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Assessing the impact of trawling on benthic megafauna: comparative study of video surveys vs. scientific trawling

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Most studies about benthic community use small-scale sampling methods focused on the infauna such as grabs or box-corers. The benthic data collected by scientific trawl surveys in all European waters, in the frame of the Common Fishery Policy Data Collection Multiannual Program, can be used to study the impact of large-scale fisheries such as trawling. However, the catchability of trawls is very dependent on the nature of the seabed as well as resulting ground-gear adaptations. Due to its non-destructive nature and its ability to focus on benthic macro-epifauna, towed video sampling appears to be a good alternative to monitor the impact of trawling on benthic communities. In the present work, we studied the influence of fishery induced seabed abrasion and video characteristics on nine indices, which can be used to monitor the effect of trawling on benthic communities, was studied. Among them, three indices specific to fishery effect detection based on biological traits appeared to be the best performing benthic indices with video data: modified-Trawling Disturbance Index, partial-Trawling Disturbance Index, and modified sensitivity index. The effectiveness of these indices to monitor the effect of trawling was evaluated and compared between trawl and video sampling. This work has highlighted that video sampling could be a good alternative, or at least a complementary method, to scientific trawling to monitor the effect of trawling on benthic communities in European waters.

Keywords: functional sensitivity indices, mega-epifauna, sampling methods, trawling effect, video

Introduction

Dredging and bottom trawling are carried out over large surfaces of the continental shelf and are the main sources of anthropogenic disturbance to seabed habitats (Hiddink *et al.*, 2007; Halpern *et al.*, 2008). However, in Europe, spatial and temporal trawl distributions may be very spatially patchy (Rijnsdorp *et al.*, 1998, 2018) with a footprint of bottom fishing on the continental shelf that varies between 28 and 99% in the management areas of the Northeastern Atlantic and between 57 and 86% in the Mediterranean Sea (Eigaard *et al.*, 2017). Although these values may be over-estimated depending on the data resolution chosen for the assessment, it remains incredibly high over most of the European continental shelves (Amoroso *et al.*, 2018). These fishing methods are known to disturb seabed sediments, damage biogenic structure and, by changing the species composition, affect the structure and the functioning of the benthic communities (Collie *et al.*, 2000; Rumohr and Kujawski, 2000; Thrush and Dayton, 2002; Hiddink *et al.*, 2006, 2017; Rijnsdorp *et al.*, 2018; Sciberras *et al.*, 2018). On any given habitat, modifications of the species composition between trawled and un-trawled area are dependent of the pressure intensity (Jac *et al.*, 2020a) and the sensitivity degree of each benthic species (Hiscock *et al.*, 1999; Borja *et al.*, 2003; Foveau *et al.*, 2017) to trawling pressure.

Most studies evaluating the anthropogenic impacts such as fishing activities on benthic communities use sampling methods such as grabs, box-corers, or dredges which are mainly focused mainly on the infauna (Eleftheriou, 2013; van Loon *et al.*, 2018). Usually, these samplings are conducted with restricted spatial coverage and relatively nearshore (Brind'Amour *et al.*, 2014). To study the impact of fishing activities on a large scale, benthic data from scientific bottom trawl surveys carried out in all European waters in the frame of the Common Fishery Policy Data Collection Multiannual Program seem to be a good alternative (Foveau *et al.*, 2017; Jac *et al.*, 2020a). Nevertheless, all these sampling methods are "destructive" and may have a lasting impact on benthic biodiversity, which, although clearly negligible in comparison to fisheries impacts, should be reduced (Trenkel *et al.*, 2019). In recent years, underwater imagery has been increasingly used to observe megafauna and habitat diversity (Mallet and Pelletier 2014). These methods allow rapid acquisition of a large amount of information on sites that may be difficult to sample (due to depth, seafloor characteristic, or topography) with classic methods (Taormina *et al.*, 2020). In addition, marine imagery is non-destructive (Mallet and Pelletier 2014). Five main techniques were developed to monitor marine biodiversity: remote underwater video (RUV), baited remote underwater video (BRUV), towed video (TOWV), diver-operated video (DOV), and remote operating vehicle imaging (ROV). However, these methods are not applied to assess the same compartments of the marine ecosystem (Brind'Amour *et al.*, 2014). Only DOV, ROV, and TOWV techniques may be deployed to evaluate the abundance of benthic species or to study the benthic substrate/habitat (Rooper and Zimmermann 2007; Cruz *et al.*, 2008; Mallet and Pelletier 2014; Sheehan *et al.*, 2016; Mérillet *et al.*, 2017; Taormina 2019). When using visual census, the quality of data is strongly dependent on environmental conditions (especially turbidity) and image resolution (resulting from technical constraints). This often results in reduced taxonomic identification levels which may decrease the amount and usefulness of the information contained in the resulting data (Flannery and Przeslawski 2015). Notwithstanding these limitations, visual observations enable the production of large amounts of information, whether taxonomical, functional, or environmental, which can be used to assess the ecological status of a site or the effect of certain pressures on a community. The data collected by video sampling may indeed be used to calculate indicators of ecological status or pressures just as well as the data usually derived from classical sampling such as grabs or trawl.

In order to monitor trawling impact on benthic communities, it is necessary to observe changes in the benthic community and particularly in the benthic megafauna, which seems more appropriate than smaller fauna to detect the effect of trawling (McLaverty *et al.*, 2020). Different indices could be used to track the modification of benthic community along the pressure intensity gradient: taxonomic diversity metrics, functional diversity indices, and functional sensitivity indices. The first will provide information on the differences in species richness and their relative dominance, homogeneity or rarity in the community. The two later are based on biological traits sensitive to physical abrasion induced by fishing (size, position, mobility, fragility, feeding mode) and thus provide information on function changes within the benthic community and on changes in sensitive species abundance (in the case of functional diversity indices and functional sensitivity indices). Previous work suggests that indices in the latter category are better suited to monitor the effect of trawling on benthic mega-epifauna (Jac *et al.*, 2020a). Although recent studies have shown the usefulness of indices based on the longevity of benthos (Rijnsdorp *et al.*, 2018; Hiddink *et al.*, 2020), there is too little information existed on the mega-epifauna studied here to use this particular trait.

The aims of this study were to (i) list or determine indices that may detect the effect of trawling on benthic fauna with a towed video sampling method and (ii) compare the ability of two sampling methods (video and trawling) to monitor the impact of fishing on benthic communities on a large scale.

Methods

Surveys

- Each year, several scientific bottom trawl surveys occur in the English Channel and in the Gulf of Lion: the Channel Ground Fish Survey (CGFS; Coppin and Travers-Trolet, 1989), the International Bottom Trawl Survey (IBTS; Auber, 1992) and the Mediterranean International Trawl Surveys (MEDITS; Jadaud *et al.*, 1994).
- In the Gulf of Lion, the sampling gear used in MEDITS, during its yearly June survey, is a four panels' bottom trawl with a 20 mm stretched mesh size at the cod-end. The sampling scheme is stratified by depth evenly distributed over the whole study area. Hauls are carried out during daytime at 3 knots and are 30 min long above 200 m and 60 min long below 200 m (MEDITS, 2017).
- Based on MEDITS protocol but dedicated to the study of the benthic fauna, EPIBENGOL survey (Vaz, 2018a) was carried out in September 2018 in the Gulf of Lion. During this survey, ten stations were sampled with trawl and video.
- In the English Channel, IBTS and CGFS are conducted yearly in January/February and October, respectively. The sampling gear used is a Very High Vertical Opening bottom trawl with a 20 mm stretched mesh size at the cod-end. The sampling is randomly stratified and evenly distributed over the whole study area and hauls are carried out during daytime for 30 minutes at 4 knots (ICES, 2015, 2017).
- Benthic fauna samples, considered as by-catch, were sorted, identified, counted, and weighed. Biomass data were chosen over abundance data because abundance was not estimated for several colonial species such as hydroids or sponges. Data were standardized according to trawling swept area and expressed in g km^{-2}. In this study, only the trawls that could be paired with a co-located video transect were considered.

All the videos used for this study were acquired between 2014 and 2019 in the English Channel during CGFS and IBTS surveys, and between 2016 and 2018 in the Gulf of Lion during EPIBENGOL, VIDEO GALION (Vaz, 2016, 2017), APPEAL MED (Labrune, 2018), and IDEM VIDEO (Vaz, 2018b). For two trawl surveys (EPIBENGOL, CGFS), video transect was carried out just before the trawl haul. After verifying that the trawl's mean position was <2 km away from that of the video transect, they were considered paired with the corresponding video transect. The video transects, collected during dedicated video surveys (VIDEO GALION,

Table 1. Characteristics of paired stations

Study area	Video (year—campaign—device)	Trawl (year—campaign)	Number of video transect paired to trawl	Number of video transect un-paired to trawl
English Channel	2019—CGFS—Pag 2	2019—CGFS	4	–
	2016—CGFS—Pag 2	2016—CGFS	11	–
		2015—CGFS	2	
		2011– CGFS	1	
	2014—IBTS—Pag 1	2015—CGFS	2	2
		2013—CGFS	1	
		2014—CGFS	1	
Gulf of Lion	2018—EPIBENGOL—Pag 2	2018—EPIBENGOL	6	1
	2017—VIDEOGALION—Pag 1	2017—MEDITS	11	–
		2016—MEDITS	3	
	2016—VIDEOGALION—Pag 1	2016—MEDITS	2	–
	2018—APPEAL MED—Pag 2	–	–	2
	2018 - IDEM VIDEO—Pag 1	–	–	3

Pag 1, Pagure 1; Pag 2, Pagure 2.

APPEAL MED, and IDEM VIDEO) or opportunistically during a bottom trawl survey (IBTS), were paired to trawl stations that were both <2 km distant and mostly less than a year apart in time (Table 1). A total of 24 videos in the English Channel and 28 videos in the Gulf of Lion were analysed but only 22 in each area could be paired with trawl stations.

Discrepancies in the number of videos per year and areas resulted from the fact that no dedicated survey could be carried out in the English Channel where the video system had to be deployed opportunistically. In contrast, dedicated surveys could be deployed in the Gulf of Lion. In order to match a video transect with a corresponding trawl haul, an unbalanced design had to be tolerated.

Towed video systems

Two towed video systems were used to carry out video transects of $\sim$500 m length (15 min at maximum 1 kt) in different locations in the Gulf of Lion and the English Channel.

The first device (Pagure 1) was a large stainless steel sled (length: 1500 mm, width: 1700 mm, height: 1250 mm, weight: 340 kg, about 100 kg in water using 272 L floats) equipped with an anodized aluminium housing that can hold a camera (here, a Panasonic HC-V700 or a GoPro Hero 4 or 5), a pair of LED lights (underwater LED SeaLite® Sphere, SLS 5100, 20/36 V, 5000 Lumens or SLS 5150, 20/36 V, 9000 Lumens) fixed on each side of the camera, two laser pointers (SeaLasers® 100 Dualmount, wavelength 532 nm Green) placed 100 mm from each other and two subCtech Li-Ion PowerPacks (25 Ah, 24 V) to power the lights and lasers (Sheehan *et al.*, 2016).

The second device (Pagure 2) is larger (length: 2000 mm, width: 1100 mm, height: 740 mm, weight: 450 kg, 30–100 kg in water using 272–380 l floats depending on currents and bottom hardness). Some equipment was also different between the small device and this larger device: the camera (here, Panasonic HC-V700 or Sony PXW-Z90), four LED lights (a pair of each light listed above) powered by an additional battery (subCtech Li-Ion PowerPack, 70 Ah, 25.2 V).

As the exact position of the video system during the haul was not known, the transect positions were trigonometrically back-calculated using GPS coordinates, vessel bearing and dimensions, sounded depth and towing cable length along the 15 min transect.

Video image analysis

Analyses of the videos were performed image by image with the Avinotes software, specially developed by J.C. Duchêne to annotate video images. Between 700 and up to a maximum of 1200 video frames (approximately half of transect) were analysed depending on video quality. For each transect, a visual evaluation of the image quality was performed with a classification system taking into account parameters related to sledge deployment (system stability and traction speed) and water turbidity (Table 2). A quality score, varying from good (3) to bad (9) image quality, was determined for each video transect by summing up the scores for each parameter.

A visual determination of sediment type (boulders, gravel, mixed sediments, sand, and muds) was also carried out for each video transect.

Using laser pointers materializing a counting window on each image, it was possible to know the surface of the seabed sampled on each image. Special care was taken during the manual creation of this window so that it would not overlap from one image to another and create an overestimation of the sampled surfaces. On each image, all organisms present in the counting window were identified to the highest taxonomic level possible (Figure 1) and their abundance recorded even for colonial species for which the number of colonies was determined. The surface sampled per profile was then determined by multiplying the average area of the counting windows by the number of images analysed. The average areas of the counting window were slightly different between the two towed video system with an average of 1032 cm^2 for the Pagure 1 and 1588 cm^2 for the Pagure 2. Data were standardized according to the average counting window area and expressed in ind m^{-2}. Taxonomically and morphologically similar organisms, like the crinoids *Leptometra* sp. and *Antedon* sp. which could not be distinguished at species or even genus level, were grouped at family level as Antedonidae.

Abrasion and habitat data

The abrasion value at each sampled station (Table 3) of the two studied areas were determined from maps (Figure 2) of swept surface area ratio per year (SAR y^{-1}), based on VMS data (Eigaard *et al.*, 2016; ICES, 2019). To avoid overlooking past impacts and reflect the probably long recovery time needed for

Table 2. Image quality classification parameters and their associated scores

Scores	Moving speed	Stability	Turbidity
1	Constant speed and ∼<1 knot over the entire transect	The camera is correctly oriented (towards the bottom) over at least 1 200 consecutive images.	The entire vision field is clearly visible
2	A few accelerations of the device but the average speed remain around 1 knot.	The camera is correctly oriented for 1 200 non-consecutive images	Far vision field blur and many suspended particles but counting windows can still be analysed
3	Approximately 50% of the transect images are not analysable	The camera is correctly oriented over less than 1 200 images over the entire transect.	Degraded identification and counting conditions in counting windows

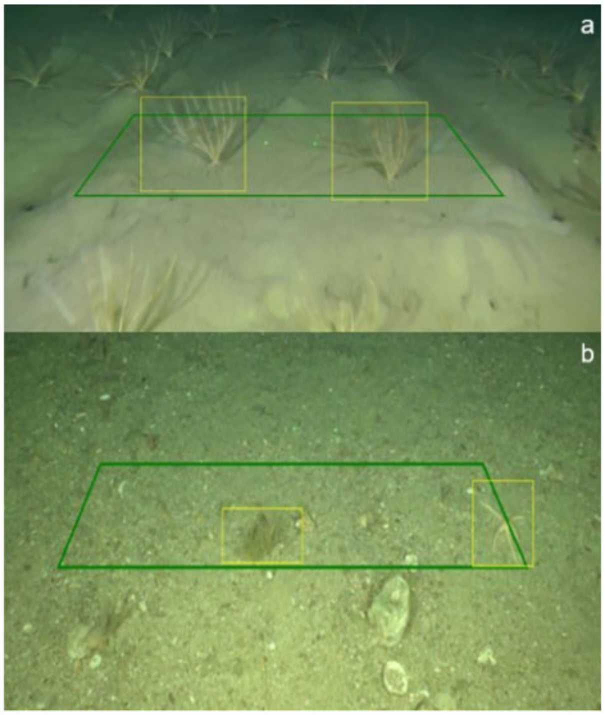

Figure 1. Example of organisms identified and counted in the counting window (green line) with video device. (a) Two individuals of Antedonidae in a sampling area of 1531 cm^2. (b) On the right, a starfish of the genus Henricia and on the left, a colony of hydrozoan, in a sampling area of 2748 cm^2.

Table 3. Abrasion ranges of the sampled stations in the two studied areas

	English Channel	Gulf of Lion
Sampled abrasion range (SAR y^{-1})	0.29–10.92–72.34	0.08–4.65–20.87
Abrasion range (SAR y^{-1}) of paired stations	0.29–8.73–72.34	0.08–4.91–20.87

The three abrasion values represent the minimum value, median and maximum value.

sensitive species, the 90th inter-annual (from 2009 to 2017) percentile of swept surface area ratio was used [as detailed in Jac *et al.* (2020a)]. Using this 90th percentile also allowed to filter out the most extreme values that may be related to measurement or computation errors. These maps' resolutions were different: 3′ × 3′ in the English Channel (www.ospar.org) and 1′ × 1′ in the Gulf of Lion (Jac and Vaz, 2018).

In the Gulf of Lion, the visual determination of sediment type did not reveal different habitats, mainly because of small differences in granulometry that are difficult to observe on video. The different habitat types were therefore defined by EUNIS level 3 (Populus *et al.*, 2017; www.emodnet.eu). Thus, stations were categorized in two habitats: Sublittoral mud (A5.3) which includes the subtidal cohesive sandy muds and Sublittoral mixed sediments (A5.4) which includes a range of sediments, including heterogeneous muddy and gravelly sands (Figure 2).

In the English Channel, the absence of significant variation in depth between the stations allowed this factor to be disregarded in the characterization of sampled habitats. Thus, habitats were categorized, based on the visual definition of sediment type observed, into two classes: coarse or mixed sediments (sediments composed of mud, sand, gravel in variable proportions).

Paired trawl stations were assigned the same habitat types as those determined in video transect as in videos.

Biotic indices

As the spatial pattern of abrasion is not independent of the presence of target species, commercial species (*Homarus gammarus*, *Crangon crangon*, *Maja brachydactyla*, *Pecten maximus*, *Aequipecten opercularis*, *Palaemon serratus*, *Nephrops norvegicus*, *Buccinum undatum*, *Cancer pagurus*, *Aristaeomorpha foliacea*, *Aristeus antennatus*, *Parapeneus longisrostris*, and *Bolinus brandaris*) and cephalopods have been removed from the two datasets.

To reduce misidentification errors, a procedure proposed by Foveau *et al.* (2017) to aggregate uncertain taxa at a higher identification level was applied.

Two types of sensitivity indices were investigated on video data: taxonomic diversity metrics and sensitivity indices specifically constructed to detect impacts on benthic communities. The effect of trawling on the species abundance was also studied.

Four common taxonomic diversity indices were calculated: species richness (SR, the total number of taxon), Shannon diversity (H′; Shannon and Weaver, 1963), Pielou evenness (J′; Pielou, 1969), and Simpson index (λ; Simpson, 1949). The last three are weighted by abundance to assess equitability between species (J′) or give more or less influence to rare species (H′ and λ). These indices were calculated in R, using the vegan 2.5-2 package (Oksanen *et al.*, 2019).

Functional sensitivity indices, based on biological traits, were selected to characterize potential responses of organisms to physical abrasion (de Juan and Demestre, 2012; Bolam *et al.*, 2014;

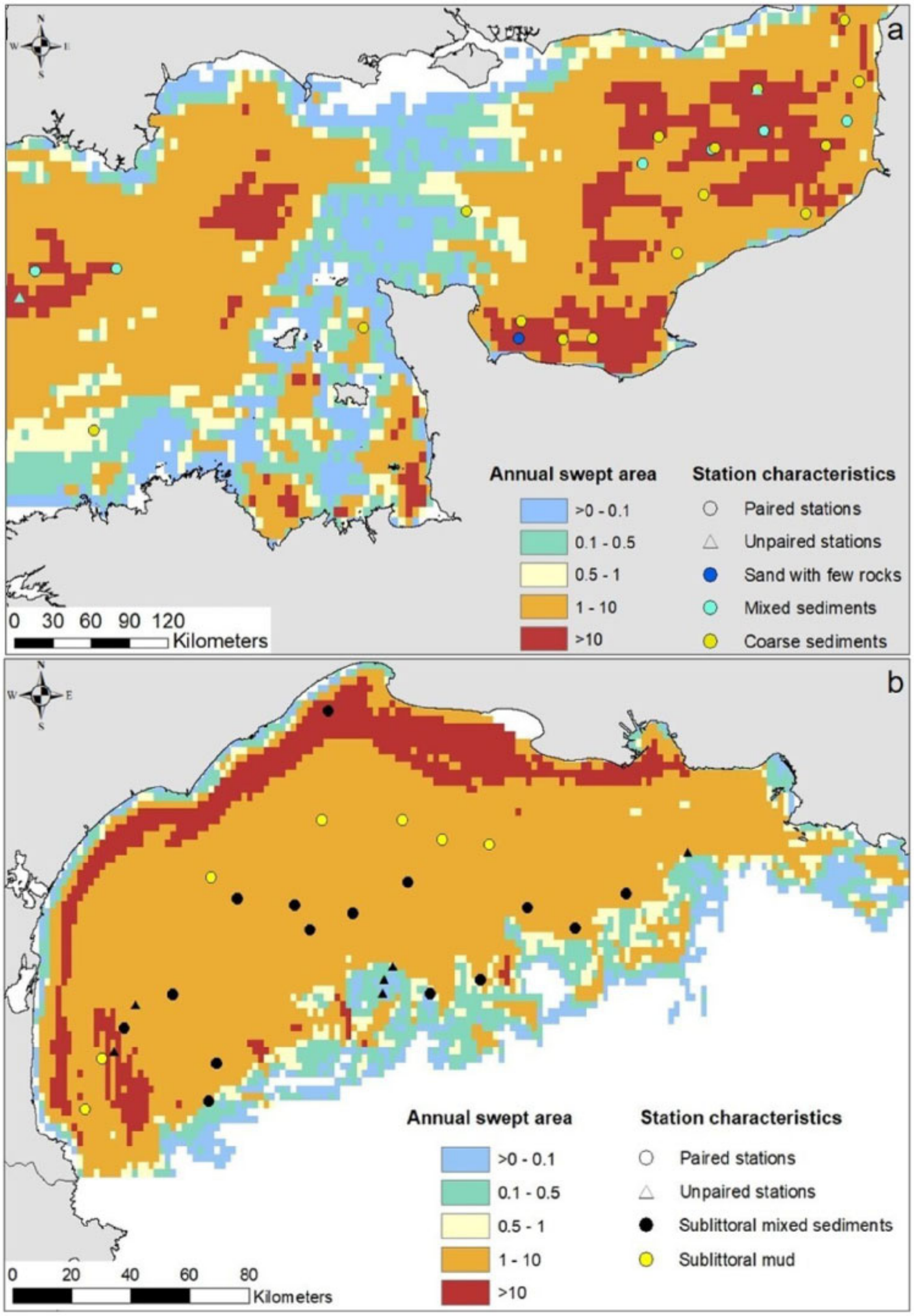

Figure 2. Location and sedimentary characteristics of video stations in the English Channel (a) and in the Gulf of Lion (b). The annual swept area was 90th inter-annual percentile of the abrasion in during the period 2009–2017.

Foveau *et al.*, 2017). These traits are (i) position of organisms in the sediment, (ii) feeding mode, (iii) mobility capacity, (iv) adult size, and (v) fragility of the structure of organisms. Each trait was subdivided into multiple "modalities" to encompass the range of possible attributes of all taxa. To allow quantitative analysis, a score was assigned to each modality, varying from low sensitivity (0) to high sensitivity (3; Table 4). When some taxa had to be aggregated at higher taxonomic level, precautionary principle commended to assign, for each trait, the highest score values (higher sensitivity) observed within that particular taxonomical grouping following the procedure described by Jac *et al.* (2020a,b). The calculated functional sensitive indices were: Trawling Disturbance Index (TDI; de Juan and Demestre 2012), modified TDI (mTDI; Foveau *et al.*, 2017), partial TDI (pTDI; Jac *et al.*, 2020a,b), and the modified Sensitivity Index (mT; Jac *et al.*, 2020a,b). TDI-based indices were developed specifically to detect trawling impact, while mT is issued from a general framework allowing to address any pressure if specific sensitivity

Table 4. Biological sensitivity traits to physical abrasion and associated scores (Foveau *et al.*, 2019; Jac *et al.*, 2020a,b)

Scores	Position in the sediment	Feeding mode	Mobility	Adult size	Fragility
0	Deep burrowing	Scavengers	Highly mobile (swimming)	Small (<5 cm)	Hard shell, burrow, vermiform, regeneration
1	Surface burrowing (first cm)	Deposit feeders/ predators	Mobile (crawling)		Flexible
2	Surface		Sedentary	Medium (5-10 cm)	No protection
3	Emergent	Filter feeders	Sessile (attached)	Large (>10 cm)	Fragile shell/structure

traits are available to detect it. Calculation methods of each of these indices were presented in Supplementary Appendix S1. All indices were calculated with R version 3.5.1 (R Core Team, 2017).

Concerning trawling data, a previous study investigated all the proposed indices and showed that functional sensitivity indices were the most useful to evaluate the impact of trawling on benthic communities (Jac *et al.*, 2020a). Here, we chose to focus only on these indices which are more suited to video data, which were then also calculated using scientific trawl data for comparison purposes.

Data analyses

Indices evaluation and selection for video derived data

To find the most appropriate indices, generalized linear models (GLM) were used to investigate which variables (abrasion, habitat, camera type, device type, and image quality) influenced the indices calculated with video data (using all video data available here). As benthic communities do not respond equally to trawling in different habitats (Kaiser *et al.*, 1998), the interaction between habitat and abrasion was included in GLMs. For each GLM, the variables were selected using forward procedure based on the Akaike Information Criterion using the MASS package 7.3-51.5 (Ripley *et al.*, 2019). The goodness of fit of the model was assessed by performing a χ^2 test between the null and the selected model.

Indices were first retained if no variables related to the video system specification (camera, video system, and image quality) influenced the model. These indices were then selected if the regression coefficient for abrasion was negative and significant.

Comparison between the two sampling methods

To assess the relevance of each of the two sampling methods to monitor the impact of trawling on benthic communities, only paired stations were used for the following analyses.

Community description

For each sampling method in the two study areas, the number of sampled taxa was counted, and the proportion of each taxonomic level was evaluated to better understand the differences in catchability between the two methods (only paired stations used for the following analysis). Underwater video techniques usually allow to observe only large (>5 cm) epifauna (Mérillet *et al.*, 2018). The diversity of biological traits sampled with trawling and video was evaluated by comparing functional spaces of all studied areas. Functional space can be defined as a multidimensional space where the axes are functional traits along which species are placed according to their functional trait values (Mouillot *et al.*, 2013). Thus a Multiple Correspondence Analysis (MCA) was performed in each area on the species-traits matrix, with the package PCAmixdata 3.1 (Chavent *et al.*, 2017) to build a multi-dimensional functional space with axes corresponding to synthetic traits summarizing several raw traits.

In order to identify differences in the structure of the communities sampled with each of the two methods, the proportion of species belonging to the different categories of the trait "Position of organisms in the sediment" was studied. This analysis was not conducted on the other biological traits because the diversity of these traits within the community is unlikely to vary between the two sampling methods.

Monitoring of trawling impact

An assessment of the relevance of each of the sampling methods for monitoring the impact of trawling on benthic communities was carried out using statistical regression and tests (only paired stations were used for the following analyses). In each area and for the two sampling methods, GLM were used to investigate which variables (abrasion and habitat), influenced previously selected indices. Interaction between habitat and abrasion was also included in GLMs. The most significant variables were selected for each GLM using forward procedure based on the Akaike Information Criterion using the MASS package 7.3-51.5 and the goodness of fit of the model was assessed by performing a χ^2 test between the null and the selected model. For each index, the regression coefficient for abrasion and the R^2 values were compared between the different sampling methods to evaluate which is the most appropriate for monitoring trawling impacts on benthic communities.

Results

Indices evaluation and selection for video derived data

All indices considered in this study were not influenced by the same variables even if, in many cases, the habitat effect was significant (Table 5). Characteristics of the video system used (device or camera type and image quality) were selected in models, only for few indices like SR, Shannon, or Abundance. Meanwhile, only sensitivity indices (TDI, mTDI, pTDI, and mT) were significantly influenced by the abrasion. As TDI was also influenced by a variable related to the video system (camera type) which is not a desirable property, it was not selected for further analysis. Graphic representation of relationship between the three selected sensitivity indices and abrasion were performed (Figures 3 and 4).

Differences in the sampled community between the two sampling method

In both study areas and using both sampling devices, it was not always possible to identify the encountered organisms at species level. The total number of taxa therefore indicated the number of different organism types distinguished at the lowest taxonomic level possible. In the English Channel, despite a significantly larger area sampled by trawling than by video (Supplementary

Table 5. Variables retained by the model selection procedure for each index over the totality of the analysed videos (Gulf of Lion and English Channel). Grey shading indicates indices meeting the selection criteria (negative relationship between abrasion and lack of significant relationship to image quality).

Indices	Selected explanatory variables	Regression coefficient for abrasion (and significance level)
SR	∼Device+ Image quality + Habitat + Abrasion	−0.013
Shannon	∼Habitat + Device	–
Simpson	∼Habitat	–
Pielou	∼Habitat	–
Abundance	∼Habitat + Camera + Device	–
TDI	∼Abrasion + Camera	−0.092***
mTDI	∼Abrasion	−1.972***
pTDI	∼Abrasion	−0.036***
mT	∼Abrasion + Habitat	−0.012***

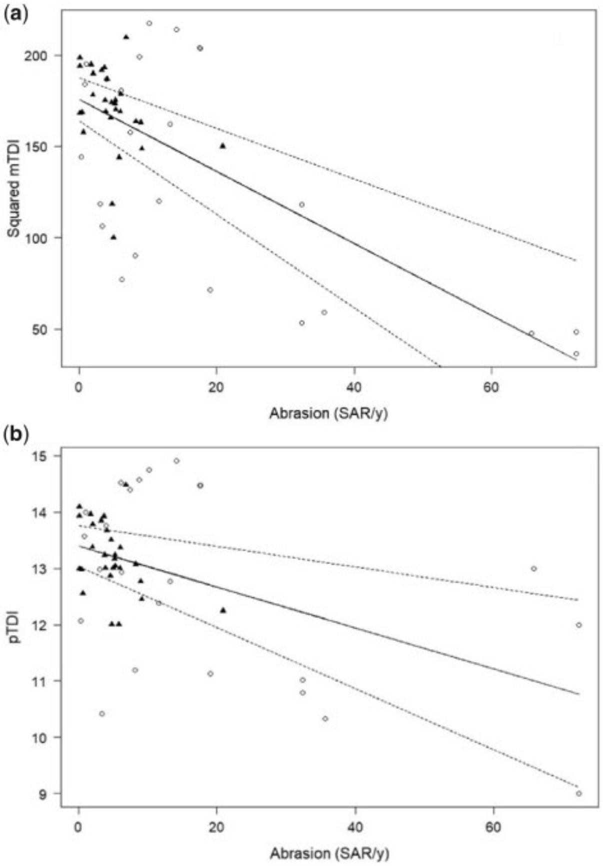

Figure 3. Relationships between fishery abrasion and (a) squared mTDI index and (b) pTDI index in all habitats. The relationship was significant and negative (black line and 95% confidence interval in dashed line) and nohabitat/area influence was detected. ○ Stations in the English Channel; ▲ Stations in the Gulf of Lion.

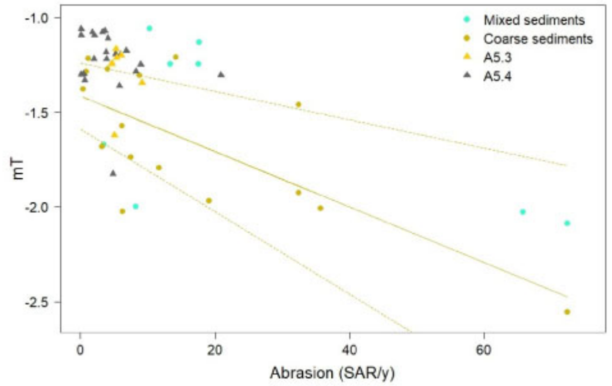

Figure 4. Relationships between mT index and fishery abrasion in all habitats. The relationship was significant and negative only for habitat "Coarse sediments" (gold line and 95% confidence interval in dashed line). ● Stations in the in the English Channel; ▲ Stations in the Gulf of Lion.

Table 6. Number of taxa by sampling method and areas

Taxonomic level	Areas	Trawl	Video
Taxon	English Channel	74	88
	Gulf of Lion	134	39
Species	English Channel	54	50
	Gulf of Lion	92	14
Genus	English Channel	49	57
	Gulf of Lion	96	26
Family	English Channel	44	53
	Gulf of Lion	89	27
Order	English Channel	26	28
	Gulf of Lion	39	19
Phylum	English Channel	8	8
	Gulf of Lion	10	7

Table B.1), a greater number of taxa were observed by video (Table 6). A total of 88 taxa representing 53 families, 28 orders and 8 phyla were observed on video and 74 taxa representing 44 families, 26 orders and 8 phyla were sampled by trawling. Only 29 species were found with both sampling methods.

On the opposite, in the Gulf of Lion, a high number of taxa were collected by trawl with 134 taxa representing 89 families, 39 orders and 10 phyla against 39 taxa representing 27 families, 19 orders and 7 phyla observed on video. Only 19 taxa were common to the two sampling methods.

Looking at the sensitivity of the most represented (>5% of the total abundance or biomass) taxa in terms of biomass or abundance in each area, it appears that these results were very contrasted between the sampling methods (Table 7). Indeed, very few species in video data are considered as non-sensitive while almost half of the species dominating the trawl-collected assemblage

Table 7. Dominant taxa observed with the two sampling methods in the two studied areas and their sensitivity score (SI; Foveau *et al.*, 2019)

Areas	Device	Species	SI
English Channel	Video	*Ophiothrix fragilis*	11
		Mytilus sp.	11
		Sertularia sp.	15
		Psammechinus miliaris	7
		Alcyonium digitatum	15
		Porifera	14
	Trawling	*Asterias rubens*	7
		Psammechinus miliaris	7
		Necora puber	6
		Ophiothrix fragilis	11
		Alcyonium digitatum	15
Gulf of Lion	Video	*Antedon* sp.	13
		Funiculina quadrangularis	14
		Cavernularia pusilla	13
	Trawling	*Gracilechinus acutus*	10
		Parastichopus regalis	12
		Antedon sp.	13
		Funiculina quadrangularis	14
		Liocarcinus depurator	6
		Astropecten irregularis pentacanthus	8

Green shading indicates that the species is considered less sensitive to trawling (SI $\leq$ 7).

were non-sensitive. In the English Channel, three species were dominant in video and trawl data (*Ophiothrix fragilis*, *Psammechinus miliaris*, and *Alcyonium digitatum*). In the Gulf of Lion, the dominant taxa observed by video were Cnidarians (Antedon sp., *Funiculina quadrangularis* and *Cavernularia pusilla*) while the trawl samples were dominated by Echinoderms (*Gracilechinus acutus*, *Parastichopus regalis*, and *Astropecten irregularis pentachanthus*) and Cnidarians (*Antedon* sp. and *Funiculina quadrangularis*).

Despite identification to the species level more frequent by trawl than by video, more than 65% of the taxa were identified to the genus level regardless of the type of sampling (Figure 5a).

The proportion of sampled infauna represents <20% of the sampled taxa regardless of the type of sampling. The main difference observed between trawling and video results from the type of epifauna observed, particularly in the Gulf of Lion (Figure 5b): more than 55% of the fauna observed by video and <35% of that sampled by trawl were erected epifauna (34% in the English Channel and 21% in the Gulf of Lion).

Individuals caught by trawl have a greater functional diversity than those observed on video, particularly in the Gulf of Lion (Figure 6).

In the English Channel, only very few differences are observed between trawl and video sampling functional spaces. However, the dominant taxa were different for each sampling type. For trawling, the assemblage of taxa was dominated by individuals that are small, mobile, living at the surface or in the first few centimetres of sediment, which are not fragile and are mainly scavengers or deposit feeders/predators. For video sampling, the taxon assemblages observed were dominated by sessile individuals, emerging, fragile, and mainly filter feeders, but also by medium-sized and flexible taxa.

In the Gulf of Lion, the trawl caught mostly large, unprotected, sedentary, and burrowing individuals also some sessile, emerging, fragile, and mainly filter feeders while no particular taxa dominance was observed by video. Moreover, highly mobile individuals are totally absent from the videos in this area.

Monitoring of trawling pressure: comparison between the two sampling methods

The comparative analysis of the influence of abrasion and habitat on selected indices computed from both sampling types is presented in the Table 8 for each studied area.

In the Gulf of Lion, whatever the gear used or the index studied, abrasion never seems to significantly influence the index.

In the English Channel, results are more contrasted. For the mTDI, habitat had a significant influence on the index with trawl sampling whereas it was the abrasion that had an influence with video sampling. For pTDI, no significant relationship was observed with habitat or abrasion and in the case of video sampling but habitat had a significant influence on the index when using trawl sampling. Finally, for the mT, the two sampling methods allowed to detect significant relationships to abrasion and the R^2 was higher when using the video derived data.

Discussion

Differences in catchability

In the two geographic areas studied here, although the difference in sampling area between trawl and video was similar, the differences in catchability between the two sampling methods were very different. The number of taxa observed with the video was slightly higher than the taxa caught with the trawl (88 vs. 74) in the English Channel and lower (39 vs. 134) in the Gulf of Lion. Several parameters may explain these differences.

First of all, the higher proportion of infauna in trawl samples collected in the Gulf of Lion can be explained by the sediment type. The Gulf of Lion is characterized by the presence of soft sediments (Populus *et al.*, 2017; www.emodnet.eu), whereas bottoms sampled in the English Channel have a higher granulometry and are sometimes even composed of blocks (Coggan and Diesing 2011). As trawl penetration is lower in coarse sediments than in fine sediments (Eigaard *et al.*, 2016), the gear catchability of the infauna is greater in areas of fine sediments. Reflecting these substrate differences, the trawls used in the English Channel and the Gulf of Lion were different (ICES 2015; MEDITS 2017), which may have increased the difference in the catchability of benthic fauna between these two gears. The gear used in the Gulf of Lion has a greater catchability of infauna than that of English Channel. In contrast, results obtained in the English Channel seem to indicate that in coarse sediment areas, video allows the observation of a greater diversity of species than does the trawl, probably because the trawl catchability of epibenthic species fixed on boulders is relatively low. Finally, the habitat type plays a major role on the species density and occupancy. Epifaunal species number and density were much higher on coarse habitats while it often exhibited overly dispersed distribution on bare soft sediments. This mostly explains the difference in diversity observed between the two areas for comparable surface sampled and also the differences between video and trawled observations in the Mediterranean.

Secondly, two slightly different devices were used for video transects and even though they were both used in both areas, the majority of transects in the Gulf of Lion was performed with a smaller device than in the English Channel, where a larger device

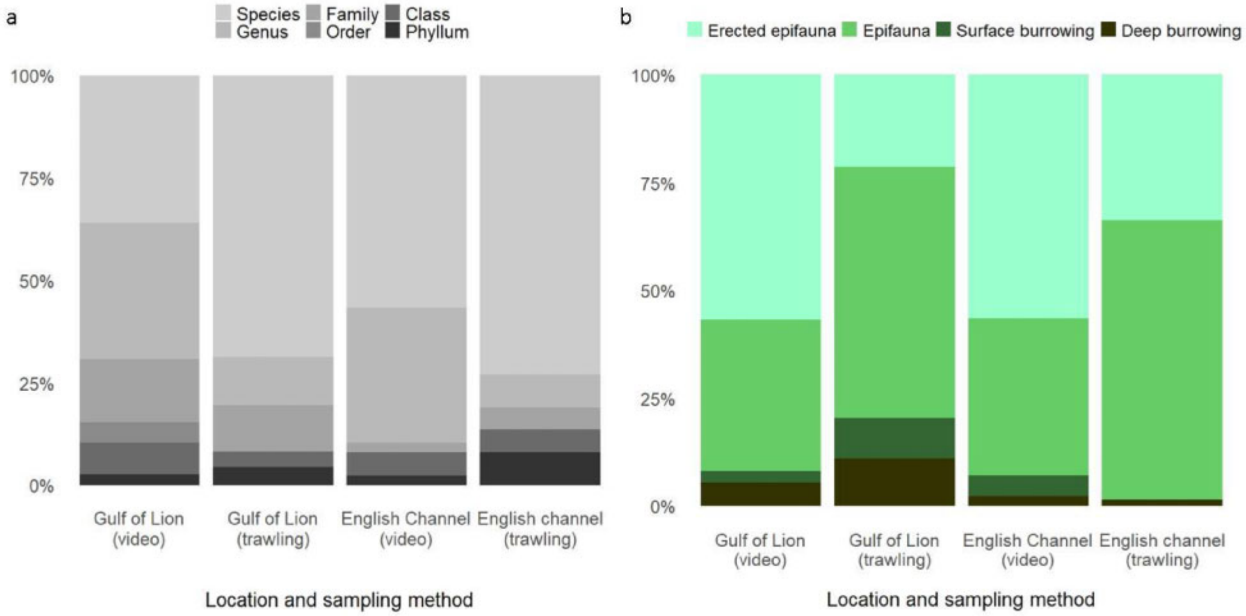

Figure 5. Proportion of each (a) taxonomic level identified and (b) category of position with the two sampling method in the two studied areas.

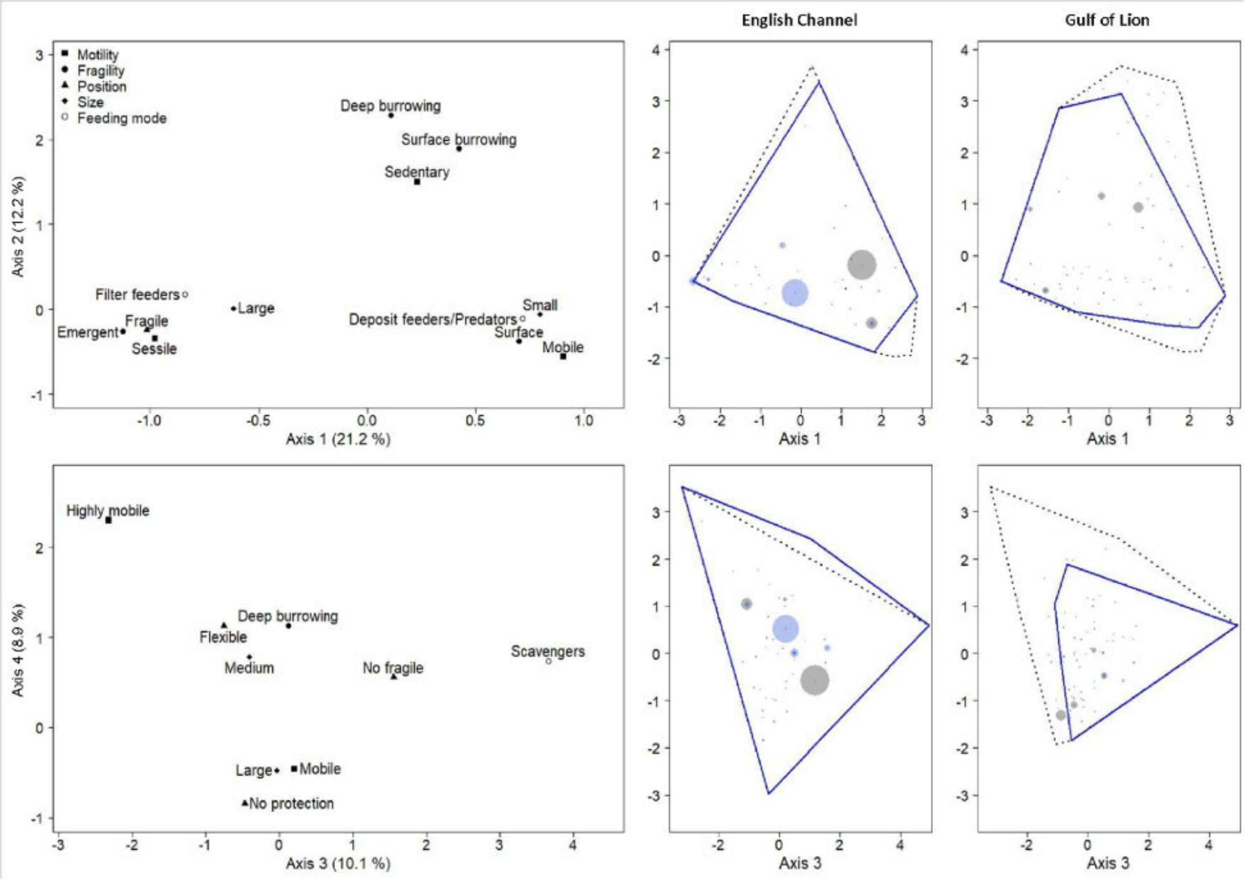

Figure 6. Multiple Correspondence Analyses of the functional traits of the different taxa observed on video and/or sampled by scientific trawling and functional space for axes 1–2 (21.2% and 12.2% variance) and axes 3–4 (10.1% and 8.9% variance) for trawl sampling (dotted polygon) and video sampling (blue line) in the English Channel and in the Gulf of Lion. The species are represented by points of diameter proportional to their density (blue points) for video sampling and their biomass (grey points) for trawling sampling.

Table 8. Outcomes of the stepwise selection procedure on the generalized linear models

		Video			Trawling		
Indices	**Areas**	**Explanatory variable**	**Significance**	r^2	**Explanatory variable**	**Significance**	r^2
mTDI	E.C	Abrasion	***	0.63	Habitat	**	0.80
	GoL	–	–	–	Abrasion Habitat	n.s*	0.87
pTDI	E.C	Abrasion	n.s	0.12	Habitat	**	0.59
	GoL	Abrasion	n.s	0.16	–	–	–
mT	E.C	Abrasion	***	0.88	Abrasion Habitat	*n.s	0.82
	GoL	–	–	–	Habitat Abrasion	*n.s	0.33

GoL, Gulf of Lion. E.C, English Channel. * indicates that $p < 0.05$; ** indicates that $p < 0.01$; *** indicates that $p < 0.001$; n.s indicates no significant effect. No explanatory variable indicate that the null model was selected.

was mostly used. Although the size of the observed areas is known to influence the number of species sampled (Crist and Veech, 2006), no significant difference was found in the sampled surfaces with both video systems. Yet, the use of different devices had significant effect on the estimation of species richness, Shannon diversity, and abundance and may partly explain the difference in diversity observed by video sampling between the two areas. Moreover, although neither sampling techniques are suited to capture infauna, the fact that much more could be caught by trawl in soft sediments may explain the differences in species diversity between trawl and video sampling in the Gulf of Lion.

Taxonomic identification of individuals

Regardless of the study area, the proportion of individuals identified at the species level is higher with trawls than with videos. This is particularly marked in the Gulf of Lion, where nearly 70% of the 134 taxa collected by trawls were identified down to the species level, compared with 36% of the 39 taxa observed on the video transects. One of the main disadvantages of using video alone is that identification at species level is particularly difficult (Flannery and Przeslawski, 2015). Species-level identification often requires sampling of specimens coupled with magnifier observations and expert knowledge (Althaus *et al.*, 2015). Determination of taxa as sponge species for which the differences between two species may require the examination of the spicules cannot be differentiated on video images. The species richness of a site may be underestimated if the species count was only done on video because several individuals may be grouped under the same taxa even though they belong to different species. However, for approaches based on the use of functional traits, the genus level is often sufficient to define the biological characteristics of individuals (Brind'Amour *et al.*, 2009; Foveau *et al.*, 2017). In this study, the rate of identification at the level of the genus appeared to be relatively close between the two sampling methods (70% of observed taxa for the video compared with 80% of taxa sampled with the trawl in the Gulf of Lion and 89% for the video compared with 82% for the trawl in the English Channel). Identification difficulties, intrinsic to video imagery, seem to have relatively little influence on approaches based on species biological traits. However, to overcome these methodological limitations, a "short list" only focusing on relevant sensitive species may be used to perform video analysis.

Functional diversity

The taxonomic diversity of a community does not always reflect the diversity of its functional structure (Törnroos and Bonsdorff, 2012), which is defined as the quantification of the position that different species occupy in the ecosystem (Mouillot *et al.*, 2013). When several species perform similar functions, the reduction in species diversity may not have any influence on the functional structure of the community (Mouillot *et al.*, 2014). In the English Channel, despite a greater number of species observed by video than by trawling, the species communities observed by both gears had a similar functional space. Therefore, despite a relatively different number of species, video observed or trawl sampled communities supported about the same number of biological traits. Despite this very significant overlap between the two functional spaces, notable differences in the type of dominant species could be highlighted with species assemblage dominated by mobile, living at the surface and mainly predator species for the trawl sampling and dominated by sessile, emergent, fragile, and mainly filter-feeding species but also by medium sized and flexible species in video observations. In the Gulf of Lion, contrary to what was observed in the English Channel, the number of species collected and the proportion of infauna species was higher in the community sampled by trawl than that observed on video. As a result, the fauna collected by the trawl also had greater functional diversity (measured as functional space) than that observed by video.

Several parameters could explain the differences between the two sampling methods. Firstly, the dominance of emergent species and the lack of burrowing species on video transects in both areas are easily explained as video observations are limited to the surface of the sediment. In contrast, for the trawl data, in the English Channel, the dominance of mobile species living at the surface could be due to the relatively low penetration of the trawl in coarse sediments, hence resembling that of the video data. The opposite is observed in the Gulf of Lion where the trawl may penetrate much deeper the fine muddy sediments (Eigaard *et al.*, 2016), thus resulting in higher infaunal diversity. Finally, with the video system moving at a maximum of 1 knot with an observation field around 1.3 m wide, mobile species capable to move fast or to quickly retract in the sediment can escape detection while, with a towing speed of 3–4 knots and about 20 m horizontal opening (ICES, 2015; MEDITS, 2017), very few mobile invertebrates or overly dispersed species may avoid capture by trawling. Regarding these results, the two sampling methods seemed complementary. The video device allowed to observe mainly fixed epifauna, regardless of the habitat sampled, this portion of the benthic community appearing, in the present work, relatively poorly sampled by the trawl on coarse habitats. Conversely, trawling was able to capture a greater diversity of infauna species on soft bottoms where this portion of the benthic community is dominant.

Indices evaluation and selection for video derived data

The procedure for selecting the factors influencing the different indices showed all of the taxonomic diversity indices tested (RS, Shannon, Simpson, Pielou, and abundance) were influenced by the type of habitat. Only the species richness was influenced by the abrasion. Although the sampling method differs, these results are partly consistent with those presented in the meta-analysis carried out by Hiddink *et al.* (2020). Pielou and Shannon did not respond significantly to trawling, as opposed to the species richness. However, as the type of video gear also has an influence on species richness, this index does not seem to be appropriate for studying the effect of trawling on benthic communities when sampling is carried out using towed video. Hiddink *et al.* (2020) also found that abundance was strongly influenced by trawling; however, this was not found to be the case in the present study. This difference probably stems from the fact that the benthic community observed is not the same since video sampling only allows us to observe a particular portion of the benthic fauna: the erected megafauna.

For the sensitivity indices, only the mT was influenced by this factor. Since both study areas were included in this analysis, the habitat effect is likely more of a "geographical" effect than an effect of the type of sediment sampled. The number of taxa observed was more than twice as high in the English Channel than in the Gulf of Lion (88 vs. 39). The absence of influence of the habitat factor and therefore of the "geographical" effect, on three functional sensitive indices suggested that despite a greater taxonomic diversity in the English Channel compared to the Gulf of Lion, the response of benthic communities' sensitivity to trawling was not significantly different between the two areas. For the mT index, the habitat factor influence could be related to the addition of the species protection status factor, not taken into account in the calculation of the other functional sensitive indices. Some species are protected in only one of the two study areas. This is the case for sponges of the genus *Tethya* sp., protected in the Mediterranean Sea (OCEANA, 2016) but not in the English Channel (OSPAR 2008). In addition, of all the individuals observed in the Gulf of Lion, 12 of the 39 observed taxa had a protected status, whereas in the Channel, this concerns only 4 of the 88 taxa. Taking into account emblematic species significantly impacted the mT index values and caused a differentiation between the two study areas. As benthic communities do not respond in the same way to trawling in different habitats (Kaiser *et al.*, 1998), the habitat influence on the tested indices was not considered problematic here.

Two criteria allowed to select video derived indices that could monitor the trawling effects on benthic communities in the two areas studied: the presence of a significant negative influence of abrasion on the index and the absence of influence of device characteristics. Only three indices met both of these criteria: mTDI, pTDI, and mT. A previous study based on scientific trawl data also suggested that these indices could be used to monitor the effect of trawl pressure on benthic communities in the English Channel, the North Sea, the Gulf of Lion, and Corsica (Jac *et al.*, 2020a,b). As these three indices are based on the same set of biological characteristics and are selected for their significant correlation with abrasion, they are highly correlated. However, Jac *et al.* (2020a) showed that, depending on the area studied, the same indices do not have the highest correlation with abrasion. Thus, although they are closely related, it seems difficult to select only one of them for the assessment of the impact of trawling on benthic communities. Monitoring the effects of trawling on benthic communities should therefore be carried out at a finer resolution (e.g. EUNIS level 4) by choosing the most sensitive index in the area studied (in application of the precautionary approach).

Monitoring of trawling pressure based on video transects?

In the Gulf of Lion, no significant influence of abrasion was detected on the three functional sensitive indices calculated with trawling data but significant influence of the habitat type was detected on mT and mTDI. These results, correlated with the lack of a significant effect of habitat on the pTDI index, suggest that the differences between habitat types were primarily related to low-sensitivity species as only the most sensitive species were included in the pTDI calculation (Jac *et al.*, 2020a). This could also explain the absence of habitat effects on indices calculated from video derived data, since the species considered most sensitive are generally those of the fixed epifauna (Foveau *et al.*, 2019) which are the species mainly observed on videos. These different results indicate that habitat affects mainly species with lower sensitivity (i.e. mobile species or infauna species) and has little to no influence on video observations. The results obtained by Labrune *et al.* (2008) indicating that there are clear links between polychaete assemblages and both bathymetry (between 10 and 50 m in their study) and sediment grain size in the Gulf of Lion, tend to support this hypothesis.

The lack of relationship between abrasion and the different indices for the two sampling methods could be explained by the small number of stations sampled and the unbalanced distribution of these stations along the abrasion gradient. Jac *et al.* (2020a) found a significant effect of abrasion for habitats A5.46 (Mediterranean communities of coastal detritic bottoms) and A5.47 (Mediterranean communities of shelf-edge detritic),—grouped here as A5.4—with a larger and better distributed dataset along the abrasion gradient (abrasion vary between 0 and 20.77 SAR.y^{-1} with a median of 2.69 SAR.y^{-1}). Their results suggest that an increase in the number of stations sampled, particularly in areas of low abrasion, could enable the detection of a significant and negative relationship between the indices studied and abrasion. For the habitat A5.3 (sublittoral mud), results were consistent with those of Jac *et al.* (2020a) which pointed out the lack of a significant relationship between abrasion and the different indices in habitats A5.38 (Mediterranean communities of muddy detritic bottoms) and A5.39 (Mediterranean communities of coastal terrigenous muds), They interpreted this lack of relationship as reflecting that the original communities of these habitats had already been completely replaced by communities adapted to trawling. Thus, in the present study, as 50% of the sampling was carried out in areas with abrasion levels higher than 4 SAR.y^{-1}, the lack of relationship between the indices and the level of abrasion most likely also reflects the replacement of the original communities by communities fully adapted to trawling.

In the English Channel, results obtained with scientific trawl data appeared similar to those obtained in the Gulf of Lion. Habitat had a significant effect on two of the three indices (mTDI and pTDI) like in the Gulf of Lion. Contrary to what was observed in the Gulf of Lion, mT was significantly influenced by abrasion, even though habitat was still a selected parameter, but not significant in the model. The different response of the mT index from those of mTDI and pTDI could again be explained by the addition of the "protection status" factor in the calculation of mT or by the different computation of biological traits between the mT and TDI-derived indices (Certain *et al.*, 2015; Foveau *et al.*, 2017; Jac *et al.*, 2020a). The relatively lower r^2 for the relationship between pTDI and abrasion than for mTDI (0.59 vs. 0.80) seemed to indicate that, as in the Gulf of Lion, habitat mainly affects species with low sensitivity.

The relationships between the video-derived indices and the parameters studied (abrasion and habitat) contrasted with those obtained with trawl sampling. For the three indices, the habitat parameter was not selected in any model and abrasion had a highly significant influence on mTDI and mT. The fraction of the benthic community that could be observed in the video appeared to be particularly sensitive to abrasion and regardless of the habitat studied. However, a great similarity between the functional spaces of the communities sampled with the two methods was observed. Differences in the behaviour of the indices in relation to the parameters studied could be explained by the metrics used in the two sampling methods, biomass data for trawling, and abundance data for video. However, since trawl catches sessile epifauna with difficulty, their biomass may be underestimated in relation to their abundance in the area and thus induce differences in the behaviour of the indices between the two sampling methods. Furthermore, the absence of habitat effect on the video indices suggests that the abundance of the species observed in the video is not significantly influenced by the habitat type. Results obtained with data from scientific trawling seemed to indicate that habitat had an effect mainly on species with low sensitivity. This therefore suggests that the portion of the benthic community not observed in the video (mobile species, small individuals, etc.) and potentially not very sensitive to trawling may differ from one habitat to another.

In conclusion, data collected from the video sampling seemed to detect a significant negative effect of abrasion while avoiding the effect of habitat type in the English Channel. The use of a towed video method appears more reliable than the use of benthic megafauna data collected during scientific trawling surveys to monitor the effect of trawling on benthic communities in coarse and mixed sediments. As the strength of the relationship (as measured by r^2) between mT and abrasion appeared higher than that of mTDI, mT seemed to be the most appropriate index in this type of environment. However, in the Gulf of Lion, where the sediments are relatively fine, no method was conclusive to assess the effect of trawling on benthic communities because, in most cases, and although generally high, abrasion could not be related to the indices. Video sampling therefore seems particularly interesting for habitats consisting mainly of hard substrates (gravel, boulders, shell sands, etc.). On soft sediment, this methodology may require a much larger observation effort (larger surface observed) and both an increase in the number of stations sampled and a stronger abrasion gradient to verify its usefulness. A recent study has shown that the size of individuals has an influence on the response of a number of indicators to the effect of trawling. Large benthic megafauna seemed to be more impacted by trawling than small benthic fauna and less impacted by various environmental parameters such as depth or granulometry (McLaverty *et al.*, 2020). Towed video, mainly sampling the large benthic megafauna in a non-destructive way, appears to be a good tool for monitoring the effect of trawling on benthic communities. Future work should be considered to determine whether size measurements of benthic megafauna' individuals, on video images, could become useful indices to monitor the effect of trawling on benthic communities.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

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