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OPINION PIECE

We can reduce the impact of scientific trawling on marine ecosystems

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ABSTRACT: The negative impacts that scientific monitoring may have on marine ecosystems has been a neglected topic, mainly on the basis that its magnitude is minor compared to commercial fisheries, even though this raises ethical and, in certain cases, conservation issues. We argue that ethical principles should lead us to reconsider marine wildlife resource monitoring such as the fish and shellfish trawl surveys providing the science-based evidence needed for fisheries management and assessment of how environmental change affects marine shelf communities worldwide. Recent scientific and technological progress has provided methods and tools which might now be harnessed to reduce the impact of marine monitoring. We review these alternative methods, consider modifications to current practices and identify areas requiring further research.

KEY WORDS: Monitoring ethics · Marine surveying · Impacts of bottom trawling · Genetic methods · Ecosystem-based management

1. ETHICS OF MONITORING

Ethics deal with the moral principles that govern human behaviour in general or the conduct of a specific activity. Concerning marine living resources, ethics have been discussed in the scientific literature primarily with respect to wild-capture fisheries (Lam & Pitcher 2012). A central issue of fishery ethics is fish welfare (Evans 2009, Metcalfe 2009, Diggles et al. 2011) as well as the social and wider ecosystem welfare (Lam & Pitcher 2012). A much debated question in this context is whether or not fish can feel pain (Braithwaite 2010, Rose et al. 2014). The answer to this question determines acceptable human behaviour in particular from a consequentialist ethical point of view (consequentialism argues that the moral value of an action derives entirely from the value of its outcome). A discussion of ethics with respect to fisheries monitoring has not yet taken place.

Monitoring of living marine resources is an integral part of sustainable fisheries and ecosystem-based management. While the biodiversity, biomass extraction and sea floor impacts of many monitoring methods are, arguably, relatively minor compared to commercial fisheries, we need to consider whether the potential impacts are justified and unavoidable. We fully agree with Costello et al. (2016, p. 268) that 'scientific methods should minimise disturbance and stress to biodiversity, and any impacts should be explicitly justified'. Thus while from a consequentialist ethical point of view the ends, i.e. fisheries management and assessment of how environmental change impacts marine shelf communities, might justify the means, i.e. trawl surveys, we argue that we should reduce monitoring impacts, if we can, without compromising the aims. The issue becomes acute if we acknowledge intrinsic rights (wellbeing, autonomy, justice) for all living beings, including animals.

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2. MONITORING METHODS: TRAWLING AND ALTERNATIVES

Regular, large-scale scientific bottom trawl surveys underpin both stock assessments and the monitoring of the effects of fishing and environmental change on marine shelf communities worldwide (Fig. 1). Similarly, many acoustic surveys use midwater trawling for species identification and size measurements. While certain species can survive hauling on board and subsequent return to the sea, many do not survive this treatment. In addition to killing many individuals, scientific trawling has a number of other potentially negative impacts on the marine ecosystem (Table 1). Realised impacts will, of course, depend on the actual survey protocol.

Recent scientific and technological progress has provided methods and tools which might help to make marine monitoring less harmful by reducing the need for bottom and mid-water trawling or providing ways for modifying trawling protocols. Below we review some of these alternative methods and practices and highlight areas requiring further research, but do not consider costs.

Visual methods are non-lethal and generally do not damage the habitat (see review by Mallet & Pelletier 2014). They have proven useful for monitoring areas with high population densities such as coral reefs, mussel beds and *Nephrops norvegicus* burrows, or habitats with sufficiently clear water. Recently, visual methods have been successfully applied to monitor midwater pelagic fish (Boldt et al. 2018). In shallow waters, videos obtained from drones (unmanned aerial vehicles) have been used (Kiszka et al. 2016). Aerial surveys are routinely used to count juvenile Atlantic bluefin tuna (Bauer et al. 2015). However, visual methods suffer from drawbacks compared to trawl sampling, including lower taxonomic resolution, restriction to clear water and small sampling volume, which makes the methods best suited for sessile species or those with limited mobility, highly dense species and relatively small survey areas (Table 1). Recent progress applying automatic image analysis for counting and classifying fish species using deep learning techniques shows promise for the increased, routine use of visual methods as automatic analysis overcomes time-consuming manual video analysis (Siddiqui et al. 2018).

Fisheries acoustics offer the advantage of sampling a relatively large volume of water while generally requiring a relatively modest amount of fish sampling to ground truth species composition and fish length, and

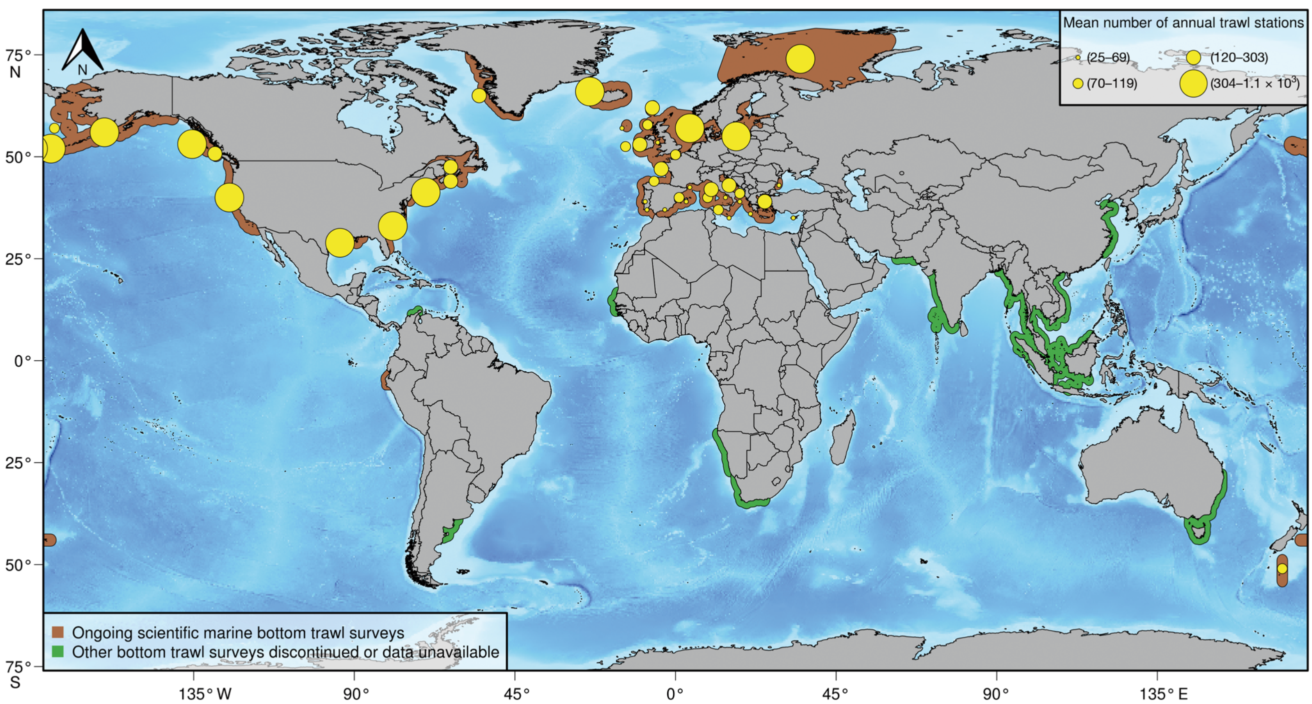

Fig. 1. Overview of locations and intensity of major regular ongoing scientific marine bottom trawl surveys for fisheries management. Yellow bubble diameter is proportional to the mean number of annual trawl stations (for details see Table S1 in the Supplement at www.int-res.com/articles/suppl/m609p277_supp.xlsx). Brown shading identifies coastline and areas of these surveys instead of actual survey areas. Green shading identifies coastline and areas of other trawl surveys, stopped, discontinued or data unavailable. The map background represents the world bathymetry extract from Etopo1 (Amante & Eakins 2009)

Table 1. Overview of observation methods potentially useable for monitoring marine living resources, and their impacts (non-exhaustive list). For trawling, research needs concern ways for reducing impacts while for all other methods, the progress needed to use the method to replace trawling is listed

Observation method	Type of information	Target species	Cause of impacts	Research needs
Trawling	By species • Abundance/biomass • Diet • Individual traits (size, sex, maturity, age, etc.)	• Demersal fishes & invertebrates • Benthic fishes & invertebrates • Pelagic fishes	• Animal handling • Mortality • Habitat modification • Lost gear material • Vessel (noise, greenhouse gas emission, etc.)	• Optimal survey design to reduce trawl duration/catches • On board catch handling procedure to increase survival • Trawl rigging modifications to reduce habitat impact • Trawl material to reduce plastic pollution
Video/photo	By species/group • Abundance/biomass • Size (e.g. stereo method)	• Demersal fishes & invertebrates • Benthic fishes & invertebrates in clear water and small survey area or at high density	• Animal reaction behaviour • Platform (noise, greenhouse gas emission, etc.)	• Optimal survey design/combination of methods to increase survey area and species covered • Estimation of observability/behaviour effects • Automatic image analysis
Acoustics	By 'acoustic' species • Abundance/biomass • Size if species known	• Pelagic fishes • Semi-demersal fishes	• Platform (noise, greenhouse gas emission, etc.)	• Species identification without trawling • Size estimation without trawling
Video trawl	By species/group • Abundance • Size	• Pelagic fishes • Demersal fishes	• Animal herding • Vessel (noise, greenhouse gas emission, etc.)	• Automatic image analysis
Environmental DNA	By location • Number of species	• All species	• Platform (noise, greenhouse gas emission, etc.)	• Development of quantitative DNA approach as abundance proxy
Close-kin mark–recapture	By population • Spawner abundance • Total mortality rate	• Fish & invertebrates, e.g. elasmobranchs	• Tissue sampling method dependent	• Genetic markers for most species • Genetic sex, maturity & age determination

no sampling for deriving a suite of ecosystem indicators (Trenkel et al. 2011). However, fisheries acoustics are often limited to the pelagic realm as they still perform poorly in detecting fish close to the sea floor. Species identification using only acoustic data without trawling has been the focus of research for many decades (Horne 2000). Recent advances in acoustic methodology, in particular broadband techniques, are expected to allow some level of species discrimination without the need for trawl sampling but are unlikely to replace identification hauls for species which are acoustically identical (Bassett et al. 2018). Thus further research and development are needed before routine acoustic surveys can circumvent identification hauls (Table 1).

Other alternative, non-lethal methods have been developed to monitor marine species, but these are not yet routinely used. For example, open-cod-end trawls equipped with video systems show promise for counting and measuring the size of mobile species (e.g. DeCelles et al. 2017). However, fine taxonomical determination of individuals on images and videos is not always possible due low system resolution or the orientation of animals in video images. For some species, the specific morphological details needed for precise identification are not visible. Thus, even though there are restrictions on the taxonomic resolution that can be achieved, existing video-trawl systems effectively sample mobile individuals in the water column as well as near the sea floor. Hence open-cod-end trawls provide an operational alternative to bottom or midwater trawling for many mobile species (Table 1).

For some rarer species where bottom trawl data are used (despite many shortcomings) for providing management advice (e.g. elasmobranch species in European waters), environmental DNA (eDNA)-based methods analysing water samples or sediments might be useful (Kelly et al. 2014). Recent applications of eDNA in aquatic habitats have confirmed the usefulness of this technique for determining species richness (Andruszkiewicz et al. 2017) including its seasonal variation (Sigsgaard et al. 2017), and for obtaining abundance proxies (Thomsen et al. 2016, Klobucar et al. 2017). There are many methodological pitfalls and challenges for eDNA related to sampling (contamination between samples), biomolecular analyses and bioinformatics (species resolution, genotyping errors, inhibition) and temporal and spatial scales (persistence and transport of DNA). However, the field is rapidly advancing, and many issues will continue to be resolved, paving the way for eDNA to replace trawling in certain cases (Table 1). Similarly, DNA barcode analysis is a non-impacting method for estimating diet diversity from faeces (Guillerault et al. 2017).

As an alternative to abundance estimation based on counting animals (trawling, video, etc.), mark–recapture-based methods, notably the recently developed close-kin mark–recapture method using genetic-based identification of related individuals, are promising alternatives for certain commercial species such as sharks, rays or tunas which can be sampled efficiently (Bravington et al. 2016a). The required sample size is proportional to $\sqrt{N}$, where N is the number of adult individuals (Bravington et al. 2016b). Hence the feasibility of the method depends on sampling and genotyping costs. For this method, tissue samples can be collected on-board fishing vessels, or at fish auction markets, avoiding additional mortality through monitoring. In the future, the sex of individuals might also be determinable with appropriate DNA markers. The research needed for making close-kin mark–recapture a viable routine monitoring method concerns primarily the development of species-specific genetic markers, e.g. single-nucleotide polymorphisms (SNPs), and, depending on tissue sampling methods, ways to determine sex, maturity and age (Table 1).

In many cases, dissecting individuals is the only feasible method for determining sex and maturity and, in these instances, non-lethal alternative methods are direly needed. Maturity and sex determination of these species based on blood sample analysis as currently applied to aquaculture and species of conservation concern (Mendoza et al. 2012) might be an option. DNA analysis might also provide indications of animal age, although to date this has only been tested for zebrafish (see review by De Paoli-Iseppi et al. 2017). Applying such methods would be a real step towards reducing trawl monitoring impacts, namely for species of conservation concern such as elasmobranchs or for other species which can be released alive. Obviously, such an approach will do nothing for trawled or otherwise sampled individuals arriving dead or dying rapidly on board. To be useable in a monitoring context where many individuals might be sampled, inexpensive and rapid test kits will need to be developed.

3. REDUCING TRAWLING IMPACTS

To avoid disrupting long trawl survey time series by a change in observation method, improvements in survey design and deployment might exist which could reduce impacts (Table 1). The number of sampling stations (Fig. 1) and swept area/volume per station directly determine the catch volume, hence the potential impact. Higher catch volumes can increase fish injury and subsequent mortality (Veldhuizen et al. 2018). Optimising survey design to reduce the number of hauls or trawl duration are potential options, but before implementing any changes, it would be wise to evaluate potential side effects. Reducing haul duration entails the risk of reducing species richness as well as modifying sampled length and density estimates (Moriarty et al. 2018). The importance of the so called 'end effect' (Battaglia et al. 2006) consisting of individuals caught during shooting and hauling will also be larger in shorter hauls, while the potential for trawl clogging will be reduced. Implementing handling methods that increase survival, such as keeping protected or fragile species in water while on board, should become standard practice on all surveys.

Reducing habitat impacts of scientific trawling is another challenge. The physical impact of bottom trawls depends on the weight and structure of the trawl doors, as well as the use of chains, bobbins and other rigging (Moran & Stephenson 2000). The development of scientific trawl gear can benefit from recent advances of commercial fishing gear (see review by McHugh et al. 2017), as well as alternative catching devices (Table 1). Furthermore, the use of a cod-end closure system could ensure sampling only the intended depth layer instead of the entire water column, limiting the spatial scope of the impact while also improving the precision of the collected data.

Gear drag impacts fuel consumption (McHugh et al. 2017), hence the carbon footprint, of scientific

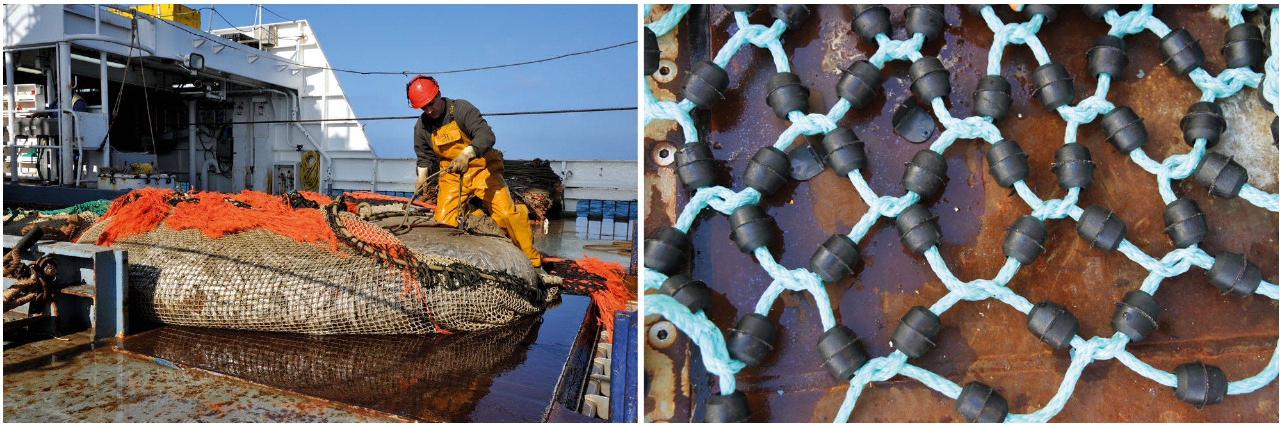

Fig. 2. Onboard RV 'Thalassa' the cod-end protective layer (orange) made of polyethylene twine (left) has been replaced by a rubber mat (right) to reduce plastic fibre pollution. Photo credits: Ifremer/Séverine Tourbot-Paul (left); Ifremer/Vincent Badts (right)

monitoring. Overall, there is likely room for reducing the carbon footprint by restructuring survey vessel fleets. This might be achievable by replacing relatively large multi-disciplinary vessels with a combination of smaller energy-efficient vessels operating in tandem with autonomous platforms and remote sensing. For example, information on school densities and distributions in the upper layers of the ocean could be collected by airborne lidar (Churnside et al. 2011) or drones (Schaub et al. 2018). Optimal ways for combining several monitoring platforms requires further exploration.

Remains from fishing gears contribute significantly to the plastic pollution of the worlds' oceans (Eriksen et al. 2014). To minimise the contribution of monitoring gear to this pollution, the use of robust gear, less prone to releasing plastic material into the environment, or, alternatively, the use of biodegradable gear materiel is an area requiring research, with commercial gear developments already underway (Kim et al. 2016). For example, recently the cod-end protection of the French survey bottom trawl was replaced by a rubber mat to reduce fibre pollution (Fig. 2).

4. CONCLUSION

Ethical considerations led us to comment on potential ways to reduce the impacts of scientific trawling as a method for monitoring living marine resources. As discussed here, this might require large changes, such as replacing survey vessels and observation technology (eDNA, open-cod-end video trawl etc.), but also small, incremental modifications of current practices (reduced trawl duration, biodegradable gear material etc.). The developments made to reduce the impacts of marine monitoring can be expected to yield solutions applicable to fisheries and other marine activities. Lastly, without needing new methods or any changes, including trawl survey catches systematically in total fishing quotas as already done in some countries (e.g. snow crab in Canada) would acknowledge the similarity of scientific and commercial fishing from an ethical point of view.

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