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Food for Thought

Behaviour in a bottom trawl: moving forward to limit catches of Atlantic cod

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The iconic Atlantic cod (*Gadus morhua* Linnaeus, 1758) has inspired a substantial body of fishing-gear research across its geographical range, with recent efforts predominately to reduce catches of this species in fisheries where their populations are fragile. Despite their iconic status and long history of study compared to other species, our understanding of cod behaviour during the capture process in a bottom trawl remains frustratingly limited. Much of our understanding is derived indirectly through catch results, supported to a limited extent by direct observations of cod *in situ* or held in laboratories. In this paper, we describe four research challenges and directions that we consider critical to advance our knowledge of cod behaviour, and ultimately, to improve the selectivity of bottom trawls to reduce catches of cod. These include the resurrection of behavioural research to directly observe and measure their reaction and sensory capabilities, and improved interpretation of their behaviour in response to a bottom trawl. It is also our view that progress in limiting catches of cod should emphasize stimulating avoidance in advance or at the mouth of an approaching bottom trawl, rather than retrospectively attempting to do so after they have entered the trawl mouth.

Keywords: Atlantic cod, bottom trawl, bycatch, fish behaviour, selectivity

Introduction

Atlantic cod (hereafter cod) has historic and cultural importance, which is difficult to overstate (Jensen, 1984; Kurlansky, 1998; Bolster, 2012). For centuries, cod has been a vital source of food and resource for the economies of nations and regions across the North Atlantic and beyond (Jensen, 1984; Kurlansky, 1998; Bolster, 2012; Meager *et al.*, 2018), and the importance of cod is perhaps best illustrated by its common reference as simply, "fish" in Newfoundland, Great Britain, and elsewhere (Kurlansky, 1998; Rose, 2007). Historically, fisheries directed for cod used hook-and-line gear or traps (Jensen, 1984), while more recently it is caught mainly using bottom trawls and gillnets (Collette and Klein-MacPhee, 2002; FAO, 2020).

The behaviour of cod has also been investigated for centuries, initially by fishers seeking to improve catch rates and landings of this species (Kurlansky, 1998; Rose, 2007). Beginning in the mid- to late-twentieth century, reactions of cod and other species to fishing gear were scientifically studied, including attempting to understand how and why they perceive and respond to stimuli, both natural and otherwise (Ben-Tuvia and Dickson, 1968; Manteifel *et al.*, 1968; Wardle, 1977). A primary motivation for these studies was also to increase catch rates, and subsequently, to support the growth of the commercial fishing industry (Engås, 1994). This research was facilitated by applying technology such as scuba equipment, cameras, and vehicles that permit visual observations and documentation of cod and other fish responding to fishing gear, complemented by land-based studies of behaviour in the laboratory (Walsh *et al.*, 2004).

Now, recent scientific research is overturning hundreds of years of tradition by developing fishing gears to avoid, limit, or reduce catches of cod. This change is inspired by widely varying and unprecedented stock conditions, including very poor status and low quotas of cod in New England (Eayrs *et al.*, 2017) and the Baltic Sea (European Commission, 2019), lengthy rebuilding times of overfished stocks of cod in Newfoundland (Rice, 2018), and excessive catches of cod and unparalleled stock sizes in Norway (Brinkhof *et al.*, 2018).

As part of our efforts to reduce cod landings in the New England multispecies flatfish fishery, we recently appraised the state of knowledge of cod behaviour through our own documented observations, the scientific literature, and the personal experiences of local fishers. This appraisal built on our prior research proving the performance of a topless trawl in the region, which reduced catches of cod by approximately 50% without significant loss of other commercial species (Eayrs *et al.*, 2017). It also resulted in the development of another highly modified bottom trawl with similar results, the ultra-low-opening trawl (Eayrs *et al.*, 2020). These outcomes are substantial achievements, although by not eliminating catches of cod in this fishery, there is still a risk that low cod quota will impede full utilization of quotas of other commercially valuable species. Further advances in trawl design are therefore still urgently needed in this and other fisheries where excessive catches of cod are occurring.

Our appraisal also clarified to us that knowledge of cod behaviour, their sensory abilities, and their responses to a bottom trawl is dated and incomplete, particularly with respect to variation in time and space. Indirect inference about the behaviour of fish based on catches, or what Walsh *et al.* (2004) termed the "trial-and-error" method, is far more common than inferences based on direct observation.

Until our knowledge improves, we expect only modest additional progress in the development of bottom trawls to reduce catches of cod. In this paper, we describe four research challenges and directions necessary to speed innovation and development and guide future research at this critical moment in the conservation and harvest of this iconic species. Our goal is to trumpet the need for new research effort, to rethink existing efforts, and to facilitate the continued development of selective bottom trawls designed to reduce catches of cod. We do not provide a full review of cod behaviour, their sensory capabilities, or their response to a bottom trawl, but instead flag and support the need to improve our knowledge and to highlight key areas that require attention. We also seek to stimulate discussion and debate, with the hope of increasing the pace of learning and knowledge of cod behaviour.

Research challenges and directions

1) Further limiting of cod bycatch should emphasize avoidance, and thus modification at the front of the net.

Minimizing the entry of unwanted species in a bottom trawl has been encouraged for many years (e.g. Walsh *et al.*, 2004; Suuronen, 2005), but most attempts to limit catches of these species are designed to facilitate their escape only after they have entered the trawl mouth. A short, non-comprehensive list of examples of this approach includes the addition of larger meshes in the top panel (sheet) of the trawl; grids, square-mesh escape windows, or separator panels in the extension piece; and variation in codend mesh size or orientation (see Catchpole and Revill, 2008; Madsen and Valentinsson, 2010; Winger *et al.*, 2010). These modifications rely heavily on mechanical filtering of unwanted fish from the trawl by size, yet they often achieve the incomplete reduction of these fish or excessive reductions in the target species (Madsen and Valentinsson, 2010) and can be at risk of clogging or blockage. Recent trends in strategies to reduce catches of cod in bottom trawls have employed complex methods of in-net selection, for example, by intentionally stimulating cod escape reactions inside the trawl (e.g. Melli *et al.*, 2019a) or by using multiple devices or modifications (Cosgrove *et al.*, 2019; Melli *et al.*, 2019b). Reviews of these and other options to reduce catches of unwanted species are available in Isaksen & Valdemarsen (1994), Graham (2010), and Kennelly and Broadhurst (2021).

In the New England multispecies flatfish fishery, we recently developed two highly modified bottom trawls and achieved approximately 50% reductions in cod in comparison to a standard bottom trawl (see Eayrs *et al.*, 2017, 2020). Both trawls were intended to limit the capture of cod by allowing their rising behaviour over the trawl headline. One was a so-called topless trawl with a headline 71% longer than the groundline (Eayrs *et al.*, 2017), and the other was an ultra-low-opening-trawl (ULOT) with a headline 8% longer than the groundline and a vertical opening of only 0.6 m (Eayrs *et al.*, 2020). Both trawls are currently the most effective gear-based solutions to reduce bycatch of cod in this fishery, and the ULOT is being taken up voluntarily by an increasing number of fishers, perhaps in part due to design simplicity and ease of handling. These two trawls also join other recent examples of modification at or before the trawl mouth designed to facilitate fish escape, such as elevating the sweeps (e.g. Rose *et al.*, 2010; Sistiaga *et al.*, 2015) or the footrope (e.g. Krag *et al.*, 2010) to discourage herding behaviour, attaching flexible material to trawl doors, clumps or ground gear to stimulate avoidance from the approaching trawl net (e.g. McHugh *et al.*, 2015; Melli *et al.*, 2018, 2019c, 2020), and very large meshes at the trawl mouth (Beutel *et al.*, 2008) or other varieties of topless trawls (e.g. He *et al.*, 2007; Krag *et al.*, 2015).

The avoidance of a bottom trawl by cod is a preferred outcome rather than taking steps to retroactively exclude them from inside the trawl. Avoidance reduces swimming time under pursuit and consequent fatigue, injury from contact with netting or other fish, stress from concentration with other fish, and likely reduces any subsequent loss of fitness or mortality (Cook *et al.*, 2019). Our understanding of escape also suggests that fish exit the codend disproportionally during the trawl retrieval process, and are subject to additional stressors from temperature gradients, displacement from habitat, and barotrauma, that may also lead to unobserved injury, delayed mortality, or increased risk of predation (Madsen *et al.*, 2008; Grimaldo *et al.*, 2009; Pol, 2017). Any reduction in mortalities resulting from prioritizing avoidance over exclusion makes a contribution, however minor, to the health of cod stocks. Emphasizing avoidance may also lead to simpler gear modifications, such as the ULOT, which may facilitate their use and uptake by commercial fishers.

2) Further improvements in cod avoidance will come from direct observation and further investigation into cod behaviour during the capture process.

Our ability to effectively reduce catches of cod in a bottom trawl is hindered by insufficient knowledge of their behaviour during the capture process. Furthermore, research and writings of cod behaviour that were revolutionary and useful in the past now seem less useful, and it is time we developed a more sophisticated and nuanced understanding of their behaviour in response to a bottom trawl.

As examples, the descriptions of cod and other fish behaviour by Wardle (1977) and Main and Sangster (1981a) are still universally considered valid and helpful and are frequently referenced in the literature. Each provides an account of fish behaviour in response to a bottom trawl, supported by direct observation and interpretation of fish behaviour. The description by Wardle (1977), including fish response to approaching trawl boards, sweeps, bridles, and ground gear, has been pivotal to our general understanding of fish behaviour during capture in a bottom trawl. It also posited how fish capabilities such as visual range and swimming ability influence response to the approaching bottom trawl. Main and Sangster (1981a) famously observed and ascribed rising or non-rising behavioural tendencies to cod, whiting (*Merluccius merluccus*), and haddock (*Melanogrammus aeglefinus*) in the mouth of a bottom trawl. Cod was described as remaining close to the seabed and swimming ahead of the approaching trawl, and then simply entering the trawl mouth. In contrast, haddock was described swimming further ahead of the trawl mouth, then rising upwards, presumably in an attempt to avoid capture. Like Wardle (1977), these descriptions were novel at the time and foundational to our knowledge of fish response to a bottom trawl. They were also doubtlessly instrumental in guiding the successful development of horizontal separator trawls that reduce cod bycatch in multispecies trawl fisheries (e.g. Main and Sangster, 1982; He *et al.*, 2008), and trawls with large meshes at the mouth and wings of the trawl such as the "Eliminator" trawl (Beutel *et al.*, 2008).

However, notwithstanding these successes, the work by Wardle (1977) and Main and Sangster (1981a) has limitations that are rarely noted or acknowledged, despite important caveats by the authors included in their texts. For example, Wardle readily acknowledged the limits of his observations, saying they were challenged by a need for "…chance observation of a variety of fish species and sizes, and these are needed in a variety of different water conditions" (Wardle, 1988). Indeed, Wardle's work was based primarily on qualitative observations limited by time and place, and in mainly shallow, clear waters suitable for daylight camera operation by scuba divers or remotely controlled underwater vehicles. Similarly, Main and Sangster, (1981a, 1981b) cautioned that their observations were "casual" and that only relatively few numbers of "isolated individuals" not in "large aggregations" were observed. Despite their caveats, however, their observations have seemingly gained over time the status of proven fact, and their observation that cod stay low in the mouth of a bottom trawl has become an aspect of cod behaviour that is widely considered doctrinal. As perhaps a consequence of this status, consideration that they may swim anywhere other than close to the bottom of the trawl as they approach the codend, including rising as they swim over the ground gear and associated sand cloud, has been relatively limited. Subsequently, we assert that while the contributions from by Wardle (1977) and Main and Sangster (1981a) have been and continue to be helpful and useful, they have been accepted too uncritically (we are guilty of this ourselves), and we contend that this acceptance is due primarily to insufficient persuasive and countervailing direct observations.

This overreliance on these classic publications, and generally on a limited amount of observations, has, in our view, slowed the development of bottom-trawl modifications designed specifically to limit catches of cod. However, relatively recently a small number of researchers has challenged the prevailing wisdom. For example, Thomsen (1993) observed and quantified cod swimming low over the groundgear of a bottom trawl but then rising as they pass through the trawl body and approach the codend. This knowledge, although contradicting what was previously "known" about cod behaviour, led to new developments in bottom-trawl design by Pol *et al.* (2003), Chosid *et al.* (2008), Eayrs *et al.* (2017), and Krag *et al.* (2010) to reduce catches of cod using a topless trawl, and by Ingólfsson *et al.* (2019) to achieve the same outcome using a demersal seine with a height of 0.6 m (interestingly, the same nominal height of the recently developed ULOT by Eayrs *et al.* (2020)). Furthermore, in a meta-analysis of separator-trawl research by Fryer *et al.* (2016), an increasing percentage of cod in the upper codend was reported as the horizontal distance (layback) between the separator panel and the footrope was increased, clear evidence that cod will rise given the opportunity in a trawl. The evidence that some, most, or all cod rise in front of a bottom trawl is now persuasive, although not fully acknowledged.

The historic and widespread use of the models by Wardle (1977) and Main and Sangster (1981a) illustrates the extremely high influence that any direct observations of fish behaviour, even if limited, can have on the development of a bottom trawl. The successful application of topless and low opening trawls to reduce catches of cod demonstrates the importance and value of acquiring more direct observations to test doctrines developed from limited observations several decades ago. The logical conclusion of this outcome is that directly observed cod behaviour, in varied ambient conditions and over longer time periods, will lead to further developments and breakthroughs in limiting and avoiding their catch in a bottom trawl.

3) Interpretation of the behaviour of cod must accompany descriptions of trawl gear studies, irrespective of the success or failure of gear modifications.

Behavioural explanations for the catch resulting from any trawl gear studies, including the use of a modified trawl or selectivity device, must be attempted when reporting study outcomes. We read, review, and otherwise see many reports and manuscripts where the results of trawl modification are presented as a statistical result only and remain uninterpreted in a behavioural context. Attempting a behavioural interpretation of results dramatically increases the value of study outcomes if including this context.

While we have at times been guilty of omitting behavioural interpretations, we have committed to explaining future results with reference to fish behaviour, and we encourage others to do likewise. Providing a behavioural context informs and explains the success or otherwise of a study and provides direction for future investigations to improve study outcomes. It also helps support broader applicability and relevance in other fisheries, and, it may provide a justification for concentrating future investigation on a particular aspect of a fishing operation or fishing gear component.

One primary impediment to quantitative behavioural interpretations is a lack of a widely accepted clear nomenclature to categorize, describe, or infer fish behaviour and response to trawl stimuli. The absence of agreed nomenclature encourages re-invention and inconsistent descriptions of fish behaviour, thus hampering both our understanding and progress towards improved bottom trawl design and selectivity. For example, Walsh and Hickey (1993) described fish swimming behaviour in terms of *cruising swimming*, *startled swimming*, *resting on bottom*, and *behaviour unknown*. Later, He *et al.* (2008) developed new terminology, describing fish behaviour in terms of *vertical position* in the water column, *change in vertical position*, *heading*, *change in heading*, and *other behaviour*. Piasente *et al.* (2004), Jones *et al.* (2008), and Yanase *et al.* (2009) described their observations in terms of events (either discrete or instantaneous actions), states (continuous actions of a relatively long duration), duration of each action, and initial orientation of each observed fish relative to the towing direction. They were then able to provide relatively comprehensive and improved descriptions of observed behaviour that significantly enhanced their understanding of fish behaviour and trawl design. Recently, Underwood *et al.* (2015) enhanced this approach by describing the initial and secondary behaviour of fish and their response to fishing gear, although their classification of behaviour included new terminology such as *pass under*, *hop*, *rise*, *run*, and *slope*. The lack of consistent terminology inhibits the power of comparison across studies and inhibits a broader sense of progress towards understanding fish behaviour more fully. What is clearly needed is a more standardized approach to the description of fish behaviour, and this standardization, perhaps developed through international collaboration, must rely on behavioural expertise and practical experience. The call for this requirement in fisheries research is unfortunately not new (e.g. Fernö, 1993).

Frequently, interpretation of catch results in a trawl gear study is supported by capturing images of cod (and other fish) in response to trawl stimuli. Methods to capture these images have become less expensive and time intensive with the development of digital high-definition cameras with high-resolution video. As noted above, we must maximally exploit these tools to observe cod interacting with a trawl. Multiple simultaneous views are now possible, generating new views of gear modifications and fish reactions to them. Frequently, however, researchers report the collection of video and other images during a study but only interpret this information qualitatively, if at all, perhaps because the video is intended to document gear behaviour, not fish behaviour. It may also be due to concerns over the potential confounding effects of cameras and artificial lighting. Nevertheless, after collecting video, relatively simple, albeit labour intensive reviews can be used to produce quantitative analyses of behaviour using standard software (e.g. Adobe Premiere, Adobe, Inc.; Final Cut Pro, Apple, Inc.; Chosid *et al.*, 2012; Bayse *et al.*, 2014). Free, readily accessible open-source video analytical tools (e.g. Viame, Kitware, Inc.; ImageJ, US National Institutes of Health, Bethesda, MD) are also available to help review, observe, categorize, and quantify behaviours of cod and other fish.

Interpretation of catch results in bottom trawl studies has benefited from improved computer power and software that have increased modeling opportunities and capabilities. For example, analyses modeling consecutive selection processes (e.g. multiple grids) during capture can be used to infer behaviour and responses of fish (e.g. Sistiaga *et al.*, 2010). However, some undesirable tendencies have developed with this greater power. It is now relatively easy to analyse catch data, particularly length-based results, with multiple statistical distributions and higher order polynomials, but a tendency has arisen to include too much flexibility and unrealistic distributional shapes in the pool of possible models ("candidate models") without reasonable justification. It is our view that model choice must consider behaviours, reactions, or biological and other physical processes, or what Fryer and Shepherd (1996) called "structural models." Large departures from, for example, the logistic, or "S-shaped" curves in most size selectivity models are not likely to be structural, no matter what empirical data or quantitative model assessments might yield. Furthermore, fitting data with unrealistic models based on strict adherence to AIC values can lead to an unrealistic interpretation of results that lack credibility and are unhelpful to subsequent studies. Stronger consideration of the value of simpler or more parsimonious (Raykov and Marcoulides, 1999) models is therefore encouraged because we expect that the underlying processes, such as selectivities in catch comparison studies, should be describable with a small number of terms (Holst and Revill, 2009). Simpler models also logically facilitate understanding in managers, fishers, and others. Indeed, the motivation for creating models is to simplify understanding of complex processes. At the very least, clarity and detail in both choices of candidate models and model selection criteria when publishing the findings of a study is necessary for readers, reviewers, and editors to consider and to evaluate.

4) New opportunities for limiting catches of cod in a bottom trawl will be found by expanding research on the behavioural and sensory capabilities of cod.

All fish react to environmental stimuli based on their physiological capability, and the likelihood or extent of their reaction may be influenced by a multitude of factors including their size, health, motivational state, developmental history, physiological limits, and prior experience, as well as environmental conditions and presence and number of conspecifics, predators, and prey (Popper and Carlson, 1998; Godø, *et al.*, 1999). While the individual sensory and behavioural capabilities of some fish species in specific circumstances have been relatively well documented, a thorough understanding of their behaviour and response to a bottom trawl is lacking and our ability to optimally apply these findings is compromised. For example, the behaviour and sensory capability of cod have been more widely studied than just about all other commercially important marine fish species, but we still cannot confidently and repeatedly predict how they will respond to the various stimuli produced by a bottom trawl, let alone how this behaviour may change over time and space or between individuals. Even when we do observe them, we cannot be certain how the presence of cameras and artificial illumination influences their behaviour.

Most gear modifications intended to reduce cod catches rely on cod perceiving the modification through sight and reacting to it by swimming. These two abilities have been investigated over the years, but not to the degree currently needed. Several researchers have documented the well-developed ability and adaptability of cod vision (Anthony, 1981; Anthony and Hawkins, 1983; Meager, *et al.*, 2010), and study of their swimming ability dates back at least 5 decades (Beamish, 1966). The effects of temperature on swimming speed and endurance (e.g. He, 1993; Winger *et al.*, 2010), condition (Martínez *et al.*, 2003), and size (He and Wardle, 1988) are reasonably well known, although persistent individual variation in cod endurance across conditions has been demonstrated (Martínez, *et al.*, 2002; Martínez, 2004). Ideally, we would follow the example of Wardle (1977, 1986) and seek to understand how the limits of fish vision and swimming performance play a central role in their catchability. Other researchers have used this knowledge to gain better understanding of how light intensity and contrasting materials influence fish swimming and response to a bottom trawl (e.g. Bridger, 1968; Dickson and Engås, 1989; Glass and

Wardle, 1989, 1995; Winger *et al.*, 2010), but clearly more work needs to be done.

One sense that possibly presents an unexploited opportunity for encouraging avoidance by cod is hearing. The auditory capabilities of cod (see Sierra-Flores *et al.*, 2015), as well as other fish (see Hawkins, 1986; Yan *et al.*, 2010; Popper *et al.*, 2019) have been reasonably well studied. Cod produce and react to sound during courtship activity (Hawkins and Rasmussen, 1978), egg production (Sierra-Flores *et al.*, 2015), and feeding (Bjornsson *et al.*, 2018), and they can directionalize sound sources (Hawkins and Popper, 2018). Cod can also sense an approaching bottom trawl at a range of 1–3 km, perhaps by hearing the ultrasonic transmissions of echo sounders or other sounds generated by the trawl itself (Buerkle, 1977; Engås, 1994; De Robertis and Handegard, 2013). They are also known to display agitation when bottom trawlers are operating nearby (Kiselev, 1968; Engås, *et al.,* 1991), although their agitation clearly does not necessarily result in their avoidance of the bottom trawl.

To date, however, our ability to exploit this knowledge is poor. Ben-Tuvia and Dickson (1968) posited quite some time ago the deliberate use of sound to influence the catchability of fish to fishing gear, but the interplay between sound and fish behaviour clearly still requires further investigation (Putland *et al.*, 2019). It also remains to be seen if auditory bycatch reduction devices, perhaps using a frequency or pitch similar to that of a predatory species, can successfully be developed to elicit cod avoidance behaviour in response to an approaching trawl.

The influence of motivation and learning on cod behaviour is also poorly understood, including how they trade off competing demands such as a need to find prey against a need to escape predation. Evaluating how cod respond to and are motivated by these demands is challenged by the confounding influence of extrinsic factors such as water temperature and light intensity, and the presence of predators and other prey species. The influence of environmental variables suggests that laboratory experiments where these factors can be controlled and regulated may be the only way to investigate how they influence cod motivation and behaviour. A controlled laboratory environment would also allow investigation into the influence of learning on cod behaviour; notably, models of fish behaviour typically assume that conspecifics react similarly and that all individuals are naïve when they encounter a bottom trawl (Winger *et al.*, 2010).

In the past, a significant infrastructure existed to assist research into the behaviour and capabilities of cod and other fish, including their response to a bottom trawl. This infrastructure included holding tanks and laboratories, and their use helped realize significant developments in our understanding of fish behaviour across the globe, from Scotland to Japan and beyond. Unfortunately, in most instances, this infrastructure is now under-utilized, unused, or has been repurposed, and much of the knowledge and experience in using this infrastructure has similarly been lost or has moved on. We believe, however, that a need for this infrastructure remains and is necessary to progress our knowledge and understanding of cod behaviour under controlled conditions. This information can then serve as a foundation for designing new fishing gear or modifying existing gear to avoid, eliminate, or limit catches of cod (or other species). It can also help inform the results of at-sea observations of fish behaviour and the catching efficiency of fishing gear under a variety of operating conditions, which may challenge the physical and technical thresholds of underwater video or acoustic equipment. We recognize that the infrastructure and staff needed to return to this capability is substantial and expensive, however, a healthier future for the iconic cod and other species should be a significant motivating factor.

Conclusion

Our appraisal of the state of knowledge of cod behaviour has clarified to us two overarching concerns. First, that modification of bottom trawls through trial-and-error alone is insufficient to adequately protect overfished cod stocks, and second, that our knowledge of cod behaviour, their sensory capabilities, and responses to a bottom trawl, and how these vary over time and space, are dated, limited, and inadequate to guide greater reductions in catches of this species.

The effort and measures needed to further reduce unwanted catches of weak cod stocks are daunting. The four research challenges described above collectively call for a renewed commitment by fishing gear technologists and fish behaviourists to documenting, understanding, and interpreting cod behaviour in response to a bottom trawl. The costs to achieve this outcome will be high, but the rewards will be higher—with hope, sustainable landings of cod and its conservation and preservation. And to reiterate, our purpose is to stress a need for further research, not to denigrate or challenge the legitimacy of earlier efforts to study cod behaviour. These earlier efforts are an essential starting point and foundation.

The avoidance or separation of cod early in the trawl capture process relies more heavily upon knowledge of their behaviour, capabilities, and responses than later separation or exclusion from inside the trawl. The benefits of avoidance are seemingly obvious and substantial, and as has been recently demonstrated, can be achieved using relatively simple, cost-effective trawl designs. Furthermore, devices such as excluder grids and separator panels that operate later in the capture process have rarely been accepted voluntarily by fishers due to perceptions they are complex, difficult to handle, and have high potential for catch loss, factors that may contribute to the rarity of voluntary adoption of fishing gear developed and tested by researchers by the fishing industry (Catchpole and Revill, 2008; Eayrs *et al.*, 2015; Eayrs and Pol, 2019).

Logically, the more we understand the behavioural and sensory capabilities of cod the greater our ability to design a bottom trawl to reduce their catch when unwanted. However, we may also not need to look far to gain new insights, as decades of grey literature, non-significant, or insufficiently novel results could be mined for observations of cod behaviour. We, like many of our contemporaries, have over the years collected hours of video on cod behaviour which typically has only been analyzed qualitatively if at all. Often poorly catalogued and largely unshared, this video represents a marvelous opportunity for mining to expand our knowledge of cod behaviour. Also, recent advances in acoustic and low-light cameras and LED lighting provide a great opportunity to collect more observations of cod behaviour (ICES, 2018; ICES, 2019), and the increased application of advanced tagging techniques, sonars, and other acoustic equipment, where applicable, to improve our understanding remains to be fully realized.

Fish behaviourists can greatly assist fishing gear technologists with less behavioural training by developing standards for describing behaviours and responses to trawl stimuli. We support the recent call by Popper *et al.* (2019) for consistency and credibility across studies, including the application of standardized best practice when studying fish hearing and other senses, as well as consistency in descriptions of behavioural observations. We call on all of us to monitor relevant behavioural journals, and on the community of fish behaviourists and others with relevant training and experience to provide leadership and guidance in this area. And while we have concentrated on the behaviour of cod because of its iconic status and importance, our concerns and suggestions expressed here also apply to less-studied target and non-target species, including where this knowledge could be leveraged to help retain these species while avoiding cod.

The principles and ideas we have expressed here could be extended to all fish in the capture process. But it is cod that is of particular cultural and economic value, and that is so widely and seriously at risk. While much of what we have said here has been written before, sometimes decades ago, the urgency to act is now much greater. Current and traditional methods to limit landings of cod in bottom-trawl fisheries may have reached a stopping point, yet sustaining cod, and fishing for cod, demands greater success than previously achieved. We must therefore dedicate ourselves to a greater understanding of their behaviour and sensory capabilities, otherwise increasingly stringent regulations, including loss of access to fishing grounds and other species in the fishery, will be the cost of failure.

Data availability statement

No new data were generated or analysed in support of this research.

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