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Efficiency of the bottom trawl used for the Mediterranean international trawl survey (MEDITS)

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Abstract — The aim of the work presented in this paper was to assess the relative efficiency of the GOC 73 sampling trawl used for the Mediterranean international trawl survey programme (MEDITS) compared with that of a typical Italian commercial trawl. The latter was chosen because it is commonly used by fishermen in the central Adriatic, where the experiment was conducted, and therefore appeared as the best possible sampler of the commercial species present in those areas. Moreover, this trawl is similar to the various trawls used for the Italian national survey programme (GRUND). Four fishing trips were conducted between 1996 and 1997 in different areas and seasons to sample different species. Each trip was conducted in the same fishing area. A codend cover mounted on the commercial trawl ensured that the codends of the two nets had the same mesh opening. The two trawls were alternated daily. Net geometry (horizontal and vertical net opening) was measured during all tows. Catch data were converted into abundance per swept area before comparing the trawls. Efficiency comparisons were performed on ten fish species, one crustacean and four molluscs belonging to the MEDITS list of main reference species. The MEDITS trawl was significantly less efficient in terms of both weight and numbers of individuals fished for hake (*Merluccius merluccius*), common sole (*Solea vulgaris*) and Norway lobster (*Nephrops norvegicus*). A highly significant difference in favour of the commercial trawl was found in the weight, but not the numbers, of common pandora (*Pagellus erythrinus*). Efficiency differences were negligible for red mullet (*Mullus barbatus*), while the MEDITS trawl was significantly more efficient for the numbers of Atlantic horse mackerel (*Trachurus trachurus*). For all the other main reference species differences were not significant. The commercial trawl was more efficient for large individuals of some species. The relative efficiency of the MEDITS trawl was especially low for small-size classes of *N. norvegicus*. The results confirm the lower efficiency of the MEDITS compared with the commercial Italian trawl for benthic species, and its greater efficiency for some others released from the bottom as well as for the pelagic ones. These data allow the results of the MEDITS surveys to be compared with those of the GRUND programme and with commercial-fleet catches in areas where the commercial trawls used are similar to the one studied here.

Trawl efficiency / bottom trawls / experimental fishing / gear research / trawl survey / Mediterranean

Résumé — Efficacité du chalut de fond utilisé pour le programme international d'évaluation des ressources halieutiques de Méditerranée (MEDITS). L'objectif de cette étude consiste à estimer l'efficacité relative du chalut d'échantillonnage GOC 73 utilisé dans le cadre du programme international d'évaluation par chalutage des ressources démersales de Méditerranée (MEDITS). Cette estimation est faite par comparaison avec un chalut de type commercial utilisé en Italie. Les raisons du choix de ce chalut commercial italien, comme référence comparative, tiennent à son utilisation courante par les pêcheurs professionnels opérant en Adriatique, zone retenue pour l'étude ; de ce fait, ce type de chalut a paru constituer le meilleur échantillonneur possible vis-à-vis des espèces halieutiques présentes sur ces mêmes fonds. De plus, ce chalut est également d'un type très proche de ceux utilisés dans le cadre du programme national italien d'évaluation des ressources (GRUND). Quatre campagnes de chalutages comparatifs ont été réalisées en 1996 et 1997 dans différentes zones et lors de différentes saisons, afin d'échantillonner différentes espèces. Pour que les maillages utilisés dans les poches des deux chaluts soient de même dimension, le sac du filet commercial était recouvert d'une double poche enveloppante. Chaque campagne a donné lieu, sur un même fond de pêche, à une permutation quotidienne du type de chalut utilisé. Des mesures de la géométrie des chaluts (ouvertures horizontale et verticale) étaient réalisées à l'occasion de chaque trait. Les données relatives aux captures ont été converties en termes d'abondance par unité de surface balayée, avant toute comparaison des résultats des chaluts entre eux. Les comparaisons d'efficacité sont faites sur dix espèces de poissons, une de crustacés et quatre de mollusques, toutes appartenant à la liste des espèces principales de référence du programme MEDITS. Pour le merlu *(Merluccius merluccius)*, la sole *(Solea vulgaris)* et la langoustine *(Nephrops norvegicus)*, le chalut MEDITS présente une efficacité significativement inférieure au chalut commercial, à la fois en poids et en nombre d'individus. Une différence hautement significative a été trouvée en poids, mais non en nombre, pour le pageot *(Pagellus erythrinus)*. Les deux types de chalut présentent une efficacité sensiblement

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identique vis-à-vis du rouget *(Mullus barbatus)*, tandis que le chalut MEDITS s'avère significativement plus efficace que le chalut commercial quant au nombre de chinchards *(Trachurus trachurus)* capturés. Aucune des autres différences relevées pour les espèces principales du programme MEDITS ne s'est avérée significative. Le chalut commercial présente une meilleure efficacité pour les individus de grande taille de quelques espèces. L'efficacité relative du chalut MEDITS est spécialement faible pour les petites classes de taille de *N. norvegicus*. Les résultats ont confirmé que le chalut MEDITS est moins efficace que le chalut commercial vis-à-vis des espèces benthiques, mais plus efficace que ce dernier sur certaines espèces dégagées du fond, de même que sur des espèces pélagiques. Ces résultats permettent de comparer les données tirées des campagnes d'évaluation MEDITS avec celles du programme GRUND, ainsi qu'avec les captures des flottilles commerciales dans les zones où les chaluts utilisés par les pêcheurs sont du même type que celui étudié ici.

Efficacité du chalut / chalut de fond / pêche expérimentale / technologie des engins / chalutage / Méditerranée

1. INTRODUCTION

Bottom-trawl surveys in the North Sea and in the Atlantic have a long tradition, as have studies on the performance of the trawl gear used for such surveys [6, 32]. In particular, trawl geometry has been studied to improve the reliability of surveys [11, 23, 24]. The efficiency of sampling trawls has also been extensively studied. Comparative fishing trials with different trawls or gear arrangements have been described by several authors [10, 12, 13, 30, 31, 33].

In the Mediterranean, national surveys have been conducted for many years [25, 28]. In Italy, some local trawl surveys were started in the early 1980s; a general survey programme (GRUND) covering the whole Italian coast started in 1985 and is still in progress [28]. GRUND is carried out by eleven teams each using a trawl that is typically employed in the area assigned to it. Although these trawls are similar in design, as they all derive from the original commercial Italian trawl, they are not identical. The main differences lie in overall size, mesh dimensions and some hanging details. Moreover, some trawls utilise improvements such as the final part of the wings split into two parts, which provides for a higher vertical opening. Studies of the performance of these trawls showed the influence of warp length and fishing depth on horizontal net opening and swept area [16] and allowed survey results obtained by different teams to be compared [17, 18].

In 1993, the European Commission (Directorate of Fisheries) encouraged a joint survey programme for demersal-resource assessment in the Mediterranean. The Mediterranean international trawl survey (MEDITS) programme was started at the end of 1993 [5]. Its aims were: (i) to contribute to the characterisation of bottom-fisheries resources in terms of population distribution (relative-abundance indices) and demographic structures (length distributions); and (ii) to provide data for modelling the dynamics of the species studied.

The programme originally involved the four Mediterranean countries of the European Union (Spain, France, Italy and Greece). Since 1996, it also includes Albania, Croatia and Slovenia. All partners, although some had national surveys in progress, undertook to adopt the protocols defined for the MEDITS programme. These make provisions for sampling gear (feature and handling), survey design, data collection and management and basic data analysis [5].

The protocols require the same sampling gear to be used throughout the study by all teams. Although there exists several sampling gears for survey purposes (e.g. the *Grande Ouverture Verticale* – GOV – trawl used in North Sea surveys), a new trawl was designed by fishery technologists based on specifications provided by the biologists involved in the programme [5]. The main specifications were: (i) ability to work in all the areas and at all the depths envisaged by the programme (10–800 m); (ii) lowest possible selectivity, to obtain good descriptions of the populations sampled; and (iii) ability to sample efficiently a great variety of species. This last feature is important because even though few species, mainly of benthic behaviour, account for a considerable proportion of the landing value, the great species diversity found in the Mediterranean requires careful fisheries management. For this reason, the programme envisages the study of a main list of 31 reference species including fish, molluscs and crustaceans [1, 5]. The GOC 73 trawl (*figure 1*) represents a compromise between these specifications. Full mesh size in the codend is merely 20 mm, and the vertical opening is slightly higher than in most commercial trawls used in many Mediterranean areas, to increase the catch of demersal species.

A 1:20 scale model of this trawl, built by the Ifremer fishing technology team, was tested in Ifremer's Lorient flume tank in December 1993. Observations and measurements were conducted on both its geometry (vertical and horizontal opening at different trawling speeds) and rigging (different possible sweep lengths and their effects on trawl behaviour). The first full-scale trawl was built at the beginning of 1994 and tested on board the Spanish research vessel *Odon de Buen* in April 1994 [7]. Different adjustments were tested, in particular the warp length/fishing depth ratio, which could not be easily observed in flume-tank tests.

The little time available for the tests before the 1994 survey cruises did not allow the gear to be properly set up. Problems arose, especially with regard to gear-

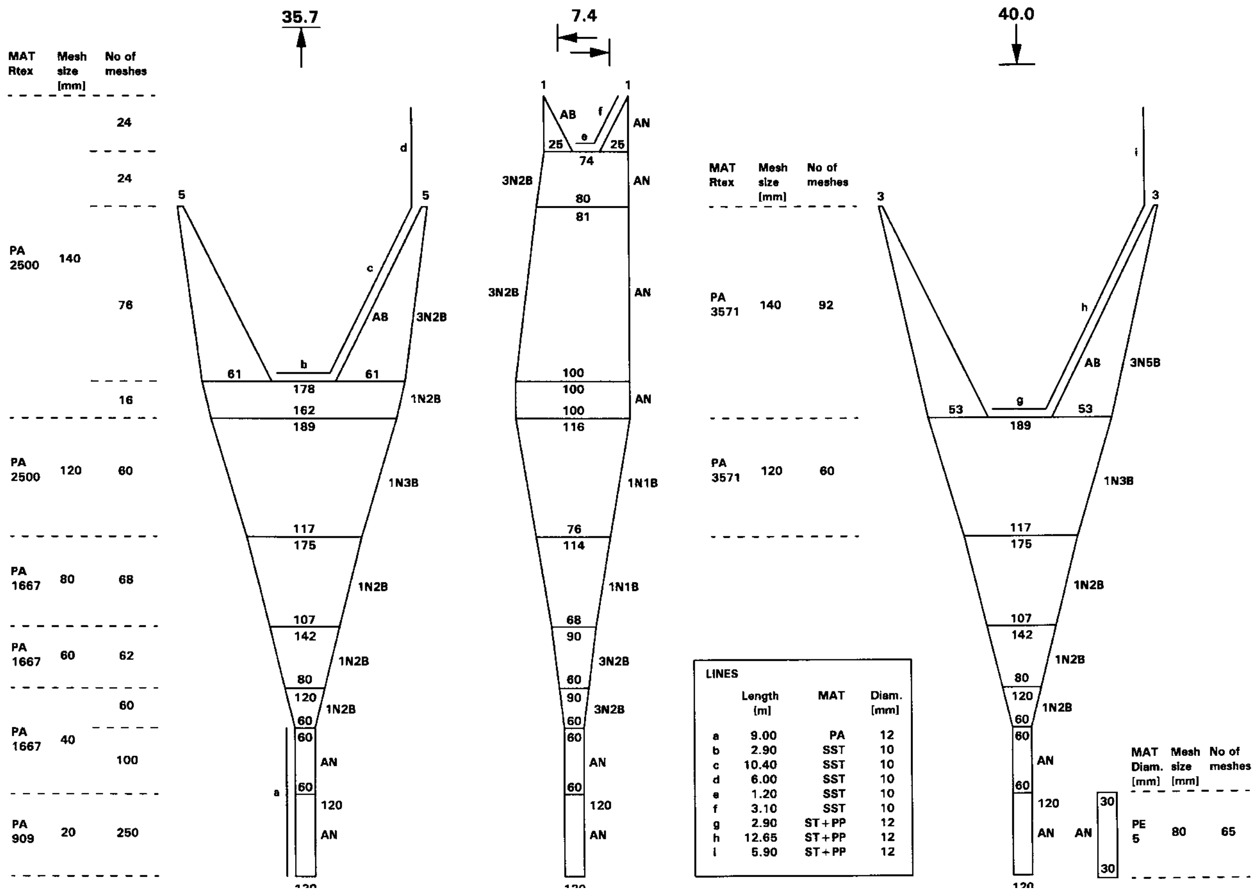

Figure 1. Design of the GOC 73 trawl, used as the standard trawl for the MEDITS programme and designed by Ifremer Sète. Its main characteristics are: headline 35.7 m, sidelines 7.4 m, footrope 40.0 m, two panels with sides, for one boat of 500–1 000 HP, pull at bollard 4.5 t, twine area 54.78 m^2. PA = polyamide, PE = polyethylene, PP = polypropylene, SST = stainless steel, ST = steel.

bottom contact in deep water. In the first MEDITS report [3], some teams working in the Tyrrhenian Sea and the Sicilian Channel (MEDITS areas M1 and M3) observed that the MEDITS trawl catches of benthic species were lower than those of the commercial trawls, while for some species released from the bottom, as well as for pelagic ones, the trawl performed with greater efficiency. These data were later confirmed by the Greek teams [4], who compared the efficiency of the MEDITS trawl with that of some commercial trawls, and by the Italian teams, who compared the 1994 MEDITS results with those of the Italian GRUND programme, which was conducted in approximately the same season [2, 4].

To address these problems, additional tests were planned for the autumn–winter 1994–1995 [8, 15]. Trawl-bottom contact was improved by reducing the vertical opening (from 3 to 2.5 m). Based on the assumption that one sampler cannot be equally effective for all species, a compromise was reached by privileging the sampling of bottom species, which account for a considerable proportion of the landing value, while sacrificing a fraction of the catches of some species of pelagic behaviour. In May 1995, the efficiency of the MEDITS trawl was compared with that of the trawl used in the framework of the GRUND programme in the Sicilian Channel [29] and conversion coefficients between the two trawls were computed for the MEDITS main reference species. The MEDITS trawl, modified following the above-mentioned tests in both features and handling, was first used for the 1995 survey cruises [1, 4]. Benthic-species efficiency improved compared with the previous year, as reported by several teams in the final survey report [4].

This paper describes an experiment conducted to assess the efficiency of the MEDITS trawl by comparing its fishing power with that of an Italian commercial trawl normally used by fishermen in the central Adriatic. The latter was chosen because its performance has been constantly improved by daily use in the fishing grounds where the experiment was carried out, and was thus considered the best possible sampler of the commercial species present in those areas. Even though this comparison does not allow the absolute efficiency of the MEDITS trawl to be assessed, it can

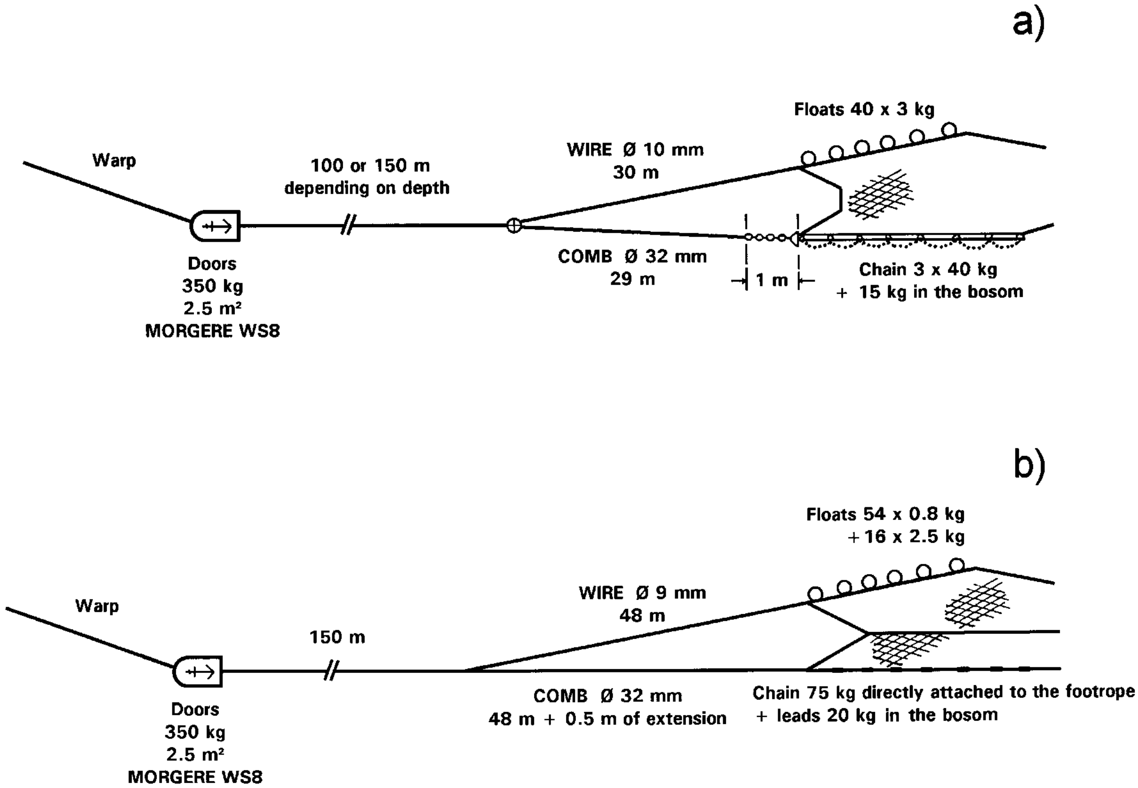

Figure 2. Gear rigging adopted for the MEDITS trawl (a) and for the Italian commercial trawl (b). COMB = combination rope, WIRE = steel wire rope.

at least quantify the performance of this trawl with respect to an efficient commercial trawl.

Other results were expected from the experiment. First of all, the comparison between the two trawls makes it possible to relate MEDITS-trawl catches to those of commercial fleets. Moreover, the Italian commercial trawl is similar in design to the different trawls used for the Italian GRUND programme. Even though the final part of its wings is split in two, unlike most of the other GRUND trawls, it can be taken to represent the mean fishing power of the trawls used for that programme. Although the project of a full inter-calibration of all these trawls with the MEDITS is at present unrealistic, these results can be used to explain some of the differences observed in the results of the two programmes.

2. MATERIALS AND METHODS

2.1. Fishing gear

The GOC 73 trawl (*figure 1*) was used for the present tests, as established by the MEDITS protocol for all survey cruises. Its rigging and all the other components of the gear (*figure 2a*) were those described in the protocol used for the 1995 MEDITS programme [1]. In particular, the warps were paid out according to depth in the measure stated by the protocol, and sweep length was varied from 100 to 150 m for depths lower and greater than 200 m, respectively (*table I*).

The design of the Italian commercial trawl employed for comparison is shown in *figure 3*. Because its codend mesh opening was 43 mm, with a standard deviation of 0.6 mm (measured during the tests with an ICES gauge calibrated to 4 kg), a cover made of the same polyamide netting and with the same full mesh size (20 mm) as that of the MEDITS trawl was used for all hauls. The cover was mounted 1 m ahead of the codend and was 1.5 times larger and longer than the codend. The use of the cover was preferred to replacing the codend with one made of 20-mm mesh to distinguish the commercial catches from those to be compared with that of the MEDITS trawl.

The commercial trawl's rigging is shown in *figure 2b*. The warp length/fishing depth ratio was that established in the MEDITS protocol, while sweep length was 150 m at all depths as used by fishermen.

2.2. Instrumentation

The tests were carried out on board 'S. Lo Bianco', an Italian 660-HP research vessel with a nozzle and a

Table I. Fishing experiment conditions: mean depth per trip for both trawls; number of hauls, trawl gear arrangement and performance per trip.

MEDITS trawl								
Trip	Mean depth (m)	No. of hauls	Warp length (m)	Sweep length (m)	Vessel speed (knots)	Vertical net opening (m)	Horizontal net opening (m)	Door spread (m)
1	73.6	13	400	100	3.17	2.48	17.2	91.6
2	15.1	20	200	100	3.09	2.91	12.3	61.6
3	219.2	13	900	150	3.15	2.45	17.7	115.8
4	112.2	9	600	100	3.06	2.42	18.1	95.8
Commercial trawl								
Trip	Mean depth (m)	No. of hauls	Warp length (m)	Sweep length (m)	Vessel speed (knots)	Vertical net opening (m)	Horizontal net opening (m)	Door spread (m)
1	73.6	12	400	150	3.17	2.04	23.6	107.7
2	15.1	17	200	150	3.09	2.01	16.5	71.7
3	219.2	11	900	150	3.13	2.00	25.3	122.6
4	112.2	9	600	150	3.06	1.96	24.3	119.0

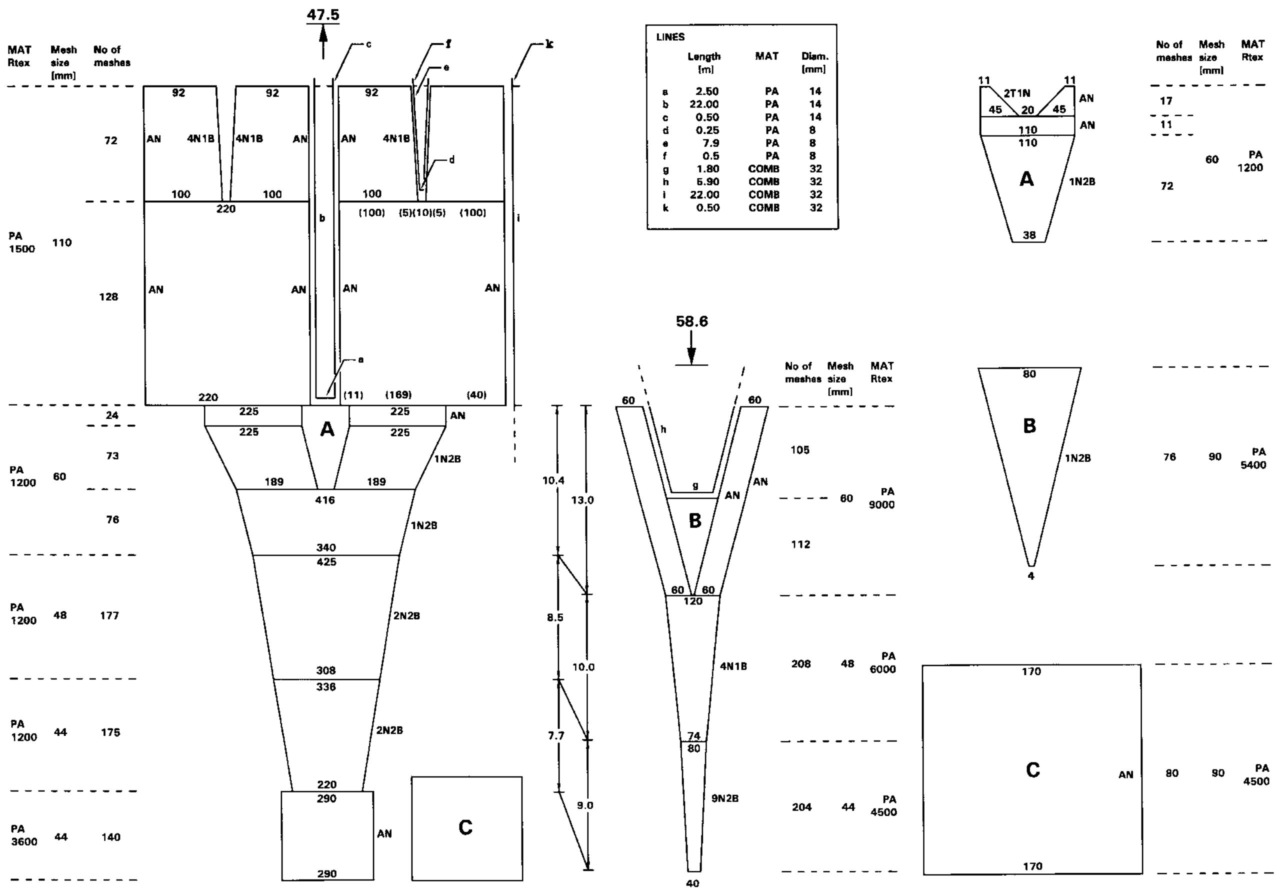

Figure 3. Design of the Italian commercial trawl employed for comparison with the MEDITS trawl. It is normally used by fishermen in the central Adriatic. Its main characteristics are: headline 47.5 m, sidelines 17.05 m, footrope 58.6 m, two panels with the final part of the wings split in two, for one boat of about 500 HP, pull at bollard 3–4 t. PA = polyamide, COMB = combination rope.

controllable pitch propeller. Its instrumentation allowed some vessel-performance parameters to be measured. In particular, a Doppler Log was used to measure instant vessel speed in relation to the sea bed.

An underwater Scanmar system was used to measure gear performance: door spread, horizontal net opening (defined as upper net wing-end spread) and vertical net opening (defined as height of the headline centre above the sea bed).

All these instruments were connected to a portable computer which recorded all measurements every 10 s on the hard disk. A set of data was collected for every haul and processed at IRPEM, Ancona. For each haul, data were averaged after discarding those collected before the stabilisation of gear performance.

2.3. Sampling areas

Four fishing trips were conducted on four fishing grounds of the central Adriatic normally exploited by local fishermen.

In the first trip (end of April–beginning of May 1996), a rectangular area of 5 × 10 nautical miles at a depth of about 70 m off the coast of Ancona was selected to ensure maximum homegeneity of the abundance of some species (in particular *Nephrops norvegicus* and *Merluccius merluccius)*. The area was subdivided into 25 rectangular sub-areas of 1 × 2 nautical miles. Random allocation of hauls (12 and 13 for the commercial and the MEDITS trawl, respectively) was performed avoiding duplication of sampling conditions.

The second sampling trip (end of August–beginning of September 1996) focused on an area lying 10 nautical miles north of Ancona at a depth of about 15 m. The closed fishing season was nearing its end and the abundance of many species was high. All hauls were made in the same direction in a small area of 1 × 5 nautical miles. The starting point and direction of each tow differed slightly owing to uncontrollable effects, such as shooting time, weather and current conditions.

The other two trips were conducted in the Pomo pit, one at its centre, at a depth of about 220 m (June 1997), and the other at its northern boundary, at about 110 m of depth (end of August–beginning of September 1997). These cruises also concentrated on small areas.

The number of hauls made with each trawl, warp and sweep lengths, gear performance and average depth for each trip are reported in *table I*.

2.4. Sampling methodology

The two trawls were used on alternate days. At the beginning of each trip the trawl to be used first was chosen randomly. Adverse weather conditions and trawl damage prevented the same number of hauls from being performed with the two trawls.

The sampling methodology of the MEDITS protocols [1] was followed for both trawls, in particular vessel speed (3 knots) and exclusively daytime hauls.

As tow duration was required to last 30 min up to depths of 200 m and 60 min in deeper water, in the first two trips they lasted 30 min. Since in the third trip the depth was close to 200 m, tows of 30 min were alternated with tows of 60 min. The same was carried out in the fourth trip.

The species caught were divided into three categories: (i) those belonging to the MEDITS main list of 31 reference species; (ii) those belonging to the 27 other MEDITS reference species; and (iii) those which are not included in the MEDITS protocol.

Total number of individuals caught, length-frequency distribution and total weight were recorded for the 31 main reference species with the exception of *Phycis blennoides* and *Spicara flexuosa*. Total numbers and weight were recorded for all the other species.

2.5. Data processing

For each trip, only the species that were caught regularly and abundantly were included in the analysis. Some of the main reference species, which were caught in only some of the hauls, were thus excluded (*Eutrigla gurnardus*, *Helicolenus dactylopterus*, *Lepidorhombus boscii*, *Lophius piscatorius*, *Mullus surmuletus*, *Pagellus bogaraveo*, *Zeus faber*, *Parapenaeus longirostris*); for other species, only the results obtained in some trips could be considered and the others were discarded. Overall, few data were discarded.

For each haul, the numbers and weight of each species were converted into number and kilograms per km^2 based on horizontal net opening (measured by the Scanmar system), vessel speed (measured by the vessel's Doppler Log) and tow duration. Tow duration was the time between the achievement of optimal gear opening and the moment when speed was reduced to recover the warp. The catch in the cover mounted on the commercial trawl was added to the catch in the codend and compared with the catch in the MEDITS trawl's codend, thus overcoming the problem of the different selectivity of the 43-mm mesh of the former.

The statistical tests were performed with the SPSS v. 7.5 software package. Normality (Shapiro-Wilk test) and homogeneity of variances (Levene's test) of catch/area data were verified before applying ANOVA and Student's *t*-tests. In many cases, these assumptions were not met. Since catch data seldom exhibited zero values because of the exclusion of species caught inconstantly and in small numbers, a common $\ln(x + 1)$ transformation was applied to all data. In general, this transformation gave good results in checking the assumptions, and the data analysis was carried out on $\ln(x + 1)$-transformed data.

Because the mean of the original (non-transformed) data may be oversensitive to extreme values and confidence intervals are large, McConnaughey and Conquest [27] suggested the use of an estimator with more desirable statistical properties, i.e. the geometric

Table II. Comparative efficiency of the two trawls for the MEDITS main list of reference species: number of hauls per trip where the species was caught; mean size per trip (total length for fishes in cm; carapace length for crustaceans in mm: mantle length for molluscs in cm); geometric mean of numbers and weight per km^2 and coefficient of variation; test results (A: ANOVA test; S: Student's *t*-test; * significant, $0.01 < P < 0.05$; ** highly significant, $P < 0.01$); efficiency coefficient (ratio between commercial and MEDITS trawl catches).

		No. of hauls		Size		No.·km^{-2}						kg·km^{-2}					
		MEDITS	Comm.	MEDITS	Comm.	MEDITS		Commercial		Diff. test	Efficiency	MEDITS		Commercial		Diff. test	Efficiency
Species	Trip					mean	CV	mean	CV	signif. *P*	coeff.	mean	CV	mean	CV	signif. *P*	coeff.
Merluccius merluccius	1	13	12	17.1	19.3	211	11 %	210	6 %	A 0.035*	1.22	9.5	41 %	14.9	19 %	A 0.007**	1.51
	3	13	11	19.4	21.1	227	5 %	380	6 %			22.1	15 %	42.2	14 %		
	4	9	9	17.0	17.5	624	4 %	691	5 %			33.5	10 %	41.5	10 %		
Micromesistius poutassou	3	13	11	15.5	16.4	1 509	7 %	1 587	7 %	S 0.846	1.05	52.4	12 %	69.2	17 %	S 0.280	1.32
Mullus barbatus	2	20	17	12.6	12.5	90 967	4 %	86 910	4 %	S 0.744	0.96	2 208.8	6 %	2 153.8	7 %	S 0.876	0.98
Pagellus erythrinus	2	20	17	7.4	7.9	2 489	10 %	3 754	5 %	S 0.061	1.51	19.0	21 %	34.8	12 %	S 0.003**	1.83
Phycis blennoides	3	12	11	–	–	81	31 %	54	16 %	S 0.379	0.66	1.2	56 %	0.6	70 %	S 0.069	0.51
Solea vulgaris	2	14	17	23.6	23.7	19	70 %	71	14 %	S 0.019*	3.75	3.9	75 %	8.7	23 %	S 0.032*	2.26
Spicara flexuosa	2	19	17	–	–	621	28 %	1 014	16 %	S 0.337	1.63	6.3	45 %	7.1	48 %	S 0.731	1.13
Trachurus mediterraneus	2	20	17	10.1	10.2	2 467	28 %	6 854	12 %	S 0.087	2.78	29.9	53 %	70.6	22 %	S 0.095	2.36
Trachurus trachurus	1	13	12	8.1	8.4	477	6 %	274	9 %	S 0.006**	0.58	2.4	16 %	1.7	35 %	S 0.053	0.71
Trisopterus minutus capelanus	1	13	12	12.1	12.1	113	15 %	110	13 %	A 0.634	0.92	2.6	38 %	2.9	21 %	A 0.567	0.93
	4	9	9	9.3	8.8	2 009	4 %	1 758	4 %			20.1	12 %	16.0	16 %		
Eledone cirrhosa	3	13	11	7.4	8.2	47	16 %	72	16 %	A 0.059	1.55	8.2	45 %	15.5	36 %	A 0.123	1.57
	4	9	9	3.9	4.1	110	19 %	178	16 %			3.7	52 %	5.5	39 %		
Illex coindetii	1	11	9	14.1	15.2	22	49 %	11	63 %	A 0.865	0.95	2.8	62 %	1.8	77 %	A 0.525	0.90
	3	10	10	15.3	14.7	10	58 %	20	35 %			2.1	63 %	3.6	41 %		
	4	9	9	9.8	8.9	959	7 %	848	9 %			40.3	12 %	26.7	18 %		
Loligo vulgaris	2	20	16	6.2	7.0	1423	11 %	1 594	27 %	S 0.819	1.12	23.9	21 %	27.3	41 %	S 0.711	1.14
Sepia officinalis	2	20	17	5.8	5.6	3 881	5 %	3 799	13 %	S 0.932	0.98	133.0	7 %	128.3	22 %	S 0.889	0.96
Nephrops norvegicus	1	13	12	35.6	36.6	135	25 %	418	17 %	A 0.000**	3.62	6.1	50 %	15.8	34 %	A 0.001**	1.79
	3	13	11	25.7	24.6	813	7 %	1 947	5 %			9.4	17 %	20.1	11 %		
	4	6	9	30.1	24.2	8	80 %	58	19 %			0.4	109 %	0.7	37 %		

Table III. Comparative efficiency of the two trawls for the other MEDITS list of reference species: number of hauls per trip where the species was caught; geometric mean of numbers and weight per km^2 and coefficient of variation; test results (A: ANOVA test; S: Student's *t*-test; * significant, $0.01 < P < 0.05$; ** highly significant, $P < 0.01$); efficiency coefficient (ratio between commercial and MEDITS trawl cat ches).

		No. of hauls		No.·km^{-2}						kg·km^{-2}					
		MEDITS	Comm.	MEDITS		Commercial		Diff. test	Efficiency	MEDITS		Commercial		Diff. test	Efficiency
Species	Trip			mean	CV	mean	CV	signif. *P*	coeff.	mean	CV	mean	CV	signif. *P*	coeff.
Boops boops	2	20	17	7 061	5 %	5 436	5 %	S 0.094	0.77	61.2	10 %	58.7	17 %	S 0.821	0.96
Diplodus annularis	2	14	13	28	73 %	70	63 %	S 0.290	2.54	3.0	85 %	6.1	74 %	S 0.186	2.05
Engraulis encrasicolus	1	10	8	56	67 %	30	83 %	A 0.010*	0.33	2.7	111 %	1.8	109 %	A 0.001**	0.40
	2	20	17	31 701	10 %	11 041	12 %			240.1	16 %	85.2	25 %		
	4	9	9	2 687	14 %	492	24 %			39.9	30 %	8.1	58 %		
Lepidopus caudatus	3	13	11	244	9 %	359	15 %	S 0.198	1.47	157.7	10 %	212.7	18 %	S 0.339	1.35
Sardina pilchardus	1	8	7	18	89 %	24	94 %	A 0.026*	2.84	1.7	116 %	2.6	109 %	A 0.001**	2.38
	2	19	17	450	28 %	3 515	11 %			12.5	36 %	76.1	19 %		
	4	8	9	55	40 %	126	25 %			3.2	52 %	6.3	47 %		
Trigla lucema	2	17	17	29	46 %	78	20 %	S 0.029*	2.72	3.7	57 %	7.5	40 %	S 0.047*	2.03
Squilla mantis	2	20	17	3 369	5 %	2 957	5 %	S 0.332	0.88	154.0	7 %	133.4	8 %	S 0.258	0.87

Table IV. Comparative efficiency of the two trawls for the species not included in the MEDITS protocol: number of hauls per trip where the species was caught; geometric mean of numbers and weight per km² and coefficient of variation; test results (A: ANOVA test; S: Student's *t*-test; * significant, $0.01 < P < 0.05$; ** highly significant, $P < 0.01$); efficiency coefficient (ratio between commercial and MEDITS trawl catches).

		No. of hauls		No.·km⁻²						kg·km⁻²					
Species	Trip	MEDITS	Comm.	MEDITS mean	MEDITS CV	Commercial mean	Commercial CV	Diff. test signif. *P*	Efficiency coeff.	MEDITS mean	MEDITS CV	Commercial mean	Commercial CV	Diff. test signif. *P*	Efficiency coeff.
Gaidropsarus megalocynodon	1	9	10	10	72 %	23	53 %	A 0.001**	2.98	0.2	108 %	0.3	85 %	A 0.000**	1.22
	3	13	11	91	9 %	220	9 %			0.8	41 %	1.8	26 %		
	4	6	9	9	76 %	47	12 %			0.1	78 %	0.3	66 %		
Arnoglossus laterna	1	11	12	43	48 %	79	23 %	A 0.030*	2.37	0.2	75 %	0.3	82 %	A 0.000**	1.32
	2	14	17	35	68 %	418	11 %			0.5	86 %	2.4	38 %		
	4	9	8	78	23 %	49	44 %			0.4	74 %	0.4	91 %		
Buglossidium luteum	2	10	14	8	103 %	47	51 %	S 0.023*	5.91	0.2	135 %	0.9	64 %	S 0.001**	3.49
Callionymus maculatus	1	13	12	72	14 %	217	11 %	A 0.000**	5.69	0.3	51 %	0.8	51 %	A 0.000**	1.45
	2	14	15	32	70 %	165	41 %			0.3	95 %	0.8	71 %		
	4	7	9	27	64 %	340	12 %			0.2	138 %	1.0	42 %		
Cepola rubescens	1	13	12	593	14 %	523	11 %	A 0.548	1.26	10.7	29 %	10.6	21 %	A 0.995	1.00
	4	8	9	38	42 %	69	23 %			1.5	58 %	1.5	58 %		
Chlorophthalmus agassizii	3	10	10	13	61 %	28	38 %	S 0.224	2.22	0.1	88 %	0.2	77 %	S 0.070	2.01
Gadiculus argenteus	3	13	11	605	8 %	1 047	8 %	S 0.022*	1.73	2.9	38 %	5.6	26 %	S 0.018*	1.93
Gobius niger	2	20	17	790	16 %	2 842	12 %	S 0.001**	3.60	8.1	44 %	30.4	27 %	S 0.000**	3.74
Lesueurigobius friesii	1	13	12	494	8 %	266	14 %	A 0.951	0.97	1.0	25 %	0.6	61 %	0.622	0.97
	3	13	11	2 093	3 %	2 157	6 %			2.9	13 %	2.8	24 %		
	4	9	9	115	22 %	189	20 %			0.3	82 %	0.5	70 %		
Liza saliens	2	16	14	49	60 %	27	52 %	S 0.404	0.55	9.9	71 %	5.4	58 %	S 0.276	0.55
Maurolicus muelleri	3	13	11	9 098	13 %	2 176	16 %	S 0.009**	0.24	10.9	35 %	3.0	63 %	S 0.006**	0.28
Sardinella aurita	2	2	3	1	310 %	2	224 %	S 0.405	2.83	0.1	312 %	0.5	228 %	S 0.253	3.37
Scomber scombrus	2	12	14	18	86 %	45	53 %	S 0.245	2.54	1.5	102 %	1.9	82 %	S 0.578	1.30
Serranus hepatus	1	13	12	81	16 %	68	20 %	A 0.654	1.10	0.6	72 %	0.5	74 %	A 0.907	0.99
	2	20	17	1 729	10 %	1 566	14 %			5.3	36 %	4.9	46 %		
	4	8	9	26	44 %	46	11 %			0.4	68 %	0.4	30 %		
Sprattus sprattus	1	8	9	25	87 %	25	71 %	S 0.994	0.99	1.8	110 %	1.3	106 %	S 0.631	0.72
Alloteuthis media	1	13	12	165	11 %	192	8 %	A 0.133	1.39	1.1	34 %	1.3	34 %	A 0.219	1.14
	2	19	17	389	26 %	871	12 %			2.7	43 %	4.4	35 %		
	4	9	9	1 982	4 %	2 064	7 %			4.3	14 %	3.8	25 %		
Sepia elegans	1	13	12	92	13 %	123	12 %	S 0.241	1.34	0.5	40 %	0.6	40 %	S 0.663	1.09
Sepiola sp.	1	8	10	9	83 %	19	49 %	A 0.201	1.59	0.1	94 %	0.2	72 %	A 0.206	1.05
	2	8	10	5	127 %	12	88 %			0.1	159 %	0.3	117 %		
	3	13	10	137	13 %	100	35 %			0.5	30 %	0.4	55 %		
	4	8	9	28	41 %	63	18 %			0.3	82 %	0.4	47 %		
Chlorotocus crassicornis	3	10	10	16	60 %	44	38 %	S 0.139	2.79	0.1	79 %	0.2	60 %	S 0.030*	2.01
Philocheras sp.	3	13	11	99	15 %	125	14 %	S 0.418	1.26	0.1	58 %	0.1	65 %	S 0.700	1.11
Plesionika heterocarpus	3	13	11	289	6 %	308	4 %	S 0.627	1.07	0.5	27 %	0.6	15 %	S 0.556	1.07
Pomatoschistus sp.	1	12	10	111	32 %	57	48 %	A 0.823	0.90	0.1	50 %	0.1	63 %	A 0.782	1.02
	4	9	9	304	24 %	475	21 %			0.3	83 %	0.4	85 %		
Pontophilus spinosus	1	11	11	26	51 %	53	42 %	A 0.238	1.54	0.1	96 %	0.2	83 %	A 0.103	1.06
	3	13	11	151	11 %	175	10 %			0.2	45 %	0.3	43 %		
Processa sp.	3	13	11	282	8 %	353	10 %	S 0.320	1.25	0.6	39 %	0.7	43 %	S 0.321	1.24
Solenocera membranacea	3	13	11	880	6 %	853	12 %	S 0.902	0.97	1.8	24 %	1.8	55 %	S 0.896	1.04

Table V. Mean number of different species caught per haul, separately computed for the two trawls and for the four trips, both inside the three species categories considered and in all the species caught; ANOVA test results: ** highly significant; $P < 0.01$.

	Trip	Mean number of species		ANOVA results	
		MEDITS	Commercial		
MEDITS main reference species	1	6.38	6.75	trip	0.000**
	2	6.85	7.53	trawl	0.002**
	3	8.69	9.82	trip × trawl	0.709
	4	8.33	9.33		
	marginal mean	7.57	8.36		
Other MEDITS reference species	1	2.92	3.42	trip	0.000**
	2	5.95	6.24	trawl	0.007**
	3	2.46	2.45	trip × trawl	0.097
	4	3.89	5.44		
	marginal mean	3.81	4.39		
Non MEDITS species	1	12.46	12.92	trip	0.000**
	2	8.50	10.65	trawl	0.000**
	3	12.54	14.09	trip × trawl	0.225
	4	10.89	12.78		
	marginal mean	11.10	12.61		
All species	1	21.77	23.08	trip	0.000**
	2	21.30	24.41	trawl	0.000**
	3	23.69	26.36	trip × trawl	0.261
	4	23.11	27.56		
	marginal mean	22.47	25.35		

mean. This estimator was thus computed by exponentiating the mean of the log-transformed data and by subtracting one. This estimator is reported in the tables and was used for all the comparisons.

A two-way analysis of variance (ANOVA) was used to compare the trawls' efficiency in terms of both number of individuals and weight for the species caught regularly and abundantly in two or more trips. Factors were the two trawls and the trips. A simple Student's *t*-test was used to compare catch data referring to only one trip. Differences were considered significant when the test probability was below 0.05 and highly significant when it was below 0.01.

For each species, an efficiency coefficient between the two trawls was computed as the ratio between the mean catch of the commercial and the MEDITS trawl. This calculation was made by subtracting the two means of the log-transformed data and then making the exponent of the result [14]. For the data from species caught in more than one trip, the marginal means computed by ANOVA were used to obtain a single coefficient.

The results are summarised in *tables II*, *III* and *IV*, one for each species category considered. These tables report the number of hauls per trip where each species was caught, the geometric mean and variation coefficient of the numbers and weight of the individuals caught by each trawl, difference-test results and efficiency coefficients. Because all the ANOVA tests showed the factor trip to be highly significant and trawl-trip interactions to be non-significant, only the probability associated with the trawl factor is reported. *Table II* also reports mean size per trip (total length for fishes, carapace length for crustaceans and mantle length for molluscs).

For the main reference species, the size-frequency distributions of each haul were converted into size-class abundance per km^2. Mean size-frequency distribution was computed for each fishing trip for the commercial (codend + cover) and the MEDITS trawl. The two distributions were then compared to assess the efficiency of the MEDITS trawl per size class. The MEDITS trawl proportion of total (MEDITS + commercial trawl) catch per size class was also computed. For each species, weighted regression lines, where the number of individuals caught was the weight variable, were computed for these proportions against size.

The mean number of species caught per haul was separately computed for the two trawls and for the four trips, both within the three species categories and for all the species caught. A two-way analysis of variance, with the trawls and trips as factors, was performed on these four sets of data. The analysis was performed on non-transformed data because normality and homogeneity of variances of the original data were met. The results are reported in *table V*.

3. RESULTS

3.1. Technical parameters

The mean horizontal opening of the commercial trawl was greater than the MEDITS' in all trips (*table I*), as was its door-spread. Both values increased with bottom depth and warp length.

The MEDITS trawl had a high vertical opening which decreased from around 2.91 m at lower depths (15 m) to about 2.42 m at greater depths (73–220 m). The vertical opening of the commercial trawl varied slightly with depth from 2.04 m to 1.96 m (*table I*).

3.2. Efficiency for the MEDITS main reference species

3.2.1. Hake (Merluccius merluccius)

Hake were caught regularly in the first, third and fourth sampling trips. In all three cruises, catch in weight per area was lower for the MEDITS trawl. The number of individuals per area caught by the two trawls was similar in the first trip, while in the third and fourth trips a larger number of individuals was caught by the commercial trawl. The difference in numbers was significant ($P = 0.035$), while the difference in weight was highly significant ($P = 0.007$). During the first trip, mean total length (TL) was much lower for the MEDITS (17.1 cm) than for the commercial trawl (19.3 cm). In the third and fourth trips differences were smaller, with TL values of 19.4 and 17.0 cm for the MEDITS and 21.1 and 17.5 cm for the commercial trawl, respectively.

The size-frequency distributions of the individuals caught by the two trawls (*figure 4a, c, e*) reflect the catch variability observed in these three trips. The average of the three size-frequency distribution values is shown in *figure 4g*.

The proportion of the MEDITS trawl catch per size class was close to 50 % of total (MEDITS + commercial trawl) catch per size class (*figure 4h*) up to approximately 30 cm, with some higher values for the MEDITS trawl between about 7 and 11 cm, and for the commercial trawl in the other size classes. In the fourth trip, where hake catches were most numerous (648 individuals·km^{-2} codend versus 234 in the 3rd trip), the catch proportion curve (*figure 4f*) was closer to the mean value. Nevertheless, compared with the commercial trawl, the MEDITS trawl missed a large number of individuals in the 30–38-cm range. The efficiency of the MEDITS trawl for the 32–33-cm size class was only 10 % of the total catch of the two trawls. Over 40 cm, there were considerable fluctuations in the efficiency of the two trawls. The very small number of individuals caught in the larger size range may explain these variations. The weighted regression line of averaged trip data (*figure 4h*) was statistically significant ($P = 0.003$).

3.2.2. Blue whiting (Micromesistius poutassou)

This species was caught only in the third trip. The efficiency of the commercial trawl was 1.32 times greater in weight and 1.05 times greater in numbers, neither difference being significant. Mean TL was 15.4 and 16.4 cm for the specimens caught by the MEDITS and the commercial trawl, respectively.

The proportion of the MEDITS trawl catch per size class was close to 50 % of total catch per size class (*figure 5b*) up to around 17 cm, and decreased for larger size classes. The weighted regression line was statistically significant ($P < 0.001$).

3.2.3. Red mullet (Mullus barbatus)

This species was regularly caught only in the second trip, even though it was present in some other hauls. There were no significant differences in efficiency between the two trawls, even though the weight and numbers of specimens caught by the commercial trawl were slightly smaller. Small differences were also found in mean TL: 12.6 cm for the MEDITS and 12.5 cm for the commercial trawl.

3.2.4. Common pandora (Pagellus erythrinus)

This species was found in some hauls of the first trip, but it was caught regularly only in the second trip. The weight efficiency of the commercial trawl was 1.83 times greater than that of the MEDITS trawl and this difference was highly significant ($P = 0.003$). As regards the number of specimens caught, the commercial trawl was more, though less remarkably (1.51 times), efficient and this difference was not significant ($P = 0.061$). Mean TL was smaller for the specimens caught by the MEDITS trawl (7.4 cm) than for those caught by the commercial trawl (7.9 cm).

The proportion of the MEDITS trawl catch per size class out of the total catch per size class (*figure 5d*) decreased with size in the whole range measured. It was close to 50 % in the 4–8 cm size range and decreased for larger size classes. The weighted regression line was statistically significant ($P = 0.004$).

3.2.5. Greater forkbeard (Phycis blennoides)

This species was regularly caught only in the third trip, although some specimens were also caught in the first and fourth trips. Even though the MEDITS trawl was nearly twice as efficient as the commercial trawl, the differences were not significant for either specimen numbers or weight.

3.2.6. Common sole (Solea vulgaris)

In the second trip, *S. vulgaris* were caught by the commercial trawl in all the hauls, but in only 14 of the 20 hauls made with the MEDITS trawl. No specimens were caught in the other trips. The commercial trawl was more efficient in terms of both weight and number of individuals, with significant differences for both ($P = 0.032$ and $P = 0.019$, respectively). The two nets caught the same fish size: 23.6 and 23.7 cm for the MEDITS and the commercial trawl, respectively.

3.2.7. Picarel (Spicara flexuosa)

This species was also found in the hauls of the first and fourth trips, but it was caught regularly only during the second. As in the case of *S. vulgaris*, the commercial trawl was more efficient in both specimen weight and numbers, although in this case differences were not significant.

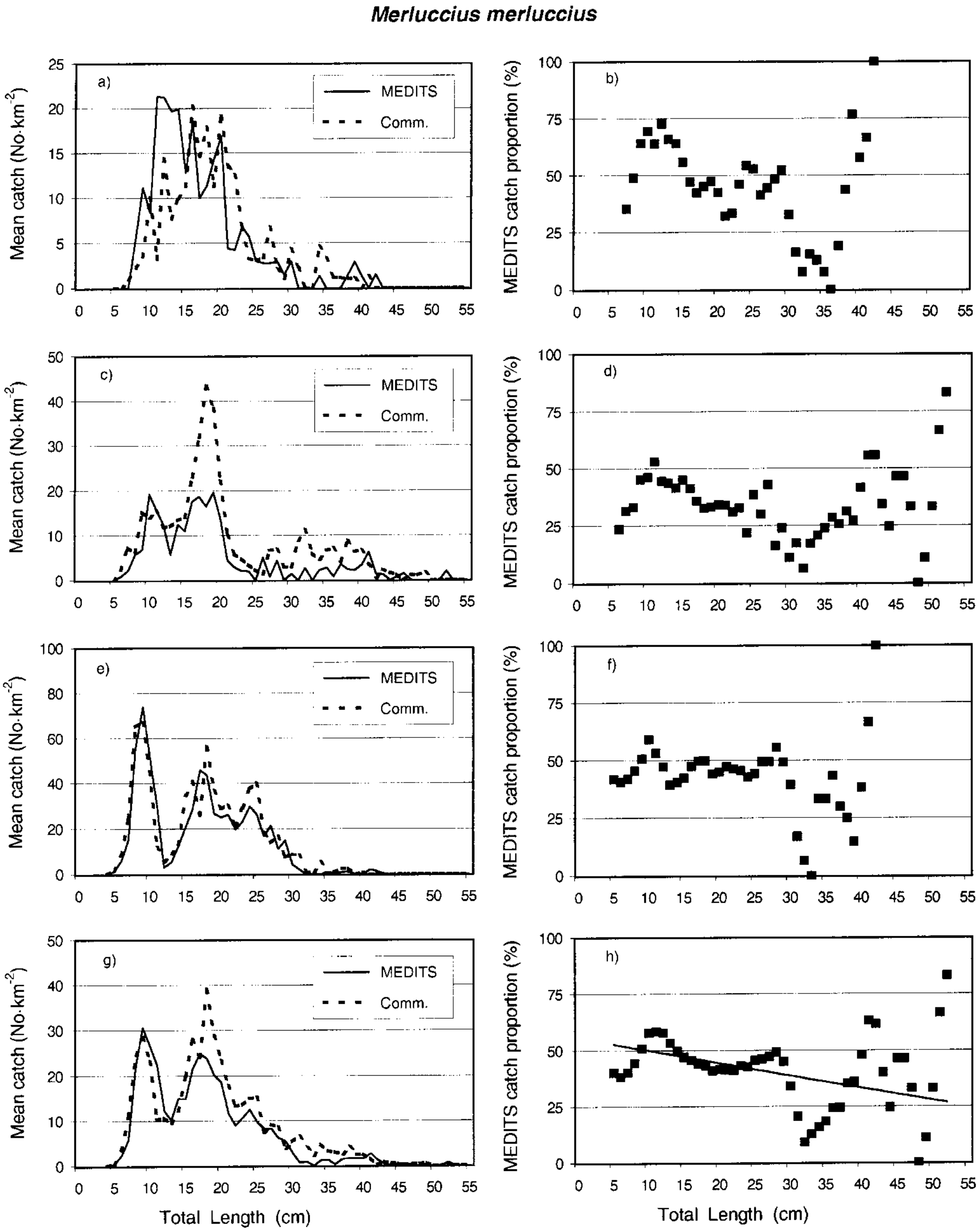

Figure 4. Mean size-frequency distributions per km² of hake (*Merluccius merluccius*) caught by the MEDITS and commercial trawls in the first (a), third (c) and fourth (e) trips and average of the three trips (g). Proportion of the MEDITS trawl catch of the total (MEDITS + commercial trawl) catch in the three trips separately (b, d and f) and their average (h). The weighted regression line of proportion against size, computed with the number of individuals caught as weight variable, is also reported for the averaged data (h).

3.2.8. *Mediterranean horse mackerel* (Trachurus mediterraneus)

They were caught in all the trips, but their presence in the captures was sporadic except for the hauls of the second trip. For this species, the MEDITS trawl was less efficient than the commercial trawl, but the differences were not significant. The mean TL of the specimens caught by the MEDITS trawl (10.1 cm) was practically equal to that computed for the commercial trawl (10.2 cm).

3.2.9. *Atlantic horse mackerel* (Trachurus trachurus)

As in the case of *T. mediterraneus*, this species was present in many hauls of all trips, but not in a regular way and sometimes with very few specimens. Only

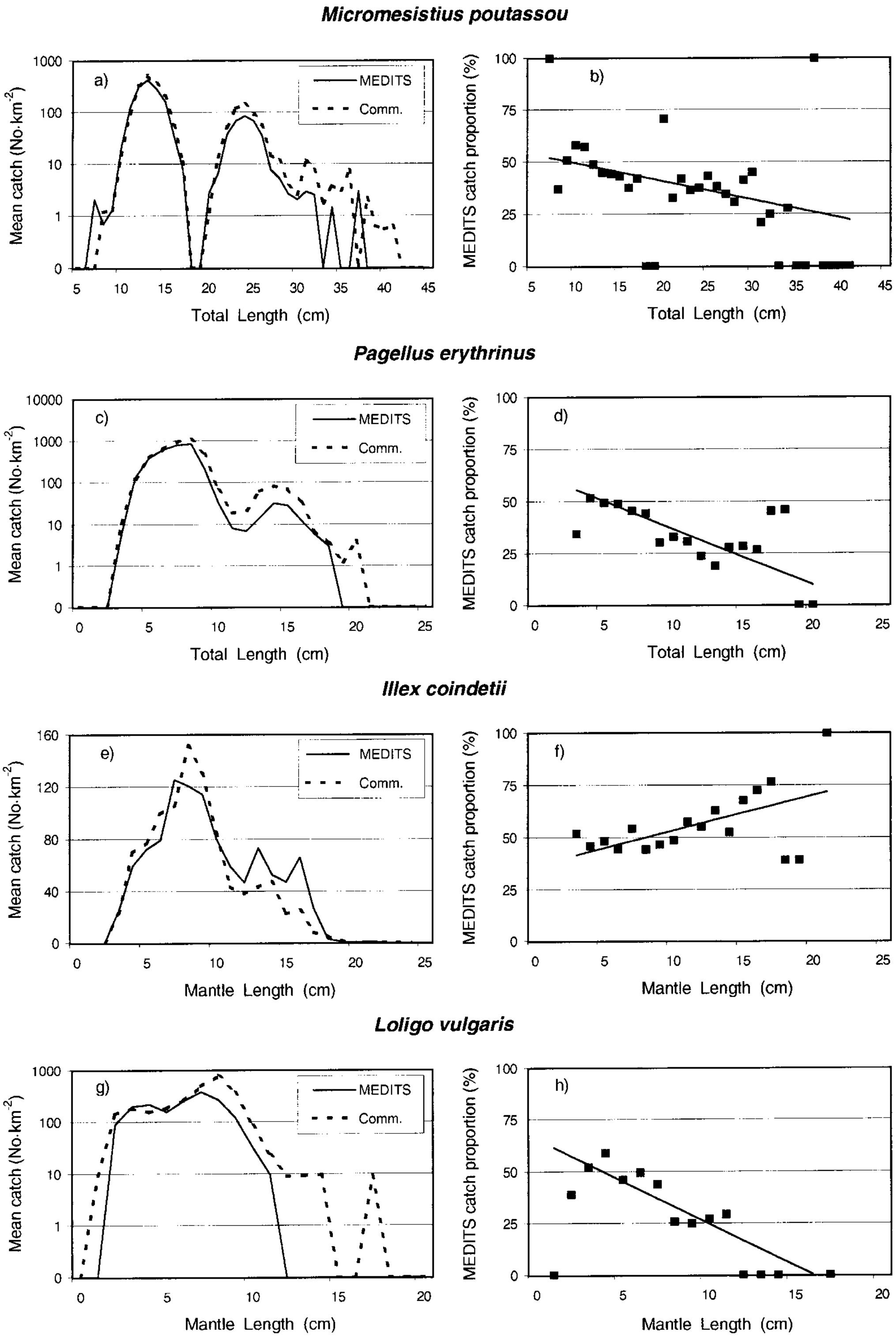

Figure 5. Mean size-frequency distributions per km^2 of blue whiting (*Micromesistius poutassou*) caught by the MEDITS and commercial trawls in the third trip (a), of common pandora (*Pagellus erythrinus*) in the second trip (c), of broadtail squid (*Illex coindetii*) in the fourth trip (e) and of European squid (*Loligo vulgaris*) in the second trip (g). Proportion of the MEDITS trawl catch of the total (MEDITS + commercial trawl) catch for the four species (b, d, f and h). The weighted regression lines of proportions against size, computed with the number of individuals caught as weight variable, are also reported.

during the first trip was *T. trachurus* caught in each haul and in a relatively high number of specimens. The efficiency of the commercial trawl for this species was low, with catches of only 71 % of the weight and 58 % of the number of the individuals caught by the MEDITS trawl. The difference was highly significant for the latter parameter (P = 0.006). Mean TL was 8.1 cm for the MEDITS and 8.4 cm for the commercial trawl.

3.2.10. Poor cod (Trisopterus minutus capelanus)

Poor cod were caught only in the first and fourth trips. There were very small efficiency differences between the two trawls in the first trip, with specimen mean TL of 12.1 for both. The MEDITS trawl was more, though not significantly, efficient in the fourth trip, when the population sampled was smaller: 9.3 and 8.8 cm for the MEDITS and the commercial trawl, respectively.

3.2.11. Horned octopus (Eledone cirrhosa)

This species was caught regularly only in the third and fourth trips, although some specimens were occasionally caught also in the first. The efficiency of the commercial trawl was about 1.5 times greater than that of the MEDITS trawl for both weight and numbers, but differences were not significant. Population sizes differed widely in the two trips: mean mantle length (ML) was, respectively, 7.4 and 8.2 cm for the MEDITS and the commercial trawl in the third trip, and 3.9 and 4.1 cm in the fourth.

3.2.12. Broadtail squid (Illex coindetii)

This species was caught regularly in the first, third and fourth trips, but abundantly only in the fourth. The low catch rates of the first two may explain the contradictory efficiency data obtained with the two nets: in the first trip, the MEDITS trawl appeared to be more efficient, but in the third the commercial trawl produced better results. In the fourth trip, when catches were abundant, the MEDITS trawl was more, though not significantly, efficient. In this trip, mean ML was 9.8 and 8.9 for the MEDITS and the commercial trawl, respectively.

The size-frequency distributions of the individuals caught by the two trawls in the fourth trip are shown in *figure 5e*. The results seem to indicate that the greater efficiency of the MEDITS trawl was mainly due to large-size individuals. The weighted regression line (*figure 5f*) computed for proportion against size was significant (P = 0.001).

3.2.13. European squid (Loligo vulgaris)

With the exception of two hauls, this species was caught only in the second trip. The commercial trawl was slightly more efficient, with non-significant differences. Mean ML was greater for the specimens caught by the commercial (7.0 cm) than by the MEDITS trawl (6.2 cm).

The proportion of the MEDITS trawl catch per size class out of the total catch per size class *(figure 5h)* decreased with size. It was close to 50 % in the 2–7-cm size range, and lower for larger size classes. The weighted regression line was significant (P = 0.001).

3.2.14. Common cuttlefish (Sepia officinalis)

This species was regularly caught only in the second trip, although some specimens were occasionally caught in the first. The catches of the two trawls were virtually equal and the differences were non-significant. There was practically no difference in mean ML: 5.6 and 5.8 cm, respectively, for the commercial and the MEDITS trawl.

3.2.15. Norway lobster (Nephrops norvegicus)

This was the only crustacean from the MEDITS main list of reference species to be caught regularly in the present experiments. It was caught in large numbers in the first and the third trips, and occasionally in the fourth. In all cases, the commercial trawl was the more efficient. The ratio between the catches of the commercial and the MEDITS trawl was about 3 for the first trip, with mean carapace length (CL) of 36.6 and 35.6 mm, respectively. The third trip focused on an area characterised by higher density and smaller mean size [20, 22] and mean CL was 24.6 and 25.7 mm, respectively. In this case, the efficiency ratio was more than double. The coefficient calculated from the ANOVA marginal means was 1.79 for weight and 3.62 for numbers. The differences were highly significant for both parameters.

The average size-frequency distributions of the individuals caught by the MEDITS and the commercial trawl in the first and third fishing trips are shown in *figure 6a*, *c*, respectively. In the first trip, when the majority of individuals caught exceeded 25 mm in CL, the relative efficiency of the two trawls did not show clear size trends (*figure 6b*). In the third trip, when most of the individuals caught by the MEDITS trawl were less than 35 mm in CL, an efficiency loss for small size classes was observed. This is clearly shown by the proportion of the MEDITS trawl catch per size class out of the total catch per size class ((*figure 6d*). The weighted regression line was statistically significant (P < 0.001).

3.3. Efficiency for the other MEDITS reference species

Among the other MEDITS reference species (*table III*), two pelagic ones, anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*), were regularly caught in the first, second and fourth trips. Captures were considerable, especially in the second. The two species showed a completely different behaviour with the two gears: while the MEDITS trawl was more efficient for *E. encrasicolus* in all three trips, the commercial trawl was much more efficient for *S.*

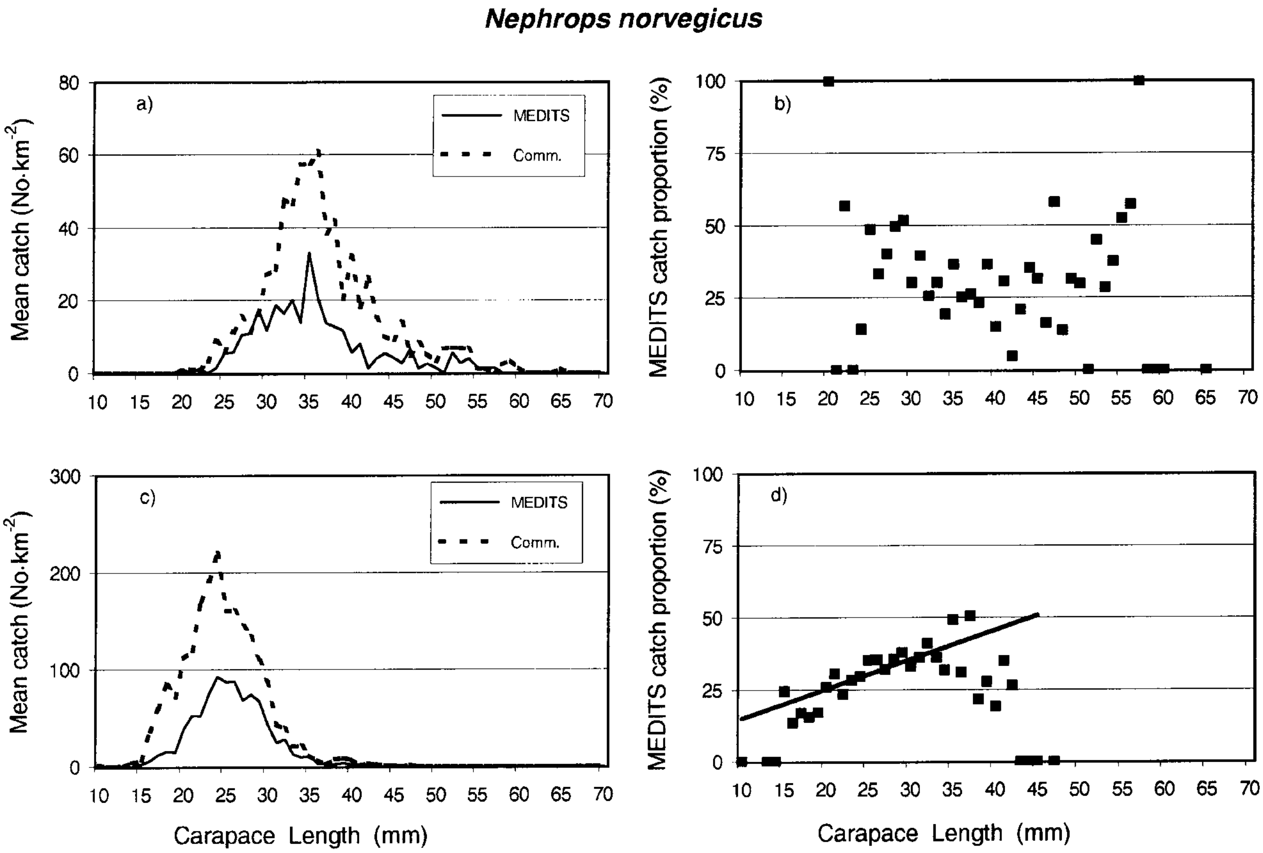

Figure 6. Mean size-frequency distributions per km^2 of Norway lobster (*Nephrops norvegicus*) caught by the MEDITS and commercial trawls in the first (a) and third (c) trips. Proportion of the MEDITS trawl catch of the total (MEDITS + commercial trawl) catch in the two trips (b and d). The weighted regression line of proportion against size, computed with the number of individuals caught as weight variable, is also reported for the third trip (d).

pilchardus. These results were highly significant for weight and significant for the number of individuals.

Another species which showed significant differences with the two trawls in both weight and numbers was *Trigla lucerna*, although captures were comparatively low. For this species, the efficiency of the commercial trawl was more than twice that of the MEDITS trawl.

The commercial trawl was also more efficient for two other species, *Diplodus annularis* and *Lepidopus caudatus*, caught in the second and third trips, respectively, but the differences were not significant.

By contrast, the MEDITS trawl was more efficient for *Boops boops* and *Squilla mantis*, two species caught during the second trip. Also in this case, the differences were non-significant.

3.4. Efficiency with other species

Among the species not included in the MEDITS protocol (*table IV*), the commercial trawl was significantly more efficient for: *Antonogadus megalokynodon*, *Arnoglossus laterna*, *Buglossidium luteum*, *Callionymus maculatus*, *Gadiculus argenteus* and *Gobius niger*.

The MEDITS trawl was significantly more efficient in fishing *Maurolicus muelleri*.

Molluscs seemed to be better sampled by the commercial trawl, but without significant differences. Differences in efficiency for crustacean species were not significant except for *Chlorotocus crassicornis* (in weight only, but the catch of this species was low).

3.5. Number of species caught per haul

The mean number of different species caught per haul by the MEDITS trawl was smaller than that computed for the commercial trawl (*table V*). This result was obtained in all trips and for all three species categories with one exception: for the other MEDITS reference species, the MEDITS trawl caught an average 2.46 species per haul in the third trip compared with 2.45 of the commercial trawl.

The commercial trawl caught about one species more than did the MEDITS when only the two MEDITS lists of reference species are considered. The difference was larger (about 1.5) when the species not included in the MEDITS lists are also considered, and obviously increased further when all the species caught are considered.

ANOVA shows that the differences between the two trawls were all highly significant (*table V*), as were the differences among the four trips, while their interactions were always not significant.

4. DISCUSSION

The estimator used to compare the catch efficiency of the two trawls was the geometric mean, although the arithmetic mean is used as abundance index in the MEDITS programme results. The reasons for this choice were that the arithmetic mean of the original data may be oversensitive to extreme values, and that confidence intervals are large [27]. For instance, for some species (e.g. *T. mediterraneus* and *S. officinalis*) an exceptional catch in a single haul was more likely to be caused by environmental factors than by trawl behaviour. The geometric mean reduces the influence of these occasional values and produces much lower confidence intervals. However, for most species, in particular those for which differences were significant, the efficiency coefficients computed with the geometric and arithmetic means were not appreciably different. Nevertheless, the efficiency differences observed between the two trawls with most species were not significant, despite logarithmic transformation, because of the great variability of catches.

The present work was performed by carrying out four fishing trips on as many fishing grounds, each characterised by different reference species. Captures of 15 of the 31 MEDITS main reference species were abundant. Some were present in more than one area: for example, *M. merluccius* and *N. norvegicus* were caught in the first, third and fourth trips. Despite their different abundance, and sometimes different mean size, efficiency comparisons gave similar results in the different areas, as demonstrated by the fact that trawl-trip interactions were not significant.

Results are reported for all the species caught abundantly, including those not belonging to the MEDITS main list of reference species, to gain a better understanding of the behaviour of the MEDITS trawl. Accordingly, data for some species, such as *A. laterna* or *B. luteum* (which belong to neither lists), have been included to better assess the efficiency of the MEDITS trawl for benthic species. The data for *E. encrasicolus* and *S. pilchardus* have been included to gain information of trawl behaviour with pelagic species, despite the fact that bottom-trawl surveys are known to be less suitable for the abundance evaluation of such species than other methods, such as acoustic techniques [26].

The general idea formed by most MEDITS programme teams is that the MEDITS trawl is particularly efficient with species released from the bottom, as well as pelagic ones, and less so with benthic ones [2, 3, 4]. These impressions were to a great extent confirmed by the present study. This trawl's efficiency was quite low with respect to the commercial trawl for strictly benthic species such as *S. vulgaris*, *A. laterna*, *B. luteum* and burrowing species such as *N. norvegicus*. However, *S. mantis*, another burrowing species [21, 22], was efficiently sampled by the MEDITS trawl, although the behaviour of this species is different from that of *N. norvegicus*.

The efficiency of the MEDITS trawl for species released from the bottom, as well as for pelagic ones, is proved by the results obtained with *T. trachurus*, *B. boops* and, especially, *E. encrasicolus*. Although the catches of *S. pilchardus* seem to demonstrate the opposite, it must be noted that the vertical opening of a trawl can considerably affect the catch of some demersal and mid-water species, and that the commercial trawl used for the present tests had a fairly high one (about 2 m). This opening was not much smaller than that of the MEDITS trawl (2.4–2.9 m), whereas that of the old, traditional Italian trawl, which does not have split wings, has a vertical opening of about 1 m [16]. This last type of trawl is still in use in some parts of Italy and is employed by some of the GRUND teams [17, 18]. An efficiency comparison between the old Italian commercial trawl and the MEDITS's for some demersal and for pelagic species would doubtlessly produce greater differences than those seen in the present experiment.

With reference to efficiency for benthic species, all the Italian trawls, including the one used in the present work and those used in the GRUND programme, share similar features. These trawls are characterised by close bottom contact: not only the footrope but also the whole lower panel – as demonstrated by the dirt found in these portions after each haul – is towed in close contact with the sea bed.

This feature is produced by their design (*figure 3*). The trawl body consists of two completely different, asymmetric panels, the upper panel being larger and shorter and the lower one narrower and longer. The former is made of a thinner netting and forms both the top and the sides of the main trawl body. The lower panel is made of heavier material and has a greater amount of slack (20–30 %) to maximise bottom contact.

By contrast, the MEDITS trawl has a high vertical opening, it consists of four panels, symmetric in pairs, and corresponding sections are made of the same netting (*figure 1*). It has been observed that the lower panel rises completely from the sea bed just after the footrope bosom, and that the footrope does not stay in close contact with the bottom [9].

The different bottom contact of the two trawls accounts for their different benthic-species efficiency.

Since in many Mediterranean areas benthic species account for a considerable proportion of the landing value, many fishermen have obviously tended to optimise these captures to the detriment of those of other species, for instance by reducing vertical net opening to increase trawl-bottom contact.

On the contrary, the MEDITS programme [5] seeks to obtain a general picture of all, and not only high-value, species present in the Mediterranean.

In fact, although the list of the main reference species was first established based on commercial value [5], this value changes from country to country, and the geographic distribution of species in the Mediterranean is so variable that some are not found in some areas. This, together with factors such as great species diversity and the potential interest in some species as biological indicators, has increased to over thirty the main list of species involved in the survey which the MEDITS trawl must be able to sample.

Moreover, this trawl must work on all types of fishing grounds and at a wide range of depths (10–800 m). The fishermen, without departing from the basic trawl design, have adapted their trawls to local sea-bed features. Moreover, in Italy fishermen customarily use one trawl at relatively low depths and another in deeper water.

Hence, because of the wide variety of reference species to be sampled and of the ductility required from the trawl, reduced efficiency for some species had to be accepted as a logical consequence of the design stage.

Regarding the trawl effect on the size of individuals caught within the different species, the commercial and MEDITS trawls showed variable results. For some species (*M. merluccius*, *M. poutassou*, *P. erythrinus* and *L. vulgaris*), the efficiency of the MEDITS trawl decreased significantly with increasing specimen size. This may be explained by the ability of medium–large size individuals to escape through the belly sections of the MEDITS trawl, where the mesh is larger than in the Italian commercial trawl [9]. In particular, the MEDITS trawl was less efficient for *M. merluccius* especially in the 30–38 cm TL range, with the minimum at 32–33 cm. Various reasons can account for this result. Fiorentino et al. [19] computed a regression line relating 50 % retention length and mesh opening on the basis of several trawl-selectivity studies on *M. merluccius*. This regression line indicates that a 50 % retention length of 32 cm corresponds to a mesh opening of 80 mm. Because the third panel of the MEDITS trawl was made of 80-mm full mesh size, the escapement of specimens of 30–38 cm in TL could occur up to this body section. Other explanations are nevertheless conceivable because the possible escapement of individuals up to TL 33 cm would suppose the ability for smaller size fish to escape as well, which in fact was not the case. An avoiding behaviour cannot be excluded. Moreover a deficit of the considered size class on the fishing grounds, along with the low number of large specimens caught, must not be excluded when investigating the different possible reasons of this size discontinuity in hake catch.

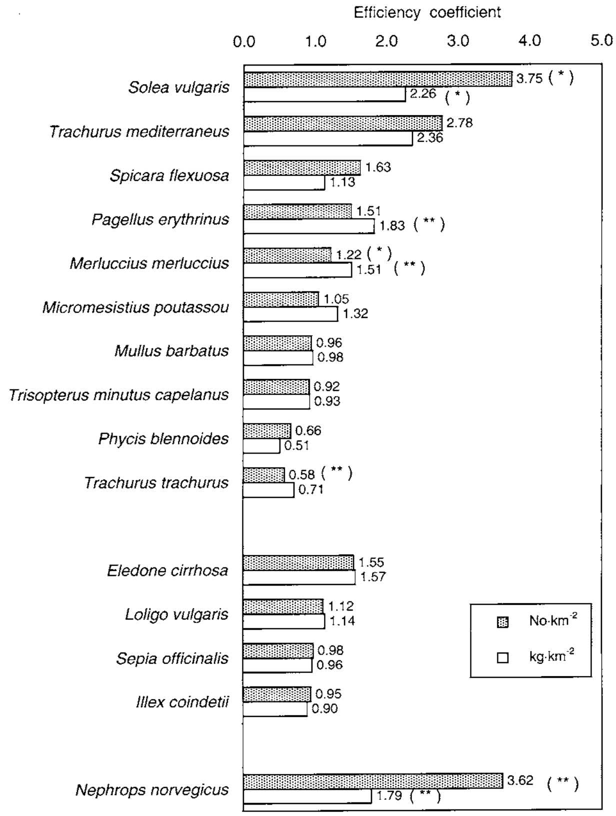

Figure 7. Efficiency coefficient (ratio between the catches in numbers and weight per km^2 of the commercial and the MEDITS trawl) for the MEDITS main reference species (* significant, $0.01 < P < 0.05$; ** highly significant, $P < 0.01$).

With *N. norvegicus*, the loss of the MEDITS with respect to the commercial trawl occurred mainly for small individuals, while for *I. coindetii*, its efficiency increased with size.

5. CONCLUSION

Efficiency comparisons were performed on ten fish species of the MEDITS main list of reference species. The commercial trawl was more efficient than the MEDITS trawl for six of these species (*figure 7*). The differences were significant or highly significant, both in numbers and weight, for *M. merluccius* and *S. vulgaris*. A highly significant difference was found for the weight, but not the numbers, of *P. erythrinus*. For *M. poutassou*, *S. flexuosa* and *T. mediterraneus* differences were not significant, but catch coefficients between the two trawls were sometimes high. The two trawls showed very low efficiency differences for *M. barbatus*, while the MEDITS trawl was more efficient for the other fish species considered. However, differences were highly significant only for the number of individuals of *T. trachurus*. The efficiency difference for the four molluscs was never significant. The efficiency of the MEDITS trawl was half that of the commercial trawl for *N. norvegicus*. This result was highly significant and was confirmed in all the trips where this species was caught.

The commercial trawl was more efficient for large individuals of some species. The MEDITS trawl was especially inefficient for small size classes of *N. norvegicus*.

The comparisons of the efficiency of the two trawls can be used to relate MEDITS survey's results to commercial fleet catches (at least those made along the Italian coasts) and to those obtained in the framework of the Italian GRUND programme.

Finally, the present results clearly indicate which features could enhance the MEDITS trawl catch of some species. Some losses in the efficiency for other species must, however, be accepted. The modification of the sampling trawl is nevertheless an important issue which needs to be carefully evaluated by MEDITS programme co-ordinators. The survey's time–data series, which started in 1994, could be altered. This option would be justified only if the efficiency of the present trawl for some important species is considered completely inadequate and such as to invalidate the reliability of the sampling activity.

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