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Seabed morphology, sediment grain size, and macrobenthic communities in a fished area and an area unaffected by fishing in the central Adriatic (Italy)

Anna Maria DE BIASI* and Stefano DE RANIERI

Centro Interuniversitario di Biologia Marina ed Ecologia Applicata, Viale Nazario Sauro 4, I-57127 Livorno, Italy

**** Corresponding author, e-mail: a.debiasi@cibm.it***

Studies performed in Italy for assessing the effects of fishing activities have been largely confined to the Adriatic Sea. They mostly investigated effects of experimentally induced impacts. The objective of this study was to compare a commercial fishing ground with an area in which no fishing was conducted. The two areas were less than 2 km apart and close to a gas platform in the central Adriatic. Seabed morphology, sediment grain size, and macrobenthic community composition were investigated. There were clear physical effects on the seabed morphology, mostly as a consequence of the trawling passage. Strong and unequivocal signs of disturbance were not detected from the grain size analysis but there was a major spatial variability of sediment distribution. There were signs of stress in the macrobenthic community, i.e., reduction of complexity and diversity, increased variability of distributional patterns, and fewer large long-lived species in the fished area.

Key words: fishing impact, otter-trawling, macrobenthic infauna, side scan sonar, Adriatic Sea

INTRODUCTION

Fishing has the greatest anthropogenic impact on the marine ecosystem (DAYTON *et al*., 1995) and has been a long-term source of disturbance since prehistory. Studies over the past twenty years indicate that fisheries can negatively influence biotic and abiotic components of the marine habitat (see JOHNSON, 2002, for review). There is now considerable interest in the role that demersal fishing disturbances play in determining the composition and structure of marine benthic communities. A growing catalogue of studies and reviews exams this topic from various points of view (DAYTON *et al*., 1995; JENNINGS & KAISER, 1998; DINMORE *et al.,* 2003), mostly in the North Sea (DEGROOT, 1984; RAMSAY *et al*., 1998; TUCK *et al*., 1998; SCHRATZBERGER *et al*., 2002).

In Italy, most assessments of the effects of fishing activities have been carried out in the Adriatic Sea where morphological characteristics (e.g., a flat sea bottom) favor the development of trawl-fishing. Many studies, mainly in the northern Adriatic, provide information on the effects of the "rapido" trawling gear or hydraulic dredge, the impacts of which were usually induced experimentally in pristine areas with environmental features similar to those of actual fishing grounds (GIOVANARDI *et al.*, 1998; PRANOVI *et al.*, 1998; 2000, 2001). Such an approach generally investigates short or medium-term effects related to an acute induced impact. However, the results of such an approach do not necessarily reflect the chronic impact caused by trawls in commercial fishing grounds (COLLIE *et al.*, 1997; THRUSH *et al.*, 1998; KAISER *et al.*, 2000).

This study is a first attempt to compare the macrobenthic communities of a commercial fishing ground (area T) with those of an unfished area (area C) about 2 km apart located near a gas platform in the central Adriatic. Area T is regularly exploited, almost exclusively by medium-sized to large otter trawlers (10 to over 100 GRT) while beam trawling is rare.

In areas with much fishing, such as the Adriatic basin, finding suitable reference (control) areas for study is extremely difficult, a condition that commonly limits study of trawling impact (THRUSH *et al.*, 1998). Gas platforms offer a practical solution to this problem. Such structures influence surrounding sediments only within a short distance from the platform (MONTAGNA & HARPER, 1996) and for a short time period after the beginning of drilling operations since effects of the operation are related more to the installation phase than to the subsequent extraction phase (FERRARI *et al.*, 2002; FABI *et al.*). Further, fish respond to visual attractions rather than physical parameters, so the attraction of the gas platform is spatially limited. Hence, since areas T and C have similar morphology and depth, differences between the two should be mainly related to the otter trawling activities.

RIJNSDORP *et al.* (1998) demonstrated that fishing efforts can be aggregated based on historical patterns of performance. In this study, side-scan sonar was used to select a highly disturbed area and to evaluate the amount of disturbance to the seabed (DE BIASI *et al.*, 2006).

MATERIAL AND METHODS

Seabed morphology: side scan sonar survey

Two areas, a larger one of 2 x 11.2 km and smaller one of 2.8 x 2.8 km, near the Daria gas platform off Fano in Pesaro e Urbino (Italy) in the central Adriatic were investigated in January 2003 to select a treatment area exposed to great fishing pressure (area T) and a control area unaffected by fishing (area C). The larger area was examined to determine which sector was most impacted by fishing activities; the smaller area to identify a control since fishing is not permitted near the platform.

A preliminary survey was conducted with a side scan sonar (C-MAX800/DF) towed parallel to the coast at 4-4.5 knots at constant height above the seabed (≤10 m). The acquisition range was set at 100 m to either side of the center of the instrument. The distance between two parallel tracks was 180 m and the emission frequency was 315-325 kHz. The vessel positions were plotted by a differential global position system (dGPS). Side scan sonar data were recorded on magneto-optical disks and downloaded onto a SUN workstation. The digital side scan sonar data were processed with Octopus Image Processing Software; raw data were geometrically corrected (slant range) using the position, heading, and speed of the ship. To estimate the intensity of the fishing impact, side scan sonar sonograms were superimposed in fixed time intervals and the number of trawl marks per square kilometer was an indirect estimate of the fishing effort.

After the preliminary survey, two areas of similar size and depth (50-54 m) were selected for the study (Fig. 1). The chosen areas are near each other to prevent the differing environmental characteristics that can result from geographical separation from introducing a further source of variability. The area closer to the Daria platform served as a control because it was unaffected by fishing activity. The northeast sector of the larger area was chosen for comparison since it was strongly affected by fishing. The two areas were investigated by side scan sonar again in February using the above protocol.

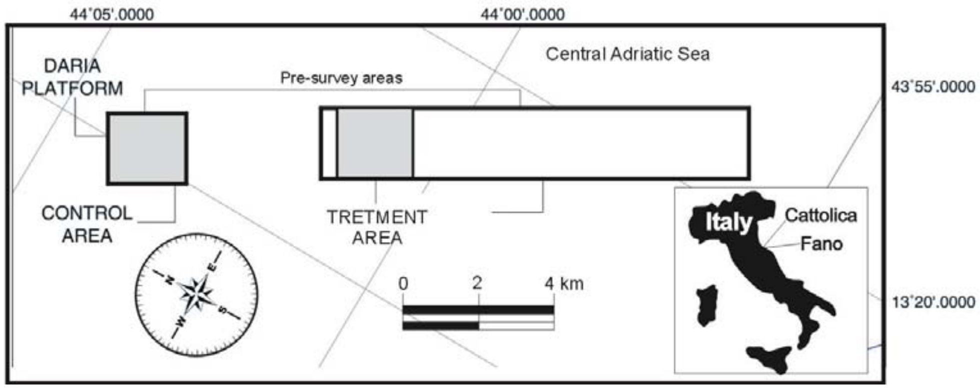

Fig. 1. The study area, chosen from the larger preliminary survey area

Particle size analysis

Sediments for particle size analysis were collected in February 2003 by a box-corer in both areas. Two stations in each area were chosen at random (T1 and T2 in the fishing area and C1 and C2 in the control). Samples were analyzed for particle size according to the Udden-Wentworth Phi classification. Samples were washed in 16% hydrogen peroxide for 24 h, then wet sieved on a 63 µm mesh to separate the fine fraction. The sand fraction was sieved through a stack of geological test-sieves ranging 0-4 Phi. The fine fraction was not analyzed.

Benthic communities

Five sediment samples were collected for benthic community analysis at each of the four stations in February 2003 with a Van-veen grab (0.10 m^2). The samples were washed through a 1-mm mesh sieve. The organisms were sorted, counted, and identified to the lowest possible taxonomic level. Polychaetes and sipunculans, at a family and phylum level respectively, were wet weighed on an electronic balance (Mettler AE 100) to an accuracy of 0.1 mg while mollusks, echinoderms, and crustaceans were wet weighted at a class level.

Data analyses were carried out using univariate and multivariate techniques. The PRIMER statistical software package was used to analyze abundance data (CLARKE & WARWICK 1994). An ordination plot was obtained by non MetricMultiDimensionalScaling (nMDS) and a similarity matrix was calculated using the Bray-Curtis index after log (x+1) transformation. Statistical differences between areas T and C were tested by 1-way ANOSIM. Relative dispersion and the Index of Multivariate Dispersion (IMD) were used to compare the relative variability between treatment and control samples (CLARKE & WARWICK, 1994). The Simper routine was used (CLARKE, 1993) to determine which taxa mostly contributed to the (dis)similarity between T and C.

Curves of cumulative abundance and biomass of the major taxa were constructed and compared according to the ABC method proposed by WARWICK (1986). Total biomass, total abundance (N), and number of species (S) were tested by two-way nested ANOVA. Two factors were analyzed: area (T vs C, fixed, at 2 levels) and station (random, 2 levels, nested in area).

RESULTS

Seabed morphology: side scan sonar survey

The preliminary side scan survey revealed that both areas T and C are almost flat with no distinct topographic regions or peculiar depth gradients. The side scan sonar images revealed that only area T was strongly affected by fishing activity. Trawl marks were oriented in all directions but mostly parallel to the isobaths.

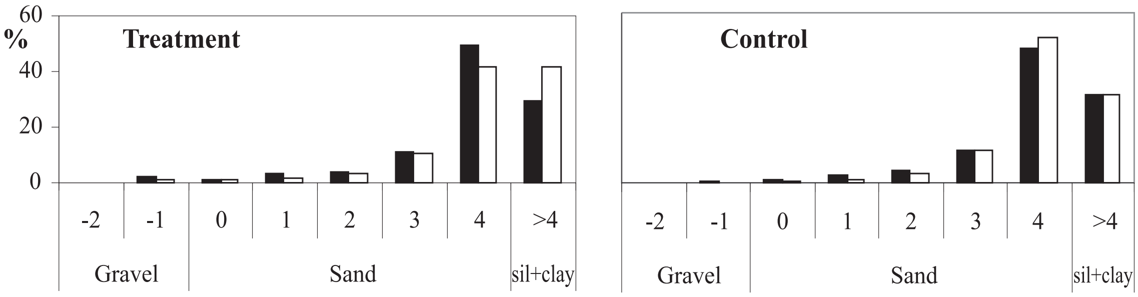

Fig. 2. Distribution of sediment grains by size (phi units) in the area subjected to fishing activity (area T) and in the area in which no fishing took place (area C) . The two stations in each area are indicated with black and white bars

In many cases the distance between two tracks corresponded to the distance between trawl doors, suggesting that the marks resulted from the passing of the trawl doors. In contrast, the trawl nets had a minor physical impact and did not leave acoustically detectable signs on the sediments. The bottom sediments of area C were not affected by trawl passage.

Sediment particle size

The sediment in both areas comprised mostly fine and very fine sand (Fig. 2). The differences between the two stations in area T were greater than between the stations in area C. The percentage of sand collected in T1 was about 10% higher than in T2, whereas the differences between C1 and C2 never exceeded 3% for any grain size fraction.

Benthic communities

A total of 719 organisms belonging to 72 species (or major groups) were collected including polychaetes, mollusks, crustaceans, echinoderms, sipunculans, and nemerteans. Polychaetes were the most abundant taxon with *Aponuphis fauveli*, *Notomastus latericeus*, and *Sternaspis scutata* being the most widespread species in almost all samples.

In the nMDS ordination plot of the abundance [log(x+1) transformation] matrix, samples from area C were located on the left and contrasted with those from area T (Fig. 3). The samplings in area C were tightly clustered, whereas those in area T were scattered on the right. This difference was also indicated by the degree of dispersion which was 0.69 for area C and 1.31 for area T. Comparison of the two areas resulted in a strong positive IMD value (+0.628). One-way ANOSIM indicated significant differences between areas but no statistical differences between stations within an area (Table 1).

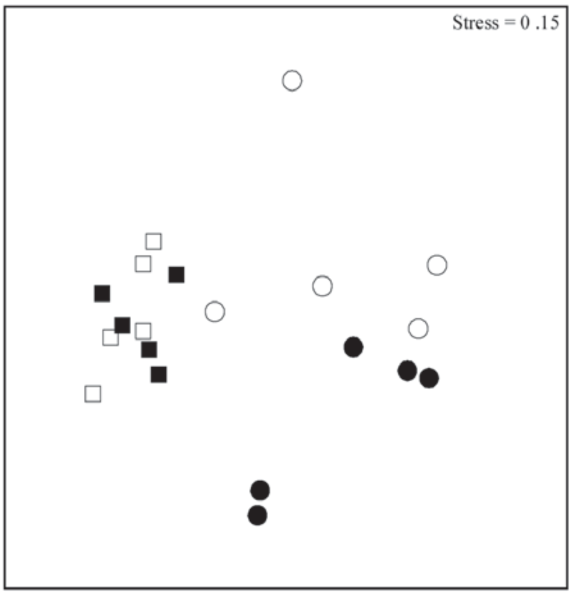

Fig. 3. Non-metric MultiDimensionalScaling on log (x+1) abundance data. Squares = area C, circles = area T. Black and white indicate stations

Table 1. One-way ANOSIM results comparing abundance data transformed according to log (x+1)

	R	Significance level
C1 vs C2	0.240	0.063
T1 vs T2	0.200	0.071
C1 vs T1	0.740	0.008*
C1 vs T2	0.700	0.008*
C2 vs T1	0.800	0.008*
C2 vs T2	0.660	0.008*

* Significantly different

Simper analysis indicated the contribution of each taxon to the (dis)similarity between the areas (Table 2). Polychaetes were the greatest contributor to the total dissimilarity with *Aphelochaeta marioni, Prionospio steenstrupii, A. fauveli, N. latericeus,* and *S. scutata* accounting for more than 25% of the total dissimilarity. The crustacean *Callianassa tyrrhena* was present only in area C.

Two-way nested ANOVA detected significant differences between areas in total abundance and

Table 2. Simper analysis results on log (x+1) abundance data (m²)

	Average abundance ± standard error (n = 10)		
Species	Area T	Area C	%
Aphelochaeta marioni Saint-Joseph, 1894	4.0±3.1	40.0±5.0	6.12
Prionospio steenstrupii Malmgren, 1867	0.00±0	36.0±11.0	5.51
Aponuphis fauveli (Rioja, 1918)	48.0±12.1	111.0±2.0	5.41
Notomastus latericeus M. Sars, 1851	48.0±12.4	11.0±4.0	4.40
Sternaspis scutata (Renier, 1807)	10.0±3.3	36.0±9.0	3.82
Callianassa tyrrhena (Petagna, 1792)	0.00±0	17.0±4.0	3.80
Nephtys incisa Malmgren, 1865	10.0±3.3	25.0±7.0	3.53
Amphipoda	1.0±1.0	14.0±3.0	3.33
Lumbrineris latreillii Audouin and Milne-Edwards, 1834	2.0±2.0	16.0±6.0	3.16
Venus casina Linné,1758	14.0±3.7	3.0±2.0	3.05
Paralacydonia paradoxa Fauvel, 1913	3.0±2.1	14.0±4.0	3.05
Chaetozone sp.	1.0±1.0	18.0±9.0	2.85
Aspidosiphon muelleri Diesing, 1851	2.0±2.0	8.0±1.0	2.51
Glycera rouxii Audouin and Milne-Edwards, 1833	6.0±2.2	14.0±3.0	2.50
Nuculana pella (Linné, 1767)	8.0±4.2	8.0±3.0	2.37
Sthenolepis yhleni (Malmgren, 1867)	6.0±2.2	6.0±4.0	2.17
Ninoe armoricana Glémarec, 1968	4.0±2.2	6.0±2.0	1.82
Paraprionospio pinnata (Ehlers, 1901)	2.0±1.3	9.0±6.0	1.74
Marphysa bellii (Audouin and Milne-Edwards, 1833)	1.0±1.0	6.0±2.0	1.71
Poecilochaetus serpens Allen, 1904	5.0±2.7	2.0±1.0	1.47
Lumbrineris gracilis (Ehlers, 1868)	1.0±1.0	6.0±3.0	1.43
Thyasira flexuosa (Montagu, 1803)	5.0±2.7	1.0±1.0	1.34
Chirimia biceps (M. Sars, 1861)	2.0±1.3	3.0±2.0	1.17
Nucula nitidosa Winckworth, 1930	3.0±1.5	2.0±1.0	1.17
Myriotrochus geminiradiatus Salvini-Plawen, 1972	0.00±0	4.0±2.0	1.12

Average dissimilarity between treatment and control = 71.96%

number of species, and in abundance and number of polychaete species (Table 3). The benthic assemblages in area T were less abundant and rich (Fig. 4). The difference was due mainly to polychaetes. Two-way nested ANOVA revealed significant differences in biomass between areas but not between sites (Table 4). Biomass was significantly higher in area C than in area T (Fig. 5). The ABC curves suggest that area T was moderately disturbed but area C was undisturbed as the abundance curve for area C always lies below the biomass curve, whereas the two curves cross each other more three times for area T (Fig. 6).

Table 3. Two-way nested ANOVA. Factors: A (fixed, 2 levels), S (random, 5 levels, nested in A). Significant differences in bold

		Total abundance (N)			No. species (S)			Polychaetes (abundance)			Polychaetes (No. species)			*Aphelochaeta marioni*		
Source	df	MS	F	p	MS	F	p	MS	MS	MS	MS	F	p	MS	F	p
Area (A)	1	3892,05	26,759	**0,035**	594,05	21,028	**0,044**	2691,2	2691,2	2691,2	259,2	51,84	**0,019**	1,689	135,65	**0,007**
Station (S)	2	145,45	0,865	0,440	28,25	2,007	0,167	92,5	92,5	92,5	5	0,461	0,639	0,012	0,323	0,729
Residual	16	168,125			14,075			164,25	164,25	164,25	10,85			0,039		
Cochran C test		C=0.569, p=0.190			C=0.569, p=0.819			C=0.599, p=0.187			C=0.29, p=0.865			C=0.47, p=0.105		
Transformation		none			none			none			none			none		

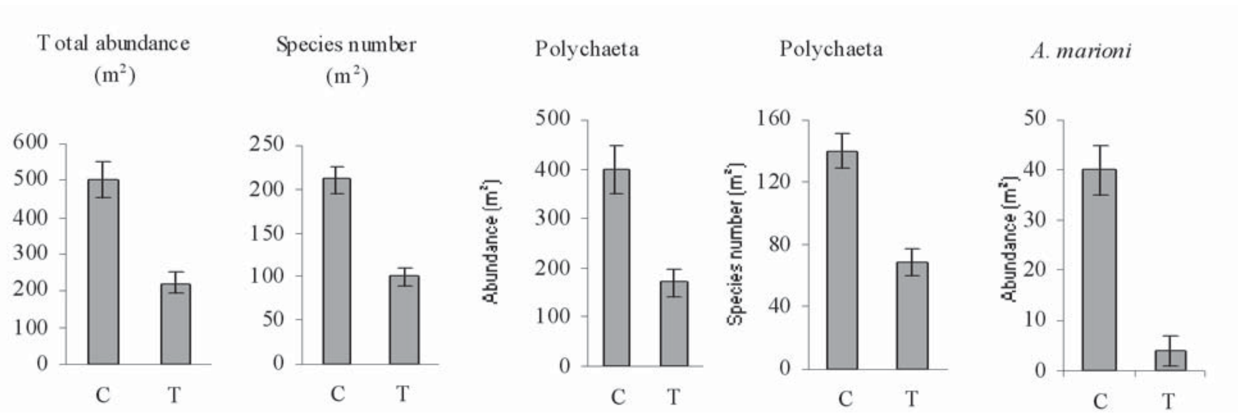

Fig. 4. Total abundance, number of species, polychaetes (abundance and number of species), and Aphelochaeta marioni in areas T and C. Bars = standard error (n = 10)

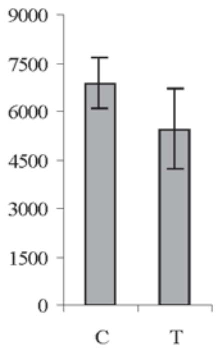

Fig. 5. Total biomass (wet weight, g/m^2) in areas T and C. Bars = standard error (n = 10)

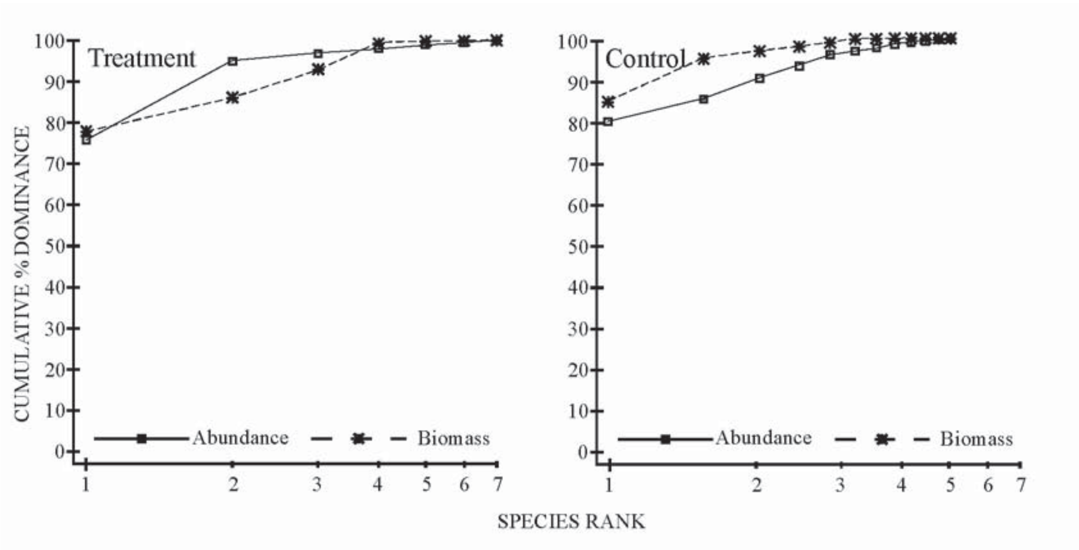

Fig. 6. ABC plots for infauna in area T and area C

Table 4. Two-way nested ANOVA. Variable: total wet weight. Factors: A (fixed, 2 levels), S (random, 2 levels, nested in A). Significant differences in bold

	Total biomass			
Source	df	MS	F	p
Area (A)	1	1,392	28,740	0,033
Station (S)	2	0,048	0,063	0,939
Residual	16	0,768		
Cochran C test		C = 0.524, p = 0.090		
Transformation		double square root		

DISCUSSION AND CONCLUSIONS

This is the first study carried out in the Adriatic Sea aimed at investigating disturbances caused by otter trawling in an actual fishing ground. Our results, although preliminary, detected differences between the fished area (area T) and the area in which fishing did not take place (area C). Firstly, side scan sonar indicated clear physical effects on the seabed of area T due to fishing activities. As reported by HALL (1994), FONTEYNE (2000), SMITH *et al.* (2000), and DE BIASI (2004), the main macroscopic effects appeared to be the consequence of the trawl door passage which leaves persistent marks in the sediment. As nets do not leave detectable marks, their impact is probably more deceitful, indirect, and difficult to quantify. Analysis of grain sizes failed to detect any differences between the two areas; both were classified as muddy sand.

Secondly, analysis of the benthic assemblages revealed significant differences in structure and composition between the areas. The community in area C was much more complex, rich, and abundant than in area T. Some species common in area C (Amphypods, *Aspidosifon muelleri*, *C. tyrrhena*, *P. steenstrupii*) were uncommon or totally absent in area T. However, these differences are not necessarily a consequence of fishing activities.

The lack of an appropriate replicated sampling design prevents evaluation of the role of spatial variability in the above differences. We cannot completely conclude that the gas platform was not a source of variability. A multidisciplinary monitoring program in the Adriatic recently determined that the effects of two gas platforms off Cattolica at depths of 22 and 70 m, subjected to different environmental conditions, were recoveredAnd certainly less severe than in area T about three years after the end of drilling operations (FABI *et al.*, 2005). Since the Daria gas platform was installed about 10 years ago, its effect, if any, should be very slight, but remains unquantified.

More interesting than the differences are the symptoms of stress detected in area T. Even if grain sizes did not differ between areas, as observed by TUCK *et al.* (1998) in Loch Gareloch and KAISER & SPENSER (1996), the greater difference between stations within area T than within area C could be related to fishing. The stochastic re-deposition of surface sediments suspended by trawling can influence their stability with a consequent increase in spatial variability.

In parallel, the benthic assemblages in area T had a higher level of patchiness in their spatial distribution in agreement with the hypothesis that physical disturbances may enhance community variability and, in turn, be related to major sediment heterogeneity (THISTLE, 1981; WARWICK & CLARKE, 1993). Other authors also observed increased variability in response to fishing (PRANOVI *et al.*, 2000; KAISER & SPENCER, 1996). Another symptom of stress in fished areas is a lower species richness (JOHNSTON, 1970).

Lastly, the ABC plots of the major taxa suggest that, in the fished area, the inequality in size between the numerical and biomass dominants is lower, so the two curves do not differ and cross each other. This is consistent with the observation that large species, even when not directly fished, are more vulnerable to fishing gears than small ones (GILKINSON *et al.*, 1998). As a result, trawled communities are increasingly dominated by small infaunal species that poorly contribute to the local biomass (SIMBOURA *et al.*, 1998; KAISER *et al.*, 2000; JENNINGS *et al.*, 2001ab).

The sampling design of this study provides just a glimpse of the situation. The absence of adequate spatial and temporal replicates prevents concluding that the differences between areas T and C were consequences of fishing activity. However, reduced complexity and diversity in the benthic community, increased variation in the benthic assemblage distributional pattern, decrease in large long-lived species, and altered physical sediment properties are clues to disturbance (TUCK *et al.*, 1998; MCCONNAUGHEY *et al.*, 2000; KENGHINTON *et al.*, 2001). These clues were detected in our study. Therefore, we can affirm that our study did not fail to detect a higher stress level in the fished area than in the area unaffected by fishing, even though area C cannot be considered an ideal choice for study. This is a promising achievement because, if these results will be confirmed by more detailed studies, then gas platforms can serve as satisfactory reference areas for future comparisons in the Adriatic Sea.

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Struktura dna, veličina čestica sedimenta i makrobentoska zajednica u eksploatiranim i ne-eksploatiranim područjima srednjeg Jadrana (Italija)

Anna Maria De Biasi* i Stefano De Ranieri

Sveučilišni centar biologije mora i primjenjene ekologije,, Viale Nazario Sauro 4, 57127 Livorno, Italija

**Kontakt adresa, e-mail: a.debiasi@cibm.it*

SAŽETAK

Talijanske studije za utvrđivanje utjecaja ribolovnih aktivnosti bile su uglavnom usmjerene na Jadransko more istražujući učinke pretežito tijekom eksperimentalnih potega. Cilj ove studije je usporedba područja izložena gospodarskom ribolovu i područja koja se gospodarski ne iskorištavaju. Dva istraživana područja su smještena 2 km od plinske platforme u srednjem Jadranu. Istraživani su: struktura morskog dna, veličina i struktura sedimenta, te makrobentoske zajednice. Jasno je uočljiv fizički učinak na strukturu morskog dna, uglavnom kao posljedica prolaska koća. Nisu utvrđeni jaki i jasni znakovi poremećaja u veličini čestica sedimenta, ali je utvrđena značajna prostorna varijabilnost u distribuciji sedimenta. U eksploatiranom području nađeni su znakovi stresa u makrobentoskoj zajednici tj. poremećaj u kompleksnosti i raznolikosti, povećane varijabilnosti u raspostranjenosti i manji broj velikih i dugoživućih vrsta.

Ključne riječi: ribolovni utjecaj, pridneno koćarenje, makrobentoska fauna, sonar, Jadransko more