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A new apparatus for the direct measurement of otter trawling effects on the epibenthic and hyperbenthic macrofauna

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A towed trawl simulator sledge (TTSS2) for collecting quantitatively small macrobenthic animals disturbed by the passage of otter trawl groundrope typical of the local fishery is described and illustrated. The TTSS2 was towed from a surface vessel at a speed within the range of commercial trawls, incorporating three sampling nets that open and close by means of an electro-mechanical system. An odometer in contact with the seabed provided a continuous record of the trawled ground. The degree of efficiency of the TTSS2—by means of the attached groundrope that stirs up the surface of the bottom ahead of the nets—was tested in the northern continental shelf of Crete (eastern Mediterranean). Additional trials with a much heavier groundrope were also performed. Analysis and comparison of TTSS2 samples with endobenthic, hyperbenthic and planktonic samples collected by means of conventional sampling gears indicate the presence of a well-defined and distinct fauna in the plume of resuspended sediment behind the groundrope.

INTRODUCTION

Demersal fishing methods (e.g. otter trawling) are commonly reported as causing severe disturbance to the sea-floor sediments and thus a variety of epi- and infaunal benthic organisms which are potential food sources for predators and scavengers are displaced, damaged or destroyed (e.g. Jennings & Kaiser, 1998). Until recently such disturbance by otter trawls was considered to be restricted to those effects caused by trawl doors (Hall, 1999). Nevertheless, it is the groundrope of the trawling rig which accounts in some cases for more than 90% of the contact of the entire gear with the seabed (Lindeboom & de Groot, 1998) and consequently it is assumed to be the major source of disturbance of the small invertebrate communities living on or just above the sediment–water interface.

Although there is a growing number of studies that have adopted comparative and experimental approaches to investigate the effects of trawling on benthic communities there are still problems and technical difficulties in carrying out trawl impact experiments (Hall, 1999). As a result, the study of the effects of towed fishing gears on benthic communities is still in need of innovative field methodologies and sampling techniques. The present paper describes a new sampling device that has been constructed to simulate the disturbance of the seabed caused by the passage of otter trawl groundropes. The device has been used both to simulate the event and to collect simultaneously the small macrobenthic animals found in the plume of the sediments thus disturbed. This innovative methodology aims to provide direct quantitative measurements of the effects of otter trawling mainly on the small epibenthic and hyperbenthic animals of soft sediments.

MATERIALS AND METHODS

Technical description of the towed trawl simulator sledge (TTSS2)

The TTSS2 was developed around the frame of the towed benthic sledge described by Shand & Priestley (1999) extensively used to carry underwater cameras to study the seabed and the benthic fauna in Scottish waters (Figure 1). The sledge was made of salt-water resistant (grade HE 30) aluminium tubing of a total length of 2.24 m, width 1.27 m, and 1.52 m height. In the air, its weight with camera equipment mounted was about 127 kg and in the water 55 kg. The TTSS2 is the second modified version of the Shand & Priestley (1999) sledge. The first version (TTSS1) was a towed trawl simulator sledge equipped with water sampling bottles constructed in order to investigate physical and geochemical effects on surface sediments caused by trawling (Institute of Marine Biology of Crete, unpublished data).

The front part of the sledge was modified to hold a metal frame divided into three sub-frames with closing doors (Figure 2A,B) and an opening–closing mechanism. The surface area of the opening of each door was 0.15 m^2 (0.58 m width × 0.26 m height). Three standard plankton nets (0.5-mm mesh size) were zipped up behind the doors in a horizontal position. The nets 1–3 were positioned above the seabed with their lower edge at heights of 5 cm, 31 cm and 57 cm, respectively. Each net was 1.6 m long and the ratio of the filtering area to the mouth area was 9:1. An Osprey 1364 CCD colour video camera

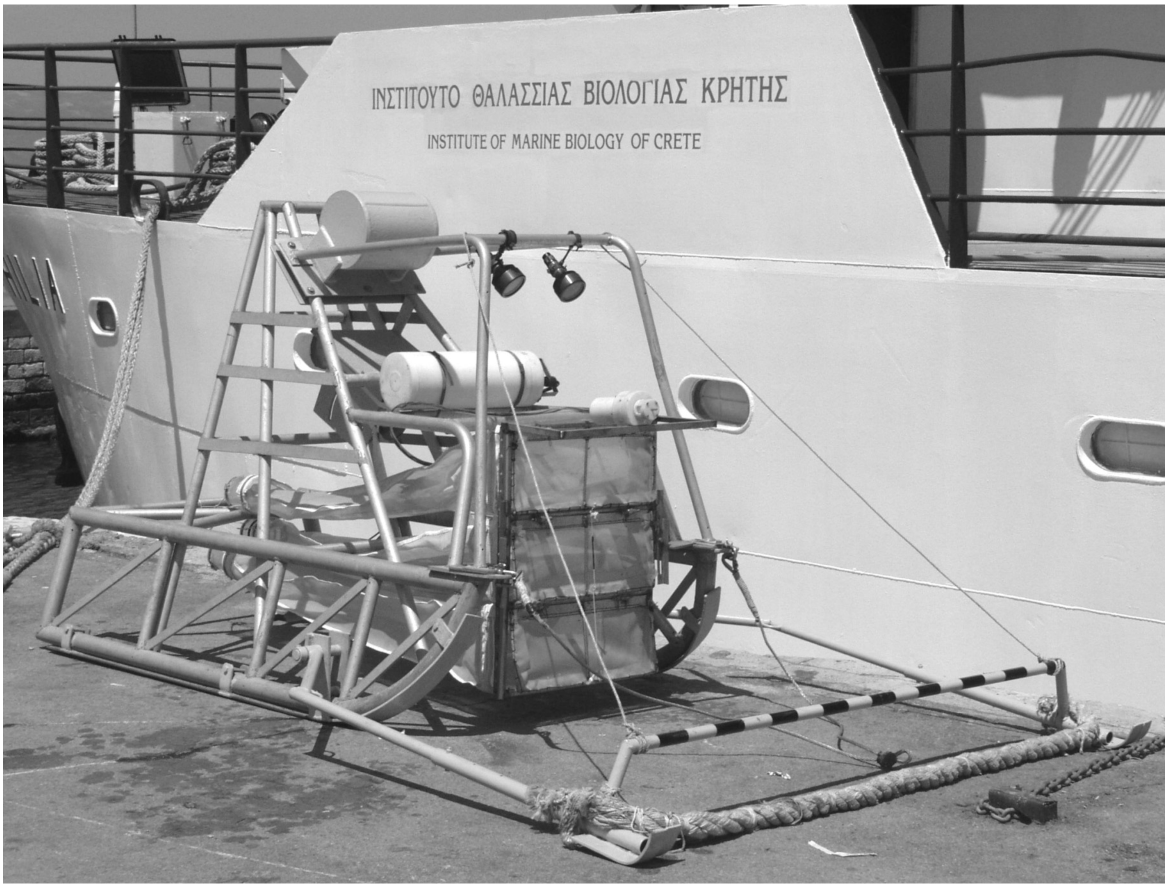

Figure 1. General aspect of the TTSS2.

mounted on a frontal bracket of the sledge ensured that the opening–closing mechanism was operating correctly.

An electro-mechanical system was mounted on the upper part of the metal frame and connected with thin wires to the three doors (Figure 2A,B). This system, also connected to an electronic controller operated from the surface, opened (horizontal position) and closed (vertical position) the three doors simultaneously. The battery package and the controller were held in a pressure housing mounted on the upper part of the sledge (Figure 2A,B). The controller was connected to the towing surface vessel through the sledge's umbilical cable that also supplied power to the underwater camera. The posterior part of the sledge ensured the protection and the support of the nets and their collectors (Figure 2A). An odometer (of 1 m circumference aluminium wheel) was mounted at the rear part of the sledge (Figure 2A). Each revolution of the wheel returned a signal recorded on a digital counter.

At the front of the sledge, there was a 1.8 m length of otter trawl groundrope positioned at a distance of 1.5 m, which could be adjusted if necessary. The groundrope was supported by two lightweight metal arms attached to the sides of the sledge and held in position by a transverse metal rod connecting the two arms in order to prevent changes in the curvature of the groundrope during operation (Figure 2B).

The RV 'Philia' towed the sledge at a normal trawling speed of 2 knots. The ratio of the wire paid out to depth was 2:1.

Experimental site

The experiments were carried out during the period of 20–30 September 2001 just before the opening of the eight-month trawling season on the continental shelf of Heraklion Bay, on the north coast of Crete (eastern Mediterranean). All samples were collected from an area of 1000 m×100 m along the isobath of 50 m centred on 35° 21.72′N–25° 06.04′E.

The physical properties of the water column were recorded with a SBE-19 conductivity–temperature–depth probe. Water temperature ranged from 24.8°C at the surface decreasing to 21.7°C close to the bottom. Salinity and oxygen concentrations remained stable throughout the water column with values of about 39 and 4.6 ml/l respectively. Depth profiles of irradiance of photosynthetically active radiation (PAR) revealed values close to the bottom reaching 7% of the corresponding ones at the water surface, indicating that the sea-floor was an integral part of the photic zone. Sediment samples were taken by means of a 0.0225 m^2 USNEL box corer. Surficial sediments (0–1 cm depth) were classified as mud with the fraction less than 63 μm making up 80 to 83% of the sediment throughout the study area. The coarse-grained constituents were mainly shell fragments and debris of bivalves, gastropods, echinoderm tests, serpulid tube fragments, foraminiferan tests and sponge needles. Sediment redox potential (Eh) profiles, made using a conventional combined electrode, showed values higher than 300 mV

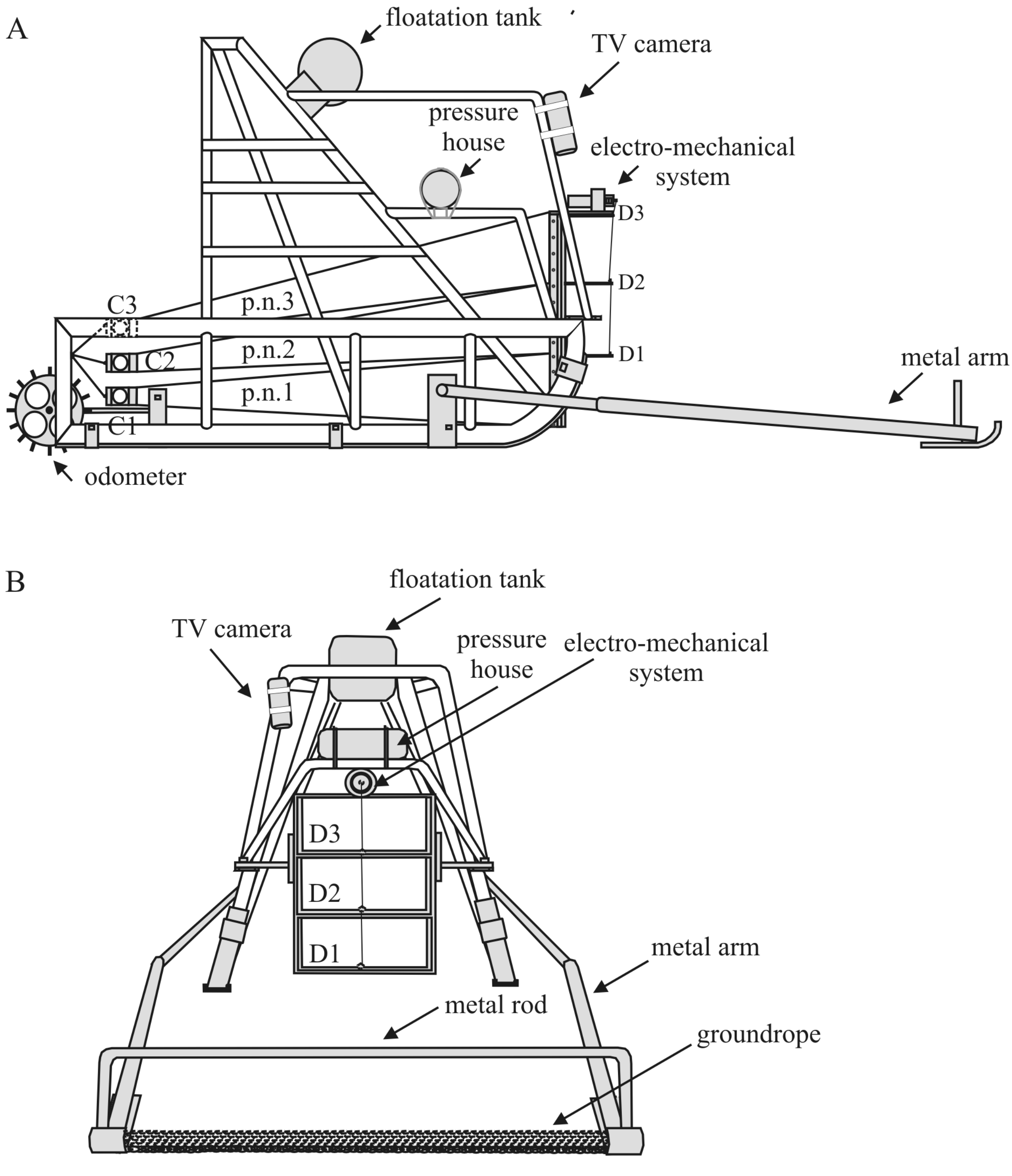

Figure 2. (A) Lateral schematic view of the TTSS2: p.n. 1–3, plankton nets; C 1–3, collectors; D 1–3, doors. (B) Front schematic view of the TTSS2.

for the top two cm of sediment, followed by an exponential decrease approaching baseline values ranging from 50 to 100 mV. Surface sediment porosity values of about 63% decreased irregularly to a depth of 6 cm where a baseline value of 49% was obtained. Sediment organic carbon and total nitrogen measurements, made using a Perkin Elmer CHN 2400 analyser, gave percentages ranging from 0.52–0.58% and 0.06–0.08%, showing little change with depth.

Field experiments design

The first set of experiments included the application of the TTSS2 equipped with a standard otter trawl groundrope of the type most commonly used in fisheries in the Cretan shelf (type A, 6.5 cm diameter and 2 kg/m weight in water). Three tows, 50 m in length, were carried out by the TTSS2. Three additional reference tows, each 500 m in length, were carried out with the same apparatus used as a hyperbenthic sledge (TTSS2 without the groundrope). Benthic and zooplanktonic macrofaunal samples were also collected by means of traditional sampling techniques. Five sediment samples were taken using a Smith McIntyre grab (0.10 m^2) and five vertical hauls were made using a WP2 zooplankton net (0.5 -mm mesh size). After collection, the sediment was sieved (0.5 -mm mesh size) and all samples collected were preserved in 10%

Table 1. *Average densities of the major taxonomic groups collected with the Smith McIntyre grab, the hyperbenthic sledge, the TTSS2 equipped with two different groundrope settings (types A and B) and the plankton net (N=number of replicates). Statistical significance of differences in densities between the two different groundrope settings was determined with Mann–Whitney* U*-test (n.s., not significant).*

Taxa	Smith McIntyre grab (ind m^{-2})	HS (ind m^{-2})	TTSS2 (A) (ind m^{-2})	TTSS2 (B) (ind m^{-2})	Plankton net (ind m^{-3})	*U*-test
	N=5	N=3	N=3	N=3	N=5	
Porifera	—	—	0.01	0.06	—	n.s.
Cnidaria	—	0.09	0.08	0.34	2.72	n.s.
Nemertini	94	—	0.02	—	—	n.s.
Sipuncula	298	<0.01	0.10	0.17	—	n.s.
Gastropoda	14	<0.01	6.25	20.78	0.64	$P<0.05$
Scaphopoda	—	—	—	0.20	—	n.s.
Bivalvia	130	—	1.05	3.94	—	$P<0.05$
Polychaeta	1446	<0.01	3.43	9.86	0.01	$P<0.05$
Crustacea (larvae)	—	0.52	2.91	3.51	2.89	n.s.
Copepoda	—	0.11	0.36	1.81	8.18	$P<0.05$
Ostracoda	—	—	0.33	0.95	—	$P<0.05$
Decapoda	68	<0.01	1.69	3.59	0.01	$P<0.05$
Mysidacea	—	0.01	10.55	4.94	—	$P<0.05$
Cumacea	10	<0.01	4.33	10.34	—	$P<0.05$
Tanaidacea	—	—	0.01	—	—	n.s.
Isopoda	74	0.01	0.21	0.55	0.01	n.s.
Amphipoda	4	0.01	5.77	11.29	0.01	$P<0.05$
Pycnogonida	—	—	0.08	0.37	—	$P<0.05$
Chaetognatha	—	0.08	0.76	2.76	2.48	$P<0.05$
Echinodermata	36	0.03	1.22	2.13	0.31	$P<0.05$
Appendicularia	—	—	0.07	0.06	0.31	n.s.
Ascidiacea	—	—	0.01	—	—	n.s.
Thaliacea	—	0.04	0.01	—	0.08	n.s.
Pisces	—	0.02	0.14	0.26	0.11	n.s.

formalin on-board, sorted under a dissecting microscope and identified to the major taxa.

The second set of experiments included three additional tows of the TTSS2 equipped with another type of groundrope (type B) of larger diameter (9.5 cm) and considerably heavier (6 kg/m weight in water) than type A.

The video camera attached to the sledge showed that resuspension ahead of the sampling nets was caused solely by the groundropes, and that the sediment cloud was no higher than the upper sampling net. All experimental sampling was carried out during daytime (0900 h–1500 h).

Data analysis

Multidimensional scaling (MDS) ordination analysis of data (Field et al., 1982) was performed using the Bray–Curtis similarity coefficient (Bray & Curtis, 1957). Data were transformed to the fourth root prior to analysis. The significance of any differences found was determined by analysis of similarities test (Clarke, 1993). The Mann–Whitney *U*-test was applied to assess any significant differences between densities of the major taxonomic groups collected from the application of the two different groundrope settings.

RESULTS

Observation of the macrofauna collected by means of the TTSS2 revealed that most of the animals caught were not damaged by the passage of the groundropes but remained intact. Even very fragile organisms such as small ophiuroids were found to be in very good condition. In addition to small-sized animals, large megafaunal elements such as shrimps, stomatopods and flatfish were occasionally caught by the TTSS2.

The use of the Smith McIntyre grab and the plankton net yielded, respectively, a total of 1088 and 1267 individuals, identified to 10 and 13 taxa (Table 1). However, the TTSS2 collected 9192 individuals identified to 24 different taxonomic groups; in sharp contrast, when the same apparatus (TTSS2) was used as a hyperbenthic sledge, it collected only 825 individuals identified to 15 taxa, despite the ten-fold length of tows performed by the latter gear (Table 1). Animal densities estimated from the TTSS2 samples were greater than those collected by the hyperbenthic sledge at least by one order of magnitude.

As expected, Polychaeta, Sipuncula and Mollusca accounted for more than 85% of the macrofauna collected by using the Smith McIntyre grab, followed by Crustacea of which more than 90% were Decapoda and Isopoda. A noticeably different pattern of taxa composition was evident in the plankton net and the hyperbenthic sledge samples, with a high proportion of Crustacea (mostly Copepoda and crustacean larvae), followed by Cnidaria and Chaetognatha. However, Crustacea accounted for 66% of the fauna collected by the TTSS2, followed by Mollusca and Polychaeta. Mysidacea, Cumacea and Amphipoda comprised the most significant component (79%) of the crustacean abundance. It should be pointed out that molluscan fauna collected by the TTSS2 comprised only Gastropoda, while the grab samples

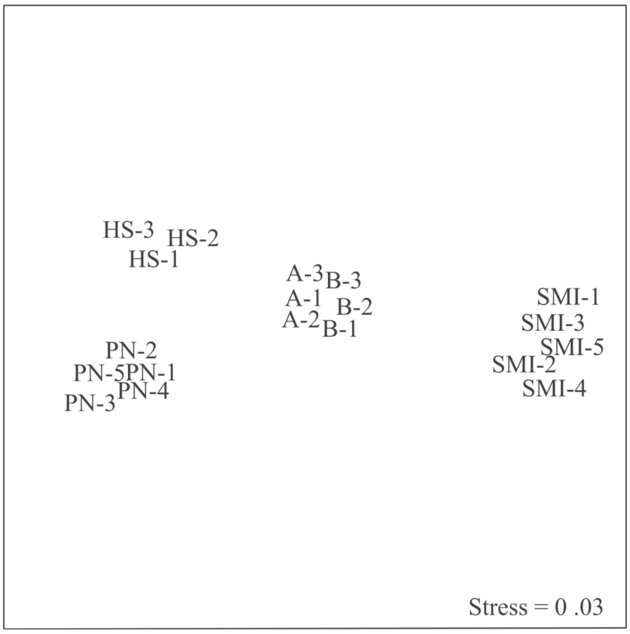

Figure 3. Multidimensional scaling (MDS) ordination plot based on density matrices of the major taxa collected by various sampling gears (R=1, $P<0.001$). SMI 1–5, Smith McIntyre grab; A 1–3 and B 1–3, TTSS2 equipped with types A and B groundropes; HS 1–3, hyperbenthic sledge; PN 1–5, plankton net.

contained almost exclusively Bivalvia. The MDS ordination plot based on the density matrices of the major taxa (Figure 3) showed marked differences between samples of all sampling gears used (R=1, $P<0.001$).

Experimental sampling with the TTSS2 equipped with a heavier groundrope setting (type B) showed significantly higher mean density values ($P<0.05$) of the major taxonomic groups (Table 1). Exceptionally, crustacean larvae densities were similar ($P>0.05$) while densities of mysids were surprisingly lower ($P<0.05$) when the heavier groundrope was applied.

A gradual decrease of the fauna from the lower net, to upper net was observed in hyperbenthic samples and also when type A groundrope was used. In sharp contrast, the passage of the heavier groundrope (type B) resulted in a significant increase in numbers of individuals in the middle net along with a very noticeable decrease in number of individuals in the uppermost net.

DISCUSSION

The comparison of the application of different sampling techniques on the continental shelf of Heraklion Bay reveals the relative efficiency of each gear in collecting organisms characterized by different behaviour and distribution patterns. The lack of certain hyperbenthic taxa (e.g. mysids) in the grab samples indicates that such quantitative gears are inadequate for sampling near-bottom highly motile benthic organisms (Brandt & Schnack, 1999). Vertically hauled plankton nets may sample macrozooplankton adequately but are not useful for collecting the fauna concentrated temporarily or permanently in the water column close to the seabed (Lasenby & Sherman, 1991). Furthermore, the application of typical hyperbenthic sampling gear revealed very limited activity of animals above the seabed, probably partly due to their close association with the sediment, at least during daylight, but perhaps also caused by the inefficiency of hyperbenthic sledges to sample adequately very close to the sediment (Mees & Jones, 1997).

Analysis of the macrofauna collected by the TTSS2, even at the level of major taxonomic groups, revealed that the new apparatus samples a very specific fauna living or sheltering at the sediment–water interface. This fauna consists mainly of small epibenthic and hyperbenthic animals suspended by the otter trawl groundrope passing over the seabed. The exposure and stress of these organisms may increase their predatory vulnerability (Jennings & Kaiser, 1998). The variability of groundrope characteristics, such as dimension and the extent of bottom contact, could cause striking differences in successive effects. Sediment penetration depth caused by the types of groundropes used in this study varied between 0.5 and 1 mm (Institute of Marine Biology of Crete, unpublished data). The use of the TTSS2, even given this small range of penetration, revealed significant changes in the composition and abundance of the fauna suspended by groundropes of differing sizes and weight. However, the size of the gear in use may influence the magnitude of the escape reaction of certain specific animal groups (Lasenby & Sherman, 1991). In the case of the present study, mysids, animals characterized by high mobility, seemed to react intensely to sediment disturbance caused by the groundrope most probably by escaping sideways as evinced by the fact that their abundance in the upper net of the TTSS2 remained stable when the two different types of groundropes were tested.

The application of the TTSS2 could be a useful tool in studies, which are aimed at identifying the direct impact of towed fishing gears on the macrobenthic communities living at the water–sediment interface and the resulting ecosystem responses. Further development of innovative field sampling devices, such as the TTSS2, which has been constructed to simulate the disturbance of muddy sediments by bottom trawling, is needed in order to ascribe observed effects to other gear components, e.g. doors, in contact with the seabed.

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