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INVITED EDITORIAL

Socio-Technical Approaches are Needed for Innovation in Fisheries

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ABSTRACT

We reflect on the innovation process that led to the development of the pulse trawl that was successfully trialed at a commercial scale, but eventually ended with the European Parliament passing legislation to ban its use. The ban was imposed despite published and emerging evidence that suggested that the environmental performance and catch efficiency of the pulse trawl was superior to the conventional beam trawl design. We used a stakeholder questionnaire to understand which factors undermined wider acceptance of the pulse trawl. The main factors where a lack of involvement of certain key stakeholders earlier in the process that would have ensured better co-development of innovation and a shared vision of the environmental or governance questions that needed to be addressed. Although the stakeholder process itself was seen to be positive, it was implemented too late in the innovation process, as was the implementation of an independent peer review process. We conclude by identifying a pathway for future fishing gear innovation processes that integrate the lessons learnt from the pulse trawl innovation process.

KEYWORDS
Trawling; innovation; stakeholders; environmental impacts; governance

Introduction

The aim of this article is to determine what lessons can be learnt from the processes that led to the development of the "pulse trawl" that ultimately was banned by the European Commission, despite the expenditure of many million Euros of public and private funds invested in research. We chart the development of the pulse trawl from its origins as a fishing gear innovation designed to save fuel in the 1980s which then expanded to include the objectives of reducing environmental impacts on the seabed and wider ecosystem by developing a more selective fishing gear, through to the adoption of legislation in 2019 that banned the use of this fishing gear in the European Union (EU). In particular, we look at the social issues leading to this outcome despite seemingly extensive engagement with stakeholders. Some stakeholders (mainly Dutch fishers and NGOs) were involved in the project from its inception, whereas the wider stakeholder community was only involved at a later stage in the development process. In a technical sense, the pulse gear achieved many of its intended innovation outcomes, with peer-reviewed evidence to support potential environmental benefits including improved fuel efficiency and reduced CO_2 emissions per unit of landed fish, reduced benthic impacts and fewer discards (e.g., Tiano et al 2019; Rijnsdorp et al. 2020a, see Appendix 1 for current list of peer reviewed publications) as compared to conventional tickler-chain beam trawls. Technical evidence alone was insufficient to prevent the gear being banned in European waters. We use the results of a questionnaire survey administered to the stakeholders consulted during the pulse trawl project to understand why stakeholder engagement did not inform research capable of addressing wider societal concerns regarding this fishing gear innovation.

Societal concerns about the marine environment

Public perceptions of human threats to the marine environment consistently identify pollution as the main threat, often followed by fishing. A global study from 21 countries (Lotze et al. 2018) reflected this pattern,

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while a pan-European study (Gelcich et al. 2014) found that pollution, then overfishing were the two most important top-of-mind environmental matters for the marine environment. They also found evidence for public concern regarding habitat and ecosystem damage by fishing gear, but the latter were both ranked lower than overfishing (Gelcich et al. 2014).

Fishing and food production

Despite societal concerns about fishing, capture fisheries remain a critical source of food and nutrition for billions of people, accounting for c. 80 million tonnes of food production per year, of which a quarter is caught by bottom trawl fisheries (Amoroso et al. 2018). In countries with a high dependence on fish for food security (e.g., in West Africa and South East Asia), fish is a critical source of protein and micro-nutrients essential for good health (Steadman et al. 2021). While bottom trawl fisheries are important to global food production, they are associated with a range of negative environmental impacts on marine species and ecosystems (see next section). While many forms of wild capture fishing out-perform terrestrial production of animal protein in terms of environmental impacts and emissions, bottom trawl fisheries are considered to be energy intensive in terms of resultant catch (food) per unit of energy invested (Hilborn et al 2020), except where management systems lead to higher harvest efficiency (Bloor et al. 2021).

Environmental effects of bottom trawling

Bottom trawl fisheries are designed to catch commercially important species that live in close association with the seabed. These fishing gears have been designed to have close physical contact with the seabed to maximize their catch efficiency, specifically for target species like flatfishes. This, however, leads to penetration of the surface sediments by heavy elements of the gear and abrasion of the seabed surface by the trawl net, and resuspension of sediments by the pressure wave and turbulence induced by the gear (Eigaard et al. 2016). The physical contact results in the removal and disturbance of infaunal and epifaunal biota, causes the resuspension of sediments, alters biogeochemical processes, and simplifies surface topography (Kaiser et al. 2002). These ecosystem effects on seabed habitats and communities have led some scientists to liken bottom trawling to clear-felling of forests (Watling and Norse 1998), and politicians and celebrities to call for a ban on the use of bottom trawling devices. The concerns about such impacts have sparked a comprehensive body of research that is now sufficiently advanced to inform models that can assess the outcome of a range of different technical modifications and management interventions designed to alleviate the direct physical impacts of bottom trawls (Hiddink et al. 2017; ICES 2019; Kaiser 2019; McConnaughey et al. 2020; Goode et al. 2021; Pitcher et al. 2022). Towed bottom fishing gears also are associated (in some fisheries) with high proportions of bycatch relative to the targeted commercial species (Hall and Mainprize 2005; Rochet et al. 2014), hence improving the selectivity of such fishing gears is also a priority.

The need for innovation

Given the combination of concerns about bottom trawling impacts and the importance of bottom trawling in global food production, there is considerable focus on re-engineering towed bottom fishing gear to reduce their environmental impact on seabed ecosystems and their associated emissions. Among bottom trawls, beam trawling is perceived to be particularly problematic. The catch efficiency of beam trawls for flatfish (in particular Dover sole *Solea solea*) increases linearly with the number of tickler chains fitted to the trawl (a tickler chain is a chain strung across the mouth of the trawl net) (Creutzberg et al. 1987; Kaiser et al. 1994). This encourages fishers to maximize the number of tickler chains which, in turn, increases the weight of the gear and drag (and hence fuel consumption) and the associated environmental impacts. Tickler chains increase the depth of penetration into the sediment, thereby directly impacting the benthos and increasing bycatch of invertebrates and other species.

This combination of outcomes has stimulated joint efforts by research scientists and the fishing industry to find an alternative mechanism to catch Dover sole and and to improve flatfish selectively, while reducing fuel consumption and seabed impact. The key to the success of a technical intervention that would achieve these aims (using a towed fishing gear), would cause Dover sole to emerge from the seabed, using minimal disruption to the seabed, that made them amenable to capture in a towed net or other device, thereby increasing catch efficiency.

The application of electric currents and fields to capture fish

Freshwater biologists have used electro-fishing techniques to sample rivers and lakes by "stunning" fish that come into contact with the electric field between two electrodes. The earliest attempts at using electrical stimuli in a variety of commercial fishing applications occurred in the 19th century, but it was not until the 1950s that applications in seawater were being explored (Soetaert et al. 2015). Although results were promising, experiments were abandoned in the mid 1980s as the use of electrical stimuli was considered too effective at catching fish and perhaps lacked the necessary selectivity to ensure that the technique could be considered to be sustainable. The initial aim of considering the use of electric fields in fishing at that time was focused on replacing the tickler chains or ground rope bobbins on conventional beam-trawl gears without reducing catch efficiency. From the mid 1970s, an additional aim was to reduce fuel consumption and hence input costs (*ibid.*). In this period, research was being conducted in the Netherlands, Belgium, UK and Germany (Soetaert et al. 2015; Haasnoot et al. 2016). Research on moving beyond 'proof of concept' to commercialization began in the mid 1980s in the Netherlands (Agricola 1985; Marlen 1985), but paused when in 1988 the EU imposed a ban on the use of electricity in fishing (EC regulation 850/98 [article 31.1]). Research started again in the 1990s with an EU funded project, "Alternative stimulation in fisheries" (AIR3-94-1850 - a collaboration between the Netherlands, Germany, Norway and Finland), with the aim of application in the brown shrimp (*Crangon crangon*) fishery (ICES. 1997). The key objective on this occasion was the reduction of fish discards that were prevalent in the shrimp fishery. Trials in the Belgian shrimp fishery started in 1997, with the principle aim of avoiding non shrimp bycatch (ICES. 1999; Soetaert et al. 2015). Trials were also conducted in the Scottish razor clam (*Ensis* spp.) fishery from 2011 (Breen et al. 2011; Murray et al. 2016). In 1999, the Netherlands started gear trials for flatfish on a research vessel, with the stated aim of reducing seafloor impacts associated with tickler chains (Marlen et al. 2001). Later studies also suggested that the pulse trawl could have beneficial size selectivity outcomes avoiding catches of juvenile sole and plaice, and indicated that there was a decrease in the catch rates of commercial flatfish, as well as bycatch of benthic species (van Marlen et al. 2014).

Flatfish pulse trawl fisheries in the North sea

In 2004, the Dutch flatfish pulse trawl was ready to be field tested on a commercial fishing vessel (Haasnoot et al. 2016). While catchability of marketable sole and plaice (*Pleuronectes platessa*) at the time was lower than conventional beam trawl gear, the significant fuel reduction meant that net revenue was higher when compared to vessels using the conventional gear. At the time, the Dutch beam-trawl fleet was under economic duress and had a negative public image (Hoof et al. 2020). The pulse trawl was seen as a potential solution to both of the latter issues.

Nevertheless, questions began to be asked about the broader ecosystem impacts of the pulse trawl; in particular, the European Commission asked the International Council for the Exploration of the Sea (ICES) for advice on *"What, if any, effects would such introduction* [of the pulse trawl] *have on non-target species in the marine ecosystems where this gear was deployed?"* ICES, were cautiously positive in their advice, but also noted that: "There are indications that the gear could inflict increased mortality on target and non-target species that contact the gear but are not retained" (ICES. 2006). The European Commission's Scientific, Technical and Economic Committee for Fisheries (STECF) advised: "Although the development of this technology should not be halted, there are a number of issues that need to be resolved before any derogation can be granted" (STECF 2006). Despite this precautionary advice, in 2006 the European Commission permitted five percent of Member States' fishing vessels in the North Sea to use the pulse gear under derogation.

Under the new Dutch fisheries innovation framework that was set up in response to the crisis in the fleet (Hoof et al. 2020), an investment scheme was made available for a group of five vessels to apply for a license (under derogation). Through an iterative process of trial and error during its use in a commercial setting, the pulse trawl's performance was further improved by interventions made by fishers. The commercial success of these fishers while using the pulse gear triggered wider interest amongst a fleet that had been suffering net financial losses for a number of years. This resulted in successful requests by the Dutch government to the European Commission in 2010 to expand the number of derogations to 42 with a further 42 added in 2014, which far exceed the 5% derogation previously agreed (Haasnoot et al. 2016). In the meantime, research continued. Between 2009 and 2015 research efforts focused mainly on the ecological impacts (e.g., Marlen et al. 2009), selectivity and bycatch avoidance (Marlen 2014). Between 2016 and 2020, the Dutch Government, as part of the EU requirements associated with the expansion of licenses in 2010 and 2014, funded a multi-annual impact assessment project (IAPF). The

IAPF was tasked to consider the wider ecosystem effects of pulse fishing, fuel efficiency and changes in carbon footprint of the fleet relative to conventional beam trawl fisheries (Rijnsdorp et al. 2020b). The IAPF was completed in 2020, and with other research, it informed further ICES advice about flatfish pulse trawling in 2020. This advice answered a special request by the EU Commission. ICES advised "…. that the change from conventional beam trawling to pulse trawling when exploiting the total allowable catch of North Sea sole contributes to reducing the ecosystem/environmental impacts of the sole fishery" (ICES 2020a). However, by this time, a decision already had been made to ban pulse fishing in the EU from 1st July 2021 (Anon. 2019). This decision followed a successful campaign against pulse fishing led most prominently by a French environmental Non-Governmental Organization (eNGO) (Kraan et al. 2020).

Social aspects of scientific innovation—the missing element

Civil society has long had a role in fisheries governance (Mikalsen et al. 2007) which includes innovation through partnerships in science-industry collaborations (e.g., Mackinson et al. 2011; Ogilvie et al. 2018; Steins et al. 2020). There has been a naïve view in fisheries science and fisheries technology that, for example, industry-led development of fishing gears is the most crucial aspect in achieving acceptance of innovation in new technology (e.g., Feekings et al. 2019, Steins et al. 2022). However, technological innovation, including fishing technology, involves more than simple innovation, design and acceptance of risk and change by potential users. Innovation in fishing gear "needs support from a wide group of actors, including industry, states, scientists and NGOs, to prevail in both practice and policy" (Haasnoot et al. 2016). Thus, the introduction of new technology must include more than design processes, but also include what is termed socio-technical transitions (Geels 2004; Grin et al. 2010; Haasnoot et al. 2016), which requires involvement of stakeholders. Embedded within technology are unwritten societal understandings and philosophies (Geels 2004). Furthermore, technology has political effects built within it, that can lead to socio-economic advantages for particular economies (Winner 1980).

The pulse trawl innovation process was guided by various stakeholder processes. We can differentiate between two periods with different foci of engagement. The first period was "the Dutch development period" begun in 2008. The foci of engagement at this time were Dutch stakeholders: fishers and NGOs. Following an assessment of the crisis of the Dutch demersal fleet (Task Force Duurzame Noordzeevisserij 2006) a fisheries innovation platform was created, Fisher Knowledge Networks were set up and funding was made available in support of innovations toward ecologically and economically sustainable fisheries (Hoof et al. 2020). The Dutch NGOs were also involved through the covenant for Sustainable North Sea Fisheries that included several fisheries improvement targets agreed between industry, NGOs and government. Pulse fishing was one of the foreseen solutions to help the fleet progress to a more sustainable position. However, once the pulse gear proved to be successful, the 5% derogation was quickly allocated, resulting in a waiting list for derogations. The Dutch government was convinced this innovation was the solution to the crisis, and with the support of the Dutch industry and NGOs they started to seek ways to arrange more licenses, first in 2010 and again in 2014. This marks the start of the second stakeholder process period, namely "the European expansion period." This time, the foci of engagement were European fishers, member state representatives, fishing industries (processors and gear manufacturers), NGOs and European political actors.

Following the second major expansion in 2014 the Dutch actors noticed that there was growing resistance against the pulse gear in the European arena. Not only was there dislike of the way the Netherlands had arranged more licenses, but concerns were also voiced about the socio-economic and ecological impacts of pulse trawling. The government commissioned a study aimed at understanding these concerns (Kraan et al 2015) and, subsequently, decided to organize annual International Stakeholder Dialogue Meetings (ISDMs). The ISDMs were set up to 1) keep people informed about the scientific process, 2) engage people in understanding whether the research was asking the correct questions, and 3) identify research needs and evidence gaps. The ISDMs were organized three times: in 2015, 2017 and 2018. The ISDMs were linked to the multi-annual IAPF research project (previous section). As part of the IAPF project, the Dutch government set up a peer-review process. An International Science Advisory Committee (ISAC) was established and tasked to monitor and evaluate the research on pulse fishing in the Netherlands and to ensure adequate linking with other pulse related research programmes. The ISAC played an important role in mediating the ISDMs in 2018 and 2019.

Despite the extensive stakeholder engagement, the peer-review process, the publication of emergent research in peer reviewed journals, the pulse trawl ended up being banned entirely (Penca 2022). Years of research and Millions of Euros of funding were invested in its development. The science and policy community needs to learn from this experience to inform future innovation processes such that they have consideration of social acceptance of innovation as a key challenge. Using the responses from a questionnaire survey amongst ISDM participants, we reflect on how future innovation projects could be structured to maximize the chance of obtaining societal buy-in and co-development from the outset, leading to more acceptable innovation solutions and more effective use of public funding to achieve positive environmental outcomes.

Post-pulse ban ISDM stakeholder survey

We evaluated the utility of the stakeholder engagement process using a semi-structured questionnaire survey approach. No personal data were collected and the questionnaire was anonymous. We distributed an online survey to all known stakeholders who participated in the 2015, 2017 and 2018 International Stakeholder Dialogue Meetings on Pulse Fisheries (ISDM). The authors of this paper were excluded from participation in the survey. The distribution list was collated based on the participant list included in the reports (2017, 2019) and provided by the Dutch Ministry of Agriculture, Nature and Food Quality (2016, names only). The Ministry could not provide us with participant email addresses due to privacy laws, thus we compiled contact details from personal knowledge and internet sources. This exercise resulted in a distribution list of 144 persons; for 14 attendees no working email addresses were found.

The online survey (Appendiices 2 and 3) consisted of 29 questions with sections that gathered potential predictor covariables, e.g. sector represented (demographic data), engagement with the ISDM, the aspects of stakeholder engagement of most importance to them, change in their perception of the pulse trawl, their perception of the role of the International Science Advisory Committee, and innovation processes in fisheries. Questions were primarily multiple-choice (conditional) with, for some questions, the option to elaborate on responses using free text. The survey closed with a comment box for any additional input (optional). We used EUSurvey, a free software package provided by the European Commission for its citizens, for the survey. Multiple reminder emails were used to encourage participation in the survey. Nevertheless, the overall response rate was low with a total of 25 responses out of 144. Respondents covered a range of stakeholders, including 8 from the fishing industry (fishers, representatives, processing, and trade), eNGOs (5), national government (2), scientists (9) and 1 other (ancillary industry) from four different countries. No responses were received from ISDM participants of the European Commission, EU or national parliament, certification standard holders or media. No responses were received from Denmark, Estonia, France and Ireland. Four respondents attended all 3 IDM meetings, 5 attended 2 meetings, 15 attended one, and 1 respondent (government) indicated that they did not participate. We decided to include the latter's responses in the analysis. A response rate of 17% is low (Nooij 1990), hence the analyses that we present are qualitative and exploratory. In addition, the distribution of participants (background and country) did not meet the criteria for representativeness in qualitative social science (Dinklo 2006). Nevertheless, the individual survey responses offer insights into how ISDM participants perceived the utility of stakeholder involvement and engagement in fisheries innovation. This information can be used to better inform future stakeholder engagement in innovation processes.

We examined the data for dissimilarity in the responses given by each respondent according to sector (science, non-governmental organization, fishing, government, fishing industry [processing and gear manufacturing]). To do this, we extracted the responses given to the conditional questions and standardized them to numeric scale (e.g., for five-point Likert scale responses, we converted answers to −2, −1, 0, 1, 2, negative numbers reflected "negative" views). We analyzed separately [not reported here] the answers that pertained explicitly to the utility of the ISAC from all other answers. We analyzed the dissimilarity of the answers given by each respondent to the survey by computing a resemblance matrix using Euclidean distance, and visualized this in an nMDS ordination plot. Our *a priori* hypotheses were that responses might be influenced by sector (e.g., science versus NGO etc, or nationality - considering that this gear innovation was a Dutch initiative). We tested for similarity among sector groups and for nationality (Dutch versus all other nationalities) using an ANOSIM test. We explored which questions had the most influence on the similarity among the responses given by the respondents using a Principal Components Analysis. In order to evaluate the influence of the stakeholder process on the "perception" of the pulse trawl, we summed the "a priori" and "a posteriori" sentiment score (a Likert scale) to indicate the relative change in "sentiment". The open-ended questions were analyzed by inductive (colour) coding, grouping of responses, and looking for similarities and differences in the responses given by the participants.

Stakeholder survey results

Similarity in responses among stakeholders

In general, the responses among respondents were highly variable and there was no clear separation overall of the respondents based on their responses when we analyzed for differences among sectors (Figure 1, ANOSIM, $R = 0.08$, $P = 0.17$), although pair-wise comparisons did indicate that there was a significant dichotomy between the responses of scientists and the two "Fishing industry" respondents (Figure 1, ANOSIM, $R = 0.84$, $P = 0.02$). Respondents did not segregate by nationality when all Dutch respondents were compared to all other nationalities (ANOSIM, $R = -0.02$, $P = 0.51$), hence there does not appear to be a "nationality" effect although it is important to note that neither English nor French fishing industry representative responded to the survey.

Principal Components 1 and 2 explained 31% and 18% of the variation among the different respondents to the questionnaire (Figure 2). The variables that influenced the differences among respondents most

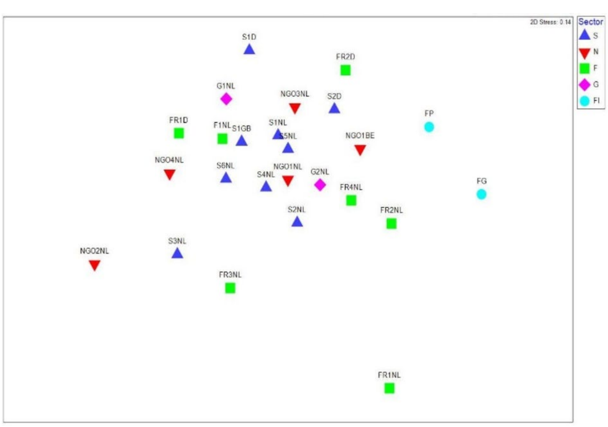

Figure 1. nMDS ordination plot of the similarity in responses to a questionnaire survey administered to stakeholders that represented science (S), Non-Governmental Organizations (N), fishing (F), Government (G) and fishing industries (FI). For the fishing industry, the symbols are labeled to indicated fishing industry representatives (FR), fishing gear manufacturer (FG) and fish processor (FP). Nationality is indicated by the ending letter (NL—The Netherlands, F—France, D—Germany, BE—Belgium, GB—Great Britain).

were the *a priori opinion* and *relative change in opinion* (PC1) and the opinion that having a dialogue meeting is good (Figure 2 Dialogue meeting good) or useful way (Figure 2 Dialogue meeting useful) to involve stakeholders in fishing gear innovation research (thus the positive responses to questions 4a and 6, see Table 1, PC2). Responses for the "Science" sector were the most consistent with a coefficience of variation (CV) of 1.31, whereas there was considerably more variation in the responses within the "Non-Governmental Organizations" (−2.74) and within the "Fishing" (−3.34) sectors, which indicates a stronger divergence in opinion within the NGO and fishing stakeholder communities when compared to the science community.

Summary of findings from the survey

In our analysis of the responses of stakeholders to the closed and open questions of the survey, we organized their feedback by distinguishing between four (inter-related) aspects of the innovation process: (1) the assessment process, (2) the engagement process, (3) communication, and (4) the political process. In the assessment process, stakeholder input is relevant for scoping potential concerns (which may go beyond anticipated ecological impacts and may also include socio-economic concerns), co-formulating the relevant scientific questions, sharing experiential knowledge, and reflecting on and discussing preliminary results. Feedback should be given on how stakeholder input was included or impacted the assessment process. In cases of a potential contentious gear innovation, the establishment of an independent scientific peer-review committee is seen as a valuable and relevant requirement. Stakeholders considered it to be important that their engagement in the fishing gear innovation process is sought from the beginning, again particularly when it concerns a potentially contentious gear innovation. In the case of the flatfish pulse trawl, international engagement only began when the gear had been well-developed, which was considered too late in the innovation process. One way of organizing engagement is by setting up an ISDM, although this in itself was not seen as sufficient; stakeholders highlighted that engagement should not be limited to an annual meeting but should be part of a continuous process involving feedback steps. Transparency and openness from the beginning was considered of key importance and related to both the engagement process as well as communication. We note that the protection of intellectual property of gear manufacturers

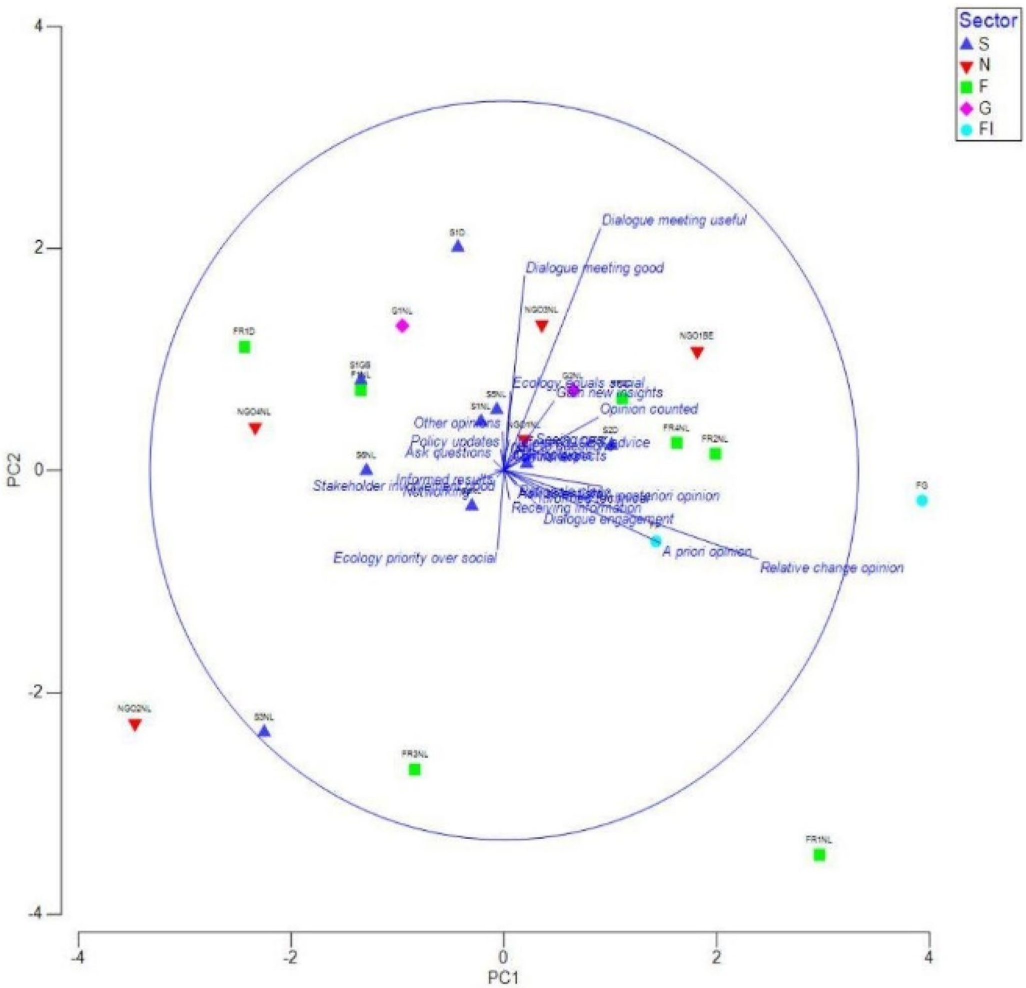

Figure 2. Principal Components Analysis showing the similarity among questionnaire survey respondents with the questions overlaid showing which of the latter accounted most for the variation among respondents in PC1 and PC2. Questions have been abbreviated—a key to the full question text is given in the Appendix 2.

Table 1. Principal component coefficients for the questions that had the largest influence (shaded numbers) on the pattern observed in the PCA among respondents to the stakeholder survey.

Abbreviated question	PC1	PC2
Dialogue meeting good	0.058	**0.527**
Dialogue meeting useful	**0.272**	**0.656**
A priori opinion	**0.441**	−0.196
Relative change opinion	**0.719**	−0.240

may at times be at odds with the desire for complete transparency. Stakeholders also pointed to the different levels of communication from some stakeholder groups (who actively campaigned against pulse fisheries) and science (who did not actively communicate about their results). Finally, many stakeholders highlighted how the political process and the scientific process in the flatfish pulse trawl case had become intertwined, which made it difficult to have an open mind toward the science and the intentions of the Dutch government in setting up an ISDM. In particular, the issuing of an increasing level of licenses in anticipation of the scientific results resulted in significant damage to a decision-making process that should, according to the Common Fisheries Policy, be science-based. Stakeholders highlighted that the assessment process and stakeholder engagement in it should be kept separate from the political decision process, although the division is not always that clear-cut. For more detail on the analysis associated with the responses to each of the questions in the questionnaire, see Appendix 4.

Discussion

The pulse trawl project

Beam-trawling for flatfish, and particularly Dover sole, is associated with high discards, seabed disturbance and

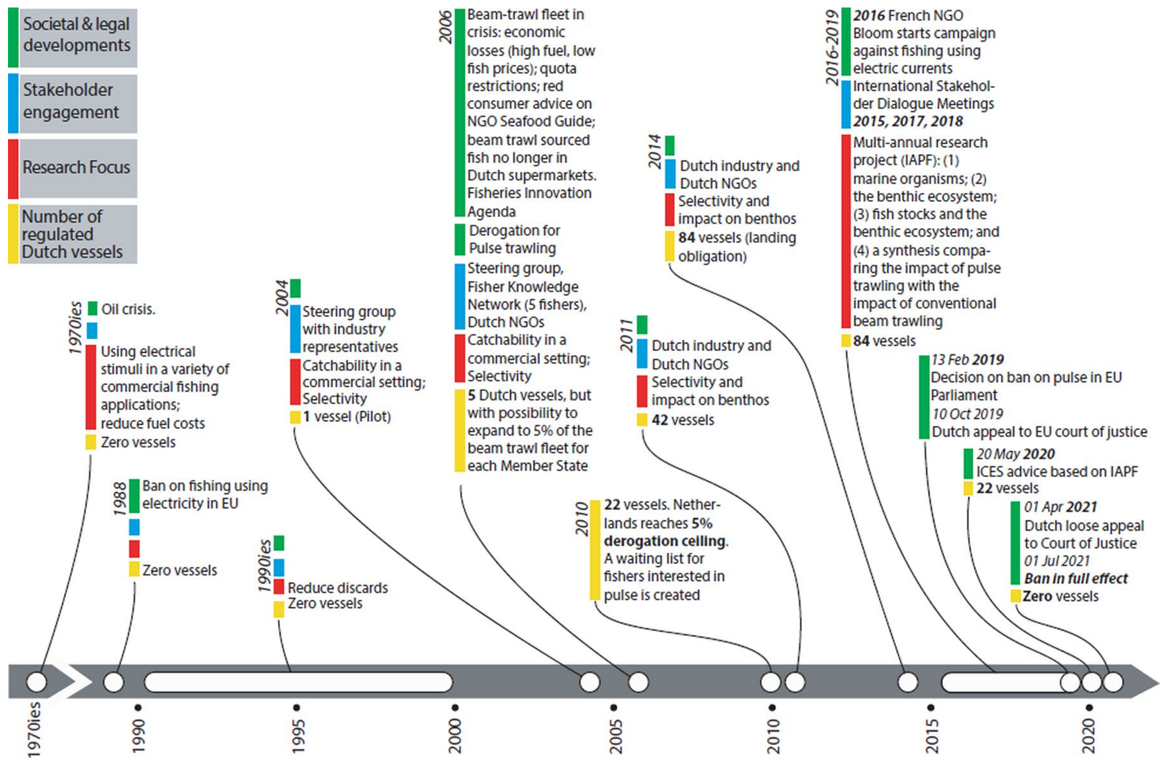

Figure 3. Timeline of pulse trawl development in the Netherlands*. Sources: Task Force Duurzame Noordzeevisserij (2006), Haasnoot et al. (2016), Hoof et al. (2020), Kraan et al. (2020), Rijnsdorp et al. (2020b), and Soetaert (2015). *From 2006 onwards, also other EU Member States made use of the 5% derogation in the North Sea.

high fuel consumption. These factors were all drivers in the history of the development of flatfish pulse trawl (Soetaert et al. 2015; Figure 3). In more recent years, following the commercial application of the gear under derogation, a number of other environmental arguments for using pulse trawls emerged. These included the potential to reduce the physical and ecological impact on benthic habitats (Rijnsdorp et al. 2020b) through a reduction of the weight of the fishing gear together with the reduced area fished to catch the same amount of target species (due to increased catch efficiency and selectivity) (Figure 3). There is now published evidence that supports all of these claims (e.g., Rijnsdorp et al. 2020a, see Appendix 1). A fishing gear innovation with multiple environmental benefits is certainly desirable, albeit that some of these benefits may have occurred coincidentally rather than intentionally, e.g., the reduced carbon footprint resulting from increased catch efficiency. The ability to use the pulse trawl in fishing grounds where conventional beam trawls could not be deployed (Turenhout et al. 2016) could also be considered a benefit for the pulse trawl fleet, but a negative impact on the fishers that encountered a new source of competition on fishing grounds that previously were inaccessible to conventional beam trawls. This issue was one of the primary causes of contention between the pulse trawl fleet and other fishers who considered it as unfair competition (Kaiser personal observations).

Insights from stakeholder perspectives

The responses from the stakeholder community (with the caveat that some key stakeholders [most notably, all stakeholders from France and UK fishers] did not participate in the questionnaire) highlight aspects of the innovation and stakeholder engagement process that resulted in a lack of support from various representative bodies and ultimately the European Parliament. Despite the multiannual IAPF research programme (Rijnsdorp et al. 2020b) and the eventual peer-reviewed publications emerging from it, that addressed a wide range of key science knowledge needs, stakeholders considered that the investment in research to understand the environment impacts of the pulse trawl (and hence the publications) came too late in the innovation process leaving too little time to address key questions posed by the stakeholder community that required an ecosystem scale assessment of potential effects. Linked to this is the timing of the increase in the size of the licensed fleet which greatly exceeded the size of an "experimental" fleet before environmental science programme had begun.

Table 2. Mean (±95% CI) and coefficient of variation for the coefficients for PC1 for the "Science," "Non-Governmental Organization" (NGO) and "Fishing" sectors. "Government" and "Fishing Industry" sectors were not analyzed due to the low number of respondents.

	Mean	95% CI	CV
Science	0.51	0.67	1.31
NGO	−0.69	1.89	−2.74
Fishing	−0.44	1.47	−3.34

The confusion of the intended outcomes of the gear development outlined above also reflects a lack of engagement with stakeholders to identify the shared "problems" that are being addressed through the innovation process. The science programme was also considered too narrow, in that it did not address social and economic impacts that might arise from the introduction of a new fishing gear. Even the ISAC lacked a social scientist at its inception. Given the extensive literature on social-ecological systems it seems incredulous that such an oversight occurred in a contemporary innovation programme. Indeed, some stakeholders suggested that a social and economic impact assessment should have been undertaken at the start of the innovation programme.

There was considerable variation in responses to the stakeholder questionnaire (Figure 1), with only the scientific community showing reasonable congruence, with the most variable views in the fishing industry and NGO community (Table 2). This variability no doubt reflects the evident split in views among different fishing industry sectors (pulse fishers versus other sectors, most notably small-scale fishers) and also the differing agendas of the NGO community. Nevertheless, the majority of stakeholders indicated that the stakeholder engagement was effective and felt that their views were listened to and acted upon, and those that changed their opinion during the engagement process generally did so in a positive manner. Despite this, the overwhelming sentiment was that the stakeholder engagement came too late in the innovation process such that stakeholders felt that the research programme could not (would not) respond to (all of) their concerns. Given the short-comings of this process and the implications for future investment in fishing gear innovation, we outline a suggested framework and considerations for future innovation.

Elements of a framework for future gear innovation pathways

Innovation in fishing gear was explored in detail by Techau et al. (2020), and by the ICES Workshop on Innovative Fishing Gear (WKING) (ICES 2020b). Techau et al. (2020) presented worldwide technologies and innovations relevant to fisheries,. They described an innovation as "any new ideas, creative thoughts, or new imaginations in the form of technology or method". They defined the term "ideality," where a successful innovation provides a more ideal solution than previously had been available, here "ideal" is defined as the positive effects divided by the costs and harms that are also present, and can be expressed by the equation below (ibid.). While this is a useful conceptual framework, it does not provide a consideration of the different weightings that may be attributed to "costs" and "harms" versus "positive effects." Moreover, these weightings may vary between different stakeholder groups.

$$Ideality = \frac{\sum positive\ effects}{\left(\sum costs\right) + \left(\sum harms\right)}$$

The WKING report (ICES 2020b) was set up to provide advice to the European Commission (EU DG-MARE) on the progress made and impact arising from innovative fishing gears in EU waters, especially the benefits for, or negative effects on, marine ecosystems, sensitive habitats and selectivity. The workshop catalogued "innovative gears," including the pulse trawl. It also examined the concept of "innovative gears," and what was needed on the "path to innovation." These sub-divided into: (1) a general definition of innovation, (2) an interpretation of innovative gear, (3) criteria of assessment, (4) level of innovation, (5) technology readiness level, (6) and (7) performance and technical readiness rating. The first three categories are particularly relevant to the current paper.

ICES (2020a) described an innovative gear as: "*a gear or a significant component of the gear that has not been used commercially and/or that is sufficiently different from the baseline in the current European Regulations, or in the absence of them, different from the commonly used gear in the specific sea basin (area) in EU waters*". WKING (ICES 2020b) detailed different innovations in terms of their outcomes, ranging from failed innovation, transformative innovation (a large jump forward), incremental innovation (steady progress), and disruptive innovation, where initially there would be costs but the eventual gain would outweigh these. In most respects, the pulse trawl could be considered as being in the *disruptive* category. WKING provided three main Criteria of Assessment for an innovative gear:

- catch efficiency—broadly, improved Catch per Unit of Effort (CPUE) for the target species
- selectivity—broadly, retention of target species, and avoidance of unwanted catches, and,
- marine ecosystem impact and in particular:
    - o seabed impact;
    - o Risk of gear loss and potential for ghost fishing and marine plastic pollution;
    - o impact on endangered, threatened, and protected (ETP) species.

Other impacts were noted, but the workshop considered these as to be the most important. WKING developed a framework for categorizing gear innovations based on "The Integration DEFinition (IDEFØ) business process mapping system http://www.idef.com/IDEF0.html"in which any process must have inputs, controls, mechanisms and outputs (IDEFO 2005).

WKING (ICES 2020b) noted that "*it is important to understand the wider social, political, and economic context in which innovations are embedded (*Haasnoot et al. 2016*)*", however their appreciation only considered the people needed "*to create, invent and introduce the innovation*". The results of the stakeholder survey included in this paper highlighted the importance of providing a remedy to this omission.

WKING provided several worked examples, including the pulse trawl (Table 3). They described it as an "*example of an innovation with limited implementation, failed to scale up and be brought to market*". We disagree with this conclusion, as the pulse trawl had considerable implementation, was scaled up for much of the Dutch beam trawl fleet, and other fisheries, and was marketed successfully. Broadly WKING's analysis of the pulse trawl can be seen as positive, although some key negative points were identified. First, pulse trawl "is in effect, too good" and has "exceptionally high technical efficiency" (ICES 2020b). We agree that this was clearly one of the key issues with the pulse trawl and was reflected in the different responses in our stakeholder survey. In addition, opposition from fishers from the UK and France was considerable, and in part at least because they felt they might be outcompeted as they were unable to afford expensive pulse trawls. However, high efficiency is probably to be welcomed if all other factors are considered equal. In a fishery managed by Total Allowable Catches, higher efficiency (i.e., CPUE) probably also means less fishing effort for the same catch. In turn this would be expected to reduce issues of benthic disturbance and possibly bycatch.

The governance dilemma that remains is about equity, as not all fishers had equal access to obtaining this efficient gear, as the initial cost to buy the gear, and adjust the fishing vessel to accommodate it, was prohibitive and only permitted for fishers that fished in ICES area IVc (where the pulse trawl was permitted for use) and only feasible for those that had a relative high Dover sole quota. Traditionally equity issues in fisheries governance are solved as part of the political process, however the lack of standard socio-economic research meant that such issues were identified too late in the innovation process (see also below). Second, pulse trawling was assessed as lacking in surveillance techniques (ICES 2020b). While this may be the case, conventional monitoring (fisheries landings, Vessel Monitoring Systems, and observer programmes) would likely have operated as well as for any other gear. The configuration of the technical characteristics of the electric pulses generated by the fishing apparatus was raised as an issue that was difficult to enforce by a number of stakeholders in the dialogue process. Third, WKING pointed out that law-makers are likely to be

Table 3. WKING (ICES 2020) assessment of the pulse trawl in the context of characteristics of innovation defined within the IDEFØ approach (Figure 3).

Inputs	High efficiency reduces fuel consumption per unit catch and reduces bycatch significantly. Investment probably available
Controls	Consumer preferences unknown - aligned with low impact fishing Legislation: detailed above High efficiency is in line with business objectives
Means / Mechanisms	Small number of people involved but with high technical skill Questions over business skills to manage the downsides of the technology. Gear appears well developed, as well as methods to achieve high efficiency, but lacking in surveillance techniques
Outputs	New knowledge and Intellectual Property (IP) have been developed. High trawl efficiency = high profitability Discards reduction proved in several scientific publications Significantly reduced benthic impact Negative outputs are primarily due to "human error" i.e. taking advantage of the exceptionally high technical efficiency Legislators likely fearful of reputation due to prior problematic implementations

fearful of reputation issues due to prior problematic implementations (ICES 2020b). We assume that this is referring to the issue of the high number of Dutch vessels allowed to fish with the pulse trawl under derogation. We agree that on the basis of what eventually transpired, this was indeed a key issue, and reputational damage likely incurred, making any further (future) introduction of pulse trawling difficult. In this context, it can also be concluded that the possible "Σharms" term in the equation above was the perceived critical factor in the issues with the pulse trawl, and clearly outweighed the significant "Σpositive effects" that were documented.

Critically, what is missing in the evaluation is some consideration of the social constraints on this innovation. The "controls" were listed by WKING (Figure 4) as customer, technical and business constraints, with social constraints unmentioned, and yet, it can be argued that these were pivotal in the final European Parliament decision on the use of the pulse trawl. This included opposition by other fishing sectors, as well as from environmental NGOs. One input is also missing: (perceived) compliance with the existing legislation, i.e. the wider extension of derogations provided to use of the pulse trawl in commercial fishing. The "mechanisms" and their interpretation appear reasonable, namely; people, infrastructures, and tools/methods, although the "business skills to manage the downsides," is possibly better represented as the social skills. The outputs do not specify ecosystem impacts. However, this was both a strength and a weakness for pulse trawl. Reduced bycatch and reduced benthic impacts were both positive outcomes. Less fuel use is both an economic and an ecological impact, i.e., reduced costs and reduced emissions of CO_2. But stakeholders were very concerned about the

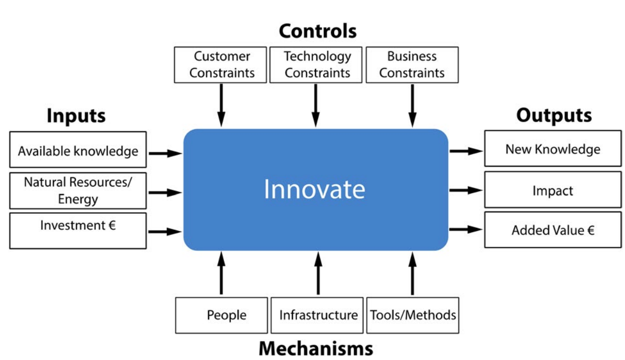

Figure 4. IDEFØ diagram of the innovation process. Inputs are transformed or consumed by the process (the raw material or ingredients). Controls specify the conditions for the function to produce the correct output. Outputs are the data or objects resulting from the function. Mechanisms are the means and resources which support the process (redrawn from ICES 2020).

impact of pulse on the fish not caught by the fishing gear, and especially electrically sensitive elasmobranchs, although the pulse trawl research project found no evidence for this. Additionally, there was no assessment of indirect social or economic impacts (outputs) on other stakeholders. Indeed, the ICES advice based on the WKING report stressed *"that technical innovations are always sociotechnical. The level of uptake and sociotechnical aspects associated with the innovation should therefore be part of the development of a more comprehensive state-of-the-art review"* (ICES 2020a).

It is possible to conclude that, in terms of the EU Special Request, and of the specific pulse trawl case, that outputs should be elaborated separately in terms of the three main Criteria of Assessment elements defined by WKING (ICES 2020b); catch efficiency, selectivity and marine ecosystem impact. It is clear that each of these were important in the pulse trawl experience, and particularly, perhaps because the opponents saw the efficiency and marine ecosystem impact differently to the developers, users and managers? Identification of the tradeoffs involved would be valuable, e.g., less benthic impact vs. possible elasmobranch effects, or increased efficiency for one fleet could represent unfair competition by another. What is clear from the above, is the consistent failure to recognize adequately the importance of addressing social and economic impacts on actors other than those directly involved in the innovation process.

Social impact assessment of gears

The International Assessment of the Pulse trawl Fishery (IAPF) process (https://www.pulsefishing.eu/research-agenda/impact-assessment-of-the-pulse-trawl-fishery) focused significant time and effort on investigating the ecological impacts of pulse trawl, which is reflected in the approach adopted by WKING (ICES 2020b). Sustainability and impact assessment, however, also includes social and human dimensions (ICGP (Interorganizational Committee on Guidelines and Principles) 1994). Investigating the human dimensions involves social impact assessment (SIA), which is *"the process of identifying the future consequences of a current or proposed action(s), which are related to individuals, organizations and social macro-systems"* (Becker 2001). Thus, SIA includes the processes of analyzing, monitoring, and managing the intended and unintended social consequences, both positive and negative, of planned interventions (policies, programmes, plans, projects) and any social change processes invoked by those interventions (Vanclay 2003). Cumulative impacts with other events or interventions should also be considered. The primary purpose is to bring about a more sustainable and equitable biophysical and human environment.

When considering SIA for gear development, as with any innovation programme, one of the most difficult challenges is properly setting the scope of the impact assessment. Focusing on Dutch fishers, fishing community residents, and local eNGOs is an initial logical choice, and yet may not cover all groups that potentially will be impacted; in addition local communities and fisheries are heterogeneous and impacts may vary amongst them. Thus, key questions surround disaggregation and distributional impacts, i.e. 1) who are the groups that will be impacted (fisher type; marine state; ports; processors, auctions, eNGOS representing civil society)?; 2) how will the impacts be distributed among stakeholders? Rarely are all subgroupings impacted to the same extent. To uncover potential impacts, one should look forward to the anticipated desired outcomes, and consider which groups could, in turn, be impacted. If, for example, it is possible that a fishing gear is to be used throughout the North Sea, including in new fishing areas, this is an entirely different consideration compared to an envisioned use constrained within the coastal zone of a marine state. As such, SIAs fit within the ecosystem approach to fisheries (EAF), whereby management should plan, develop, and manage fisheries in a way that address the multiplicity of societal needs with sustainability objectives (Jennings and Revill 2007).

Conclusions and looking forward

The pulse trawl project was focused on providing a technical innovation to a specific fishing gear to improve the sustainability of a specific (flatfish) fishery, and we acknowledge that there are many other accepted management and technical interventions that have achieved the same aim and have been acceptable to society (e.g., rotational closures, use of turtle excluder devices). The innovation process surrounding the pulse trawl was an ambitious project which moved ahead too quickly after the initial positive experiences (less environmental impact and economic benefits from fuel savings) in the early sea trials with a small experimental fleet. The initial research focused on technological and environmental issues and did not explicitly consider socio-economic impacts. When unforeseen consequences emerged, the research programme and budget was insufficiently adaptive to address these issues in a comprehensive way. While the international stakeholder engagement process was undertaken in a constructive manner, it was implemented too late in the process and hence did not feed into the development of the scientific evaluation process which was largely determined a priori. Similarly, the introduction of the independent International Science Advisory Committee came too late with relatively little ability to influence the direction of the scientific programme informed by stakeholder feedback. Future pathways of innovation in respect of fishing gear would benefit from adopting the approach outlined by WKING (ICES 2020b) with the addition of a further step that embeds a social impact assessment once it has been determined that the proposed innovation reaches the "transformative" or "disruptive" threshold. An outstanding issue remains how to address the different weightings placed on the definition of "harms" and "benefits" in the evaluation of new innovations, as the "benefits" for some can bring "harm" to others. This (ethical) trade off still requires a political decision making process, our point is that the underlying facts can come to the table more timely when a social impact assessment is done.

A future pathway to innovation

The WKING report helpfully differentiated between incremental innovations (e.g., changing a mesh size or configuration) and step-changing or potentially disruptive technologies. While the former addresses fishing gear that are already in use, the latter addresses fishing gear designs or techniques that are not in current use within a given sea area, and it is these fishing gears that necessitate the development of a pathway of co-development and stakeholder engagement and consultation. We would recommend the following procedures to ensure appropriate engagement occurs for gears that defined as potentially step-changing or disruptive, an assessment the fishing industry, science and managers together should make.

First, an independent oversight committee (such as the International Science Advisory Committee) would be set up once the fishing gear concept had proceeded past the "proof of concept" stage (clearly if a fishing gear does not function effectively it is unlikely to be adopted). In our analysis of the "pulse trawl process," the stakeholders considered that the ISAC was valuable, but implemented too late to be effective, hence this process needs to be embedded early in the innovation pathway. Second, an SIA would be commissioned to identify the potentially impacted groups and the distribution of the impact. The ISAC (distancing this process from Government bodies) would convene a wider stakeholder community with representatives of the different impacted groups identified in the SIA, to scrutinize the potential of the fishing gear to improve/worsen fishing effectiveness and profitability, ecosystem impacts, environmental performance (e.g., CO_2 emissions) and impact on other stakeholder communities, or to have other unintended outcomes. Having co-identified the areas that required additional research, a programme would be built around an agreed prioritized list of knowledge needs. Evaluation and feedback would be a continuous process, with scope to modify the research pathway as new information became available (adaptive research). Another potential pre-requisite is to define limits to any experimental fishing fleet, such as in which area of the sea it can be used before seeking permission for the new technique to be adopted more widely. Such decisions can be made at the regional seas level in the EU (article 18 of the CFP) via joint recommendations (EU 1380/2013). Implementation of these simple interventions would ensure that innovation is "co-owned" with a meaningful role for stakeholders to provide input and shape the scientific evidence gathering process. The "pulse trawl process" incorporated many of the correct elements of engagement, however they were systematically implemented too late in the process for them to be effective.

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Appendix 1. Pulse trawl related publications updated 6 feb 2022 (those papers from the IAPF project are highlighted with *)

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Appendix 2. Original list of all questions (excluding demographic questions [1,2] and those specifically related to the ISAC [17, 18]), including choice of potential responses where relevant, administered to the pulse trawl stakeholders

3-A. Do you think it is necessary to involve stakeholders in research into fishing gear innovation?
4-A. If stakeholders are to be involved in research into fishing gear innovations, is the setup of an international stakeholder dialogue meeting, as was done for the flatfish pulse fishery, a good way to do this?
5. Which International Stakeholder Dialogue Meetings did you attend? (number attended)
6. Did you find the International Stakeholder Dialogue Meetings useful? (scale of 1-5)??
7-A. What aspects of the International Stakeholder Dialogue did you find most useful? (Please tick boxes that apply, maximum is 3)
   Being informed on policy updates in relation to the flatfish pulse gear
   Being informed on control & enforcement aspects
   Hearing others' opinions on pulse fishing
   Opportunity to ask clarifying questions directly to policy (Dutch government, European Commission)
   Expressing my own opinions on pulse fishing
   Networking with other stakeholders
   Getting information about the research programme into the flatfish pulse fishery
   Being informed about (intermediate) research results
   Being informed about ICES advice
   Being informed on technical aspects of the gear
   Seeing pulse gear in operation
   Opportunity to ask clarifying questions directly to scientists about the flatfish pulse
   Opportunity to ask clarifying questions directly to fishers using the flatfish pulse
   Providing input on research questions
8. Did you gain new insights from the information presented on the International Stakeholder Dialogue Meeting(s)? (0, 1, 2)
9. Before the International Stakeholder Dialogue Meeting(s) my general opinion on pulse for flatfish was: (five point −2 to 2)
10. Did your opinion about the flatfish pulse gear change since the first time you attended an International Stakeholder Dialogue Meeting? (five point −2 to 2)
10a. Sentiment change i.e. Q9 + Q10
12-A. Did you feel your own contribution or collective input from the International Stakeholder Dialogue Meeting(s) was taken into account in the research programme? (0, 1, 2, 3)
13. Prior to attending the International Stakeholder Dialogue Meeting(s) were you aware about the International Science Advisory Committee? −1 to 1
14. Which of the following statements about the International Science Advisory Committee (ISAC) do you agree with most?
   I feel ISAC was open to concerns from stakeholders.
   I feel I could approach ISAC members with any concerns in relation to pulse fishing for flatfish.
   I have not approached ISAC members, but I would not have felt comfortable doing so.
   I have not approached ISAC members, but I would have felt no reservations doing so.
   I have approached ISAC members and felt I was taken seriously.
   I have approached ISAC members but felt I was not taken seriously.
15. Which of the following statements about the International Science Advisory Committee (ISAC) do you agree with most?
   ISAC had an independent role during the International Stakeholder Dialogue Meetings.
   I doubt whether ISAC was independent during the International Stakeholder Dialogue Meetings.
   ISAC was an effective independent intermediary during the International Stakeholder Dialogue Meetings.
16. What is your opinion on the following statement?: A scientific peer-review committee should only oversee the science and not have an active role in meetings such the International Stakeholder Dialogue Meetings. (-2 to 2)
19-A. Do you agree with the following statement?: Any research programme into the impacts of innovations in fisheries should have an independent scientific peer review committee. −1, 0, 1)
20. Which of the following statements do you agree with most?
   A research programme into innovative fishing gear should focus on both ecological/environmental and socioeconomic impacts. Both have equal priority.
   In a research programme into innovative fishing gear, the ecological/environmental impact assessment should have priority over researching socioeconomic impacts.
21. The intention of the flatfish pulse fisheries innovation programme was to develop a technology that would significantly improve selectivity (less discards), seabed disturbance and fuel efficiency of the North Sea common sole fishery compared to the traditional fishing gear (beam-trawl with tickler chains). Was this rationale/intention clear to you?

Appendix 3. List of the original questions with their associated abbreviated label for the purpose of labeling the PCA ordination plot (Figure 2)

Original question	Abbreviation PCA
3a. Do you think it is necessary to involve stakeholders in research into fishing gear innovation?	Stakeholder involvement good
4a. If stakeholders are to be involved in research into fishing gear innovations, is the setup of an international stakeholder dialogue meeting, as was done for the flatfish pulse fishery, a good way to do this?	Dialogue meeting good
5. Which International Stakeholder Dialogue Meetings did you attend? (number attended)	Dialogue engagement
6. Did you find the International Stakeholder Dialogue Meetings useful? (scale of 1-5)?	Dialogue meeting useful
7a. Being informed on policy updates in relation to the flatfish pulse gear	Policy updates
Being informed on control & enforcement aspects	Control aspects
Hearing others' opinions on pulse fishing	Other opinions
Opportunity to ask clarifying questions directly to policy (Dutch government, European Commission)	Ask questions
Expressing my own opinions on pulse fishing	My opinions
Networking with other stakeholders	Networking
Getting information about the research programme into the flatfish pulse fishery	Receiving information
Being informed about (intermediate) research results	Informed results
Being informed about ICES advice	Informed ICES advice
Being informed on technical aspects of the gear	Informed technical
Seeing pulse gear in operation	Seeing gear
Opportunity to ask clarifying questions directly to scientists about the flatfish pulse	Ask scientists
Opportunity to ask clarifying questions directly to fishers using the flatfish pulse	Ask fishers
Providing input on research questions	Input to questions
8. Did you gain new insights from the information presented on the International Stakeholder Dialogue Meeting(s)? (0, 1, 2)	Gain new insights
9. Before the International Stakeholder Dialogue Meeting(s) my general opinion on pulse for flatfish was: (five point −2 to 2)	A priori opinion
10. Did your opinion about the flatfish pulse gear change since the first time you attended an International Stakeholder Dialogue Meeting? (five point −2 to 2)	A posteriori opinion
10a. Sentiment change i.e. Q9 + Q10	Relative change opinion
12-A. Did you feel your own contribution or collective input from the International Stakeholder Dialogue Meeting(s) was taken into account in the research programme? (0, 1, 2, 3)	Opinion counted
A research programme into innovative fishing gear should focus on both ecological/environmental and socioeconomic impacts. Both have equal priority.	Ecology equals social
In a research programme into innovative fishing gear, the ecological/environmental impact assessment should have priority over researching socioeconomic impacts.	Ecology priority over social
21. The intention of the flatfish pulse fisheries innovation programme was to develop a technology that would significantly improve selectivity (less discards), seabed disturbance and fuel efficiency of the North Sea common sole fishery compared to the traditional fishing gear (beam-trawl with tickler chains). Was this rationale/intention clear to you?	Rationale clear

Appendix 4. Detailed qualitative analysis of open responses that informed the summary in the results section of the main body of the paper.

In response to the question "Do you think it is necessary to involve stakeholders in research into fishing gear innovation?" the majority of respondents (19/25) said "yes." Five respondents chose "it depends" of which four were scientists. In the follow up question designed for the "it depends" category, the main concern for these respondents related to potential bias. They emphasized that stakeholders should not be brought in and allowed to influence scientific results (i.e., science should be objective). The timing of stakeholder participation in the process was also noted as a potential problem such that stakeholders might not have been engaged at the appropriate point in time. One participant (fishing industry) commented that although there is need for stakeholder participation in research, this becomes less meaningful when decisions on gear acceptance are political and influenced by NGO campaigns rather than by science. While this is an interesting comment, it reflects more on the process that occurs following stakeholder engagement in science, when stakeholder groups are engaged in influencing political decision-making, including through shaping public opinion.

When asked "If stakeholders are to be involved in research into fishing gear innovations, is the setup of an international stakeholder dialogue meeting (IDM), as was done for the flatfish pulse fishery, a good way to do this?"– 80% of respondents (20) chose "yes" with the remaining 20% (5) choosing "no." When asked to elaborate on their response, the respondents answering negatively commented that the IDM was insufficient as a means of engagement on its own; a point also raised by some respondents answering positively. Stakeholders who answered "no" commented that the dialogue was not really a true "discussion" and was too much focused on "broadcasting. " The meeting was also seen as being "too Dutch". Stakeholders from the "no" and "yes" group shared the feeling that the IDM was introduced too late in the process of gear development and commented that stakeholders should be involved continuously (even being included in commercial fishing trips). Some respondents who answered positively considered that the IDM was unable to counter alleged misleading information from some NGOs.

Respondents were asked "If your opinion about the flatfish pulse gear changed over time, what caused the change?" The majority (16/25) of respondents did not change their opinion over the course of the stakeholder engagement, and of the remainder, eight changed positively (three much more positive) and only one changed their perspective negatively (a representative from an NGO). The imparting of developments in the scientific research and information shared at the IDM influenced positive changes in opinion about the pulse gear. In other parts of the questionnaire respondents also noted the value of seeing the fishing gear in operation at sea.

When asked "Did you feel your own contribution or collective input from the International Stakeholder Dialogue Meeting(s) was taken into account in the research programme?" Less than one third (7) thought their input was taken into account, whereas far more respondents "did not know" of which most (7/10) were scientists. The two respondents who responded negatively were a fishers' and an NGO representative. The fishers' representative commented that the political decision had already been made before the scientific results became available. In relation to this comment, it is interesting to note a comment by an NGO representative (who answered "to some extent"). This representative pointed out that that the pulse gear was only ever compared to the traditional beam trawl and "never assessed as an independent technique"; this was considered a missed opportunity and the NGOs backed out because the impacts of the pulse gear were not clear.

Stakeholders were asked a series of open questions which generated useful insights on the innovation process and insights for consideration in the future. In response to the question "…If you were to advise European institutions on the development of innovations in fisheries in future, what, if anything, would you suggest they do differently than was done for the pulse gear for flatfish programme?" 25 responses were submitted with only two respondents suggesting no change in the process. The remaining answers and suggestions were coded and clustered in themes. Most suggestions were related to science (7), followed by politics (7). Other themes were: innovation and how that should be organized (5), stakeholder participation (4), and transparency (2). The science related suggestions varied between provision of better (quantity and quality) science, and timing of research, i.e., that the scientific evaluation of pulse fishing should have started sooner in the innovation process. The suggestions related to politics referred to the issuing of too many pulse fishing licenses prematurely (before the science process had concluded), resulting in disproportionate upscaling of the fleet. Three respondents also questioned the independence of the researchers involved in the research using phrases such as: "politically driven scientists" (government official) and "political interests involved in the scientific programme" (NGO representative), and the ISAC: "there was some perception that the international committee was a Dutch endeavor" (scientist). The suggestions on stakeholder participation were to include more stakeholders, in a more engaged manner and to do more with what they suggested: "Take the advice of the NGOs on board. We brought forward good points and would have liked to support the pulse. However, with the ecological impacts not clear, this was no longer possible".

When asked about "Which stakeholders should be involved in fisheries innovation processes?" (multiple options possible) stakeholders identified the following (listed in order of the most mentioned(#)): government (19), fishers and their representatives (17), NGOs (13), scientists (9), technicians (engineers, inventors)(5), processing and trade companies (4), media (1), EU science working group members (1), fishing communities (1), chefs (1), consumers (1), law enforcement (1) and gear suppliers (1). The stakeholder group "government" was in fact a diverse and multi-level group representing the different governance aspects of fisheries: EU (commission and parliament) and member states, policy makers, management/ministries. Other responses to this question indicated how broad stakeholder participation should be: "all who want to," "those impacted" or "as many as possible." Some were more limiting but non-directive: "only people with detailed knowledge" or rather expressed the timing aspect: "same as now, but all from the start."

We wanted to understand how the introduction of an independent "International Science Advisory Committee" influenced opinions and sentiment by asking "Do you agree with the following statement?: Any research programme into the impacts of innovations in fisheries should have an independent scientific peer review committee?" 17 respondents replied "yes" while 1 respondent chose "no" and 7 chose "maybe." Specific comments included the suggestion to form a specific "EU-science working group" to address fishing gear innovation more broadly. Several respondents considered that for "small" (incremental) innovations, an ISAC would be over-burdensome, and hence an ISAC was only necessary when an innovation is likely to be contentious like pulse fishing, a point we return to in the discussion. One drawback noted was that "always working with an independent committee could send out the message" that "the researchers in the research programme are not independent." A final point was that an ISAC could not address political choices that resulted in mishandling of critical issues or processes (e.g., the issue of licenses) that then affected sentiment toward the innovation, nor could it address political processes beyond the conclusions supported by scientific evidence. This comment highlights the boundaries of influence and remit of an independent scientific oversight body and is not dissimilar to the advice given by science advisors regarding Covid restrictions and the subsequent decisions made by various Governments.

Stakeholders had useful suggestions in response to the questions "Would you propose changes to the fishing gear innovation process trajectory….?" Nine people provided suggestions. Reprioritizing the order in which research was undertaken was flagged to carry out "…. research into the gear impact during the development before larger-scale implementation." This comment also highlights that expansion of the fleet was considered premature in light of the scientific process. Another suggestion was more focused on identifying the shared problem, an approach that might foster co-development of the solution. One further comment was that innovation is not a linear process but rather one that requires feedback loops, to accommodate unexpected outcomes for instance. In addition, it was seen as important to maintain "out of the box thinking" by implementing a phase to scope for alternative techniques to avoid an unwillingness to consider alternative solutions. Other considerations involved a framework for modeling potential social and economic impacts and ecological impacts in advance of commencing a research programme.

Finally, in an open general question *stakeholders were given the opportunity to share any further thoughts on fisheries innovation processes* in general or the pulse trawl in particular. Many of these points reiterated those highlighted above, and included the late timing of the involvement of international stakeholders through the IDM as well as setting up ISAC, and the way the pulse was only ever assessed in relation to the conventional gear. There were also a number of novel comments. Stakeholders felt that the impact of the gear on the wider environment was examined too late in the process. Some also pointed out that more attention should have been paid to the socio-economic aspects, some of which (competition with other fisheries and fishers) were seen as a important driver in the political discussion. A related point is that the flatfish pulse trawl was considered to be too effective irrespective of controls on the total amount of catch. Attention was also raised to the lack of transparency and openness from the start of the innovation journey, noting that some of the commercial companies involved had intellectual property to protect. Questions were also raised about the role of the European Commission and their consent to increasing the number of licenses (under derogation). Finally, some stakeholders felt that the scientific evidence had been poorly communicated by the scientific community when compared to the more professional communications of those stakeholders who objected to the pulse gear.