to the composition of the committee responsible for concluding on the measures to be taken.

The conflicts on bycatch mitigation relate to questions of identity, tradition, modes of production and individual consumption, which are often barriers to set alternative governance systems to foster the transformation of human-nature interrelations. Lessons can be drawn from the conflicts on bycatch mitigation to experiment adaptive management and set up a polycentric governance system. Adopting a critical and reflexive approach in bycatch research can contribute to the identification of best practices with regards to the role of governance in conservation conflicts.

The lack of consideration of fishers' needs and voice can undermine support of constituents and produce opposition, potentially undermining the long-term success of sustainability initiatives. Restoring a climate of trust requires understanding the needs, concerns, and motivations of the groups of fishers (Calderwood et al., 2021). The conflicts analyzed in this paper emphasize the critical importance of fishers' motivation and readiness to adapt to bycatch reduction policies. Fishers' fears and doubts should be taken seriously, and the objectives and solutions must be meaningful to them (Ears and Pol, 2022; Suuronen, 2022).

There are still important knowledge gaps regarding how to evaluate the outcomes of co-design processes in a context of tension. Further research should be realized on methods to measure to what extent collective learning is generated and how it enhances the resilience of communities beyond the research projects. Further studies should also be realized on the interactions between fishers and scientists with regards to bycatch mitigation and on fishers' perception of their political representation.

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CC did the bibliographic research and wrote the article. JR assisted in the writing and literature search. AD provided assistance with the bibliography. CM is the research project leader and assisted with the bibliography. All authors contributed to the article and approved the submitted version.

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