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Do visual transects provide true population density estimates for deepwater fish?

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This study assesses the impact species ecology, fish reactions, and natural behaviour have on visual strip transect counts of deepwater fish carried out with an ROV (remotely operated vehicle). Two terraces and one canyon were visited on the continental slope of the Bay of Biscay. Species such as rabbit fish (Chimaeridae) and North Atlantic codling (*Lepidion eques*) appear to have avoided the ROV. The vertical distance off the bottom provided evidence that some individuals, in particular slickheads (Alepocephalidae) might have been missed by being above the ROV. GLM modelling showed the importance of depth, current speed, and relative surveying direction on transect counts. Natural and reaction behaviour of deep-sea fish will lead to variable and biased population density estimates.

Keywords: behaviour, deep-sea, ROV, slope fishes, visual transects.

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Introduction

Traditionally, bottom-trawl surveys are used to obtain abundance indices for fisheries management. However, visual census methods using remotely operated vehicles (ROV) or submersibles are increasingly used to achieve the same goal (e.g. Grassle *et al.*, 1975; Adams *et al.*, 1995). While it is well established that trawl catches can only give relative abundance indices owing to unknown and varying individual catchability, the question remains open as to whether visual census can provide accurate population density estimates. Adams *et al.* (1995) found that ROV estimates were generally higher and more precise compared with trawl-based abundance estimates for some shelf and deep-sea species. Similar results were obtained by Cailliet *et al.* (1999). In contrast, Krieger (1992) found trawl estimates for Pacific Ocean perch to be about double those obtained with a submersible, which was explained by the herding effect of the bottom trawl.

If visual transect methods provided true population abundance estimates it would be possible to estimate trawl catchability by simply dividing trawl-based estimates by visual-based estimates (Krieger and Sigler, 1995; Somerton *et al.*, 1999). However, previous studies suggest that this might not be the case for all species, and it is suspected that some of the factors known to affect trawl estimates might also impact visual transect estimates. The factors affecting bottom-trawl catches can be grouped into those related to gear configurations, species ecology, and fish biology (see Wardle, 1993; Engås, 1994; Godø, 1994 for reviews).

In terms of species ecology, depth, geographic distribution, and macro-habitat preferences will determine broad-scale visual transect counts for individual species. As for fish biology, reactions and natural behaviour seem particularly relevant. Both avoidance and attraction to ROVs and submersibles have been observed (e.g. Krieger and Sigler, 1995; Uiblein *et al.*, 2003). The vertical distribution of individuals in the water column will determine the proportion of a population that can potentially be surveyed by visual methods; individuals resting on the sea floor or swimming close to it will be more easily encountered. Temporal variations in transect counts are expected if activity patterns are linked to variations in current strength (Michalsen *et al.*, 1996). For example, sheltering in local depressions or on the contrary making use of drifting prey by moving away from the bottom can be linked to current strength (Uiblein *et al.*, 2002, 2003). Thus, feeding and living habits might influence numbers encountered by an ROV.

The objective of this study was to assess the impact of species ecology, fish reactions, and natural behaviour on visual strip transect counts of deepwater fish.

Materials and methods

Study sites

Three sites were visited during late August 2002 with the IFREMER ROV ''Victor 6000'' in the Bay of Biscay (Table 1). Meriadzek Terrace has rather flat and sandy bottoms, St Nazaire Terrace is gently sloping with fine, gluey sediments at times, and Belle Ile Canyon is more varied with gentle slopes, with fine sediments, big boulders, and vertical walls. At each site, a depth range from 1500 m to 1100 m was surveyed always working upslope during over 72 h of continuous operations.

Visual strip transects

The ROV advanced along predefined transect lines (POSIDONIA USBL positioning system) while video recording ahead and transmitting the images in real time to the research vessel. The survey design consisted of perpendicular lines (nominal lengths: 300 m along depth gradients and 60 m across) with a total length of 24 km (Meriadzek), 20 km (St Nazaire), and 20 km (Belle Ile). Actual strip length was calculated from ROV speed records (every 5 s) and start and end times of a transect. Strip width was calibrated to 5 m at around 1.5 m ahead of the ROV by using a plastic chain of known length and thereafter keeping all survey parameters constant (fixed camera settings, surveying speed $0.25\ m\,s^{-1}$, and ROV bottom 0.8 m above the seafloor). The upper visual limit was around 2.5 m above the seafloor. All fish observed along the strip transect were counted in real time when they passed a virtual line on the video monitor and individual taxa were later identified when replaying videos. For a number of species, taxonomic identification was performed down to the family level only, as visual identification to the species level was judged unreliable. In this paper, only the results for more abundant or commercially important species/families are presented. The ROV has eight frontal floodlights (total 2700 W), which were all in operation for standard transects.

Environmental factors

An autonomous lander equipped with current meter (FSI3DACM), temperature probe (Micrel), and turbidity meter was deployed at each site at a depth of around 1500 m for the duration of ROV operations (Table 1). The current was measured 1 m above the seafloor. For modelling purposes, environmental variables were transformed into factors. Current speed was grouped into weak ($<0.07\ m\,s^{-1}$), medium ($0.07-0.12\ m\,s^{-1}$), and strong ($>0.12\ m\,s^{-1}$). The category limits were fairly arbitrary, but ensured that all three levels were encountered at all sites. Transect survey direction with respect to current direction, referred to as relative transect direction, was categorized by assuming that the current direction measured by the lander was representative of the current direction at the location of the ROV at the same time. Three cases were distinguished: transects against the current (relative courses from 135° to 225°), transects at right angles to the current (courses from 45° to 135° and 225° to 275°), and transects in the same direction as the current (courses from 275° to 45°). Furthermore, three depth strata were defined: 1200−1300 m, 1300−1400 m, and 1400−1500 m. Daytime was defined to start at 4 UTC and to end at 19 UTC.

Natural and reaction behaviour

Individuals higher up in the water column will not be observable by the ROV. Thus, if individuals were distributed homogeneously in the water column above the ground, it seems likely that there were individuals above the ROV which were not censored. The distance off the ground of individuals was measured from videos using body length as reference due to the lack of grids to estimate absolute distances.

Several experiments were carried out to investigate a possible attraction or repulsive effect of the ROV (floodlights, engine noise, etc.) which might bias observed numbers and consequently population density estimates. Point observations aimed at testing an attraction effect. For this, the ROV was put into a stationary position facing downstream for at least 20 min and the behaviour of all individuals appearing in front of the ROV was recorded. If the ROV attracted individuals, these would be expected to be seen swimming towards it. The experiment was repeated

Table 1. Details of operations. Dives carried out with ROV ''Victor 6000'' and lander mooring depths. Starting positions for the ROV are identical to mooring positions of the lander.

Area	Start lat.	Start long.	Start of dive [UTC]	End of dive [UTC]	Dive depth range [m]	Lander depth [m]	Tidal amplitude
Meriadzek Terrace	47°39′N	8°11.4′W	22 Aug 2002 11:46	25 Aug 2002 14:32	1092−1466	1463	Above average
St Nazaire Terrace	46°15′N	4°42.6′W	26 Aug 2002 08:41	29 Aug 2002 13:00	1122−1518	1497	Average
Belle Ile Canyon	46°20.5′N	4°41.4′W	30 Aug 2002 07:51	2 Sept 2002 06:34	1055−1553	1503	Below average

six times at each study site. In order to investigate a repulsive effect, survey speed and floodlight intensity were varied. Thus, if individuals escape ahead of the ROV, more individuals might be seen at higher survey speeds, as they would have less time to react. A series of transects were done at double ROV speed ($0.5\ m\ s^{-1}$), where double-speed transects (40 on Meriadzek Terrace and 22 on St Nazaire Terrace) and standard-speed transects (40 and 33, respectively) were carried out in random order. Strong currents on St Nazaire Terrace hindered the execution of more double-speed transects. Similarly, if floodlights make some individuals escape, more individuals might be seen at a lower light level. To test this hypothesis, 21 transects at reduced light intensity (1200 W instead of 2700 W) were randomly alternated with 20 standard transects on St Nazaire Terrace. In addition to the transect experiments, the individual reaction behaviour to the approaching ROV during standard transect was categorized into reaction before appearing in view, reaction once detected, and no reaction at all. Individuals showing signs of burst swimming or rapid fin movements were classified to have reacted beforehand.

Statistical modelling

In order to determine which environmental and technical factors might explain ROV counts, generalized linear models (GLM) were used. The total number of individuals per transect line of a given species were modelled as Poisson distributed variables allowing for over- and under-dispersion by fitting the models using a quasi-likelihood approach with a log-link function. The appropriateness of the Poisson distributions was verified by inspecting residual plots. The tested variables were site, depth, current speed, day–night index, transect length, and relative transect direction. Only first-order effects were tested and a Wald test was used to identify variables with explanatory powers. The counts from the experimental transects were analysed the same way, with the only difference that transect speed and transect light level were added as explanatory factors. The two speed experiments were analysed separately because due to differences in current speed they cannot be considered replicates.

Results

Visual transect counts

The realized ROV transect design was balanced with respect to environmental variables; an exception was Belle Ile Canyon, where most transects were carried out in conditions of weak to medium currents (Table 2). Strongest currents with peaks of around $0.45\ m\ s^{-1}$ were registered at St Nazaire Terrace. The total number of individuals of a given species encountered was small for most species (Table 3). The dominant species in all areas was the cutthroat eel (*Synaphobranchus kaupi*). The second most important group, morid cods (Moridae), was mainly made up of North Atlantic codling (*Lepidion eques*). Cat sharks (Scyliorhinidae) were represented by *Apristurus* spp. and *Galeus murinus*. The composition of dogfish sharks (Squalidae) was diverse, the main members being *Centroscymnus* spp., *Deania calceus*, and *Etmopterus princeps*.

Ecology

For many species, significant differences were found between study sites in the counts per transect line (Table 4). Depth stratum was a significant factor for most species, while for all species, transect length was a significant factor. Relative transect direction was a significant factor for a number of species, while current speed was a significant factor for a different set of species. Cutthroat eel, false boarfish (*Neocyttus helgae*), and spiderfish had lowest abundances at intermediate currents. Visual transect

Table 2. Number of visual strip transects realized for the different levels of environmental and design factors at each study site. Depth range: a. 1150–1300 m, b. 1300–1400 m, and c. 1400–1500 m. Transect length: long 300 m and short 60 m. Relative survey direction: against current (relative courses from 135° to 225°), same as current (relative courses from 275° to 45°) and across current (relative courses from 45° to 135° and 225° to 275°). Current speed as measured by lander: weak $<0.7\ m\ s^{-1}$, medium $0.7–0.12\ m\ s^{-1}$, and strong $>0.12\ m\ s^{-1}$.

Area	N	Depth range	Transect length	Relative survey direction	Current speed [$m\ s^{-1}$]	Day/night
Meriadzek Terrace	187	a 113	Long 95	Against 104	Weak 33	D 124
		b 41	Short 92	Same 35	Medium 72	N 63
		c 33		Across 48	Strong 82	
St Nazaire Terrace	147	a 69	Long 73	Against 69	Weak 32	D 72
		b 26	Short 74	Same 28	Medium 60	N 75
		c 52		Across 50	Strong 55	
Belle Ile Canyon	125	a 51	Long 64	Against 45	Weak 49	D 68
		b 21	Short 61	Same 31	Medium 62	N 57
		c 53		Across 49	Strong 14	

Table 3. Total number of individuals encountered on visual transects.

Name	Species	Meriadzek Terrace	St Nazaire Terrace	Belle Ile Canyon
Slickheads	Alepocephalidae	3	4	3
Spiderfish	*Bathypterois dubius*	114	455	215
Rabbit fish	Chimaeridae	15	7	11
Roundnose grenadier	*Coryphaenoides rupestris*	9	13	39
Morid cod	Moridae	225	161	327
False boarfish	*Neocyttus helgae*	15	0	29
Cat sharks	Scyliorhinidae	40	8	6
Dogfish shark	Squalidae	8	4	6
Cutthroat eel	*Synaphobranchus kaupi*	1 049	1 245	1 138
Spiny scorpionfish	*Trachyscorpia c. echinata*	6	3	7

counts showed significant differences between daytime and night-time for certain species.

Natural and reaction behaviour

The shape of the vertical distribution of a number of species suggested that a proportion of the near bottom population might have been above the ROV (Figure 1). This seems true for slickheads in particular. In contrast, all individuals of spiny scorpionfish (*Trachyscorpia cristulata echinata*) were always encountered resting on the seabed.

The degree of reaction to the approaching ROV varied by species (Figure 2). While spiny scorpionfish hardly ever reacted, nearly all cat sharks did react after being detected. Rabbit fish (Chimaeridae) had the largest proportion (10%) of individuals that seemed to have reacted to the ROV before coming into view.

The strip transects carried out at two light levels revealed a significant effect of the floodlight level used by ROV for morid cods, for which counts were higher at the lower light level (Table 5). The opposite effect was found for cutthroat eel, with significantly lower counts at the reduced light level. No significant light level effect was found for any other species or family. Doubling ROV speed significantly reduced counts of cutthroat eel in strong current conditions (St Nazaire Terrace) and roundnose grenadier in moderate current conditions (Meriadzek Terrace), but had no impact on other species' counts (Table 5).

Point observations were carried out in order to observe whether individuals might show active swimming towards the stationary ROV. Ten out of 74 cutthroat eels observed were attracted and actively moved towards the ROV, while seven individuals drifted by when first seen and then actively swam towards the ROV. Two North Atlantic codlings ($n = 6$) showed clear signs of interest in the ROV, but not individuals ($n = 10$) belonging to other species.

Discussion

Ecology and behaviour

Environmental conditions, in particular current strength, played an important part in explaining variability in the numbers of individuals observed by the ROV. However, given the way the ROV transects were carried out, current strength was confounded with the depth and day–night factors, because any particular depth stratum was only

Table 4. Score (Wald) test for important factors for visual counts per transect line using GLM with overdispersed Poisson error and log-link function. Significance levels: $* < 0.05$; $** < 0.01$. Blank cells: factor not significant.

Species	Area	Depth stratum	Transect length	Relative survey direction	Current speed	Day/night
Alepocephalidae			**		*	
B. dubius	**	**	**		**	**
Chimaeridae			**			
C. rupestris	**		**	**		
Moridae	**	**	**			
N. helgae	**	**	**		**	**
Scyliorhinidae	**	**	**			
Squalidae			**			
S. kaupi	**	**	**	**	**	**
T. c. echinata		**	*			

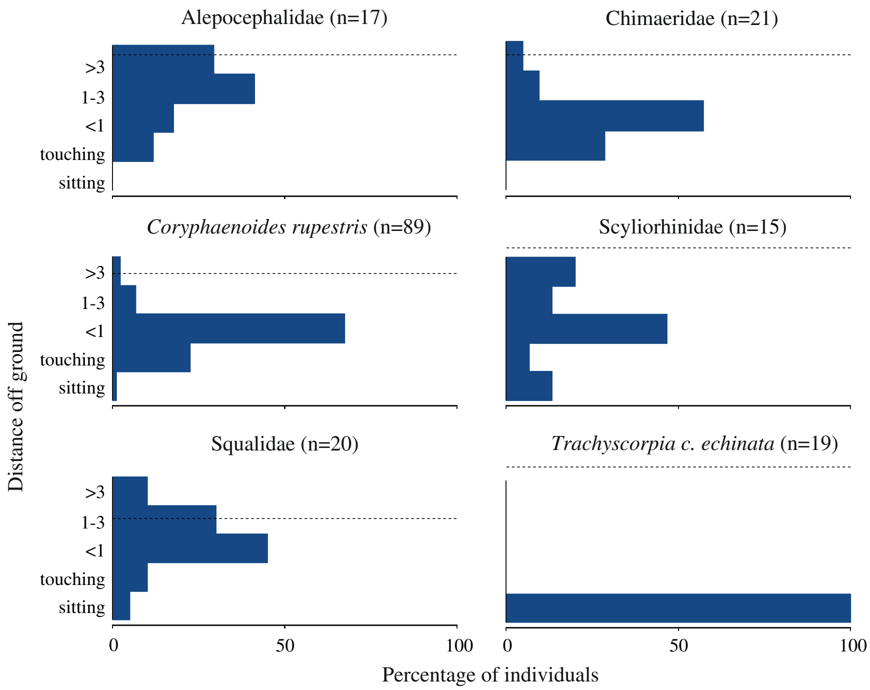

Figure 1. Natural vertical distribution of individuals (sample size in parentheses) encountered by the ROV. Distance off bottom is measured in body lengths. For reference, the horizontal dotted lines indicate about 2 m above ground.

visited once. Hence, it is not possible to disentangle the different factors. For example, cutthroat eel is a scavenger that detects its prey by olfaction (Uiblein *et al.* 2002) and might therefore be more or less abundant according to current conditions. In addition, variations of their position in the water column in response to local conditions (Uiblein *et al.* 2002) are likely to make this rather small eel-shaped species more or less detectable on videos. Indeed, the results of the experimental transects at double speed and half light level seem to suggest that some individuals might not have been detected by the observers at the reduced light level or double surveying speed.

The vertical distribution above the seafloor put clear bounds on the detectability by the ROV for a number of

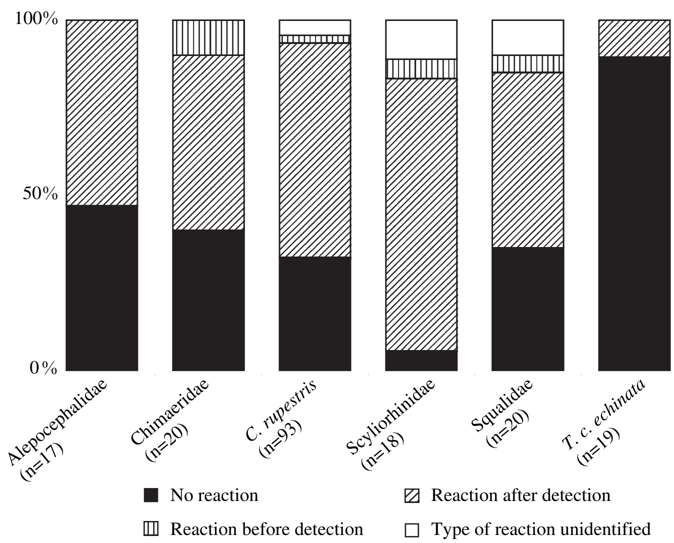

Figure 2. Observed reaction behaviour (%) to the approaching ROV of selected species (sample size in parentheses). Observations come from all three sites and also from operations other than strip transects.

Table 5. Number of individuals observed during experimental transects and ANOVA results (Wald test). Light level: full 2700 W, reduced 1200 W. ROV speed: standard 0.25 m s^{-1}, double 0.5 m s^{-1}.

	Light level St Nazaire			ROV speed Meriadzek			ROV speed St Nazaire		
	Full	Reduced	p-Value	Standard	Double	p-Value	Standard	Double	p-Value
Alepocephalidae	1	1	0.80	2	1	0.57	1	0	0.40
B. dubius	38	30	0.30	12	21	0.06	30	28	0.13
Chimaeridae	3	1	0.51	2	2	0.86	1	1	0.76
C. rupestris	0	0		0	0		8	0	0.01
Macrouridae	7	5	0.58	44	20	0.02	14	11	0.46
Moridae	9	27	0.002	64	67	0.29	40	29	0.50
Scyliorhinidae	3	2	0.77	4	7	0.17	0	0	
Squalidae	0	1	0.05	2	0	0.10	2	1	0.77
S. kaupi	118	82	0.01	277	220	0.18	395	192	0.008
T. c. echinata	0	0		0	4	0.01	1	1	0.73

species. For example, the shape of the slickheads' vertical distribution suggested that a proportion of the near bottom population might have been above the ROV. This interpretation is supported by the high slickhead numbers that were found in bottom-trawl catches also carried out during this study (results reported elsewhere). The picture is less clear for other species.

The ROV clearly attracted individuals of cutthroat eel as indicated by the transects carried out at two light levels and the point observations. Unfortunately it cannot be excluded that during the point observations some of the interest was stimulated by the odour diffusing from the bait carried by the ROV. Indeed, disturbance reactions rather than attraction of this species to an approaching submersible have been noted before (Uiblein *et al.*, 2003). North Atlantic codling (morid cods) avoided the ROV at close distance and encounters were higher at the lower light level. No evidence of any attraction was found for roundnose grenadier, for which Gordon *et al.* (2002) have found increased catches for a trawl fitted with lights compared to one without lights. The differences might be due to the small number of individuals that were encountered during the present study.

Repulsion by the ROV is more difficult to observe directly. The fact that some rabbit fish were detected when already showing disturbed behaviours might indicate that this family is sensitive to the noise disturbance created by the ROV, although it cannot be completely excluded that they reacted to its lights. However, active avoidance of submersibles by rabbit fish has been observed before (Lorance *et al.*, 2000). The low surveying speed necessary for visual observations might have played a role in this context. Comparative trawl studies by Gordon and Bergstad (1992) have shown that fast-swimming species, such as squalid sharks, slickheads, and black scabbardfish (*Aphanopus carbo*), were more abundantly caught by a wider trawl operated at higher trawling speeds. Indeed, some large sharks such as *Deania calceus* were seen swimming fast far ahead of the ROV.

Absolute density estimates

This study provides evidence that natural and reaction behaviours of deepwater fish influence ROV visual transect counts. The reasons vary between species. In terms of reactions to the ROV, evidence for avoidance was found. Unfortunately, this study does not allow quantification of the bias these reactions might introduce. Natural behaviour creates variability, but also bias. In the case of directional swimming, which leads to the survey direction being important, bias correction is possible given that swimming velocity and direction are known (Trenkel, 2003). The impact of activity patterns can be mitigated by strict sampling protocols, as done for trawl surveys. The vertical observation range of the ROV ''Victor 6000'' does not cover the vertical distribution of all studied species. Future technological developments which combine acoustics and stereophotometry should help to overcome the problem by providing information for a larger vertical range.

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