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Impact of experimental trawling on the benthic assemblage along the Tuscany coast (north Tyrrhenian Sea, Italy)

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The impact of repeated experimental otter trawling, in the north Tyrrhenian Sea (Mediterranean) was investigated using a spatially replicated sampling design. Macroscopic modifications of the seabed morphology were assessed by sidescan sonar. Alterations of the sediment texture and changes in macrobenthic infauna were assessed using a box-corer. The most obvious modifications of the seabed were trawl tracks caused by the passage of trawl doors through the sediments. Ephemeral but significant changes in the sediment composition were observed. Changes in the benthic assemblage were detected only 48 h after experimental trawling. The clearest changes were detected in the molluscan component. The present study suggests that recovery from trawling may take place within one month.

Keywords: fishing impact, grain size, molluscs, north Tyrrhenian Sea, soft bottoms, trawling.

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Introduction

In recent years, there has been an increasing awareness of the wide effects of fishing on marine ecosystems (e.g. Jennings and Kaiser, 1998; Hall, 1999; Collie *et al.*, 2000; Kaiser and de Groot, 2000).

In Italy, most of the studies undertaken to assess the impact of fishing have been carried out in the Adriatic Sea, which for its morphological characteristics such as flat sea bottoms has always favoured the development of trawl-fishing. Most studies focused on the northern Adriatic, assess the ecological impacts caused by "rapido" trawl gear (Giovanardi *et al.*, 1998; Pranovi *et al.*, 1998, 2000, 2001; Hall-Spencer *et al.*, 1999). Fewer studies were carried out in the Tyrrhenian Sea where the impact of illegal trawling within 3 miles of the coast with special reference to its effects on seagrass beds was assessed (Ardizzone *et al.*, 2000).

The aim of this study was to investigate the impact of repeated experimental trawl disturbance induced by otter trawling, in the northern Tyrrhenian Sea (Mediterranean). In particular, macroscopic modifications of the seabed morphology, alterations to the sediment texture and changes in macrobenthic infauna were assessed. If trawling had no effects on the seabed, then a trawled area should not be significantly different from adjacent unfished areas.

This study took advantage of the restriction in commercial trawling in the investigated area to zones beyond 3 nautical miles of the Italian coasts according to the EC regulation 1626/94.

Material and methods

Study area

The study was carried out in an area off the Tuscany coast in front of S. Vincenzo (northern Tyrrhenian Sea) approximately 2 km long and 1.5 km wide (Figure 1). This area was selected after a preliminary survey performed in the summer 1998 for selecting an area unaffected by previous illegal fishing activities and for calculating the minimum sampling area suitable to investigate the benthic communities (De Biasi, 1999). This pre-survey was carried out in a marine area 5 km long and 2.5 km wide between 15- and 35-m depth. Sidescan sonar and underwater video camera were used to investigate the bottom morphology whereas sediment samples were collected to investigate the benthic communities and sediment grain size. For this survey, an unfished marine area located at 32–34-m depth characterized by mud or muddy sand was selected. In addition, the species/area cumulative curves (calculated using only the box-corer samples collected at the same depth range)

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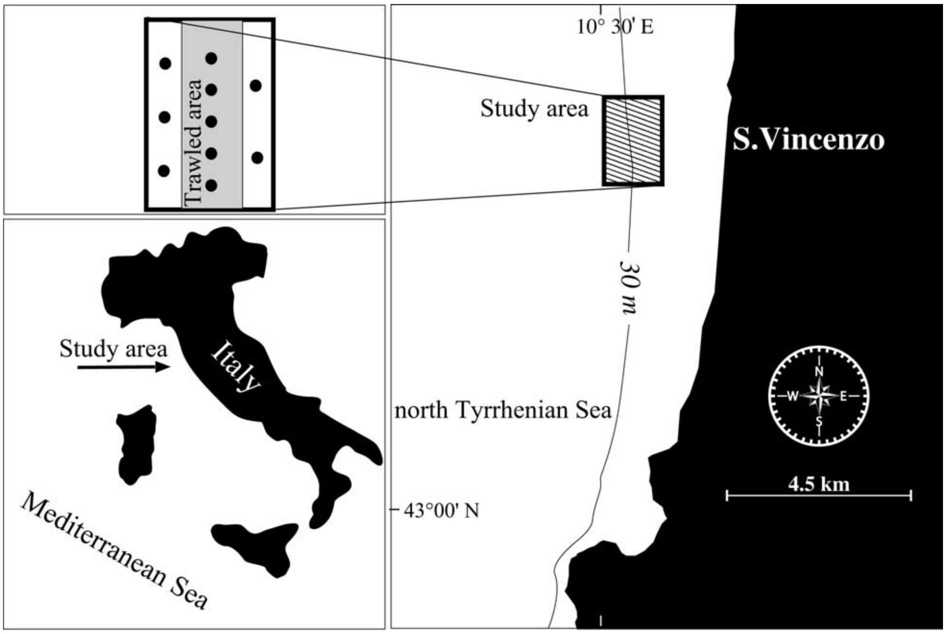

Figure 1. Study area.

suggested that six replicates were adequate to provide an accurate assessment of the species present in the area.

Experimental design

The experimental cruise was carried out in October 1998 using the commercial otter trawler "S. Margherita" moored at Piombino harbour. The fishing disturbance was induced by 14 repeated tows each of which lasted for 1 h over a period of 24 h. The trawler used for the experimental fishing was a medium-sized vessel (19.5 m overall length, 30.4 gross tonnage, 270 hp), typically using a bottom-trawl net and mostly exploiting fishing grounds located at shallow depths (<150 m).

The fishing gear had the following principal characteristics: two oval iron doors weighing 250 kg each, headline of 26 m length, footrope of 32 m length provided with 36 leads of 1 kg each, without chains; codend of 7 m length provided with 350 meshes of 40-mm stretched mesh size; towing speed was about 3 knots for each experimental fishing operation.

Survey procedure

Sidescan sonar

The seabed morphology was assessed using a Datasonics TTV-195. The survey was carried out before trawling, immediately after, 24 h after, 48 h after, and one month after. It was towed along parallel way-lines, about 2 km long, from south to north at a speed of 1.8–2 m s^{-1}. The range of the sidescan sonar was set at 100 m either side of the centre of the instrument. The distance between two parallel tracks was 160 m. The emission frequency varied between 185–225 kHz.

Sediments and benthic communities

Samples were collected by box-corer, with a frame made of 20 × 20 × 30-cm stainless steel box (sampling area: 0.04 m^2), before and after (immediately after – only for sediment analysis – 24 h, 48 h, one month) the experimental cruise in ten stations: five inside the fished area (hereafter T = treatment) and five in the unfished area (hereafter C = control). Two controls were located landward and three seaward with respect to the fished area (Figure 1). Sediment samples were analysed for their particle size according to the Udden–Wentworth Phi classification. Each sample, after washing in 16% hydrogen peroxide for 24 h, was wet sieved on a 63-μm mesh sieve to sort the fine fraction. The sand fraction was sieved through a stack of geological test-sieves ranging from 0 Phi to +4 Phi. The fine fraction was then analysed by sedigraph.

Six replicates were collected for community investigation. Sediments were sieved on board through 1-mm mesh sieve and then fixed in 10% buffered formalin. Samples dyed with Rose Bengal were sorted in laboratory, macrofaunal species were counted and identified to the lowest possible taxonomic level.

Statistical analysis

Data from the six replicate fishing treatment and control box-corer samples were pooled prior to analysis. The PRIMER statistical software package was used to perform analyses of the community data. The data set comprised a total of 201 taxa, of which 46 occurred only as a single specimen. Since such a large number of species occurred at low abundance, the taxonomic resolution was reduced because these low abundance species could impair ability to detect any subtle effects of fishing disturbance. Furthermore, fishing disturbance is likely to affect closely related taxa in a similar manner.

The reduced data set contained a total of 35 taxa or species. A cluster analysis, using the Bray–Curtis similarity index was performed on fourth root transformed data. The resultant similarity matrix was used to perform non-metric multidimensional scaling (nMDS). The differences between seaward and landward controls before the experimental trawling were tested by the one-way ANOSIM. No significant differences were detected ($R = 0.146$, $p = 0.17$), so landward and seaward controls were considered jointly in the other analyses. An *a priori* one-way ANOSIM-test was then performed to determine any significant differences between the fished and control treatments for each of the time intervals before and after the creation of the fishing disturbance. To establish which taxa contributed most to either the similarity or dissimilarity between groupings of data, the SIMPER routine was carried out. The contribution of each species to the Bray–Curtis similarity was calculated after fourth root transformation and the species ranked in order of their contribution to separating each group. Species frequency distribution for each of the groups of fished and control areas was examined graphically using k-dominance curves. The percentage of the commonest species is plotted in the first rank, then the percentage abundance of the next commonest is added and this combined total plotted in the second rank, and so on so as to obtain a cumulative ranked species abundance curve, i.e. the k-dominance curve (Lambshead *et al.*, 1983). The same analysis was carried out at the family level.

Results

Bottom topography

The sidescan sonar records from the survey carried out before trawling indicated that both the treatment and control areas were flat and devoid of any distinct topographic features. The seabed appeared homogeneous, covered in fine sediments without tracks caused by previous fishing activities. Immediately after trawling evidence of a considerable disturbance in the experimental area was detected. The tracks were produced by the passage of trawl doors and ran mainly in a north–south direction concurring with the direction of the experimental trawling. In some cases, the distance between two different tracks corresponded to the distance between the trawl doors. By contrast, the trawlnet did not leave any evident marks suggesting only minor physical impact. Twenty-four hours after disturbance, appreciable modifications were not detected. Forty-eight hours after experimental trawling had ceased, the marks of the sonograms appeared less distinct. One month later, these tracks were almost invisible. No fresh trawl tracks were recorded in the control area.

Sediment particle size

The bottom surficial sediments, both in the treatment and in the control stations were almost cohesive and mostly constituted by silt and can be classified as poorly sorted fine silt.

By contrast (Figure 2) the silt and clay percentage in T and C changed over time, landward controls showed higher percentage of silt than treatments while seaward controls showed lower percentage of silt than treatments, although both these differences are not statistically significant. In addition, these differences did not appear to have any effect upon the capability of detecting the fishing impact. In fact, immediately after trawling in the landward control an increase of the clay percentage with a parallel decrease in silt percentage was observed. Twenty-four hours later the situation was completely recovered.

Benthic communities

In all, 10 584 individuals belonging to 201 taxa were collected over the study period. Of these 108 were polychaetes, 32 molluscs, 44 crustaceans, and 10 echinoderms.

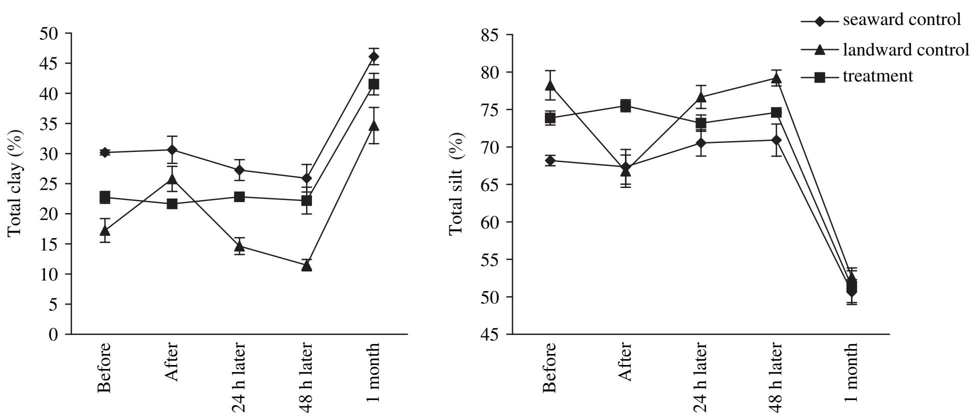

Figure 2. Percentage of clay (left) and silt (right) before and after experimental trawling. Bars indicate standard error.

Less abundant taxa included cnidarians, phoronids, sipunculans, platyhelminthes, nemerteans, and nematodes.

From one-way ANOSIM, no significant differences were detected between T and C (before R = 0.092, p = 0.25; 24 h R = 0.008, p = 0.44; 48 h R = 0.080, p = 0.25; one month R = −0.080, p = 0.6) at any time interval.

After reducing the matrix to the 35 major taxa the analyses were re-run. According to the ANOSIM, no significant differences were detected when comparing the fished and unfished sites prior to (R = −0.028, p = 0.61), 24 h after (R = 0.13, p = 0.17), and one month after (R = 0.028, p = 0.33) the fishing disturbance. However, 48 h after fishing small but significant differences between the fished and unfished sites were detected (R = 0.24, p = 0.008). Maldanidae, *Levinsenia gracilis*, *Praxilella* sp., and *Euspira macilenta* were more abundant at trawled sites, whereas Flabelligeridae, *Cossura soyeri*, and *Brada villosa* were more abundant at control sites (Table 1).

The ordination plot from the multidimensional scaling (nMDS) is shown in Figure 3, where only the centroids are shown. Station-points which are more similar to one another in their faunal composition occur closer together on the bidimensional plane. Although T and C were separated in the first survey – i.e. before the experimental trawling – they become more distinct once the experimental trawling commenced. The most evident differences were observed 24 and 48 h after the disturbance.

Moreover, the communities of both treatment and control sites changed differently over time. The reference point gradually changed during the one month period underlying a temporal gradient affecting the benthic community. On the contrary, the temporal gradient of the treatment was not as linear and clearly distinct as the control.

Different results were obtained taking into account molluscs. While there were no significant differences in the fished and unfished sites prior to (R = −0.016, p = 0.25), 24 h after (R = 0.020, p = 0.39), and one month after (R = −0.074, p = 0.70) the fishing disturbance had occurred, significant differences were found 48 h after trawling (R = 0.436, p = 0.02). Turritellidae, Thyasiridae, and Corbulidae were more abundant at treatment sites whereas Montacutidae and Lucinidae were more abundant at control sites (Table 2). Corbulidae and Turritellidae resulted, respectively, more ($p < 0.05$) and less ($p < 0.01$) abundant in T than in C.

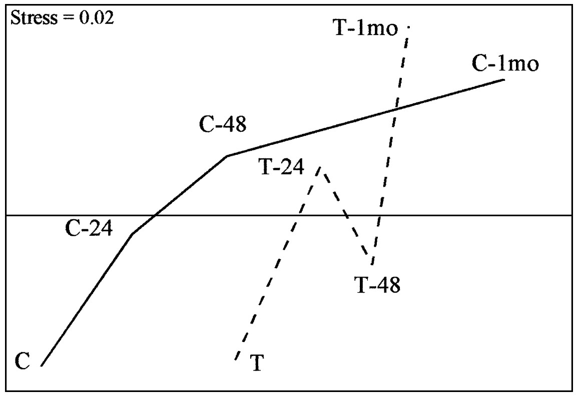

Figure 3. Ordination plot from nMDS on species abundance matrix with pre- and post-trawling (24 h, 48 h, one month) stations. T = treatment, C = control.

The k-dominance curves for Mollusca showed essentially no difference between treatment and control (Figure 4). Twenty-four hours after trawling, however, the T curve lay over the C curve, and after 48 h the two curves clearly separated with the T lying over the C one. One month later, the separation was less marked, and the control curve almost resumed its pre-trawling position.

Discussion

The most evident modifications to the seabed inflicted by trawling appear to be the tracks left in the sediments. These signs are clearly due to the trawl doors' passage that left distinct marks visible in the sidescan sonar records. By contrast, no modifications were observed as a consequence of the passage of the net. However, the absence of macroscopic alterations does not necessarily infer that there has been no impact.

Table 1. Mean abundances (±95% CI) of infaunal species (or taxa) samples at treatment and control sites 48 h after experimental trawling.

	Treatment	Control
Maldanidae	8.2 ± 2.7	5.4 ± 7
Flabelligeridae	0 ± 0	1 ± 0.6
Levinsenia gracilis	5.4 ± 2.9	2.8 ± 3.1
Praxilella sp.	1.6 ± 1.2	0.8 ± 1.1
Cossura soyeri	0.4 ± 0.5	2.4 ± 2.8
Brada villosa	0.2 ± 0.4	1 ± 0.6
Euspira macilenta	2 ± 2.4	1 ± 1.5

Table 2. Mean abundances (±95% CI) of molluscs (family level) sampled at treatment and control sites 48 h after experimental trawling.

	Treatment	Control
Turritellidae	69 ± 41	9.6 ± 11
Thyasiridae	12 ± 4.1	9.2 ± 3.6
Montacutidae	0.8 ± 0.7	3.6 ± 5.7
Lucinidae	4.2 ± 1.3	5.6 ± 3.4
Corbulidae	2.8 ± 0.4	1.2 ± 1.4
Nuculidae	4.7 ± 1.4	4 ± 1.4

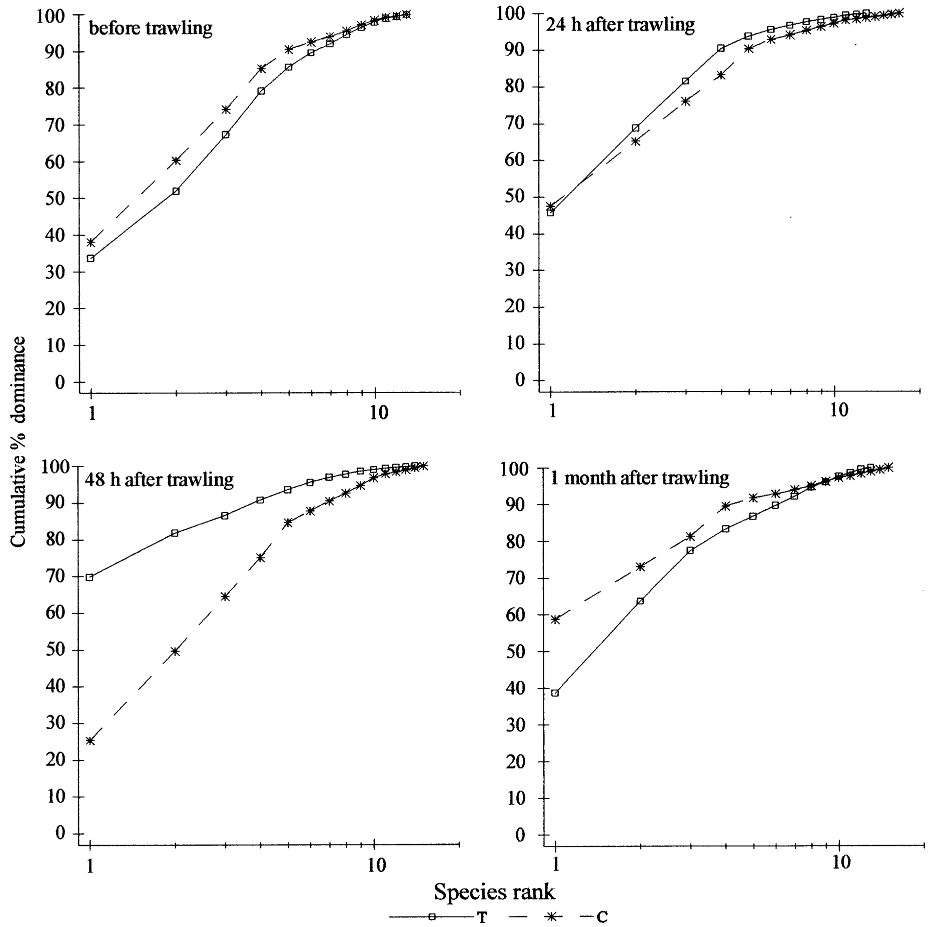

Figure 4. Curves of k-dominance of samples taken at treatment (T) and control (C) sites for mollusc families.

The impact of nets on sediments is probably more subtle, indirect, and difficult to quantify or requires other methodological approaches. The passage may induce sediment re-suspension and re-deposition. The results of the present study appeared consistent with this hypothesis. In fact, although ephemeral some alterations in the sediment size distribution were observed. In the landward controls, the content of silt significantly decreased while the clay content significantly increased. These variations in the texture of the sediment may indicate that trawling re-suspended the fine fraction of the sediments and currents transported them landward, where they settled. The very short temporal and spatial scale over which these changes occurred allowed the exclusion of other external factors that could have affected the investigated area. If any alternative event really had happened, its effects would have been highlighted for all the sampling stations. Actually, such changes in the sediment composition were observed only for a set of samples suggesting that the impact was local.

The difficulties in relating trawling to variations in sediment grain size have been documented already. Tuck *et al.* (1998), for example, found no significant changes in sediment particle size which suggested that the effects on the grain size are not strong and unambiguous. In addition, contrasting results can be a consequence of different time and spatial scale over which the studies have been carried out. In the present study, significant changes were detected only immediately after trawling and they completely disappeared 24 h later. This means that sediment alterations require studies at very short temporal scale.

Parallel demonstration of impact of trawling on the benthos is not an easy task and a wide range of conclusions, even contradictory, have been reported in the scientific literature (Drabsch *et al.*, 2001). In the present study, only some members of the benthic assemblage appeared to be affected by trawling and the biological effects were as ephemeral as the physical ones in accord with some previous studies (Kenchington *et al.*, 2001). It is noteworthy that in such a short period, i.e. 48 h, a well-defined temporal gradient in the controls was observed. In contrast, this temporal gradient was not apparent for the treatments. The different patterns observed may be due to the experimental trawling that affected the temporal dynamics of the benthic assemblages locally. Thus, control and impacted sites changed differently over time. Unfortunately, a comparison with other authors is difficult because daily studies are not common as they are labour intensive, expensive, and the results can be too local for a large consensus among scientists (De Biasi *et al.*, 2002). In addition, there is a lack of previous similar studies with which to compare this one. Although it is incontestable that otter trawling affects the seafloor environment, the kind and degree of impact is difficult to demonstrate (Messieh *et al.*, 1991) and not necessarily consistent among different localities.

In the present study, the clearest changes were detected in molluscan assemblage. The k-dominance curves indicated a shift to dominance of fewer species in the fished area 48 h after the experimental trawling. Some authors suggested that trawling can directly crush or remove, above all, the near-surface organisms (Gilkinson *et al.*, 1998; Hall-Spencer *et al.*, 1999; Bergman and van Santbrink, 2000). However, these effects cannot be totally responsible for the observed pattern, because they should have been observed even 24 h after trawling. Other processes acting more slowly must be invoked to explain a delayed effect. Specific studies carried out by Morton (1996) in an area subjected to suction dredging and trawling suggested that the impact documented upon the benthic molluscan community was a secondary result related to the sediment plumes. However, the same conditions could be advantageous for other organisms. For example, Thyasiridae and Corbulidae, typically considered opportunistic taxa and indicative of instability of surficial layer of sediment (Picard, 1965; Bellan, 1991), can increase in these disturbed conditions. This result is difficult to interpret. These taxa are relatively restricted in their movements, so the hypothesis that they could have been attracted to carrion from the surroundings is not convincing. Moreover, the observed pattern is not consistent with other authors who, analysing long-term data, described large-size bivalves as sensitive to fishing disturbance (Ball *et al.*, 2000). In addition, these data cannot be compared with those of authors who focused their attention mainly on the physical damage to the infaunal bivalves rather than their short-term behaviour and movements (Rumohr and Krost, 1991; Gilkinson *et al.*, 1998).

The experiment presented here describes short-term changes associated with experimentally induced disturbance. All the features taken into account showed some effects 48 h after the trawl impact followed by a very fast recovery within one month. Even the physical macroscopic impact on the seabed morphology clearly decreased within this interval. Moreover, only slight effects were observed. This result can depend on the type of habitat where the study was performed. In shallow areas, the benthic communities experience continual disturbance at various scales (Hall, 1994) both natural and anthropic forming a background which could confound the effects due to a small-scale induced disturbance (Kaiser and Spencer, 1996).

In addition, these results do not necessarily reflect the chronic impact caused by trawls on a real commercial fishing ground (Thrush *et al.*, 1995; Collie *et al.*, 1997; Kaiser *et al.*, 2000) and a general model can, therefore, not be inferred.

This study examined only the effects of a very small spatial scale disturbance. It cannot be excluded that small-scale and short-term disturbances permit a rapid recolonization from surrounding areas. Such recovery mechanisms cannot be effective under frequent large-scale disturbances as other authors suggested (Thrush *et al.*, 1998). On real fishing grounds, wide areas are damaged making the recolonization difficult. It is well known that the fishing effort is not homogeneously distributed. It is usually concentrated in areas that yield the best catches and that do not have obstructions that can damage the gears (Rijnsdorp *et al.*, 1998). Consequently, the recolonization processes are complex and difficult to predict. The relations, if they exist, between the recovery in a never or very low exploited sea bottom and in a highly fished area remain uncertain (Collie *et al.*, 2000).

However, experimental studies, although they do not necessarily reflect a general phenomenon, are important tools for basic studies allowing treatment − control comparisons to be made which is not generally possible in commercially exploited areas. The problem is to identify the appropriate spatial and temporal scales to be able to infer the results from an experimental study to commercial fishing grounds.

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