FINAL REPORT

Comparison of rapid methodologies for quantifying environmental impacts of otter trawls

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R.A. Coggan[1], C.J. Smith[2], R.J.A. Atkinson[1],
K.-N.Papadopoulou[2], T.D.I. Stevenson[1] , P.G. Moore[1]
& I.D.Tuck[3]

[1] University Marine Biological Station Millport (UMBSM)
Millport, Isle of Cumbrae KA28 0EG, Scotland, UK.

[2] Institute of Marine Biology of Crete (IMBC)
PO Box 2214, 71003 Iraklio, Crete, Greece

[3] Fisheries Research Services, Marine Laboratory Aberdeen (MLA),
PO Box 101, Victoria Road, Aberdeen AB11 9DB, Scotland

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SCIENTIFIC SUMMARY

The research reported here evaluates and compares a suite of rapid methodologies for quantifying the environmental impacts of otter trawls. These represent an alternative to traditional methods, which are notoriously slow and costly, and cover a range of readily accessible technologies, from basic biological sampling to advanced remote sensing. Rapid methodologies will be of benefit to the real-time, ecosystem-based approach to fisheries management.

Investigations were carried out on Scottish *Nephrops* (Norway lobster) grounds and on Aegean grounds that support a multispecies fishery. Sites were selected to reflect a range of trawl impacts, based on detailed information on fleet activities. Scottish sites (Clyde Sea area; muddy substrata) covered three nominal levels of fishing intensity (heavy, moderate and light). Aegean sites (off northern Crete) covered a continuum of trawling intensity, sampling across a narrow commercial trawling lane on muddy substrata during open and closed seasons. For comparison off Crete, trawl impact was experimentally manipulated on an adjacent, but previously unfished, sandy site.

The methodologies evaluated divided into four broad categories: acoustic, visual, biological and sedimentological. Acoustic methods comprised the use of bottom-discriminating sonar (RoxAnn^{TM}) and sidescan sonar. Effects attributable to trawling were not detected by the former method, but sidescan sonar enabled trawl marks to be detected and enumerated. Sidescan survey strategies and analytical approaches are discussed. Visual methods used underwater television, deployed either on a towed-sledge (best for transect-type surveys) or mounted on a remote operated vehicle (ROV) (best for 'spot' surveys). A semi-quantitative method for assessing biogenic and anthropogenic impact was applied to the analysis of the video record. Visual methods were limited in their area of coverage, but had high resolution, being the only methods to give some indication of the age or longevity of trawl marks. They also provided a better rapid assessment of the ecological significance of impacts than other methods.

Biological sampling was specifically directed at the benthic megafauna (mostly epifauna). Trials of sampling gear showed that a 2-metre beam trawl was more appropriate for the Clyde Sea area (<100 m deep, high epifaunal density) and a 2-metre Agassiz trawl for the Aegean (>100 m deep, low epifaunal density). Benthic megafauna collected from sites subject to different degrees of trawling impact enabled several investigative approaches, comparing tissue damage in selected species and analysing the structure, population density and functional group composition of the sampled communities. All of these approaches detected effects attributable to trawling impact, and these are discussed.

Sedimentological methods comprised granulometry, a suite of geotechnical tests and sediment profile imagery (SPI). Although granulometry and load resistance penetrometry showed some potential in assessing trawl impact to sediments, only SPI provided relatively rapid information on sedimentary differences between trawled and untrawled areas that appeared to be attributable to trawling.

The operational constraints affecting the various methodologies utilised are compared and discussed, and their cost-effectiveness examined. Finally, a list of recommendations is given on techniques suitable for the rapid assessment of otter trawl impacts on soft substrata. The importance of using two or more complementary methods for rapid assessment is emphasised. Ultimately, the choice of methods will be largely determined by the specific goals of an investigation and the financial and material resources available.

RÉSUMÉ SCIENTIFIQUE

Au cours de la présente étude nous avons évalué et comparé un ensemble de méthodes de quantification rapides de l'impact environnemental des chaluts. Ces nouvelles méthodes sont présentées comme une alternative aux méthodes traditionnelles notoirement lentes et coûteuses, et couvrent une gamme de techniques faciles à mettre en œuvre allant de l'échantillonnage biologique de base jusqu'à la télédétection fine. Ces techniques d'évaluation rapides permettront d'optimiser la gestion des pêcheries en temps réel, à l'échelle de l'écosystème. L'étude a été réalisée sur des fonds à langoustines (*Nephrops norvegicus*) d'Ecosse d'une part et sur des fonds de la mer Egée supportant une pêche multispécifique d'autre part. Les sites ont été sélectionnés de façon à couvrir une large gamme d'impacts de chaluts, basé sur des informations détaillées sur les activités de pêche: les sites écossais (Mer de Clyde, substrat vaseux) couvrant trois niveaux d'intensité de pêche (fort, modéré et léger), les sites de la mer Egée (au Nord de la Crête) reflétant quant à eux un continuum d'intensité de chalutage. En Méditerranée, l'échantillonnage a été réalisé à travers une étroite bande de chalutage, sur un substrat vaseux, pendant la saison d'ouverture de la pêche puis pendant la saison de fermeture. Pour permettre une comparaison avec ces échantillonnages, des chalutages expérimentaux ont été réalisés sur un site adjacent sableux, mais jamais pêché auparavant.

Les techniques évaluées dans cette étude peuvent être réparties en quatre larges catégories : acoustiques, visuelles, biologiques et sédimentologiques. Les techniques acoustiques mettent en œuvre l'utilisation d'un sonar permettant de discriminer les types de fonds (RoxAnn^{TM}) ainsi que d'un sonar latéral. L'impact des chaluts n'est pas détecté par le premier, mais par contre le sonar latéral s'est avéré efficace dans la détection et le dénombrement des marques de panneaux. Les stratégies d'échantillonnage et de traitement de la donnée à partir de l'utilisation du sonar latéral sont discutés. Les méthodes visuelles sont basées sur la vidéo sous-marine, opérée à soit partir d'un traîneau benthique (optimisé pour des études de type transect) soit à partir d'un ROV (véhicule téléguidé) (optimisé pour les études stationnelles). Une méthode semi-quantitative d'évaluation des impacts biogènes et anthropiques est appliquée à l'analyse des enregistrements vidéos. Ces méthodes visuelles sont limitées par leur surface de couverture, mais font preuve d'un degré de résolution élevé, et constituent la seule méthode donnant une indication fiable sur l'âge et la longévité des traces de chaluts. Elles fournissent également une meilleure et plus rapide évaluation de l'importance écologique des impacts que les autres méthodes.

L'échantillonnage biologique visait directement l'épi-mégafaune benthique. Plusieurs engins de prélèvement ont été testés qui ont montré qu'un chalut à perche de 2m d'ouverture est plus efficace en mer de Clyde (moins de 100m de profondeur, forte densité en épifaune), alors qu'un chalut d'Agassiz de 2m d'ouverture s'est révélé plus approprié en mer Egée (plus de 100m de profondeur, faible densité en épifaune) La mégafaune récoltée sur les sites soumis à des pressions de pêche différente ont permis d'élaborer plusieurs approches d'évaluation de l'impact, comparant les dommages causés aux tissus de certaines espèces sélectionnées ou analysant la structure ou la densité de populations, ou encore la structure fonctionnelle des communautés échantillonnées. Toutes ces méthodes démontrent des effets attribuables à l'impact des chaluts, effets qui sont discutés.

Les techniques sédimentologiques incluent la granulométrie, une gamme de tests géotechniques et l'imagerie de profil de sédiment (SPI). Bien que la granulométrie et la résistance à la pénétration se montrent capable d'estimer l'impact des chaluts, seule la SPI fournit rapidement une information sur les différences sédimentologiques entre les sites chalutés et non chalutés qui soit imputable au chalutage.

Les contraintes opérationnelles affectant les différentes techniques employées sont comparées et discutées, et leur rapport coût/efficacité évalué. Enfin, une liste de recommandations est donnée pour l'emploi de techniques appropriées destinées à l'évaluation rapide de l'impact des chaluts sur les fonds meubles. L'importance d'utiliser deux (ou plus) méthodes complémentaires est soulignée. En conclusion, le choix des méthodes est largement déterminé par les buts spécifiques de l'étude, ainsi que par les ressources matérielles et financières disponibles.

NON-SPECIALIST SUMMARY

The effects of towed fishing gear on the marine environment have received increasing attention in recent years. Such gear affects much more than the species caught; as the gear is dragged across the sea bed it disturbs both the sediments and the organisms and plants living in or on the sediments. The physical characteristics of the seabed can be radically altered, causing long-term changes to fragile habitats and affecting the number and diversity of organisms that can live there. Many of the species affected by towed fishing gears have no commercial value, but they play important ecological roles. Some organisms are less tolerant to disturbance than others, so their numbers may decline in areas that are impacted by trawling. Numerous species also suffer physical damage when caught in, or passed over by, towed fishing gear. Often the evidence of this can be seen in damaged shells (molluscs), missing or regenerating legs (crustaceans) or regenerating arms (starfish). Animals that die on the sea bed or that are discarded, dead, from fishing boats can attract large numbers of scavengers to the area, thus altering the balance of the sea bed community. It is important that the environmental impact of towed fishing gear can be assessed and monitored, so that fisheries can be managed in a responsible way.

Some of the methods commonly used in the past to investigate the effects of fishing gear have relied on taking samples of sediment from the sea bed using mechanical grabs. These samples are sieved to remove the animals which are then identified, counted and weighed, and this information analysed to see if there are any effects on community structure that may be attributable to trawling impact. Such methods have been criticised for taking too long (sometimes years), for investigating a fraction of the fauna which is not the most vulnerable to fishing gear and for giving equivocal results. There is a need for more rapid and reliable methods of assessing trawl impacts, to underpin and support the move towards an ecosystem-based approach to fisheries management. The aim of this project was to evaluate a suite of methods that might be suitable for this purpose. Methods were selected on the basis that they had the potential to generate information quickly; that is in days or weeks rather than months or years. The methods were applied to areas where otter trawls were the main type of fishing gear, this being one of the most common gears used in European waters.

The otter trawl gets its name from the two ‘otter boards’ (or trawl doors) that are attached to the trawl warps (wires) on either side of the net. These boards act like hydrofoils, keeping the mouth of the net open and they come in various designs, made of wood or metal, so they are always heavy (hundreds of kilos). In practice, they drag along the sea bed like a plough drags across a field, leaving furrows and berms in the sediment. The trawl net can itself cause disturbance and damage as it skims the sediment, flattening mounds and filling-in burrows, knocking over any erect life forms (like sea-pens) and tumbling round-bodied animals such as sea-urchins and whelks. As the bag of the net brushes over the sea bed, clouds of sediment particles are stirred into the overlying water, later to resettle either at the site trawled or elsewhere if transported away by currents. This pulse of falling sediment can smother small filter-feeding organisms.

Two geographically separate regions were studied, one in the northeast Atlantic (namely Scottish waters) and one in the Mediterranean (specifically the Aegean Sea). In Scotland, the study took place in the Clyde Sea area where otter trawling for the Norway lobster, *Nephrops norvegicus* (also known as scampi, Dublin Bay prawns and langoustine), is the main fishery. In the Aegean, the study was in waters just north of Crete where otter trawls are used in a 'multi-species' fishery, catching a variety of fish and 'shrimps'. Both areas have predominantly muddy sediments.

Based on a detailed knowledge of the activities of the local fishing fleet, study sites in the Clyde Sea area were selected to represent different perceived levels of fishing impact (heavy, moderate and light). In the Aegean, two sites were chosen. The first incorporated a narrow commercial fishing lane, where fishing impact was heaviest at the centre of the lane and least towards the edges. This site was investigated during open and closed seasons, when fishing was permitted or prohibited, respectively. The other site was an unfished sandy ground that was trawled experimentally, enabling the effects of a quantifiable impact to be investigated.

The assessment methods evaluated in the study fell into four categories: acoustic methods, visual methods, methods based on biological sampling, and methods based on an examination of the sea bed sediment. The acoustic methods used were bottom-discriminating sonar (RoxAnn™) and sidescan sonar. Here, analysis of a reflected sound signal gave information on various characteristics of the sea bed. Effects attributable to trawling were not detected by bottom-discriminating sonar, but sidescan sonar enabled trawl marks (scours made by otter boards) to be detected and counted. Various survey designs and analytical approaches are discussed, their application depending on the type of fishing ground studied.

Visual methods were based on the use of underwater television. Two systems were evaluated, one with a TV camera mounted on a sledge that was towed behind the survey vessel, and the other with the camera mounted in a remote operated vehicle (ROV) that was deployed whilst the survey vessel was stationary or moving very slowly. The towed-sledge system proved to be an effective method for investigating transects across large areas of the sea bed. A semi-quantitative procedure for assessing the extent of natural and/or man-made disturbance to the sea bed was applied to the video record of the sledge surveys. The ROV system was most suitable for close examination of small areas of sea bed, allowing the characteristic marks left by different parts of the trawl gear to be identified and enabling direct measurement of the width or depth of these marks. Visual methods provided high-resolution (i.e. detailed) surveys of limited spatial areas, in contrast to sonar methods that could cover larger areas, but with lower resolution (fine detail could not be seen). Also, visual methods were the only ones evaluated that gave some indication of the age of trawl marks and they proved better than the other methods at providing a rapid assessment of the ecological significance of the impacts of trawl gear.

Biological sampling was aimed at collecting 'megafauna', that is the larger animals like whelks, crabs and starfish that usually live on the surface of the sediment or in the extreme upper layer. These are the animals most likely to be affected by trawling. They were sampled using small trawls (only 2 metres across the mouth), though the one used in the Aegean had to be a heavier design in order to sink quickly in the far deeper water there. Samples were collected from different sites representing different degrees of trawl impact. The extent of damage to selected species (e.g. broken shells in whelks, lost arms in starfish and feather-stars) was assessed and compared between sites. Also, the variety and abundance of animals caught at different sites were analysed and compared. All of these approaches detected differences between sites that could be attributable to trawling, and these are discussed.

Several methods were used to investigate possible effects of trawling on the composition and structure of the sediment. These were an analysis of the size-distribution of the grains that comprise the sediment, analyses of the degree of compaction of the sediment, and the use of a specialised camera to photograph a vertical profile through the surface and upper layers of the sediment, thus recording its structure. Although the first two methods have potential and revealed some information that may be attributable to trawling, only the last method (Sediment Profile Imagery) provided relatively rapid information on differences between the sediment in trawled and untrawled areas that appear to be a direct result of trawling.

The operational constraints affecting the various methodologies evaluated here are compared and discussed, and the cost-effectiveness of the various techniques is examined. Finally, a list of recommendations is given on techniques suitable for the rapid assessment of otter trawl impacts on muddy sea beds. It is important to use two or more complementary methods of assessment, but the choice of methods will be largely determined by the specific goals of an investigation and the financial and material resources available.

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LIST OF ACRONYMS

2MB	2-metre beam trawl
ANOVA	Analysis of Variance
ANCOVA	Analysis of Covariance
BU-GU	Biosedimentology Unit, Glasgow University
CFP	Common Fishery Policy
D-GPS	Differential Global Positioning System
DG XIV	Directorate General No. 14, Fisheries
DML	Dunstaffnage Marine Laboratory, Oban
EC	European Commission
EXP-C	Control site at Gouves, Aegean.
EXP-FL	Commercial fishing lane at Gouves, Aegean.
EXP-T	Experimental trawling site at Gouves, Aegean.
FL-IN	Commercial fishing lane by Dia Island, Aegean.
FL-OUTN	Northern control site by Dia Island, Aegean.
FL-OUTS	Southern control site by Dia Island, Aegean.
GPS	Global Positioning System
ID	Inside diameter
IMBC	Institute of Marine Biology, Crete
LOA	Length overall
MDS	Multi-dimensional scaling
MLA	Marine Laboratory, Aberdeen
MLRP	Micro-scale Load Resistance Penetrometer
PRIMER	Plymouth routines in multivariate ecological research
ROV	Remote Operated Vehicle
SCUBA	Self Contained Underwater Breathing Apparatus
SNH	Scottish Natural Heritage
SPI	Sediment Profile Imagery
UMBSM	University Marine Biological Station, Millport
UWTV	Underwater Television.

CONVENTIONS

Conventions used in this report are as follows:

- Figures are placed at the end of the section where they are first mentioned.
- Tables are normally incorporated with the text, soon after they are first mentioned.
- A hierarchy of spatial areas has been adopted such that: Region>Area>Site>Station.

1. INTRODUCTION

Context

Recent researches have highlighted the massive impact of demersal towed gears, particularly beam trawling, on the marine benthos of shelf seas (Lindeboom & de Groot, 1998; Jennings & Kaiser, 1998; Hall, 1999; Bergman & Van Santbrink, 2000; Kaiser & de Groot, 2000; Kaiser *et al.*, 2000). For example, eighty years of increasingly intensive beam trawling have completely re-structured the benthic ecosystem of the North Sea. The considerable socio-economic importance of the fishing industry means that such impacts are unlikely ever to disappear. Quantitative assessment of these impacts is urgently needed. Data from as wide a variety of fisheries and ground types as possible are needed to facilitate management decisions allowing regulation of fisheries at the ecosystem level. This will aid the resolution of conflicts between conservation on the one hand and economic exploitation on the other (see Moore, 1999; Kaiser & de Groot, 2000; Moore & Jennings, 2000). However, it is clear that significant problems need to be overcome before integrated fisheries management becomes a reality under the Common Fisheries Policy (CFP) (Symes, 2000).

In Europe and elsewhere, fisheries management has been increasingly coming to terms with the need to widen its brief from management of purely target species to the consideration of ecosystem effects. In recent years, this has been reflected in Calls for Study Projects within the framework of the EC Common Fisheries Policy, for example in evaluating the impact of towed gear on soft-sediment sea beds and benthic ecosystems, and in addressing the problem of discards. The inspection and monitoring responsibilities under the CFP necessitate the identification and optimisation of strategies by which these objectives can be delivered. The programme of research detailed in the present Report has addressed the *methodological* side of the quantitative assessment of the impact of towed gear on particulate sea beds and benthic ecosystems. The aim has been to identify and evaluate rapid and cost-effective methods of assessing the environmental impact of *otter trawls* and thus to generate recommendations leading to more efficient monitoring protocols. The focus is therefore on appropriate methods for detecting and evaluating gear impacts, not on the biological or physical minutiae of the impacts themselves. Otter trawling is a major capture technique in European fisheries, but surprisingly one of the least studied in terms of its environmental impact.

The trawl fisheries responsible for the impacts studied in this report

This investigation of rapid methodologies for assessing otter trawling impacts has taken place in N. Atlantic (Clyde Sea) and Mediterranean (S. Aegean) study areas subject to differing trawling impacts. The major trawl fishery in the Clyde Sea area is for the burrow-dwelling Norway lobster (*Nephrops norvegicus*) (Bailey *et al.*, 1986; Anon., 1999, 2000) which is one of the most valuable shellfish resources in the NE Atlantic. It is commercially exploited throughout its geographic range, from Icelandic waters to the Mediterranean and Moroccan coast. Annual landings are around 60,000 tonnes (FAO, 1995 and FAO web-site), making the species one of the most valuable lobster resources in the world. Scottish landings in 1995 were almost 22,500 tonnes, with a value of over £45M (~ €73M), making it the second most valuable species landed here. Whereas ‘Total Allowable Catch’ (TAC) limits have maintained the tonnage landed in recent years close to the above level, the value has now increased to almost £60M (~ €98M) (Fisheries Research Services database, Marine Laboratory Aberdeen). Annual Clyde Sea landings are around 4,000 tonnes. *Nephrops* trawling (using several types of otter trawl, with single rigs having a mesh of 70 mm and twin rigs a mesh of 80 mm) takes place at different intensities on a variety of benthic substrata, ranging from muddy sands through sandy muds to soft muds. An area closed to fishing was also investigated.

The CFP is not implemented as rigorously in the Mediterranean as in northern European waters for a combination of reasons, including less well developed fisheries, relatively poor policing, the less international nature of fishing grounds and the multispecies nature of demersal fisheries (as opposed to highly selective targeting). In Greece, for example, one basic type of demersal trawl is used on all grounds, to a depth of around 500 m, in a multispecies fishery. Management measures include a four month closed season (June – September, inclusive) and a net mesh size set at 40 mm (previously smaller). In 1995, even with its large artisanal fishery, demersal trawl landings made up 19% of the tonnage of fish landed, but represented over 30% of the market value at approximately €24 M (~£15M). The grounds investigated in the present study were off the north coast of Crete and included a commercially fished area and one on which fishing effort was controlled experimentally.

Recent impact studies

Despite a high degree of interest over the last decade in evaluating fishing gear impacts on the marine environment in northern European waters, otter trawl gears remain poorly studied. The EC-funded IMPACT-I research programme (de Groot & Lindeboom, 1994) investigated the impact of beam trawls in the North Sea. IMPACT-II (Lindeboom & de Groot, 1998) extended the study to include analyses of historical impact trends in fisheries data, a review of gear types in use and their impacts on target and non-target species (including discards) and case-studies of the impact of certain gears in fished and unfished areas. It also investigated the consequences of discard practices, with particular emphasis on predator and scavenger responses. Gear effects on sandy substrata, particularly of beam trawls, received the most attention.

The environmental impact of toothed dredges operated in coarse sediments has also received much attention, most recently from work in Manx (Bradshaw *et al.*, 2000), Scottish (Hall-Spencer & Moore, 2000c), French (Hall-Spencer *et al.* 2001) and Italian waters (Pranovi *et al.* 1998; Giovanardi *et al.*, 1998; Hall-Spencer *et al.*, 1999), building on a foundation of earlier studies (e.g. Caddy, 1973; Chapman *et al.*, 1977; Eleftheriou & Robertson, 1992). The degree of impact varies with ground type and associated fauna. For example, Bradshaw *et al.* (2000) demonstrated that community structure from gravelly substrata reflected dredging intensity. Hall-Spencer & Moore (2000c) showed that scallop dredging could kill and bury 70% of living maerl (a coralline algal habitat of special conservation significance in EU waters) in the dredge path, and Hall-Spencer *et al.* (1999) showed the large bivalve *Atrina fragilis* was particularly vulnerable to destruction by Rapido trawling in the Mediterranean. Kaiser *et al.* (2000) investigated infaunal and epifaunal composition and scarring on shells of long-lived molluscs on scallop-dredged Manx grounds, concluding that fishing had caused significant and widespread changes.

The valuable IMPACT II study did address some aspects of otter trawling. For example, direct impacts of a partial otter rig (doors and modified rockhopper ground gear, lacking the net) on faunal composition and the sea bed were investigated in a small, shallow Clyde Sea loch where commercial trawling was prohibited for military reasons (Tuck *et al.* 1998). Also, impacts of trawling on Irish Sea *Nephrops* grounds were investigated indirectly by taking grab samples for faunal and granulometric analyses, and by SCUBA and underwater TV observations along transects radiating from two wreck sites. This work is discussed by Ball *et al.* (2000), together with the sea loch work mentioned above. They concluded that the most obvious physical impact was that of the trawl doors, and that trawling resulted in a reduction in the abundance of large, fragile organisms and an increase in the abundance of opportunistic species. Recovery appeared to be slower on muddy than on coarser grounds.

Dramatic effects have been seen in the Mediterranean where illegal trawling has severely impacted seagrass (*Posidonia oceanica*) meadows and their associated communities in some areas (Ardizzone *et al.*, 2000). In other Mediterranean studies, Smith *et al.* (2000) showed that the abundance, biomass and diversity of benthic fauna were reduced by trawling activity and these changes were still apparent at the end of a four month closed season. There have also been several recent otter trawl impact studies in non-European waters, e.g. Schwinghamer *et al.*(1998) and Prena *et al.* (1999), where effects on sediment and fauna have been examined.

Other otter trawl-based work reported in IMPACT II was mainly directed towards discard studies and to changes in catch composition following repeated trawling. Many studies have demonstrated the subsidy to avian and benthic scavengers provided by discard practices and trawl damage to organisms *in situ* (e.g. Hill & Wassenberg, 1990; Kaiser & Spencer, 1994; Kaiser & Ramsay, 1997; Ramsay *et al.*, 1997; Bergman & Van Santbrink, 2000; Camphuysen & Garthe, 2000; Demestre *et al.*, 2000; Fonds & Groenewold, 2000; Bergmann *et al.*, 2001b).

Thus, IMPACT-II and associated publications gave a valuable insight into some of the effects of otter trawling and highlighted the need for further study. It recommended that more attention should be devoted to the development of appropriate sampling gears for use in stony and (very) silty areas. Furthermore, it stated that studies should be encouraged on commonly overlooked parts of the benthic fauna, i.e. large and rare infauna and epifauna that may be vulnerable to fisheries. The penetration depth (and hence disturbance-creating potential) of towed gears will be markedly affected by differences in gear and ground hardness. The ICES Study Group on the Effects of Bottom Trawling (Anon., 1988) concluded that areas with a soft bottom or with low tidal flows were the most likely to be physically affected by bottom trawling. Such conditions pertain to the study sites chosen for the present study.

The present work thus builds on the results of IMPACT-II and associated studies (in which one of the partners, MLA, participated) and on the project partners' own experience of impact studies of towed gear using a range of techniques including underwater TV, sidescan sonar and RoxAnn™ (Atkinson, 1989; Eleftheriou & Robertson, 1992; Hall-Spencer, 1995; Tuck *et al.*, 1998; Hall-Spencer *et al.*, 1999; Smith *et al.*, 2000). Since past studies on the impact of towed gears have focused mainly on beam trawls towed over sandy substrata, the present study has addressed otter trawling on muddy substrata, the exception being one Aegean site that was predominantly sandy.

Investigative approaches

A variety of approaches are available to study both impacts on the physical environment, such as changes in sediment compaction or granulometry, and direct or indirect impacts on the biota. Different methods are appropriate over a range of spatial scales, from large-scale approaches (such as the analysis of fleet activities), through surveys of areas and specific sites, to the fine-scale examination of characteristic impact features.

Traditionally, many impact studies have focused on effects of trawling on macrofaunal community structure or the physico-chemical structure of sediments on a the small scale (Gibbs *et al.*, 1980; BEON, 1990; Van Dolah *et al.*, 1991; Eleftheriou & Robertson, 1992; De Biasi, 1999, Ball *et al.*, 2000), typically collecting samples with a 0.1 m^2 grab sampler. The effort involved in sample collection is relatively low. However, processing of samples can take considerable time and effort (Kingston & Riddle, 1989) with the involvement, in the case of macrofaunal samples, of many experts in different faunal groups. A large amount of samples are required to ensure an area is adequately represented, and backlogs can easily build-up such that samples often remain incompletely analysed. The turn-around time from sampling to presentation of results can be on the scale of years and, although this method can be very accurate in highlighting affected communities, faunal groups or even species, it is poor in terms of rapid feedback. Impacts may be detected, but results are often inconclusive. Such methods have not been used in the present investigation, with the exception of investigation of possible trawling effects on sediment geotechnics for which there was no alternative but to use small core-collected samples.

In contrast, a variety of more rapid, broad-brush, techniques are available, and most of these can be used to assess impacts over large areas. Such methods include interrogation of fleet records (Kaiser *et al.*, 1996, Jennings *et al.*, 2000), the use of data loggers on commercial vessels (Rijnsdorp *et al.*, 1998; Marrs *et al.*, 2000a), and the use of bottom-imaging techniques like sidescan sonar (Service & Magorrian, 1997; Service, 1998; Schwinghamer *et al.*, 1998) or RoxAnn™ (Kaiser *et al.*, 1998; Service, 1998; Schwinghamer *et al.*, 1998) that reveal bottom features, as does underwater television (UWTV) (Smith *et al.*, 2000; Hall-Spencer *et al.*, 1999). Thus, fishing area and fishing intensity can be variously quantified and the impact visualised at the sea bed.

Door marks on soft grounds are discernible using sidescan sonar and underwater television. These methods are complementary because sonar methods only provide a partial picture of the extent of a trawl's impact on the ground. The net itself leaves no sonar-discernible ground signature, but its effect can be seen using UWTV. RoxAnn^{TM} surveys at short intervals (hrs) after trawling have also detected sedimentary changes caused by trawl suspension of fine sediment (Schwinghamer *et al.*, 1998; Fonteyne, 2000) and trawl-induced sedimentary changes have been shown to persist for several months (Ball *et al.*, 2000).

Since the impact of otter trawling is mainly surficial, the organisms most impacted are likely to be the epibenthic megafauna (e.g. sea pens, echinoderms, crustaceans, molluscs). Such organisms are inadequately sampled using quantitative sampling gear like grabs and corers that are designed for infaunal macrofauna since they are sparsely distributed. Atkinson (1989), Hall-Spencer & Atkinson (1999) and Hall-Spencer *et al.* (2001) have investigated the impacts of towed gear on the more deeply buried elements of the megafauna. Some of these biomass dominants were affected little by the passage of towed gear, again reinforcing the importance of concentrating on epifaunal species in the present study.

The best method for collecting sparsely distributed large macrofauna and megafauna is using lightweight, fine-meshed beam trawls (e.g. Kaiser *et al.*, 1994; Jennings *et al.*, 1999a) or Agassiz trawls (e.g. Smith *et al.*, 2000) that skim the surface. Because of the relatively large size of individual species, samples can generally be rapidly sorted, identified, enumerated and weighed on board the catching vessel with perhaps only a small fraction of the catch needing to be preserved and returned to the laboratory for further examination. The remainder of the sample can be returned to the sea, a conservation strategy that may help reduce sampling impact. Kaiser *et al.* (1994) used a 2-metre beam trawl with suitably modified tickler chains to good effect to study epibenthic megafauna in the Irish Sea. Bergman & Van Santbrink (1994) criticised such gear as being semi-quantitative only and presented their Deep Digging Dredge as a better method. In digging to 10cm, however, this complex and costly sampler captures both epifauna and infauna, and analysis of the catch is time-consuming and therefore expensive. Whatever the merits of this dredge, we rejected it as a method to be considered at present since it does not appear to meet our criteria for rapid, cost-effective sampling.

Indirect methods may also be applied to assess fishing impacts, either using growth interruption marks in the shells of long-lived bivalve molluscs (Witbaard & Klein, 1994), or examining the extent of damage to trawled organisms, e.g. arm damage in asteroid or ophiuroid echinoderms (Kaiser, 1996). Quantitative assessments of population densities of organisms vulnerable to particular gears have also been used successfully in the past (Kaiser *et al.*, 1996). Several approaches are possible, comparing densities before- and after-fishing treatments or ‘within’ versus ‘outside’ trawled zones (Kaiser & Spencer, 1996) or estimating the standing stocks in areas experiencing different degrees of fishing intensity. A secondary impact of towing demersal gear over a sea bed is leaving a considerable swathe of injured organisms in the trawl track (Bergman & Van Santbrink, 2000), thus attracting scavenging organisms. The damage load sustained by fragile invertebrate epifaunal organisms like starfish and brittlestars may be a longer-term integrator of total trawling impact than information gained from infaunal studies, will perhaps only relate to trawling intensity over the preceding 1-2 years (Kaiser, 1996).

Trawl-damaged animals provide an artificial food subsidy to an area which, over time, generally seems to shift the trophic composition of the fauna in favour of scavenger or opportunist species (Kaiser & Spencer, 1996; Kaiser & Ramsay, 1997; Ramsay *et al.*, 1997). Thus, an analysis of the functional group composition of the epibenthos of an area may convey useful information on the impact of fishing on that ground. The fauna can be grouped by feeding type (carnivore, scavenger, surface deposit feeder, sub-surface deposit feeder or filter feeder) or by mobility (mobile, discretely mobile/sedentary or sessile). The latter group are permanently attached to the substratum and so are perhaps one of the best indicators of trawling impact as, once they are removed from the environment, the only way that they can move back into the area is by recruitment, settlement and growth. Sessile fauna include organisms such as pennatulids (sea pens), some crinoids (feather stars) and the ascidians (sea-squirts). Discretely mobile / sedentary fauna can be classified as those that will only move within a small radius or are slow movers and can include large burrowing fauna, such as thalassinidean mud shrimps, Norway lobsters (*Nephrops norvegicus*), echiuran worms and irregular echinoids (starfish & ophiuroids). Motile fauna would include the non-burrowing decapods, cephalopod and fish species that are benthic in habit.

2. OBJECTIVES

The *Objectives* of the project and the specific *Tasks* listed in the Project Proposal are reproduced here, as they are referred to throughout this report.

Objectives

1) To identify from fleet and local data, the regional pattern of demersal trawl fishing and identify grounds which differ in trawling intensity.
2) To identify the most efficient, cost-effective strategy for studying and quantifying the environmental impact of otter trawls, using a suite of rapid-assessment methods.
3) To accomplish objective (1) by investigating grounds that experience different levels of trawling activity, but within the context of highly significant target fisheries and including major grounds within these fisheries.
4) To compare and contrast otter trawling impacts on Atlantic (Clyde Sea) and Mediterranean (Aegean) grounds, thus ensuring panEuropean added value through equal involvement and close collaboration between the island-bound partners for which such exchange is sociologically and scientifically invaluable.
5) To ensure effective dissemination of results by modern methods of communication, e.g. World Wide Web, underwater video, information brochures, conference attendance and publication in the scientific literature.

Tasks

Task 1:- To establish the local spatial patterns of fishery exploitation as far as is possible from existing databases for each of the partner's areas and select study sites based on best available information relating to fishery practices.

Task 2:- To select most appropriate lightweight towed gear (either small beam trawls or Agassiz trawls) for sampling epibenthic megafauna and investigate number of replicates required.

Task 3:- To survey the sea bed microtopography using sonar imaging techniques at precisely located co-ordinates on each of the grounds selected within each partners' area, at the most informative time(s) of the year, thus giving consideration to closed seasons in the Mediterranean.

Task 4:-To sample epibenthic megafauna using standardised lightweight towed gear and, on each study ground, to deliver the information noted in the subtasks below.

Sub Task 1. Assessments of the damage load of vulnerable elements of the benthos, notable starfish, brittlestars, crustaceans and molluscs, but also sea pens, sponges and ascidians if present.

Sub Task 2. Assessment of the variability between samples.

Sub Task 3. Assessments of the population densities of selected epibenthic megafauna.

Sub Task 4. Analyses of the functional group composition of the epifaunal megabenthos.

Task 5:- To ‘ground-truth’ the data from Tasks 3 & 4 using towed underwater television techniques and, where appropriate, ROV or SCUBA diving on at least one occasion on each ground. These are also rapid assessment methodologies. They also allow scale effects to be addressed.

Task 6:- To relate data from Tasks 1 – 5 to granulometric structure and degree of sediment compaction / penetrability of each site. Sedimentological data combined with underwater television will also provide ground truthing to the sonar studies.

Task 7:- Data analysis and synthesis.

3. SITES & METHODS

3.1 Site Selection (Task 1)

Clyde Sea

In the Clyde Sea, site selection was based on our local knowledge of the *Nephrops* trawl fishery (Marrs, *pers. comm.*), supported by new data from an on-going EC Study Project mapping the fine-scale distribution of fishing effort by otter trawlers targeting *Nephrops* (Marrs *et al*., 2000a). In the latter project approximately 20% of the Clyde otter-trawl fleet had been fitted with position logging devices, data from which were used to determine precisely where they had been fishing on a daily basis. An effort map was constructed based on twelve months available data (Appendix I). The available information (i.e. long-term local knowledge supplemented by short-term effort map) was used to select, *a priori*, sites representing three nominal intensities of otter trawl activity; categorised as heavy, moderate and light (H, M, & L). A total of nine sites were explored in preliminary surveys between August and November 1999 using sonar, video and trawling. As a result of these surveys, six sites (two in each of the three categories of fishing intensity) were selected for continued study. Each site was approximately 1 NM^2 in area (Fig. 1) with the lightly impacted sites selected to encompass areas where commercial trawling was prohibited. The relevant authorities granted permission to operate in the restricted area, L2.

Aegean

Two areas were chosen for the studies in the Aegean to compare the different investigative methodologies, across both fine and coarse sediments. Both areas were situated in the southern Aegean in the vicinity of Iraklion Bay, Crete (Fig. 2)

One of the principal commercial trawling lanes in Iraklion Bay follows the 200 m contour and narrows in a valley behind Dia Island where trawlers often haul their nets (Fig. 3). This narrow constriction allowed for easy identification of the trawling lane and adjacent non-trawled control areas. That lane is mostly definable by the contours and quite easily distinguishable. The area had been identified previously and work had been carried out there for some time with respect to trawling impacts on sediment characteristics and macrofaunal community structure. The sediments were characterised by relatively soft silty clays. A towed underwater video-sledge was used to identify precise sites within the areas for a more detailed sampling programme and these consisted of a general sampling area within the trawling lane

(FL-IN) and two control sites, one to the north of the lane on the beginning of the slope up to Dia Island (FL-OUTN) and the other to the south of the trawling lane (FL-OUTS).

The second sampling area at Gouves (Fig. 2) was characteristic of shallower trawling grounds (60-120 m depth). Commercial trawling is carried out in the area, as evidenced by scrapes recorded on video, but less was known about fishing activity in this area. An experiment was set up with two small well defined areas consisting of a short experimentally fished lane (EXP-T) and adjacent control lane (EXP-C). The lanes were situated in topographically restricted areas, protected from accidental commercial trawling by rocky and calcareous algal reefs. Sediment composition was mixed, but was generally coarse sand with some mud and, in localised areas, calcareous sand/rock fragments were present on the sediment surface.

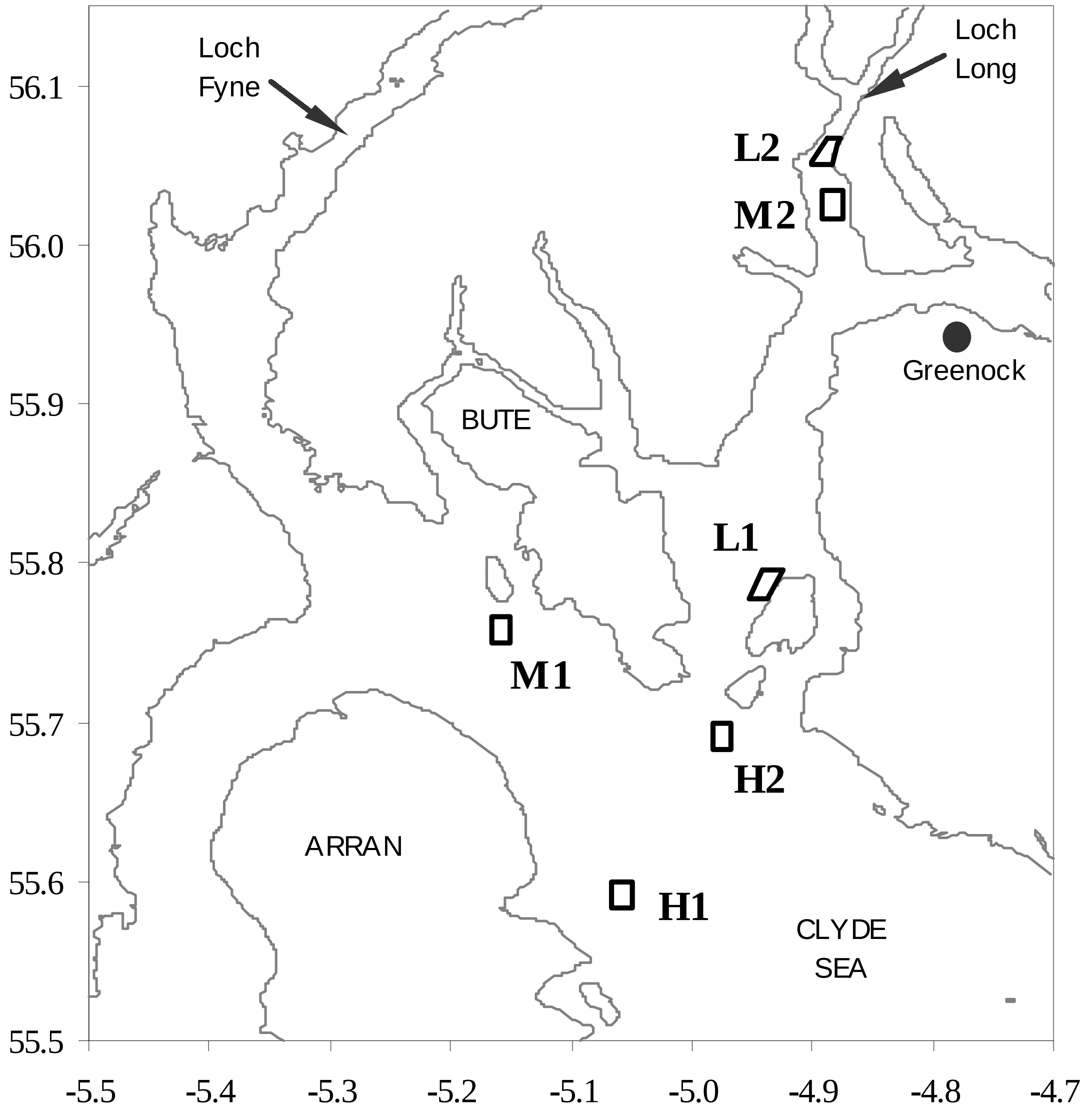


Figure 1. Field sites selected for study in the Clyde Sea area, Scotland. H1 & H2 = heavily impacted, M1 & M2 = moderately impacted, L1 & L2 = lightly impacted (Latitude and Longitude in decimal degrees).

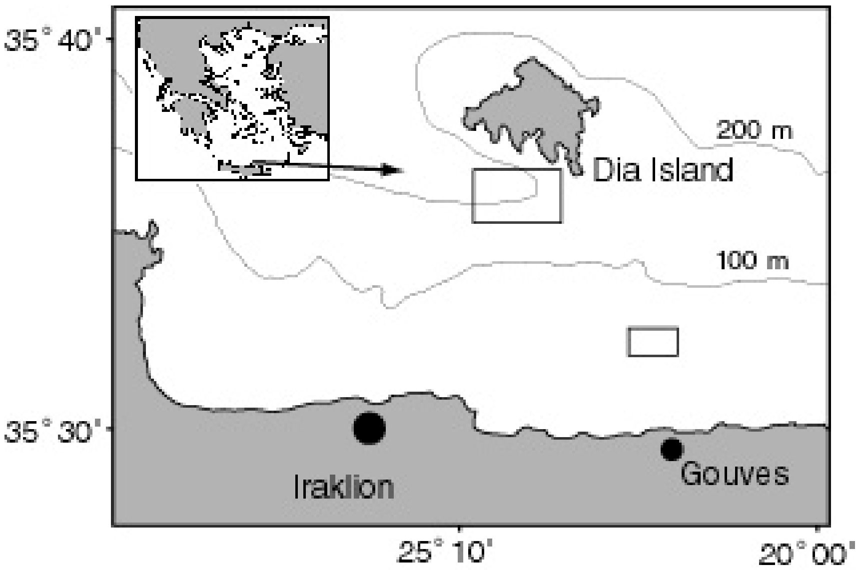


Figure 2. Geographic area of the Aegean experimental areas in the Bay of Iraklion. The two areas investigated are shown in the boxes, indicating the Dia Island area (see Fig. 3) and the Gouves experimental area. (Latitude and longitude are given in degrees and minutes)

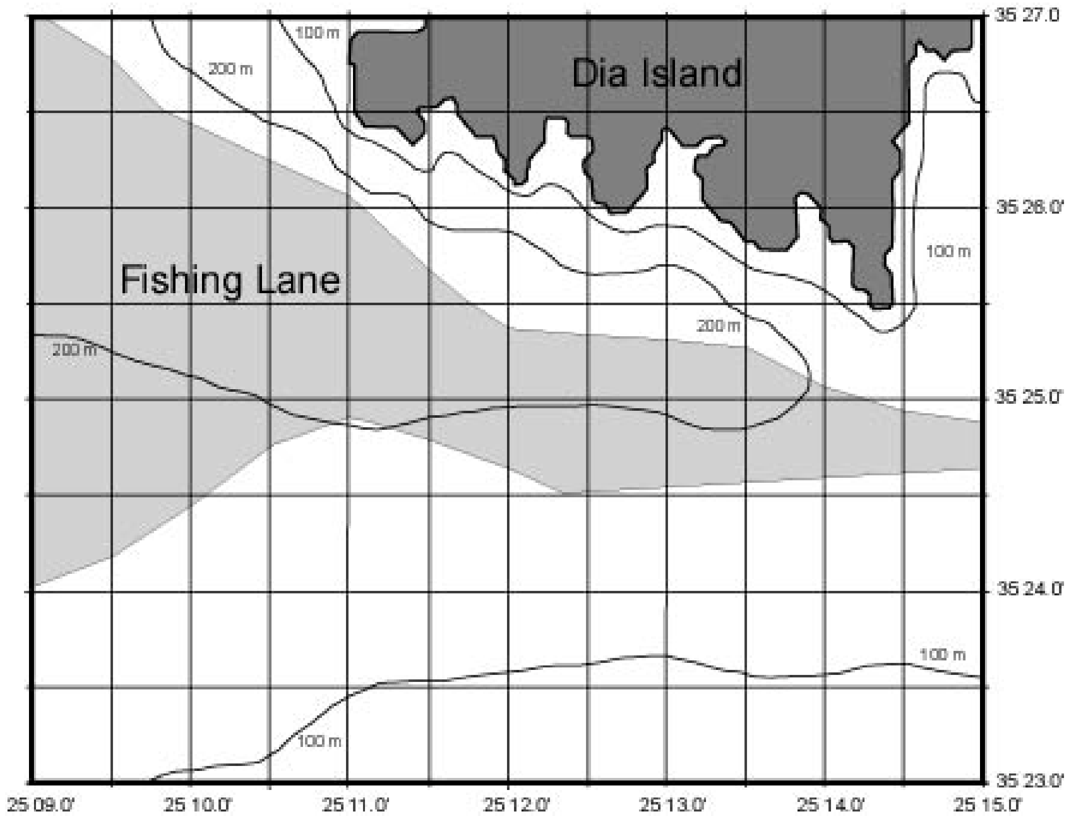


Figure 3. Dia Island area of investigation showing the approximate area of the commercial fishing lane around the 200 m depth contour. (Latitude and longitude are given in degrees and minutes)

3.2 Gear Selection (Task 2)

Clyde Sea

At the start of the project gear trials were undertaken in the UK to select an appropriate lightweight trawl for use in sampling epibenthic megafauna. An Agassiz trawl and a small beam trawl (Fig. 4) were evaluated. Both gears had a mouth width of 2 metres and were rigged with 20 mm stretched mesh net. The Agassiz trawl is used routinely by UMBSM and was rigged without tickler chains to minimise damage to the catch. The beam trawl was built to a proven design detailed by Jennings *et al.* (1999), who included a chain mat, a cod-end liner and an anti-chafe panel in the rig to optimise catch and durability on sand substrata in the North Sea. These items proved inappropriate in the soft substrata of the Clyde Sea causing the net to fill with (or retain) mud, so they were removed leaving only a single chain to weight the footrope.

The efficiency of the two gears was compared by towing them side-by-side on single warps in a series of four 15-minute tows at 70 m depth on a muddy substratum typical of demersal fishing grounds in the Clyde Sea. As reported in the results section, the small beam trawl proved preferable to the Agassiz trawl for sampling epibenthic megafauna from the Clyde Sea.

Aegean

The same two gears as tested in Scotland were available for work in the Aegean for the collection of megafaunal samples, the small 2 m beam trawl and the 2 m Agassiz trawl. The Agassiz was the principal gear of choice in previous studies in the Aegean. However, trials were held to compare both gears, with five replicate hauls being made at both sites for each gear. Haul duration was 30 minutes in Dia Island and 15 minutes in the Gouves area.

Although the survey vessel could potentially tow twin gears, there was no previous experience with this methodology so individual tows were made for each gear in each area, finishing the replicate hauls before switching gears. The catch was processed on-board and in the laboratory with identification made to species level where possible, and abundance and biomass estimated. Comparisons were made of community statistics including mean species per haul and mean abundance and biomass standardised to a swept area of 1000 m^2.

At the conception of the project it was intended that the same trawl gear be used in both the Clyde and Aegean Seas in order to allow direct comparison of results. However, this proved to be inappropriate due to sedimentological and bathymetric differences between the two regions. In the Clyde Sea area, sediments were very soft and the Agassiz trawl quickly filled with mud. In the Aegean there were greater spatial restriction in sampling sites, due to rock reefs and outcrops, and the small beam trawl could not be towed for long enough at every site to produce an adequate amount of material for study. At the deeper Aegean sites (200 m) it was necessary to use the heavier Agassiz trawl in order to ensure the gear remained in contact with the sea bed.

a)

b)

Figure 4. Small trawls used for sampling epibenthic megafauna. a) 2-metre Agassiz trawl (photo. courtesy of M. Bergmann), b) 2-metre beam trawl.

3.3 Sonar Imaging Methods (Task 3)

3.3.1 Sidescan Sonar

3.3.1.1 Clyde Sea

Sidescan sonar is an acoustic method of surveying the sea bed and works on a similar principle to a ship's echo sounder. A transponder is towed a few metres above the sea bed and the echo signals interpreted by computer software to provide a visualisation of a strip of sea bed. The displayed image represents the acoustic properties (reflectivity) of the sediment. As well as detecting large objects, such as shipwrecks or rock outcrops, it can also reveal scour marks left in soft sediments by components of demersal trawl gear.

In the Clyde Sea, two surveys of different designs were conducted using a Geoacoustics 159D Sidescan towfish, Geoacoustics 5210 Transceiver and an Isis PC-based data recording package. The towfish was flown at an average height of 6 m above the sea bed and operated at a frequency of 100 kHz giving a swathe width of 240 m. In the first survey (November 1999) each site was covered following a series of close parallel tracks (Fig. 5a) to enable a mosaic image of the entire site to be constructed. In the second survey (May 2000), a grid pattern was followed (Fig. 5b) from which a series of single frame 'snapshots' were analysed to determine the density of trawl marks and describe the pattern of their orientation.

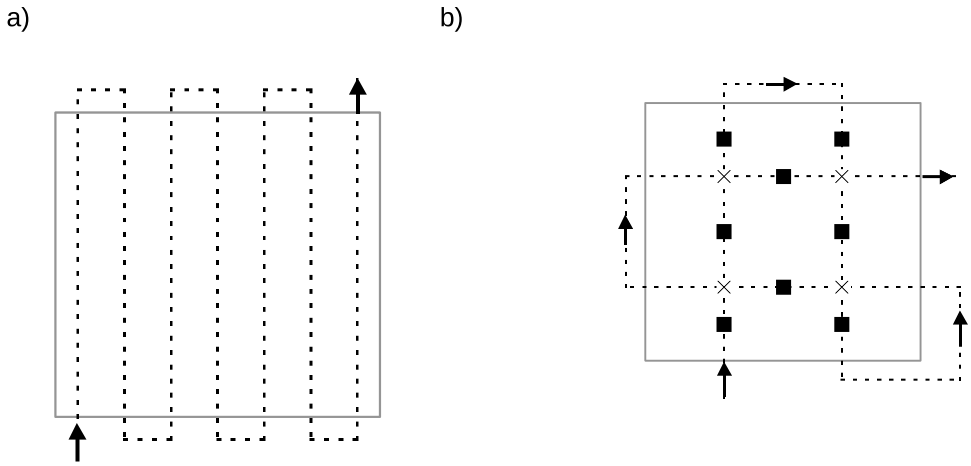


Figure 5. Stylised survey design for sidescan sonar surveys in the Clyde Sea area. a) a series of parallel passes, b) an open grid pattern from which 'snapshots' were taken. Filled squares represent 'frames', i.e. single snapshots. X represents 'intersects', i.e. paired frames taken at the same point but from perpendicular axes.

During the first survey it was noted that trawl marks produced strong images on the sidescan sonar if they happened to run approximately parallel to the survey track, but they became progressively more faint as their orientation deviated from the parallel, eventually disappearing as it approached the perpendicular. The orientation of the mark determined its ability to reflect the sonar signal back to the transducer, as represented schematically in Fig.6.

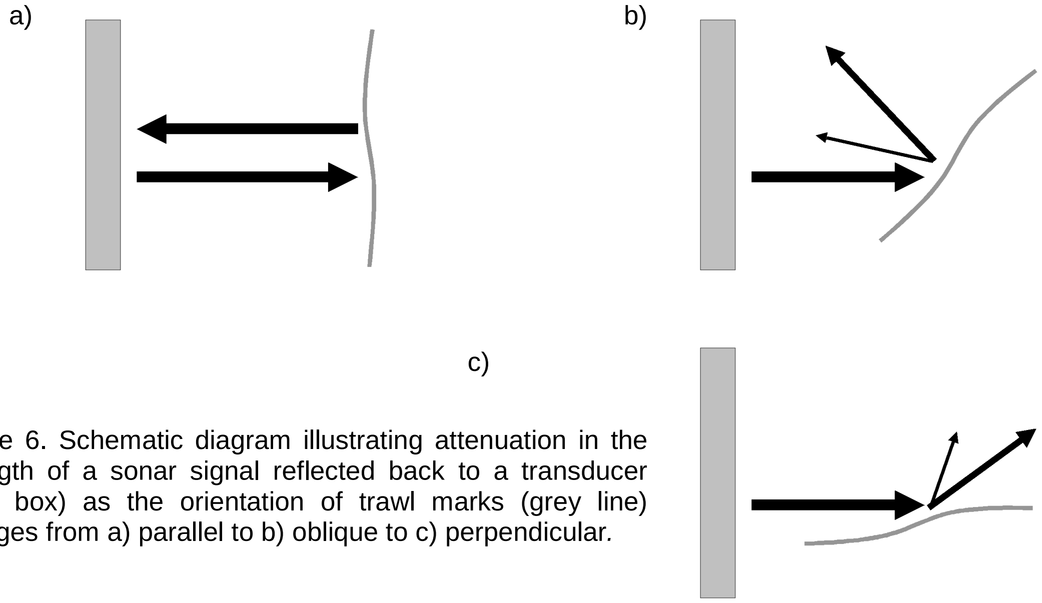


Figure 6. Schematic diagram illustrating attenuation in the strength of a sonar signal reflected back to a transducer (grey box) as the orientation of trawl marks (grey line) changes from a) parallel to b) oblique to c) perpendicular.

This attenuation of the return signal meant that the parallel-pass survey design was not well suited to making quantitative assessments of the density of trawl marks, as marks which ran approximately perpendicular to the survey track were not well detected. Hence the second survey was designed to overcome this limitation, the perpendicular axes of the open grid survey pattern ensuring that marks could be properly detected irrespective of their orientation.

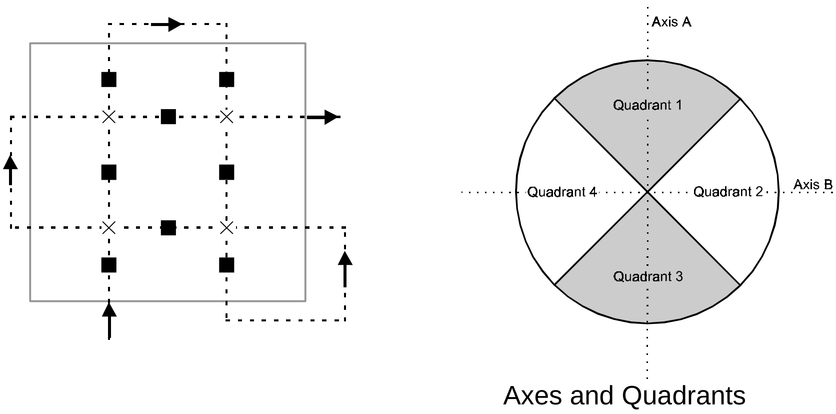


Figure 7. Schematic diagram explaining the nomenclature of Axes and Quadrants relative to the open grid survey pattern used in sidescan sonar surveys in the Clyde Sea area.

In the open grid survey, individual 'snapshots' were extracted from the sonar record at various places along the survey track. These snapshots were referred to as 'frames', being analogous to frames from a movie film. At the intersection points on the grid (marked X in Fig. 5b) it was possible to obtain paired frames representing the same region of sea bed but taken on different axes. To circumvent the effect of signal attenuation, frames taken when travelling on axis A (Fig. 7) were used to estimate the density of trawl marks whose orientation lay in the paired quadrants 1 and 3, and frames from axis B for paired quadrants 2 and 4.

There were two objectives for the quantitative analysis:

I. to obtain a quantitative estimate of the density of trawl marks at each site.

II. to determine any pattern in the orientation of trawl marks.

I. Estimate density of trawl marks

For each frame (including those at intersects) a count was made of the number of trawl marks whose orientation lay in the target quadrants. This was achieved by drawing a reference line across a printout of the frame and measuring the angle (θ) of each trawl mark which crossed the reference line. (Fig. 8). If θ lay in the range 45° to 135° (i.e. within ±45° of the direction along which the survey vessel was travelling) the mark was counted and the angle θ noted. Otherwise the mark was ignored.

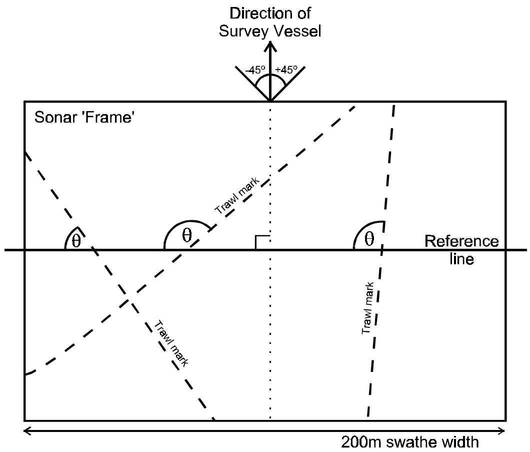


Figure 8. Schematic diagram illustrating the method for quantitative analysis of snapshot frames taken by sidescan sonar surveys in the Clyde Sea area.

This resulted in several counts on axis B and several on axis A. The mean number of trawl marks per frame was calculated for each axis and the following indices derived

Index of Trawl Density $D = a + b$

where a = mean tracks per frame for axis A and b = mean tracks per frame for axis B

Index of Trawl Orientation $O = a / b$

Values of *O* close to 1 indicated that trawl marks were evenly distributed between axes while values far greater or smaller than 1 show there was a preferred direction of tow at the site.

II. Determining patterns in the orientation of trawl marks

A compass bearing for each of the trawl marks counted in *I* above was determined from its measured angle, θ, and the known direction in which the survey vessel was travelling. These bearings could be plotted to obtain a visual representation of the angular pattern of trawl marks on the sea bed. However, it is not possible to tell from a trawl mark in which direction the fishing boat was travelling when the mark was made. It is equally likely to have been travelling on the bearing we had derived or in the opposite direction on a reciprocal bearing. It was therefore desirable to standardise the way in which the orientation of marks was expressed. The option chosen was to express all directions such that they had a southerly component (Fig. 9), i.e. bearings of trawl marks lay in the range 090° to 270°. This had the advantage of avoiding computational problems associated with the change in the compass scale from 360° to 000° about the North cardinal point.

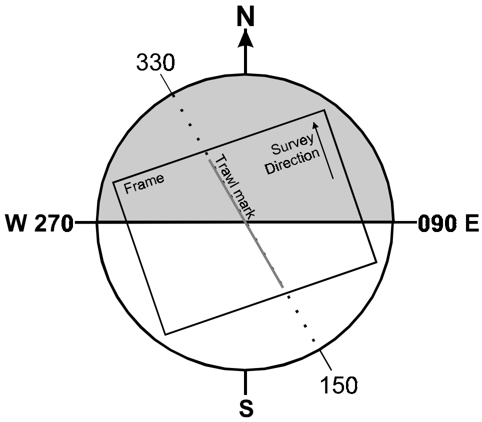


Figure 9. Schematic diagram illustrating how the orientation of a trawl mark can be described by one of two bearings (e.g. 330° or the reciprocal bearing 150°). For surveys in the Clyde Sea area, bearings were standardised to have a southerly component (i.e. lie between 090° and 270°)

A simple graphical presentation of the results was constructed to show the percentage frequency of trawl marks in each 22.5° sector from 090° to 270°; the sectors were numbered 1 to 8 consecutively. To avoid bias caused by there being more frames (i.e. sampling points) on one axis than the other, data for each axis were treated separately before deriving an average percentage frequency of marks in each sector, as shown in the worked example below:

Axis A
10 frames
338 marks counted

Sector	n	% freq
1	0	0
2	0	0
3	96	28.4
4	106	31.4
5	53	15.7
6	83	24.6
7	0	0
8	0	0
∑	338	100

Axis B
6 frames
154 marks counted

Sector	n	%freq
1	30	19.5
2	17	11
3	0	0
4	0	0
5	0	0
6	0	0
7	71	46.1
8	36	23.4
∑	154	100

Sector	% freq Axis A	%freq Axis B	Av % freq (A+B)/2
1	0	19.5	9.7
2	0	11	5.5
3	28.4	0	14.2
4	31.4	0	15.7
5	15.7	0	7.8
6	24.6	0	12.3
7	0	46.1	23.1
8	0	23.4	11.7
∑	100	100	100

The data for each site were then plotted as shown in Fig. 10, the length of each line being determined by the magnitude of the average % frequency for that particular sector.

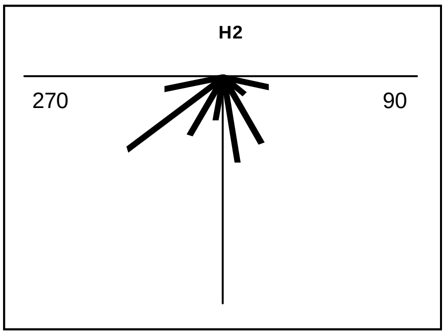


Figure 10. Illustration of plot used to visualise directional patterns in the trawl marks at a site surveyed by sidescan sonar using an open grid survey pattern.

3.3.1.2 Aegean

Similar sidescan sonar equipment was used in the Aegean as in Scotland (Geoacoustics 196D Towfish, SS941 Transceiver, GeoPro LC Processor). All Aegean sidescan surveys were carried out at a frequency of 410 kHz. This higher frequency has a better resolution although lower effective range.

The Dia Island fishing ground ranged from 180-250 m depth and because of the large amount of cable required, grid transects were found to be impractical. At the end of a grid line the vessel must complete a turn, and unless the turn is very wide, cable is taken in or the vessel speeds up, this will result in the towfish losing speed and coming into contact with the sea bed. Sidescan tows were carried out as curved transects generally diagonally across the fishing ground. As explained in the previous sections, tows parallel to the main axis of trawling gave the best images from the trawl door marks and tows perpendicular gave the worst images. In addition, with parallel tows the same trawl marks will be in view for a long period of time, whereas with perpendicular tows, different marks are constantly seen. It should be noted that whatever the plans were, the precise direction of tow was largely dependent on the prevailing weather.

Mosaicing of the tracks was carried out to obtain geo-referenced maps of the separate tracks rather than to cover the whole survey site as was done for the far smaller sites in Scotland, but this did not prove useful (see discussion).

The sidescan was deployed over the stern of the vessel with a counting block used to assess the amount of wire paid out. This was important in the calculation of layback for correct positioning of the sidescan maps, and was simply calculated as:

Layback = SQRT(SQR(cable out) - SQR(depth - towfish height)) + Distance of DGPS to cable out block

Layback was calculated after any changing events (depth, towfish height, cable in or out). Recording was begun when the towfish was within about 20 m of the sea bed and trawl marks may have been visible. With the 410 kHz frequency a swathe was set for 180 m – even though the image was not so clear to the edges. Trawl marks were most distinct when the towfish was within 10 m of the sea bed, optimally at 8 m. It was rarely possible to keep the towfish at this height and in practice it was 8-15 m above the sea bed (as a result of changing tow course, speed, bathymetry and amount of cable paid out).

Sidescan sonar was used in all the sampling trips except the first two, when the equipment was still in the procurement stage. This effectively gave a periodic sampling, although when the tracks were finally analysed the data were pooled, as there was no periodic coverage of exactly the same tracks.

In playback in the laboratory, each sidescan track was investigated for trawl density and direction of trawling. At one minute intervals (where the towfish was within 15 m of the sea bed), latitude and longitude were noted and a count made of the number of trawl marks within a 180 x 180 m square. The counts were used as an absolute and were not divided by 2 to give a total for the number of trawls, because of the lack of a complete area picture and anecdotal information that sidescan images of trawl marks do not necessarily show matched pairs. The principal direction of trawl marks was also noted through software functions when dragging the pointer along the axis of a trawl mark. All directions were standardised to a 180 degree arc for the same reasons as the Scottish methodology. Agassiz and towed sledge marks could be identified separately from trawl door marks and were excluded from the analysis.

3.3.2 Bottom-discriminating sonar (RoxAnn™)

At the most basic level, signals from a vessels echo-sounder are used to determine depth, which is a function of the time taken for a sound signal to bounce off the sea bed and return to the echo-sounder. However, more information is available as the nature of the echo signal changes depending on the type of substratum from which it is reflected, so it is possible to analyse and interpret the echo signal itself to obtain information about the properties of sea bed. Such methods are known generically as ‘bottom-discriminating sonar’ but are frequently referred to by the trade name of an instrument first marketed for this specific application, namely RoxAnn™ (see Pinn & Robertson, 1998, and references therein). This system returns data for depth of water and the roughness (E1) and hardness (E2) of the substratum. It was envisaged that the disturbance caused to the sea bed by otter trawls might affect E1 and/or E2.

3.3.2.1 Clyde Sea

A RoxAnn™ survey was conducted at each site using a Simrad 38 kHz single beam sonar transducer, Simrad EK500 scientific echo-sounder and a RoxAnn™ unit, following the survey design in Fig. 5a. The transducer was housed in a towed-fish, deployed from the survey vessel at a depth of 4 m and towed at a speed of 8 kt. Prior to analysis, the depth, E1 and E2 data were inspected graphically to identify anomalous depth records and their corresponding E1 and E2 values (Fig. 11). Such anomalies were attributable to objects in the water column (probably fish or gelatinous zooplankton) and were removed from the data set.

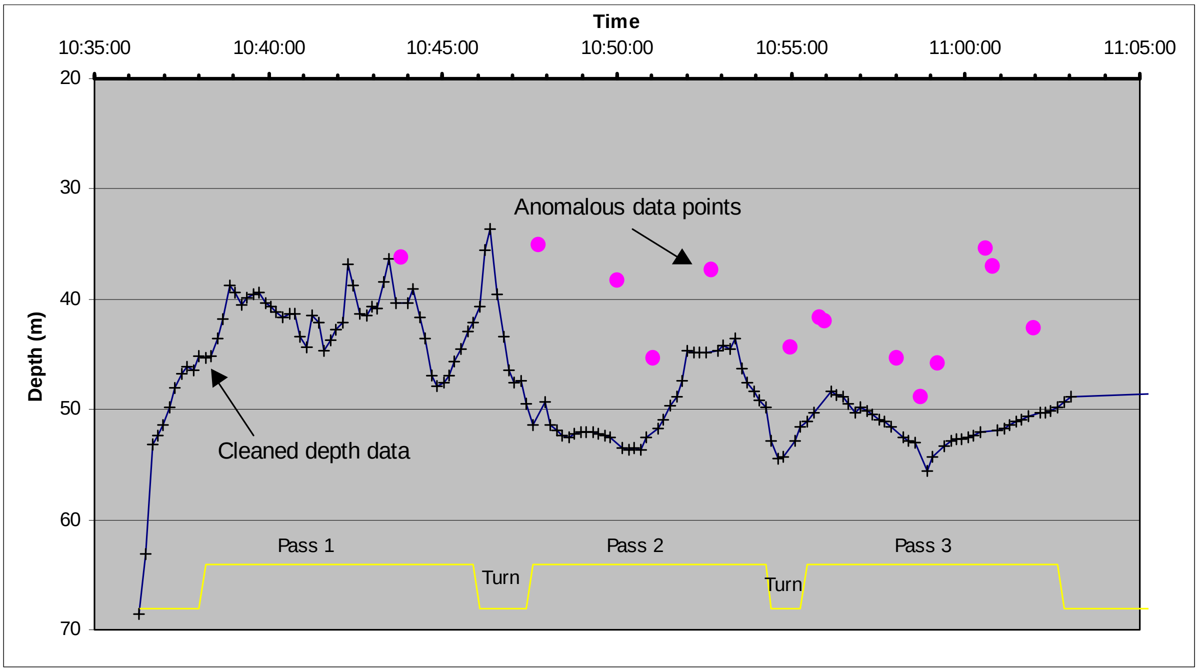
False colour composite images of the entire sea bed at each sampling site were generated using surface-modelling software applied to the E1 and E2 data (for details of methodology see Greenstreet *et al.*, 1997). These images were compared between sites, similar hues of colour indicating similar sediment properties.

Schwinghamer *et al.* (1998) used RoxAnn™ to investigate the effects of repeated trawling on sandy sediments in the Northwest Atlantic and analysed E1 and E2 data separately. Following their example, E1 and E2 data were further investigated by frequency-distribution analysis (histograms) and interpretations made from a visual comparison of the distributions between sites. [Note: Schwinghamer *et al.* (1998) incorrectly attribute E1 to hardness and E2 to roughness. RAC personal communication with Donald Gordon, corresponding author.]

3.3.2.2 Aegean

The RoxAnn™ survey in the Aegean was carried out using the RoxAnn™ system integrated with a Simrad EK500 scientific echosounder, with transducer hull mounted on the survey vessel. The 120 kHz frequency was used for mapping in both the Dia Island and Gouves areas. Survey was carried out at a speed of 8 kt. In Dia Island a system of multiple parallel tracks was followed crossing the trawling lane at an angle close to perpendicular. At the Gouves experimental area, due to the constricted nature and narrow experimental and control lanes the vessel followed a track along the lanes with a double pass. RoxAnn™ data were exported (Excel files) to GIS software systems, firstly ArcInfo for construction of shape files, then ArcView for image processing and interpretation.

a)



b)

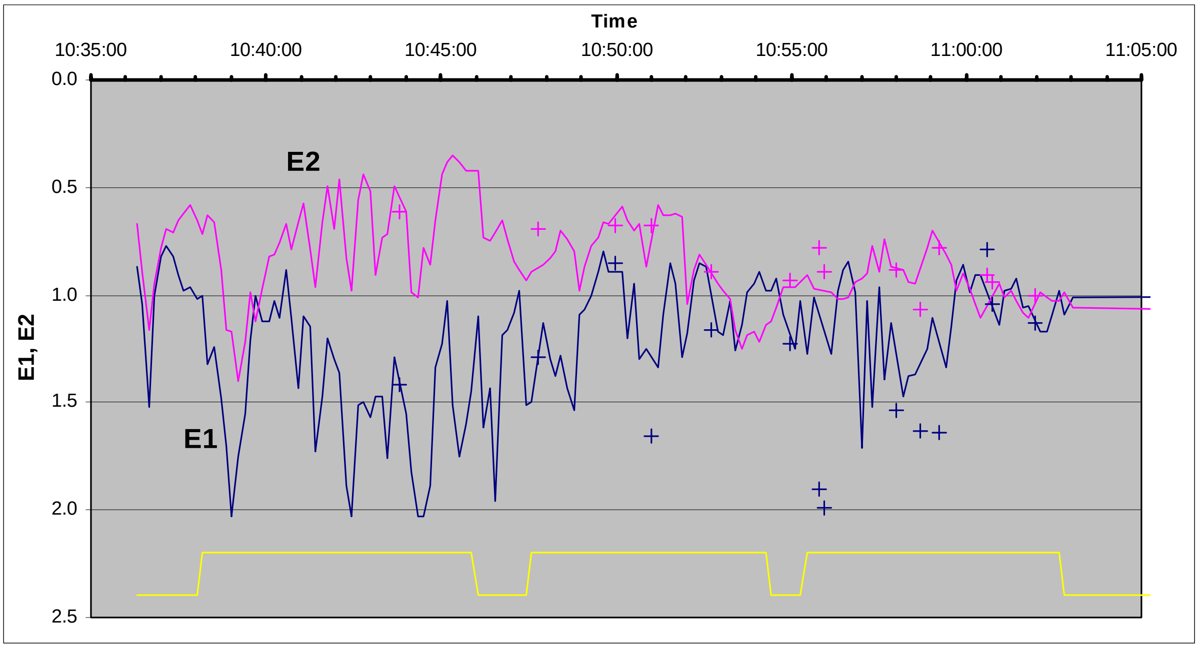


Figure 11. Illustration of the method for identifying anomalous data from the RoxAnn™ survey in the Clyde Sea area. Anomalous points are sought in the depth data (a) and their corresponding points in the E1 and E2 data (b) identified. These data are removed from the data set prior to analysis. For clarity of presentation, this example plots the anomalous data separately from cleaned data.

3.4 Faunal Sampling Methods (Task 4)

Clyde Sea

Samples of epibenthic megafauna were collected from each of the six study sites between April and June 2000. Five replicate tows were made at each site using a pair of 2-metre beam trawls (one on each trawl warp) rigged with 20 mm stretched mesh net and no tickler chains. Each tow lasted 15-minutes, giving a total of 5 pairs of samples per site. Each sample was kept in a separate container, weighed and processed. For the first of each pair of samples, the catch was fully sorted, taxa identified to the lowest taxonomic level possible (usually species) and the frequency and weight of each taxon recorded. These data were used in describing the community structure at the sites. The second of each pair of samples was used merely to increase the sample size of selected taxa (large gastropods and starfish) on which assessments of damage were to be carried out (see below).

Although tows in the Clyde Sea were standardised to 15 minutes duration, several variables could potentially affect the amount of time the trawl was actually in contact with the sea bed. If towed against the tide, the gear would tend to sink slower and lift faster than if towing with the tide. Also, the depth differed between sites, so there would naturally be a greater sinking time at the deeper sites. As trawl duration was comparatively brief, this variability could introduce an unacceptable error in simple ‘velocity x time’ estimates of swept area used to determine population density, so more accurate methods were sought. In an attempt directly to measure the distance towed along the sea bed, an odometer was developed for the exploratory survey (Fig. 12a). The device used a magnetically activated counter to record the number of rotations of the wheel (Fig. 12b) but difficulty was encountered in incorporating a suitable brake or clutch mechanism that would allow the wheel to turn freely when in contact with the sea bed but prevent it from turning as the net was being shot or hauled. It was also not possible to protect the odometer from material that might foul it when operating. The odometer method was thus abandoned in favour of refining the ‘velocity x time’ approach by attaching a time-depth recorder to the trawl to get a more precise and accurate estimate of the time that the gear was in contact with the sea bed. This proved successful and is detailed further under 3.4.3 (Task 4, sub-task 3), below.

Aegean

The Agassiz trawl was shot at high speed and the required amount of warp paid out. Vessel speed was reduced and the tow considered to start when the vessel speed reached the normal towing speed of 2 kt. DGPS position and depth were recorded every 5 minutes. Each tow in the Dia Island area was approximately 30 minutes duration. At Gouves the tows were 15 minutes duration in both the control and experimental areas. At the end of the tow, the ship turned away from the tow line and the Agassiz trawl was winched in. On deck the cod-end was emptied into a basin, labelled with station identification number and photographed. The catch was then rough sorted into major groups. Where possible the fauna was identified on deck, enumerated, weighed and discarded. In the case of certain species, morphometric data were also collected. The rest of the fauna was placed into containers with 10% formalin for laboratory processing. In the laboratory individuals were identified, enumerated, weighed and again, where necessary, morphometric data recorded.

a)

b)

Figure 12. Odometer developed and tested by UMBSM for measuring distance covered by the 2-metre beam trawl. a) attached to the trawl frame, b) magnetically activated trip counter.

3.4.1 Methods for assessing the damage load of fauna (Task 4, Sub Task 1)

3.4.1.1 Clyde Sea.

Even perfunctory inspection of a commercial trawl catch shows that many animals are damaged in the process of trawling. Animals that are not wanted by the fishermen (because they are too small, the wrong species or have no marketable value) are returned to the sea as 'discards'. Some of these discarded animals will die from their injuries but many will survive, repair their injuries and be vulnerable to capture by subsequent trawling events. The practice of discarding unwanted catch therefore provides a mechanism that might alter the damage load of species vulnerable to trawling. A quantitative assessment of damage load may therefore provide indications of the relative trawling impact at different sites.

Taxa that are suitable for such a study must meet certain criteria. Firstly, they should be widespread in their distribution, so ensuring that they are likely to be present at each site sampled. Secondly, they must be relatively robust and have a high probability of surviving the trawling process. Thirdly, they should repair injured tissue in such a way as to leave a clearly visible mark or indication of previous damage. The method chosen to sample such taxa should not in itself cause gross injury.

Samples taken by 2-metre beam trawl during the preliminary trawl survey in 1999 were analysed to determine which taxa met the above criteria. Certain taxa were only present at a few sites (e.g. sea-pens, sponges, ascidians) and others suffered high mortality as a result of trawling (e.g. brittlestars; Bergmann *et al.*, 2001a). The most suitable species for this study were deemed to be the starfish, *Asterias rubens,* and two large gastropods, namely the common whelk, *Buccinum undatum*, and the red whelk, *Neptunea antiqua.* Starfish can shed injured or trapped arms by autotomy and regenerate the lost arm over a period of time (several months) (Fig. 13a). Large marine gastropods can repair quite extensive damage to the lip of their shells over several weeks; a rapid secretion of shell filling in the gap until the proper shape of the shell is restored (Fig. 13b) (Mensink *et al.*, 2000). Normal growth then proceeds, leaving a tell-tale scar in the shell. The whole shell therefore records damage sustained throughout an individual's lifetime.

Damage assessment was carried out on starfish and whelks collected in the main beam trawl survey. Morphometric data (size and wet weight) were recorded for each individual. In starfish, size was taken as the length of the longest arm, from the tip of the arm to the centre of the mouth, and measured to a precision of 0.5 cm below. In whelks, size was taken as the maximum height of the shell and measured to 1 mm below. Mass was measured to the nearest gram.

An important aspect of the damage assessment was to differentiate between fresh damage caused by the sampling method and older damage that existed prior to sampling. In this way bias attributable to sampling damage could be eliminated. Hence, the protocols for recording damage were as follows:

In starfish, counts were made in the following categories:

- number of complete arms (excluding regenerating arms)
- number of regenerating arms
- number of fresh autotomy wounds (i.e. open wounds at the autotomy plane indicating arms lost as a result of sampling)
- number of healed autotomy wounds (i.e. healed wounds at the autotomy plane indicating arms lost prior to sampling but which have not yet begun to regenerate)
- number of intact arms showing past damage (scars of previous injuries)

These categories were not mutually exclusive, so a complete arm showing a damage scar would be included in two categories. A regenerating arm showing no sign of any other damage would only be counted in the 'regenerating arm' category (i.e. it was not considered to be an intact arm showing past damage).

In whelks, the damage load of the shell was assessed by examining separately the growing edge (lip) of the shell and then each of the three largest whorls. Damage was categorised as 'recent' or 'past' and sub-categorised as 'light' or 'severe'. Recent damage was any which had not yet been repaired whilst past damage was indicated by an obvious repair scar. Light damage was indicated by small chips or scars where just a few millimetres of shell had been removed and severe damage by more substantial breakages or scars. Cracks in the shell (most frequent in the columellar region) were ignored. So, for each individual, the frequency of light or severe scars on each of the three largest whorls was recorded, while damage to the lip of the shell was noted as light, severe or absent.

As part of the analysis, the effect of 'data reduction' was tested. Identical analyses were performed on data pooled for all three of the largest whorls and on a subset of these data relating to only the largest whorl. If the two sets of data gave similar results then it would be valid to recommend collecting data from the largest whorl only.

Analytical methods

The primary objective in analysing the data was to compare different analytical approaches with a view to recommending what data should be collected and how it was best analysed. Nominal fishing intensity was regarded as a 'pseudo-factor', a convenient categorisation of the 'impact' variable as opposed to an experimentally manipulated factor where each site within a category received the same impact. Hence analyses were directed toward the statistical testing of differences between sites (rather than between impacts) and inferences drawn regarding the effect of fishing intensity. For both starfish and whelks, the assessment of damage load was approached in two ways, the first addressing the frequency of past damage in the population and the second addressing the severity of that damage. Appropriate indices were sought to express damage load. Recent damage was considered to have been caused by the sampling equipment and so was treated separately.

3.4.1.2 Damage Assessment in the Aegean

In the routine Agassiz trawls the fauna was characterised by generally small body size and low abundance. It was not possible to identify suitable fauna carrying scar damage for historical analysis, so a different approach was used to that in Scotland. In the Aegean, damage assessment was carried out from otter trawl catches with the aim of identifying direct damage incidence and damage mechanisms. Damage assessment was carried out during the consecutive otter trawling experiment (first 8 trawls) at Gouves with particular emphasis on the echinoderm catch. Hauls were approximately 1000 m in length and a 26 mm stretched mesh codend was used. Echinoderms were found in reasonably high numbers and trawl induced damage could be evaluated on deck immediately without resorting to fixing the animals which could have led to further damage.

For each trawl all of the echinoderms, or a sub-sample if they were numerous, were separated from the rest of the catch. The numbers of each species damaged were noted according to the categories shown in Table 1. It should be noted that *severely damaged* individuals were a subset of *damaged*.

For *Ophiura ophiura*, the number of regenerating arms was also recorded. In the case of the ophiuroids, asteroids and crinoids, regenerating arms were defined as intact and not damaged. Numbers of each species were noted and percentage occurrence of *damaged* and *severely damaged* individuals calculated.

Table 1. Definitions of two damage categories applied in damage assessment of echinoderm groups caught in the repeat otter trawling at Gouves, in the Aegean.

Group	Damaged	Severely Damaged
Ophiuroid	Any arms broken or missing	3 or more arms missing
Asteroid	Any arms broken or missing	3 or more arms missing for a 5-armed species, 4 or more for a 7-armed species
Echinoid	Broken or missing spines	Test ruptured
Crinoid	Broken or missing arms or cirri	More than 50% of arms badly damaged or missing
Holothuroid	Scraped	Body ruptured

a)

b)

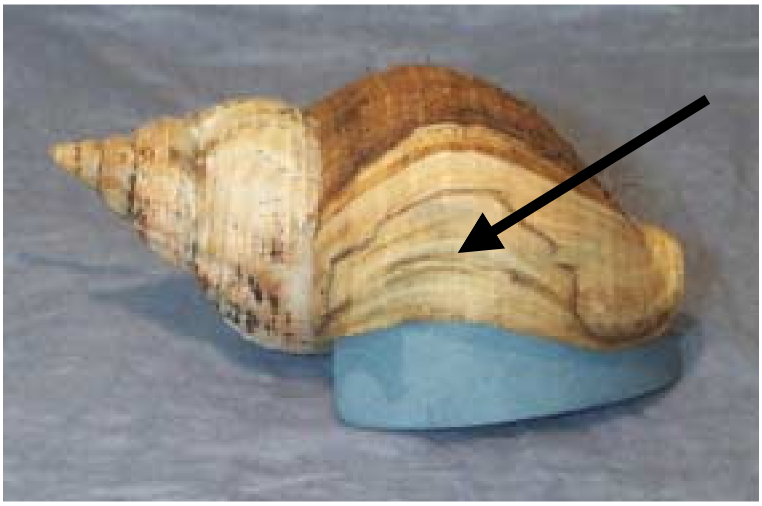


Figure 13. Examples of features used in the damage assessment of epibenthic megafauna from the Clyde Sea area. a) starfish, *Asterias rubens*, with three regenerating arms, b) a whelk, *Buccinum undatum*, (81 mm shell height) showing repair to an area of severe damage on the largest shell whorl (arrowed).

3.4.2 Methods for assessing the variability of fauna (Task 4, Sub Task 2)

3.4.2.1 Clyde Sea

Repeated use of demersal fishing gear in an area has the potential to considerably alter the structure of sea-bed communities. The abundance of some species will decrease as they are removed or killed by the fishing activity but for others, particularly the scavengers, it may increase due to the greater availability of carrion. Physically fragile species can quickly become locally extinct and in the longer term other species may die out as the physical nature of the habitat changes and becomes unsuitable for them. A progressive shift in community structure from a high diversity/low abundance configuration towards a low diversity/high abundance configuration usually reflects increasing ecological stress in the environment. Studies of the variability in benthic communities over time (or between different sites) might therefore provide a means of rapidly assessing fisheries impact in an area.

The composition of the epibenthic megafaunal community at each sampling site was determined from samples taken in the 2-metre beam trawl survey, the data recorded being the abundance and biomass of each taxon (species). Identification was based mainly on Hayward & Ryland (1995), Wheeler (1978) but also consulted were the series of *Linnean Society Synopses of British Marine Fauna* and the Scottish Marine Biological Association / UMBSM series *Fauna of the Clyde Sea Area*.

The different samples and sites were compared following a recognised approach for studying change in marine communities (Clarke & Warwick, 1994) employing the statistical package PRIMER (v. 5) with the aim of representing the communities and discriminating between sites and impact levels.

3.4.2.2 Aegean

Similar methodologies were used in the Aegean as in the Clyde Sea for assessing the variability of fauna. The composition of the fauna was determined from the 5 replicate samples taken with the 2 m Agassiz trawls in the Dia Island and Gouves experimental area during different sampling periods.

At Dia Island three adjacent sampling sites were identified, the commercial fishing lane (FL-IN) and two control sites, one to the north of the lane (FL-OUTN) and one to the south (FL-OUTS). The commercial trawling season takes place from October 1 to May 31, with a closed season between June 1 and September 30. Replicate Agassiz trawl samples were analysed on a seasonal basis from each site in the following months; September 1999 (closed season), November 1999 and April 2000 (open season) and September 2000 (closed season).

In the Gouves experimental area two adjacent sites were initially identified, an experimental trawling lane (EXP-T) and a control site (EXP-C). Both were approximately 1000 m long by 100 m wide. During the last sampling period additional replicates were taken from an adjacent commercial fishing lane (EXP-FL) approximately 1 km distant. The first set of samples were taken in April 2000, after which the experimental trawling lane was subjected to a quantified impact, namely 12 hauls of a commercial sized otter trawl over a 2 day period. The second set of Agassiz trawl samples was taken 24 hours after this experimental trawling. Repeat sampling in the same area was carried out in June and September 2000.

Whenever possible, samples were processed on-board and the fauna identified, counted and weighed. Otherwise they were preserved in formalin and processed in the IMBC laboratory. Identification was carried out with the aid of a variety of publications publications (e.g. Fischer *at al.* 1987a & b; Falciai & Minervini, 1992; Hayward & Ryland, 1995; Ingle, 1993 and Mortensen, 1977). Data from the two areas were treated separately, standardised to a swept area of 1000 m^2 and analysed using PRIMER (v5) statistical software to investigate trends and differences both within and between trawling and control areas.

3.4.3 Methods for assessing population densities of fauna (Task 4, Sub Task 3)

3.4.3.1 Clyde Sea

For the Clyde Sea area, population densities were determined using the ‘swept area’ method applied to catch data from the 2 metre beam trawl samples. Swept area was estimated from the towing speed of the vessel, as recorded by the GPS navigation system, and an accurate (± 20 seconds) estimate of the time that the sampling gear spent in contact with the sea bed. The latter was determined from a graphical analysis (Fig. 14) of data collected by a ‘Minilog-TD’ time-depth recorder (Hydrosphere UK Ltd) attached to the trawl and set to record depth every 10 seconds. Densities were calculated from biomass, abundance and swept area data pooled by site (as opposed to deriving a mean density from the 5 samples taken at each site).

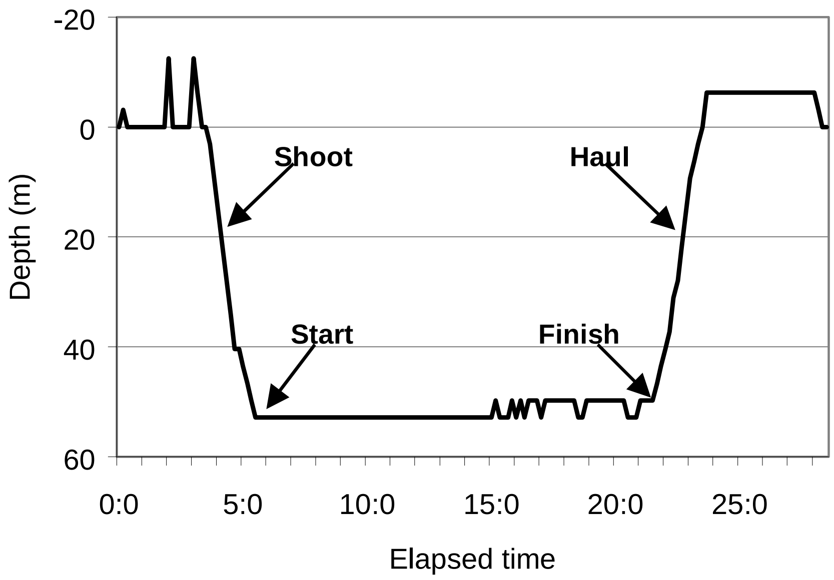


Figure 14. Example plot of time-depth data recorded by a Minilogger attached to the trawl gear used in the Clyde Sea area. The plot clearly shows when the trawl reached the sea bed after shooting, and when it left the sea bed on hauling

At the conception of the project, the principal objective in determining population densities was to provide a *standardised* set of data to enable valid comparisons to be made between the epibenthic megafaunal communities found at different sites. In the event, standardisation of data was an integral part of the PRIMER analysis of communities carried out under Task 4, sub-task 2, so similar comparisons based on population density were superfluous. However, whereas the PRIMER analysis addressed the question of similarities (or differences) between sites it did not provide absolute measures of population density. Such measures are valuable in their own right enabling an empirical comparison between sites and study areas.

For the Clyde Sea area, three analyses were undertaken using population density data. Firstly, biomass data for the 70 taxa of epibenthic megafauna were aggregated according to ecologically / taxonomically significant groups (e.g. round-fish, flat-fish, bivalves, crabs etc) and compared between sites. Secondly, biomass data were used to rank the importance of the 70 species at each site and over the study area as a whole. Thirdly, the population density of sites was compared based on the total biomass (for all 70 taxa) at each site.

3.4.3.2 Aegean

In the Aegean, population densities were also determined using the swept area technique. For each haul, the distance covered was estimated through incremental addition of distance moved every 5 minutes between DGPS position fixes. Although almost all hauls were standardised to 30 minutes duration at the Dia Island area and 15 minutes in the Gouves experimental area, it was found that simple calculation of distance covered, using speed x time calculation, was not sufficiently accurate, experience showing that a 30 minute tow could cover a variable distance of 1000-2000 m. Consequently, the distance covered by each haul was calculated from DGPS data. As the Agassiz had a width of 2 m the distance was multiplied by 2 to calculate the area swept. This was used to standardise the catch data (abundance and biomass) to an area of 1000 m^2 to enable valid comparison of population densities between sites. As benthic fauna in the Aegean are relatively small in size, and Agassiz trawl catches quite low, comparison of population densities were based on abundance rather than biomass data. This avoided the problem of bias inherent in analyses of biomass due to the chance occurrence of single, but rare, organisms of unusually large size (e.g. a large fish of starfish).

Data were compiled for each sampling area and period and the dominant species identified. Abundance data for these species were subject to statistical testing (t-test or ANOVA) to identify differences between trawling and control areas. Total biomass from replicate trawls along with species and abundance data are presented elsewhere (section 4.2).

3.4.4 Methods for analysing functional group composition of fauna (Task 4, Sub Task 4)

3.4.4.1 Clyde Sea

Taxa recorded in the epibenthic megafauna were assigned to functional groups (Appendix III-A) based on accounts of their ecology drawn from the literature (e.g. Mortensen, 1977). Two criteria were used to define functional groups; the dominant trophic mode (1 = predator-scavenger, 2 = suspension feeder, 3 = deposit feeder) and the predominant foraging habit (a = burrow dwelling, b = sedentary, c = motile). So, for example, group 1c = motile scavengers/omnivores (e.g. *Nephrops norvegicus*) and group 2b = sedentary suspension feeders (e.g. *Aporrhais pespelecani*). In all, seven functional groups were recognised (1a, 1c, 2b, 2c, 3a, 3b and 3c).

Differences in the functional group composition of the communities at the six sampling sites were investigated in two ways. Firstly, the functional group codes were applied to the species-by-samples catch data used previously (Task 4, sub-task 2; sections 3.4.2 and 4.4.2) and the data aggregated using the functional groups as a factor (analogous to the previous practice of aggregating data by progressively higher taxonomic levels). Data were then amenable to the MDS analysis (described earlier) to determine patterns in the similarity (or dissimilarity) between samples and sites.

Secondly, to investigate the importance of each functional group at each site, simple group-by-site tabulations were constructed summarising:-

i) the number of taxa in each functional group at each site,

ii) the % of total biomass that each functional group contributed at each site and

iii) the % of total abundance that each functional group contributed at each site.

These tables were examined to determine trends among sites that might be attributable to differences in trawling impact. This second analysis was considered more appropriate than a SIMPER (similarity percentages) analysis in PRIMER due to the limited number of functional groups.

3.4.4.2 Aegean

Species recorded were assigned to functional groups (Appendix III-B & C) based on accounts of their ecology drawn from the literature (e.g. Mortensen, 1977; Fischer e*t al.* 1987a & b) as above. Differences in the functional group composition of the communities at Dia Island and the Gouves experimental area were investigated in two ways. Firstly, catch data aggregated by functional groups were used for CLUSTER, SIMPER and MDS analyses to determine patterns in the similarity (or dissimilarity) between samples and sites. Secondly, to investigate the importance of each functional group at each area and site, the following variables were calculated for each area:

- the total and the average number of taxa in each functional group at each site,
- the average number of functional groups present per site,
- the average percentage species, abundance and biomass contribution of each functional group per site,
- a repeat analysis for Dia Island area focused on the commercial fishing lane and differences between open and closed fishing seasons,
- a repeat analysis for Gouves experimental area focused on the experimental trawling lane and differences between before- and 24 hrs after- experimental trawling.

3.5 Underwater Television Methods (Task 5)

Underwater television was used to 'ground truth' observations made by sonar methods and trawl sampling. From the video record it was possible to judge if patterns or structures recorded by sonar were real or artefactual and whether the sonar techniques had been successful in detecting disturbance to the sea bed. It also provided the opportunity to cross-check whether or not certain elements of the epibenthic megafauna had been under represented in the beam trawl samples. Underwater TV is a rapid assessment method in itself, so its application in the context of monitoring impacts of demersal fishing gear was evaluated. Two methods were assessed; the 'towed video-sledge' (Holme & Barrett, 1977) used to survey transects of a site and 'remote operated vehicles' (ROV) used for 'spot' surveys stations within a site. In the Clyde Sea, two complete surveys were executed with each type of equipment to provide material for the quantitative and qualitative assessment of trawl impacts and to identify the nature of marks caused by specific elements of the towed gear. In the Aegean, a towed video-sledge was used during all the sampling periods with a quantitative analysis of images performed at the Dia Island trawling area and adjacent control area. Previous experience with ROV systems was also used to evaluate their potential use as a rapid methodology for investigating trawling impacts.

3.5.1 Video-sledge

3.5.1.1 Clyde Sea

The UMBSM video-sledge (Fig. 15a) was fitted with a Konsberg-Simrad colour TV camera and the video images recorded in VHS format, overlain with a time signal generated by a FOR-A VTG-33 video timer. The sledge was towed at a speed of approximately 1 kt. In the preliminary survey (October 1999) all sites were sampled by simple straight transect method but in the second survey (May 2000) the transect at each site was in two parts, one perpendicular to the other. Once during each survey a 'calibration' was done, recording the image of a square grid (having 20 cm divisions) laying flat in the field of view. This image could be traced onto a monitor screen before analysing the video footage to provide perspective and enable distances to be measured (and therefore speeds to be estimated).

A protocol for analysing video-sledge surveys was developed. Firstly, the footage was viewed in its entirety and note made of each species that occurred, for comparison against the species list for that site derived from trawl samples. Secondly, the site was characterised in terms of the biogenic and anthropogenic modelling visible on the sediment surface by closely studying ten 2-minute video clips from each site and scoring each clip according to 4-point scales of biogenic and anthropogenic modelling (Appendix II). These derived data were analysed graphically and/or statistically to compare sites and assess variability within a site. The ten video clips were chosen *a priori* by dividing the entire track of the transect (as recorded on the survey vessel's GPS-based navigation system) into ten equal sections and viewing the first two minutes of video for each section.

3.5.1.2 Aegean

The IMBC video-sledge was fitted with an Osprey (OE1360 Osprey Electronics, Aberdeen, now Kongsberg-Simard) low light-sensitive colour camera with two wide angle 500 W underwater lighting units (Versabeam, Deep Sea Power & Light, Aberdeen). The camera had a frame view of approximately 65 cm width at the bottom of the frame and 95 cm at the top (in the oblique view). The sledge was towed from the stern of the research vessel on a trawl warp (12 mm) to which the electrical cables of the camera and lights were attached. Flotation was added to the warp at the sledge end of the cable to help keep the towing cable from disturbing the sediment in front of the sledge.

DGPS position of the towing vessel was recorded every 5 minutes whilst the sledge was deployed on the sea bed and the output from the TV camera recorded on videotape (S-VHS), together with a time signal. Major features were continually noted by the operators in an immediate assessment. For detailed analysis, the videotape was examined ashore. For each video tape or sledge track, the same methods were applied as used in Scotland. Every 5 minutes of tape, 2 minutes (one minute either side of a 5 minute position recorded mark) were examined using the anthropogenic and bioturbation scale shown in Appendix II. In addition the density of the crinoid *Leptometra phalangium* was also recorded on a similar categorised scale (0, absent; 4, more than 40 individuals on a 2 minute recording). Data were plotted as density maps in the fishing lane off Dia Island.

a)

b)

Figure 15. Equipment used for underwater television surveys in the Clyde Sea area. a) towed video-sledge, b) Hyball ROV (Hydrovision, Aberdeen, UK)

3.5.2 Remote Operated Vehicle (ROV)

3.5.2.1 Clyde Sea

The ROV surveys were conducted in association Scottish Natural Heritage (SNH) who had expressed an interest in the project and offered to assist on a cost-free basis. They provided trained ROV pilots and a 'HyBall' ROV (Hydrovision, Aberdeen) equipped with a 360° scanning sonar and a single function manipulator arm (Fig. 15b). Ship-time and support facilities were provided by UMBSM. The preliminary survey was undertaken in October 1999 but the second survey had to be spread over June and November 2000 and January 2001 as completion was delayed due to technical failure of the ROV in June and November.

The ROV was normally deployed whilst the survey vessel was at anchor and images recorded on Hi-8 or (latterly) digital video formats. A series of short 'spot-dives' were undertaken at each site and detailed inspection made of individual features on the sea bed. A scale object, in the form of a wire or plastic cuboid grid, was routinely carried in the manipulator to enable *in situ* measurements to be made of features of interest.

In June 2000 a mark simulating a trawl door was made in the sediment at site L2 by dragging three links of 75 mm chain (weighing *ca* 60 kg in total) over a distance of 0.5 NM, starting in an area where trawling was prohibited and finishing in an area where it was allowed. This mark was inspected with the ROV when it was 7 days old and again at 8 months old to record temporal changes in the nature of the mark.

3.5.2.2 Aegean

The assessment of ROV systems for investigations of fishing gear impacts was based on previous use of ROV systems in the Aegean. The assessment was based on direct experience with a variety of missions of two systems:

1. An observation vehicle, a Benthos Mini Rover Mk II, equipped with pan and tilting video and a single function one plane manipulator.

2. A light work class vehicle, a DSSI Max Rover Mk II, equipped with several video cameras, scanning sonar, autopiloting features, navigation tracking system and a light 5-function manipulator.

Additionally experience was drawn from working with other ROV systems both experimental and production vehicles.

3.6 Sedimentological Methods (Task 6)

Sediments are disturbed by towed demersal fishing gear. As well as turning over ('tilling') the sediment, towed gear causes substantial re-suspension of sediments, forming a cloud of material that eventually re-settles on the sea bed, subject to dispersal by currents and tides. Such disturbance is likely to affect the physical properties of the sediment, so these were investigated.

3.6.1 Clyde Sea – Granulometry and sediment geotechnics

In the Clyde Sea area undisturbed core samples were taken from each of the six study sites. As fishing effort was not constant throughout the year, samples were collected in each quarter of the year (Spring, Summer and Autumn 2000, and Winter 2001) to enable seasonal variations to be considered.

Two coring devices were used. Both operated in essentially the same manner to collect undisturbed core samples. For the first quarterly sample, taken in April 2000, a Bowers & Connelly 4-channel multi-corer (Fig. 16a & b) was borrowed from the Dunstaffnage Marine Laboratory (DML). This accommodated four core tubes, two of 100 mm inside diameter (ID) and two of 75 mm ID. Unfortunately, a few weeks later this corer was lost during a DML research cruise, so the remaining core sampling was completed using a modified Craib core (Fig. 16c & d). The Craib core held only a single core tube and required extensive modification of the core head and bottom-catcher device to accommodate the tubes that had been made for the Bowers & Connelly corer. Core sampling was consequently standardised on the 100 mm ID core tubes as these could be used for any of the main analytical techniques detailed below. The design and development work for the modification of the Craib core was undertaken by Dr P.R.O. Barnett, formerly of the Scottish Association for Marine Science and currently an Honorary Research Associate at UMBSM.

The geotechnical testing of samples was conducted by specialists in this field, namely Mr P.S. Meadows, Dr A. Meadows and Mr J.M.H. Murray of the Biosedimentology Unit of the Institute of Biomedical and Life Sciences of Glasgow University (BU-GU). Six tests were chosen with a view to provide a range of geotechnical signatures for any change in sediment structure. The properties tested were shear strength, load resistance, dry bulk density, water content, mean particle size and particle size sorting. Shear strength is known to quantify sediment structure in an engineering context, and load resistance is a novel micro-scale approach. Dry bulk density and water content are standard geotechnical parameters and are likely to change with sediment disturbance. Mean particle size and sorting are routinely used by sedimentologists to distinguish between different sedimentary ecosystems, particularly in terms of different degrees of disturbance associated with high and low energy sea bed environments.

Shear strength was measured using a Geonor Fall Cone apparatus (Meadows & Tait, 1985, 1989, Meadows & Meadows, 1991; Meadows *et al.*, 1994) and expressed as $kN \cdot m^{-2}$. Load resistance was measured using a micro-scale load resistance penetrometer (MLRP) developed by Muir Wood *et al.* (1993), Meadows, P.S. *et al.* (1998) and Murray *et al.* (2000) and expressed in kN. The experimental protocols for measuring load resistance described in these three papers were followed with minor modifications. Water content was measured by the lost weight method following drying at $80^{o}C$ for 24 hours and 3 hours cooling in a desiccator. Percentage water content was calculated following BS1377 (1975) as (weight loss / dry weight) x 100. Dry bulk density was measured on the same samples as % water content, calculated as (dry weight of sediment) / (volume of sediment) and expressed as $g \cdot ml^{-1}$.

Granulometric analysis of sediment samples was carried out by Fisheries Research Services (Marine Laboratory, Aberdeen) using a light-scattering based particle sizer (Malvern Mastersizer E, laser particle counter). This analysis determined the size-frequency distribution of particles, expressed as percentages at half-phi size intervals from 1 to 11 (phi (ϕ) = $-\log_2$ of particle diameter in mm). These data were used by the BU-GU to calculate the Graphic Mean (M_Z) of particle size and the Inclusive Graphic Standard Deviation (σ_I) which is a measure of particle sorting (Folk, 1974; Buchanan, 1984).

All geotechnical techniques were applied to fresh cores (i.e. within 24 hours of sampling). with a sediment depth of 14 to 18 cm and covered by the original overlying water collected *in situ*. The geotechnical properties of the sediment were tested at three depth layers in the cores, namely 0-2 cm, 4-6 cm and 8-10 cm depth from the water-sediment interface (Fig. 17). One core was used solely for the MLRP, measuring load resistance over a 10 cm depth profile of the core (see Murray *et al.*, 2000). Data were post-processed to derive a mean value for load resistance in each of the three depth layers under study (based on 26 sample measurements for each 2-cm depth horizon). A duplicate core was used for all other measurements as follows: the overlying water was siphoned off and a piston used to bring the sediment surface to the top of the core tube. Shear strength was determined (as the mean of six measurements) before the sediment was extruded by 2 cm and the 0-2cm depth layer sliced off the core. Four samples were taken from this slice for determination of % water content (and subsequently dry bulk density) and one for granulometric analysis. The sediment was then extruded a further 2 cm and this layer sliced off and discarded, leaving the 4 cm depth horizon exposed. The measuring and sampling process was repeated for the 4-6 cm and 8-10 cm depth layers.

An analysis of these data was provided by BU-GU but revised by UMBSM in the light of information gleaned from the other surveys that form an integral part of this report. Results are here analysed by graphical methods and a nested ANOVA, using the (hierarchical) factors season, fishing intensity, site and sediment depth layer.

a)

b)

c)

d)

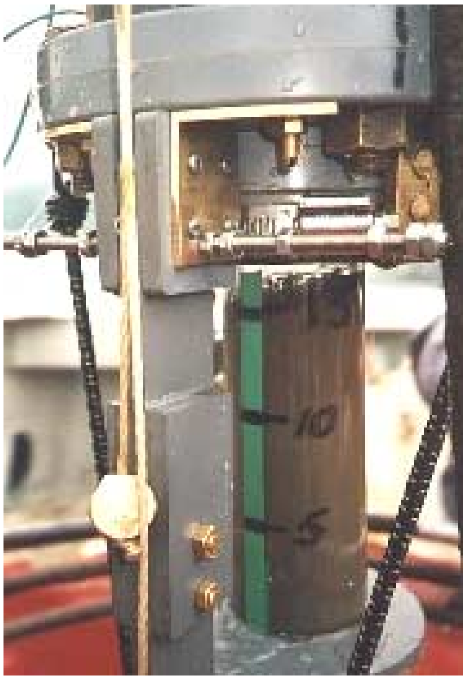


Figure 16. Sediment coring devices use to sample sediments in the Clyde sea area. a) Bowers & Connelly 4-channel multi-corer, b) multiple corer head, c) modified Craib corer c) high quality core sample taken by modified Craib core, the scale on the core tube showing depth of penetration (cm) into the sediment.

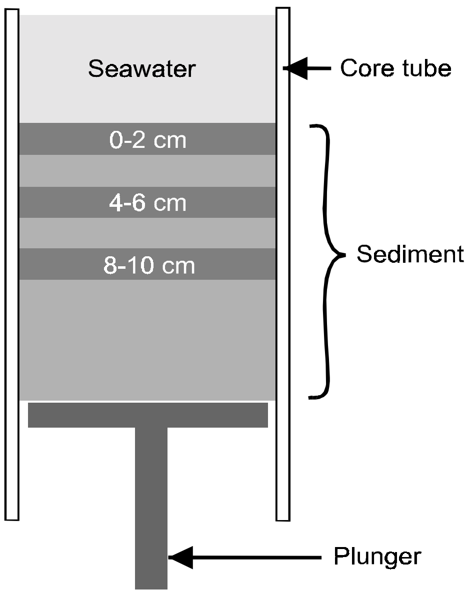


Figure 17. Schematic illustration of protocol for sampling three depth layers in sediment samples collected by coring in the Clyde Sea area (see text).

3.6.2 Aegean – Granulometry and Sediment Profile Imagery (SPI)

Prior to the start of the project, sediment samples had been taken at the Dia Island and Gouves areas. At each sampling area sediment was retrieved utilising a 0.1 m^2 Smith-McIntyre grab, from which a sub-sample was taken using a 5.5 cm diameter core tube to 5 cm sediment depth. The sample was extracted, stored in a labelled plastic bag and frozen. Sediment particle size analysis was carried out using a modified version (without the addition of hydrogen peroxide) of the methods of Folk (1974) and Buchanan (1984), in which samples were wet sieved to separate the sand from silt-clay fractions; sand fractions were determined by dry sieving and the silt-clay fractions by pipette analysis.

The SPI system allows the upper 20 cm of the sediment including the delicate water/sediment boundary layer to be documented. It is a standardised technique for imaging and analysis of sediment structure in profile, originally developed in the U.S (where it is designated by the acronym REMOTS, for Remote Ecological Monitoring Of The Seafloor). The frame is dropped onto the sea bed and the weighted camera prism slides down hydraulically dampened rams to penetrate the sediment. The camera is triggered on lowering into the sediment on a time delay. The penetration depth of the camera is dependent on the density of the sediment and weight of the frame system. A photograph of the IMBC SPI system is shown in Figure 18 with a schematic in Figure 19.

Figure 18. Photograph of the IMBC SPI system.

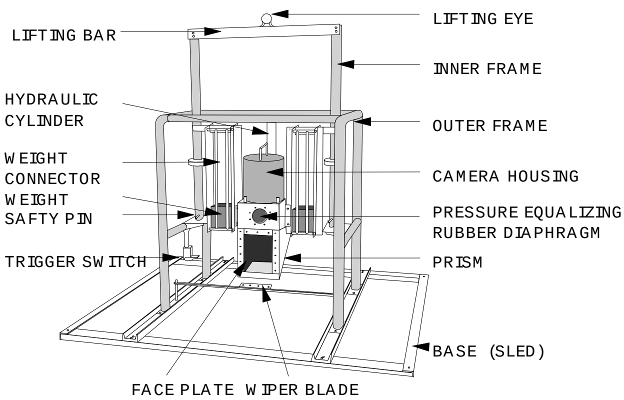


Figure 19. Schematic of the SPI system.

Functioning like an inverted periscope, the camera consists of a wedge-shaped prism with a front face-plate and a back mirror mounted at a 45 degree angle to deflect the profile of the sediment-water interface up to the camera (see Figures 20 and 21). The camera is mounted horizontally on top of the prism. The device provides images of the sediment column 15 cm wide and up to 23 cm deep, lit by the camera flash situated in the prism.

Figure 20. Detail of the prism camera.

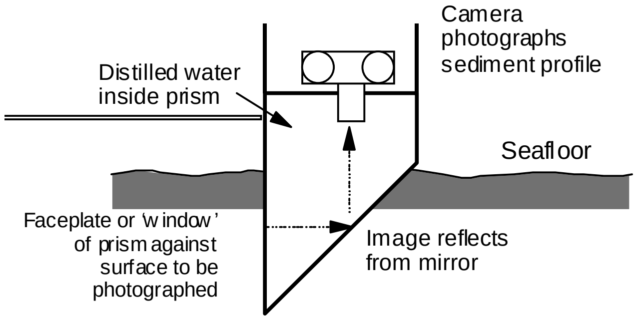


Figure 21. Schematic of prism operation.

Analysis of physical and biological parameters was undertaken in Adobe PhotoShop and consisted of measurement of maximum, minimum and average penetration. Bottom roughness was given as the difference between maximum and minimum penetration. The colour scale, brightness and contrast were adjusted to highlight sediment features and descriptive information was noted for each photograph. This included sediment type, presence of animal tubes, fauna, feeding voids, clasts, interface characteristics, layers, reduced sediments and any other recurring feature of note.

The SPI system was used at both of the Aegean study areas. The system was deployed vertically to land on the sea bed and allowed to sit for 30 seconds, to give time for penetration and automatic triggering of the camera. The system was then raised approximately 10 m above the bottom and lowered for a replicate photograph. Replicates were in groups of 5 or 8 depending on the number of stations to be covered. A 36 exposure film was used in each of the areas split between control and impacted sites. The use of the system was weather dependent, as in rough weather it could inadvertently trigger during descent.

RESULTS

A log of sampling and survey events undertaken in the Clyde Sea area and Aegean are presented, respectively, in Tables 2 & 3 for reference.

Table 2. Schedule of sampling and survey events for studies undertaken in the Clyde Sea area by UMBSM. Light-grey boxes indicate preliminary surveys.

Year	1999									2000												2001		
Month	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Site selection					░	░	░																	
Gear trials		■																						
1st Sidescan survey								■																
2nd Sidescan survey														■										
RoxAnne™ survey						■																		
1st Faunal sampling					■		■			■														
2nd Faunal sampling													■	■	■									
1st video-sledge survey							■																	
2nd video-sledge survey														■										
1st ROV survey							■																	
2nd ROV survey														■	■					■		■	■	
Sediment coring									░				■			■			■				■	

Table 3. Schedule of sampling and survey activities for studies undertaken in the Aegean Sea area by IMBC. Light-grey boxes indicate surveys outwith of the project from which data was used in the analysis. * indicates months of the closed season for the commercial fishery.

Year	1999									2000											
Month	A	M	J*	J*	A*	S*	O	N	D	J	F	M	A	M	J*	J*	A*	S*	O	N	D
Site selection						■							■								
Gear trials													■								
Sidescan								■					■		■			■		■	
RoxAnn™																		■			
Faunal sampling	░					■		■					■		■			■		■	
Video-sledge	░					■		■					■		■			■		■	
Damage assessment													■								
SPI	░					■		■					■		■			■		■	
Dia Island	░					■		■					■		■			■		■	
Gouves Experimental													■		■			■		■	

4.1 Site Selection (Task 1)

Clyde Sea

The general characteristics of the six sites studied in the Clyde Sea area are given in Table 4. Their relative positions within the Clyde Sea area have been shown previously (Fig. 1) and larger scale charts of each site are included later (Fig. 23). The two heavily fished sites, H1 and H2, had a soft mud substratum and were typical of the main *Nephrops* trawling grounds in the northern sector of the Clyde Sea which are fished throughout the year by vessels from several Clyde ports (e.g. Troon, Tarbert & Girvan, and in good weather smaller boats form Rothesay & Greenock). The moderately fished sites were geographically separate, site M1 being in the Clyde 'basin' but site M2 being within the confines of Loch Long. Site M1 had a sandy-mud substratum and was fished mainly by trawlers landing into Tarbert, Loch Fyne. Site M2 had a soft mud substratum and was usually fished by only two or three trawlers local to Greenock and Bute. (Information on fishing vessel activity from Marrs, *pers. com.* and Marrs *et al.*, 2001)

Table 4. General characteristics of the six survey sites in the Clyde Sea area.

Site Code	Nominal Fishing Intensity	Depth range (m)	Predominant sediment	Gross topography
H1	Heavy	80-100	Mud	slight slope
H2		70-90	Mud	flat
M1	Moderate	50-70	Sandy mud	slight slope
M2		50-70	Mud	slight trough
L1	Light	30-40	Muddy sand	slight slope
L2		60-90	Mud	moderate trough

Selection of 'control' sites proved difficult as the *Nephrops* fleet was well established and highly skilled, so suitable 'virgin' grounds were unlikely to exist. Consequently, we made the best approximation to a 'control' by selecting 'lightly fished' sites, L1 and L2, both of which incorporated areas where fishing was prohibited (see Fig. 23). Like the two moderately fished sites (M1 & M2) the two lightly fished sites were geographically separate. Site L1 was adjacent to a heavily fished area but was itself lightly fished, as trawlers tended to avoid the site due to navigational hazards and the proximity of the 'fishing prohibited' zone in the southern end of the site. This site proved to be quite different to all the others, being the most shallow (see Table 4) and having the hardest substratum (muddy-sand). Site L2 had a soft mud substratum and was only fished occasionally at its southern extremity. Fishing was prohibited in the northern half of the site, so fishing vessels entering the southern half (usually from site M2) were either turning or lifting their gear to avoid the prohibited zone.

Aegean

General characteristics for the six sites studied in the Aegean are given in Table 5 and the two areas of study have been shown previously in Fig.s 2 and 3. The sites were less discrete than in the Clyde Sea study, covering larger spatial areas. At Dia Island, the main site (FL-IN) comprised the commercial fishing lane, where trawl impact was considered greatest at the centre of the lane and least towards the edges of the lane. Good control sites were available to the north and south of the fishing lane (FL-OUTN and FL-OUTS respectively). Generally, Dia Island sites were between 150 and 250 m deep and the sediment comprised soft mud. The Gouves experimental area was a shallower sandy-‘maerl’ plateau at 70 – 80 m depth. Two sites were initially selected here, a short experimental trawling lane (EXP-T) suitable for manipulative trawling and a similar sized control area (EXP-C) (their relative locations are shown later in Fig. 41). Later in the study a third site was added, being a commercial fishing lane (EXP-FL) approximately 1 km to the north of the experimental trawling lane. It was felt that the inclusion of this site would add valuable information to the study.

Table 5. General characteristics of the six survey sites in the Aegean Sea.

Study Area	Site Code	Nominal impact	Depth range (m)	Predominant sediment	Gross topography
Dia Island	FL-IN	Fished	200-250	mud	moderate trough
	FL-OUTN	Control	200-230	mud	slope
	FL-OUTS	Control	150-190	mud	slight slope
Gouves	EXP-T	Manipulated	70-80	sand/maerl	flat
	EXP-C	Control	70-80	sand/maerl	flat
	EXP-FL	Fished	80-90	sand/maerl	flat

4.2 Gear Selection (Task 2)

Clyde Sea

Results of the gear trials comparing the Agassiz and beam trawls in the Clyde Sea are given in Table 6. The Agassiz trawl gave larger catches as the narrow frame of the trawl allowed the gear to sink into the substratum, collecting both infauna and epifauna. Conversely, the small beam trawl had wide shoes, causing it to skim the substratum and making it more selective of the target catch (epibenthic megafauna). In all tows the beam trawl samples were of a significantly higher quality than those from the Agassiz trawl, containing far less mud, fewer infaunal bivalves and causing less damage to organisms. The beam trawl gave adequate sample sizes at the slower towing speed (2.5 kt) and was chosen as the preferred gear for sampling epibenthic megafauna in the Clyde Sea. A towing speed of 2.5 kt was adopted in order to minimise damage to the catch.

Table 6. Catch weight and tow speed for four gear trials in the Clyde Sea area comparing a 2-metre beam trawl and a 2-metre Agassiz trawl. Gears were towed side-by-side on single warps for 15 min. duration at 70 m depth on mud substratum.

	Catch Weight (kg)		
Tow	Beam Trawl	Agassiz Trawl	Tow speed (kt)
1	11.0	14.0	3.5
2	8.0	12.5	3.5
3	8.5	9.5	2.5
4	6.5	9.0	2.5

Aegean

Results for the gear trails comparing the Agassiz and beam trawls in the Aegean are given in Table 7. Samples in the Gouves experimental area were collected in approximately 70 m depth on maerly sands of the experimental trawling lane. Simple indices (no. of species present, abundance, biomass) were considerably higher for the beam trawl samples. However, confidence intervals were also considerably higher indicating greater variations between the individual beam trawl samples, particularly for biomass values. Samples from the beam trawl were also noted to contain a higher number of mollusc species, including infaunal bivalves, than the Agassiz trawl.

The Dia Island samples were collected from the fishing lane area at approximately 200 m depth on silty sediments. A different result was found in this area with the samples from Agassiz trawls having higher indices than those from the beam trawl (Table 7). Confidence intervals were similar, but applied to the lower values from the beam trawl samples, again indicated a higher variability.

Table 7. Comparison of Agassiz and beam trawl gears in the Aegean. The mean number of species per haul and the overall abundance and biomass per 1000 m^2 swept area are given for replicate Agassiz trawls (n=6 at Gouves, 5 at Dia) and beam trawls (n=5 at both Gouves and Dia) in the Gouves and Dia Island areas. Also shown are 95% confidence intervals.

		Agassiz	95% CI	Beam	95% CI
Gouves	Species	29.5	3.0	50.8	8.8
	Abundance	103.3	17.8	284.7	95.2
	Biomass	142.5	80.9	532.1	480.6
Dia Is.	Species	23.2	3.7	15.2	4.3
	Abundance	275.7	87.8	121.0	77.3
	Biomass	793.4	279.2	299.9	245.2

The Agassiz trawl had been the previous standard gear for megafaunal investigation in the Aegean. The comparison with the beam trawl was made to investigate whether it was possible for all project partners to use the same standard gear. It was felt that the lower performance of the beam trawl at Dia Island was due to the overall lighter nature of the gear, even though extra chain weight was attached to the runners and the outer bag of the cod end. For routine trawling at 200 m depth, 600-700 m of tow wire is used. The gear at the end of the wire needs to be heavy enough to maintain contact with the seabed and in this respect it was felt that the Agassiz trawl was performing better and that the beam trawl may have been more liable to skip over the seabed. The Agassiz is much more ‘robust’ and is also double sided allowing for more flexibility in orientation on the seabed (i.e. it can fish either way up). With the decision that the Agassiz was a ‘better’ gear in the deeper water site, it was adopted as the standard Aegean sampling gear.

4.3 Sonar Imaging Methods (Task 3)

4.3.1 Sidescan Sonar

4.3.1.1 Clyde Sea

First survey (parallel pass design): sidescan image mosaicing.

During the first survey (November 1999) which employed the parallel pass design (Fig. 5a) it was immediately clear that sidescan sonar had the ability to resolve trawl marks left in the soft sediments of the Clyde Sea. These showed up clearly on the real-time monitor and paper plotter, as did massive structures such as rock outcrops or mega-ripples which occur naturally in the sediment.

The parallel pass survey design was of limited use as it did not properly detect trawl marks that ran approximately perpendicular to the survey track. This made it unsuitable for quantitative assessment of the density of trawl marks, although a simple visual inspection of the sonar images did provide a reasonable qualitative assessment.

An attempt was made at MLA to visualise entire sampling sites by constructing mosaic images of the parallel passes. Without the assistance of a fully automated mosaicing system, this would be a highly involved and time-consuming procedure. Specific problems were encountered with mosaicing data from the L2 site where the accompanying geo-reference data were incomplete due to the local mountainous terrain causing intermittent loss of the D-GPS signal. When printed on an A4 sized sheet, the mosaic image of a site was of low resolution. While these proved useful for identifying the existence and position of massive structures (e.g. rock outcrops or mega-ripples in the sediment), small-scale features such as trawl marks were not adequately resolved at this print size (Fig. 22a).

Second survey (grid pattern): single frame snapshot analysis.

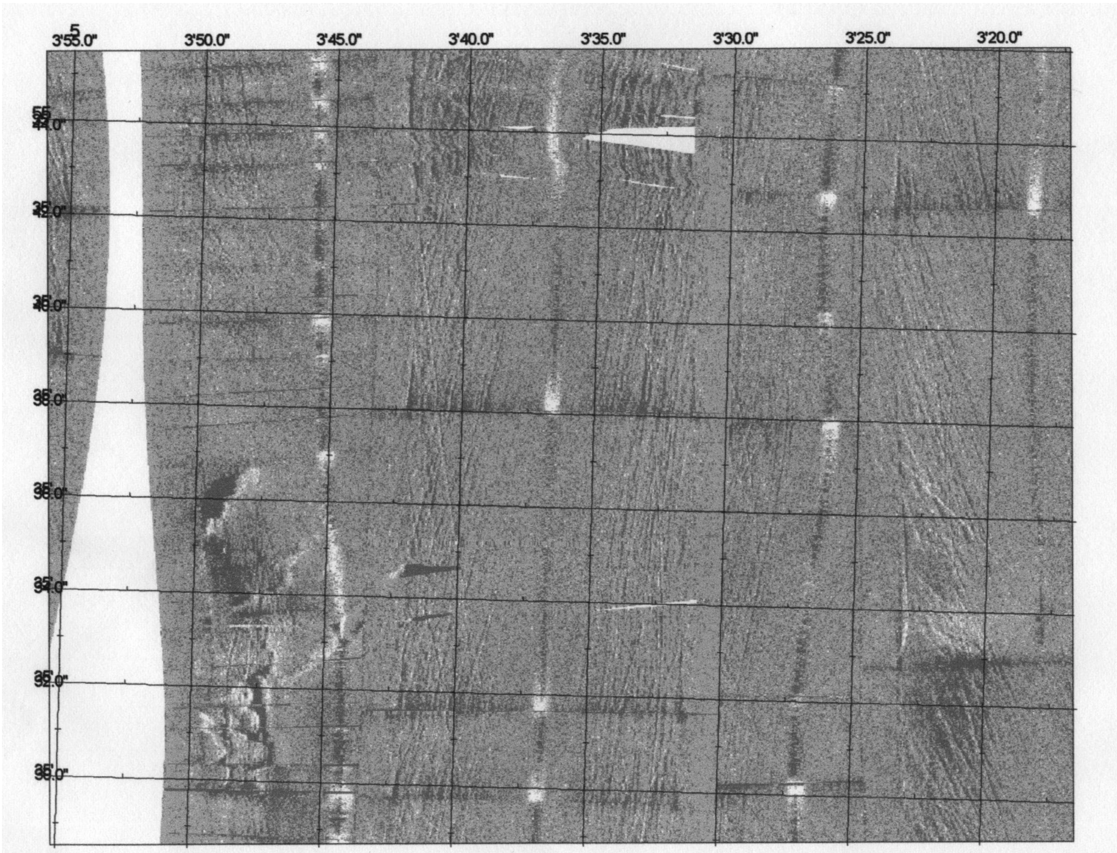
The track followed at each site on the second survey (grid pattern) and the locations from which the snapshot frames were taken are shown in Fig. 23. At each site, 16 images (Fig. 22b) were analysed as described previously; 8 from the lettered locations, and 8 from the survey track intersects (two per intersect). However, the confined channel at location L2 made the full execution of the grid pattern used at the other sites impossible. Here, only two track intersects (two images per intersect) were carried out. It took approximately 1.5 h to survey each site using this open grid survey pattern, as opposed to 3 h per site using the parallel passes pattern.

Results of the analysis are presented graphically in Fig. 24, including the calculated indices, Trawl Density (*D*) and the Trawl Orientation (*O*). The relative values of *D* obtained from each site broadly reflect the original categorisation of the sites according to their nominal trawl impact. Heavily fished sites had a high value for *D*; moderately fished sites an intermediate value, and site L1 a low value.

Site L2 had a higher value for *D* than anticipated, bearing in mind that fishing was prohibited in the northerly part of this site. This may be explained in the light of the constraints imposed on the survey track during the survey and knowledge of the behaviour of trawlers fishing in the south-western corner of the survey box. Trawl marks were only found in frames *a* and *b* and the intersect point between them (see Fig. 23). Vessels entering the restricted area from the south naturally try to get as close as possible to the prohibited zone before lifting their nets. The geography of the area and the free channel to the west of the restricted zone means they normally head for the SW corner of the survey box. So, although there is zero impact at the northern frames (*c, d, e* & *f*), circumstances cause a concentration of trawl marks in the SW corner, elevating the overall value of *D* to a level similar to the adjacent site, M2. However, at M2, trawl marks were more evenly distributed throughout the site.

The importance of conducting a sidescan survey on two opposed axes is highlighted by the high degree of directionality in the orientation of trawl marks observed at sites M1, M2, L1 & L2 (Fig. 24). At these sites, directionality is consistent with vessels following isobaths or operating within navigational constraints, for example the presence of land and prohibited zones. There was a slightly greater preference in trawl direction at site H1 than H2, which had a uniformly even sea bed, clear of obstructions. The randomness in trawl orientation at site H2 is confirmed by the Index of Trawl Orientation (*O*) having a value close to 1. At site H1, the bathymetry slopes gradually downward from West to East and there are foul areas in the NW corner, perhaps explaining the slight preference in trawl orientation in the 180° to 270° sectors. Prevailing weather conditions prior to the sidescan survey may also contribute to fishing vessels having a preferred direction of tow.

a)



b)

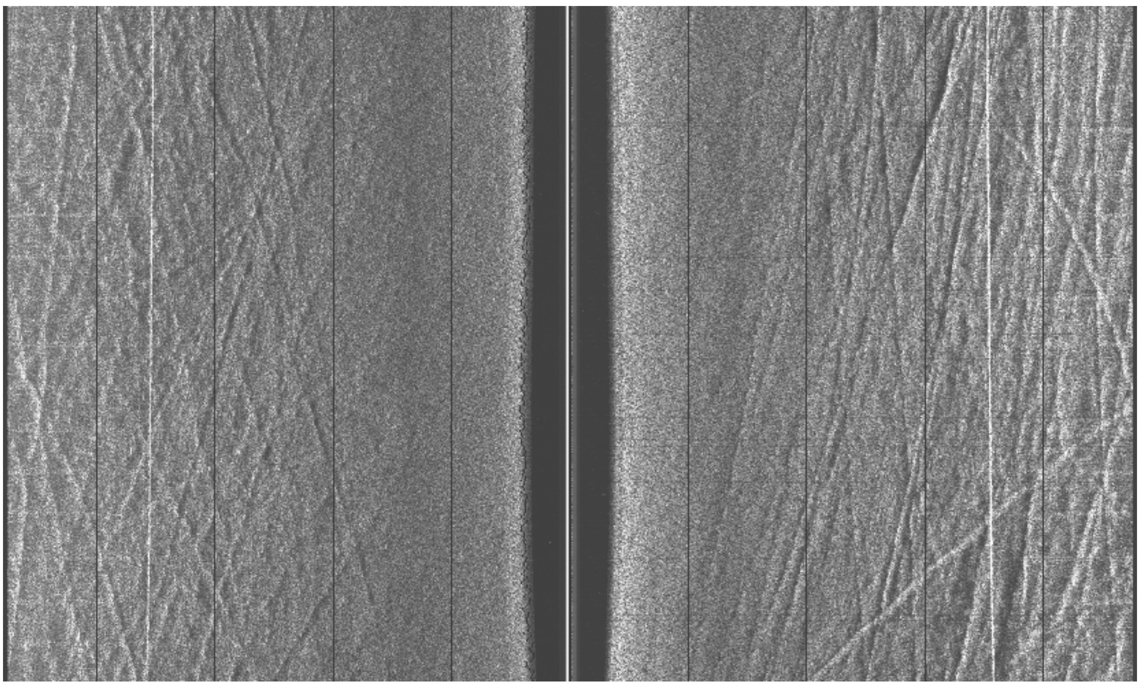


Figure 22. Images from sidescan sonar surveys in the Clyde Sea area. a) Extract of a mosaic image of site H1 overlain with a Lat./Long. grid. b) a single ‘frame’ snapshot from site H1 showing trawl marks on the sea bed.

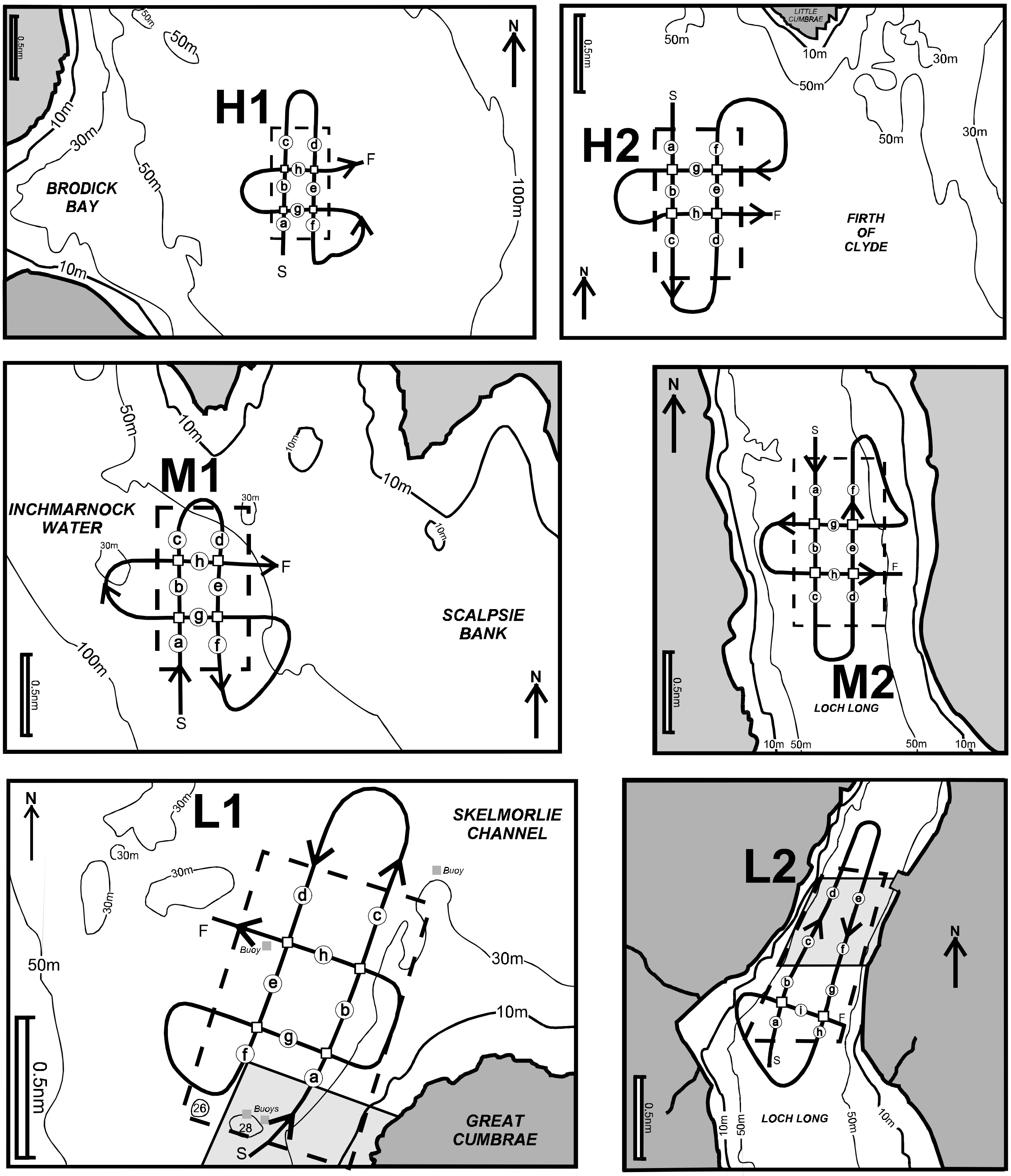


Figure 23. Charts indicating the tracks taken on the second sidescan sonar survey at each of the six sites in the Clyde Sea area. The dashed line shows the site boundary. Shaded areas in L1 and L2 indicate the zones in which trawling is prohibited. S and F indicate the start and finish of the survey track (respectively). Circled letters show the positions of the individual sonar snapshot ‘frames’; the intersect snapshots were taken where the lines of the survey track cross (open squares).

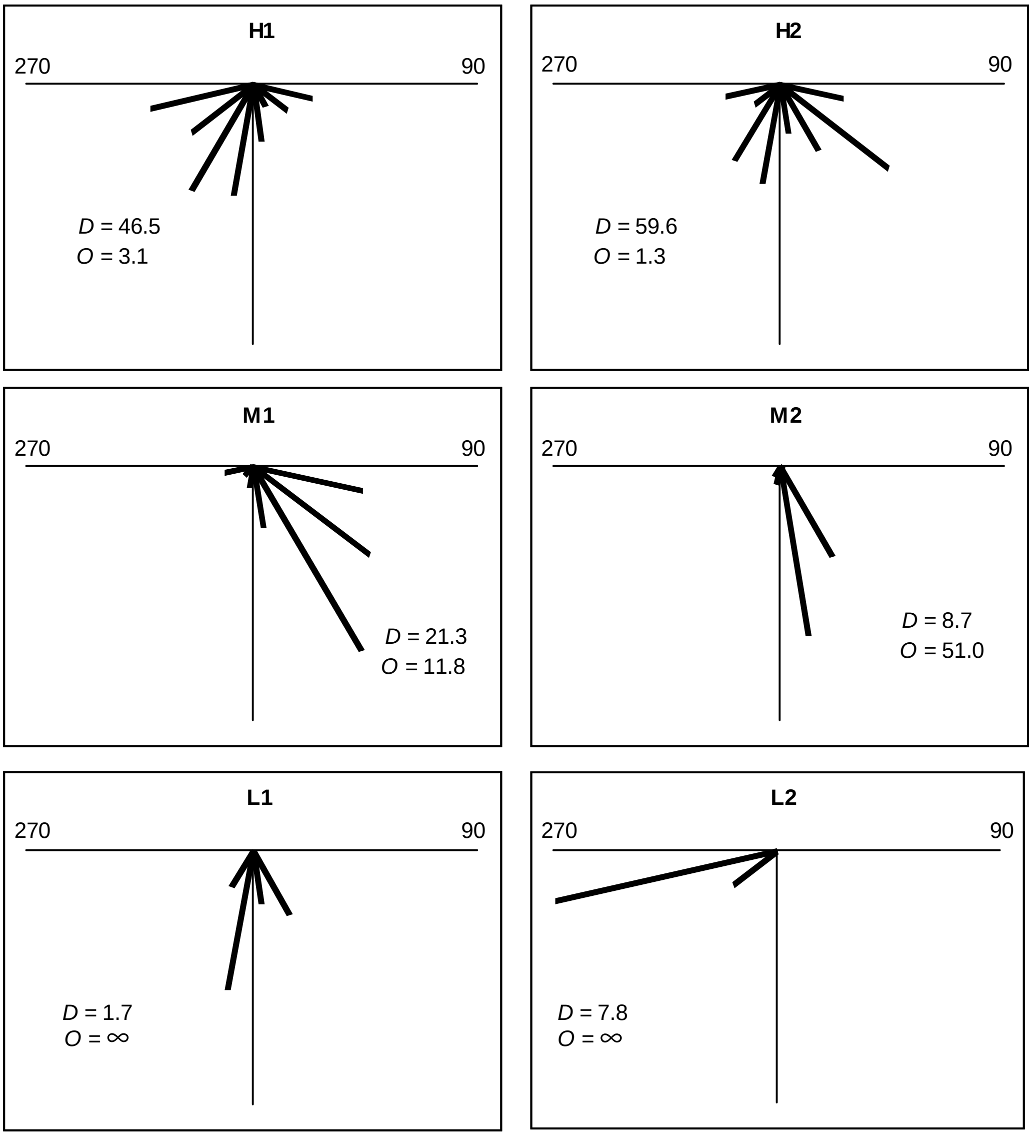


Figure 24. The pattern of orientation of trawl marks at each of the six sampling sites in the Clyde Sea area. The 180^o arc from 90^o to 270^o is divided into 8 equal sectors. Spline length is proportional to the frequency of marks in that sector. *D* is the Index of Trawl Density; *O* is the Index of Trawl Orientation.

4.3.1.2 Aegean

A variety of different bottom features could be seen on the sidescan images. Marks of trawl doors were evident in both coarse and fine sediments. Door marks were not always noted to be paired and this may have been due to:

- One of the door pairs being out of the sidescan view
- The two individual marks from a pair having a different image when viewed from one side. A trawl door mark is not symmetrical: a door can dig deeper on one side of the plough mark and push excavated sediment in towards the trawl thus the door marks may have different shadow patterns.
- One of each of the pair doors being on different sides of the sidescan and with slightly different gain settings to the transducers one may not have been so apparent.
- The rigging of the trawling gear being uneven such that one door was not in constant contact with the sediment.
- The towing vessel turning causing one door to lose contact with the sea bed.

The marks of scientific gear were evident including the Agassiz trawl and the towed video-sledge, both of which could be verified by measuring the distance between the runners. On one occasion the footprint of the SPI frame was visible.

In the Dia Island site the slope towards the island was noted through the side of the sonar facing the island giving a much darker image (higher reflectance from the more angled sea bed). Patches of coarser sediment and small boulders were also noted at the bottom of the slope. In the Gouves site, harder patches of sediment were also noted as was the presence of rocky and calcareous reefs.

Some consideration was given to estimating the degree of freshness of trawl marks and therefore ageing. Old deep-digging marks can potentially show better defined sidescan signatures than fresh shallow-digging marks, so ageing of marks is not possible. The depth to which a trawl door penetrates is dependent on multiple factors such as weight of gear, tow speed, weather, turning, hauling, etc.

Sidescan features pertaining to trawling impacts at 410 kHz are shown in Figures 25 to 32 for soft and coarse sediments. Parallel scale bars are at 20 m intervals with all figures showing a swathe of 180 m, 90 m to each side of the towfish. Gain settings between figures may be different, all images have been ‘soft’ filtered in processing, but no further image manipulation has taken place. All images are screen shots from the sidescan tracks. Figures 25 to 28 were taken at approximately 200 m depth on the commercial trawling lane at the soft sedimentary Dia Island site. Figures 29 & 30 were taken at approximately 70 m depth at the coarse sedimentary Gouves site. Some images (Fig.s 27 & 28) have been closed-up, where the track under the towfish is interpolated.

Figure 25 shows along-track images of trawl door marks with a towfish height of approximately 15 m above the sea bed. Marks are visible to the edges of the image although they tend to fade at 80 m from the towfish. Trawl marks were relatively clear and countable. Figure 26 shows similar marks in very close vicinity where the towfish is much closer to the sediment (4 m above). The gain setting remains the same and trawl marks are not evident beyond 80 m; however, they are clearer to see.

Figures 27 and 28 show closed-up images (no information on height of towfish above the bottom is visible and the track between left and right sides is interpolated) of trawling marks perpendicular to the axis of tow. At 10 m above the sea bed, the cross-track marks are less evident than along-track. Closer to the sea bed (5 m), well defined tracks (that have ‘deeper cuts’ and higher sediment spoil ramparts) are evident, but poorly defined or older tracks are not.

Figures 29 and 30 show images from coarse sediments from the Gouves experimental area. Trawl tracks are evident but are much more ‘diffuse’ because of the lesser penetration into the sea bed. It is likely that the marks are enhanced by dragging of coarser fragments (maerl) into the door depressions. These fragments have a higher reflectivity showing up as dark streaks in the cross-track images. Trawl marks were visible through this phenomenon whilst the towfish is high above the bottom.

Figure 31 shows the experimental trawling lane at Gouves on the right hand side of the image with diffuse marks from the trawl doors and clearer defined marks from the skids of the Agassiz trawl. High reflectance (darker area) marks in the upper left hand corner of the image are probably coarser sediments with maerl fragments surrounding an out-of-picture outcropping reef.

Figure 32 again shows along-track trawl marks at Dia Island with the feint imprint of the video-sledge running diagonally across from bottom left to upper right. This mark was checked by measuring the width of the parallel mark that matched the distance between the sledge runners (1.2 m).

Figure 33 shows the pattern of sidescan sonar tracks across the commercial trawling lane at Dia island. The lane is diagonally across the screen from mid-top right to mid-bottom left. From general observation the trawling lane was within the coverage of the scans which should also have covered areas outside of the lane. The island of Dia (not shown) is within the grid to the top of the view and towards the right hand side. After the visual examination of the sidescan tracks, the estimation of trawl mark density and the division of counts into categories (0 representing no marks, 5 representing more than 50 marks in 180 m swath), the data were plotted in Fig. 34, as a density contour map. Darker shading represents a greater number of tracks counted on the images. Two tracks were excluded from this plot, both of which represented cross-track tows where the visibility of trawl marks were at their weakest and the data probably gave large underestimations. The plot does highlight the main part of the commercial lane in the vicinity, although the interpolation generated by the plotting program leaves something to be desired. These data covered all the year including both the trawling and non-trawling season. No real differences could be seen on examination of the individual traces over time – the door marks persisted through the non-trawling period and freshness could not be accurately ascertained from sidescan images.

The direction and intensity of trawl marks are shown in Fig.s 35 and 36. Figure 35 has the averaged counts from all the tracks in a particular grid box. The grid boxes correspond to those shown in the previous figures. The main direction of trawling is North West – South East that follows the contours and the edge of Dia Island. Blank boxes indicate no trawling marks were observed. Coverage can be seen in the track plot in Fig. 33. Trawling density was highest towards the north west and in the centre of the figure where the average number of trawl marks in a 180 m swathe had a maximum of 45.1. Average density of marks in the middle of the trawling lane ranged from 20-30 per 180 m swathe and 5-10 per 180 m swathe at the edges of the lane. Figure 36 shows the same data after categorisation on a scale of 0-4. Here all counts below 10 are in the first zero category. This has effectively filtered the data to indicate the principal axis of the trawling lane and it discards data from the periphery or accidental recording of scientifically induced marks (Agassiz trawl). Here, blank boxes indicate <10 trawl marks were observed. Again, the principal axis and direction of the lane is clearly evident.

Practical Considerations

Sidescan sonar is an excellent tool for wide area survey with respect to defining trawled areas. In addition, data can be used in a quantitative way to estimate impact intensity.

It was not possible to estimate the age of trawl marks. Fresh marks may have been evident from sharply defined scar marks on the sidescan traces, but it was not possible to distinguish old marks from marks that might have been relatively fresh but had even more recently been re-trawled over.

Set-up for the sidescan was extremely important in terms of a variety of features

- hardware and software settings (gain, filtering, gamma correction, recording resolution)
- frequency used
- direction of tow in relation to trawling marks on the sea bed
- height of towfish above the sea bed
- sediment type

Positioning accuracy of the sidescan was highly dependent on correct layback of the towfish (i.e. correctly knowing the horizontal separation between the vessel and the towfish) which had to be calculated with any major changes (winching in or out more wire, change in depth, change in height of the towfish above the bottom).

Attempts to produce mosaic maps of the area were not successful for two reasons. Firstly it was not possible in the Aegean to utilise a parallel pass approach (see below) and secondly the resolution of the mosaics did not allow trawling marks to be seen with the same resolution as the original track recordings.

Early in the project, speed of tow was very low which led to positional errors because the D-GPS could not process an accurate course. Later in the project a depressor weight was used on the towing line and this allowed greater speeds to be used whilst maintaining the towfish near to the sea bed.

Grid-based surveys were not able to be carried out effectively in the Aegean because with deeper fishing grounds, a large amount of tow wire was required which made turning a very long and difficult manoeuvre. Consequently, an open zig-zag pattern was used. Local topography on the Dia Island ground was also unfavourable to grid surveys. The steep shelf meant that in deploying from the north, by the time the correct amount of wire was out and the fish was at the correct tow height, the North control area had been passed and the towfish was into the fishing lane.

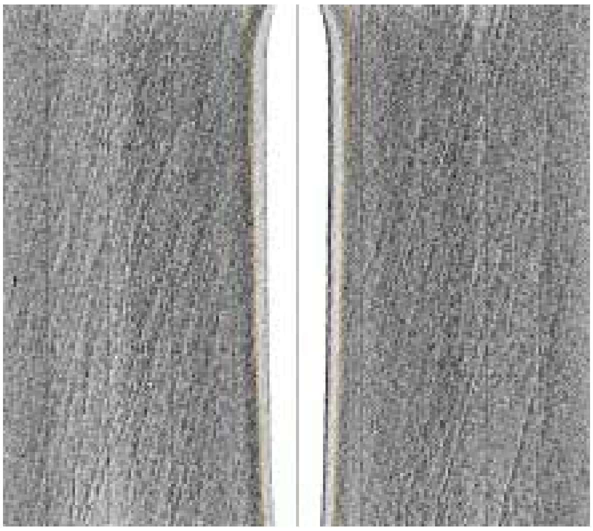


Figure 25. Along-track sidescan sonar image (Dia Island, Aegean Sea) recorded with towfish at 15 m above soft sea bed.

Figure 26. As Fig. 25 but with towfish at 4 m above soft sea bed.

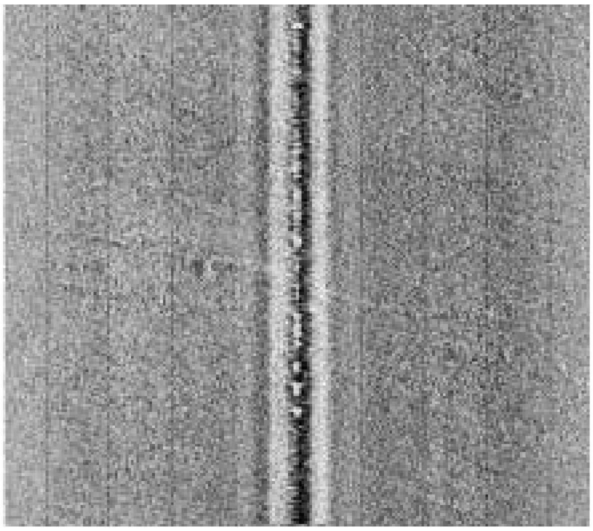


Figure 27. Cross-track sidescan sonar image (Dia Island, Aegean Sea) recorded with towfish ~ 10 m above soft sea bed.

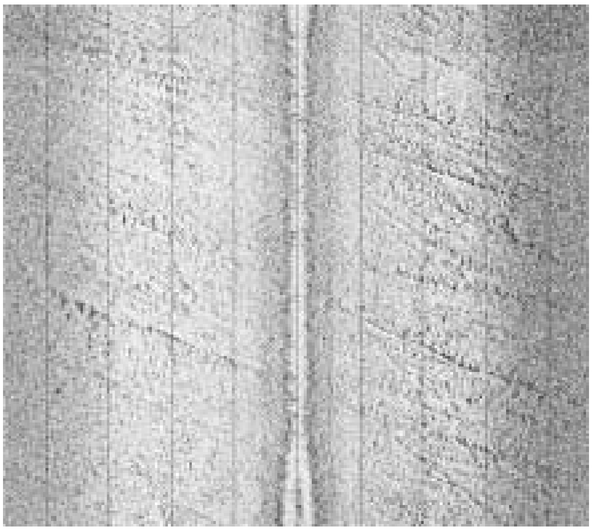


Figure 28. As Fig. 27 but with towfish ~ 5 m above soft sea bed.

Figure 29. Diagonal-track sidescan sonar image (Gouves, Aegean Sea) recorded with towfish ~18 m above coarse sea bed.

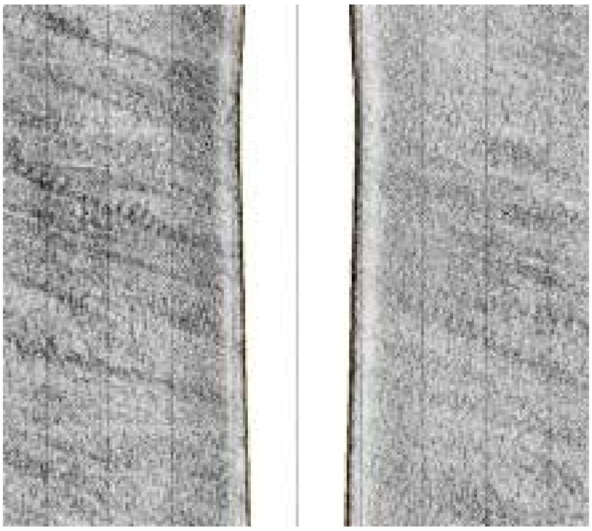


Figure 30. As Fig. 29 but with cross-track orientation.

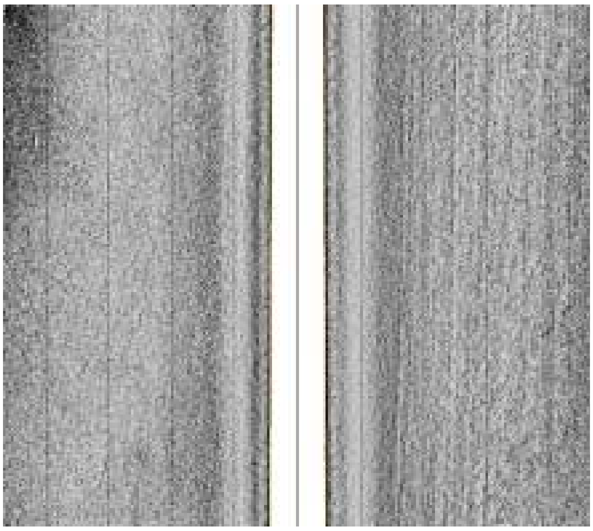


Figure 31. Diffuse otter trawl marks and well defined Agassiz trawl marks on coarse sea bed, Gouves, Aegean Sea.

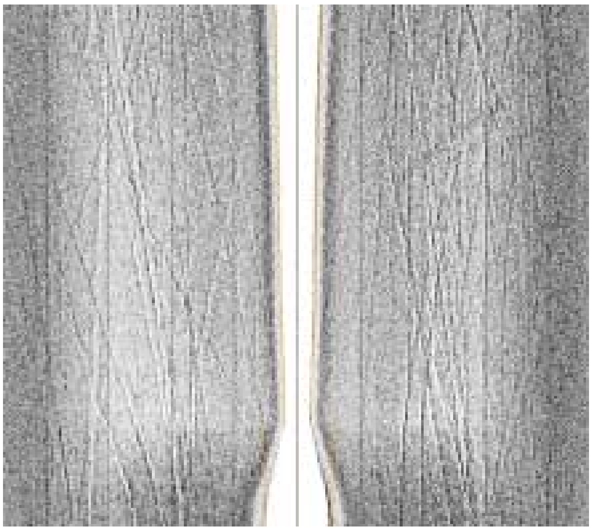


Figure 32. Paired marks from video-sledge (upper left) running diagonally across trawl marks on soft sea bed, Dia Island, Aegean.

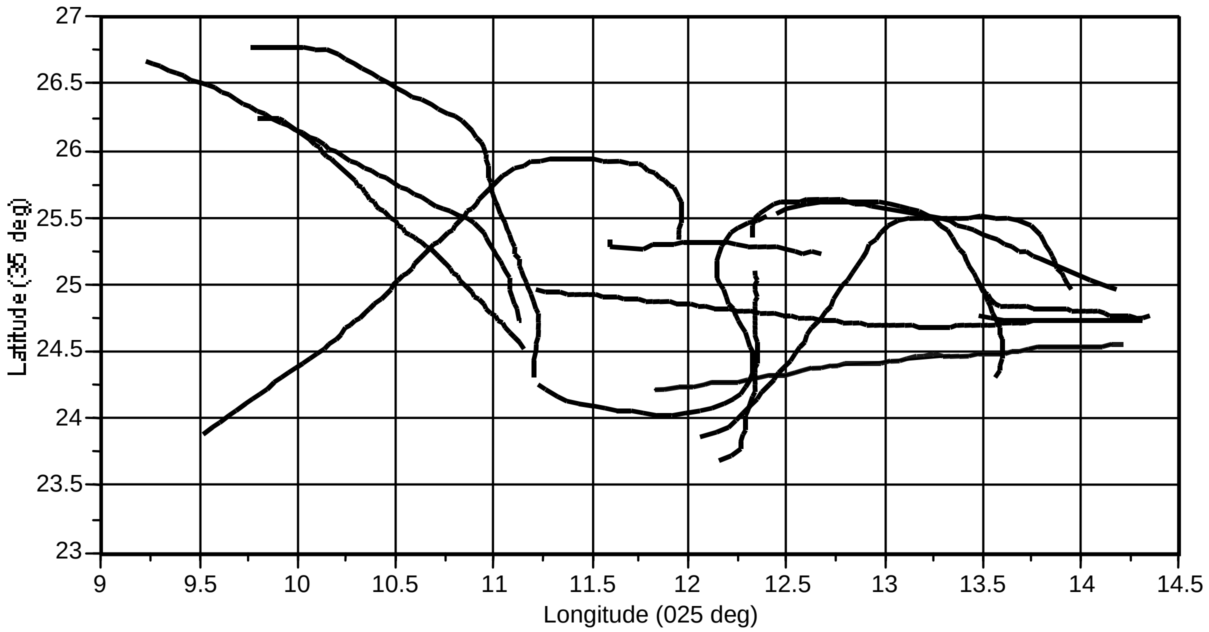


Figure 33. Geo-referenced track positions for sidescan sonar surveys made in the area of the Dia Island commercial trawling lane, Aegean Sea.

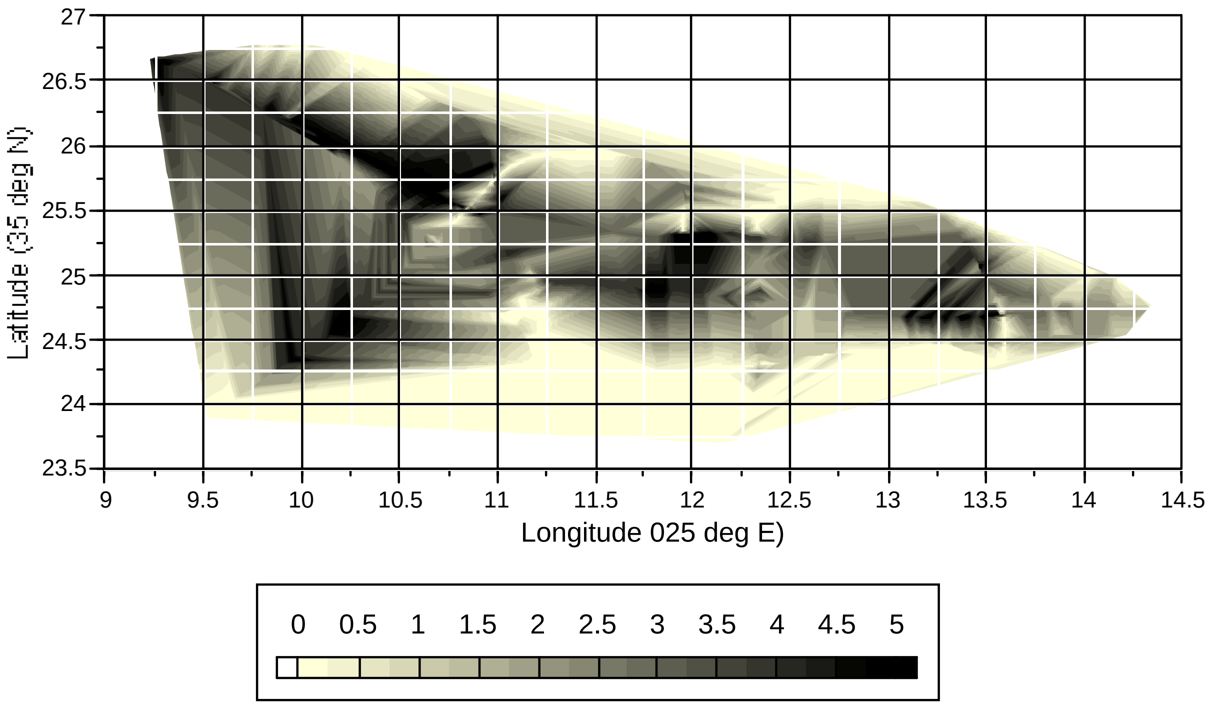


Figure 34. Density contour map of trawl marks at the Dia Island commercial trawling lane, Aegean Sea. Density categories are explained in the text, with darker shading indicating higher density of trawling marks.

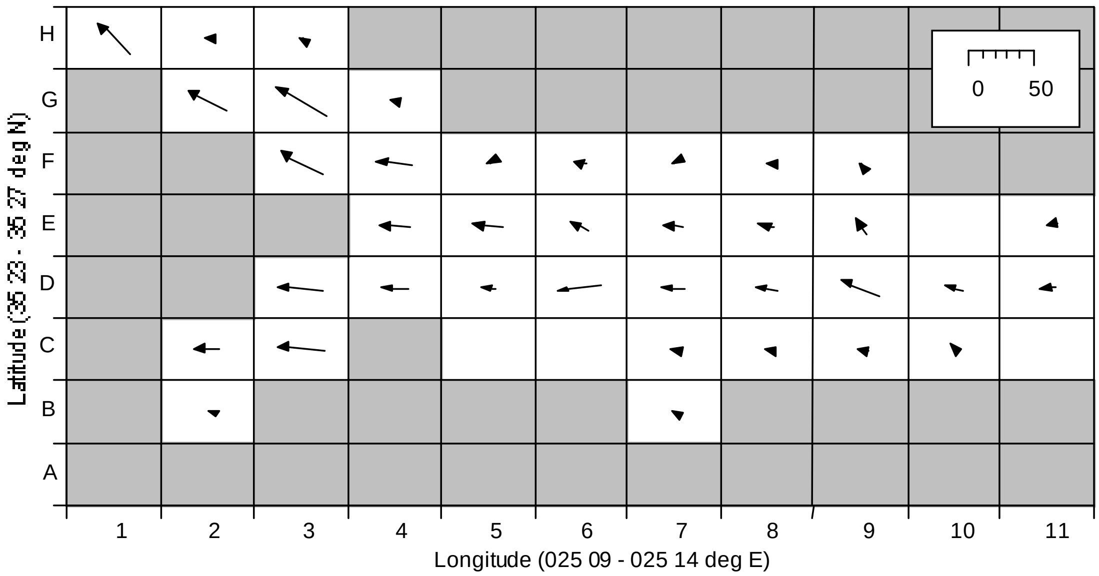


Figure 35. Vector chart showing the direction and intensity of trawl marks in the Dia Island commercial trawling lane, Aegean Sea. Arrow shaft 0-50 indicates average number of trawl counts from 180 m swathes averaged over geographical boxes. Blank boxes indicate no trawl marks, greyed boxes were not surveyed.

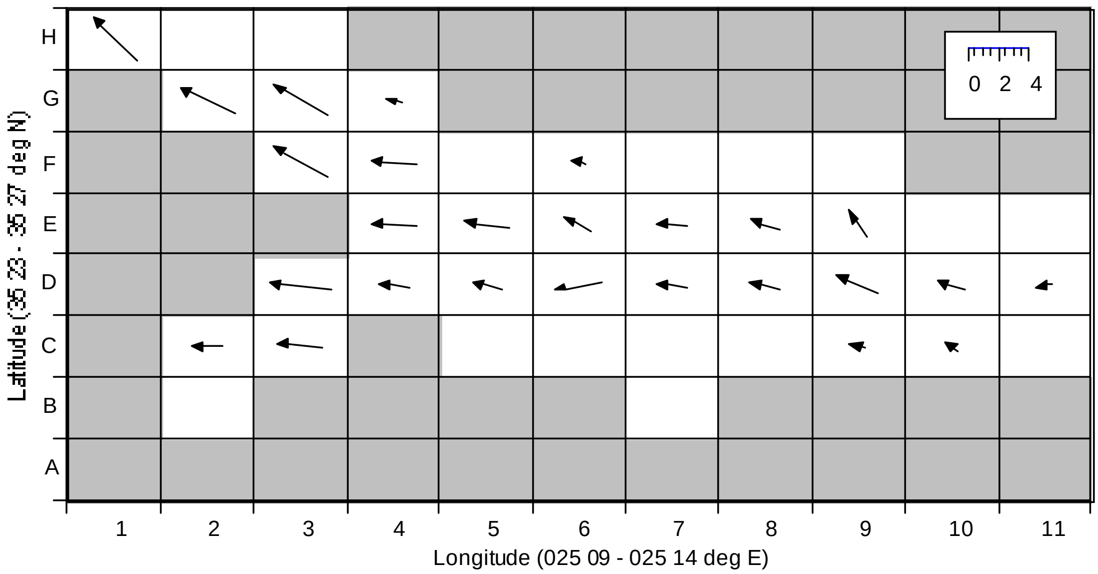


Figure 36. As Fig. 35 but with frequency of trawl marks categorised on a scale of 0-4 (filtering peripheral counts). Blank boxes indicate <10 trawl marks, greyed boxes were not surveyed.

In Summary – Sidescan Sonar

Clyde Sea

- Sidescan sonar is a useful method for detecting and enumerating marks left on the sea bed by otter trawls.
- The design of the survey is important. Proper quantitative assessment can be achieved using a grid-based survey track. Only qualitative assessment can be achieved using a parallel-pass survey track.
- The grid-pattern survey was more effective and more time efficient than the parallel-pass survey. Time required for data collection was reduced by half and data processing was significantly quicker.
- The method of single frame analysis developed here provides accurate and reliable estimates of the relative density of trawl marks at each site and could be adapted to provide estimates of absolute densities.
- The orientation of trawl marks can be analysed using methods developed here, showing if sites are characterised by a preferred or a random towing direction.
- Surveys would benefit from information on the persistence of trawl marks, which will vary with sediment type and hydrographic conditions.

Aegean

- Set-up of sidescan is extremely important for best visualising trawling marks
- Where there is a unidirectional component to towing, a sinusoidal track along the main direction is the most efficient approach
- Acoustic imaging is not affected by turbidity.
- Analysis of the data does not require a high level of experience.

4.3.2 RoxAnn™

4.3.2.1 Clyde Sea

Comparison of the false colour composite images generated from E1 and E2 data from the survey in the Clyde Sea area revealed between-site differences (Fig. 37), but these could be attributed to known differences in sediment type (as determined by the British Geological Survey (1985) and further supported by our own granulometric analyses of the sediments). This method of analysis could not distinguish between sites on the grounds of differing fishing impacts as it failed to differentiate between the two adjacent sites in Loch Long (M2 and L2) which had very similar substrata but were categorised as 'moderate' and 'low' impact sites, respectively.

Frequency-distribution analysis of E1 and E2 data was also unable to separate sites according to their relative fishing intensity (Fig.s 38 & 39). The heavily fished sites (H1 & H2) were smooth compared with the moderately fished sites (M1& M2), but the lightly fished site L1 was also smooth and comparable with H1&H2. The adjacent sites in Loch Long, M2 and L2, were again practically indistinguishable despite their different impact status while the moderately fished site, M1, was characterised by a relatively even distribution over a large range of E1 values compared with other sites. These results were consistent with later observations made by underwater TV, much of the apparent roughness in the Loch Long sites being attributable to biogenic modelling in the form of high concentrations of large burrow systems belonging to megafaunal Crustacea such as the Norway lobster, *Nephrops norvegicus*, and infaunal thalassinidean mud shrimps (e.g. *Jaxea nocturna*, *Calocaris macandreae, Callianassa subterranea* and *Upogebia* spp.)

Four of the six sites had markedly soft substrata (H1, H2, M2 & L2) and again the adjacent sites in Loch Long were very similar to each other. The M1 site was of moderate hardness and the L1 site was harder than all others. These results are consistent with later observations made in the sediment coring work. The value of choosing six sites rather than three is well justified here. There is a marked modal progression in the E2 frequency distribution between the H1, M1 and L1 sites. Had the survey been restricted to these sites alone it is likely that the results would have been interpreted as showing a progressive softening of the sediment with increasing fishing intensity. This is clearly not universally the case.

RoxAnn™ has successfully been applied as a habitat-mapping tool in numerous studies elsewhere. The application in this study was quite different and has not been successful. This was an unexpected outcome given that Pinn & Robertson (1998) reported that the E1 signal was highly sensitive to bioturbation (specifically the density of burrows of *Nephrops norvegicus*) and repeated experimental trawling has been reported to increase E1 (roughness) in muddy habitats (Tuck *et al*., 1998) and increase E2 (hardness) in sandy substrates (Schwinghamer *et al*., 1998). It is notable that these studies were carried out on homogeneous substrates and further work by Pinn & Robertson (2001) on a wider range of sediment types (including heterogeneous sediments) showed that a relationship between E1 and burrow density could not be detected. Instead, they attributed the majority of change in the acoustic signal to changes in sediment type. Considering these factors as a whole, it would appear that bottom-discriminating sonar may have an application in monitoring changes over time in trawl impacts at particular sites (i.e. a time-series of surveys at one site). However, it cannot be so readily applied to the wider task of differentiating between sites according to their differing trawl impact as the between-site differences in sediment type confound any differences which might be attributable to trawl impacts.

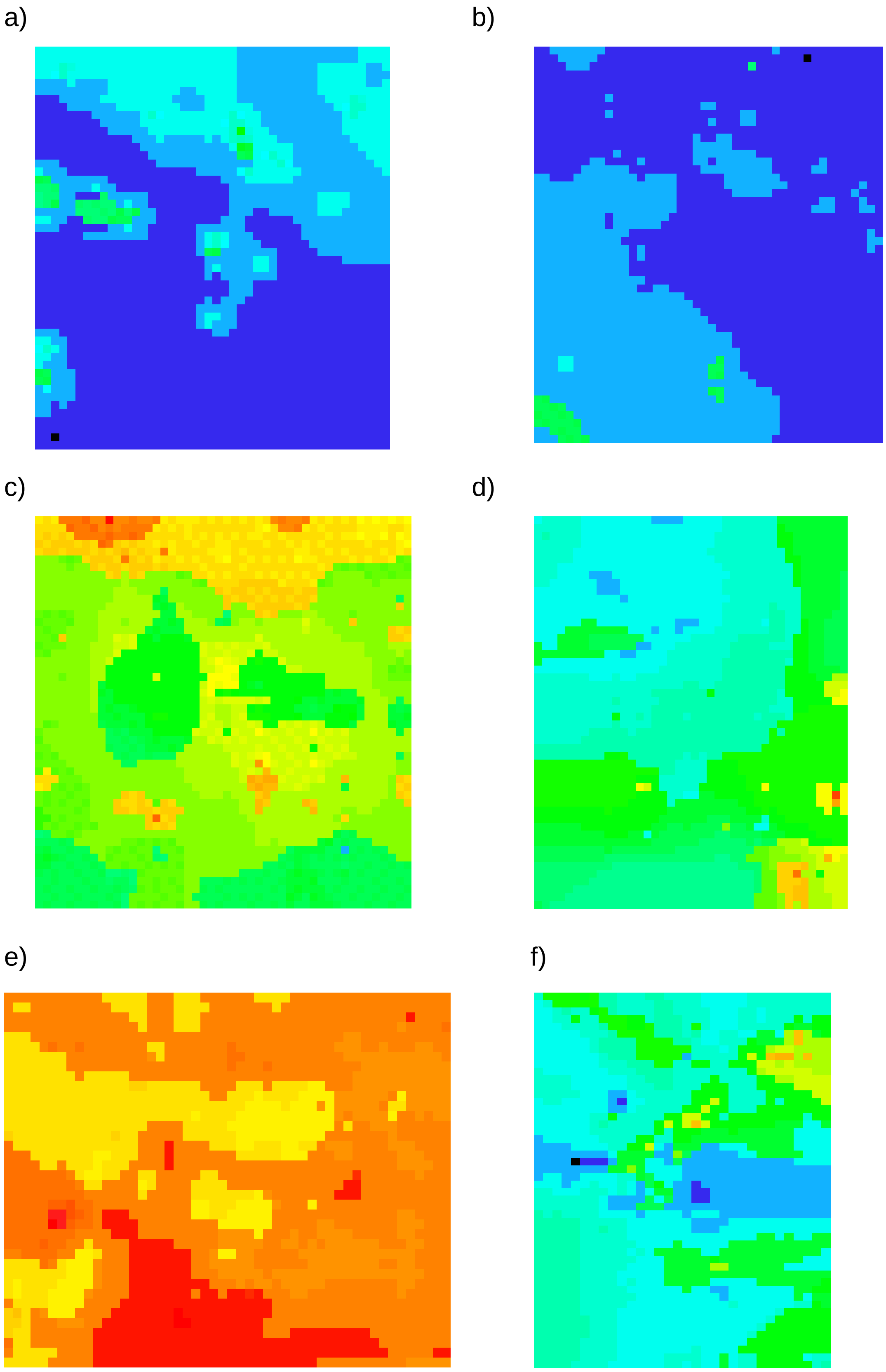


Figure 37. False colour composite images of RoxAnn™ data (E1 & E2) for the six sampling sites in the Clyde Sea area. Heavily impacted sites a) H1 b) H2; moderately impacted sites c) M1 d) M2; lightly impacted sites e) L1 f) L2.

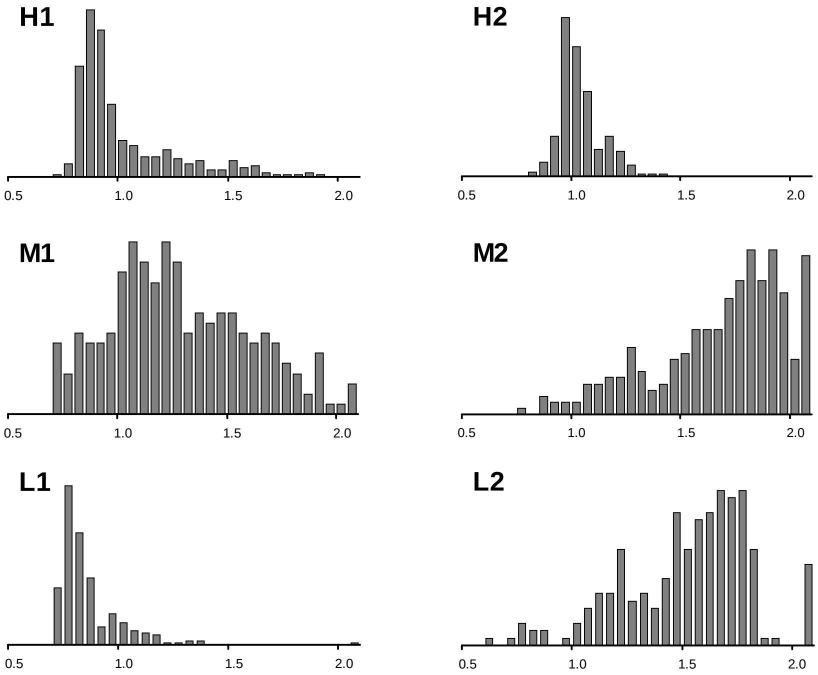


Figure 38. Frequency distributions of the RoxAnn™ parameter E1 (roughness) for six sampling sites in the Clyde Sea area representing three nominal level of fishing intensity (H = heavy, M = moderate, L = light).

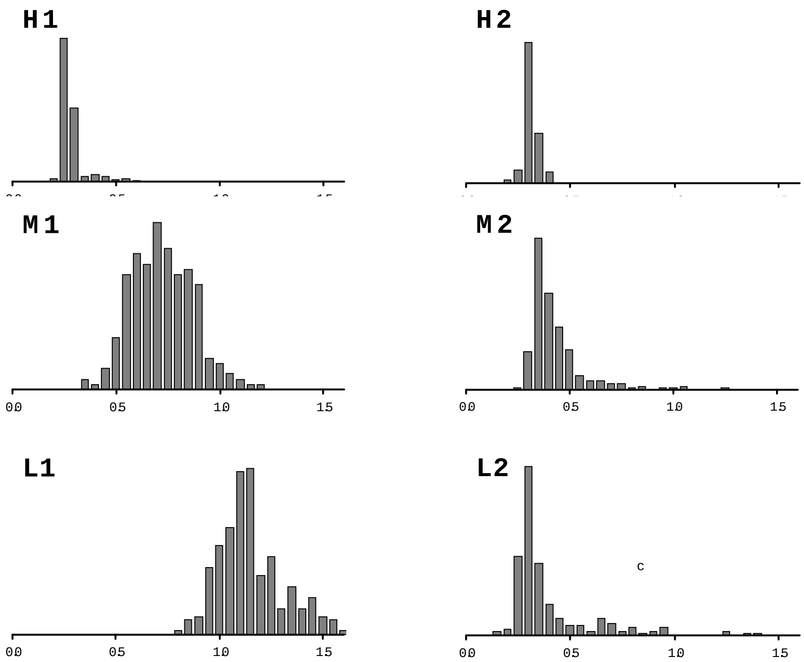


Figure 39. Frequency distributions of the RoxAnn™ parameter E2 (hardness) for six sampling sites in the Clyde Sea area representing three nominal level of fishing intensity (H = heavy, M = moderate, L = light).

4.3.2.2 Aegean

Investigation of the RoxAnn™ data revealed that little information was evident in the combined E1 and E2 values as there was a general uniformity in the study sites with respect to E1 (roughness). The analysis and presentation of data therefore concentrated on the E2 value (hardness). The survey carried out in Iraklion Bay (in geographic reference to the north coast of Crete and Dia Island) which included the detailed parallel track survey in the Dia Island area and the along track survey in the Gouves experimental area, is shown in Fig. 40.

Figure 41 shows the tracks in the Gouves experimental area in more detail. The track is composed of the individual colour-coded hardness values with yellow indicating softer seabed and dark blue indicating harder seabed. The divisions of hardness were arbitrarily chosen for 10 hardness settings and do not refer to specific bottom characteristics. The area was known to have mixed sands with maerl areas and rock reefs with maerl. The marked boxes indicate the experimental trawling lane to the right of centre and the control lane/site in the upper right hand side. Maerl reefs marked the south end of the experimental trawling lane, with another set of reefs separating the two sites. There is no interpolation between tracks as the dividing reefs would not be adequately represented.

It was impossible to discern any clear trawling impacts at the Gouves experimental area because of the high level of heterogeneity in the area. The high level of uniformity of roughness (E1) was thought to be due to maerl fragments on the seabed and the presence of reefs. Trawl doors do not penetrate to any appreciable depth in coarse sediments as compared to softer sediments and any trawl marks would have been masked by the patchy presence of maerl. The hardness value (E2) was much more variable, again due to the difference in reflectivity between sand, maerl and rock. Trawling may remove maerl fragments decreasing hardness values, but this would be again masked by the high level of local heterogeneity.

Figure 42 shows the detailed tracks from the Dia Island area. Colour coding was the same as for Gouves, but with slightly different ranges. The dashed lines indicate the approximate boundaries of the commercial trawling lane and the tracks were selected to overlap the lane into the control areas to the north and south. The area was thought to consist of heterogeneous silty sediment, becoming slightly coarser to the north at the bottom of the slope up to Dia Island. A specific repeated feature was noted in the eastern mid section of the trawling lane. This feature is best represented in an interpolated map shown in Fig. 43. This false colour image shows the interpolated track data draped over the bathymetry of the ground. The yellow colouring represents hardest E2 values and dark brown, softer E2 values. Depth ranged from

150-250 m and the map shows harder sediment in the head of the valley leading up from 200 m depth.

The E1 values (roughness), as noted above, were very uniform showing no notable changes in the Dia Island RoxAnn™ survey, indicating a high uniformity in roughness. However, the E2 values (hardness) indicated the presence of harder sediments at the neck of the 200 m contour that had not been previously known or visualised. The links between these values and trawling are not thought to be very high. Whilst it is possible that there may be some compaction of sediments as this is the main hauling area for the commercial trawlers, it is more likely to be due to a geological phenomenon such as collection of harder sediments falling down the head of the valley or to hydrodynamic forces, with stronger currents funnelled into this particular area.

There are several important points that should be taken into consideration concerning RoxAnn™ surveys. Firstly the use of RoxAnn™ is physically limited in deeper waters because of the angle of the echosounding beam. The system is depth dependent because the area footprint of the beam represented by one pixel on screen is related to the square of the depth. In depths of 10 m the area may be in the range of less than 10 square metres, but at 100 m depth this will be in the range of several thousand square metres. The area represented by one pixel is therefore much larger and fine structures or bottom differences may not be visualised. The second major point is that the accuracy of interpolated figures is dependent on the distance between tracks and the actual rate of change and heterogeneity of the seabed. Close parallel tracks may be time consuming, but interpolation between the tracks may be quite accurate whereas widely spaced tracks may lead to very inaccurate interpolations as the heterogeneity in an area could be much higher than displayed. Lastly, RoxAnn™ needs to be ground truthed to be interpolated correctly, i.e. an independent sampling technique should be used in conjunction with RoxAnn™ whether it be sediment sampling with a grab or core, or *in situ* imaging such as side scan sonar or video.

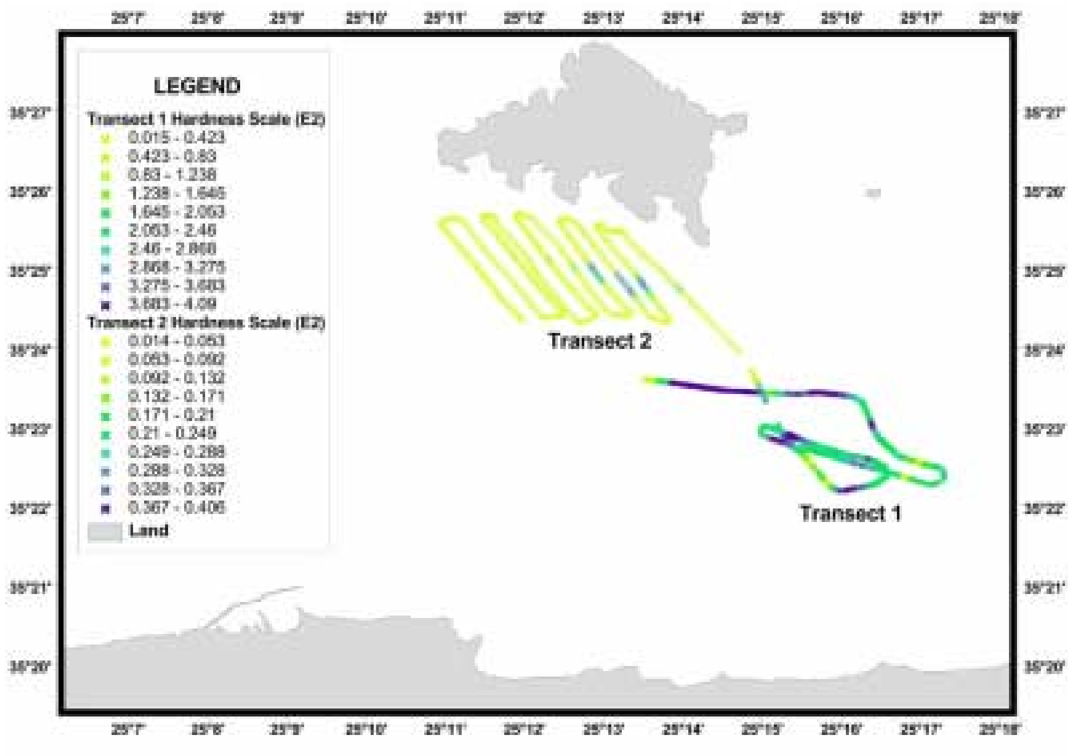


Figure 40. RoxAnn™ E2 values along survey tracks in the Bay of Iraklion, Aegean, showing the overall Gouves experimental area (Transect 1) and Dia Island trawling area (Transect 2).

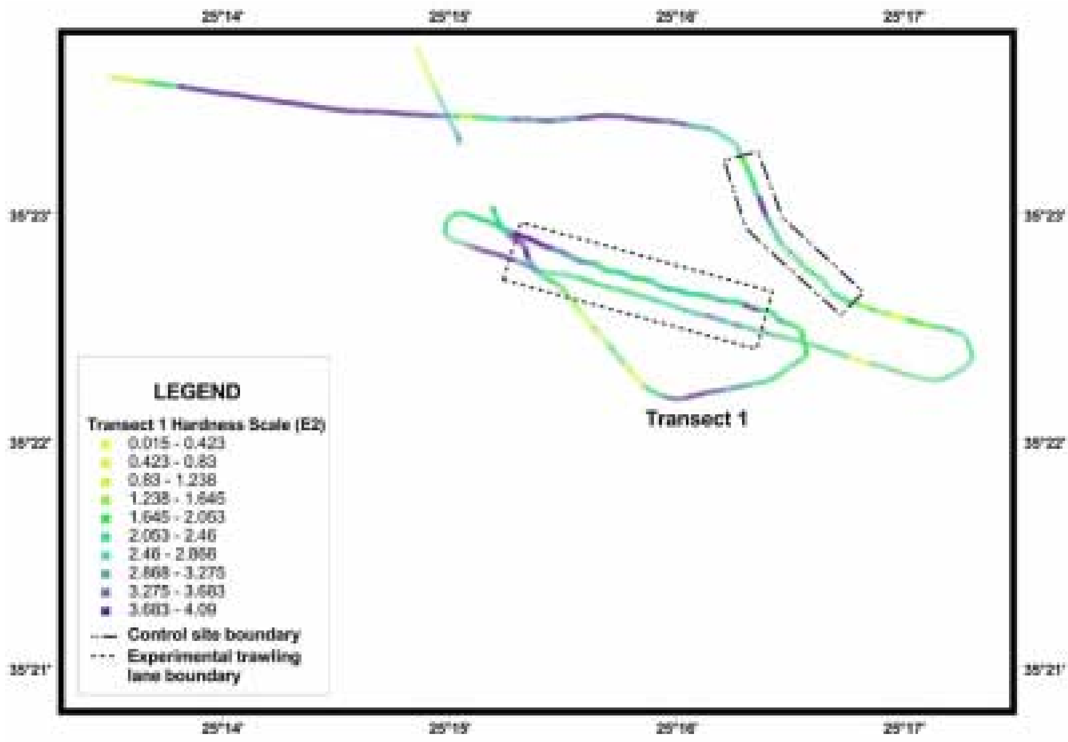


Figure 41. RoxAnn™ E2 values in the Gouves experimental area (Transect 1), Aegean. The upper right box delimits the control site, with the experimental trawling lane in the central box.

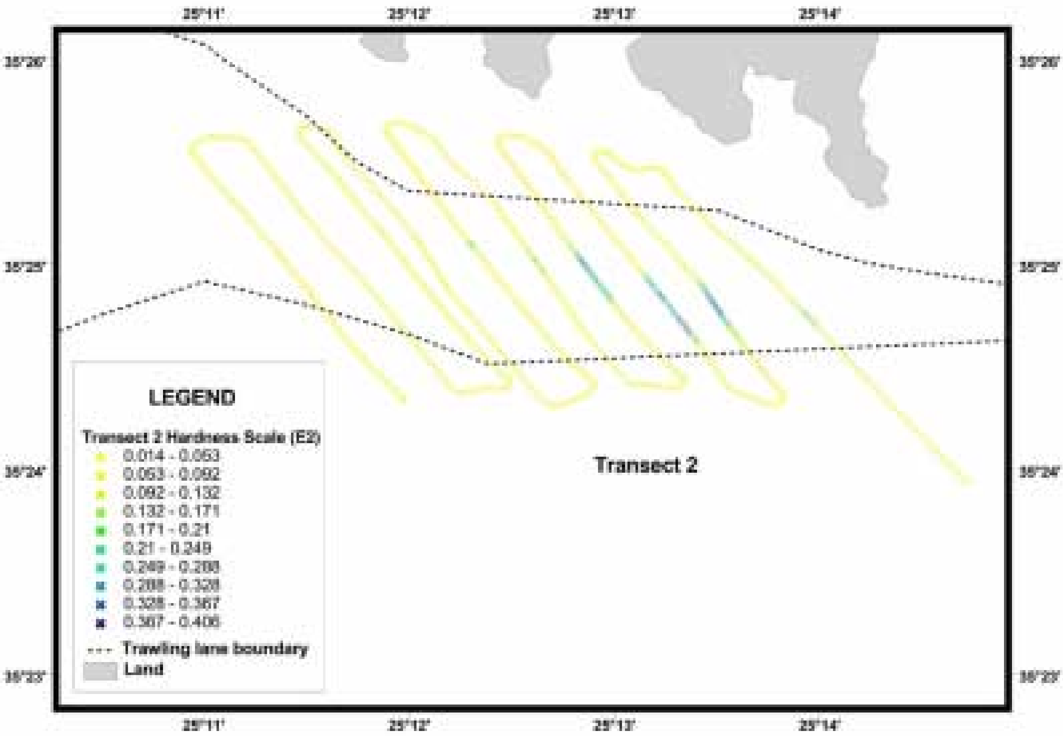


Figure 42. RoxAnn™ E2 values in the Dia Island area (Transect 2), Aegean. The dashed line shows the approximate boundaries of the commercial trawling lane to the south of Dia Island.

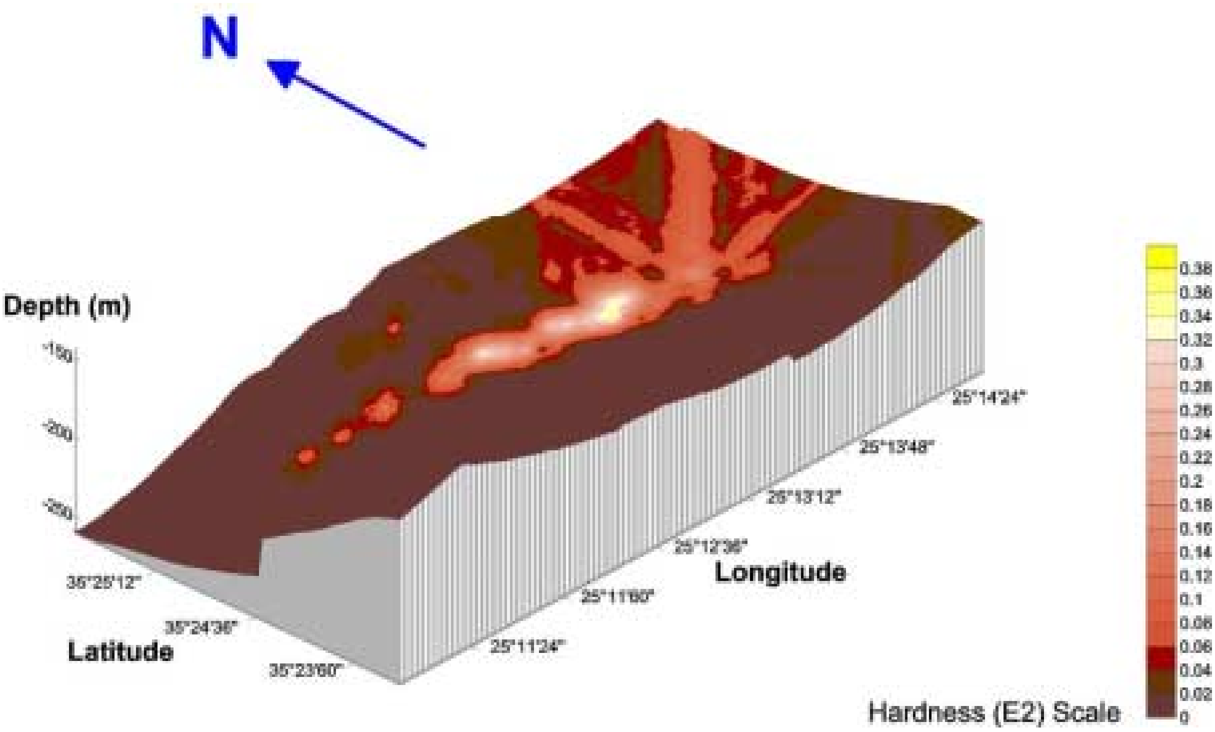


Figure 43. False colour interpolation map of RoxAnn™ E2 values draped over bathymetry in the Dia Island trawling area, Aegean.

In Summary – RoxAnn™

Clyde Sea

- In our studies, bottom-discriminating sonar (e.g. RoxAnn™) was not able to differentiate between soft sediment sites on the basis of their differing fishing intensity (by otter trawls). If a trawling effect existed it was confounded by sedimentary differences between sites.
- There is strong evidence to support the view that bottom-discriminating sonar (e.g. RoxAnn™) is not the method of first choice when attempting to detect otter trawling effects in predominantly soft, muddy sediments. However, we note that other studies (see Fonteyne, 2000) have successfully applied RoxAnn™ to detect changes in sediment characteristics attributable to impacts of heavier gear (commercial, heavy beam trawls) on firmer sediments.
- At soft sediment sites, bottom-discriminating sonar (RoxAnn™) might have an application in a time-series study, monitoring temporal changes at particular sites rather than attempting to make comparisons between sites. There would be a strict requirement for ‘ground-truthing’ the data in order that the instrument can be properly calibrated.

Aegean

- RoxAnn™ data did not clearly discriminate trawling impacts on either of the coarse or soft silty sedimentary areas studied in the Aegean.
- The capabilities of RoxAnn™ as a surface-mounted system are limited by water depth, resolution decreasing as depth of water increases.
- Much care should be taken in using interpolated images as this may not be a true representation of the bottom characteristics. Parallel track separation should be dependent on local heterogeneity.
- RoxAnn™ interpretation requires periodic groundtruthing.

4.4 Faunal Sampling Methods (Task 4)

Clyde Sea

In the preliminary trawl survey (August 1999 – January 2000) nine sites in the Clyde Sea area were sampled by 2-metre beam trawl to assess their suitability for the main quantitative survey. Four sites were sampled 4 times and five sites were sampled twice. All 26 trawl samples were analysed and the data used to decide

- which six sites were best suited for use in the main survey.
- the sampling frequency required in the main survey to ensure a sound statistical basis for quantitative analysis.
- the species of epibenthic megafauna best suited for assessment of damage load.

In the main, quantitative survey (April – June 2000) six sites were sampled 5 times each with twin trawls. One of each twin trawl was fully analysed and the other used to increase sample size for species selected for damage assessment.

Aegean

In the Aegean, two areas had been selected for quantitative investigation of the megafauna/epifauna, the first a commercial trawling area at Dia Island, characterised by a silty sediment at 200-250 m depth and the second an experimental trawling area at Gouves characterised by a sandy-maerl sediment at 65-70 m depth. Control and impacted sites were identified in each area and these were sampled in time series. The sampling protocol called for 5 replicate Agassiz trawl samples during each period at each site, which was successfully completed in the majority of cases. Each sample analysed was fully examined for megafaunal/epifaunal community structure, estimation of dominant species and functional group attribution. Damage assessment was not completed on Agassiz trawl samples. Instead, a complementary approach was used to the Clyde Sea where incidence and mechanism of damage was estimated from the otter trawl samples taken during the experimental trawling impact in Gouves.

4.4.1. Assessment of the damage load of fauna (Task 4, Sub Task 1)

4.4.1.1 Clyde Sea

Large gastropods *(Buccinum undatum* and *Neptunea antiqua)*

Preliminary investigation of the scar frequencies on the shells of *Buccinum undatum* showed that light scarring was common and that the frequency distribution of scars could be normalised by a $\log_{10}(x+1)$ transformation, thus satisfying the pre-requisite for parametric statistical testing. Conversely, severe scars were relatively rare and their frequency distributions 'right skewed' such that they could not be normalised by transformation. Hence frequencies for severe scars were analysed using non-parametric tests. Statistical tests were performed using MINITAB (v 12.22).

A total of 272 *Buccinum undatum* and 134 *Neptunea antiqua* were examined. ANOVA on shell heights showed there were significant differences between sites, with *B. undatum* at site H2 being smaller than at other sites and *N. antiqua* at site L1 being smaller than at H2 (Table 8). Such differences were controlled for in parametric analysis by employing ANCOVA with shell height as the covariate.

Table 8. Number (n) of individuals of *Buccinum undatum* and *Neptunea antiqua* sampled at six sites in the Clyde Sea area, with data on minimum, maximum and mean shell heights. Also results of ANOVAs on shell height for samples where n ≥ 10.

	Buccinum undatum				*Neptunea antiqua*			
Site	n	min	max	mean	n	min	max	mean
H1	16	63	105	83.9	10	67	128	104.9
H2	100	37	110	71.1	16	82	137	110.8
M1	17	39	97	79.8	12	59	143	114.0
M2	3	91	97	93.0	18	59	132	99.2
L1	93	24	119	82.2	63	64	125	96.6
L2	43	51	101	79.1	14	54	137	97.8
ANOVA	$F_{4,264} = 6.74$, $p < 0.01$				$F_{5,127} = 3.21$, $p < 0.01$			

Presence/absence of recent and past damage

The majority of individuals had some form of recent damage to the growing edge of their shells (Table 9). Only at the two low impact sites was a moderate proportion (11.8% & 16.3%) of *B. undatum* free of recent damage. Greater proportions of *N. antiqua* (up to 33%) remained free of recent damage at all sites. There was no apparent relationship between the nominal fishing impact at a site and the proportion of animals showing light or severe damage to the growing edge of the shell. This is consistent with the sampling method itself causing the recent damage observed. *Neptunea antiqua* had notably more robust shells, showing a lower incidence of severe recent damage than *B. undatum*.

Table 9. Summary data on the presence or absence of recent and past damage to the shells of *Buccinum undatum* and *Neptunea antiqua* sampled from six sites in the Clyde Sea area representing three levels of trawling activity (H = heavy, M = moderate, L = light). Data are standardised (i.e. percentages of the sample at each site), with minimum sample size set at n=10. Where present, recent damage to the growing edge of the shell was categorised as either light or severe. However, for past damage shell whorls could contain both light *and* severe scars. The significance (signif.) of between-site differences was determined separately for each damage category, applying the 'G-test' to original count data. 'ns' not significant, '*' significant at p = 0.05, '**' significant at p = 0.01.

		Recent Damage			**Past Damage (scars)**					
		Growing Edge			Largest whorl			3 largest whorls		
Species	Site	None	Light	Severe	None	Light	Severe	None	Light	Severe
Buccinum undatum	H1	0.0	31.3	68.8	0	100	19	0	100	63
	H2	4.0	43.0	53.0	0	98	22	0	99	56
	M1	5.9	29.4	64.7	24	71	35	0	100	94
	M2[†]	-	-	-	-	-	-	-	-	-
	L1	11.8	48.4	39.8	8	80	48	0	95	86
	L2	16.3	27.9	55.8	14	72	51	5	81	77
	signif.	*	ns	ns	-	**	**	-	**	**
Neptunea antiqua	H1	20.0	70.0	10.0	0	100	0	0	100	30
	H2	12.5	62.5	25.0	0	100	25	0	100	44
	M1	33.3	58.3	8.3	0	92	58	0	92	83
	M2	22.2	66.7	11.1	44	39	22	17	78	56
	L1	14.3	81.0	4.8	11	87	30	3	95	63
	L2	26.7	53.3	20.0	20	73	47	0	87	73
	signif.	ns	ns	ns	-	**	*	-	ns	ns

[†] n <10 for *B. undatum* at site M2, so no data are presented.

For past damage in the form of light scars on the largest whorl, between-site differences were highly significant (Table 9). Such scars were present in nearly all *B. undatum* and 100% of *N. antiqua* at heavily fished sites, but on fewer animals at moderate and lightly fished sites. For severe scars, the relationship with fishing intensity was reversed, with fewer animals showing severe scars at heavily fished sites. This would be consistent with a scenario where the probability of survival following severe damage was inversely related to fishing intensity.

When considering data pooled for all three largest whorls, the between-site differences were not significant in *N. antiqua* but remained highly significant in *B. undatum*, although the aforementioned trends became less obvious.

Scar frequency

Between-site differences in scar frequency (i.e. the 'damage load') were first investigated by graphical analysis, plotting cumulative-frequency distributions (Fig. 44). In *B. undatum*, a pattern emerged showing higher frequencies of light scars at the more heavily impacted sites (Fig. 44a & b). The separation of heavily impacted from other sites was better represented by the data for light scars on the largest whorl (Fig. 44a), while the gradient from light, to moderate, to heavy impact sites was best represented by data for light scars pooled for all three largest whorls (Fig. 44b). For severe scars the pattern was reversed, with scar frequency showing an inverse relationship with fishing pressure (Fig. 44c & d). In *N. antiqua*, an impact-related pattern was not revealed in the light scars (Fig. 44e & f), though a weak pattern did emerge for severe scars on all three largest whorls (Fig. 44h).

Between-site differences in the frequency of light scars were tested by analysis of covariance (ANCOVA), using the MINITAB General Linear Model (GLM) applied to $\log_{10}(x+1)$ transformed frequency data, specifying shell height as the covariate. The test was applied to each of four data sets (*B. undatum* or *N. antiqua*, largest whorl or three largest whorls) and in all cases there were highly significant differences between sites (Table 10) with the interaction term (site * shell height) being non significant ($p > 0.05$).

Table 10. Summary of result of statistical tests comparing scar frequency between sites (not impacts) for *Buccinum undatum* and *Neptunea antiqua* sampled in the Clyde Sea area. Parametric tests could be applied to data for light scars, but only non-parametric tests could be applied to data for severe scars. ANCOVAs specified shell height as the covariate. Numbers in parenthesis show degrees of freedom.

		Buccinum undatum		*Neptunea antiqua*	
Scar Type & Test	Whorls	Test result	p-value	Test result	p-value
Light scars: ANCOVA / GLM	Largest	$F_{4,262} = 24.06$	< 0.001	$F_{5,126} = 7.88$	< 0.001
	3 largest	$F_{4,262} = 21.54$	< 0.001	$F_{5,126} = 5.60$	< 0.001
Severe scars: Mood's median	Largest	$\chi^2 = 20.9$ (4)	< 0.001	$\chi^2 = 11.4$ (5)	< 0.05
	3 largest	$\chi^2 = 39.4$ (4)	< 0.001	$\chi^2 = 11.2$ (5)	= 0.08

A plot of mean frequency with 95% CIs (Fig. 45a, b, e & f) thus gives a good visual representation of the between-site relationships and an *a posteriori* pairwise comparison of means (Tukey test) confirmed that the following differences were statistically significant:

Data set	*Significant differences*
B. undatum, Light scars, largest whorl:	H1& H2 > all others
B. undatum, Light scars, 3 largest whorls:	H1 & H2 > L1 & L2
“ “ “	M1 & L1 > L2
N. antiqua, Light scars, largest whorl:	M2 < H1, H2, M1, L1
N. antiqua, Light scars, 3 largest whorls:	M2 < H1, H2, M1, L1

These result infer that for *B. undatum* the frequency of light scars was significantly greater at heavily fished sites, while for *N. antiqua* frequencies did not reflect the nominal differences in fishing intensity. Furthermore it is clear that little statistical advantage was to be gained by extending the counting of scars from one whorl to three whorls.

For severe scars, data could not be normalised so were subjected to non-parametric analyses. Between-site differences in the frequency of severe scars were tested using Mood’s median test (MINITAB v.12.22) which incorporated a multiple comparison among medians. Significant differences were found when using both data sets (largest whorl, three largest whorls) for *B. undatum* but in only one data set (largest whorl) for *N. antiqua* (Table 10). Such differences were not well visualised in graphical plots analogous to those used for the data on light scars (Fig. 45c, d, g & h), although a satisfactory visualisation was achieved by a schematic representation of the comparison among medians (Fig. 46). It can be inferred that *B. undatum* showed a tendency to have fewer severe scars at heavily fished sites while in *N. antiqua* the frequency of severe scars was not related to fishing intensity.

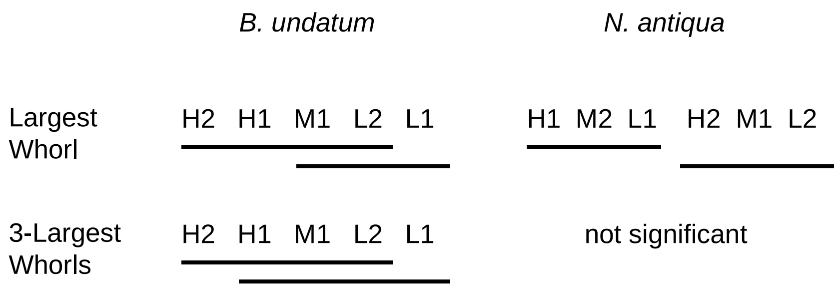


Figure 46. Stylised representation of the relationship between sampling sites in the Clyde Sea area as derived from a multiple comparison among medians (Mood’s median test) applied to data for frequency of severe scars on *Buccinum undatum* and *Neptunea antiqua*. Horizontal bars indicate groups of sites among which the medians were not significantly different. Hence, for the largest whorl in *B. undatum*, site L1 differs from the group of other sites and sites H2 & H1 differ from M1, L2 & L1.

Buccinum undatum

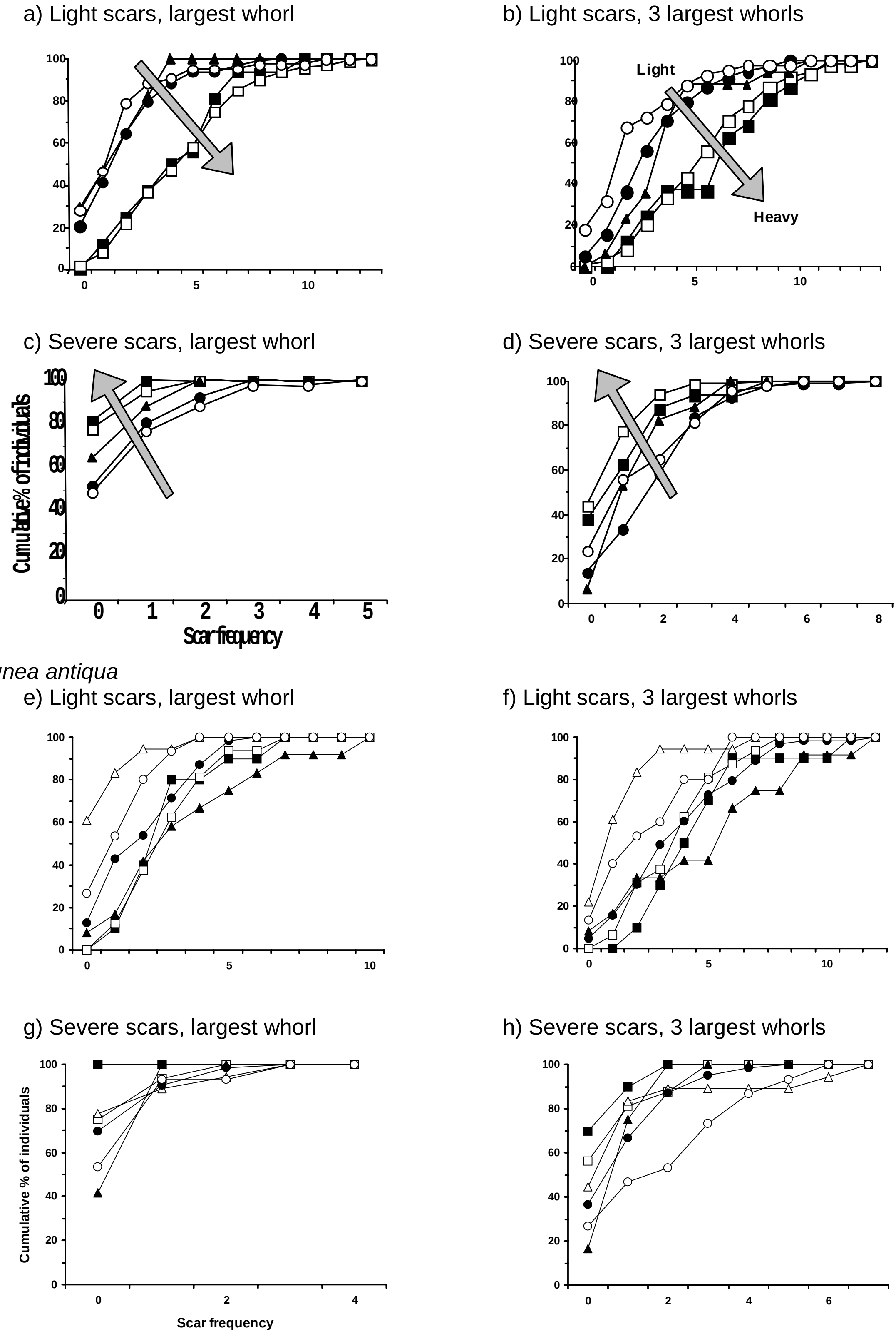


Figure 44. Cumulative frequency distributions for shell scars in two large gastropod species (*Buccinum undatum* and *Neptunea antiqua*) sampled from six sites in the Clyde Sea area representing three nominal levels of fishing intensity: squares = heavy, triangles = moderate, circles = light. Plots to the left are for data solely relating to the largest shell whorl, those to the right are for pooled data from the three largest shell whorls.

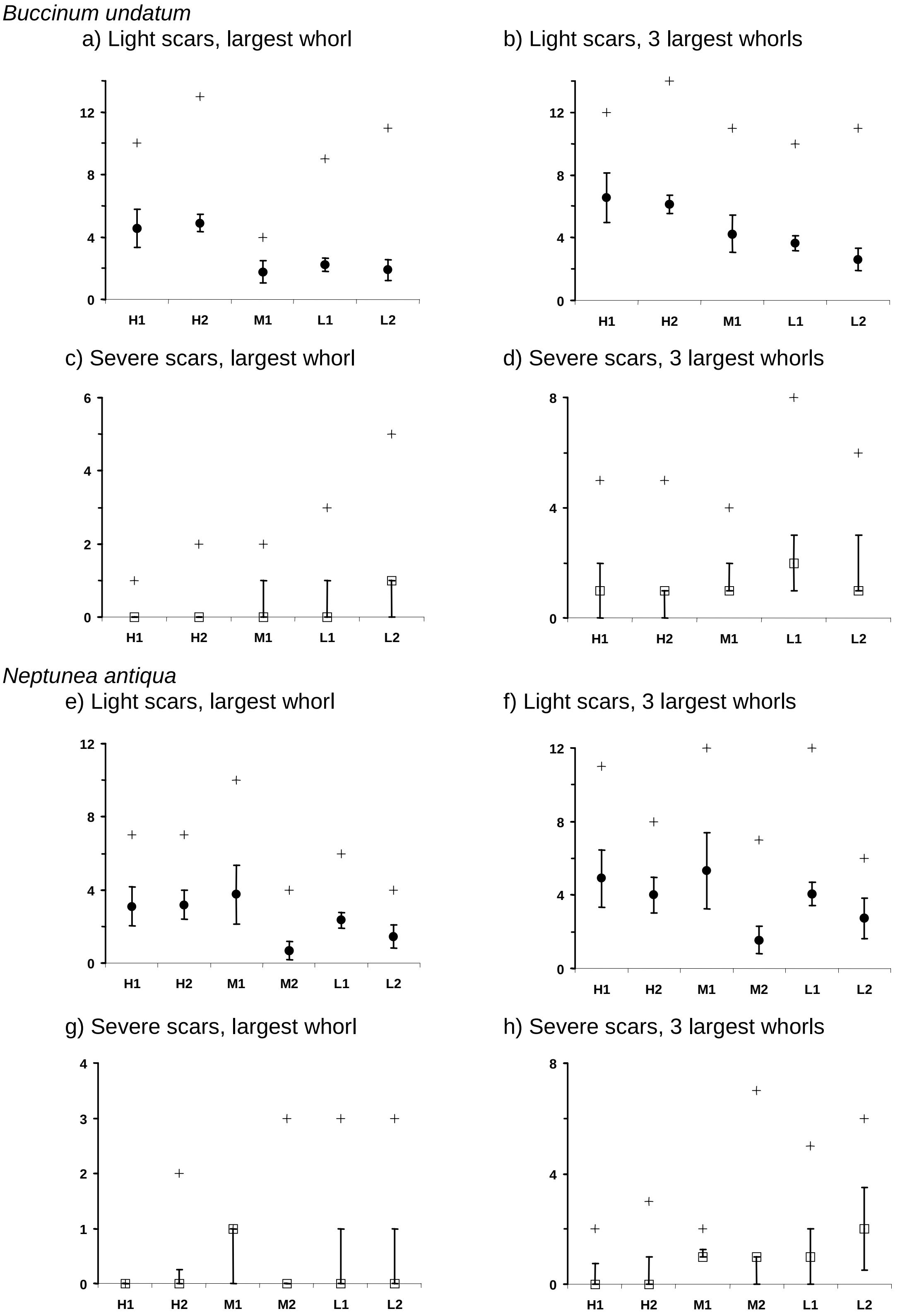


Figure 45. Summary plots characterising the frequency distributions of light and severe scars on the shells of two large gastropod species, *Buccinum undatum* and *Neptunea antiqua*, sampled at six sites in the Clyde Sea area representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = light). Location parameters for light scars are mean ± 95% CI (filled circle) and for severe scars are median (open squares) with inter-quartile ranges. Also, + = maximum frequency.

Starfish *(Asterias rubens)*

A total of 1204 *Asterias rubens* from the Clyde Sea area were inspected for damage. Size-frequency distributions were compared between sites (Fig. 47) and showed site L1 to be anomalous, having a greater proportion of small individuals. Intuitively, smaller individuals were likely to be more susceptible to damage than larger ones, as less force was required to break-off an arm (see also Lawrence, 1992) so it was important to recognise the anomaly at site L1 prior to interpreting the results of the damage assessment. A minimum sample size of 50 animals per site was chosen, so site H1 was excluded from the analyses.

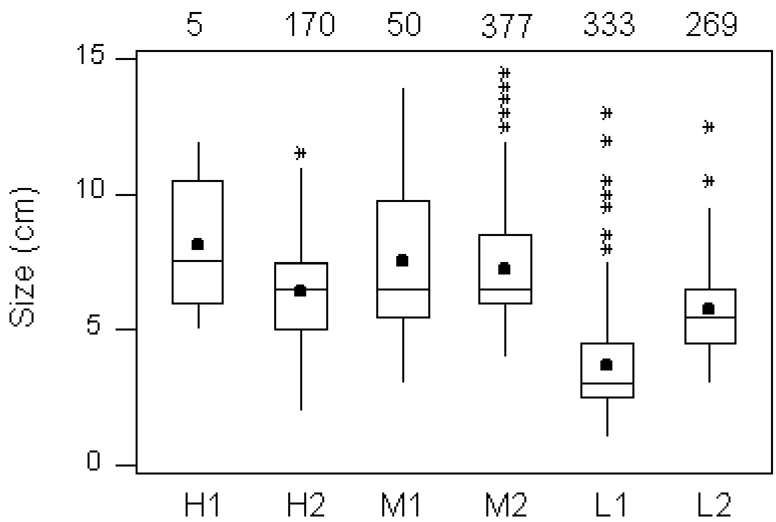


Figure 47. Box and whisker comparison of size-frequency distributions for the starfish, *Asterias rubens*, sampled from six sites in the Clyde Sea area representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = light). Boxes delimit the inter quartile ranges, with cross-bars indicating the median. Whiskers indicate Q1 – 1.5(Q3-Q1) and Q3 + 1.5(Q3-Q1) and * represent outlying points. Filled circles represent means and numbers show sample frequency for each site.

A prerequisite for a valid damage assessment was that the sampling method should not cause extensive damage to the sample. Only 3.5% of the starfish sampled showed fresh autotomy wounds (indicating arms lost as a result of sampling), so further analysis was considered valid. The effect of sampling damage could be eliminated from the original data by a simple combination of some damage categories, thus obtaining a *derived* data set that reflected the state of the individuals immediately prior to sampling. This was achieved as detailed in the following scheme:

Original data		Derived data
Complete arms (excluding any regenerating) + Arms with open wounds at autotomy plane	=	Entire arms
Arms with healed wounds at autotomy plane	=	Missing arms
Regenerating arms	=	Regenerating arms
Intact arms showing past scars or abrasion	=	Scarred arms

Data were examined at three progressively more detailed levels (below) and interpreted with due regard to the size anomaly in animals from site L1:

i) Presence/absence of damage to ***individuals*** *(Table 11)*

Setting aside the anomalous site (L1), the proportion of individuals showing damage increased with increasing fishing impact. This was best indicated by scoring damage to individuals on a presence / absence basis (the far right column in Table 11) although the trend was clearly reflected when considering individuals having one or more regenerating arms. Notably fewer animals at heavily fished sites had a full complement of entire arms. Site M2 showed an increased proportion of animals with scarred arms and this is most likely to be attributable to the presence of high quantities of dead bivalve shells at this site. These tend to fill up the cod end of trawls, greatly increasing the mechanical abrasion experienced by the catch during hauling.

Table 11. Damage assessment for the starfish *Asterias rubens* sampled from five sites in the Clyde Sea area representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = light). The four descriptive categories are derived from original damage observations (see text). Figures are expressed as the percentage of individuals in each sample showing each damage category.

Site	All arms Entire	Missing Arms	Regenerating Arms	Scarred Arms	Damage in any category
H2	84.1	1.2	14.7	5.3	20.6
M1	92.0	2.0	8.0	4.0	12.0
M2	90.7	1.6	7.7	8.8	17.0
L1	80.8	4.2	15.6	5.4	22.8
L2	93.3	0.7	5.9	3.3	9.7

ii) Presence/absence of damage to ***arms*** *(Table 12)*

Calculating damage indices on the basis of the expected number of arms in the sample rather than the number of individuals had a diluting effect on the trends observed in section *i)* above. This is undesirable for this particular set of data where the general level of damage is low.

However, in a situation where nearly all the animals showed some sort of damage, there may be an advantage in relating damage indices to ‘number of arms’ rather than ‘number of animals’.

Table 12. As Table 11 but with figures expressed as a percentage of the expected number of arms in each sample.

Site	Entire Arms	Missing Arms	Regenerating Arms	Scarred Arms	Damage in any category
H2	96.24	0.24	3.53	1.06	4.82
M1	97.20	0.40	2.40	0.80	3.60
M2	97.88	0.37	1.75	2.60	4.72
L1	95.32	0.90	3.84	1.08	5.83
L2	98.59	0.15	1.26	0.74	2.16

iii) The extent of damage to individuals (Figure 48)

From the point of view of rapidly collecting data in a field situation, the simplest data to record are the number of entire arms or the number of regenerating arms. Inherent in each count is a scalar measure (0 to 5) of the extent of damage to each individual. In the case of counts of entire arms, data should be adjusted to account for arms lost during sampling. Such data were selected from our derived data set and tabulated to give the percentage frequency at each site of individuals with 0, 1, 2, 3, 4 or 5 entire or regenerating arms. When displayed graphically (Fig. 48) these data enable a clear and simple comparison between sites. Allowing for the anomalous site L1, the damage load of individuals is seen to be highest at the most heavily fished site. Here, the proportion of individuals with one regenerating arm (11.8%) was nearly double that at the M1, M2 and L2 sites (6.0%, 6.6% & 5.6%, respectively). However, the most severe damage was recorded at site M1 where some animals only had two entire arms. The two data sets show similar results, though data on regenerating arms would be simpler to collect.

a) b)

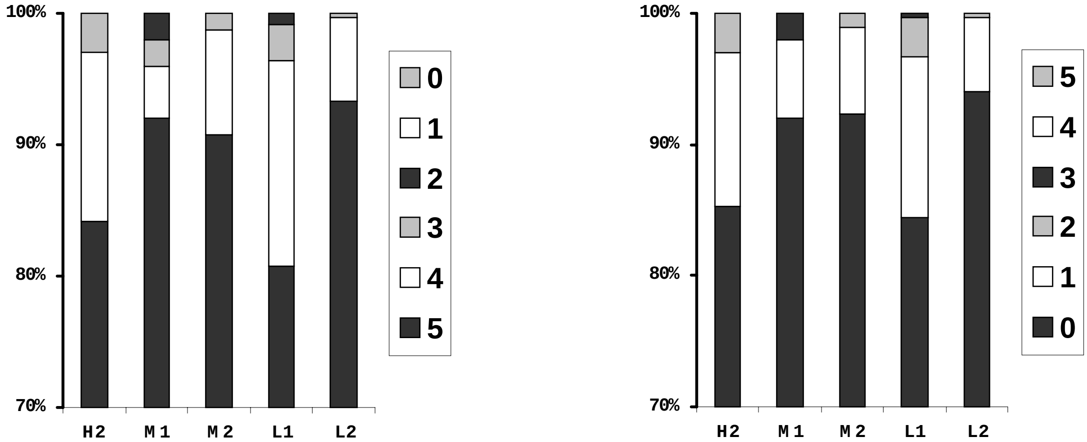


Figure 48. Two ways of showing the damage load of starfish. a) percentage of the sample having ‘n’ intact arms, b) percentage of the sample having ‘n’ regenerating arms.

4.4.1.2. Aegean

In the Aegean, damage assessment was carried out on the echinoderm fraction of the catch, during the consecutive otter trawling experiment at Gouves. A total of 14 echinoderm species were identified in the first eight trawls, including the two most common ophiuroids (*Ophiocantha setosa* and *Ophiura ophiura*), seven asteroids (the starfish *Astropecten irregularis, Luidia sarsi, L. ciliaris, Echinaster sepositus* and *Marthasterias glacialis*, and the cushion stars *Sphaerodiscus placenta* and *Anseropoda placenta*), three echinoids (short-spined *Sphaerechinus granularis*, long-spined, *Centrostephanus longispinus* and thick-spined *Cidaris cidaris*), one crinoid (*Antedon mediterranea*) and one large holothurian (*Stichopus regalis*).

The incidence of damage to the 14 species studied is shown in Table 13 which details the number of damaged individuals for each category (note that *severely damaged* is a subset of *damaged*) of each species as well as by percentage of the total in the sample. The two ophiuroid species both had high incidences of *damage*, (85% of *O. setosa* and 97% of *O. ophiura*). However, in terms of *severe damage* (three or more arms missing) their respective values were 10% and 7%. The ophiuroids are known as brittlestars because of their tendency to break under mechanical strain or to autotomise their arms. *Ophiocantha setosa* has very brittle arms, but they are very flexible. Most of the damage observed to this species was to the arm tips. *Ophiura ophiura* is a larger species living on the sediment surface or slightly buried. Its arms are less flexible with the major axis of movement in the horizontal plane and arms are thus prone to breakage if moved in the vertical plane. Although experiencing less *severe damage* it had a greater amount of ‘half arm’ *damage* than *O. setosa*. The average occurrence of arm regeneration of *O. ophiura* was 9.9%, ranging from 4-20%. This could be considered the minimum ‘background’ level of regeneration for this species through accidental breakage/disturbance/predation, although it may be underestimated as some regenerating limbs could have been broken-off during collection and therefore not measured.

All specimens of the starfish *E. sepositus* caught were undamaged. This species was caught in low numbers. Generally speaking, the individuals were small, hardy, with some degree of flexibility and therefore not easily damaged in the trawl. *Luidia ciliaris* had the greatest amount of *damage* due to trawling (91.7% of sample). This species has seven arms and is larger that its congener *L. sarsi*. It was easily damaged and lost arms in a process starting with a tear on either the dorsal or lateral side of the arm perpendicular to its horizontal axis which may leave the arm partially attached for some time. The percentage occurrence of *severe* *damage* in the two *Luidia* species was similar (25-26% of sample). This was amongst the highest for the echinoderms. *Astropecten irregularis* exhibited lower rates of *damage* (50.8% of sample), but still had significant levels of *severe damage*. Catches of this species mostly comprised small individuals and in a population of larger individuals a higher degree of *damage* may have been more evident. *Marthasterias glacialis* was one of the largest asteroids but relatively few were caught. It is spinous and also mucilagenous and was often twisted when caught and arms appeared to be autotomised rather than torn off.

Table 13. Damage assessment for echinoderms caught by otter trawls in the Aegean Sea. Data includes total number of individuals in the sample, number of *damaged* and *severely damaged* and percentage frequency of the two damage categories in the sample. Data are pooled from 8 consecutive trawls.

Species	Number	Damaged	Severely Damaged	Percentage Damaged	Percentage Severely Damaged
Ophiocantha setosa	371	314	39	84.6	10.5
Ophiura ophiura	361	350	26	97.0	7.2
Astropecten irregularis	130	66	26	50.8	20.0
Luidia sarsi	88	69	23	78.4	26.1
Luidia ciliaris	12	11	3	91.7	25.0
Echinaster sepositus	10	0	0	0	0
Marthasterias glacialis	6	4	1	66.7	16.7
Sphaerodiscus placenta	14	0	0	0	0
Anseropoda placenta	90	61	17	67.8	18.9
Sphaerechinus granularis	29	8	4	27.6	13.8
Centrostephanus longispinus	40	40	4	100	10.0
Cidaris cidaris	50	29	2	58.0	4.0
Antedon mediterranea	19	19	11	100	57.9
Stichopus regalis	8	0	0	0	0

The two cushion stars (starfishes with short arms but larger diameter central body area), *Sphaerodiscus placenta* and *Anseropoda placenta*, had quite different morphologies which accounted for their different damage rates. *Sphaerodiscus placenta* was the smaller and thicker with a small degree of flexibility and was undamaged. *Anseropoda placenta* was larger, flatter and more flexibile. It was easily torn across the arms or central area; something which did not happen in *S. placenta* because of its greater thickness.

The different degree of damage sustained by the three echinoids was related to their different body forms. All received damage to the spines, *C. longispinus* had the longest, thinnest and most brittle spines and 100% *damage* was recorded (i.e. all individuals had sustained broken spines). *Cidaris cidaris* sustained less *damage* (58% of sample), the less dense but much thicker spines tending to be shed rather than snapped or broken (individuals becoming ‘shaved’). *Sphaerodiscus granularis* had dense short spines, which were more difficult to break, and consequently it sustained the least amount of overall *damage* (27%). *Severe damage* to the echinoids was 4-14% by fatal crushing of some kind, when the protection afforded by the spines had been lost or the rigidity of the test overwhelmed.

All crinoids of the species *A. mediterranea* were *damaged*, with 58% exhibiting *severe damage*. Crinoids are among the most brittle echinoderms and their arms or basal cirri are easily damaged. This species is found clinging to objects on the sediment surface and is similar to the species *Leptometra phalangium* found in the control area adjacent to the fishing lane at Dia Island, but cleared from the trawling lane by commercial fishing.

Stichopus regalis is a large holothurian and all found were intact and in good condition. This species has a tough skin and hydro-elastic body and as such is resistant to mechanical damage. If left for a long time on deck, packed with other individuals or under the sun, they extruded their intestines or, in rare but more severe cases, sloughed their skins and broke into pieces. This damage, however, was a post-trawling impact and not due to the mechanical action of the trawl *in situ.*

In the Aegean the echinoderms where the easiest group to assess for damage, although not directly comparable with some of the species examined in Scotland. The Aegean study showed what kind of mechanical damage was inflicted to the different species – breakage of hard/brittle parts, tearing of softer parts and general crushing injuries. It was evident that species suffer differential damage related to their morphology, whilst different size classes may also exhibit different degrees of damage. Starfish and brittlestars are able to autotomise and regenerate arms but it was not known what degree of damage was due to autotomy and what was due to physical damage. However, this may be an academic argument because after trawling the animal is still damaged. Certainly the asteroids and ophiuroids have the potential to regenerate damaged arms, although much energy must be used up in this process and those individuals may be at higher risk than others to predation at this time. A broader question concerns the survival of damaged individuals and to what extent a damaged individual may be able to survive if returned to the sea – this concerns not just physical damage, but also exposure to air. Echinoids with broken tests will not survive and assuming that broken spines and stress from passage in the trawl and on deck are not lethal, this was the only taxon where direct mortality could be measured (severe damage was effectively a measure of mortality).

In Summary – Damage Assessment

Clyde Sea

Large gastropods

- Recent damage (i.e. damage to the growing edge of the shell) was deemed to have been caused by the sampling gear, so should be excluded from any assessment of damage load attributable to commercial fishing gear.
- *Buccinum undatum* proved a better indicator species of trawl damage than *Neptunea antiqua*.
- The frequency of light scars increased with fishing intensity but that of severe scars decreased.
- There was no appreciable effect on the analyses of reducing the number of shell whorls over which scar frequency was counted. Little was gained by considering damage to more than the largest whorl.

Starfish

- Damage assessment of starfish offers a promising method for discrimination of heavily fished sites from other sites.
- There are certain limitations in the application of the method. Comparisons between populations with highly different size-frequency distributions need to be addressed with caution as susceptibility to damage varies with body size.
- Careful consideration must be given to the types of damage recorded. Damage caused by sampling should be quantified, as high levels may invalidate further damage analyses.
- Scoring damage on a presence / absence basis or simply counting the number of regenerating arms gave similar interpretations as analyses based on a more involved categorisation of damage.

Aegean

- Direct investigations of gear-caught fauna allows assessment of susceptible fauna and the mechanisms of damage. This may lead to the identification of key indicator species.
- Further research should be taken into the survivability of fauna with respect to the lethality of particular types of damage.

4.4.2 Community Analysis - assessment of the variability of fauna (Task 4, Sub Tasks 2)

4.4.2.1 Clyde Sea

A total of 91 taxa were recorded in the 30 beam trawl samples taken at the six study sites in the Clyde Sea area. Some of these taxa were excluded from the analyses (e.g. most of the gadoid fishes) as they were not true representatives of the epibenthic megafauna, leaving 70 taxa in 43 Families, 20 Orders and 11 Classes (Appendix III-A). Catch composition was analysed to establish the community structure at each site and samples compared to examine variability within and between sites. Data were analysed using a suite of routines available in the PRIMER software package. Where required, data were standardised (effectively turned into percentage counts for each sample) to control for the slight between-sample variability in the area swept by the trawl (see methods section).

Univariate analyses

The PRIMER routine ‘DIVERSE’ was applied to a species-by-samples matrix containing abundance data for 70 species in each of 30 trawl samples from the Clyde Sea area. Six univariate measures or indices commonly used in community analysis were calculated for each sample, namely the number of species (S), the number of individuals (N), Margalef’s richness (d), the Shannon-Weiner Diversity index (H′), Pielou’s Evenness (J′) and Simpson’s Dominance (λ). The indices were compared graphically, plotting mean and 95% confidence intervals for the indices at each site (Fig. 49). For each index there were significant differences between sites (ANOVA; $p<0.001$ for all indices except the number of individuals (N) where $p<0.01$). Site L1 was again seen to be anomalous, with a greater number of species than all other sites (leading to an elevated index of richness) and significantly more individuals than site H1. Three indices separated heavily fished sites from other sites, showing them to have a lower diversity (H′) and evenness (J′) and a higher dominance (λ). This suggests that communities at these sites are stressed resulting in a few species dominating the fauna at H1 and H2. However, there is no indication as to which elements of the communities differ.

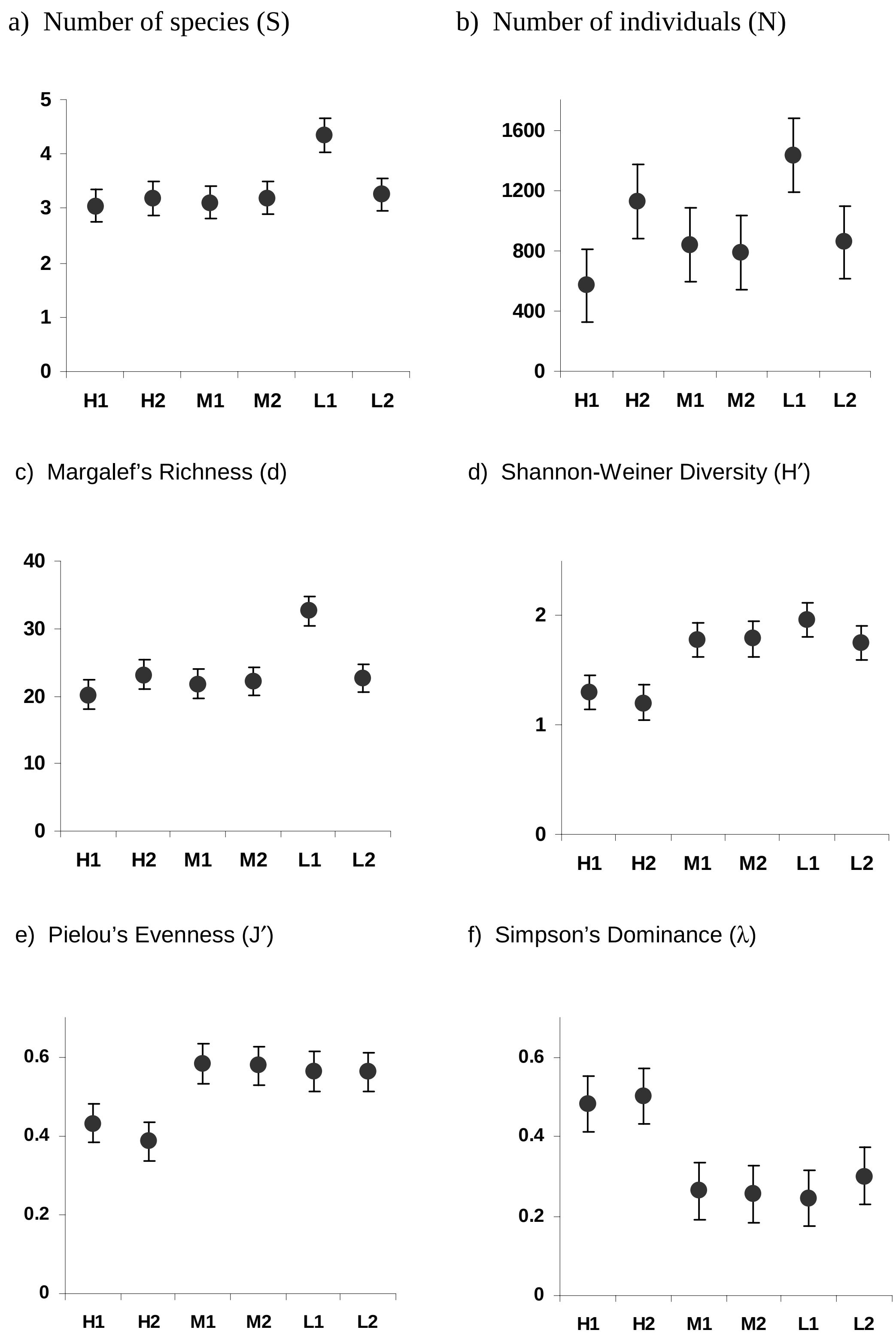


Figure 49. Comparison between univariate measures and indices derived from abundance data for epibenthic megafauna collected by small beam trawl at six sites in the Clyde Sea area representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = light). Plotted points are means for 5 samples at each site, error bars show 95% CI calculated assuming a common variance (Warwick & Clarke, 1994, p. 6-1; Zar, 1996, p.191)

Multivariate Analyses

One of the most effective methods available in PRIMER to visualise relationships between samples and sites uses a technique known as non metric multi-dimensional scaling (MDS). A full explanation is not within the remit of this report, but the concept is simple. Briefly, abundance (or biomass) data are used to derive a measure of the similarity between samples (e.g. Bray-Curtis similarity coefficient) which are displayed in a similarity matrix (Fig. 50). These coefficients are converted to ranks (hence the term '*non metric*'), the most similar samples being ranked as 1, the next most similar as 2, and so on. Points for each sample are then positioned in a plot (2- or 3- dimensional) such that the distance between points reflects their rank similarity. In this way, the most similar samples are positioned closest together while the most dissimilar samples are farthest apart.

Abundance data

	Sample			
Species	W	X	Y	Z
A	17	0	0	0
B	21	0	0	13
C	16	25	0	18
D	0	19	35	17
E	0	34	43	12
F	0	0	0	0

⇒⇒⇒

Bray-Curtis Similarity Matrix

Sample	W	X	Y	Z
W	-			
X	24.2	-		
Y	0.0	67.9	-	
Z	50.8	68.1	42.0	-

⇓
⇓
⇓

Rank Similarity Matrix

Sample	W	X	Y	Z
W	-			
X	5	-		
Y	6	2	-	
Z	3	1	4	-

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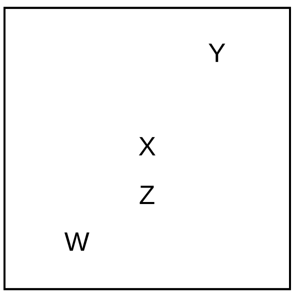


MDS plot

Figure 50. Schematic illustration of the concept and construction of a non-metric MDS plot.

A non-metric MDS plot was constructed for the 30 trawl samples using species abundance as the raw data. The plot (Fig. 51a) shows several groupings of sample points, the points within each group usually being from a single site, showing that differences between sites were greater than differences within sites. However, the basic MDS plot lacks any sense of the empirical values in the similarities between sites, values that were evident in the Bray-Curtis similarity matrix. These values can themselves be displayed in the more familiar form of a dendrogram (Fig. 51b) which is the graphical output of a cluster analysis (‘CLUSTER’ routine in PRIMER). Here, the similarity between samples or groups of samples can be read-off from the dendrogram, but while it clearly indicates clusters of samples, it is difficult to visualise the relationship between the different clusters.

The benefits of MDS plots and dendrograms can be combined in a single illustration by superimposing ‘contours’ of similarity on the MDS plot (Fig. 51c). The set of samples to be enclosed by a particular contour is simply determined by drawing datum lines across the dendrogram (Fig. 51b), in this case at 70% and 60% similarity. The resulting image is uncomplicated and easier to interpret than either of the source images.

In analyses of communities in the Clyde Sea area, sites H1 & H2 were close together on the MDS plot, indicating they were more similar to each other than to the remaining sites. Sites M1 and L1 were clearly distinct, with the dendrogram showing site L1 to be highly dissimilar to all other sites. Sites M2 and L2 appeared quite similar in the contoured MDS plot, something not unexpected as they were geographically adjacent (see Fig. 1). At the 70% similarity level, samples from these two sites formed two clusters but these were not site specific; one cluster having 3 samples from site L2 while the other had all 5 samples from M2 and two from L2. The splitting of the L2 samples into different clusters became significant in the light of our observations of the activity of fishing vessels at site L2. The site was chosen on the understanding that fishing was prohibited in the area. In fact the prohibition only applied to the northern half of the site (see Fig. 23), the southern half being open to fishing, but on a ‘restricted access’ basis. Field records showed that the three L2 samples which formed a single cluster were taken in the ‘prohibited’ area whilst the two that clustered with the M2 samples were taken in the ‘restricted access’ area. This observation hints that MDS analysis of selected biota might be extremely powerful at discriminating between fished and unfished areas.

Sites M2 and L2 were clearly dissimilar to their partner sites M1 and L1, showing that the moderate and low impacted sites do not necessarily group together according to their nominal impact level. It must be recognised that low impact sites selected from geographically distinct areas are not likely to be similar in their faunal composition. However, the act of disturbing such sites (by fishing) will be likely to result in a reduction in their biodiversity, making them more similar and bringing them closer together on an MDS plot. A good analogy would be to consider the long-term effect of repeated ploughing on two very different wildflower meadows. As the more specialist species and those intolerant to disturbance die out, the species composition of the two meadows will become more and more similar until both are dominated by the same generalist species that are tolerant to disturbance. The characteristic effect of disturbance is, therefore, to reduce dissimilarities between sites, causing them to become more homogeneous.

The contoured MDS plot proved to be a highly effective method of assessing the relationships between samples and sites. It had further advantages in that it was robust in the face of quite severe ‘data reductions’. Figure 52 shows the effect of progressively reducing the taxonomic level to which organisms were identified (alternatively called ‘aggregation’ of data). The original spatial pattern in the MDS of Fig. 51 remained unchanged when identification was reduced to the Family level (Fig. 52a), was slightly altered at the Order level (Fig. 52b) and only became indistinct at the Class level (Fig. 52c). In practice, this shows that it is not necessary to identify everything to species level; identifying taxa to Family level would appear to be sufficient for this application.

A second type of data reduction was modelled by converting the abundance data (in the species-by-samples data matrix) from absolute frequencies to a simple presence / absence score, i.e. taxa that were present in a sample were scored as ‘1’ while those that were absent were scored as ‘0‘. This had an appreciable effect on the MDS (Fig. 53), which showed a significant loss of information. This is an important outcome for studies of epibenthic megafauna, demonstrating they do not follow the paradigm of studies based on meiofaunal taxa (notably nematodes, Clarke & Warwick, 1994) where environmental stress tends to lead to species substitutions and consequently the reduction of abundance data to a presence/absence score has little effect on the MDS plot.

Having established that there were differences between sites, the data were examined further to see which taxa (if any) contributed most to these differences. The PRIMER routine ‘SIMPER’ (“similarity percentages”) performs a pairwise comparison of samples, computing an average similarity within a site and an average dissimilarity between sites. It further computes the contribution that each species makes to the average similarity (or dissimilarity) and lists these in rank order. Figure 54 shows output from this analysis in an extract comparing site L2 with M2. The top five species contributed a cumulative 48.1% of the average dissimilarity, with the gastropod *Aporrhais pespelecani* being the most important, contributing 15.4%. So, it was possible to identify which species were most important in determining the extent of similarity (or dissimilarity) between sites.

In a similar way it was possible to identify which species contributed most to the dissimilarities between the nominal impact levels by repeating the SIMPER analysis but specifying 'impact' (H, M & L) rather than 'site' (H1, H2, M1, M2, L1, L2) as the factor for comparison. Extracts from the output of this analysis (Fig. 55) showed that *Aporrhais pespelecani* was ranked either first or second in terms of its contribution to the average dissimilarity for each of the pairwise comparisons between impact levels (HxM, HxL, MxL).

A 'compound summary' of these multivariate analyses can be presented in a simple graphic, overlaying the now familiar MDS plot with a bubble plot where the size of the bubble reflects the relative abundance of *A. pespelecani* in each of the 30 trawl samples (Fig. 56). There was a significant positive correlation between the level of fishing intensity at a site and the abundance of *A. pespelecani*, suggesting that it might be a suitable indicator species of fishing intensity. It is important to recognise that a causal relationship is not proved by this analysis. That would require further detailed study of the autecology of this species.

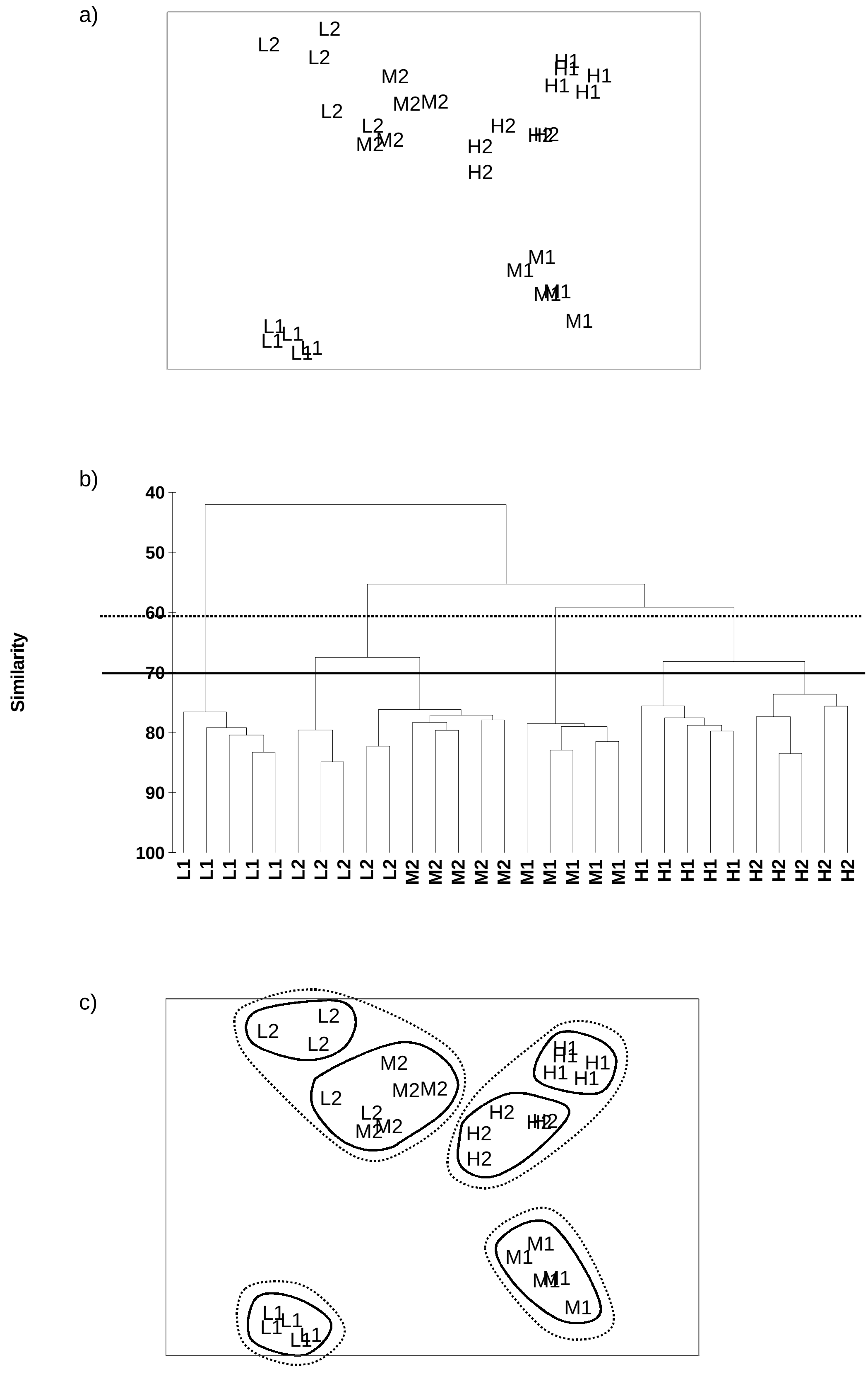


Figure 51. Stages in producing a contoured MDS plot representing similarities (or differences) between 30 samples of epibenthic megafauna taken from six sites (H1, H2, M1, M2, L1, L2) in the Clyde Sea area representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = light). a) basic MDS plot, distance between samples representing their similarity, b) dendrogram showing clusters of samples at specified similarities (60% dotted line, 70% solid line), c) clusters superimposed on the MDS, effectively illustrating 60% and 70% similarity ‘contours’.

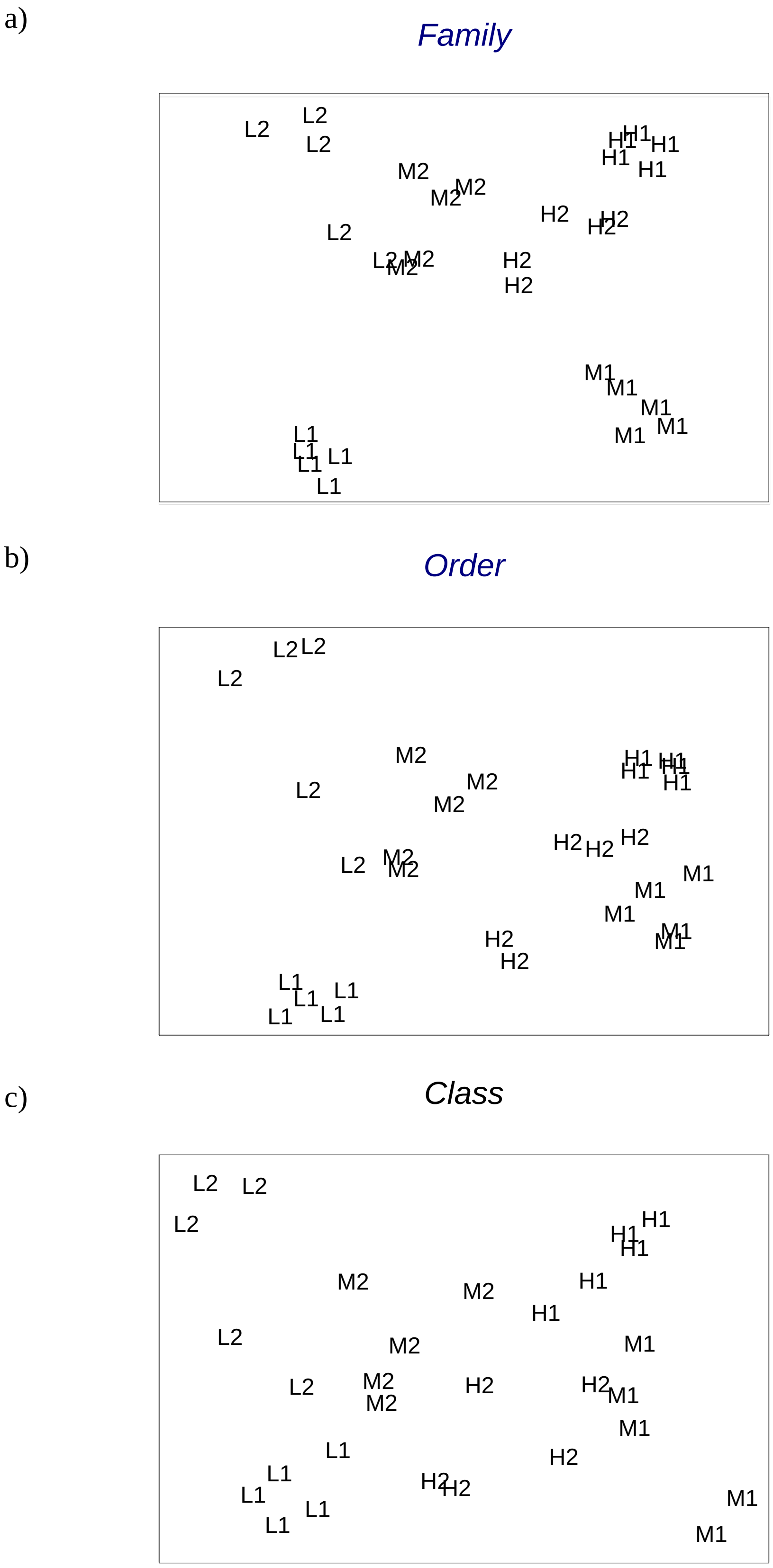
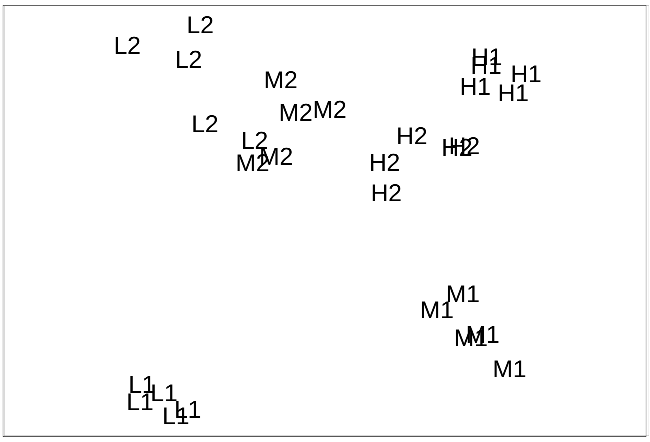


Figure 52. Effect on MDS plot of progressively reducing taxonomic resolution used to identify specimens from 30 samples of epibenthic megafauna taken from six sites in the Clyde Sea area representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = light).

a)



b)

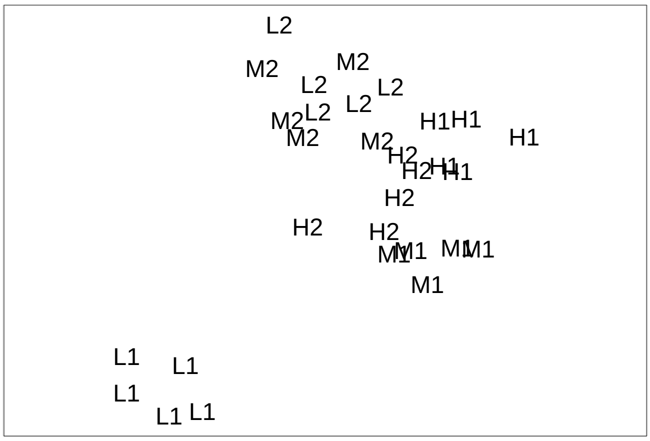


Figure 53. Effect on an MDS plot of reducing abundance data (a) to presence-absence data (b) for 30 samples of epibenthic megafauna taken from six sites in the Clyde Sea area representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = light).

SIMPER
Similarity Percentages - species contributions

Parameters
Standardise data: Yes
Transform: Square root
Cut off for low contributions: 90.00%
Factor name: Site *Factor groups:* H2, H1, M1, M2, L1, L2

Groups L2 & M2

Average dissimilarity = 36.10

Species	Group L2 Av.Abund	Group M2 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Aporrhais pespelecani	105.00	299.00	5.56	2.16	15.39	15.39
Ophiura ophiura	175.00	127.00	4.50	1.75	12.46	27.85
Munida rugosa+sarsi	303.00	170.00	3.42	2.12	9.49	37.34
Aphrodita aculeata	45.80	6.00	2.23	4.24	6.18	43.53
Calocaris macandreae	19.40	2.80	1.66	1.09	4.60	48.13
Asterias rubens	66.40	43.00	1.48	1.37	4.10	52.23
Liocarcinus depurator	17.40	44.20	1.42	1.53	3.93	56.15
Pseudamussium septemradiatum	15.60	2.20	1.32	1.29	3.67	59.82
Dichelopandalus bonnieri	45.20	31.20	1.19	1.44	3.28	63.10
Buccinium undatum	4.40	0.20	1.03	2.97	2.86	65.96
Pandalus montagui	6.20	11.00	0.94	1.32	2.61	68.57
Lumpenus lampretaeformis	0.00	2.80	0.87	3.13	2.42	70.99
Processa sp.	3.40	0.60	0.85	1.46	2.35	73.34
Amphiura chiajei	3.20	0.40	0.81	1.03	2.24	75.58
Nephrops norvegicus	5.40	9.80	0.72	1.13	1.98	77.57
Aequipecten opercularis	2.40	0.60	0.72	1.05	1.98	79.55
Carcinus maenas	2.40	5.60	0.63	1.36	1.73	81.29
Pagurus bernhardus	22.80	13.80	0.61	0.88	1.70	82.98
Psammechinus miliaris	1.40	0.60	0.59	1.04	1.62	84.61
Pleuronectes platessa	1.40	2.80	0.55	1.21	1.51	86.12
Liocarcinus holsatus	0.60	1.60	0.49	1.39	1.36	87.48
Hippoglossoides platessoides	0.00	1.20	0.48	1.18	1.34	88.82
Spirontocaris lilljeborgi	1.00	0.20	0.46	1.19	1.27	90.10

Figure 54. Extract of an analysis generated by the SIMPER (‘similarity percentages’) routine of the PRIMER statistical package calculating the average dissimilarity between **sites** based on a species-by-samples data matrix recording the abundance of epibenthic megafauna in 30 samples taken from six sites in the Clyde Sea area representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = light).

SIMPER
Similarity Percentages - species contributions

Parameters

Standardise data: Yes
Transform: Square root
Cut off for low contributions: 50.00%
Factor name: Impact *Factor groups:* H, M, L

Groups H & M

Average dissimilarity = 48.33

Species	Group H Av.Abund	Group M Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Turritella communis	5.60	183.30	5.42	1.27	11.20	11.20
Aporrhais pespelecani	523.90	231.00	4.83	2.11	9.99	21.19
Ophiura ophiura	138.90	69.80	4.12	1.26	8.53	29.72
Munida rugosa+sarsi	3.20	89.60	3.73	1.20	7.71	37.43
Dichelopandalus bonnieri	45.50	15.90	2.97	1.50	6.15	43.58

Groups H & L

Average dissimilarity = 63.94

Species	Group H Av.Abund	Group L Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Aporrhais pespelecani	523.90	59.60	10.06	4.26	15.73	15.73
Munida rugosa+sarsi	3.20	186.40	6.04	1.47	9.44	25.17
Ophiura ophiura	138.90	273.10	5.07	1.45	7.94	33.11
Ophiura albida	0.80	240.00	4.38	0.96	6.85	39.96
Turritella communis	5.60	100.60	2.87	1.54	4.49	44.45

Groups M & L

Average dissimilarity = 55.55

Species	Group M Av.Abund	Group L Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Aporrhais pespelecani	231.00	59.60	5.30	2.28	9.54	9.54
Turritella communis	183.30	100.60	4.89	1.24	8.80	18.34
Ophiura ophiura	69.80	273.10	4.34	1.52	7.82	26.16
Munida rugosa+sarsi	89.60	186.40	4.33	1.45	7.80	33.96
Ophiura albida	0.10	240.00	4.14	0.95	7.45	41.41

Figure 55. As Fig. 54, but calculating the average dissimilarity between **impacts** (i.e. nominal level of fishing intensity).

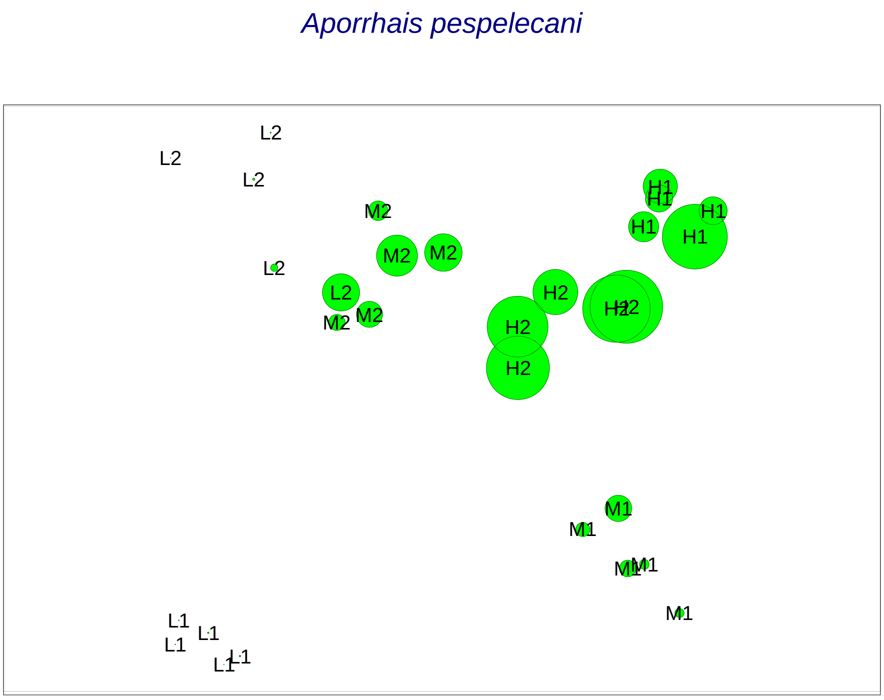


Figure 56. MDS plot as in Fig. 51a, overlaid by a bubble plot depicting the relative abundance of the gastropod *Aporrhais pespelecani* in each of the 30 trawl samples.

4.4.2.2 Aegean

The total number of epibenthic megafaunal taxa recorded in the Agassiz trawl samples from Dia Island and the Gouves experimental area, were 127 and 173 respectively. This excludes infaunal and pelagic taxa caught incidentally in the samples. Catch composition was analysed to establish the community structure in each area and to assess variability within and between the specific sampling sites. The sites were assigned acronyms as follows. At Dia Island: FL-IN = inside the commercial fishing lane, FL-OUTN = control site outside and to the north of the fishing lane, FL-OUTS = control site outside and to the south of the fishing lane. At Gouves: EXP-T = experimentally trawled area, EXP-C control area and EXP-FL commercial fishing lane. Catch data (abundance and biomass, standardised to a swept area of 1000 m^2) were analysed using a suite of routines available in the statistical package PRIMER.

Univariate analyses

The PRIMER routine ‘DIVERSE’ was used to calculate the number of species (S), the number of individuals (N), Margalef’s richness (d), the Shannon-Weiner diversity index (H′), Pielou’s evenness (J′) and Simpson’s dominance (λ) for each sample. Biomass was also calculated for each sample. A series of ANOVAs were used to test for differences in these indices between sampling periods, with the significance values from these tests being presented in Table 14 for Dia Island, and Table 15 for the Gouves experimental area. A graphical comparison of the indices (except Simpson’s dominance) over the different sampling periods is also presented (plotting mean and 95% confidence intervals) for Dia Island (Fig. 57) and the Gouves experimental area (Fig. 58).

In the Dia Island area there was little difference between sites in the community indices calculated for the closed fishing season (Sept. 1999 and Sept. 2000) or early in the open fishing season (Nov. 1999). The only exception to this was in Sept. 1999 when Margalef’s richness index showed a significantly greater value at the southern control site (FL-OUTS). However, towards the end of the fishing season (April 2000) there was a highly significant difference in the number of species, and a significant difference in the species richness (Margalef’s index), again due to these indices having greater values at FL-OUTS (Table 14 & Fig. 57). At this time, abundance and biomass were noted to be substantially greater at all three sites than during other sampling periods (Fig. 57), and the Shannon-Weiner diversity index (H′) and Pielou’s evenness (J′) were noted to be lower (by approx. 30% in comparison with Sept. 1999 and Sept. 2000).

Table 14. Significance values (P) for ANOVA tests on seven univariate indices of community structure applied to epibenthic megafauna sampled from three sites in the Dia Island area (FL-IN, FL-OUTN and FL-OUTS) over four sampling periods. Shading indicates occasions when there were significant differences between the sites, lighter shading for P<0.05, darker shading for P<0.01. † Indicates sampling periods during the closed fishing season.

Index	†Sept. '99	Nov. '99	April '00	†Sept. '00
No. of species	0.069	0.369	0.006	0.215
Abundance	0.281	0.122	0.484	0.902
Biomass	0.986	0.153	0.339	0.733
Margalef	0.019	0.415	0.013	0.266
Shannon	0.123	0.589	0.137	0.611
Pielou	0.176	0.196	0.266	0.787
Simpson	0.142	0.625	0.218	0.692

Table 15. Significance values (P) for t-tests on six univariate indices of community structure applied to epibenthic megafauna sampled from two sites in the Gouves experimental area (EXP-T and EXP-C) over four sampling periods. 'April 1' and 'April 2' refer, respectively, to samples taken immediately before and after experimental trawling. In addition, Sept.* gives P-values of ANOVA tests when samples from the commercial fishing lane (EXP-FL) were also included in the analysis. Shading indicates occasions when there were significant differences between the sites, lighter shading for P<0.05, darker shading for P<0.01. † Indicates sampling periods during the closed fishing season. (All samples were taken in the year 2000)

Index	April 1	April 2	†June	†Sept.	†Sept.*
No. of species	0.104	0.341	0.007	0.011	0.011
Abundance	0.214	0.088	0.006	0.024	0.001
Biomass	0.370	0.065	0.113	0.240	0.050
Margalef	0.119	0.935	0.166	0.024	0.034
Shannon	0.558	0.804	0.145	0.028	0.018
Pielou	0.877	0.523	0.965	0.483	0.796

In the Gouves area, none of the indices showed a significant difference between the experimental trawling site (EXP-T) and the control site (EXP-C) either before or immediately after (24 hrs) experimental trawling (columns 'April1' and 'April2' in Table 15). However, two months later (June), highly significant differences were evident between these two sites in both the number of species present and the overall abundance. Four months later (September) there were significant differences between the two sites for all the indices except biomass and Pielou's evenness (Table 15).

The commercial fishing lane at Gouves (EXP-FL) had a substantially impoverished fauna, as evidenced by the comparatively low values for most indices for the EXP-FL site in Fig. 58.

Abundance and biomass were up to 30% and 70% lower, respectively, at EXP-FL than at the other two sites, which is reflected in an order of magnitude change in P-values for the abundance and biomass indices between the September and September* columns of Table 15. Significant differences were also shown for the number of species, the species richness (Margalef) and diversity (Shannon-Weiner) when the commercial fishing lane was included in the analysis for the Gouves area in September (Table 15). It is also noted from Fig. 58 that several indices show similar values in the commercial fishing lane as they do in the experimentally trawled area four months after it was trawled.

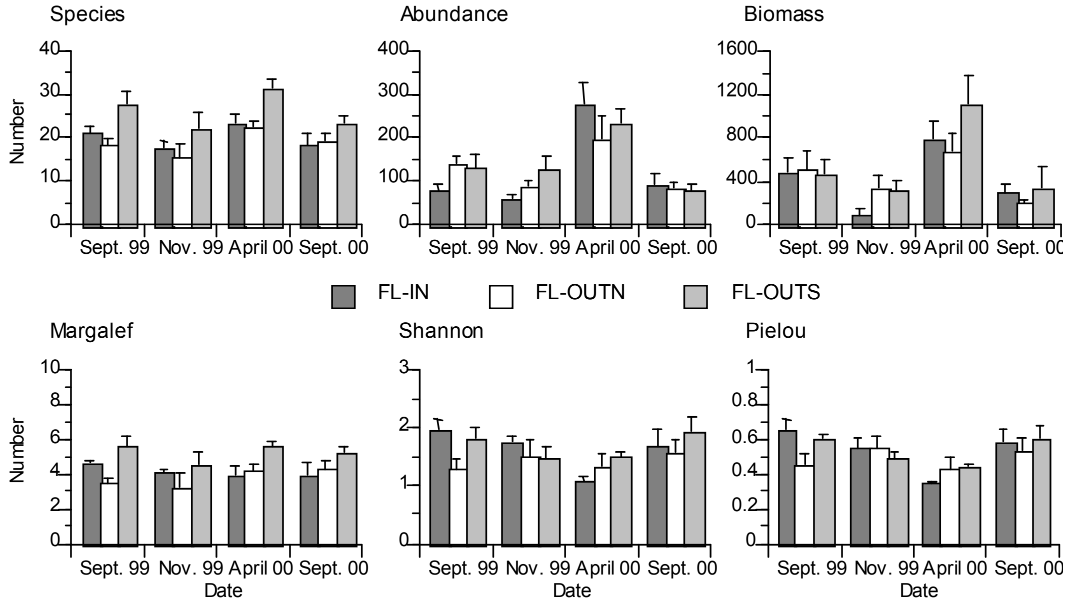


Figure 57. Comparison of means of univariate indices describing epibenthic megafaunal communities from three sites at Dia Island, Aegean Sea, in four sampling periods. Indices are: number of species (per trawl), abundance (1000 m^{-2}), biomass (1000 m^{-2}), Margalef's richness, Shannon-Weiner diversity and Pielou's evenness. Error bars are standard error of the mean.

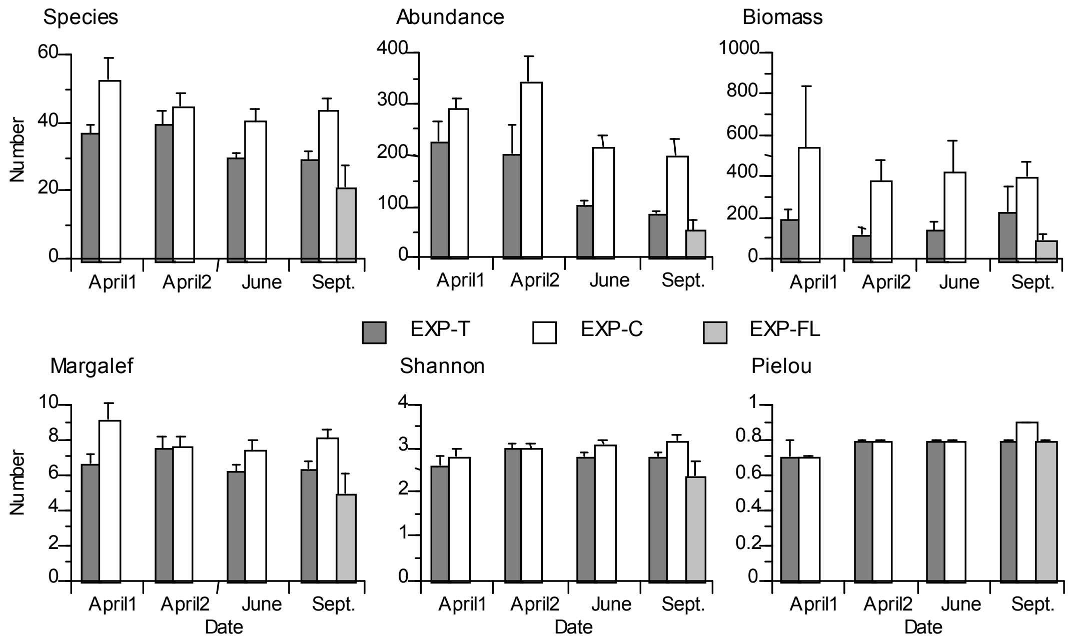


Figure 58. Comparison of means of univariate indices describing epibenthic megafaunal communities from three areas at Gouves, Aegean Sea, in different sampling periods. Indices are as for Fig. 57. Error bars are standard error of the mean.

Multivariate Analysis

The graphical outputs of the cluster analysis ('CLUSTER' routine in PRIMER) for the Dia Island area and the Gouves experimental area are shown in Fig.s 59 and 60. At the 45 % similarity level, tows from the Dia Island area formed a number of clusters. One cluster was almost exclusively formed by the south control tows while the remaining clusters exhibited no spatial or temporal pattern. In the Gouves experimental area a small cluster of four samples was notably different to all the others, three of these samples being taken inside the commercial fishing lane. At the 45 % similarity level, the Gouves samples formed two main clusters; one almost exclusively formed by the EXP-T tows while the other was almost exclusively formed by the EXP-C tows.

MDS analysis of abundance data from the Dia Island area (Fig. 61) did not produce any striking spatial (commercial fishing lane *vs.* the two control sites) or temporal (between sampling periods or open and closed fishing seasons) groupings of samples. When the MDS plot is labelled with spatial information (Fig. 61b) the weak clustering of samples from the FL-OUTS site is evident, reflecting the cluster analysis. Overlaying the MDS plot with bubble plots of the relative abundance of the most dominant species (Fig. 62) highlighted their importance in determining patterns, with *Aporrhais serresianus* being least abundant in the southern control site (FL-OUTS) while *Leptometra phalangium* was almost exclusively confined to that site.

MDS analysis of abundance data from the Gouves experimental area did not produce any distinct spatial (experimental *vs.* control areas) or temporal (between sampling periods) groupings of samples (Fig. 63 a). However, when labelled according to sampling site (Fig. 63b) a weak sorting of samples was evident, with those from the control site occurring on the left of the plot, those from the experimental area in the centre and those from the commercial fishing lane on the right. Overlaying the MDS plot with bubble plots of the relative abundance of the most dominant species (*Hyalinoecia tubicola, Inachus parvirostris* and *Ophiura ophiura*, Fig. 64) did not contradict this.

Average dissimilarity (as computed by the SIMPER routine in PRIMER) between the commercial fishing lane and the two control sites in the Dia Island area ranged between 50.5 % (FL-IN cf. FL-OUTN) and 57.6 % (FL-OUTN cf. FL-OUTS) in a pair-wise comparisons of sites (Fig. 65). For these comparisons, the 10 most important species contributed a cumulative 49.5, 53.0 and 54.4 % of the average dissimilarity, with *Aporrhais serresianus*, *Leptometra phalangium* and *Parapenaeus longirostris* being most important and contributing a cumulative 31.6, 33.5 and 33.7 %.

Average dissimilarity between the commercial fishing lane, the experimental and the control sites in the Gouves area ranged between 55.2 (EXP-C *cf*. EXP-T) and 72.3 (EXP-C *cf*. EXP-FL) (Fig. 66). The top 10 species per group of sites contributed a cumulative 28.7, 32.1 and 36.3% of the average dissimilarity, with *Hyalinoecia tubicola* being one of the most important and contributing a cumulative 3.9, 4.3 and 5.0 %.

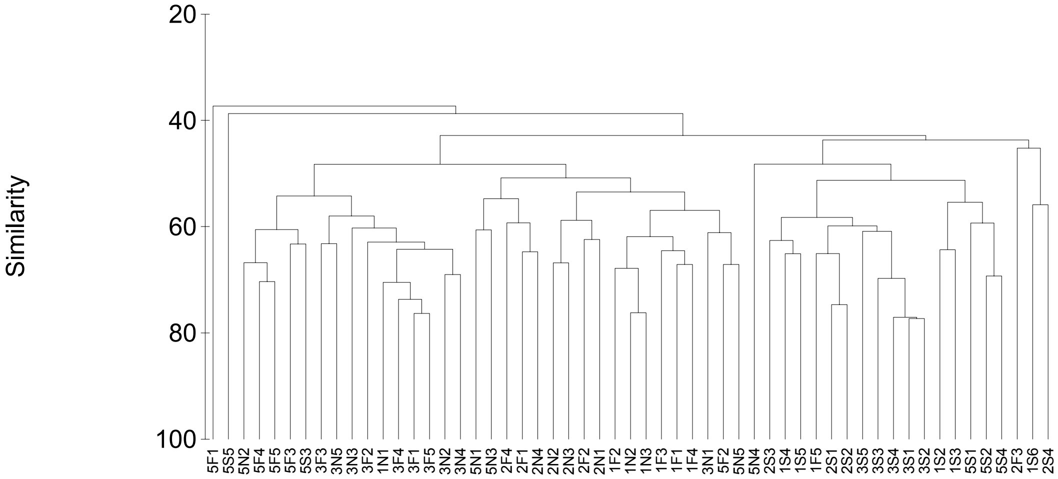


Figure 59. Similarity dendrogram for Dia Island area (Aegean). 3-character sample labels encode sampling period (1, 2, 3, 5), sampling site (F = FL-IN, N = FL-OUTN, S = FL-OUTS) and replicate number (1 to 5).

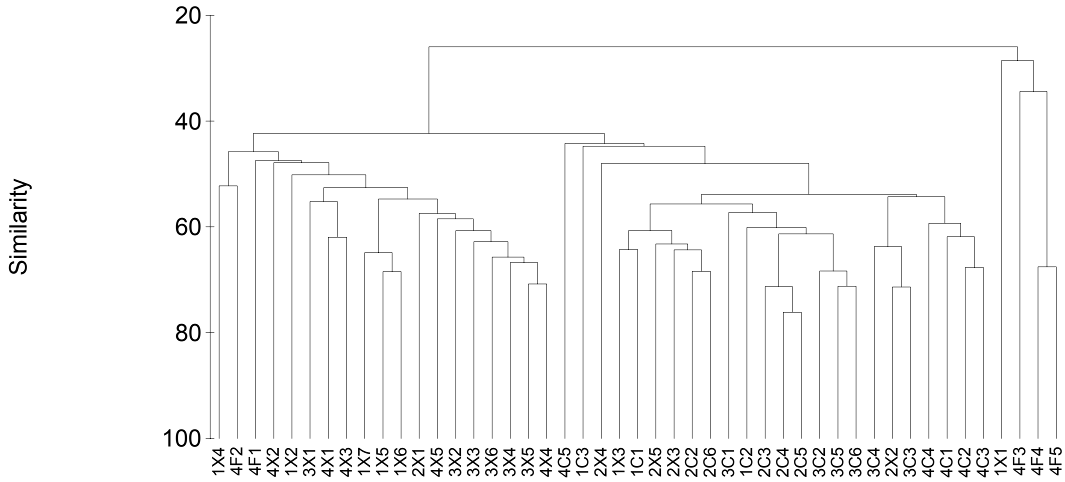
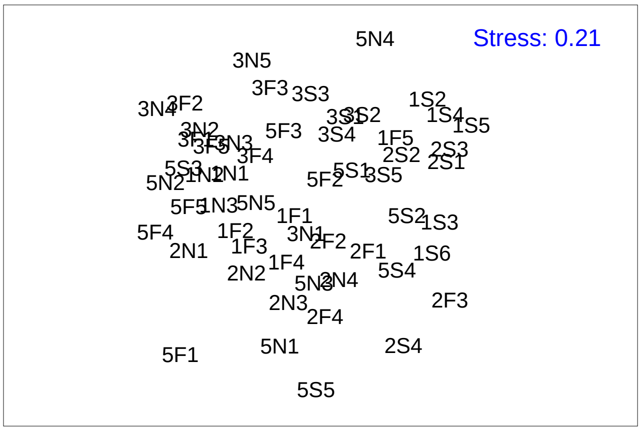
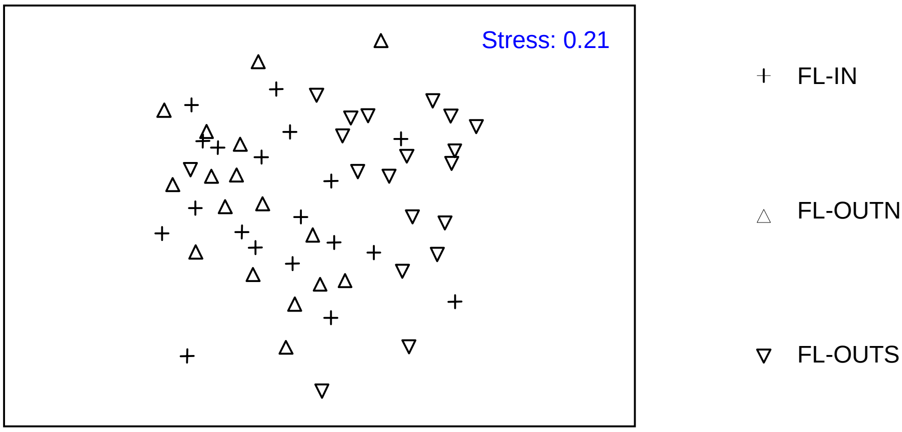


Figure 60. Similarity dendrogram for the Gouves experimental area (Aegean). 3-character sample labels encode sampling period (1 to 4), sampling site (C = control area EXP-C, X = experimental area EXP-T, F = commercial fishing lane EXP-FL) and replicate number (1 to 7)

a)



b)



c)

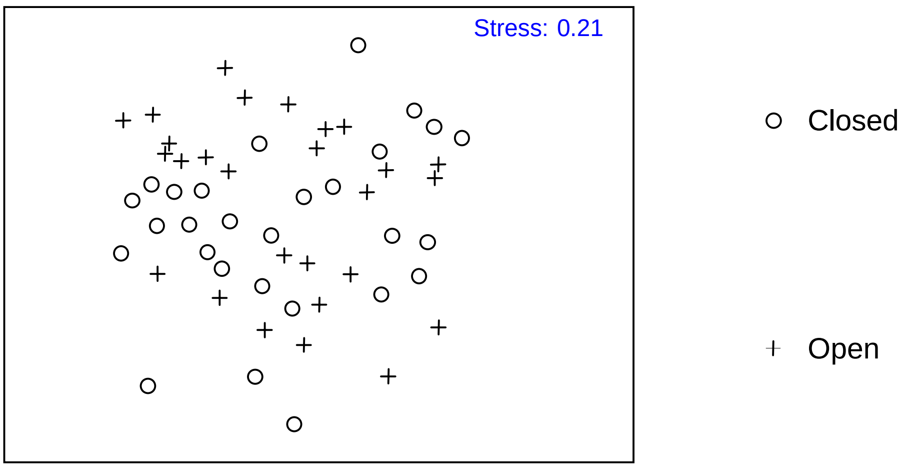
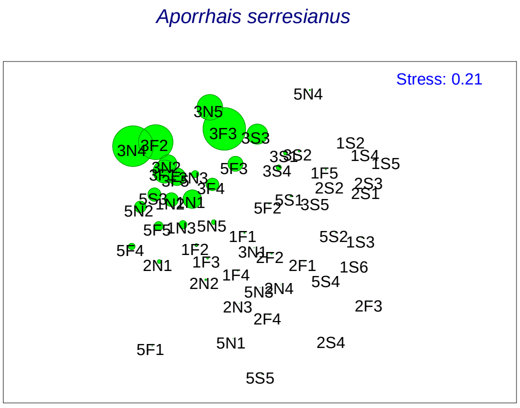


Figure 61. MDS plots for Dia Island catch data (Aegean). a) with each sample identified by 3-character code, b) with samples labelled according to sampling site (i.e. spatially) and c) with samples labelled according to open or closed fishing season (i.e. temporally).

a)



b)

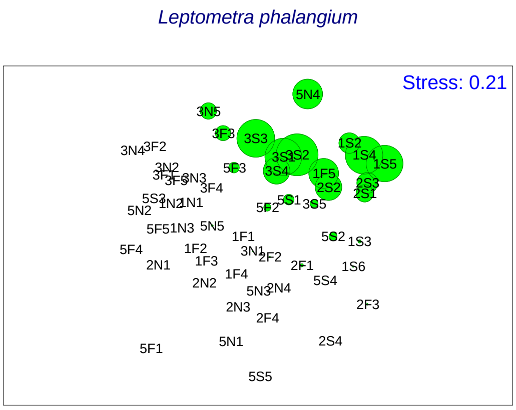
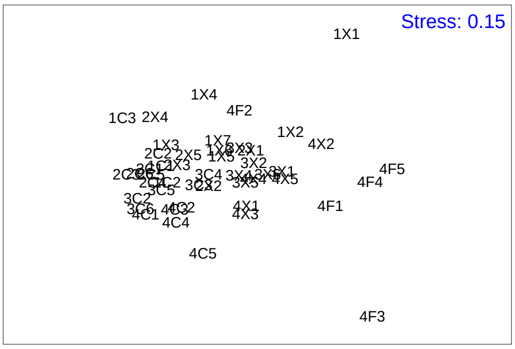


Figure 62. MDS plots for samples from Dia Island (Aegean) overlaid with bubble plots indicating the relative abundance of two of the most important species, a) the gastropod, *Aporrhais serresianus,* and b) the crinoid, *Leptometra phalangium*.

a)



b)

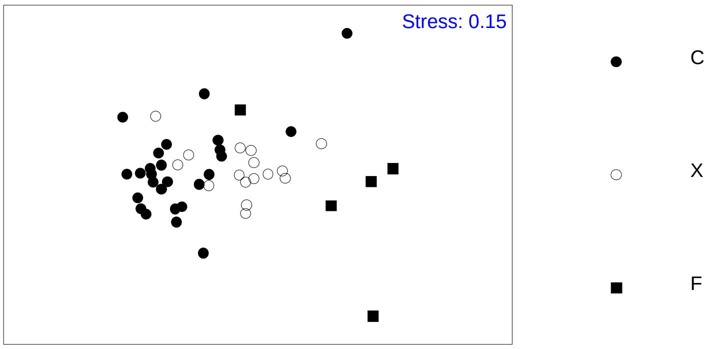
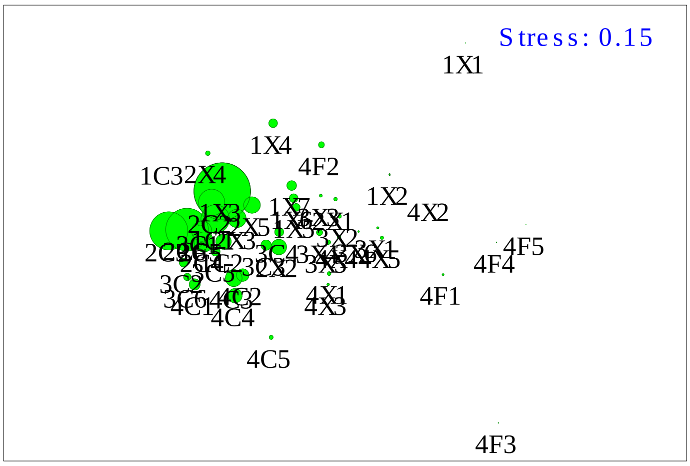
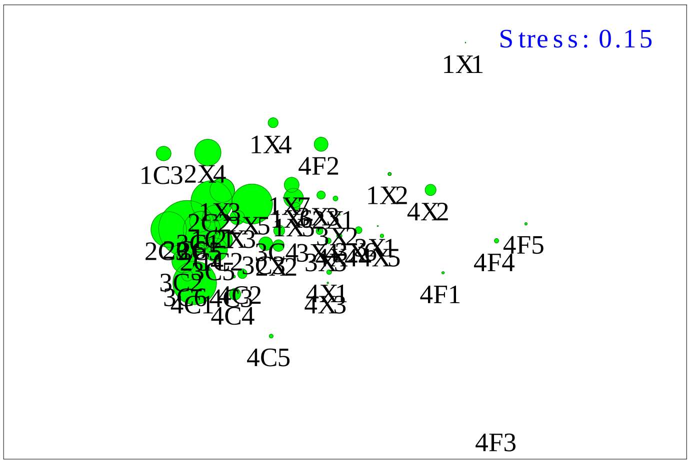


Figure 63. MDS plots for samples from the Gouves experimental area (Aegean). a) labelled with 3-character sample code and b) labelled according to sampling site (C = EXP-C, X = EXP-T, F = EXP-FL).

a)



b)



c)

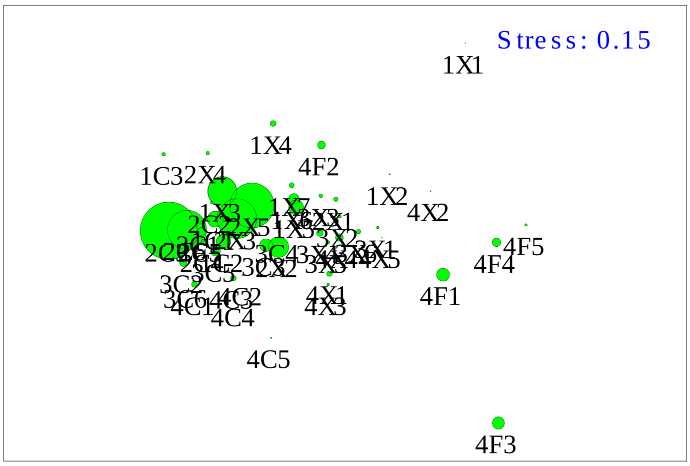


Figure 64. MDS plots for samples from the Gouves experimental area (Aegean) overlaid with bubble plots indicating the relative abundance of three of the most important species, a) the polychaete, *Hyalinoecia tubicola*, b) the crustacean, *Inachus parvirostris* and c) the echinoid, *Ophiura ophiura*.

SIMPER Similarity Percentages - species contributions

Sample selection: All
Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%

Factor groups: Impact
FL-IN, FL-OUTN, FL-OUTS

Groups FL-IN *&* FL-OUTN
Average dissimilarity = 50.53

Top 10 Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Aporrhais serresianus	64.10	64.31	8.66	1.41	17.15	17.15
Leptometra phalangium	12.42	10.13	4.10	0.92	8.11	25.26
Parapenaeus longirostris	28.11	26.11	3.19	1.20	6.31	31.57
Ophiura ophiura	1.34	6.06	2.77	1.51	5.49	37.05
Leuserigobius friesii	5.22	4.66	1.89	1.29	3.74	40.79
Plesionika heterocarpus	1.95	2.08	1.79	1.05	3.54	44.33
Stichopus regalis	1.68	2.49	1.59	1.35	3.14	47.47
Chlorotocus crassicornis	3.43	2.67	1.55	1.33	3.06	50.52
Latreillia elegans	0.83	0.49	1.01	1.28	2.00	52.52
Chloeia sp.	0.36	0.62	0.94	1.16	1.87	54.39

Groups FL-IN *&* FL-OUTS
Average dissimilarity = 55.50

Top 10 Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Leptometra phalangium	12.42	58.49	7.75	1.59	13.96	13.96
Aporrhais serresianus	64.10	17.88	7.70	1.29	13.88	27.84
Parapenaeus longirostris	28.11	36.83	3.22	1.22	5.81	33.65
Leuserigobius friesii	5.22	6.52	1.41	1.25	2.54	36.19
Chlorotocus crassicornis	3.43	4.10	1.36	1.20	2.46	38.65
Chlamys septemradiata	0.15	1.44	1.34	1.30	2.41	41.06
Stichopus regalis	1.68	1.28	1.34	1.26	2.41	43.47
Ophiura ophiura	1.34	0.40	1.14	1.12	2.06	45.52
Scoloplax macroramphosa	0.16	0.95	1.13	1.46	2.04	47.57
Caryophilia smithii	0.35	1.26	1.09	1.13	1.96	49.53

Groups FL-OUTN *&* FL-OUTS
Average dissimilarity = 57.59

Top 10 Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Aporrhais serresianus	64.31	17.88	8.08	1.31	14.03	14.03
Leptometra phalangium	10.13	58.49	8.08	1.62	14.02	28.05
Parapenaeus longirostris	26.11	36.83	3.12	1.29	5.42	33.47
Ophiura ophiura	6.06	0.40	2.70	1.61	4.69	38.16
Leuserigobius friesii	4.66	6.52	1.85	1.32	3.22	41.38
Chlorotocus crassicornis	2.67	4.10	1.52	1.33	2.65	44.03
Plesionika heterocarpus	2.08	0.08	1.43	0.99	2.48	46.50
Stichopus regalis	2.49	1.28	1.42	1.37	2.47	48.98
Scoloplax macroramphosa	0.06	0.95	1.23	1.70	2.14	51.12
Caryophilia smithii	0.22	1.26	1.10	1.09	1.92	53.03

Figure 65. Extract of an analysis generated by the SIMPER (‘similarity percentages’) routine of the PRIMER statistical package for data from the Dia Island area (Aegean), giving pair-wise comparison of the dissimilarity between the three sampling sites, FL-IN, FL-OUTN and FL-OUTS. The ten species contributing most to the dissimilarities are listed for in each comparison.

SIMPER Similarity Percentages - species contributions

Sample selection: All
Standardise data: No
Transform: Square root
Cut off for low contributions: 90.00%

Factor groups: Impact
EXP-C, EXP-T, EXP-FL

Groups EXP-C *&* EXP-T
Average dissimilarity = 55.18

Top 10 Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Hyalinoecia tubicola	39.02	14.84	2.36	1.47	4.28	4.28
Hermione hystrix	21.28	11.90	1.93	1.42	3.49	7.78
Opisthowings	4.07	11.75	1.81	1.34	3.29	11.06
Ophiacantha setosa	11.86	9.25	1.53	1.30	2.77	13.83
Pagurus prideaux	12.31	3.37	1.51	0.84	2.74	16.57
Cidaris cidaris	7.55	1.16	1.39	1.29	2.52	19.09
Epimeria cornigera	11.35	12.90	1.39	1.25	2.51	21.61
Palicus caronii	6.42	0.51	1.38	1.45	2.50	24.11
Eurynome aspera	7.62	2.34	1.29	1.45	2.34	26.45
Ophiura ophiura	9.80	9.19	1.26	1.20	2.28	28.73

Groups EXP-C *&* EXP-FL
Average dissimilarity = 72.25

Top 10 Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Hyalinoecia tubicola	39.02	5.12	3.61	1.72	4.99	4.99
Hermione hystrix	21.28	1.61	3.22	1.58	4.46	9.46
Pagurus prideaux	12.31	1.18	2.52	0.96	3.49	12.95
Ophiacantha setosa	11.86	0.81	2.28	1.68	3.15	16.10
Epimeria cornigera	11.35	3.72	2.03	1.05	2.81	18.90
Eurynome aspera	7.62	0.17	2.01	1.86	2.78	21.69
Palicus caronii	6.42	0.00	1.90	1.58	2.62	24.31
Inachus parvirostris	12.08	2.96	1.88	1.57	2.61	26.92
Antedon mediterranea	6.62	0.61	1.88	1.60	2.60	29.52
Cidaris cidaris	7.55	0.00	1.85	1.26	2.57	32.08

Groups EXP-T *&* EXP-FL
Average dissimilarity = 62.94

Top 10 Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Hermione hystrix	11.90	1.61	3.09	1.66	4.90	4.90
Gobius gasteveni	7.49	3.88	2.81	1.40	4.47	9.37
Epimeria cornigera	12.90	3.72	2.80	1.38	4.45	13.82
Opisthowings	11.75	8.45	2.47	1.35	3.92	17.75
Hyalinoecia tubicola	14.84	5.12	2.46	1.58	3.91	21.66
Ophiacantha setosa	9.25	0.81	2.16	1.27	3.43	25.09
Ophiura ophiura	9.19	8.52	1.87	1.53	2.97	28.05
Pagurus prideaux	3.37	1.18	1.80	1.45	2.86	30.92
Gobius geniporus	4.17	1.01	1.75	1.42	2.78	33.70
Antedon mediterranea	2.93	0.61	1.62	1.51	2.57	36.26

Figure 66. Extract of an analysis generated by the SIMPER (‘similarity percentages’) routine of the PRIMER statistical package for data from the Gouves experimental area (Aegean), giving pair-wise comparison of the dissimilarity between the three sampling sites, EXP-C, EXP-T and EXP-FL. The ten species contributing most to the dissimilarities are listed for in each comparison.

In Summary – Community Analysis

Clyde Sea

- Community analyses can quickly assess variability between samples of epibenthic megafauna and highlight taxa that may be useful 'indicators' of the extent of trawl impacts.
- It is not necessary to identify taxa to species. Identification to Family produces much the same result. Adopting a lower level of taxonomic resolution should significantly reduce the amount of time required to process samples.
- It is necessary to count the frequency of each taxon. The analyses are compromised if taxa are merely scored on a presence/absence basis. This stricture may depend on the species richness, or otherwise, of the data set.
- Multivariate analyses can now be considered routine and may provide significant analytical advantages over univariate tests.
- Communities at the heavily fished sites had a lower diversity of epibenthic megafauna which was dominated by a small number of species.

Aegean

Dia Island - Deep muddy area.

- Community analysis showed few differences between sites during the closed fishing season and at the beginning of the open fishing season. A substantial increase in the abundance and biomass of all three sites was, however, found in April 2000, towards the end of the fishing season. Furthermore, there was a reduction in diversity, evenness, richness and number of species and an increase in abundance in the commercial fishing lane.

Gouves - Shallow maerl area.

- Community analysis showed significant differences between the control and the experimental area two and four months after the impact of experimental trawling. Similar differences were noted between the control area and the commercial fishing lane.
- Community indices had substantially lower values in the commercial fishing lane in September 2000 during the closed fishing season.

- Manipulative experiments in the form of a known, quantifiable trawl impact proved successful in simulating community response to trawling in a commercial fishing lane.
- Commercial fishing lanes in the Dia and Gouves area had impoverished fauna compared with control sites.

Overall Summary.

- Community analyses did reveal differences between areas subject to different fishing impacts and also between open and closed fishing seasons. They constitute an important tool in assessing fishing impacts and provide data that complement other assessment methods.
- Multivariate analyses can have advantages over univariate analyses, particularly in identifying 'indicator' species and providing a better visualisation of results. However, the results of multivariate analyses were not as clear cut in the Aegean as in the Clyde Sea area. Several factors may contribute to this, including the differences in sampling protocol and the lower abundance but greater diversity of epibenthic megafauna in the Aegean (compared with the Clyde Sea area).
- Univariate analyses provide significant information and should be used in conjunction with multivariate analyses. The two types of analyses are complementary. In some circumstances, univariate analyses may provide a clearer interpretation than multivariate analyeses.

4.4.3 Assessment of the population densities of fauna (Task 4, Sub Task 3)

4.4.3.1 Clyde Sea

Population densities for each taxon at each site in the Clyde Sea area are given in Appendix IV, providing a valuable archive for future comparative studies. The pattern of data presented in Appendix IV is summarised in Figure 67, a graphical comparison of the data aggregated into 18 ecologically / taxonomically significant groups. The groups are defined in Appendix IV and intentionally labelled with (mostly) common names or terms (e.g. flatfish, roundfish, bivalves) to assist understanding of a wider audience. It is recognised that some terms (e.g. 'mesogastropods' and 'neogastropods') are strictly redundant in modern taxonomic nomenclature (now known collectively as Caenogastropoda), but they are retained as they are still in common use in popular texts such as Hayward & Ryland (1995).

The density of mesogastropods (*Aporrhais* spp. & *Turritella communis*) showed a direct relationship with fishing impact, being the dominant group at the heavily fished sites, less important in moderately fished sites and of only minor importance in lightly fished sites. Squat lobsters (mostly *Munida rugosa*) show an opposite trend but it should be noted that the sites they dominate, namely sites M2 and L2, were adjacent sites in Loch Long so the trend may be partly or wholly attributable to other factors. The neogastropods (*Buccinum undatum*, *Neptunea antiqua* & *Colus gracilis*) had a low, but less variable, density across sites being most dense at the shallower site L1. This even distribution supports their selection as organisms of potential use in comparing the damage load of fauna between sites experiencing different fishing pressures. The bivalves (mostly *Aequipecten opercularis*) would clearly be an unsuitable choice due to low population density in the samples from most sites although a different sampling gear could undoubtedly be more selective for bivalves (most of which are infaunal). Scavengers, such as hermit crabs and starfish did not show a marked increase in population density at moderately or heavily fished sites, a response often cited as being typical of fishing disturbance.

Brittlestars had a patchy distribution within some sites, and this may be related to patchiness in preferred sediment types or indicative of 'aggregating' behaviour which would preclude evenness in spatial distribution. The large polychaete *Aphrodita aculeata* is a surface/shallow burrowing micro/meso carnivore that occurred at low densities in most samples. These characteristics suggest that it may also be a suitable candidate as a species whose population structure and dynamics can be compared between sites, but this was not addressed in the current study. The erect colonial sea pen *Virgularia mirabilis*, was present at a very low densities in samples from moderately and lightly fished sites (see Appendix IV), but was absent in those from heavily fished sites. Underwater TV records suggest that it is more frequent than trawl records indicate, and is not properly represented in the trawl samples. This is most likely attributable to their habit and behaviour, being 'rooted' into the sediment, able to bend when struck by an object (e.g. trawl gear) and able to retract into the sediment when disturbed. Being apparently fragile, they may be suitable candidates as indicator species for studies of disturbance, but sampling would have to be achieved by a different means.

The 20 most important species (in terms of biomass) occurring in samples from the Clyde Sea area (Table 16) can be considered to characterise the epibenthic megafauna of soft substrata in this geographical region and form a useful reference for comparison with other regions. Interestingly, when analysed site by site, these rank order data did not reveal any notable pattern relating to nominal fishing intensity, indicating that such analysis is not useful in this instance as a rapid assessment method. It may, however, have application in a time-series study of a particular site where more acute changes in rank biomass of species are likely to result from changes in fishing impact, especially at the onset of a fishery or following its cessation. It is noteworthy that the target species of the current fishery, *Nephrops norvegicus* is ranked highly at the heavily fished sites. Such information may be of interest to fishers and fishery managers in identifying sites suitable for the fishery and, more importantly, sites not suitable for the fishery due to low rank biomass.

Trawl disturbance to the sea bed may temporarily increase the productivity of its biota, for example by exposing infaunal organisms and thus attracting predators. However, as trawling intensity increases, productivity will decrease due to destruction of habitat and increased rates of removal and/or mortality of fauna. Hence, a significant decrease in biomass (or abundance) can indicate overfishing.

The biomass at the six sites in the Clyde Sea area ranged between 4.0 and 8.7 $g \cdot m^{-2}$ (Fig. 68) but it is invalid to assume that this is an effect of trawling as the habitat was not uniform at all sites and consequently some sites may have had a higher 'carrying capacity' than others. Application of population density analyses for rapid assessment purposes is best suited to a time-series study at a particular site, or comparing 'zones' within a uniform habitat (e.g. the trawled lane at Dia Island, Crete).

Table 16. The 20 most important epibenthic megafaunal species in the Clyde Sea area as ranked by their mean biomass (g·1000 m^{-2}) at six sites representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = light). Also, ranks for these species at each site.

Taxon	Mean biomass	Rank overall	Rank at site H1	H2	M1	M2	L1	L2
Aporrhais pespelecani	1646.4	1	1	1	1	2	15	3
Munida rugosa+sarsi	1208.5	2	10	15	11	1	2	1
Asterias rubens	553.0	3	16	4	7	3	7	2
Ophiura ophiura	543.1	4	19	2	13	5	3	4
Nephrops norvegicus	360.7	5	2	3	2	8	16	7
Liocarcinus depurator	321.9	6	11	8	5	4	8	5
Buccinum undatum	247.4	7	5	5	8	16	4	8
Neptunea antiqua	217.1	8	4	7	6	7	5	13
Aequipecten opercularis	192.2	9		23	18	22	1	17
Pagurus bernhardus	166.1	10	22	6	9	12	6	12
Aphrodita aculeata	138.0	11	7	9	12	15	9	6
Lumpenus lampretaeformis	130.2	12	12	13	3	13		
Turritella communis	89.5	13	18	29	4		11	
Dichelopandalus bonnieri	88.0	14	3	12	25	9	51	9
Pleuronectes platessa	45.3	15	29			11	17	10
Hippoglossoides platessoides	44.5	16	17	19	15	14	10	
Glyptocephalus cynoglossus	42.2	17	6	11	19	24	36	14
Enchelyopus cimbrius	40.8	18	8	10	13	17		19
Carcinus maenas	37.6	19				6		14
Pseudamussium septemradiatum	26.6	20	26	33	23	23		11
Total no. of taxa		70	31	39	33	35	52	31

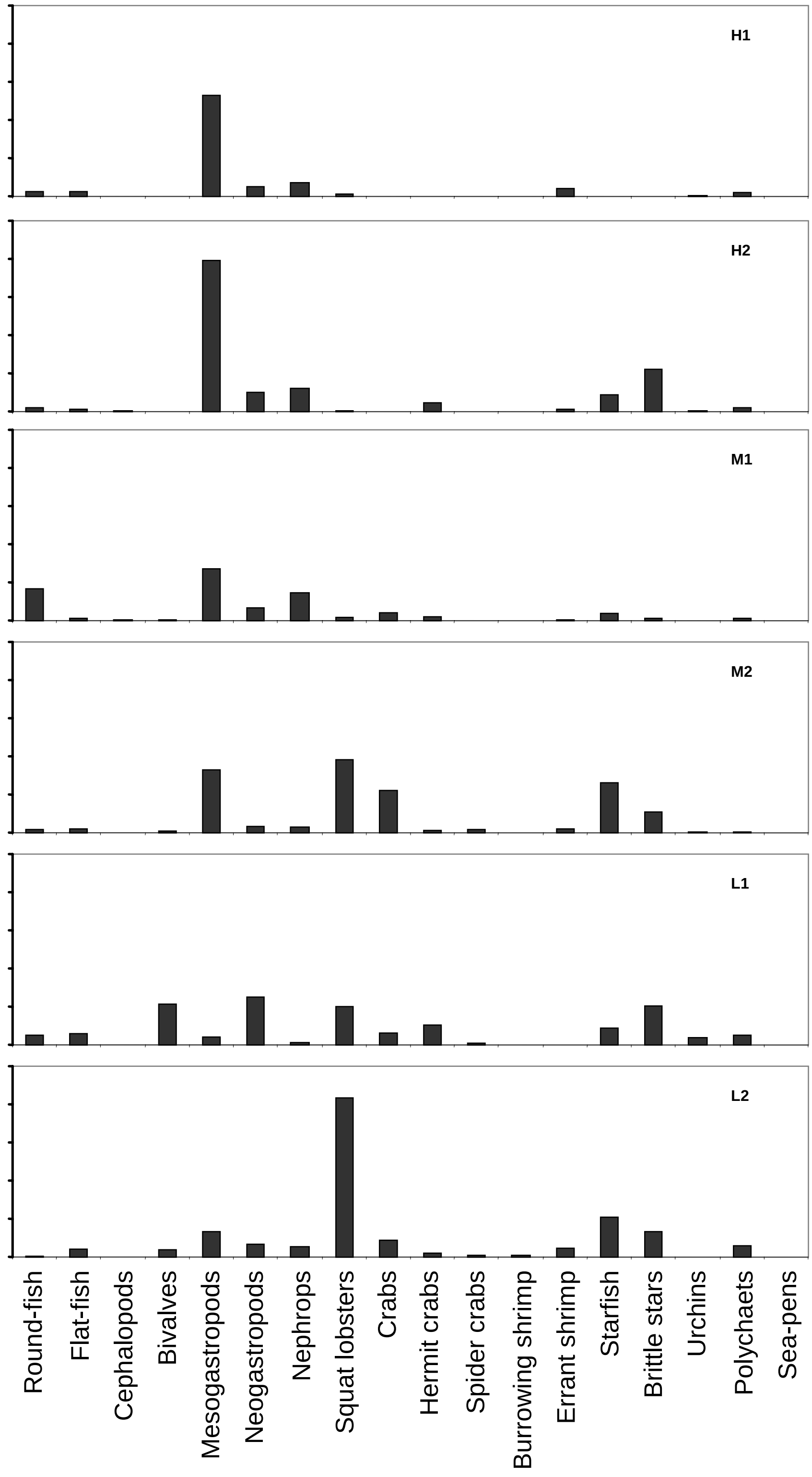


Figure 67. Biomass of 18 groups of taxa representing significant ecological elements of the epibenthic megafauna at six sites in the Clyde Sea area representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = light). Y-axis gives density, with tick marks every 1.0 g·m^{-2}. Groups are defined in Appendix IV.

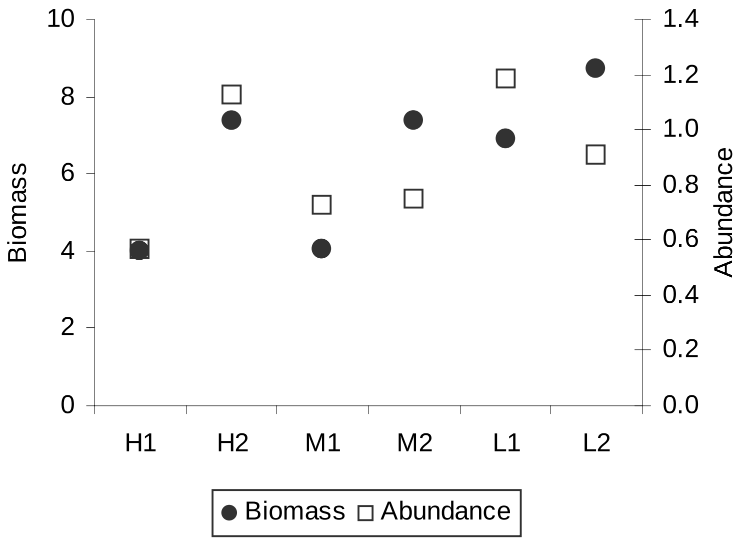


Figure 68. Total biomass and abundance of epibenthic megafauna sampled by small beam trawl at six sites in the Clyde Sea area representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = light). Biomass in $g \cdot m^{-2}$, abundance in number$\cdot m^{-2}$.

4.4.3.2 Aegean

Megafauna were collected from the two areas by Agassiz trawling over a time series with 5 replicate trawls taken on each sampling occasion in each of the sample sites. The time series analysed for Dia Island included September 1999, November 1999, April 2000 and September 2000. Samples were taken in the trawling lane (FL-IN) and two control sites, one to the north of the lane (FL-OUTN) and one to the south of the lane (FL-OUTS). It should be noted that trawling in the lane is temporally controlled by an open fishing season from the beginning of October to the end of May followed by a closed season from the beginning of June until the end of September. As noted in the methods, the Agassiz haul duration was 30 minutes, but tow lengths were found to vary between 1000-2000 m distance and so all data was standardised to 1000 m^2 swept area.

A total of 127 megafaunal species were identified from the Agassiz trawl samples from the Dia Island area, with a total of 21034 individuals. The common species were recorded at all the three sites within the area. The megafauna were highly dominated in terms of abundance (and biomass) by very few species. Table 17 shows the top 13 species and their overall dominance of the community in terms of abundance. The dominants would change position in the tablulation slightly if this were repeated with biomass, but some of the smaller more numerous species would be replaced by some larger bottom fish. These species were the common species found within the top 10 dominant species from each station. Three species, the gastropod *Aporrhais serresianus*, the shrimp *Parapenaeus longirostris* and the crinoid *Leptometra phalangium* were responsible for approximately 80% of the megafaunal abundance.

Table 17. Dominant megafaunal species from the Dia Island area, Aegean Sea, and their percentage dominance in terms of the abundance within all the samples from the trawl lane and two control sites.

Species	Percent	Species	Percent
Aporrhais serresianus	36.3	*Plesionika heterocarpus*	1.0
Parapenaeus longirostris	22.9	*Latreillia elegans*	0.6
Leptometra phalangium	20.8	*Chlamys septemradiata*	0.5
Leuserigobius friesii	4.1	*Caryophyllia smithi*	0.5
Chlorotocus crassicornis	2.6	*Scaphader lignarius*	0.5
Ophiura ophiura	1.9	*Alpheus glaber*	0.4
Stichopus regalis	1.3	Total	93.4

The mean abundance (with standard error bars) for the dominant species are shown in Figure 69 with significance levels from analysis of variance carried out between the sites shown in Table 18. The gastropod *Aporrhais serresianus* indicated seasonal fluctuations at all three sampling sites. It was highest in the trawling lane and in the northerly control site with least abundance in the southerly control site. A highly significant difference was noted between sites in September 1999. The shrimp *Parapenaeus longirostris* indicated an increasing abundance through the winter and spring months with a significant difference between sites in April 2000. Abundance was generally higher at the southerly control site. *Leptometra phalangium* had highest abundances in the southerly control site, which was significantly higher during the trawling season. The burrowing goby *Leuserigobius friesii* indicated significantly higher abundances in the control sites towards the beginning of the trawling season (November 1999), but was found in lower abundance later in the season at all sites. *Ophiura ophiura* (= O. texturata) had highest abundances in the northerly control site, significantly so in September and April. *Stichopus regalis* was present throughout the study in all samples at low abundance. There was a significant difference between the sites at the beginning of the trawling season in November with reduced abundance in the trawling lane and northerly control site. The bivalve *Pseudamuseum septemradiatum*, the coral *Caryophyllia smithi* and the opistobranch mollusc *Scaphader lignarius* were all found in higher abundances at the southerly control station and were rare in the other two stations. The burrowing shrimp *Alpheus glaber* was found in low abundance but consistently in all the sites during all the sampling seasons.

The time series for sampling at Gouves included immediately before and 24 hours after experimental trawling in April 2000, followed by repeat sampling in June and September. A total of 173 megafaunal species were identified from the Agassiz trawl samples from the Gouves experimental trawling area, with a total of 8770 individuals. The area included the experimental trawling lane (EXP-T) and adjacent control site (EXP-C) that were sampled before and after experimental trawling as well as a commercial fishing lane (EXP-FL) identified later in the project and sampled during the last visit, approximately 1 kilometre distant. The common species were recorded at all the three sites within the area. Table 19 shows the top 12 species and their overall dominance of the community in terms of abundance. The 12 dominant species accounted for approximately 66% of the total abundance from the area with one species, the polychaete *Hyalinoecia tubicola* representing 15% of the faunal abundance.

Table 18. Significance values (P) for ANOVA tests between the different areas for each sampling period for the dominant megafaunal species from the Dia Island area, Aegean Sea. Lighter shading indicates significant difference (P<0.05), darker shading indicates highly significant difference (P<0.01).

Species	Sept. 99	Nov. 99	April 00	Sept. 00
Aporrhais serresianus	<0.0001	0.2342	0.0791	0.6186
Parapenaeus longirostris	0.2679	0.1556	0.0129	0.4785
Leptometra phalangium	0.1538	0.0124	0.0010	0.8551
Leuserigobius friesii	0.3262	0.3958	0.0231	0.0785
Chlorotocus crassicornis	0.2473	0.3958	0.1652	0.4603
Ophiura ophiura	0.0035	0.1485	0.0083	0.2123
Stichopus regalis	0.1055	0.0415	0.5770	0.4854
Plesionika heterocarpus	0.4971	0.3499	0.3926	0.2776
Latreillia elegans	0.2230	0.7767	0.1607	0.6835
Pseudamuseum septemradiatum	0.1947	0.3803	0.1198	0.0184
Caryophyllia smithi	0.1933	0.8433	0.2556	0.2769
Scaphader lignarius	0.3278	1.0000	0.0154	0.5991
Alpheus glaber	0.3472	0.4954	0.5014	0.6103

Table 19. Dominant megafaunal species from the Gouves experimental fishing area, Aegean Sea, and their percentage dominance in terms of the abundance within all the samples from the experimental trawling lane, control sites and commercial fishing lane.

Species	Percent	Species	Percent
Hyalinoecia tubicola	15.1	*Pagurus prideaux*	4.4
Hermione hystrix	8.8	*Pleurobranchia meckeli*	3.9
Epimeria cornigera	6.1	*Gobius gasteveni*	3.6
Ophiacantha setosa	5.4	*Eurynome aspera*	2.7
Ophiura ophiura	5.2	*Antedon mediterranea*	2.6
Inachus parvirostris	5.0	*Cidaris cidaris*	2.5
		Total	65.9

The mean abundance (with standard error bars) for the dominant species are shown in Fig. 70 with significance levels from analysis of variance carried out between the sites shown in Table 20. The first sampling (April 1) occurred immediately before the experimental trawling impact and the second sampling 24 hours afterwards (April 2). For all the dominant species there were no significant differences in abundance between the control and the experimental trawling sites before the experimental trawling event. In the majority of cases there were higher abundances of dominants in the two experimental sites than in the commercial fishing lane sampled at the end of the experiment. The exception to this was a significantly higher abundance of *Ophiura ophiura* in the commercial trawling lane. The dominant tubicolous surface dwelling polychaete worm *Hyalinoecia tubicola* decreased in abundance in the experimental trawling lane after the trawling event and was significantly lower in abundance than in the control site. The polychaete *Hermione hystrix* indicated an initial increase after the experimental trawling and then decreased with again significantly lower abundance than in the control area. Both of the ophiuroids *Ophiura ophiura* and *Ophiacantha setosa* had similar trends in the trawling lane and control site with a general increase over time. The hermit crab *Pagurus prideaux* and the spider crab *Inachus parvirostris* had significantly lower abundances in the trawling lane immediately after, and 2 months after, the trawling impact respectively. The opisthobranch mollusc *Pleurobranchia meckeli* was one of the few species with a consistently higher abundance in the trawling lane area, whilst the crab *Eurynome aspera*, the crinoid *Antedon mediterranea* and the echinoid *Cidaris cidaris* had consistently higher abundances in the control area.

Table 20. Significance values (P) for t-test comparison of means between the different sites (experimental trawl site and control site) for each sampling period for the dominant megafaunal species from the Gouves area, Aegean Sea. Lighter shading indicates significant difference (P<0.05), darker shading indicates highly significant difference (P<0.01). April 1 and April 2 refer to immediately before and after the experimental trawling. September* refers to the inclusion of the samples from the commercial trawling lane and testing between the three sites by ANOVA.

Index	April 1	April 2	June	September	September*
Hyalinoecia tubicola	0.9197	0.0159	0.0009	0.0092	<0.0001
Hermione hystrix	0.4523	0.5107	0.0020	0.0269	0.002
Epimeria cornigera	0.1392	0.7109	0.4517	0.0554	0.035
Ophiacantha setosa	0.4704	0.4263	0.8904	0.1810	0.116
Ophiura ophiura	0.7746	0.9876	0.3873	0.8528	0.027
Inachus parvirostris	0.1411	0.1233	0.0022	0.2979	0.292
Pagurus prideaux	0.4053	0.0209	0.2698	0.7904	0.887
Pleurobranchia meckeli	0.3797	0.1112	0.0019	0.1059	0.342
Gobius gasteveni	0.9891	0.0874	0.9485	0.0420	0.082
Eurynome aspera	0.0936	0.0129	0.0282	0.0493	0.004
Antedon mediterranea	0.3717	0.1386	0.0098	0.1850	0.039
Cidaris cidaris	0.1267	0.0316	0.0307	0.0317	0.002

In Dia Island there were some differences between the grounds, evident from the distributions of the megafaunal dominants. For example, *Leptometra phalangium* was found in very high numbers in the southern control ground, and lesser in the northerly control ground and the trawling lane in between. Its absence from the northerly control site may be due to this being the start of the slope up to Dia Island. Another example, *Ophiura ophiura* was found in Dia Island in highest dominance in the northerly control site, low numbers in the trawling lane and lower still in the southerly control site. The same species was found in equal numbers in the Gouves experimental trawling lane and the adjacent control site. At the end of the Gouves experiment it was found in highest abundance in the commercial trawling lane. It was very difficult to find exactly suitable control grounds. If too close to a trawling area they may be affected indirectly by trawling activities and if too far away they may have had different environmental characteristics. Knowledge of control sites, however, is essential to investigate temporal changes that may also be affecting the fauna on the trawling ground, effects that might otherwise be inappropriately attributed to trawling. The choice of two control areas at Dia Island certainly made the interpretation of the data more difficult, but it covered a wider variety of species within the trawling ground.

The much reduced abundance of *L. phalangium* in the trawling lane at Dia Island is easily understandable because it has low motility, is extremely fragile and is easily damaged or removed by trawling. This was also noted for two other low motility/sessile species, the cup coral *Caryophyllia smithi* at Dia Island and the crinoid *Antedon mediterranea* at Gouves. The burrowing shrimp *Alpheus glaber* was one of the few species at Dia Island with no significant differences between the sampling areas during the study. Whilst within the sediment it retains a degree of protection from trawling, near the sediment surface it would be at risk from deeper digging trawl doors. As a burrower it also may have some ability to deal with sediment disturbance. It is more difficult to understand the distributions of more motile species because of ‘wandering populations’. Some organisms, such as scavengers, may be attracted to trawl disturbed areas, having an abundance mediated by immigration and removal. Other species may be randomly at risk with movement over large areas, for example, the large surface-deposit feeding holothurian *Stichopus regalis*.

Trawling impacts were not clearly evident with all the dominant megafaunal species. This could be due to a number of different factors:

- variations in numbers – where the distribution of a particular species may not be adequately sampled by the Agassiz trawl or where unusually high numbers in one sample would skew the results (e.g. some of the maximum abundances of *Aporrhais serresianus* in Dia Island with high error bars)

- different functional responses to trawling - some species being removed/damaged or other species being attracted or unaffected in trawled areas.

On this latter important point, where possible, data should be analysed with respect to the knowledge of the functional ecology of different species.

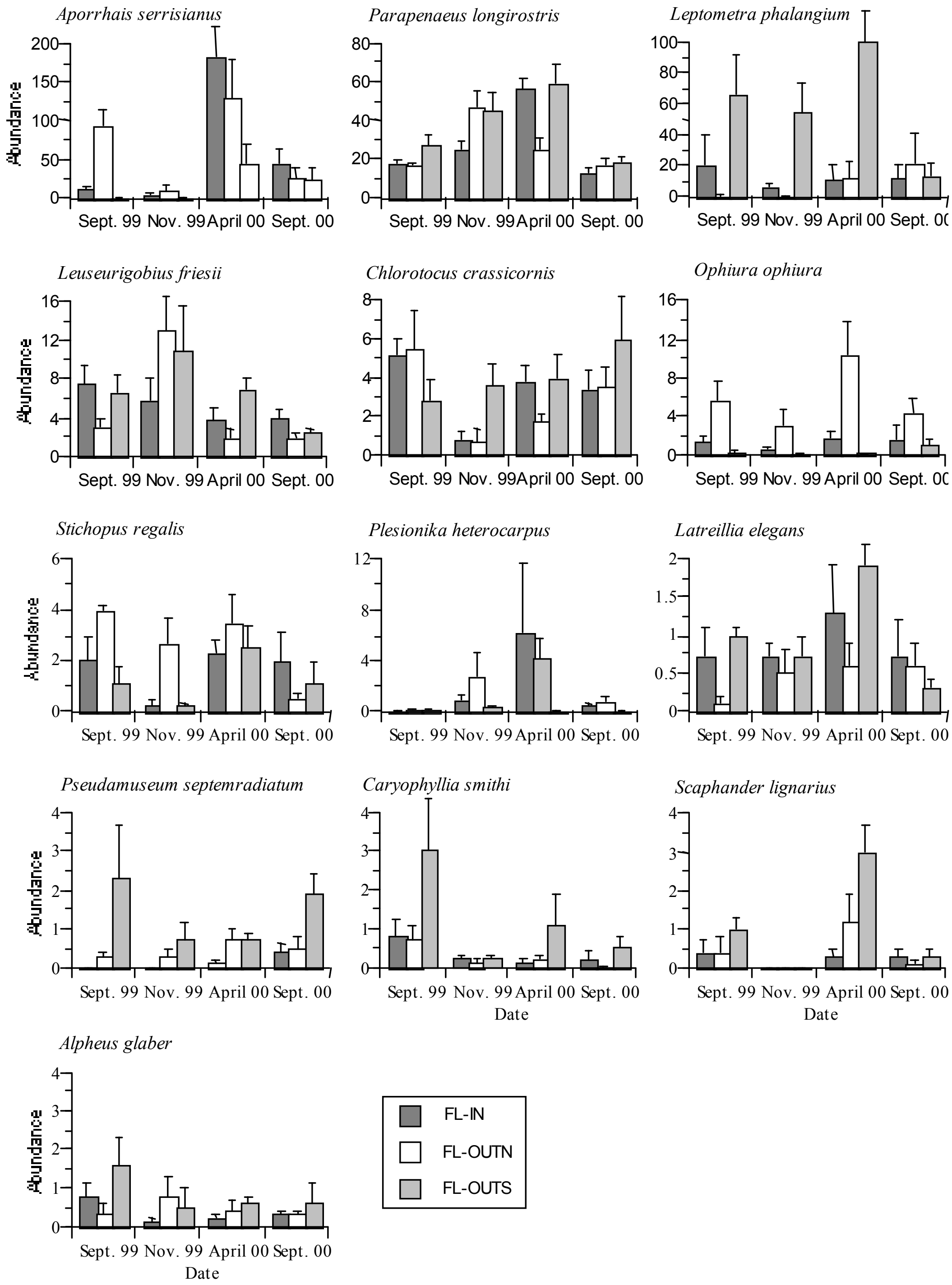


Figure 69. Abundance of dominant megafaunal species at the three sampling areas at Dia Island, Aegean Sea, (FL-IN, trawling lane; FL-OUTN, northern control area; FL-OUTS, southern control area) during the different sampling periods. Abundance per 1000 m^2 is mean of 5 replicate Agassiz hauls. Error bars are standard error of the mean.

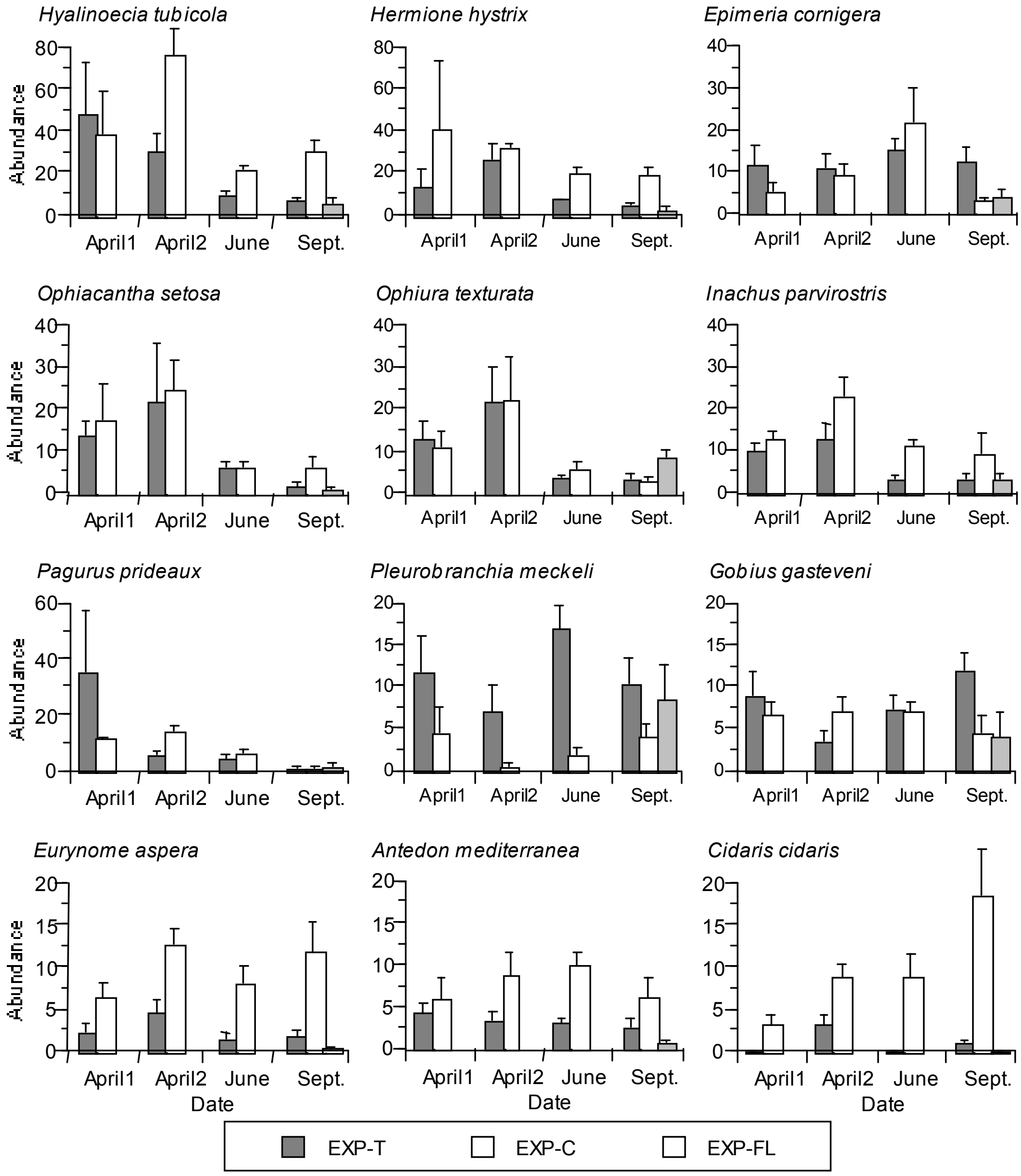


Figure 70. Abundance of dominant megafaunal species at the three sampling areas at Gouves, Aegean Sea, (EXP-T, experimental trawling lane; EXP-C, control area; EXP-Fl, nearby commercial fishing lane) during the different sampling periods. Abundance per 1000 m^2 is mean of 5 replicate Agassiz hauls. Error bars are standard error of the mean. (NB. *Ophiura texturata* = *O. ophiura*)

In Summary – Population Density

Clyde Sea

- Analysis of population density data showed interpretable trends when undertaken at the species level or with species data aggregated into ecologically / taxonomically significant groups. The population density of certain taxa was shown to vary in relation to nominal fishing impact at sites in the Clyde Sea. Such taxa may be used as indicator organisms to assess relative fishing impact. The results are analogous to, but less detailed than, the community analysis in section 4.4.2.
- Analysis of rank order data or total biomass data had a limited application as such data can be greatly influenced by between-site differences in habitat type. As a rapid assessment method, such analyses would only be suitable for samples from the same site or very similar habitats.
- Increased fishing intensity may affect biomass at a particular site, but this has not been tested here by experimental manipulation.

Aegean

- Megafaunal species may provide a useful insight into the impact of trawling on the seabed.
- In the analysis of individual megafaunal species, it is important to have reference to their ecological functionality for high discrimination data interpretation.

4.4.4 Analysis of the functional group composition of fauna (Task 4, Sub Task 4)

4.4.4.1 Clyde Sea

Of a total of 70 taxa of epibenthic megafauna recorded in samples from the Clyde Sea area, the majority (77%) were motile predator-scavengers (Table 21). Sedentary suspension feeders were the second ranked functional group (8.6% of all taxa), with the remaining four groups having ≤ 3 taxa each. The decrease in the frequency of taxa per group reflects progressively greater specialisation in feeding strategies / niches.

Table 21. Number of taxa (total = 70) of epibenthic megafauna from the Clyde Sea area assigned to each of seven functional groups describing their dominant trophic mode and predominant foraging habit.

Functional Groups		Number of Taxa
Code	Description	
1a	predator-scavenger; burrow-dwelling	1
1c	predator-scavenger; motile	54
2b	suspension feeder; sedentary	6
2c	suspension feeder; motile	3
3a	deposit feeder; burrow-dwelling	3
3b	deposit feeder; sedentary	2
3c	deposit feeder; motile	1

A clear pattern emerged in the two dimensional representation of the MDS analysis of catch data (biomass) aggregated by functional groups (Fig. 71). Rather than forming distinct clusters representing the three nominal levels of fishing activity (H, M, L) the samples were distributed in a more linear fashion along an apparent gradient from low, to moderate, to high impact (acting from left to right in Fig. 71). Thus, it can be inferred that the functional group composition of a community does alter as fishing intensity increases.

This inference is supported by the second approach to functional group analysis based on inspection of Table 22. In terms of the number of taxa, all sites were dominated by group 1c and, with the exception of one of the low impact sites (L1), they all supported similar numbers of these motile predator-scavenger taxa. Likewise, all sites supported similar numbers of sedentary suspension-feeding taxa (group 2b) and a single taxon of motile deposit feeder (group 3c). The data suggest that high impact sites might be characterised by higher numbers of burrow-dwelling deposit-feeding taxa (group 3a) and an absence of motile suspension feeders (group 2c). However, it is unsafe to infer a causal relationship with fishing intensity as the frequency of taxa in these groups was extremely low, so the same pattern could result from a purely random distribution of these rarer taxa.

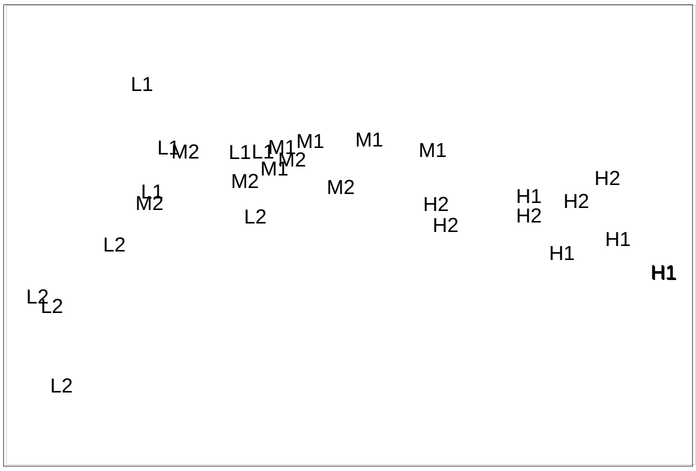


Figure 71. Multi-dimensional scaling (MDS) representation of the similarities (and differences) between the functional group composition of 30 samples of epibenthic megafauna from the Clyde Sea area. Five replicate samples were taken from each of six sites (H1, H2, M1, M2, L1, L2) representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = light). This analysis employs the same data that were used to investigate variability in the taxa of epibenthic megafauna (Task 4, sub-task2; sections 3.4.2 and 4.4.2). However, here the data have been aggregated according to the seven functional groups represented by the taxa (see section 3.4.4.). This figure relates to an analysis of biomass (rather than frequency) data.

There also appears to be a relationship between fishing intensity and the % biomass (and % abundance) of groups 1c and 2b. As nominal fishing intensity increased, these parameters decreased in the case of motile predator-scavengers (group 1c) but increased in the case of sedentary suspension feeders (group 2b). As fishing intensity increased there was an apparent shift in the functional group composition of the epibenthic megafauna away from predation / scavenging and toward suspension feeding. This is consistent with two major effects of a trawl fishery: firstly, the targeting and removal of motile predator-scavenger taxa (mostly fish and Crustacea) that are highly vulnerable to the fishery as target or by-catch species; and secondly, an increase in the availability of particulate and suspended organic and inorganic material, which is a direct consequence of both the discard practices of the fishery and episodic localised re-suspension of sediment following trawl disturbance of the substrata.

Sites L1 and M1 have other interesting features worthy of note. Site L1 supported a greater diversity of functional groups than other sites and appeared anomalous when considering the number of taxa in group 1c which was notably more specious here than at other sites (Table 22). Site L1 is known to be anomalous in terms of habitat features, being shallower than other sites and having a different substratum (muddy-sand as opposed to the mud or sandy-mud of other sites). However, the site did not appear to be anomalous when considering the pattern across sites in % biomass and % abundance, suggesting that these parameters are more robust in the light of minor between-site differences in habitat.

Table 22. Functional group composition of the epibenthic megafauna sampled at six sites (H1,H2, M1, M2, L1, L2) in the Clyde Sea area representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = light), giving the number of taxa, the percentage of total biomass and the percentage of total abundance contributed by each functional group at each site. NB. blank cells represent zero values, 0.0 indicates a value > zero but < 0.1.

	Functional Group	SITE H1	H2	M1	M2	L1	L2
number of taxa	1a					1	
	1c	23	31	25	28	42	24
	2b	4	5	6	4	4	4
	2c				1	1	1
	3a	3	2	1	1	1	1
	3b	1	1	1	1	1	1
	3c					1	
	Total	31	39	33	35	52	31
% biomass	1a					0.2	
	1c	32.6	45.9	66.3	77.1	81.2	89.7
	2b	66.3	53.7	33.6	22.9	18.5	9.8
	2c				0.0	0.0	0.0
	3a	1.1	0.4	0.0	0.1	0.0	0.4
	3b	0.0	0.1	0.0	0.0	0.0	0.0
	3c					0.0	
% abundance	1a					0.0	
	1c	25.3	39.3	36.1	61.1	82.2	82.9
	2b	72.4	58.7	63.5	38.5	17.5	14.4
	2c				0.0	0.1	0.0
	3a	1.8	0.8	0.0	0.4	0.0	2.3
	3b	0.6	1.2	0.4	0.1	0.0	0.4
	3c					0.1	

At site M1, there is a point of interest in the relative proportions in % biomass and % abundance for groups 1c and 2b. At other sites, the % biomass and % abundance for a particular functional group were approximately equal (e.g. at site L2, group 1c accounts for 89.7 % of biomass and 82.9% of abundance). However, at site M1 the % abundance for group 1c was approximately half the value of the % biomass, indicating a low number of relatively large motile predator-scavengers. For group 2b the situation was reversed, with % abundance being approximately double the value of the % biomass and indicating a high number of relatively small sedentary suspension feeders. Examination of the population densities of taxa at this site (Appendix IV) shows that this unusual pattern is attributable to two species which were characteristic of this site, namely the fish *Lumpenus lampretaeformis* (a motile predator-scavenger) and the gastropod *Turritella communis* (a sedentary suspension feeder).

4.4.4.2 Aegean

A total of 127 species of epibenthic megafauna were recorded in samples from the Dia Island area and were assigned to five functional groups (IC, 2B, 3A, 3B & 3C as defined in section 4.4.4.1. above) describing their dominant trophic mode and predominant foraging habit. Of these 127 species, 76 occurred at the northerly control site (FL-OUTN), 101 at the southerly control site (FL-OUTS) and 73 in the commercial trawling lane (FL-IN). At all three sites the majority of species were motile predator-scavengers (Table 23). Sedentary suspension feeders were the second-ranked functional group at all three sites, with least representation in the commercial trawling lane. The remaining three functional groups accounted for only 1.3-6.9% of the species.

The average number of functional groups per site was lowest in the commercial fishing lane (3.8) and slightly higher at the control sites (3.9 and 4.1 in FL-OUTN and FL-OUTS respectively). The average percentage contribution of motile predator-scavenger species (group 1C) ranged between 76.3% in the commercial trawling lane and 70.4 % in the south control site. There was a statistical significant difference between the sites FL-IN & FL-OUTS ($p<0.02$ ANOVA test) and FL-IN & FL-OUTN ($p<0.02$ ANOVA test) with higher percentage contribution of motile predator-scavengers species in the commercial fishing lane. Sedentary suspension feeders (group 2B) were ranked second in terms of their average percentage contribution in all three sites, with values ranging between 16.6% (in FL-OUTS) and 13.3% (in FL-IN). There were no significant differences between sites for the remaining functional groups with the exception of sessile deposit feeders (group 3B) with a reduced contribution in the commercial fishing lane ($p<0.02$ ANOVA test).

The figures for total species contribution (%) agree well with those for the average % species contribution, showing the significance of motile predator-scavengers (ranked first with >70% and with marginally higher numbers in the commercial lane) and sedentary suspension feeders (ranking second and with marginally lower numbers in the commercial lane).

However, this pattern was not repeated when considering the average % abundance or % biomass figures, with the striking difference that there was a marked reduction in the contribution of motile predator-scavengers (group 1C), counterbalanced by a substantial increase in the contribution made by sedentary suspension feeders (group 2B). This increase was mainly due to the presence of large numbers of the gastropod *Aporrhais serresianus* and the crinoid *Leptometra phalangium.* There was little difference between the three sites in the % abundance contribution with motile predator-scavengers and sedentary suspension feeders ranging between 49.7-51.4 and 45.2-47.0 % respectively (Table 23).

In terms of the average % biomass, motile deposit feeders (group 3C) ranked first, with values ranging between 39.1 and 41.8 % and with no obvious differences between sites. Their importance in terms of biomass was mainly attributable to the presence of the echinoderm *Stichopus regalis* which is much larger than any other common megafaunal species found in the area. The % biomass contribution of motile predator-scavengers and sedentary suspension feeders ranged between 30.01-34.17% and 25.25-28.09 % respectively.

In conclusion, results provided by this analysis varied greatly between the parameters considered (biomass, abundance or species numbers) and, with the exception of % species contribution, differences between sites were relatively small, especially when considering the large variation indicated by the high 95% confidence intervals. It should be noted that the analysis pools changes over a time period of a year (Sept. 1999 to Sept. 2000 in the case of Dia Island area) without exploring seasonal trends contemporary with fishing activities (i.e. during the open and closed fishing seasons).

Table 24 summarises the results of a parallel analysis based on data for the commercial fishing lane only, grouped temporally (by ‘open’ and ‘closed’ fishing season) and aggregated by functional groups. The open fishing season (O) includes tows conducted in November and April 2000 (9 tows in total) and closed fishing season (C) tows from September 1999 and 2000 (10 tows in total). The functional group dominance or percentage contribution patterns exhibited by each variable concur with the results of the previous analysis comparing sites over a whole year. Motile predator-scavengers species dominated both O & C periods (>70%), motile predator-scavengers and sedentary suspension feeders species had equal abundances (around 50%) while motile deposit feeders ranked first (>30%) in terms of biomass. Values were remarkably similar between open and closed seasons, but exhibited high standard deviation and confidence interval values. The only exception to this was a significant increase ($p < 0.001$, ANOVA test) in the open season in the absolute abundance of motile predator-scavengers (group 1C).

In addition to the above analyses the use of Average Dissimilarity, Cluster and MDS analyses was also investigated. Average dissimilarity between sites (as computed by the SIMPER routine in PRIMER) aggregated by functional groups was similar between all three comparisons (FL-IN & FL-OUTN, FL-IN & FL-OUTS and FL-OUTN & FL-OUTS) but values varied greatly depending on the variable used (species, abundance or biomass) ranging from 21% to 56 % in the case of species and biomass data respectively.

Temporal grouping the commercial trawl lane tows (for open and for closed fishing seasons) again produced varied results depending on the variable used (C & O group minimum and maximum average dissimilarities were 21.8 and 56.1 % for species and biomass data respectively).

Cluster- and MDS- analysis on species, abundance and biomass data aggregated by functional groups did not seem to group samples either spatially (by site) or temporally (by open or closed season). However, in MDS analysis (Fig. 72) samples were distributed in a more or less linear fashion but tows conducted during the closed season were generally separated from those during the open season. A repeat MDS analysis based solely on data from the fishing lane did not produce any seasonal groupings of samples (of certain months or between the open and closed fishing seasons).

In the Gouves experimental area, a grand total of 173 species of epibenthic megafauna were recorded and were assigned to six functional groups (IC, 2B, 2C, 3A, 3B & 3C as defined in section 4.4.4.1. above). A total of 135 species was recorded from the experimental area (EXP-T), 132 from the control area (EXP-C) and 59 from the commercial trawling lane (EXP-FL). In all three sites, the majority of these species were motile predator-scavengers (Table 25) with slightly greater proportions in the commercial trawling lane. Sedentary suspension feeders were the second ranked functional group (in all three sites, with minimum values in the commercial trawling lane), with the remaining four functional groups contributing less than 10 % of the species. The average number of functional groups per tow was significantly lower ($p<0.0001$) in the experimental fishing lane (EXP-T; 2.4) compared to the control site (EXP-C; 4.02).

The average % species contribution of motile predator-scavengers (group 1C) was high and relatively similar between sites (ranging from 81.4 to 85.6%, Table 25). Sedentary suspension feeders (group 2B) were the second ranked functional group in all three sites, with values ranging between 11.0% and 12.6%. The very low number of tows conducted in the commercial trawling lane (5 as opposed to 19 and 23 in the control and experimental areas respectively) resulted in markedly high confidence intervals.

In contrast to results from the Dia Island area, at Gouves the average % abundance and % biomass figures agreed well with those for the total or average species number. There was a highly significant difference in % abundance of motile predator-scavengers (group 1C) between EXP-C and EXP-T, with fewer in the control area ($p< 0.0001$). Average % abundance contribution of motile predator-scavengers and sedentary suspension feeders was very similar in the experimental area (EXP-T) and the commercial fishing lane (EXP-FL). There seemed to be little difference between the three sites in the % biomass contribution with motile predator-scavengers and sedentary suspension feeders ranging between 73.7-88.8 % and 10.9-17.9 % respectively (Table 25). A small increase in the average % biomass contribution of motile deposit feeders (group 3C) was again due to the presence of the large echinoderm *Stichopus regalis*.

Cluster- and MDS- analysis on catch data aggregated by functional groups did not show distinct groupings among samples, either spatially or temporally. However, cluster analysis on the average number of species showed slight evidence of grouping and the MDS analysis for average abundance (Fig. 73) showed a moderately linear pattern with 3 of the 5 samples from the commercial trawling lane being notably different to the majority of other samples from other sites.

In addition to the above analyses, differences between samples collected from the Gouves experimental trawling site (EXP-T) before and immediately (24hrs) after experimental disturbance by otter trawling were also investigated, the results being presented in Table 26. Once again, these highlight the overall dominance of motile predator-scavengers (group 1C) and a tendency towards a marginally higher dominance immediately after trawling (however this was not statistically significant).

Table 23. Functional group analysis for three sites by Dia Island, Aegean, as determined from samples collected by Agassiz trawl. Functional groups (1C, 2B, 3A, 3B, 3C) as defined in section 4.4.4.1. Av. = average SD = standard deviation and CI = 95% confidence intervals. Shaded values in bold denote statistically significant differences.

Site		FL-OUTN			FL-OUTS			FL-IN		
Species (Tows)		76 (17)			101 (19)			73 (19)		
		n	%		n	%		n	%	
Species recorded	IC	57	75.0		71	70.3		58	79.5	
	2B	10	13.2		11	10.9		6	8.2	
	3A	4	5.3		7	6.9		4	5.5	
	3B	4	5.3		7	6.9		3	4.1	
	3C	1	1.3		5	5.0		2	2.7	
		Av.	SD	CI	Av.	SD	CI	Av.	SD	CI
Funct.Groups.		3.94	0.75	0.34	4.11	0.94	0.42	3.79	0.79	0.35
No. of Species	IC	13.53	3.94	1.77	18.37	4.67	2.10	15.37	4.30	1.93
	2B	3.18	1.07	0.48	4.05	1.22	0.55	2.58	1.22	0.55
	3A	0.94	0.83	0.37	1.26	1.28	0.58	0.89	0.66	0.30
	3B	0.41	0.71	0.32	1.00	0.88	0.40	0.32	0.48	0.21
	3C	0.94	0.24	0.11	1.53	0.96	0.43	0.84	0.60	0.27
% Species	IC	**70.52**	7.37	3.31	**70.41**	8.33	3.75	**76.28**	6.47	2.91
	2B	16.58	3.71	1.67	15.81	4.62	2.08	13.33	6.46	2.91
	3A	5.53	6.15	2.76	4.20	3.88	1.74	4.60	3.40	1.53
	3B	1.92	3.28	1.47	**4.00**	3.82	1.72	**1.54**	2.38	1.07
	3C	5.44	2.31	1.04	5.58	3.23	1.45	4.25	3.13	1.41
%Abund.	IC	51.28	31.05	13.96	49.69	23.09	10.38	51.38	23.90	10.75
	2B	45.68	31.70	14.25	46.96	23.35	10.50	45.20	25.84	11.62
	3A	0.68	1.00	0.45	0.95	1.33	0.60	0.74	0.95	0.43
	3B	0.22	0.63	0.28	0.78	1.03	0.46	0.38	0.84	0.38
	3C	2.14	1.73	0.78	1.62	2.14	0.96	2.31	4.39	1.97
%Biomass	IC	34.17	26.20	11.78	30.30	30.34	13.64	30.01	23.34	10.49
	2B	25.25	25.29	11.37	30.31	23.52	10.57	28.09	23.52	10.57
	3A	0.08	0.11	0.05	0.18	0.49	0.22	0.10	0.18	0.08
	3B	0.02	0.04	0.02	0.09	0.19	0.09	0.04	0.12	0.06
	3C	40.48	29.21	13.13	39.13	34.27	15.41	41.76	30.33	13.64

Table 24. Functional groups analysis for the Dia Island commercial fishing lane, comparing open and closed fishing seasons. Functional groups (1C, 2B, 3A, 3B, 3C) as defined in section 4.4.4.1. Samples for open season collected in Nov. & Apr. 00, for closed season in Sept. 1999 & 2000. Abundance and biomass data are standardised to 1000 m^2 swept area. Av. = average, SD = standard deviation, CI = 95% confidence interval. Shaded values denote statistically significant differences.

Fishing Season		- - - - - -OPEN - - - - - -			- - - - - CLOSED - - - - -		
No. of Tows			9			10	
		Av.	SD	CI	Av.	SD	CI
Funct.Groups.		3.56	0.88	0.58	4.00	0.67	0.41
No of Species	IC	16.11	4.08	2.66	14.70	4.60	2.85
	2B	2.56	1.42	0.93	2.60	1.07	0.67
	3A	0.89	0.78	0.51	0.90	0.57	0.35
	3B	0.22	0.44	0.29	0.40	0.52	0.32
	3C	0.89	0.78	0.51	0.80	0.42	0.26
% Species	IC	77.72	6.92	4.52	74.99	6.10	3.78
	2B	12.91	8.23	5.38	13.71	4.79	2.97
	3A	4.17	3.70	2.42	4.98	3.25	2.02
	3B	0.97	1.95	1.27	2.05	2.70	1.68
	3C	4.23	3.83	2.50	4.27	2.56	1.58
Abundance	IC	**64.94**	20.13	13.15	**35.22**	12.15	7.53
	2B	112.21	121.03	79.07	45.57	45.46	28.17
	3A	0.51	0.70	0.45	0.64	0.58	0.36
	3B	0.17	0.42	0.28	0.41	0.59	0.36
	3C	1.45	1.36	0.89	1.95	2.27	1.41
% Abund.	IC	53.24	26.70	17.44	49.70	22.41	13.89
	2B	45.35	26.93	17.60	45.07	26.28	16.29
	3A	0.63	1.10	0.72	0.83	0.84	0.52
	3B	0.05	0.10	0.07	0.67	1.09	0.67
	3C	0.74	0.70	0.46	3.73	5.78	3.58
Biomass	IC	90.27	41.54	27.14	77.3	73.87	45.78
	2B	164.23	174.94	114.29	70.34	75.80	46.98
	3A	0.14	0.16	0.11	0.18	0.17	0.11
	3B	0.05	0.13	0.08	0.28	0.65	0.40
	3C	230.02	261.94	171.13	246.31	262.62	162.77
% Biomass	IC	39.52	30.30	19.80	21.44	10.07	6.24
	2B	28.54	15.78	10.31	27.69	29.74	18.43
	3A	0.14	0.26	0.17	0.07	0.06	0.04
	3B	0.00	0.01	0.01	0.08	0.17	0.10
	3C	31.80	26.14	17.08	50.73	32.31	20.03

Table 25. Functional groups analysis for three sites at the Gouves experimental area, Aegean.. Explanation as for Table 23.

	Site	**EXP-C**			**EXP-T**			**EXP-FL**		
	Species (Tows)	135 (19)			132 (23)			59 (5)		
		n	%		n	%		n	%	
Species recorded	1C	94	69.6		91	68.9		44	74.6	
	2B	26	19.3		29	22.0		11	18.6	
	2C	2	1.5		2	1.5		1	1.7	
	3A	3	2.2		4	3.0		1	1.7	
	3B	5	3.7		2	1.5		2	3.4	
	3C	5	3.7		4	3.0				
		Av.	SD	CI	Av.	SD	CI	Av.	SD	CI
	Funct.Groups.	**4.02**	1.68	0.75	**3.13**	0.87	0.36	**2.40**	1.67	1.47
No. of Species	1C	35.74	5.64	2.53	27.26	5.89	2.41	**17.20**	9.60	8.42
	2B	5.47	3.19	2.79	4.26	2.24	0.92	2.80	4.15	3.64
	2C	0.74	0.56	0.49	0.65	0.57	0.23	0.20	0.45	0.39
	3A	0.63	0.60	0.52	0.17	0.39	0.16	0.20	0.45	0.39
	3B	0.42	0.61	0.53	0.09	0.29	0.12	0.40	0.55	0.48
	3C	1.47	0.90	0.79	0.30	0.56	0.23			
% Species	1C	81.35	7.06	3.18	83.85	5.29	2.16	**86.57**	12.93	11.33
	2B	11.76	5.48	4.80	12.57	4.97	2.03	11.01	10.99	9.63
	2C	1.55	1.12	0.98	1.87	1.61	0.66	0.43	0.97	0.85
	3A	2.13	2.04	1.79	0.69	1.37	0.56	0.43	0.97	0.85
	3B	0.83	1.14	1.00	0.18	0.61	0.25	1.55	2.43	2.13
	3C	2.39	1.77	1.55	0.84	1.76	0.72			
% Abundance	1C	**88.05**	5.19	2.33	**93.11**	3.16	1.29	**93.64**	6.23	5.46
	2B	9.50	5.28	4.63	5.58	2.92	1.19	5.44	5.37	4.71
	2C	0.87	0.93	0.82	0.85	0.99	0.41	0.11	0.26	0.23
	3A	0.58	0.72	0.63	0.16	0.33	0.13	0.23	0.51	0.45
	3B	0.23	0.41	0.36	0.03	0.09	0.04	0.58	0.82	0.72
	3C	0.77	0.68	0.60	0.26	0.66	0.27			
% Biomass	1C	73.69	23.45	10.54	86.58	17.37	7.10	**88.80**	14.73	12.91
	2B	17.91	15.72	13.78	10.64	12.31	5.03	10.93	14.86	13.02
	2C	0.03	0.06	0.06	0.03	0.05	0.02	0.00	0.00	0.00
	3A	1.39	5.82	5.10	0.03	0.08	0.03	0.02	0.05	0.04
	3B	0.26	0.97	0.85	0.02	0.07	0.03	0.25	0.52	0.46
	3C	6.72	12.33	10.81	2.71	12.90	5.27			

Table 26. Functional groups analysis for the experimental trawling lane at Gouves, Aegean, in April 2000, comparing before- and (24 hrs) after- experimental otter trawling. Abbreviations as for Table 24.

EXP-T		------ Before ------			------ After ------		
No. of Tows			5			5	
		Av.	SD	CI	Av.	SD	CI
No. of Species	1C	29.80	3.56	3.12	32.80	6.72	5.89
	2B	5.60	1.52	1.33	5.20	2.95	2.59
	2C	1.00	0.71	0.62	0.60	0.55	0.48
	3A	0.00	0.00	0.00	0.60	0.55	0.48
	3B	0.20	0.45	0.39	0.20	0.45	0.39
	3C	0.40	0.89	0.78	0.20	0.45	0.39
% Species	1C	**80.87**	3.80	3.33	83.21	5.85	5.13
	2B	15.21	3.78	3.31	12.68	5.16	4.52
	2C	2.56	1.64	1.44	1.48	1.44	1.26
	3A	0.00	0.00	0.00	1.74	1.64	1.44
	3B	0.45	1.02	0.89	0.38	0.86	0.75
	3C	0.91	2.03	1.78	0.50	1.12	0.98
Abundance	1C	214.23	86.96	76.22	189.70	119.20	104.48
	2B	11.03	3.53	3.10	10.75	8.55	7.50
	2C	2.31	3.18	2.78	2.62	3.58	3.13
	3A	0.00	0.00	0.00	0.45	0.41	0.36
	3B	0.17	0.39	0.34	0.21	0.46	0.41
	3C	0.35	0.77	0.68	0.21	0.46	0.41
% Abund.	1C	93.68	2.35	2.06	92.50	3.99	3.50
	2B	**5.28**	2.22	1.94	5.45	3.21	2.81
	2C	**0.90**	0.93	0.81	1.50	1.64	1.43
	3A	0.00	0.00	0.00	0.42	0.44	0.39
	3B	0.05	0.10	0.09	0.07	0.17	0.15
	3C	0.09	0.20	0.18	0.05	0.12	0.11
Biomass	1C	164.85	119.75	104.96	109.53	77.90	68.28
	2B	29.69	22.78	19.96	11.29	11.87	10.40
	2C	0.05	0.08	0.07	0.06	0.08	0.07
	3A	0.00	0.00	0.00	0.08	0.08	0.07
	3B	0.01	0.03	0.02	0.07	0.15	0.13
	3C	0.06	0.14	0.12	0.01	0.01	0.01
% Biomass	1C	79.49	16.05	14.07	85.64	17.62	15.44
	2B	20.44	15.98	14.01	14.13	17.51	15.35
	2C	0.03	0.04	0.04	0.05	0.06	0.06
	3A	0.00	0.00	0.00	0.12	0.14	0.12
	3B	0.01	0.01	0.01	0.06	0.15	0.13
	3C	0.03	0.08	0.07	0.00	0.01	0.01

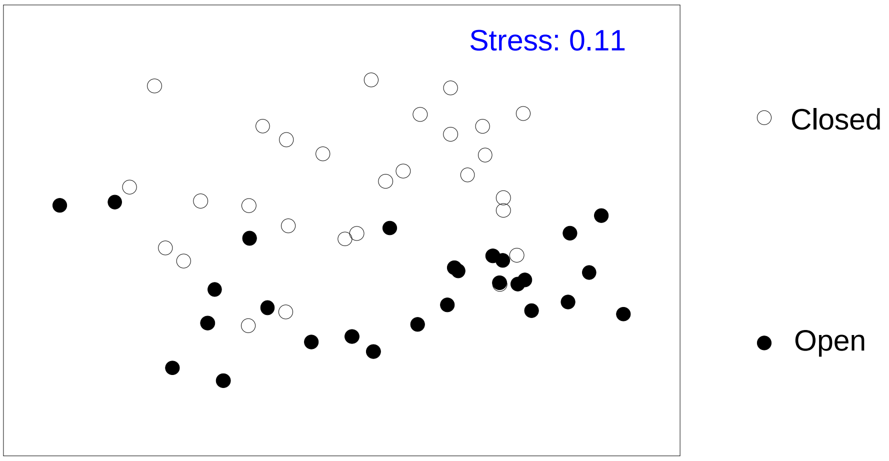


Figure 72. MDS analysis of functional group composition of epibenthic megafauna from sites at Dia Island, Aegean, in the open and closed fishing seasons. Agassiz trawls data has been aggregated by functional group.

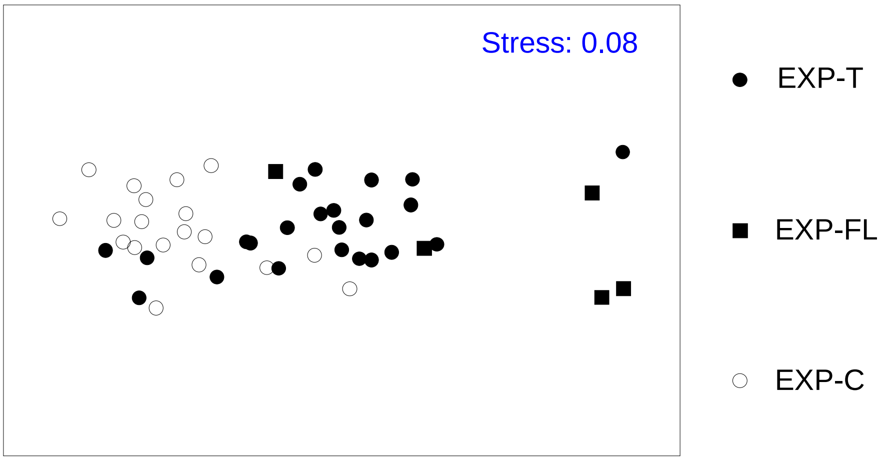


Figure 73. MDS analysis of functional group composition of epibenthic megafauna at the three sites in the Gouves experimental area, Aegean. Agassiz trawls data has been aggregated by functional group.

In Summary – Functional Group Composition

Clyde Sea

- Functional group analysis of the Clyde data suggest that a relationship exists between the intensity of trawl fishing experienced by a site and the functional group composition of the epibenthic megafauna at that site.
- As fishing intensity increases there is a shift in the functional group composition of the epibenthic megafauna away from predation - scavenging and toward suspension feeding.
- The method could be applied to assessing the relative fishing intensity at a number of sites (if control sites are available) or at a single site over time. It is not well suited to providing a scalar measure of the instantaneous fishing intensity at a site (*cf.* sidescan sonar methods).
- The method may be best suited to supplement and/or support more quantitative methods of rapid assessment.

Aegean

Dia Island - deep muddy habitat.

- Functional group analysis in the Aegean showed no striking spatial or temporal differences between control and impacted sites at Dia Island.
- Univariate analyses differentiated the commercial fishing lane at Dia Island from the two control sites in terms of percentage species contribution, with increased numbers of motile predator-scavengers species in the commercial fishing lane. However even this statistically significant difference was only subtle (approx. 5% more than in the control sites). Differences between the open and closed fishing seasons were even more subtle (around 3%).
- Multivariate analyses pointed to some differences in the abundance pattern between the open and the closed fishing seasons, but neither multivariate or univariate analyses directly identified the cause or ecological significance of these differences.
- Both analyses showed a high degree of variability in the data. Certain megafaunal species may not be sampled adequately by the Agassiz trawl when towed over distances of 2-3 km and unusually high numbers in one tow indicate a patchy distribution, which may bias results. The patchy distribution of commercial trawling effort could also contribute to the

observed variability, with pristine pockets and heavily impacted areas both clearly noted in the video records of the area.

Gouves area - shallower 'maerl' habitat.

- Functional group analysis in the Gouves area showed an overall dominance (% species, % abundance and % biomass) of motile predator-scavenger species and a tendency towards marginally higher dominance in the commercial trawling lane and immediately after experimental trawl disturbance.
- As with the Dia Island area only subtle spatial or temporal differences were noted.
- Low numbers of observations and the highly heterogeneous nature of the shallow maerly sediments in the area were considered to contribute significantly to the variability in the data.

In General

- Functional group analysis requires in-depth knowledge of the ecology of the species involved and assignment of species to functional groups may not always be straightforward, especially in respect of species which are capable of switching trophic modes or which have contradictory feeding modes cited in the literature.
- Samples invariably contain species from a range of niches (e.g. demersal fish, epibenthos, benthic infauna). Prior to analysis, species which are true representatives of the epibenthic megafauna have to be identified, and data selected accordingly. Such selection is not always straightforward, and the inclusion or exclusion of certain species, which may dominate the sample, can have dramatic effects on the analysis.
- There is little evidence to suggest that functional group analysis could offer a useful stand-alone method for the rapid assessment of the impact of otter trawls. Its use is, however, recommended to provide complementary information, having the potential to provide useful insights into the wider community response to trawling impacts, as well as the distribution patterns of numerically dominant or ecologically important species.

4.5 Underwater Television Methods (Task 5)

General comments

Underwater TV systems (video-sledge and ROV) were used to 'ground truth' observations made by sidescan sonar both in the Clyde Sea area and the Aegean, confirming that marks detected by the sonar were the furrows and berms created in the sediment by the otter boards of the trawl gear. The converse was also validated, i.e. the absence of trawl marks in a sidescan survey reflected the genuine absence of otter board marks in the sediment. Video footage revealed smaller marks, attributable to other parts of the trawl gear, which had not been detected by the sidescan sonar. In the Clyde Sea, these were typically marks formed by the bobbins of the ground-rope and were approximately 5 – 10 cm in width and 2 – 5 cm in depth (measured by ROV – see section 4.5.2). Marks left by otter boards typically had widths > 15 cm and depths >10 cm. This demonstrated the lower limit of resolution of the sidescan sonar. Similar marks were noted in the Aegean.

In the Clyde Sea, TV observations also revealed that some megafaunal taxa were more common that anticipated from trawl samples. These were notably taxa which were 'rooted' in the sediment, such as tube-building worms (Sabellidae), burrowing anemones and the sea pen *Virgularia mirabilis.* Though not strictly 'epibenthic' in habit, these had been noted in trawl samples but were often damaged.

4.5.1 Video-sledge

4.5.1.1 Clyde Sea

Semi-quantitative analysis of the extent of anthropogenic and biogenic disturbance of the sediment proved simple to apply. An initial period of training was required to familiarise the observer with the range and variety (particularly the extremes) of disturbance visible in the video record. When scoring anthropogenic disturbance it was particularly important to focus on the frequency of disturbance and overcome a natural tendency to score fresh marks more highly than weathered marks. With increasing experience it was possible to detect subtle differences between sites in the form of some biogenic structures. In unimpacted areas, the burrows of some mud-dwelling organisms (*Nephrops norvegicus*, some thalassinidean mud-shrimps and some worms) were characterised by high spoil mounds, giving them the appearance of small volcanoes. At moderately fished sites the spoil mounds were characteristically smaller and wider, and were scarce on highly impacted sites. This difference can be attributed to the frequency with which such mounds are destroyed by the passage of trawl gear. Attempts to measure or estimate the vertical extent of objects recorded from a sledge mounted video camera proved unsatisfactory and the strength of the technique lay in visual characterisation of sites.

Scoring of anthropogenic and biogenic disturbance on separate 4-point scales allowed some objective comparison between sites, a comparison that would have been difficult to report on a purely subjective basis. As there were two 4-point scales, each video clip was given one of sixteen (4 x 4) possible scores. Scores were tallied for each site surveyed and represented on a 3-dimensional Cartesian grid (Fig.s 74 & 75) the height of each bar showing the frequency with which each score had occurred. These figures indicate clearly the variability of disturbance within a site, and sites were characterised by a clustering or spread of points within the grid. A low anthropogenic score characterised lightly impacted sites, though site L2 showed far higher levels of biogenic modelling than site L1. The frequency of ‘a0’ scores (no anthropogenic disturbance) reduced as nominal fishing impact increased and heavily fished sites had the greatest variability in scores.

This scoring technique enabled a relatively detailed comparison of multiple sites over time (i.e. the two surveys from different years). A valid, but less detailed, comparison was achieved based on the means of the biogenic and anthropogenic scores at each site. These were used as Cartesian co-ordinates to position points on a 2-dimensional grid (Fig. 76), showing more clearly the relationships between sites.

It will be noted that for some sites it was not possible to apply the scoring method to all ten 2-minute video clips; only nine clips were analysed for site H2 in 1999 and only five for site L2 in 2000. This reflects variability in the quality of video footage, which had two main causes, water clarity and sledge attitude. Water clarity was naturally variable from day to day depending on weather conditions and the proximity of vessels that were actively trawling in the area. The plume of sediment thrown into the water by a trawl takes many hours to re-settle, can drift considerable distances with the tide and may remain discrete or become dispersed. Meeting such a plume can lead to a short inconvenience in poor visibility or the complete abandonment of a sledge deployment. The attitude of the sledge can also change as the survey vessel manoeuvres or responds to deviations from the target towing speed. The commonest effect was for the front of the sledge to lift, causing the camera to lose sight of the sea bed. Towing lightweight gear effectively at slow speed requires an appreciable degree of skill on the part of the skipper of the survey boat.

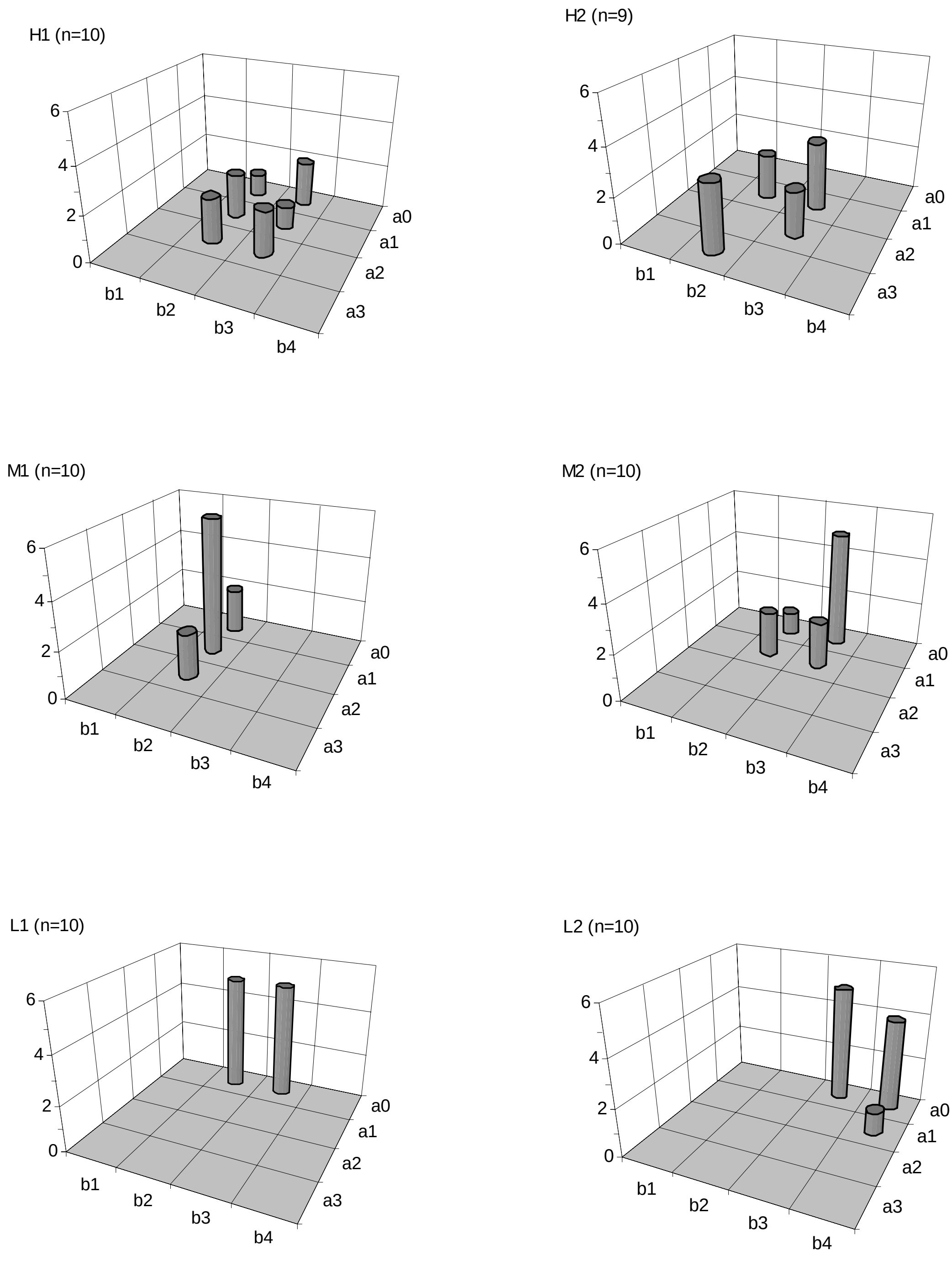


Figure 74. Graphical representation of the analysis of visual transects captured by a sledge-mounted underwater TV camera deployed at six sites in the Clyde Sea area representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = light). Multiple 2-minute video clips were assessed for disturbance to sediment and scored on two 4-point scales, one rating anthropogenic disturbance (a0 – a3) the other rating biogenic disturbance (b1 – b4). 'n' indicates number of video clips analysed per site. This assessment relates to the 1999 survey.

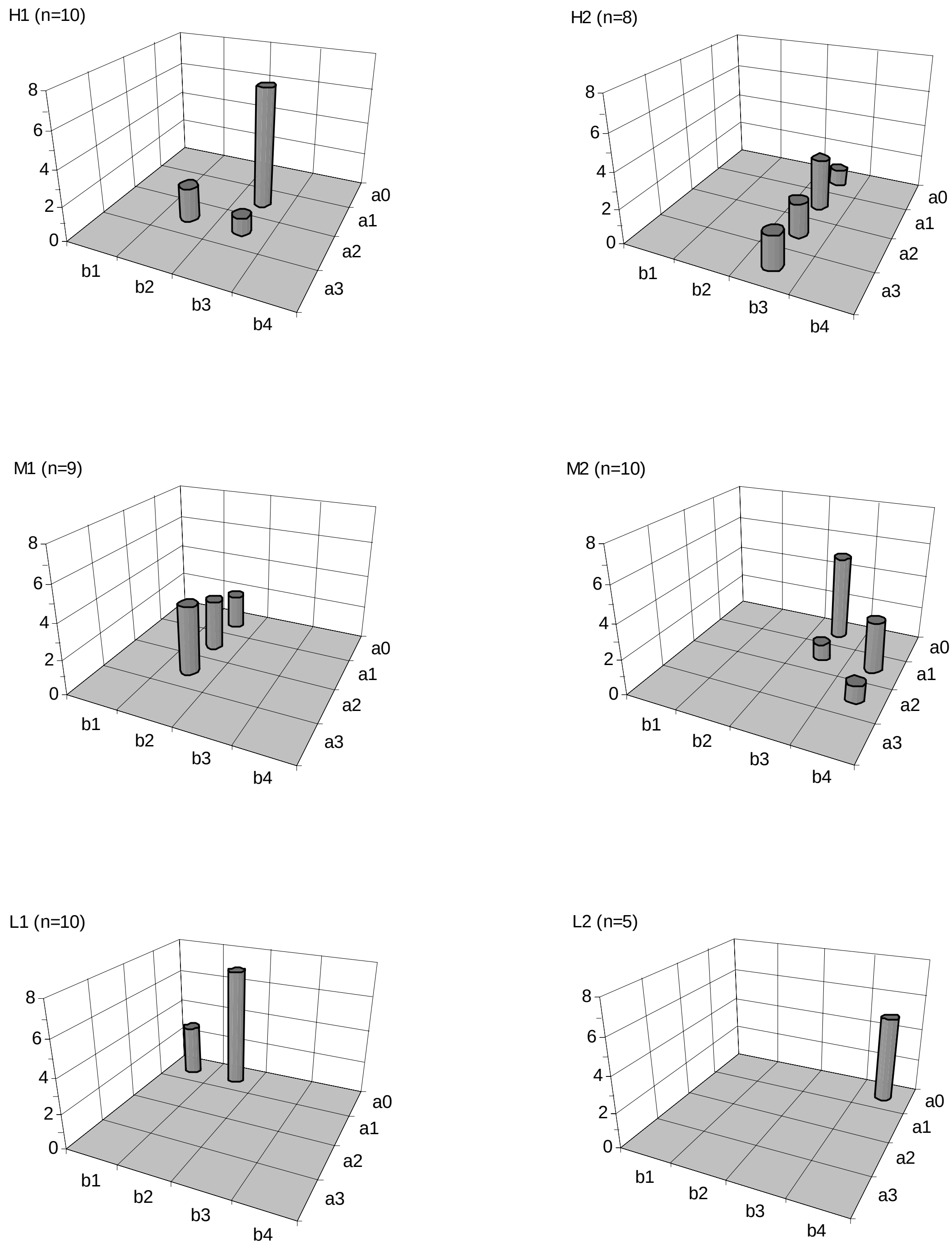
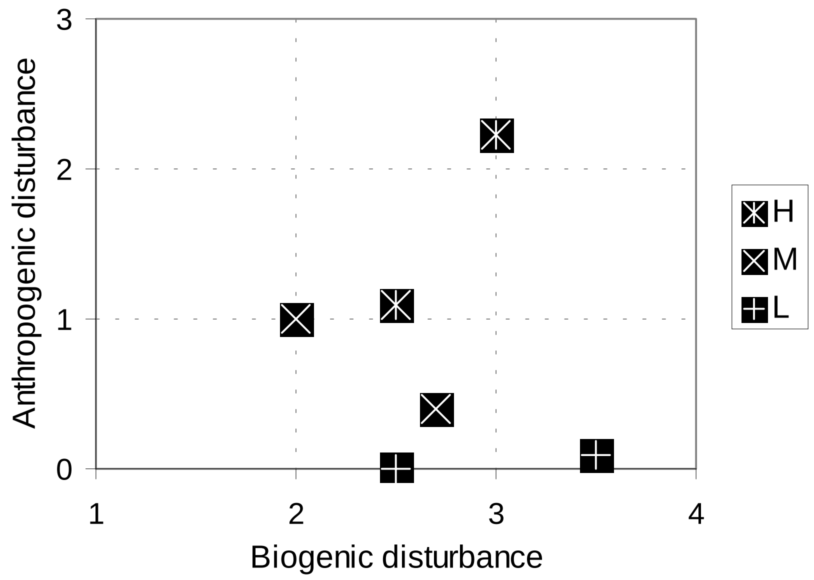


Figure 75. As for Fig. 74, but this assessment relates to the year 2000 survey.

a)



b)

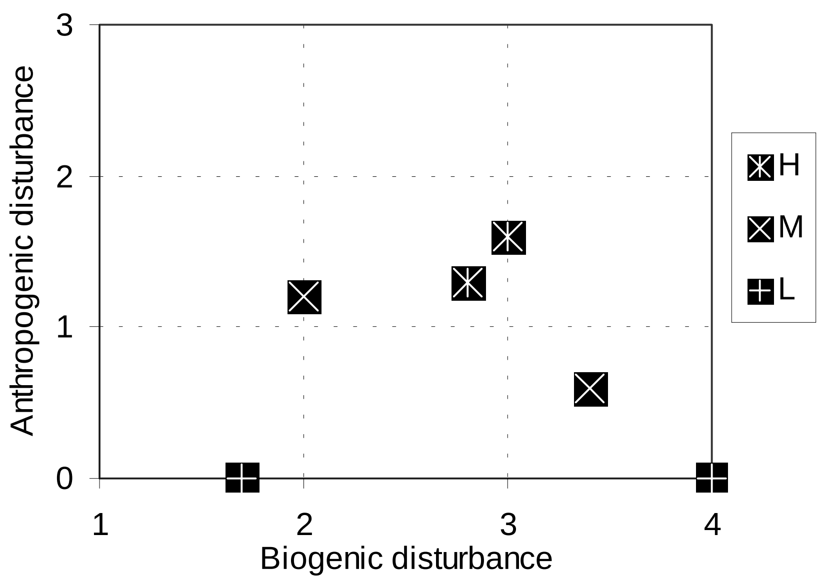


Figure 76. Summary representation of Fig. 74 (a, 1999) and Fig. 75 (b, 2000). Points for the six sites within the Clyde Sea area representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = light) are positioned in a 2 dimensional grid, the Cartesian co-ordinates of each point being the mean scores for the biogenic and anthropogenic disturbance at that site.

4.5.1.2 Aegean

Around the commercial fishing lane in Dia Island, the towed video-sledge generally gave clear images of the sediment with the exception of occasional turbidity clouds that obscured the view. This occurred when the system was towed in the vicinity of recent trawling activities. Sediments appeared generally soft with some slightly coarser, possibly harder, elements (appearance of maerl fragments) to the extreme north edge of the surveyed areas corresponding to the bottom of the slope up to Dia Island.

Trawling impacts were readily evidenced through:

- Large furrow marks (from trawl doors): deep continuous plough marks in the sediment surface, extending to at least 20 cm sediment depth, triangular in section but non-symmetrical, with a spoil heap principally on one side of the mark.
- Scrape marks (from sweeps and trawl wires): parallel sets of non-continuous scrape marks on the sediment surface with small furrows and channels with a penetration of a few centimetres.
- Flattened areas (from ground ropes and nets) with no characteristic topographical surface features.
- Areas with a ‘soft’ appearance to the sediment surface with resettled suspended matter.

Figure 77 shows a variety of images demonstrating some of the different sedimentary impacts of trawling and additionally an adjacent untrawled area. The images are from Dia Island, on a soft silty sediment at approximately 200 m depth.

Fresh trawl marks had very clean-cut surfaces and irregular shapes, with spoil heaps with lighter grey coloured mud clasts visible. Older marks had been overlain by fresh marks and were characterised by much smoother edges, with bioturbation holes in the side cuts of door marks and new spoil mounds in the furrows. In some areas flattened by the passage of trawl nets and ground ropes, old door marks appeared to below the flattening level with untouched biogenic features in them. Trawling marks were evident all through the year including the closed season. Fresh marks were less visible in the closed season indicating that they were biogenically re-worked, but substantial marks still remained noticeable across the 4-month break.

The traces of towed scientific equipment were also visible on the sediment surface, notably the skid marks of the towed video-sledge (two close parallel marks) and the Agassiz trawl (two close parallel marks with centre scrape marks from drooping tow warp). On at least one occasion the footprint of the SPI drop camera imaging system was noted.

Biogenic impacts were noted through the presence of various sized mounds characteristic of thalassinidean burrowing shrimps and echiuran worms. Burrow openings descended vertically (characteristic of the burrowing shrimp *Calocaris macandreae*) or obliquely (characteristic of the burrowing crab *Goneplax rhomboides*). On the sediment surface the crinoid *Leptometra phalangium* was evident, normally in small aggregations; the ophiuroid *Ophiura ophiura* was seen either on the sediment surface or buried (as star traces); and the holothurian *Stichopus regalis*, and occasionally the shrimp *Parapenaeus longirostris*, were present on the surface. Some fish were also seen, particularly gobies and some flatfish on the sediment surface. More rarely seen were scorpion fish, triglids, *Serranus hepatus* in burrow openings and, on one occasion, the shark *Oxynotus centrina*.

The track plots of all the video-sledge tows are shown in Fig. 78. During each sampling period, the sledge was generally towed in a zig-zag pattern across the fishing lane from the unfished areas to the north and south. At each position fix, water depth was also noted and this was used to plot a bathymetric contour map of the area covered by the sledge shown in Fig. 79. In the plot, the valley to the south of the island is depicted with its deepest area to the West (250 m) rising to more even depths across the ground to the East (200 m).

Figure 80 shows the spatial mapping of anthropogenic features on the 0-3 scale defined in Appendix II. The trawl lane is clearly depicted through the middle of the surveyed area by the darker shading. There were some minor inconsistencies within the area with respect to anthropogenic impacts which may be due to not accounting for the layback (distance of the sledge behind the towing vessel) when position fixing.

The mapping of the bioturbation impact factor in Fig. 81 exhibited an opposite trend to that of anthropogenic impact where, generally speaking, areas of high levels of bioturbation features occurred in areas with low levels of anthropogenic impact and vice versa. Bioturbation features were more pronounced to the south of the trawling lane than to the north; this was matched with the recording of coarser sediments at the base of the slope up to the island.

The distribution of the crinoid *Leptometra phalangium* in Fig. 82 matched that of the high bioturbation levels, on the south side of the trawl lane. Individuals were only ever observed in the middle of the trawl lane (east side) during the closed trawling season, although they were found on the southern periphery of the trawl lane during the trawling season. The only individuals found to the north of the lane were on the far eastern edge and none was observed on the northern periphery at the bottom of the Dia Island slope.

Observations from the towed video-sledge on the coarser sediment at the Gouves experimental site gave some slightly different findings. Penetration of the trawl doors was much less and small scrape marks were rarely visible. Larger door marks were evident as shallow scrapes approximately 40 cm wide, with no strong traces of spoil heaps or sediment clasts. Maerl sand and maerl/shell fragments tended to collect along the scrape marks making them more visible to the eye. The experimental trawl marks were evident for approximately 3-4 months and then became indistinguishable from more recent Agassiz trawl marks.

A number of features were noted on the sediment surface in the experimental area before trawling and consistently over time in the control area. These were mostly in the form of sessile epifaunal species such as ascidians and sponges, bryozoans and hydroid masses as well as occasional polychaete tubes (*Sabella pavonina*) and mobile forms, including hermit crabs, asteroids and ophiuroids. The ophiuroid *Ophiocantha setosa* was observed in large aggregations especially towards the edges of the experimental trawling lane. Maerl sand and larger maerl pieces were evident in complexes of different types of red algae (harder *Lithothamnion* and *Lithophyllum* type as well as soft-fronded species) with some other algae present (browns/greens).

Because of the nature of the narrow experimental fishing lane and continued use of the Agassiz trawl in this area for scientific purposes it was not possible to utilise the quantitative methodology for analysis as undertaken at the Dia Island ground.

Practical Considerations

The towed video-sledge proved to be an excellent tool for identification and estimation of trawling gear marks on the sea bed. Its only operational disadvantages in comparison to sonar methods may be its susceptibility to poor visibility, and the speed of data collection. Resolution was much higher, and additionally, it allowed the semi-quantitative assessment of the age of trawl marks. Other features of importance may also be seen including lesser anthropogenic marks (flattening, scrape marks) as well as biological features, such as the presence and abundance of identifiable fauna. *Leptometra phalangium* is a relatively large species and occurred frequently enough to estimate population densities. This is a fragile species of limited motility and would be a suitable key indicator species for un-impacted areas.

Given the relative definition of the fishing lane, positioning of the sledge was fairly important. Tracking for this study was undertaken by recording the position of the towing vessel and ignoring the layback which may have been in the order of 200 m maximum. Layback can never be assumed to be precisely behind the towing vessel and it was known that the sledge was often off-set from the towing line (i.e. to the left or right of the vessel) because of windage and wave action. The only way to correct for this is to have an acoustic tracking beacon on the sledge (which was not available at the time of data collection).

The selection of a 2 minute observation period in every 5 minutes of tow was arbitrary, but worked well in the Aegean. With hindsight it could have been reduced to 30 seconds or one minute. The advantage of a longer time period is in a greater representation of sea bed conditions in an area, but the disadvantage is in the variety of different features that may be noted from a clear area to a freshly trawled area, leaving the observer in a dilemma as to what to record. On the other hand shorter time periods may miss important features that are located between the observation periods.

The anthropogenic and bioturbation scales also proved to be adequate for analysis in the Aegean. Again they are arbitrary in that they could have been based on 10 point scales instead of 4. The anthropogenic scale also could be improved to include the density of trawling marks on the sea bed, which may be an important factor overlooked by the current scale.

a) Trawl door mark with bioturbation mounds in the background.

b) Fresh spoil heap from trawl door mark with scrape marks in the background.

c) Wire scrape marks on flattened ‘soft’ sediment with feeding trail mark evident.

d) Old trawl door marks with rounded edges.

e) Bioturbation mounds in an untrawled area.

f) Surface epifauna – the crinoid *Leptometra phalangium* on the sediment surface

Figure 77. Video grabbed images of trawled and untrawled areas from the Dia Island commercial trawling lane and adjacent control area.

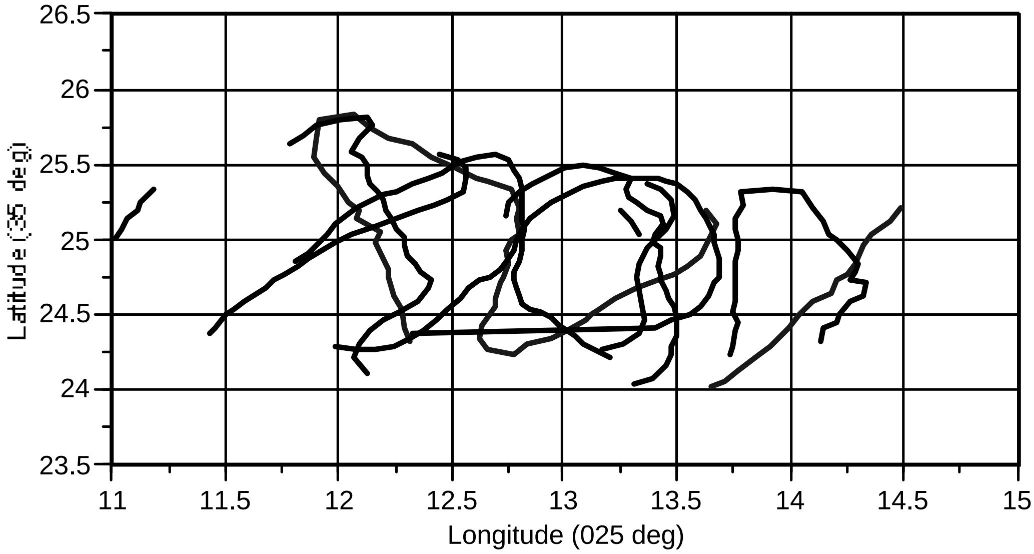


Figure 78. Geo-referenced track positions for video-sledge surveys made in the area of the Dia Island commercial trawling lane, Aegean Sea.

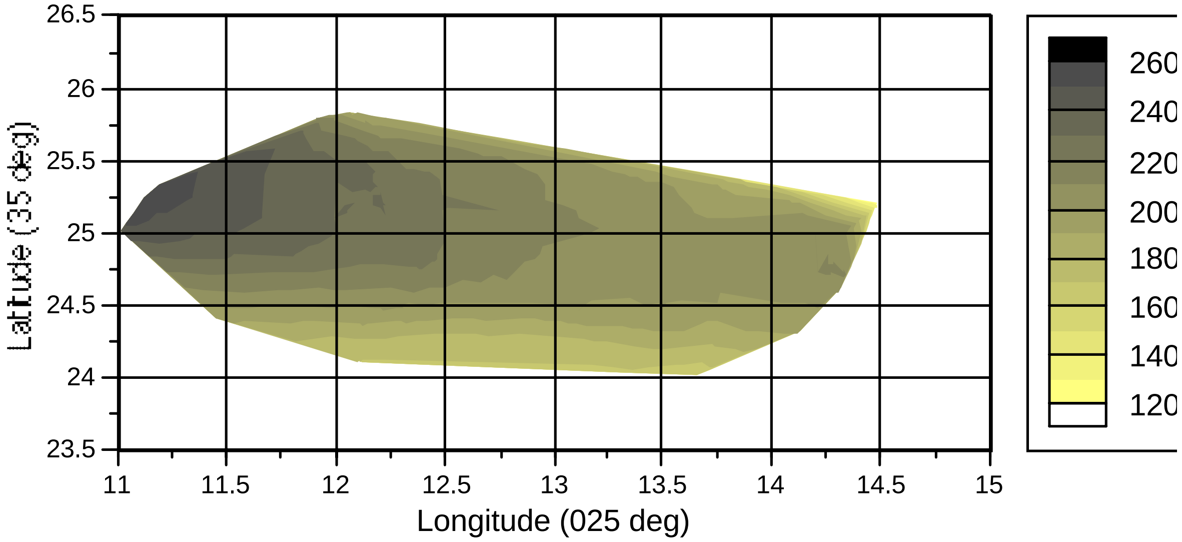


Figure 79. Bathymetric contour map (depth in m) covering the area of the video-sledge surveys on the Dia Island fishing ground, Aegean Sea.

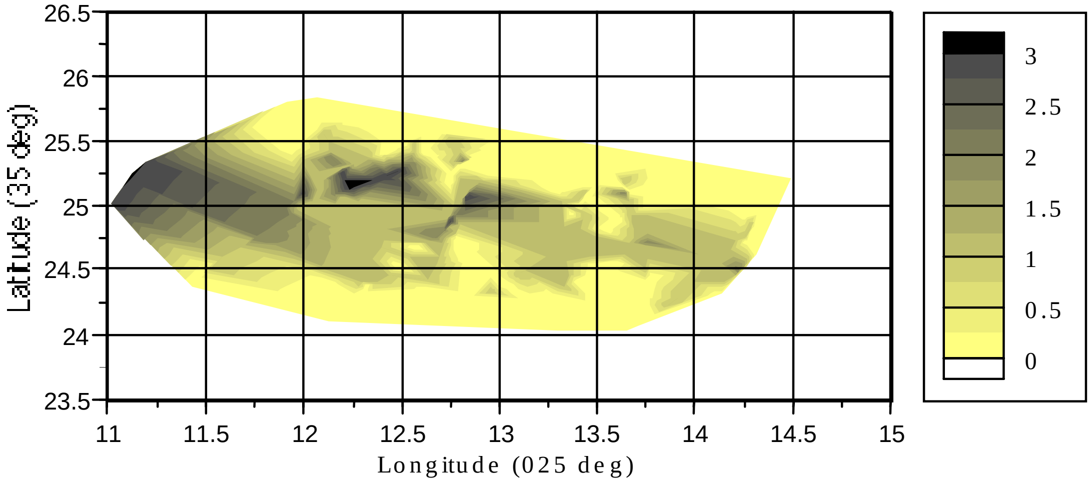


Figure 80. Contour map of anthropogenic impact (Scale 0-3, see Appendix II) on the Dia Island fishing ground, Aegean Sea, as determined from analysis of video-sledge surveys.

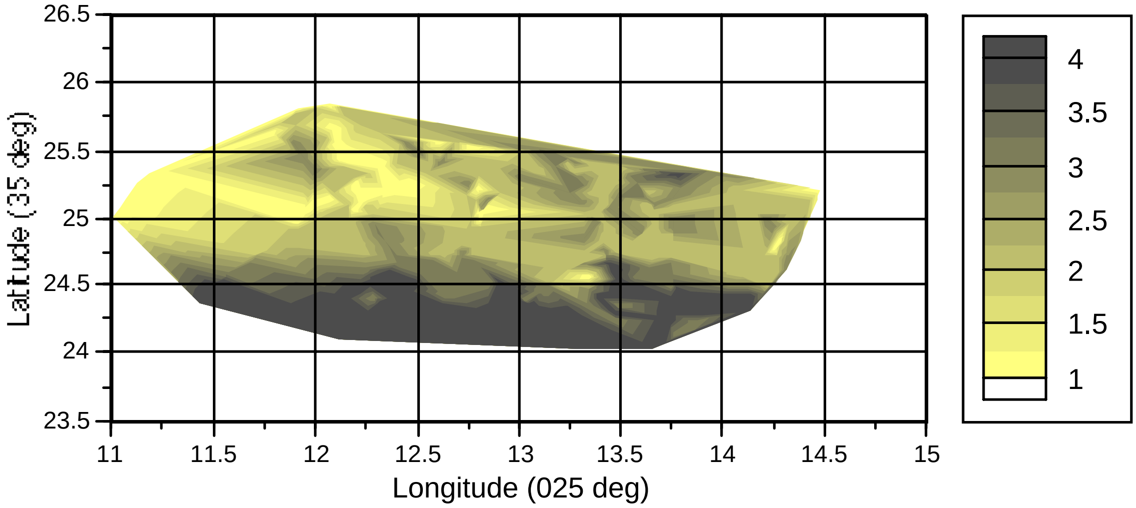


Figure 81. Contour map of bioturbation factor (Scale 1-4, see Appendix II) on the Dia Island fishing ground, Aegean Sea, as determined from analysis of video-sledge surveys.

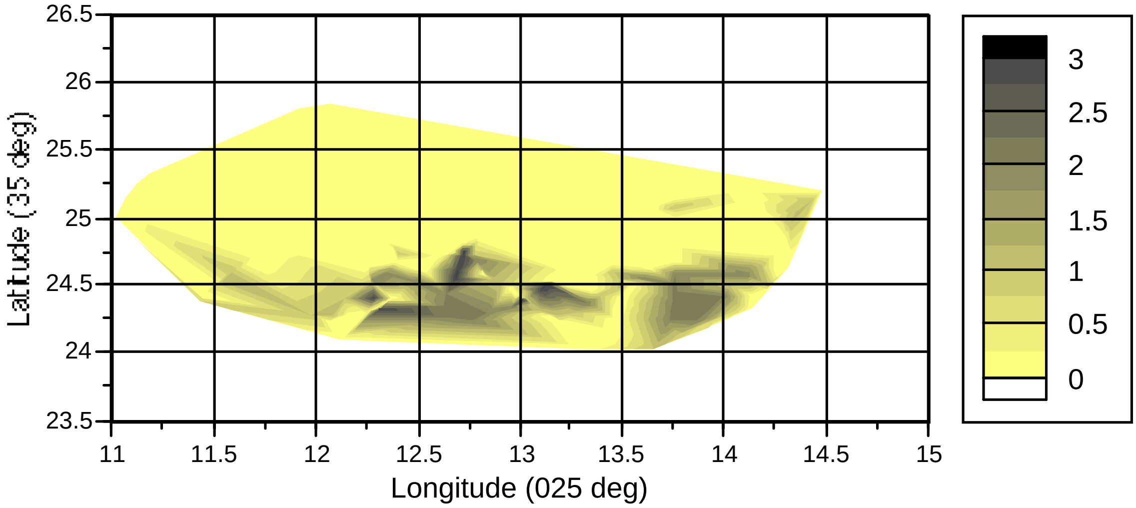


Figure 82. Contour map of the density of *Leptometra phalangium* (Scale 1-3, 0=zero, 3=many) on the Dia Island fishing ground, Aegean Sea, as determined from analysis of video-sledge surveys

4.5.2 Remote Operated Vehicle (ROV)

4.5.2.1 Clyde Sea

A total of 29 deployments were made with the ROV in the Clyde Sea area, three of which had to be aborted due to technical problems. Operation in the soft sediments of the Clyde Sea required careful piloting of the ROV to prevent reduction in visibility caused by disturbing the fine, silty sediment. The metal grid cube, held in the manipulator arm of the ROV and used as a scale object, was suspected of interfering with the ROV's navigation compass and was replaced by a plastic version in later deployments.

Surveys using the ROV were able to characterise a site as fished or unfished, but the extent of fishing impact was difficult to gauge; subjective interpretation tended to give greater weight to fresh disturbance of the sediment. Certain features were characteristic of unfished areas, for instance the fragile tube structures sometimes seen on the sediment surface, the well-defined form of the tracks left by large gastropods and the high spoil mounds adjacent to some burrows (Fig. 83a, c & e). On fished grounds, freshly disturbed areas were characterised by an appearance of 'freshly tilled soil', the crumb structure of the spoil being angular and well defined (Fig. 83b). Over time this structural form became weathered and less well defined (Fig. 83d). Burrows in fished areas tended to have less extensive spoil mounds than in unfished areas (compare Fig. 83e & f). Several ROV 'spot dives' were required at each site to ensure good area coverage and an equal chance of encountering trawl marks. Single dives could give a false impression of the overall condition of a site, happening by chance to land in an area that had not been disturbed for some time, or one which had been repeatedly trawled in the recent past.

The use of a scale object enabled *in situ* measurements to be made of the marks found and thus helped in determining which types of mark were attributable to which parts of the trawl gear (Fig. 84). Deep furrows and high berms were attributed to otter boards, the foot of the board acting like a ploughshare as it was dragged through the sediment, leaving disturbances with a vertical extent in the order of 10 to 40 cm depending on the softness of the substratum (Fig. 84a & b). The rubber rollers on a footrope were the most likely origin of swathes of parallel castellated marks (Fig. 84c & d); the depth and spacing of these marks (~ 5cm deep by 5cm wide) matching closely the dimensions of the gear. Lighter imprints (Fig. 84e) seemingly caused by light tackle dragged across the sediment leaving shallow scrape marks (of 1 to 2 cm depth) in the surface were attributed to chain used to weight the sweeps or footrope of a ‘clean’ net (i.e. one having a plain groundrope). Series of much broader, but still relatively shallow scrapes (Fig. 84f), typically with an arête between them, matched well with the dimensions of the series of metal bobbins that characterise the ground tackle of rock-hopper gear. Fresh marks were relatively easy to characterise in this way, and even quite severely weathered marks could be recognised by experienced observers.

The temporal change in the characteristics of the experimental mark were recorded on two occasions, viz. seven days after and eight months after the mark was made (a medium term observation was hampered by technical problems with the ROV). In the observation at +7 d, the disturbed sediment still had a well defined and complex ‘fractal’ structure (Fig. 85a) but after 8 months this had become greatly smoothed so the mark was only recognisable by the gross topographical outline (Fig. 85b). The 360° scanning sonar facility of the ROV proved useful in searching for, and measuring the lateral extent of, the mark (Fig. 85c).

Experience gained from observations made by the ROV proved useful when reviewing the video records made on the TV sledge transects. The growing experience of the observer led to better recognition of specific features and, in particular, sequences of features that indicated the video record had captured a traverse across an entire set of marks left by a single trawling event.

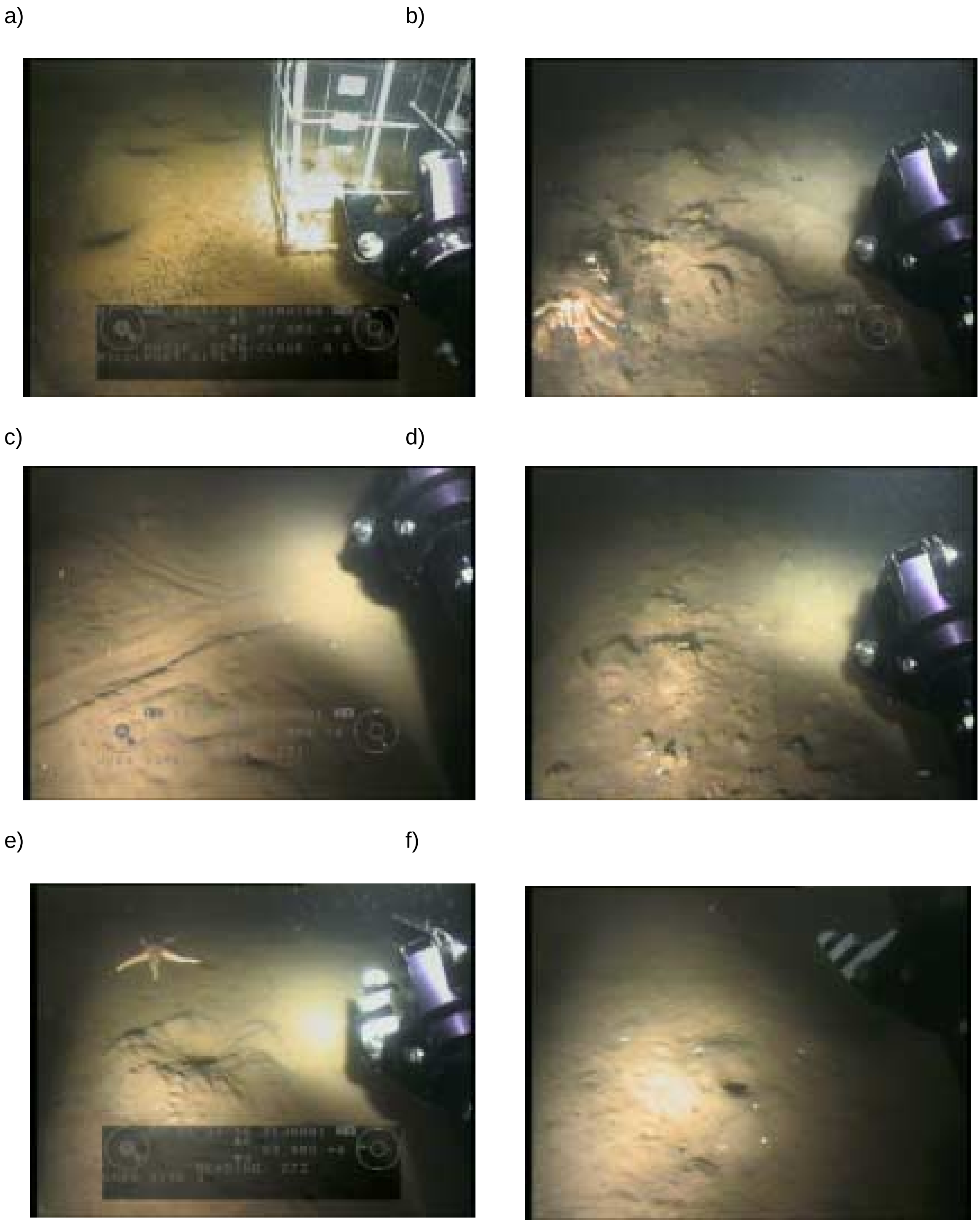


Figure 83. Images of the sediment acquired by ROV typical of undisturbed sites (left) and disturbed sites (right) in the Clyde Sea area: a) fine, fragile tube structures on the sediment surface, b) freshly 'tilled' sediment, c) tracks of the large gastropod *Buccinum undatum* in undisturbed silt, d) tilled sediment after several days 'weathering', e) a burrow in an unfished area showing the extent of the spoil mount (and incidental starfish) compared with f) a similar burrow in an impacted area with reduced spoil mound. The scale cube in a) has a grid mesh of 5 cm.

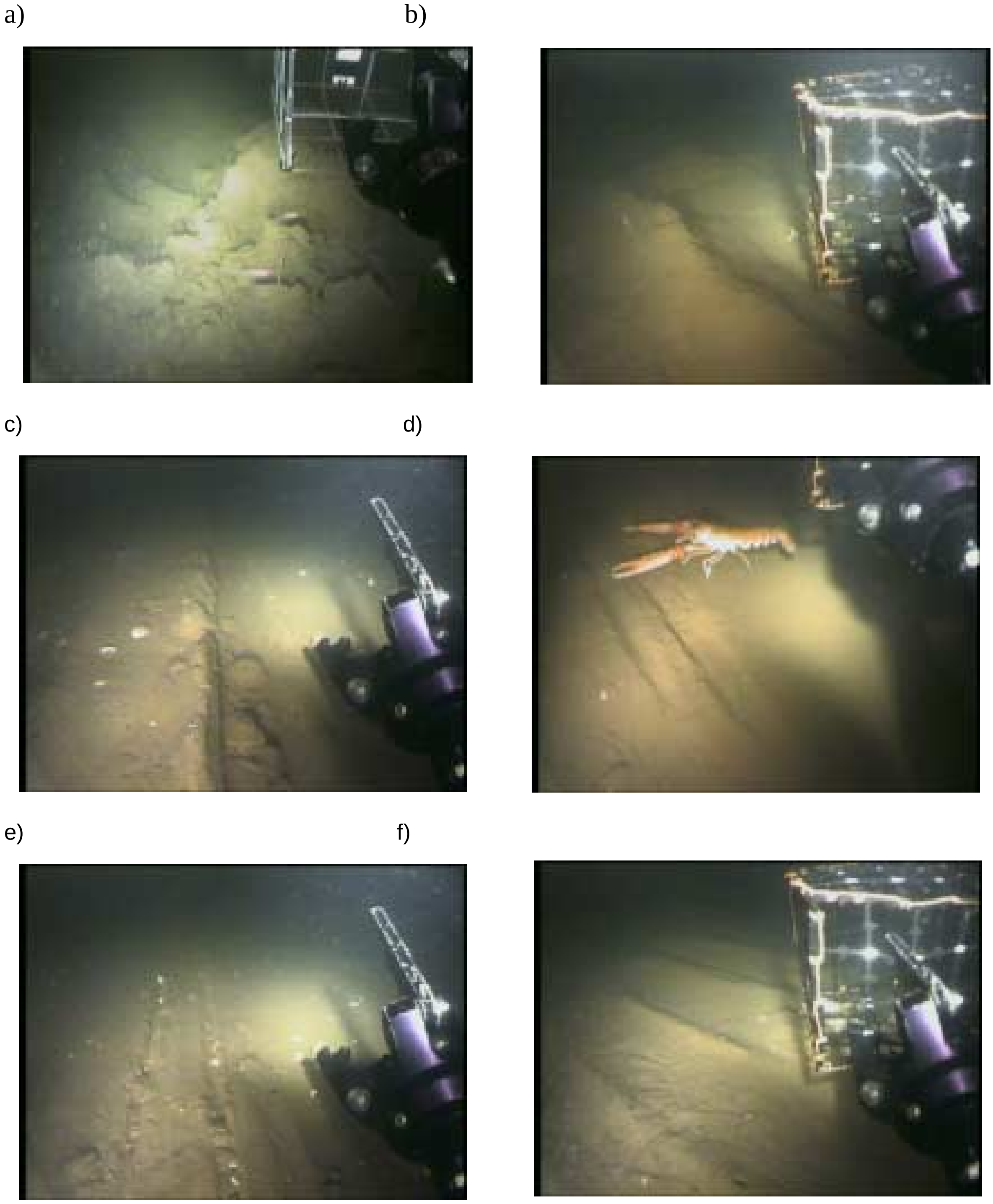


Figure 84. Marks in the sediment from the Clyde Sea area characteristic of certain parts of trawl gear: a) fresh, heavy disturbance caused by a trawl door; b) trawl door mark worn smooth over time by ‘weathering’; c) fresh castellated marks attributed to rubber rollers of a ground-rope; d) roller marks after weathering; e) fine drag marks attributed to chains weighting the sweeps or ground rope of a net ; and f) broad cup-shaped marks attributed to the bobbins of rock-hopper gear. The scale cube has a grid mesh of 5 cm in a) and 3 cm in b) and f).

a)

b)

c)

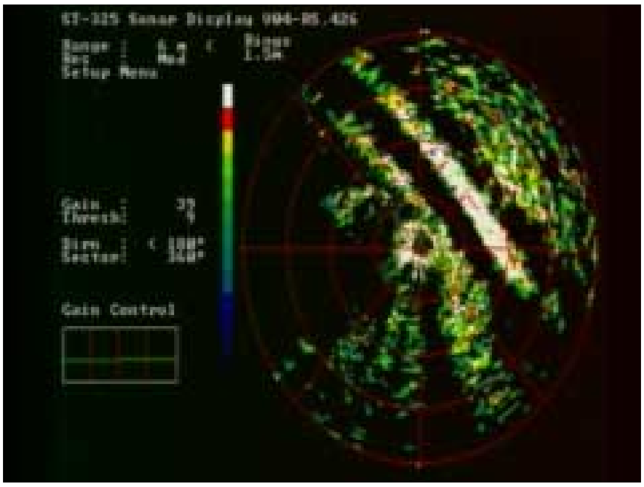


Figure 85. Images taken with an ROV of an experimental mark made at site L2 in the Clyde Sea area; a) 7 days after the mark was made and b) & c) 8 months after it was made. c) is a sonar image taken with the ROV sitting on the sea bed immediately adjacent to the mark. The mark was made in an area where fishing is prohibited to monitor the natural decay and longevity of a disturbance simulating that which would be made by an otter board.

4.5.2.2 ROV Experience in the Aegean

IMBC has experience in running two ROV systems, a small light workclass eyeball ROV (Benthos MiniRover Mk II) and a medium workclass light intervention ROV (DSSI MaxRover Mk II). The Benthos MiniRover is similar in capabilities to the Hyball used in the Scottish part of this study. It is primarily for observation although it has a very simple single function manipulator that has limited capabilities. The ROV is small sized (35 kg) but a high mobility when not constrained by the cable and it is easy to deploy and retrieve by personnel lifting it in and out of the water. The system carries a single colour CCD camera fitted to a pan and tilt mechanism and a 35 mm camera and flash. The medium workclass ROV is much larger (750 kg) taking up all the science space on a 26 m research vessel. The system carries 3 colour CCD cameras a 5 function manipulator, and a more complex system of navigational and sensing system (auto-piloting for direction, height or depth, and a scanning sonar) and a 50 kg payload.

The experience of ROV systems in IMBC with respect to investigations such as trawling impacts is similar to that experienced by UMBSM. The small ROV is ideal for undertaking spot surveys. It has limited navigational abilities and sensors, so is best used in one specific area that can be geographically positioned by the overhead support vessel and then used on a short horizontal excursions of up to 50 m from the vessel. The ROV is able to fly around above the bottom and stop at specific features to investigate them in detail. The towed video-sledge is almost always moving during operations and this leads to a lower quality of video compared with a system that can be stopped. The ROV is also able to move in and out on an object, effectively ‘zooming’ the view. By rotating around features a complete view can be made and 3-D shapes better understood. The simple manipulator can be used for placement and retrieval of objects such as scale bars, but tasks such as coring and probing more difficult through limitations in dexterity (manipulation), control (executing particular movements with payload), power (maintaining position/orientation, lifting and deploying) and payload.

Larger ROVs are often equipped with positioning systems so that long excursions by live-boating are possible whilst keeping an accurate record of the ROV track. With such standard features as auto-altitude and settable camera positions, the large ROV can undertake the work of a towed video-sledge for quantitative transects. Sensing and intervention is far less limited and with a large payload the ROV can accommodate a wide variety of instrumentation for detailed environmental investigations, for example;

- scaling laser systems for making sea bed measurements in 3-D

- optical stereo imaging systems for accurate 3-D measurements
- probe systems (manipulator operated) for measurement of sediment physico-chemical characteristics
- core systems (manipulator operated) for quantitative recovery of sediments for biological or physico-chemical analysis
- scanning sonar or sidescan sonar for short to long range measurement of large physical features.

The payload capabilities means that large ROV systems can multitask and perform a variety of functions that are normally singly done from a surface vessel deploying traditional remote instrumentation.

Small ROV systems are economic to run and are becoming more common and available to researchers. They can be hired at low cost or shared through institutions relatively easily. Large ROV systems are comparatively expensive to run and tend to remain in the domain of large companies (offshore oil, survey and exploration) with very few in research institutions. Despite their capabilities their size and operational costs (mobilisation, transport, crewing, insurance, rental, etc.) means that access and availability to limited budget science is low

With all ROV operations, both large and small self-made turbidity problems are difficult to minimise. Care should be taken such that,

- operations where possible should be directed into the water current,
- maintenance of an altitude of at least 1 m above the sea bed,
- use of experienced pilots
- precise planning of work close to or on the sea bed

In Summary – Underwater Television

Clyde Sea

- The underwater TV techniques provide a visual record of the anthropogenic disturbance and biogenic modelling of sediments which can be subjected to semi-quantitative analysis to provide spatial and/or temporal comparisons between sites.
- The towed video-sledge is best applied to transect type surveys, while the ROV is best for 'spot' surveys and obtaining *in situ* measurements of centimetre to decimetre scale disturbance features. The methods can investigate gross topographical features (e.g. megaripples) only in very clear waters.
- TV/video is the only method tested which proved suitable for assessing the age of marks.
- Visual methods give a better rapid appreciation of the ecological significance of impacts than other methods, but require the observer to have significant experience of a diversity of conditions and habitats if maximum information content is to be extracted.
- TV can successfully characterise marks left by different parts of the trawl gear.
- A skilled ROV pilot is required when operating on soft muddy sediments as great care is needed to prevent local resuspension of sediments, which would be deleterious to visual observations.

Aegean

- Underwater TV is one of the few techniques giving immediate information on both the physical and biological environment over intermediate scales
- Optical imaging is affected by turbidity and effort should be made to tow into any prevailing currents.
- During analysis of recorded material, utilising the methods outlined frequency and duration and detail of quantitative assessments are best set according to local heterogeneity.

4.6 Sedimentological Methods (Task 6)

4.6.1 Granulometry

4.6.1.1 Clyde Sea

Granulometric analysis of sediment cores from the Clyde Sea area showed that four of the six sites (namely H1, H2, L2, M2) had a similar overall grain structure, with a mono-modal size-frequency distribution peaking at 6 ϕ (Fig. 86). However, sediments at sites M1 and L1 had a bi-modal size frequency distribution, site L1 having a higher proportion of larger particles (first modal peak at 3.5 ϕ), while site M1 had lower modal peaks at 4 and 6 ϕ, indicating a more even distribution of particle sizes. Sites M1 and L1 were therefore regarded as being anomalous in terms of their sediment type, and this was taken into account when interpreting the results of other geotechnical measurements (i.e. load resistance, shear strength, % water content and dry bulk density).

The granulometric structure at the three depth layers (0-2 cm, 4-8 cm and 8-10 cm) in four seasonal samples (spring, summer, autumn and winter) was compared between sites in a graphical analysis of mean particle size (M_Z) and particle sorting (σ_I) (Fig.s 87 and 88). Heavily impacted sites (H1 & H2) were characterised by an increase in particle size and sorting with depth zone in the spring but not in other seasons, consistent with the sediment becoming mixed and homogenised as the year progressed. This was partly reflected at one of the moderately fished sites, M2, which showed an elevated sorting value at all depth zones in spring, indicating a greater scatter of particle sizes (i.e. poorer sorting). This difference in the spring sample was not evident at the lightly fished site, L2, where particle size and sorting were more or less constant throughout the year. Data for sites M1 and L1 are considered to reflect the anomaly in sediment type at these sites. At site L1, mean particle size was consistently higher than at other sites reflecting the greater proportion of larger particles occurring there. At site M1, towed video-sledge surveys had revealed the sediment surface to be notably patchy, indicating a variety of sediment types ranging from soft mud to muddy sand. It is this patchiness of the sediment that is considered responsible for the apparent seasonal differences in mean particle size at this site (Fig. 87) as the corer could not be deployed in exactly the same spot within the site in all seasons.

At fished sites, fishing effort is not constant throughout the year but tends to mirror the annual cycle of daylight hours as vessels tend not to operate during hours of darkness. The data presented above for the four sites with similar sediment types appear to indicate a seasonal effect that might be related to fishing pressure, with sediments becoming homogenised in periods of high effort and returning to a more natural, poorly sorted state following periods of low effort. The effect appeared more marked at heavily fished sites than at a moderately fished site and was not evident at a lightly fished site. However, a suitable explanation has not been forthcoming and further investigation is required, particularly to identify the particles that cause an elevation in mean particle size in the 8-10 cm depth layer at sites H1 and H2 (possibly faecal pellets, Foraminifera or shell fragments) and why they are not present at site L2. For the present, we can only conclude that the results of granulometric analysis are equivocal.

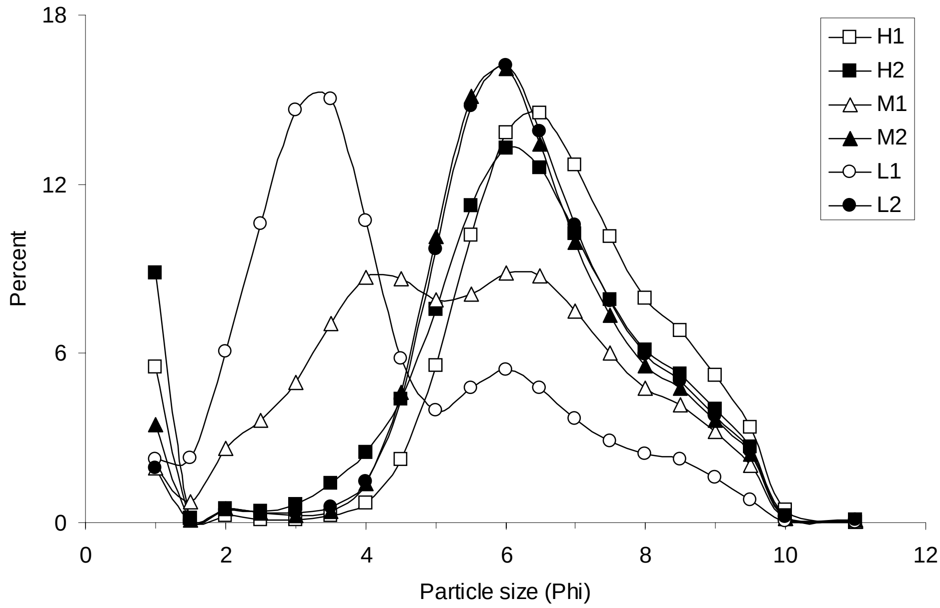


Figure 86. Overview of the frequency distributions of particle size in sediments taken from six sites in the Clyde Sea area representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = low). Each point represents the mean value for 3 depth layers (0-2 cm, 4-6 cm and 8-10 cm) at four times of year (spring, summer, autumn, winter), so n = 12. Particle size is expressed in Phi-units ($\phi = -\log_2$ of particle diameter in mm), so a larger phi value represents a smaller size of particle.

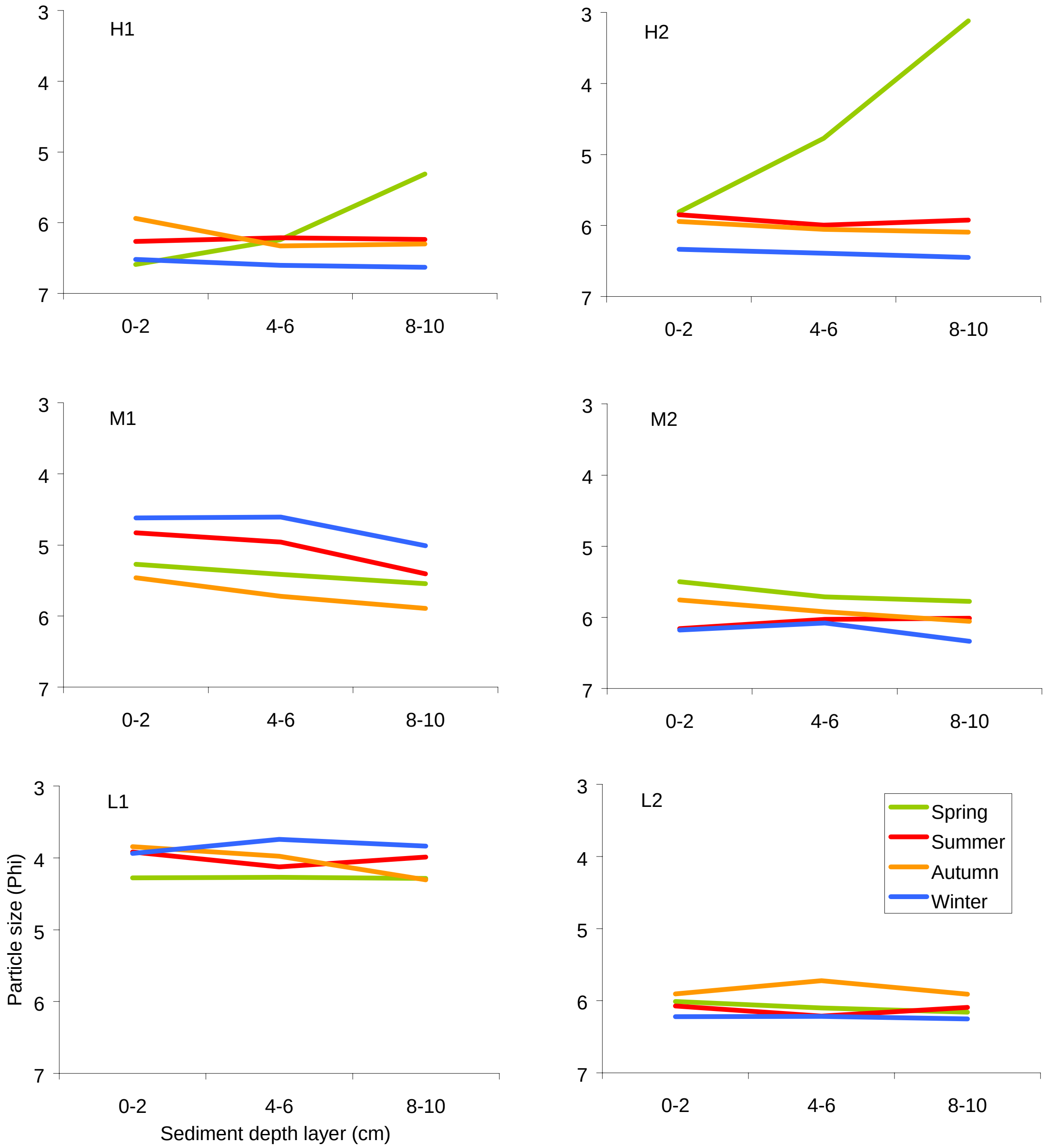


Figure 87. Mean particle size (M_Z (ϕ)) of sediment sampled at 3 depth layers in core samples collected over four seasons at six sites in the Clyde Sea area representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = light). (NB. lower values of phi mean indicate larger particle size).

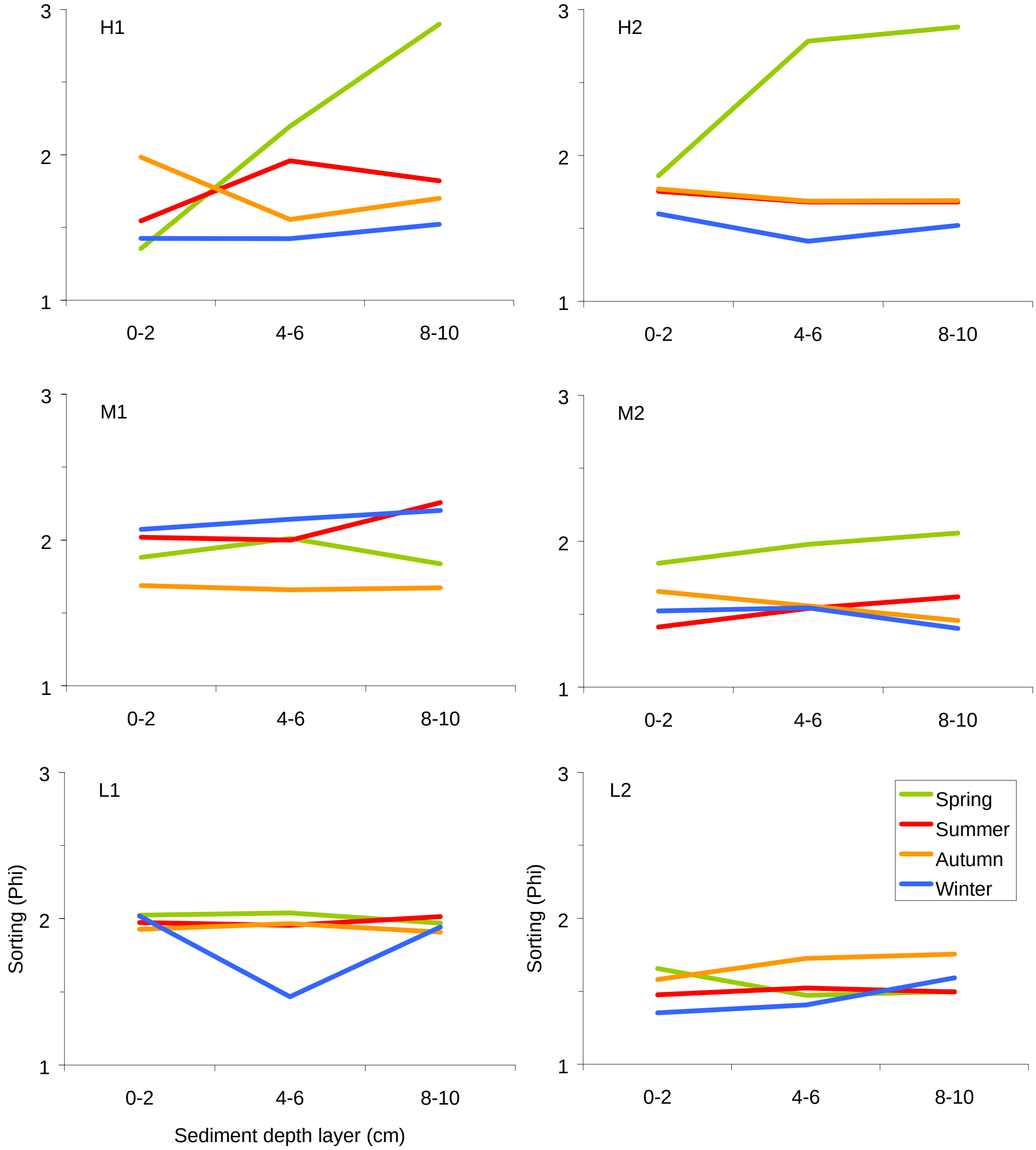


Figure 88. Sorting (σ_I) of sediment sampled at three depth layers in core samples collected over four seasons at six sites in the Clyde Sea area representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = light). (NB. a high value for σ_I indicates poorer sorting, i.e. a greater scatter of particle size).

4.6.1.2 Aegean

Data from the granulometry of the Dia Island area are shown in Table 27. The median grain size indicated that all areas sampled were classified as predominantly silts and were quite similar ranging between 0.016-0.019 mm with confidence intervals representing 5-20% of the median values. The percentage of clay was low and relatively stable, but there were some differences between sand and silt content with silt ranging between 84-91% with the lowest and highest content exhibited by the two trawling lane areas. The differences were taken up by the variation in the sand content, ranging between 5-13%. Confidence intervals for sand silt and clay were all low indicating no large variability between the samples, but also indicating that the second trawling station (FL-IN2) was probably significantly different from the other stations.

Table 27. Granulometric analysis of sediments around the Dia Island area, Aegean Sea, including the northerly and southerly control stations (FL-OUTN and FL-OUTS) and from two stations in the trawling lane (FL-IN1 and FL-IN2). Data shown include the average median grain size (Md), percentage sand, silt and clay, all with 95% confidence intervals calculated form 7 replicates (n).

	Md (mm)	95% CI	Sand %	95% CI	Silt %	95% CI	Clay %	95% CI	n
FL-OUTS	0.018	0.003	8.92	1.20	88.15	1.14	2.93	0.28	7
FL-OUTN	0.017	0.001	8.36	1.35	88.49	1.31	3.15	0.18	7
FL-IN1	0.016	0.003	5.40	1.82	91.38	1.87	3.22	0.37	7
FL-IN2	0.019	0.003	13.07	1.91	84.11	2.04	2.83	0.22	7

The Gouves area sampling stations were selected prior to the experiment and, consequently the experiment was moved to adjacent sites due to sampling difficulties. They do not therefore relate to the exact sediments of the trawling experiment, but are indicative of the kind of sediments in this area. Data from Gouves area are shown in Table 28. The median grain size indicated that all areas sampled were classified predominantly as sands, ranging between 0.10-0.13 mm. Confidence intervals represented 40-60% of the median values. The percentage of sand, silt and clay indicated a classification as silty sand. Percentage clay values were low and stable between samples. The dominant fraction, i.e. sand, ranged between 66-74% with a corresponding percentage of silt ranging between 24-32 %. Confidence intervals for the sand and silt were extremely high representing 30-80% of the percentage values, indicating high variation within the individual sampling areas and no significant differences between the areas.

Table 28. Granulometric analysis of sediments around the Gouves area, Aegean Sea, including an original selected experimental trawling lane (EXP'1 and EXP'2) and selected control station (EXP-C). Data shown include the average median grain size (Md), percentage sand, silt and clay, all with 95% confidence intervals calculated form 5 replicates (n)

	Md (mm)	95% CI	Sand %	95% CI	Silt %	95% CI	Clay %	95% CI	n
EXP'1	0.128	0.050	73.79	21.81	24.62	20.97	1.59	0.91	5
EXP'2	0.105	0.061	68.18	26.14	30.07	25.43	1.75	0.73	5
EXP-C	0.107	0.067	66.04	25.17	32.15	24.59	1.81	0.61	5

The two study areas, Dia Island and Gouves, represented quite different environments, one a silt and the other silty sand. The deeper (200 m) silty Dia Island site had a much high degree of sedimentary homogeneity than at the shallower (70 m) Gouves site. Although the Gouves samples were not taken in the exact positions of the experimental trawling lane and control site, they are indicative of the area, expressing high sedimentary heterogeneity. One of the Dia Island trawl lane sites was different from the others in the area, with a lesser degree of silt and more sand, which may or may not have been attributable to trawling activities. On the one hand the difference may have been natural variability in local area sedimentology, but it could also have been due to a high intensity of trawling activities removing fine fractions (resuspended and deposited elsewhere). The inconclusive results indicate that the methodology needs to be matched with other methodologies for a clearer understanding to be achieved. With the high degree of spatial heterogeneity caused by trawling gears (flattening, ploughing, different levels of impact and recovery), the best interpretation of granulometric analysis would have been through directed sampling, i.e. having a view of where the sample was taken from, or having other types of information in the area at the same time.

4.6.2 Sediment Profile Imagery (Aegean)

The SPI system was deployed during each of the investigatory cruises in the Dia Island and Gouves sites. A variety of typical images are shown in Fig.s 89 to 94 for Dia Island and Fig.s 95 to 100 for Gouves and this is followed by an detailed analysis of penetration and roughness in the different areas. The images show the vertical sediment water interface in the foreground and in some cases, sediment surface in the background. On the left of each image is a centimetre scale bar with normal uncropped frame size of approximately 20 cm height and 15 cm width. Features in the images could be resolved at the millimetre scale and these included epifauna and flora, infauna, surface features such as burrow openings, mounds and faunal tubes, sub-surface bioturbation traces, gross granulometry (sands, silty clays, shell fragments), biogenically remodelled sediments, sedimentary layers, anoxic sediments, feeding voids and burrow lumens.

There are a number of permanent features in some of the images, including the reflection of the flash in the top centre of the faceplate, the yellow/white faceplate wiper in the top of the low penetration images and a horizontal grey bar in the background of some of the images which is part of the SPI metal support framework. Differential penetration causes some differences in illumination and exposure patterns. The images shown have been adjusted in software with some changes only to sharpness, brightness and contrast, to better highlight the example features.

Figure 89 shows a typical image from an undisturbed soft silty sediment in the Dia Island control area with bioturbation features, including small mounds and voids (burrow or feeding voids) in the sediment. In the centre of the image, standing on the sediment surface is a polychaete tube and a probable branching foraminiferan structure. The scale bar indicates a maximum penetration of approximately 12 cm and minimum 7 cm. Sediment layering is irregular indicating vertical mixing. Figure 90 shows another image of a bioturbation structure and shows deep penetration of the system through a mound formed by a deep-burrowing species (thalassinidean shrimp or echiuran worm). There is a 15 cm layer of lighter coloured sediment on a deeper slightly darker coloured sediment layer.

Figures 91 & 92 are from trawl impacted sediments. The first image exhibits a very irregular broken sediment surface, both in the fore- and background and there is a vertical mark of blackened sediment indicating highly localised reducing conditions characteristic of buried organic matter, possibly a dead organism. Penetration is similar for both images, 6-7 cm with no biogenic relief indicated. The second image shows flat sediment, probably trawl flattened;

however, there are small structures present on the surface which may be recovering foraminiferan tubes.

Figure 93 also shows a disturbed sediment surface which in this case is the opening to a burrow structure in the centre of the frame. At the base of the burrow opening the void contains highly fluidised sediment. The last of the Dia Island images, Fig. 94, shows a highly layered medium penetration sediment with no major surface bioturbation features although there are a number of small tubiculous structures. The layering to a depth of 1 cm from the sediment surface may be from recently deposited sediments resuspended due to trawling.

From the Dia Island SPI images, it was noted that in the control area, particularly the southern control site, there was a high degree of roughness from bioturbation activities as well a larger amount of small features such as surface fauna and tube/branches as well as internal faunal/bioturbation traces. The trawling lane had a larger number of ‘unnaturally disturbed’ images. Unfortunately it was not possible at this time to find a way to numerically characterise these factors for a statistical analysis.

Figures 95 to 100 are from the coarser sediments around the Gouves experimental area. Figure 95 shows relatively typical sandy sea bed from the control area with low penetration of the SPI system to a maximum of 2.5 cm (compared to Dia Island). The sediment surface has a degree of roughness and there is a bioturbation mound visible in the background. Bioturbation traces and biogenically remodelled sediments are also evident in the profile (lighter coloured fine sediments in the mound on the far right and coloured vertical traces in the centre of the image). Figure 96 is from the experimentally trawled area and shows almost no penetration and very little topographical relief. Some shell/dead maerl debris is visible on the sediment surface. Further natural variability in the Gouves area is indicated in Fig.s 97 & 98. The former shows an amount of detritus on the sediment surface, which probably includes polychaete tubes and foraminiferan structures and topographical relief. Penetration is 0.5-2 cm. Figure 98 from the control areas shows a complicated epifloral and faunal community including a wide variety of sponges, calcareous (maerl) and non-calcareous algae. Penetration is shallower, ranging from 0.5-1 cm. The surface features represent a ‘climax community’ in the area.

Figure 99 shows a scrape mark in the experimentally trawled area as a diagonal shallow channel, approximately 5 cm wide and 2 cm deep, approximately the same depth of penetration as the SPI system. The sediments on either side of the mark seem to be quite flat, although there is a spine or thin tube sticking out of the sediment adjacent to the scrape mark. The profile indicates that there is some biogenic reworking of the sediment, even though the surface is flat. The final figure from Gouves (Fig. 100) was taken from the commercial fishing lane in close vicinity to the experimental site. In this case there was no penetration of the SPI system into the sediment. The surface was quite flat and was marked by debris of shell and maerl fragments.

In the analysis of the Gouves images, the observer was again able to make descriptive observations that were not amenable to be statistical analysis. The control area had a much higher amount of surface detritus and epifauna/flora as well as biogenically reworked sediments. The experimentally trawled area was much flatter without these features.

Numerical data were obtained through measurement of penetration and surface roughness. In the Dia Island area the SPI system was deployed in the fishing lane (FL-IN) and two control stations, one to the north of the lane (FL-OUTN) and one to the south of the lane (FL-OUTS). The average penetration and sediment surface roughness from these sites are shown in Table 29.

Table 29. Mean penetration and surface roughness (cm) from sediment profile images with 95% confidence intervals (95% C.I.) from the three sites in Dia Island, FL-OUTS, the southern control site, FL-OUTS the northern control site and FL-IN the fishing lane. ANOVA gives the P-value significance from analysis of variance, n is the total number of images for each site, n.s. is non-significant.

Site	Penetration		Roughness		Number
	Mean	95% C.I.	Mean	95% C.I.	of images
FL-OUTS	8.72	0.70	1.67	0.36	30
FL-OUTN	7.99	0.59	1.30	0.36	28
FL-IN	9.24	0.47	1.38	0.27	100
ANOVA	< 0.05	-	n.s.	-	-

The data shown are the mean measurements from all the images taken across the different sampling dates. Data were combined because trawl marks were still evident in the trawling lane during the complete closed season (i.e. all the year round). More images were available for analysis in the trawl lane due to equipment failures in the other sites (bad weather affecting deployment, false triggering of the system whilst not in the sediment, or problems with the camera system). Least penetration was shown in the northern control site (8 cm), with deepest penetration in the fishing lane (9.2 cm). The analysis of variance indicated a significant difference in penetration depth between the Dia Island sites.

In terms of roughness (the difference between maximum and minimum penetration within each image) the southern control site exhibited the highest amount of surface roughness (1.7

cm) whilst the northern control site and the fishing lane were similar (1.3-1.4 cm); however, there was no significant differences between the sites.

At the Gouves experimental area, the data from each of the images for each site were also combined for analytical purposes. Three areas were sampled, the experimental fishing lane (EXP-T), the adjacent protected control area (EXP-C) and an adjacent commercial fishing lane (EXP-FL). The mean penetration and roughness data for the three sites are shown in Table 30.

Table 30. Mean penetration and surface roughness (cm) from sediment profile images with 95% confidence intervals (95% C.I.) from three sites in the Gouves experimental area, EXP-C the control lane, EXP-T the experimental trawling lane and EXP-FL an adjacent fishing lane. ANOVA gives the P-value significance from analysis of variance and n is the total number of images for each site.

Site	Penetration		Roughness		Number
	Mean	95% C.I.	Mean	95% C.I.	of images
EXP-C	1.19	0.22	0.99	0.16	52
EXP-T	0.83	0.15	0.60	0.13	62
EXP-FL	0.09	0.14	0.19	0.29	10
ANOVA	<0.0001	-	<0.0001	-	-

Images from the experimental trawl and control areas were collected during each of the sampling trips. Images from the commercial fishing lane in close vicinity were only collected on the last sampling trip for comparative purposes and consequently there were fewer images available for this area. Penetration in all areas was low with deepest penetration at the control site (1.2 cm) and shallowest in the commercial fishing lane (0.1 cm) where, on a large number of occasions, the camera had no penetration of the sediment. Analysis of variance indicated a highly significant difference between the sampling areas in terms of sedimentary penetration. In the case that the commercial fishing lane was somehow anomalous, a comparison of means was carried out between the experimental and the control site images, which still indicated a highly significant difference ($P<0.0002$) between the two sites.

Sediment surface roughness was also found to be low for all three sites in the Gouves area. This parameter was highest in the control site (1.0 cm), lower in the experimental trawling area (0.6 cm), but considerably lower in the commercial trawling area (0.2 cm). Again the analysis of variance indicated a highly significant difference between all three sites in terms of sediment surface roughness and also in the comparison of means between just the experimental trawling and control sites ($P<0.01$)

Penetration of the SPI system into the sea bed is determined principally by sediment type and compaction. It will penetrate much deeper into soft muds than compacted muds and far less into sandier sediments. The presence of large objects on the sediment surface will also restrict penetration. In the soft sedimentary Dia Island area, the average penetration was greatest in the trawling lane and less in the control stations, whilst there were no differences in surface roughness. From video observation, the northerly control area was known to have slightly coarser sediments, but the southerly control station and the trawling lane seemed to be quite similar. In the coarse sedimentary area of Gouves, the results were the opposite; with greater compaction in the experimental trawling lane and commercial trawling area (decreasing penetration) and with significantly lower surface roughness in these same areas compared with the control area.

Theoretically, trawling may have a number of opposing effects on the sediment. Increasing stiffness can be caused by scraping and removal of softer superficial layers and compacting of deeper layers. However, the trawl doors may throw up sediments, increasing the water content and therefore increasing penetrability, and the settlement of resuspended material may also lead to less compacted surface layers. Sediment surface roughness may also have been contradictorily affected by trawling where removal of surface material can lead to a decrease in roughness as can resettlement of resuspended material. However, the scraping action of trawl doors and warps leads to increased surface roughness. In contrast to softer sediments, in hard sediments the trawling gear penetrated the sediment less, so less material is pushed up and there is a greater flattening of the surface.

Whilst the measurements from SPI images may not always be able to clearly indicate differences in areas that may be attributable to trawling (or other factors), descriptive information may prove very useful in the analysis of the images and future developments in the analysis of SPI images should concentrate on being able to quantify such observations. The trained observer is able to differentiate between normal biogenic relief and disturbed relief from external action and to identify other features that indicate particular activities (presence or absence of types of infauna and epifauna, burrows, feeding voids, bioturbation traces, presence of anoxic sediments, sediment layers, gross granulometry, etc.).

The system is remotely deployed and therefore is haphazardly placed on the sea bed. The images are of high resolution allowing identification of small features and in some cases particular organisms, but has a limited scale, with an image width of 15 cm, which is equivalent to half the width of a 0.1 m^2 grab sample. A large number of replicate images are therefore required to take into account the natural variability within a particular area so that overall area assessment can be made with confidence. In the case of fishing gear impacts, and considering the variable impacts of different parts of the fishing gears, we suggest, this should require more than 10 replicates.

Originally it was thought that the lack of penetrability in coarse sediments would mean that this technique would be of very limited value in revealing information in such grounds. However, the images still gave useful data, predominantly relating to the sediment surface but they also generated very useful descriptors of sediment disturbance and other sedimentary features.

The technique is relatively rapid in terms of deployment although there is a time lag caused by development of the film, before the success of sample collection is known and interpretation can be carried out. Interpretation can be undertaken relatively quickly in a matter of hours, either on photographic prints, projection of slides, or in the case of this analysis through digital scanning of the film for image processing. An experienced observer is required to identify various sedimentary and biotic features and traces. The whole process could be speeded up with the replacement of photographic film camera with a digital camera that would allow for immediate downloading of the images. The SPI system used for this study was difficult to use in rough weather as it tended to trigger in the water column, and in common with many ‘high tech’ instruments, it required care in set-up and attention to details.

Figure 89. SPI image of bioturbation mounds, Aegean Sea.

Figure 90. SPI image through a large bioturbation mound, Aegean Sea.

Figure 91. SPI image of trawl impacted sediment, Aegean Sea.

Figure 92. SPI image of trawl flattened sediment, Aegean Sea.

Figure 93. SPI image of burrow opening, Aegean Sea.

Figure 94. SPI image of resettled suspended sediments, Aegean Sea.

Figure 95. SPI image of bioturbated sand from Gouves (EXP-C), Aegean Sea.

Figure 96. SPI image from the experimentally trawled area (EXP-T) at Gouves, Aegean Sea.

Figure 97. SPI image of undisturbed sand at Gouves (EXP-C), Aegean Sea.

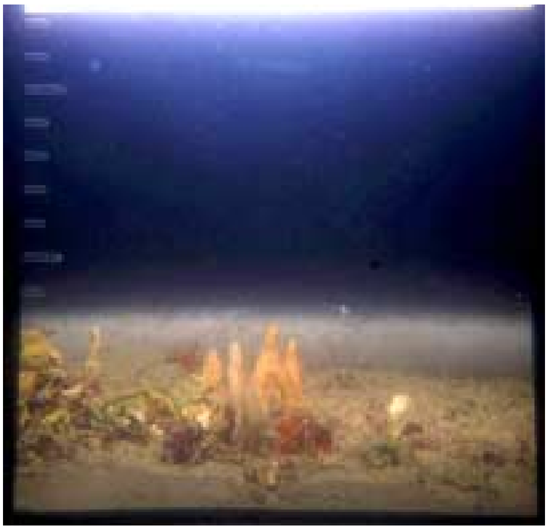


Figure 98. SPI image epifauna and flora on sand at Gouves (EXP-C), Aegean Sea.

Figure 99. SPI image of scrape mark on the sediment surface at Gouves (EXP-T), Aegean Sea.

Figure 100. SPI image of the sandy commercially fished area (EXP-FL), Gouves, Aegean Sea.

4.6.3 Geotechnical properties of sediments (Clyde Sea)

A nested ANOVA on the geotechnical measurements (load resistance, shear strength, % water content and dry bulk density) revealed that the majority of the variability was attributable to site and depth layer factors (the latter being the 0-2 cm, 4-6 cm and 8-10 cm depth layers selected in the sediment cores, see Fig. 17). No relationship with season or fishing intensity was evident (Table 31).

Table 31. Summary of results of nested ANOVA on four geotechnical tests performed on sediment samples from the Clyde Sea area, giving the % of total variance accounted for by each of four factors.

	Geotechnical Test			
Factor	Load resistance	Shear strength	Dry bulk density	% water content
Season	0.00	0.00	1.56	0.00
Fishing impact	0.00	0.00	0.00	0.00
Site	41.38	30.67	90.90	85.79
Depth layer	58.62	69.33	7.55	14.21

The ANOVA results appeared to be greatly influenced by the anomalous sediment structure at sites M1 and L1 revealed in the granulometric analysis, causing the ‘site’ factor to be a major source of variance. Depth layer was also an important factor, particularly in the load resistance and shear strength where a relationship with depth is only to be expected. The possibility therefore arose that seasonal or site effects may have been masked by the large variability attributable to site and depth layer, so further analysis of data was undertaken for each geotechnical test and is presented here in summary graphical form.

Load resistance was compared between the four sites with similar sediment type (sites H1, H2, M2 and L2). To investigate how load resistance changed with depth, data were standardised for each core by converting absolute values to a percentage of the load resistance recorded in the deepest depth layer of each core (Fig. 101). The results bear a notable resemblance to the granulometric analysis detailed above, in that samples at the heavily fished sites (H1 & H2) appear different in spring to other times of year, the spring curve lying below the curves for other seasons, which are themselves very similar. A less distinct effect is evident at the moderately fished site (M2) with the spring curve again lying below the other curves, but these are now less uniform than at the heavily fished sites. At the lightly fished site, the spring curve lies above the other curves, that are themselves fairly uniform. It would therefore appear that there is some variability in sediment load resistance that could be attributable to the factors of season and fishing impact. The effect appears to mirror the results of the granulometric analysis, showing stratification in the sediment in spring being homogenised later in the year. Seasonal variation in load resistance is not as marked at the moderately fished site and was even less so at the lightly fished site. Without further (and lengthy) investigation it is not possible to establish a cause and effect relating to fishing intensity and the influence of the geographical separation of sites cannot be discounted at this stage.

A similar approach was used to investigate the data for shear strength, but the data proved more variable than those for load resistance and effects relating to season or fishing intensity were not evident. Shear strength characteristically increased with depth layer and was of similar magnitude in the four sites with similar sediment type (H1, H2, M2, L2), ranging between 0.1 and 2.5 $kN \cdot m^{-2}$ depending on the depth layer sampled. At the two other sites, M1 and L1, where the sediment comprised higher fractions of larger particles, the range was an order of magnitude higher with maximal values of 15.2 and 22.8 $kN \cdot m^{-2}$, respectively.

Dry bulk density and water content are inversely related and, as anticipated, dry bulk density increased with depth while water content decreased. Dry bulk density was markedly lower at all six stations in winter but there was not a concomitant rise in the % water content, and consequently a systematic error is suspected in the determination of dry bulk density for the winter samples. There was no apparent relationship with fishing intensity in these parameters and again measurements for sites M1 and L1 differed markedly from those at other sites.

An overview of the latter four geotechnical tests was achieved by pooling data by season and depth layer to calculate an overall mean value for each parameter at each of the six sites (Fig. 102). For each test, comparison among sites reveals a common feature, namely that sites M1 and L1 differ radically from the other sites. This feature is attributed to the coarser sediment types at this pair of sites when compared with the remaining four sites. It also highlights the importance of basing analyses on site-by-site comparisons and refraining from the temptation to pool data for sites within the same category of fishing impact, which could lead to erroneous interpretations.

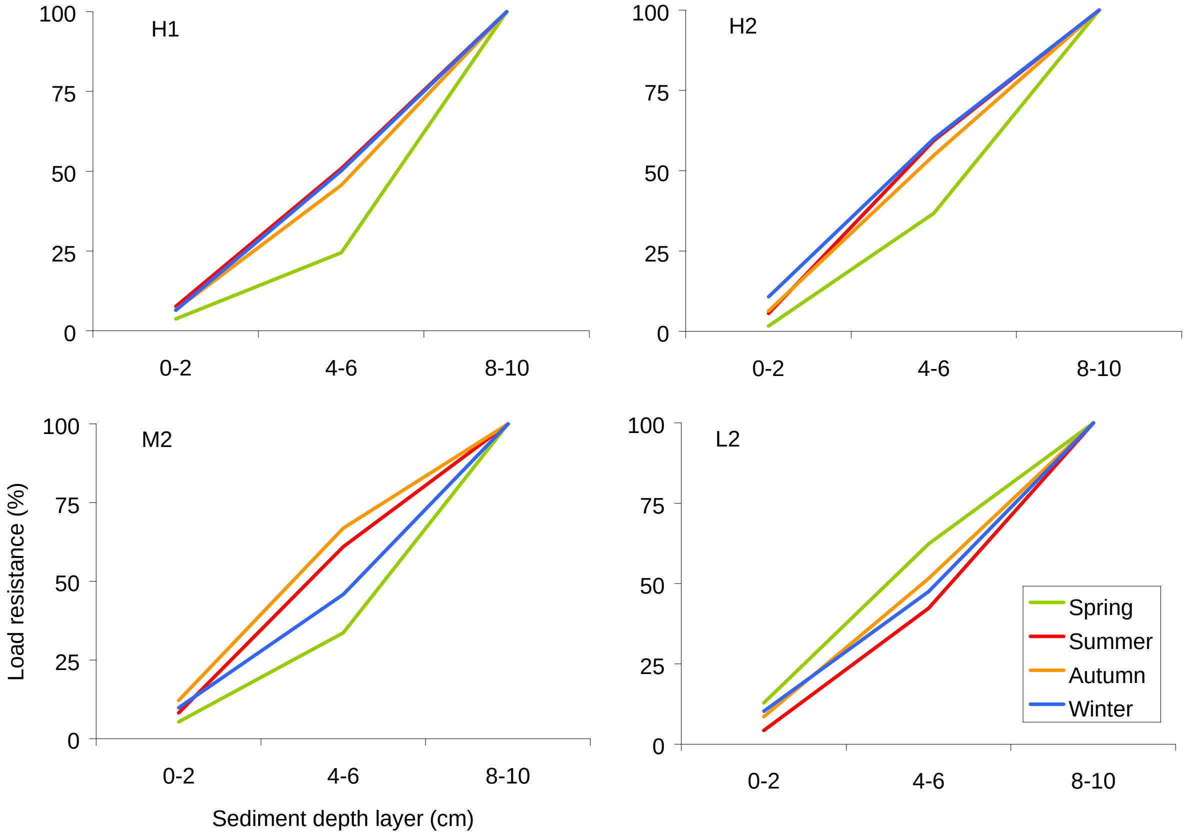


Figure 101. Load resistance in sediments sampled at three depth layers in core samples collected over four seasons at four sites in the Clyde Sea area representing three nominal levels of fishing intensity (H = heavy, M = moderate, L = light). NB. Data have been standardised to percentages of the load resistance measured in the deepest layer (see text).

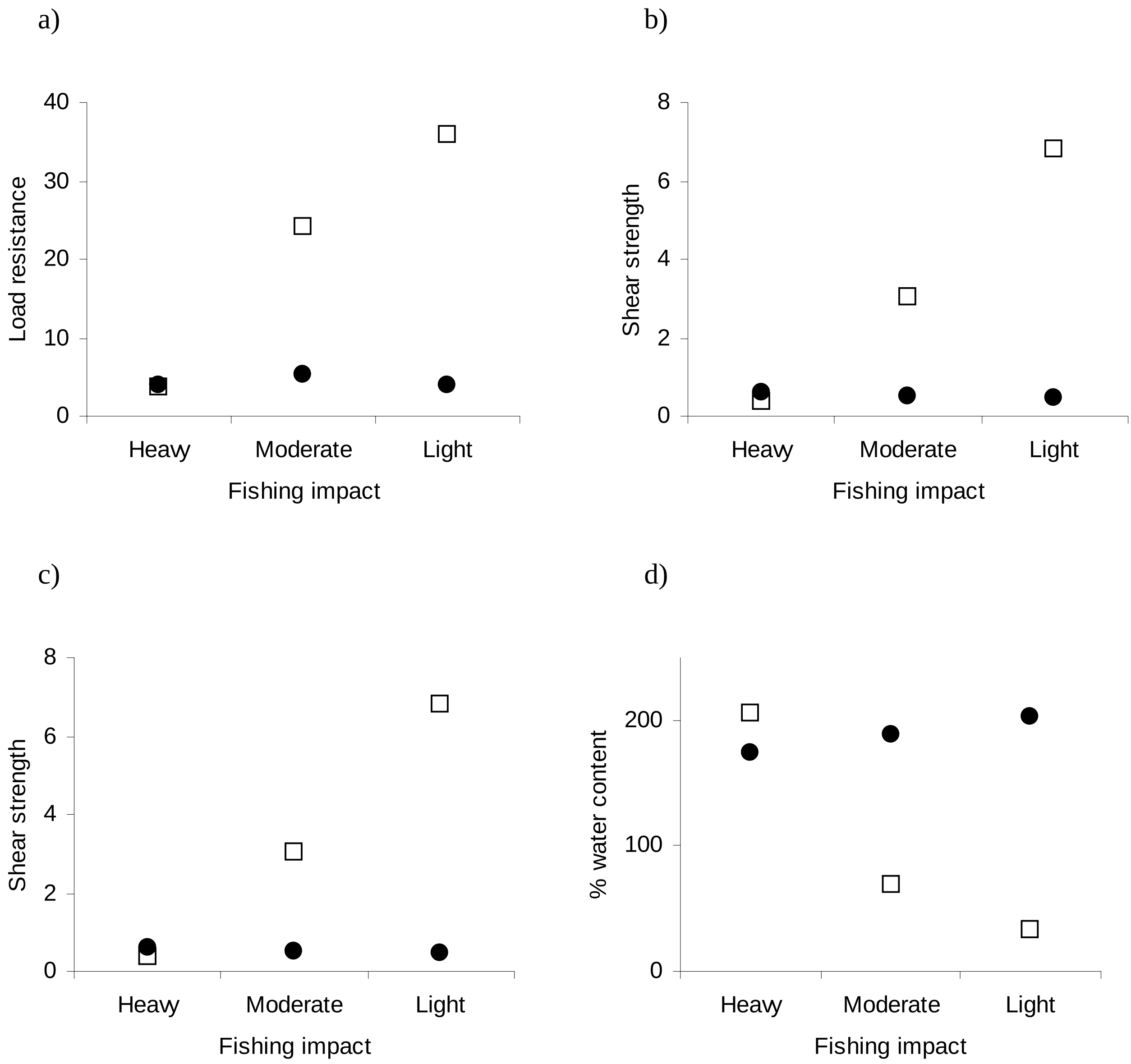


Figure 102. Summary of four geotechnical parameters measured in sediment core samples from six sites in the Clyde Sea area representing three nominal levels of fishing intensity (H = heavy, M = moderate and L = light). a) Load resistance (kN), b) shear strength ($kN{\cdot}m^{-2}$), c) dry bulk density ($g{\cdot}ml^{-1}$) and d) % water content. Each data point represents the mean of measurements pooled for three depth layers over four seasons (see text). Open squares represent sites H1, M1 and L1; filled circles sites H2, M2 and L2.

In Summary - Sedimentology

Clyde Sea

- Results of sediment analyses were equivocal. Two parameters, namely granulometry and load resistance penetrometry, detected a seasonal difference in the sediment profile structure. However, the cause of such differences was not identified and a causal relationship with fishing activity could not be established.
- Results of the test on shear strength were highly variable and likely masked the effects detected by load resistance penetrometry.
- Results of tests on dry bulk density and % water content were notably invariable, so no seasonal or fishing related trends were detected.
- The study highlighted the dependence of the geotechnical tests on the particle size structure of the sediment, making them generally unsuitable for rapid assessment of trawl impacts.

Aegean

- SPI is one of the few techniques giving relatively quick information on both the physical and biological environment over small scales.
- The technique was able to indicate both qualitative descriptors provided by an experienced observer and quantitative differences (penetration and roughness) between trawled and non-trawled areas.
- The technique gave differing results from different trawled sedimentary regimes with potential increases of penetrability in soft sediments and decreases in penetrability in coarse sediments.
- The technique requires a trained observer with significant experience of a diversity of conditions and habitats.
- In heterogeneous environments, or where trawling increases the heterogeneity of the environment (soft sediments), large numbers of replicate images need to be taken for confident analysis.
- The technique could benefit from advances in camera technologies to allow much more rapid analysis.

5. DISCUSSION

Physical disturbance

Chronic fishing disturbance has changed the community structure of shelf seas (Kaiser *et al.*, 2000). Intensively fished parts of the North Sea are swept by trawls, chiefly beam trawls, several times per year (>400 times in some places), while other patches are much less heavily fished (Moore & Jennings, 2000). Assessments of the average area swept by trawls in the North Sea gave a poor indication of the direct impacts of trawling on the biota (Jennings *et al*., 1999b). Although stable soft-sediment (muddy sand) habitats are generally very susceptible to trawling, few studies have addressed fishing impacts in such habitats (Jones, 1992; Collie *et al*., 2000a; Smith *et al*., 2000; Sanches *et al.*, 2000). Low-energy sedimentary environments are likely to be more affected by bottom trawling, with impacts lingering for longer than on energetic sandy bottoms (Tuck *et al*., 1998; ICES, 2000). It is clearly important that efficient methods be identified and adopted if cost-effective assessments of such widescale impacts are to be made in order for them to have as wide a relevance as possible. The objective of this programme has been to assess a spectrum of techniques for their effectiveness as rapid methodologies for monitoring the benthic impact of otter trawling gear. These techniques have been compared and contrasted, leading ultimately to the generation of recommendations concerning the most efficient and cost-effective approaches.

Otter trawling is one of the most important methods of demersal fishing in European coastal seas. Trawl doors are intuitively perceived to be the part of the fishing gear that has greatest impact (Hall, 1994), yet there are comparatively few studies on this issue. The persistence of trawl door marks (as ‘plough furrow’ or ridge and berm features) on the sea bed will depend on local hydrographic conditions and bottom stability. In shallow waters, highly dynamic conditions may obliterate the physical evidence of the passage of a trawl in a matter of days. In deeper waters, however, trawl marks will persist for months or even years (Krost *et al.*, 1990; Schwinghamer *et al.*, 1998). To date, most work on such features has focused on sandy bottoms in relatively shallow water. Service & Magorrian (1997) have shown that isolated otter door scars were the most readily identified, and that with increasing intensity of trawling individual marks tended to merge into a general background texture. Thus the power of this technique in delineating fishing pressure may well vary with impact pressure. Krost *et al.* (1990) reported that trawl track frequencies in Kiel Bay increased with greater water depth and with decreasing mechanical resistance of the sediment as it changed from sand to mud. Gilkinson *et al.* (1998) investigated door damage to sand-living bivalves in an experimental tank designed to simulate the sea bed in an area of the Grand Banks. Here, penetration was superficial (2 cm) and, although some bivalves were displaced, few were damaged. On muddy grounds, trawl doors cut furrows which are an order of magnitude deeper (Marrs *et al.*, 1996). This disrupts/ destroys the burrows of species such as *Nephrops norvegicus*, but Marrs *et al.* (1996) showed that some *Nephrops* at least were able to re-establish openings to their disrupted burrows within these scours.

The majority of RoxAnn™ units are sold to fishers for ground discrimination and site finding. Recently, RoxAnn™ has been adopted by scientists for mapping sea bed habitats and their associated benthic communities, e.g. Magorrian *et al.* (1995), Greenstreet *et al.* (1997), Southeran *et al.* (1997), Pinn *et al.* (1998) and Tuck *et al*. (1998). As the method is based on the ability of the system to distinguish types of sea bed on the basis of their hardness (softness) and roughness (smoothness) there was a potential that it might be able to detect biogenic or anthropogenic disturbance of sediments. Rees (1993) indicated that bioturbation may affect the acoustic signal of RoxAnn™ and subsequently Pinn & Robertson (1998) reported that changes in *Nephrops norvegicus* burrow density could be detected using RoxAnn™ over a uniform sediment type. However, more recent work by Pinn & Robertson (2001) has drawn attention to the fact that the relationship between *Nephrops* burrow density and the acoustic output of RoxAnn™ is significantly more complicated than was previously thought. Crucially, over heterogenous sediment types such a relationship could not be detected.

Tuck *et al.* (1998) used RoxAnn™ in conjunction with sidescan sonar to identify experimental trawl disturbance in a previously unfished sheltered Scottish sealoch; the post-disturbance RoxAnn™ signature of the site differed from the pre-disturbance signature. Our experience of comparing sites with similar soft sediments but different intensities of fishing disturbance has shown that even minor heterogeneity in sediment between sites tends to mask any trawl effects. The need for careful ground-truthing of RoxAnn™ outputs is very apparent, and this may restrict its appeal as a rapid assessment method of first choice. The practical deficiency of hull-mounted RoxAnn™ relates to the effect of water depth on resolution power, since the beam footprint varies with depth, i.e. the method is less good in deeper water.

Our work has shown that sidescan sonar represents a considerably more effective method of ground discrimination in the context of surface physical features (see also Collie *et al.*, 1997; Lindeboom & de Groot, 1998; Friedlander *et al.*, 1999; Giovanardi *et al.*, 2000). We have shown that although trawl door marks are well defined using this method, smaller scale features (e.g. ground rope, bobbin impacts) are less well resolved; if at all. The key to successful quantification and analysis of sidescan records of trawl marks has proved to be the design of the survey. On open grounds, and/or where trawling directions may be mixed, a grid pattern lends itself to quantitative analysis better than a parallel-pass approach. We estimate that the use of a grid pattern reduces time required for data collection by half and significantly speeds-up data processing. The single-frame method of counting track density adopted herein is an adaptation of a similar method that has been applied to good effect on a much larger study area (2700 km^2) in the east Pacific (Friedlander *et al*., 1999). Our method proved accurate and reliable and we would advocate its use for quantifying the density of trawl marks. Data on preferred tow orientation can also be extracted using this method. On grounds where fishing boats are forced - by geographic and/or topographic confinement - to trawl in a unidirectional orientation (as in the Aegean site at Dia island), the design of survey is still important, but there a sinusoidal track along the main direction of tow proved to be the most efficient approach, commensurate with practicalities dictated by ship manoeuvrability. Unlike hull-mounted RoxAnn™ the effectiveness of sidescan is independent of water depth as the transducers are always ‘flown’ close to the sea bed at a relatively constant altitude.

A feature of underwater TV, in common with sidescan sonar and RoxAnn™, as an approach is that they generate (semi-) permanent visual records that can be archived and/ or analysed (and reanalysed) in different ways at leisure *post hoc*. A towed video-sledge lends itself to transect-type surveys, while the ROV is best for ‘spot’ checks. The video-sledge is more useful in obtaining quantitative data in an area survey because of the fixed camera view and the greater ease of tracking the distance covered. Simple ROVs do not have the required tracking system or a fixed reference point of view whilst larger, more capable ROV systems that do, are not generally available (given high cost, size, accessibility). The disadvantage of the sledge is in its continual movement and inability to stop, investigate and observe features of interest that ‘pass by’. Underwater TV methods have an improved resolution (*cf*. acoustic systems; above), but their field of view is necessarily more restricted (and dependent on water turbidity). In our experience, it was only TV/ video methods that lent themselves to an assessment of the relative age of trawl marks and the physical magnitude of trawl scar marks (i.e. penetration). They were also applicable to assessing bioturbation features following a disturbance event, giving potential insights into changes in community structure.

It should be stressed, however, that the interpretation of these images requires acquisition of considerable skills both on the part of the operators (skipper, ROV pilot) and the data analyst. TV proved to be the only technique used that was capable of discriminating the impacts of other parts of the trawl gear than just the otter doors. Studying the impacts of bottom fishing on benthic epifauna on Georges Bank (E. coast of USA), Collie *et al.* (2000b) found that results from videos and still photographs were generally consistent although less detail was visible in the videos.

A remaining area of comparative ignorance concerns the longevity of trawl marks. We noted that in a soft-bottom trawling ground, trawling increased spatial heterogeneity (door tracks, scrapes, flattened areas, untouched areas). Conversely, in a hard-packed sedimentary ground, trawling decreases spatial heterogeneity, and the ground is swept clear; as are solid surfaces (Van Dolah *et al*., 1986). Clearly such anthropogenic disturbance features will decay with time due to the combined erosive action of physical forces (sea bed currents, continued deposition of sediment, bottom type considerations, hydrographic regime and seasonal weather factors) and biological agencies (microbial binding processes, faunal bioturbation rates). That rate of decay will depend on the outcome of this complex natural interaction, as well as on the intensity of fishing activity on the ground (Krost *et al*., 1990; Schwinghamer *et al*., 1998; Tuck *et al.*, 1998). A recent meta-analysis, based on various impact studies worldwide, has shown that recovery rates of muddy-sand and muddy habitats are comparatively slow, i.e. of the order of hundreds of days (Tuck *et al*., 1998; Collie *et al*., 2000a). The considerable complexity of this issue means that predicting the longevity of trawl impacts on any particular ground is likely to be fraught with difficulty. Further work is needed to tease apart these issues.

Biotic disturbance

Ecologists have interpreted disturbance in a number of ways: a) as a negative force that destroys climax assemblages, causing deterioration of ecosystems to an unstable state (Clements, 1916); or b) as a positive or necessary portion of community dynamics preventing competitive exclusion by dominants in particular in space-limited environments (Dayton, 1971; Connell, 1978; Dye, 1992). Disturbances come in a continuum of intensities and frequencies, from catastrophes to chronic disturbances (Dethier, 1984). Characteristics of the disturbance regime, like spatial extent, intensity and frequency, are generally correlated (Sousa, 1985). Depending on your point of view (deterministic *vs* stochastic), populations may be considered to be in equilibrium or not (Mallia, 1997). Among non-equilibrium models, Connell's intermediate disturbance hypothesis (1978) has been supported by evidence from rocky shores (Lubchenco & Menge, 1978). Counter hypotheses that envisage community composition being expressable as multiple stable points (Sutherland, 1974) or in terms of patch dynamics (Sousa, 1979) equally have their advocates. Patchiness encompasses spatial variability over the time since local disturbance occurred (Sousa, 1984), compounded by biological activity. Bergmann (2001) noted that there is a conspicuous lack of knowledge of the population dynamics and habitat architectural function of epifauna of soft-sediment habitats and their ecological role in relation to infaunal commuities. An accurate understanding of the dynamics of the physical structural aspects of sea beds thus cannot be achieved without consideration being given to background biological processes.

Community analyses

Analysing the structure of marine benthic communities can be a difficult and time-consuming (and therefore costly) business. The traditional approach of grab sampling for macrofauna is difficult to implement without trained teams of taxonomically competent personnel (which is why it is so costly, see Olsgard *et al.*, 1997), so faster and more efficient techniques for impact assessment have been sought (Smith & Papadopoulou, 1999). Difficulty and costliness escalates dramatically as the size of organisms considered decreases from megafauna > macrofauna > meiofauna > microbes. Community analysis that restricts consideration to large, conspicuous, easily identified megafauna should by rights therefore be the most rapid. Our analyses have shown that data sets for such organisms (even restricted ones), analysed by standard methods (like PRIMER) can quickly assess community differences between areas subjected to different levels of fishing activity, and highlight taxa of potential indicator significance. Also, the degree of taxonomic resolution required for robust analysis of compositional data may not demand full identification to species. Warwick (1988) showed that the information content of higher taxa is often sufficient to generate ecologically sound insights into patterns in communities, and adopting a lower level of taxonomic discrimination should facilitate sample and data processing. (Olsgard *et al.*, 1997). In the case of the Clyde Sea data, MDS analysis at Family level proved to be just as effective as species data in discriminating megafaunal epibenthic community patterns on grounds experiencing different levels of trawling intensity.

The issue raised here as to whether quantitative or qualitative (presence/ absence) data are sufficient is interesting. In our Clyde Sea data it was clear that quantitative data (counts of taxa) were more informative than presence/ absence data. This result may not be one of general applicability, however, since it may depend on the entity richness of the data matrix under consideration. Some years ago, Moore (1974) compared qualitative and quantitative data sets for a highly biodiverse (387 spp.) kelp holdfast community, and found that the noise generated by the added information content of quantitative data obscured, rather than enhanced, understanding the underlying ecological structuring factors. The restricted number of species presently considered (70 in the Clyde Sea area, 135 in Dia Island, Aegean) may necessitate a quantitative approach. Certainly, and consistent with most other workers' experiences (Watling & Norse, 1998; Collie *et al*., 2000b), communities at heavily fished sites had a lower diversity of epibenthic megafauna. As a general rule, epibenthic organisms, particularly erect sessile colonial forms, are the first to suffer when demersal fishing gears are towed over sea beds (Van Dolah *et al*., 1986; Giovanardi *et al.*, 2000; Hall-Spencer & Moore, 2000a, b).

Analyses of population density data revealed identifiable trends in community composition when data were considered either at species level or when information was aggregated into functional ecological groups. Functional group analysis has been advocated recently (Grall & Glémarec, 1997; Phillips *et al*., 1997; BIOMAERL team 1999) as a way of examining how ecosystems adapt to disturbance including by anthropogenic stressors. Presently, as fishing intensity increased in the Clyde Sea area there was a shift in trophic composition of the epibenthic megafauna away from scavenging organisms and towards suspension feeders (note also Pranovi *et al*., 1998). This switch, however, was not representative of the Crete situation where predators increased on the trawl track (see also Kaiser & Spencer, 1994; Kaiser & Ramsay, 1997). Thus, at present, it is clear that generalising about the functional responses of ecosystems to stressors like fishing may be premature. Having said that, it is interesting to note that from the functional group analysis of the Clyde Sea data, station L1 did not emerge as anomalous (as it did when analysed using a range of other biological parameters and physical factors). This could suggest that the 'functional group' approach might be considered to be more robust in the face of various sources of heterogeneity.

Damage analysis

Towed demersal gears cause physical damage to epibenthic megafauna. Damage is inflicted not only to animals caught by the gear but also to those left on the sea bed in the wake of the gear (Bergman & van Santbrink, 2000; Jennings *et al.*, 2001). The altered morphology of certain epibenthic species, most notably long-lived bivalves or gastropods (Andersson, 2000; Kaiser *et al*., 2000; Mensink *et al.*, 2000; Ramsay *et al*., 2000), starfish (Kaiser, 1996) or brittlestars (Bergmann, 2001; Bergmann *et al.*, 2001a), caused by physical damage gives an insight into dynamic processes and offers a promising tool for studying trawl impacts relatively cost-effectively, especially for heavily trawled sites (Kaiser, 1996). Assessing damage to certain hard-shelled organisms, e.g. prosobranch gastropods or bivalve molluscs, however, is especially attractive since it allows a retrospective analysis of damage, as a record of past disturbance events is retained in the structure of the shell (Witbaard & Klein, 1994; Ramsay *et al*., 2000). Opportunities present themselves to compare old damage with fresh damage in long-lived shelled organisms or organisms capable of regeneration (Gilkinson *et al.*, 1998; Mensink *et al.*, 2000; Ramsey *et al.*, 2000). A direct approach is the short-term assessment of trawl damage to organisms which can be carried out directly on catches from commercial otter trawls. This gives an instant indication of the vulnerability of by-catch species to damage whilst in the trawl and a comparative measure of the degree of damage caused by different rigs or gears.

Our studies in the Clyde Sea showed that the historical damage load (i.e. shell scars) of the gastropod *Buccinum undatum* was related to nominal fishing intensity, both in terms of the proportion of the population showing damage and the frequency of damage to individuals. Furthermore they highlighted the importance of categorising the severity of damage (light vs severe scars) as these two categories showed opposite trends as fishing intensity increased. While light scarring load increased with fishing intensity, severe scarring decreased. The difference is thought to be attributable to the different abilities of individuals to survive the different categories of damage. Light damage will rarely result in immediate mortality but severe damage is potentially fatal and more so on heavily fished sites where there is an increased opportunity for the damaged animal to be predated upon (Ramsay & Kaiser, 1998). Hence fewer animals on heavily fished sites will recover from severe damage, so fewer living animals will show severe scars.

Damage assessment of starfish (Kaiser, 1996; Ramsay *et al.*, 2001.) also offered a promising method for discrimination of heavily fished from other sites in the Clyde but highlighted the issue of patchiness in terms of the variability in the population size-frequency between sites. Size structure will depend on several natural factors, most notably feeding and growth conditions, but will also be subject to influence by historical demersal fishing practices (Rogers & Ellis, 2000). Energy availability will also govern reproductive performance, and it is typical of many marine organisms (both vertebrate and invertebrate) that recruitment can vary locally both spatially in any one settlement season depending on larval supply and settlement opportunity (Barnes, 1956; Moore, 1975; Wethey, 1985) or from one year to another depending on climatic variation (Raimondi, 1990; Gaines & Bertness, 1992). Local populations of any species may thus differ considerably in size composition, for many reasons. Since damage inflicted by trawls varies with the size of individuals this feature requires consideration (Marrs *et al.*, 2000b). It is also not impossible that identically sized individuals could be differently damaged by gear impact at different times of year, comparing say the non-breeding season with the breeding season when ripe animals with turgid gonads might be more vulnerable to mechanical stress.

Aegean studies showed that ophiuroid, asteroid and crinoid echinoderms were most prone to arm damage, but it was not clear if arms were lost directly by the mechanical action of the gear or by autotomy provoked by escape reactions. Damage may also be sustained on deck during catch sorting and exposure to aerial conditions prior to discarding (likely to be more stressful at higher Mediterranean air temperatures).

The cost-effectiveness of using damage as a measure of impact is influenced markedly by the choice of assessment scale. Simple protocols may be just as informative as complex ones in the long run. It should always be remembered that sampling devices and sampling processes may themselves generate damage, i.e. the organism on the deck will almost certainly not be of the same quality as that same organism *in situ*. Any sampling technique that is unduly damaging renders itself ineligible for recommendation as a rapid assessment tool. The small, light-weight beam or Agassiz trawls used presently are becoming a standard gear for such assessments (Kaiser *et al.*, 1994; Ramsay *et al.*, 1997) and, providing that tow duration is kept short and the catch is handled carefully on deck this assumption has merit. Clearly the duration of tow will relate to the population density of organisms on the sea bed, and in cases where populations are sparsely distributed, longer tow durations will be needed to secure a sufficient catch for analysis. This introduces the potential for problems, depending on the composition of the ground, for animals in the cod end to be damaged by churning against stones and other hard objects (including other shelled organisms) (Franceschini *et al.*, 2000).

The 2-metre beam trawl worked extremely well in the Clyde Sea and is highly recommended for future studies. Being a light gear it has certain limitations of use, as shown by experience in the Aegean, but is well suited to studies in water <100 m deep. It causes far less damage to the sample than does an Agassiz trawl and is more selective for epifauna (rather than infauna).

Sediment analyses

Consideration of sediment geotechnics did supplement interpretation of the other types of data gathered but in itself the sediment analytical results proved equivocal. In the first place it should be stressed that a key proposition in all *ex situ* work is that the core sample extracted is undisturbed and representative of conditions at the sea bed. Core diameter is important in this regard since the narrower the tube the more that surface friction effects of the tube wall interfere with the results. Two of the analyses attempted (granulometry and load resistance penetrometry) detected a seasonal difference (in spring) in the sediment structure and mechanical properties which appeared to be enhanced at sites experiencing heavy fishing pressure in the Clyde Sea. However, causality could not be established. The possibility that there are seasonal differences in sediment coherence seems very likely, given that seasonal variation in organic coatings, e.g. of benthic microbiota, will have differing binding effects on sediment particles (Holland *et al.*, 1974; Meadows & Tufail, 1986; Meadows *et al.*, 1994, Yallop *et al.*, 2000). What was clear, was that the outcome of the geotechnical tests depended on the particle size-structure of the sediment. Thus comparisons between sites of differing trawling intensity can be confounded by variations in granulometry. Shear strength results were highly variable and likely masked the effects detected by load resistance penetrometry. Results of the test on dry bulk density and percentage water content were notably invariable, as no seasonal or fishing impact-related trends were discovered.

Sediment Profile Imagery (SPI), e.g. REMOTS (Rhoads & Cande, 1971; Rumohr & Schomann, 1992), is one of the few techniques giving relatively rapid information return on physical characterisation of the bottom (including sub-surface stratification) and biota, albeit only over very small spatial scales. The technique is amenable to the generation of both qualitative (operator descriptive information) and quantitative data (e.g. on penetration depth, surface roughness), and these data can be compared between sites experiencing differing degrees of trawling impact. Penetrability of sediments will of course be ground-type dependent. The prism penetrates much deeper in soft sediments than in hard-packed sand. Even with slight penetration of more difficult sediments, however, the method has its uses in that sediment surface descriptors can still be valuable. There is certainly under-utilised scope for SPI technology to be deployed alongside sediment geotechnics to greater effect than using either technique in isolation.

Relevance to the Common Fisheries Policy and its future

Since 1983, European fisheries have been managed through implementation of the Common Fisheries Policy. During this time, a number of changes have occurred in fisheries, and the CFP has been required to address problems different from those envisaged on its inception. The CFP has tried to take into account the biological, economic and social dimensions of fishing, but it is accepted that it has failed to deliver sustainable exploitation of fisheries resources. The CFP is currently under review, and its future has recently been the subject of report by the European Commission (Green Paper on the future of the Common Fisheries Policy).

The Green Paper identifies “improving conservation and the protection of marine ecosystems” as one of the four main objectives of a future CFP. In response to this objective it suggests that the future CFP could be adapted to facilitate the implementation of the Biodiversity Action Plan and the Strategy for the integration of environmental considerations, which have recently been adopted. Such developments in the CFP would clearly require considerable input in terms of scientific advice on the effects of fishing activities on different habitats and communities. There are a number of aspects of the functioning of marine ecosystems and the effects of fishing on them, where data are limited, and rapid methods of quantifying environmental impact would have a valuable role to play in improving the depth of our knowledge about this important issue.

If an environmental dimension is to be integrated into policy making in a future CFP, then the current levels of environmental disturbance due to fishing need to be quantified. The rapid approaches identified within this study offer cost-effective techniques, which could be included in existing research vessel cruises. FRS Marine Laboratory already aim to include beam trawl sampling in the 2001 groundfish surveys, as a means of collecting additional data on benthic communities.

6. CONCLUSIONS

Several techniques are available that can lend themselves to the rapid assessment of trawling impacts on the sea bed. Some are non-intrusive (e.g. RoxAnn™, sidescan sonar, ROV) but most involve some minimal impact during sampling (e.g. SPI, sediment coring, towed video-sledge, lightweight beam or Agassiz trawling). Some methods give instantaneous outputs (e.g. RoxAnn™, sidescan sonar), some require delays of varying duration before results can be accessed (e.g. film-based SPI) or data analysed (e.g. community analyses). Optical methods (video, ROV, SCUBA diving) are affected by seawater turbidity but acoustic methods (RoxAnn™, sidescan sonar) are not. The interpretation of some measurements derived *ex situ* (e.g. sediment geotechnics) will always carry the proviso that data may not be entirely representative of the natural conditions *in situ*. However, continued technological advances in ROV equipment will likely enable *in-situ* measurements to be made in the near future.

In our experience, bottom-discriminating sonar (RoxAnn™) has not offered sufficient discrimination power to distinguish between soft muddy grounds experiencing differing degrees of fishing intensity. In particular, if the granulometry differs between compared sites then this factor may mask trawling impact differences. The method may have utility in the context of a time-series study, i.e. monitoring within-site variability without the problems associated with between-site heterogeneity (e.g. Tuck *et al.*, 1998), but will still require groundtruthing by a complementary method such as TV or granulometry.

Sidescan sonar has emerged as a powerful tool for detecting and enumerating otter trawl marks on the sea bed (Schwinghamer *et al*., 1998; *Tuck et al.*, 1998; Friedlander *et al.*, 1999). The set-up of the sonar system is crucial (towing altitude, swathe pattern, 'tuning' of instrumentation). Where there is a strong unidirectional component to trawl tows then a sinusoidal swathe along the main axis of tow is the most efficient pattern. Otherwise a grid pattern offers the best opportunities for quantification. The pictorial output from this method is readily understood and a simple but effective system of quantitative analysis has been developed here and will be widely applicable by non-specialists (i.e. it does not require a high level of experience). Sidescan sonar provides the best potential, so far, for geo-referencing reliable data, including scope for GIS applications and long term monitoring.

Underwater TV (sledge or ROV) is one of the few techniques giving immediate 'real time' feedback on both the physical characteristics and biological assemblages on the sea bed, albeit only over intermediate spatial scales. SCUBA diving of course is another such method, but its routine applicability is highly limited in terms of time and depth of survey. ROVs largely overcome these limitations and enable prolonged observation with the minimum of (physiological) stress to the observer. All methods that rely on optical imaging are, of course, affected by turbidity. As such, efforts should be made to tow into any prevailing currents. Such practical considerations can sometimes delimit the feasibility of particular desired survey schemes based on other considerations. It will be necessary to adjust whatever data are recorded, *viz.* the frequency and duration of tape interrogation, and the detail of observations to be made according to local heterogeneity of bottom (including benthic community) composition. It is probably advisable to coarsely scan the entire taped record of an area before setting up the detailed strategy for data extraction, so that the scheme adopted can be all embracing. One advantage of taped records, of course, is that they can always be re-run and re-analysed in different ways if requirements change.

Sediment Profile Imaging (SPI) techniques require a trained observer with significant experience of a diversity of conditions and habitats to get the most out of the resultant pictures. In heterogeneous environments, because of the small scale of the sampler, large numbers of replicate images need to be taken for confident analysis. This would certainly apply to grounds that are heavily trawled, since the scale of impact of different components of the trawl gear is very different, and local patchiness can be extreme. Advances in camera technology (e.g. moving towards a digital format) will allow much more rapid analysis of the data (since it will obviate the need for film processing). The practical difficulty with SPI-type systems is that operating efficiency is more sea-state dependent than other methodologies as turbulent sea conditions can result in the mechanism firing of the camera in mid-water.

Assessing the damage caused to epibenthic faunal elements by trawling allows recognition of the susceptible life forms on the sea bed and can lead to the recognition of key indicator species. It offers an indirect index of trawling intensity but it is necessary to be aware of the potential for the sampler to inflict damage during the process of sample collection. With certain organisms, like crustaceans, hard-shelled molluscs, starfish and brittlestars, it is possible by careful scrutiny to differentiate between long-standing damage and that inflicted during the collecting process. In the Clyde Sea data above, recent damage sustained by the gastropod *Buccinum undatum* (damage to edge of body whorl) was deemed to have been caused during sampling. Even closely related species can differ widely in their susceptibility to damage, thus *B. undatum* was more heavily damaged than *Neptunea antiqua* in the same area.

Follow-up work on the survival of sublethally damaged species can be used to assess the degree of morbidity represented by different damage loads but, to date, almost all such work has been restricted to species in Northern European waters (see Kaiser & Spencer, 1995;

Bergmann *et al*., 2001a; Bergmann & Moore, 2001a, b and Ramsey *et al.*, 2001 for examples).

Epibenthic communities at heavily fished sites are stressed. They support a lower diversity of epibenthic megafauna dominated by a smaller number of species. Analysis of population density data proved to be robust when undertaken at the species level or with data aggregated to ecologically / taxonomically significant groups. The population densities of certain taxa was shown to vary in relation to nominal trawling impact at sites in the Clyde Sea area, and such data can be used to help select suitable indicator taxa (whether species or groups). Such designations can be viewed as complementary to the outputs from community analyses by numerical methods. Analysis of rank order data or ranked biomass had only limited application, as between-site differences in habitat type were greatly influential in the outcome. In a homogeneous habitat, such an approach may have merit as a rapid assessment technique. We should stress, however, that it would be unsafe to conclude that increased fishing intensity has no effect on total biomass. This study has not addressed this null hypothesis and no manipulative experiments have been done to test it.

Functional group analysis suggested that a relationship existed between trawling intensity and the functional composition of the epibenthic megafauna at particular sites. In the Clyde Sea, as fishing intensity increased the ecosystem shifted from predator-scavenger toward suspension-feeder domination. This pattern, however, was not repeated in the Aegean, where the population of predator-scavengers increased in the commercial fishing lane. How much the Clyde Sea result was a property of particular circumstances remains unresolved, since this is not an expected result. Normally, the expectation is that scavengers and predators increase on grounds that are heavily disturbed by fishing, i.e. utilising the damaged and moribund material left in the wake of the gear (see Ramsay *et al*., 1997).

Cost-effectiveness

A prime consideration in any survey work is cost-effectiveness. Ship-time and the time of skilled scientists are usually the most expensive considerations in any offshore marine survey. Some years ago, Kingston & Riddle (1989) analysed the mobilisation, fieldwork and laboratory analytical costs of ship-based macrofaunal sampling. They noted that because of the high costs involved there is the potential for considerable waste if the methods are not those most appropriate to the objectives. In the absence of comparative analysis, the danger they identified is that information may be acquired that is not of direct relevance at the expense of information that is (or might be). This realisation has been the driving force behind the present programme.

From the point of view of comparing cost-effectiveness, issues relating to international differences in costs of manpower, ship facilities and exchange rates make costs *per se* difficult to compare. We circumvent this difficulty by basing our comparison on a universal comparator, namely time, and present our analysis in tabular form with regard to three particular aspects we consider most important when evaluating the rapid assessment methodologies studies in this report. These aspects are ‘operational considerations’, ‘institutional logistical considerations’ and ‘comparative economics’.

The information shown in Table 32 addresses important points of operational consideration identified during this study when using the different rapid methodologies. For specific electronic instrumentation there will be manuals with manufacturers recommendations for their correct use. However, we have found that there were a number of basic points to be considered concerning what conditions the different techniques will be used in. For example, weather affects all the methodologies, some more than others: the SPI system cannot be used in very bad weather and the tow systems, particularly towed sledge should not be used with the wind behind the towing vessel as the overall speed over the ground may be too fast to allow good images to be recorded (lack of resolution through blurring). Specific advice on considerations cannot be given, because they are greatly situation-dependent, e.g. on local conditions and on the data requirements. Points for consideration also cover examination of material, i.e. whether it involves images or samples. The exact type, or details of the analysis cannot always be pre-planned, but may have to be adapted depending on the data gathered.

The institutional logistical considerations for the methodologies (equipment and analysis of data) are given in Table 33 which compares the general availability of the equipment to the scientific community, complexity of use, skill level required, interpretability of the results, back-up requirements and general applicability towards estimation of otter trawling impacts.

The high technology equipment/methodologies have the highest needs in many of the categories in comparison with the biological methodologies which have the lowest. The most applicable methodologies were felt to be sidescan sonar, towed video and lightweight beam trawling.

The comparative economics of the methodologies are given in Table 34. The area coverage by each methodology is estimated with respect to data gathering in one hour of ship time (at an approximate depth of 100 m). The acoustic, optical and beam trawl sampling generally cover strips or swathes, whilst coring and SPI deployments are not continuous and are therefore given as the area that can be *represented* in one hour. RoxAnn™ could also be included under the same category, because the data are often presented as maps produced by interpolation between tracks, thus covering multiple square kilometres (although with much reduced resolution and confidence). The relationship between scale and resolution of various methodologies is mostly an inverse function, although RoxAnn™ is the exception because its resolution is dependent on water depth. The capital cost of equipment in EUROs is indicative and different systems may vary in cost depending on specification and manufacturer. The more specialised the equipment (high technology), the higher the capital cost. With the exception of the ROV, the cost of acoustic equipment is the highest; however, these methodologies give the greatest area coverage and can be considered to be true mapping tools. Processing time for the majority of the methodologies for one hour of data gathering is in the order of a day or less, with the quickest being optical image analysis of video and SPI. Sedimentary samples take longer to process as there are involuntary delays necessary for drying and extractions. The time taken to process biological samples is related to the abundance and richness of the fauna as well as the skills of the scientific personnel (knowledge of the fauna, speed of processing etc.). The majority, if not all, of the fauna could be processed on-board immediately after collection given experienced personnel and sufficient time.

We believe that choice of methodology is dictated by the scientific questions being asked, and the resources available to provide the answers. This will concern the area of coverage, the scale of sampling, the resolution and type of the data. Sampling may involve a preliminary or one-off survey or may require repeat monitoring of a particular site. The use of a nested sampling approach would be recommended so that more than one methodology is used to encompass a range of coverage, scale and resolution. If resources are limited the single technique that provides the best information in rapid time is the towed video-sledge.

Table 32. Summary of important operational considerations relating to rapid methodologies assessed for otter trawling impact studies.

Basis	Method	Considerations
Acoustic	RoxAnn™	• Water depth and resolution • Interpolations and tracks • Changing frequencies • Use of the individual E1, E2 values • Groundtruthing
	Sidescan Sonar	• Direction of travel • Inability to discern old vs new marks • Requirement to investigate individual otter door marks (marks are rarely matched pairs) • Frequency of the sonar (resolution and scale dependant) • Height of the towfish above the sea bed • Positioning of the system (GPS, DGPS, layback) • Instrument settings and tuning • Weather, water depth, length of wire and grid patterns • Speed of tow • Data interrogation protocols
Optical	Towed Video	• Correct speed of tow • Weather, water depth, length of wire and grid patterns • Turbidity • Positioning • Data interrogation protocols • Counting criteria (ageing, intensity of trawl marks, levels of bioturbation)
	ROV	• Quantitative counts (fixed altitude and calibrated camera) • Measurements (placement of scales, laser scales, scanning sonar) • Ability to move in desired direction • Turbidity • Limited excursions • Pilot skills
	SPI	• Number of replicates • Penetration in coarse sediments • Weather
Sampling	Biological Data – Beam Trawls	• Number of replicates • Taxonomic level • Efficiency of processing (adequate catch volume, vs. processing time) • Accuracy of swept area measurement
	Biological Data – Damage Assessment	• Tow duration • Minimise sample damage (selection of low impact collection gear, rapidity of sample processing) • Suitable fauna (scar bearing and abundant) • Natural background damage load • Knowledge of repair rate
	Geotechnical Properties	• Acquisition of undisturbed core samples • *In situ* methodologies • Adequate non-pseudo replication • Knowledge of habitat heterogeneity • Requirement for supporting granulometry studies • Immediate processing necessary on site

Table 33. Institutional logistic considerations relating to rapid methodologies assessed for otter trawling impact studies. Availability; poor, fair, moderate, good. Complexity; low, medium high. Skill Level Required; low, medium high. Back-up Requirements; low, medium high. Interpretability; simple, average, complex. Applicability; higher number of stars more applicable.

Method	Availability	Complexity	Skill Level	Interpretability	Back-up Requirements	Applicability
RoxAnn™	fair (increasing)	high	medium	complex	high	*
Sidescan Sonar	moderate	high	high	average (simple)	high	***
Towed Video	poor	medium	high	simple	medium	***
ROV	moderate	high	high	simple	high	**
SPI	poor	medium	medium	complex	medium	**
Biological Data – Beam Trawls	good	low	low	average	low	***
Biological Data – Damage Assessment	good	low	low	average	low	*
Geotechnical Properties	poor	medium	medium	complex	low	*

Table 34. Comparative economics of the rapid methodologies assessed for otter trawling impact studies standardised to 1 hours ship time data gathering at 100 m depth. Cost of equipment is indicative as prices vary according to system complexity. Processing time is related to the one hour of data collected, more data may not require exact multiples of this. * This is the rough area that can be representatively covered in 1 hour.

Method	Area Coverage (km^2)	Scale (m)	Resolution (m)	Equipment Cost (€)	Processing Time
Sidescan Sonar	1	180	0.2	32,000	8 hrs
RoxAnn™	0.1	10	10-100	22,000	2 hrs
Towed video-sledge	0.002	1	0.02	16,000	1-2 hrs
ROV	0.001	1-2	0.01	20-40,000	1-2 hrs
Beam Trawls	0.008	2	-	1,600	-
Faunal Analysis	-	-	-	-	8 hrs
Functional Groups	-	-	-	-	8 hrs
Damage Assessment	-	-	-	-	6 hrs
Sediment Cores	2*	0.1	0.01	8,000	-
Granulometry	-	-	-	-	2 days
Ex situ Geotechnics	-	-	-	-	2 days
SPI	2*	0.15	0.002	26,000	2 hrs

7. RECOMMENDATIONS

The ideal technique with which to assess and monitor the impacts of trawling on epibenthic fauna probably does not exist. It would possess the following characteristics. It would be rapid, efficient and non-destructive. The precision of its outputs would be spatial scale- and depth-independent. It would be capable of unambiguous interpretation, of replication between grounds, and would be independent of sea conditions. It would be cost-effective and readily available.

Based on our researches and conclusions above, we offer the following as recommendations relating to the best approximation to this unattainable ideal as techniques suitable for the rapid assessment of otter trawl impacts on soft bottoms:

- Use at least two complementary techniques that operate on different scales of resolution (for example sidescan sonar and biotic sampling, or sidescan sonar and ROV).
- Use RoxAnn™ only where grounds are homogeneous and only after site-specific ground truthing. For exploratory surveys in unknown territory this method may be insufficient on its own to characterise trawl impacts, since confounding variables will complicate interpretation.
- Base the design of the sidescan survey on local conditions, bearing in mind that proper quantitative assessment is best achieved using a grid-based survey. Only qualitative assessments can be derived from parallel-pass survey tracking. The grid pattern is far more time efficient than a parallel-pass survey in terms of the time taken to collect, process and interpret data.
- Single-frame analysis of sidescan records, as developed herein, provides accurate and reliable estimates of the relative density of trawl marks at each station and could be adapted to provide estimates of their absolute densities.
- The orientation of trawl marks can be analysed using methods developed herein, to reveal whether sites are exploited in a preferred or random towing direction. This information could be derived in other ways, for instance by equipping the fishing fleet with GPS data loggers.
- The choice of organisms selected as damage indicators should be based on a preliminary survey of local conditions rather than a pre-selection reliant on data derived from the literature. It is clear that closely related species can differ considerably in their vulnerability to damage (cf. *Buccinum undatum* and *Neptunea antiqua*). Within a single

species, both absolute size of individuals and their reproductive state can influence their susceptibility to damage.

- Choose a simple damage assessment protocol, commensurate with the objectives of the survey. Our experience proved there was no appreciable benefit from gathering shell-scar data from gastropods for more than the largest (body-) whorl, or for recording more features in starfish than simply the number of regenerating arms.
- Sampler-induced damage should be quantified and sampling gear selected on the basis of minimising sampling damage.
- Community analyses of epibenthic megafauna are far more rapidly executed than equivalent studies of more diverse (and hence taxonomically complex) macrobenthic infauna. In general, for assessment of trawl impacts, one should eschew grab sampling and macrofaunal analysis as being too inefficient and costly. Megafaunal indicators of trawl impacts will emerge from analyses using standard available packages (like PRIMER). Taxa need not be identified to species; identification to Family was just as satisfactory. This factor may offer potential for robust approaches to tackling trawl-impact studies in regions of the world where the taxonomy of marine benthos is still poorly known. Furthermore, it will undoubtedly speed up the data gathering process.
- For the moment, the need to acquire frequency data (as opposed to presence/absence data) for studies based on epibenthic megafana remains. In theory, data can be reduced to presence/absence records for highly diverse communities, but the threshold of diversity at which this switch can be made has yet to be established.
- Multivariate community analyses are simple to apply and can provide significant analytical advantages over univariate tests. However, univariate analyses should not be ignored. The two analyses are complimentary and should be used together. As with all statistics, it is necessary that the properties of ‘off the shelf’ methods are fully appreciated by the analyst if pitfalls in interpretation are to be avoided.
- The methods developed here for analysing video footage collected by towed video-sledge with respect to biogenic and anthropogenic modelling of sediments should be adopted and, where desirable, adapted to the meet the specific requirements of a survey.
- TV/video is the only method recommended for assessing the relative age of trawl marks *in situ*. In shallow water this might be possible using SCUBA diving, but since most otter trawling takes place in relatively deep water, the opportunities for direct observations are limited.

- TV methods should be used if there is a need to characterise marks left by particular parts of the gear. The discriminatory ability of TV is much better than sidescan sonar, but the spatial scale of its output is much more restricted.

- Sediment geotechnical analyses should not be used as a principal method for the rapid assessment of trawl impacts. The necessary equipment is not widely available and the results are highly dependent on the granulometric structure of sediments. They may, however, provide useful information that complements other methods, particularly in time-series analyses of a single site. Sediment profile imagery (SPI) is more applicable as a rapid assessment method.

8. SUGGESTIONS FOR FURTHER WORK

Several areas of ignorance have come to light during the course of these researches, hence we make some recommendations for further work:

- Insufficient is known about the *in situ* decay rates of trawl marks on different sediment types and in different hydrographic regimes. Ideally, this would be best studied by direct observations (SCUBA diving) if a satisfactory site were available. *In situ* time-lapse TV approaches could only be contemplated on very few grounds due to logistical problems.
- The relative importance of the physical and biological processes that affect the decay rates of trawl marks requires investigation.
- The structural and functional significance of trawl-furrowed sediments to benthic biodiversity requires to be established.
- The accurate interpretation of sidescan sonar images of trawl marks would benefit from research designed specifically to investigate the attenuation of signals from trawl marks as their orientation changes with respect to the towed fish.. The micro-topographic form of differently sculpted furrows may also influence back scattering of the signal such that particular features may not generate a signal.
- The *in situ* action of otter trawls in relation to a number of variables, e.g. towing speed, turning, symmetrical or other rigging of towing warps, will differ on grounds of different sediment properties, and will be responsible for leaving different types of traces in their wake. These aspects need to be addressed systematically, ideally in a pristine area to avoid ambiguity.
- Some of the 'rapid assessment' methods described here should be added to schedules for forthcoming research surveys with a view to accumulating information on the spatial patterns of fishing impacts.
- A better understanding of the population dynamics and functional properties of benthic megafaunal species is necessary to illuminate spatial and temporal differences in growth rates and repopulation potential.
- Research is needed to establish at what level of biodiversity it becomes superfluous to record frequency information on epibenthic megafauna in order gain an understanding of gross spatial patterns at the community level. At what level of biodiversity does simple presence/absence data provide comparable results?

- A combination approach to sedimentological investigations involving SPI observations in conjunction with geotechnical analyses would create useful synergies.
- Evaluations should be made of emerging technology and new techniques, e.g. STING (Sea bed Terminal Impact Newton Gradiometer – Jasco Research Ltd, UK), sub-bottom profilers, sea bed plough etc.

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Crete (IMBC)

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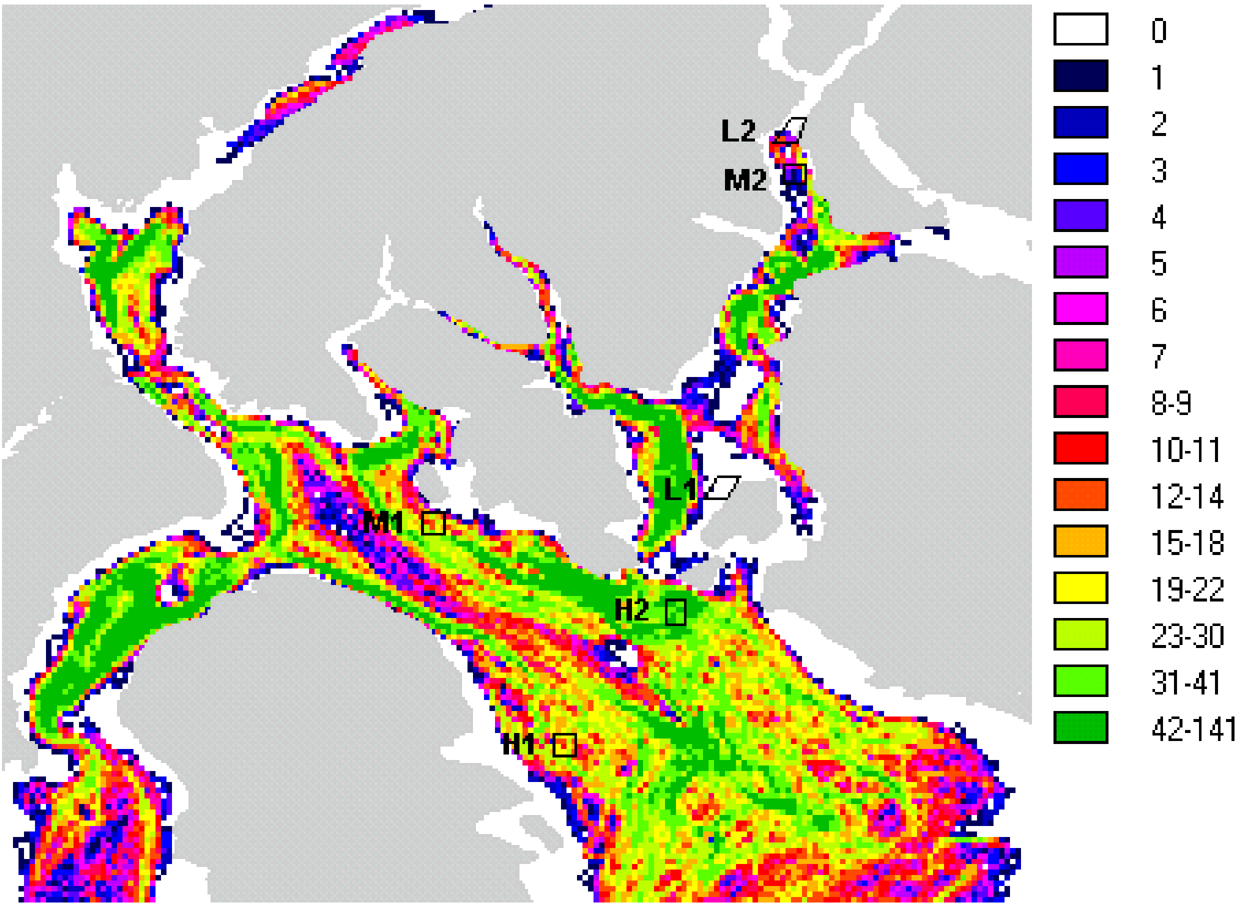
APPENDIX I.

Microscale effort mapping of trawlers fishing for *Nephrops norvegicus* in the Clyde Sea (courtesy of Marrs *et al*., 2000a). The coloured scale shows the number of otter trawls made in each pixel during the year November 1998 to October 1999. Data were collected from 18 vessels operating throughout the Clyde Sea (representing ~20% of the Clyde *Nephrops* fleet). These data were used to complement the knowledge of local fisheries experts when selecting sampling sites for the current study. The chosen sites are outlined and labelled with their site code.



APPENDIX II.

Four-point scales for scoring biogenic and anthropogenic disturbance to sediments

	Biogenic modelling		Anthropogenic modelling
1	Sediments smooth, flat or slightly undulating, rarely containing burrow mounds/holes or sedentary epifauna. Some tracks of errant organisms may be visible.	0	No evidence of trawl marks or catch discards
2	Sediments with moderate biogenic modelling. Occasional burrow mounds/holes (possibly in patches) or pits/depressions in homogeneous sands/muds/ clays. In heterogeneous, sediments, occasional patches of biogenic material (e.g. shell, maerl).	1	Fresh or recent trawl marks rare. Generally marks are smoothed or worn with little penetration, well weathered by physical forces, further sedimentation or biogenic re-working of sediment. Minor evidence of discards.
3	Sediments with high biogenic modelling. Frequent burrow mounds/holes in sands/muds/clays. Frequent patches of biogenic material forming composite sediments (e.g. muddy shell gravel).	2	Occasional fresh or recent trawl marks. Generally marks are significantly aged with reduced definition. Biogenic structures largely re-built / re-emerging subsequent to a trawling impact. Moderate evidence of discards.
4	Sediments with complex biogenic modelling (even if modified by trawl impact). Abundant burrow mounds/holes in homogeneous sands/muds/clays. Shell or maerl the predominant component in composite sediments.	3	Frequent, well defined fresh or recent trawl marks. Trawl doors leaving furrows & associated dumps of tilled sediment. Sweeps and net causing some flattening of biogenic structures which have not yet been re-built. Major evidence of discards

Note: Interpretation should be made giving due consideration to the modification which one factor can have on the other (anthropogenic impacts modifying biogenic structures & *vice versa*). For the purpose of illustration (an extreme example), a trawl passing over a previously untrawled and highly biogenic sediment (B4) will cause severe modification to the sediment relief, smoothing it considerably. The biogenic impact should, however, still be recorded as a B4. Similarly, trawl marks made in highly biogenic areas may be rapidly modified by organisms clearing burrow openings or making new burrows.

APPENDIX III-A

Taxa of epibenthic megafauna recorded from small beam trawl samples from sites in the Clyde Sea area. Also, the Functional group to which each taxon was assigned. Functional groups describe the dominant trophic mode of the organism (1= predator-scavenger, 2 = suspension feeder, 3 = deposit feeder) and the predominant foraging habit (a = burrowing dwelling, b = sedentary, c = motile)

Phylum	Class	Order	Family	Taxon	Functional Group
Annelida	Polychaeta	Errantia	Aphroditidae	*Aphrodita aculeata*	1c
Arthropoda	Crustacea	Anomura	Axiidae	*Calocaris macandreae*	3a
			Galatheidae	*Galathea dispersa*	2c
				Galathea squamifera	2c
				Munida rugosa+sarsi	1c
			Paguridae	*Pagurus bernhardus*	1c
				Pagurus cuanensis	1c
				Pagurus prideauxi	1c
			Porcellanidae	*Pisidia longicornis*	2c
		Astacidea	Nephropidae	*Nephrops norvegicus*	1c
		Brachyura	Goneplacidae	*Goneplax rhomboides*	1c
			Majidae	*Hyas araneus*	1c
				Hyas coarctatus	1c
				Inachus dorsettensis	1c
				Macropodia tenuirostris	1c
			Portunidae	*Carcinus maenas*	1c
				Liocarcinus depurator	1c
				Liocarcinus holsatus	1c
				Necora puber	1c
		Caridea	Hippolytidae	*Spirontocaris lilljeborgi*	1c
			Palaemonidae	*Palaemon serratus*	1c
			Pandalidae	*Dichelopandalus bonnieri*	1c
				Pandalus montagui	1c
			Processidae	*Processa sp.*	1c
Cnidaria	Anthozoa	Pennatulacea	Virgulariidae	*Virgularia mirabilis*	2b
Echinodermata	Asteroidea	Forcipulata	Asteriidae	*Asterias rubens*	1c
				Marthasterias glacialis	1c
		Phanerozonia	Astropectinidae	*Astropecten irregularis*	1c
			Poraniidae	*Porania pulvillus*	1c
	Echinoidea	Clypeasteroidea	Spatangidae	*Brissopsis lyrifera*	3a
				Echinocardium cordatum	3a
		Diadematoidea	Echinidae	*Echinus acutus*	1c
				Echinus esculentus	1c
				Psammechinus miliaris	1c
	Ophiuroidea	Ophiurae	Amphiuridae	*Amphiura brachiata*	3b
				Amphiura chiajei	3b
			Ophiactidae	*Ophiopholis aculeata*	3c
			Ophiocomidae	*Ophiocomina nigra*	1c
			Ophiolepidae	*Ophiura albida*	1c
				Ophiura ophiura	1c
			Ophiotrichidae	*Ophiothrix fragilis*	1c
Mollusca	Bivalvia	Pteriina	Pectinidae	*Aequipecten opercularis*	2b
				Pseudamussium septemradiatum	2b
	Cephalopoda	Myopsida	Sepiolidae	*Rossia macrosoma*	1c
	Gastropoda	Mesogastropoda	Aporrhaiidae	*Aporrhais pespelecani*	2b
				Aporrhais serresianus	2b
			Turritellidae	*Turritella communis*	2b
		Neogastropoda	Buccinidae	*Buccinum undatum*	1c
				Colus gracilis	1c
				Neptunea antiqua	1c

continued ……

Phylum	Class	Order	Family	Taxon	Functional Group
Pisces	Chondrichthyes	Lamniformes	Scyliorhinidae	*Scyliorhinus canicula*	1c
	Osteichthyes	Gadiformes	Gadidae	*Enchelyopus cimbrius*	1c
			Zoarcidae	*Zoarces viviparus*	1c
		Perciformes	Callionymidae	*Callionymus lyra*	1c
				Callionymus maculatus	1c
			Cepolidae	*Cepola rubescens*	1a
			Gobiidae	*Pomatoschistus grp 1*	1c
				Pomatoschistus grp 2	1c
			Lumpenidae	*Lumpenus lampretaeformis*	1c
			Pholidae	*Pholis gunnellus*	1c
		Pleuronectiformes	Bothidae	*Phrynorhombus norvegicus*	1c
			Pleuronectidae	*Glyptocephalus cynoglossus*	1c
				Hippoglossoides platessoides	1c
				Limanda limanda	1c
				Microstomus kitt	1c
				Pleuronectes platessa	1c
			Soleidae	*Microchirus variegatus*	1c
		Scorpaeniformes	Agonidae	*Agonus cataphractus*	1c
			Cottidae	*Taurulus bubalis*	1c
			Triglidae	*Eutrigla gurnardus*	1c
Totals 6	11	20	43	70	

APPENDIX III-B

Taxa of epibenthic megafauna recorded from Agassiz trawls at Dia Island, Aegean, and the functional groups (FG) to which they were assigned.

No.	Cat.	Species	F.G.	No.	Cat.	Species	F.G.
1	Asc	*Ascidia mentula*	2B	65	Fish	*Cepola rubescens*	1C
2	Asc	*Ascidia sp.*	2B	66	Fish	*Chlorophthalmus agassizi*	1C
3	Cru	*Alpheus glaber*	3A	67	Fish	*Citharus linguatula*	1C
4	Cru	*Calappa granulata*	1C	68	Fish	*Zeus faber*	1C
5	Cru	*Calocaris macandreae*	3A	69	Fish	*Gadella maraldi*	1C
6	Cru	*Chlorotocus crassicornis*	1C	70	Fish	*Gaidropsarus mediterraneus*	1C
7	Cru	*Dardanus arrosor*	1C	71	Fish	*Gobiidae*	1C
8	Cru	*Ebalia desayhesi*	3C	72	Fish	*Gobiosocidae sp.*	1C
9	Cru	*Ebalia nux*	3C	73	Fish	*Helicolenus dactylopterus*	1C
10	Cru	*Ebalia tuberosa*	3C	74	Fish	*Labridae sp.*	1C
11	Cru	*Epimeria cornigera*	1C	75	Fish	*Lappanella fasciata*	1C
12	Cru	*Ergasticus clouei*	1C	76	Fish	*Lepidotrigla cavillone*	1C
13	Cru	*Goneplax rhomboides*	1C	77	Fish	*Lepidotrigla diujeidei*	1C
14	Cru	*Hippolytidae sp.*	1C	78	Fish	*Leuserigobius friesii*	1C
15	Cru	*Hyppolite leptometra*	1C	79	Fish	*Lophius budegasa*	1C
16	Cru	*Inachus parvirostris*	1C	80	Fish	*Merluccius merluccius*	1C
17	Cru	*Latreillia elegans*	1C	81	Fish	*Mora moro*	1C
18	Cru	*Liocarcinus maculatus*	1C	82	Fish	*Ophidion rockei*	1C
19	Cru	*Macropipus tuberculatus*	1C	83	Fish	*Phycis blennoides*	1C
20	Cru	*Macropodia longipes*	1C	84	Fish	*Scoloplax macroramphosa*	1C
21	Cru	*Macropodia longirostris*	1C	85	Fish	*Scorpaena elongata*	1C
22	Cru	*Macropodia rostrata*	1C	86	Fish	*Scorpaena sp.*	1C
23	Cru	*Monodaeus couchii*	1C	87	Fish	*Serranus cabrilla*	1C
24	Cru	*Munida iris rutlandi*	1C	88	Fish	*Serranus hepatus*	1C
25	Cru	*Oplophoridae sp.*	1C	89	Fish	*Symphurus nigrescens*	1C
26	Cru	*Pagurus prideaux*	1C	90	Fish	*Torpedo marmorata*	1C
27	Cru	*Palinurus elephas*	1C	91	Mol	*Abra alba*	3A
28	Cru	*Parapenaeus longirostris*	1C	92	Mol	*Abra longicallus*	3A
29	Cru	*Parthenope macrochelos*	1C	93	Mol	*Aporrhais serresianus*	2B
30	Cru	*Parthenope sp.*	1C	94	Mol	*Callista chione*	2B
31	Cru	*Philoceras bispinosus*	1C	95	Mol	*Caloplocamus ramosus*	1C
32	Cru	*Pisa sp.*	1C	96	Mol	*Cardium sp.*	2B
33	Cru	*Plesionika heterocarpus*	1C	97	Mol	*Chlamys septemradiata*	2B
34	Cru	*Plesionika narval*	1C	98	Mol	*Cuspidaria cuspidata*	3B
35	Cru	*Plesionika sp.*	1C	99	Mol	*Cuspidaria rostrata*	3B
36	Cru	*Pontocaris lacazei*	1C	100	Mol	*Dentalium sp.*	3B
37	Cru	*Pontopilus spinosus*	1C	101	Mol	*Doris sp.*	1C
38	Cru	*Processa canaliculata*	1C	102	Mol	*Eledone cirrhosa*	1C
39	Cru	*Processa sp.*	1C	103	Mol	*Fusinus sp.*	1C
40	Cru	*Rissoides pallidus*	1C	104	Mol	*Gibbuba divaricata*	3B
41	Cru	*Scyllarus caparti*	1C	105	Mol	*Natica hebrea*	1C
42	Cru	*Solenocera membranacea*	1C	106	Mol	*Natica milepunctata*	1C
43	Cru	*Squilla mantis*	1C	107	Mol	*Nucula sp.*	3B
44	Cru	*Synalpheus sp.*	3A	108	Mol	*Octopus vulgaris*	1C
45	Ech	*Amphiura chiajei*	3B	109	Mol	*Rondeletiola minor*	1C
46	Ech	*Amphiura filiformis*	2B	110	Mol	*Rossia macrosoma*	1C
47	Ech	*Astropecten irregularis*	1C	111	Mol	*Scaphader lignarius*	1C
48	Ech	*Brissopsis*	3A	112	Mol	*Sepia elegans*	1C
49	Ech	*Cidaris cidaris*	1C	113	Mol	*Sepia officinalis*	1C
50	Ech	*Holothuria sp.*	3A	114	Mol	*Sepia orbignyana*	1C
51	Ech	*Lapidoplax digitata*	3A	115	Mol	*Sepietta oweniana*	1C
52	Ech	*Leptometra phalangium*	2B	116	Mol	*Tellina sp.*	3B
53	Ech	*Luidia sarsi*	1C	117	Mol	*Tonna galea*	1C
54	Ech	*Marthasterias glacialis*	1C	118	Mol	*Turritela communis*	2B
55	Ech	*Ophiura texturata*	1C	119	Var	*Caryophylia smithi*	2B
56	Ech	*Spatangus*	3A	120	Var	*Cerianthus sp.*	2B
57	Ech	*Sphaerodiscus placenta*	1C	121	Var	*Chloeia sp.*	1C
58	Ech	*Stichopus regalis*	3A	122	Var	*Funiculina quadrangularis*	2B
59	Ech	*Tethyaster subinermis*	1C	123	Var	*Hermione*	1C
60	Fish	*Argentina sphyraene*	1C	124	Var	*Hyalinoecia*	1C
61	Fish	*Arnoglossus laterna*	1C	125	Var	*Paramuricea clavata*	2B
62	Fish	*Arnoglossus thorii*	1C	126	Var	*Sigalionidae*	1C
63	Fish	*Callionymus phaeton*	1C	127	Var	*Sternaspis scutata*	3C
64	Fish	*Capros aper*	1C				

APPENDIX III-C

Taxa of epibenthic megafauna recorded from Agassiz trawls at the Gouves area, Aegean, and the functional groups (FG) to which they were assigned.

No.	Cat.	Species	F.G.	No.	Cat.	Species	F.G.
1	Asc	*Ascidia mentula*	2B	61	Cru	*Pontocaris cataphractus*	1C
2	Asc	*Ascidia sp.*	2B	62	Cru	*Pontocaris lacazei*	1C
3	Asc	*Halosynthia papillosa*	2B	63	Cru	*Processa canaliculata*	1C
4	Asc	*Microcosmus polymorphus*	2B	64	Cru	*Processa edulis*	1C
5	Asc	*Microcosmus vulgaris*	2B	65	Cru	*Processa macrophthalma*	1C
6	Asc	*Molgula sp.A*	2B	66	Cru	*Processa nouveli*	1C
7	Asc	*Polycarpa sp.A*	2B	67	Cru	*Scyllarus caparti*	1C
8	Asc	*Polycarpa sp.B*	2B	68	Cru	*Scyllarus pygmaeus*	1C
9	Asc	*Styela sp.*	2B	69	Cru	*Solenocera membranacea*	1C
10	Cru	*Alpheus glaber*	3A	70	Cru	*Squilla mantis*	1C
11	Cru	*Atelecyclus rotundatus*	1C	71	Cru	*Synalphaeus sp.*	3A
12	Cru	*Athanas amazonae*	3A	72	Cru	*Upogebia sp.*	3A
13	Cru	*Atlantoidea*	3A	73	Ech	*Amhiura chiajei*	3B
14	Cru	*Calappa granulata*	1C	74	Ech	*Amhiura filiformis*	3B
15	Cru	*Callianassa sp.*	3A	75	Ech	*Anseropoda placenta*	1C
16	Cru	*Chlorotocus crassicornis*	1C	76	Ech	*Antedon mediterranea*	2B
17	Cru	*Dardanus arrosor*	1C	77	Ech	*Astropecten irregularis*	1C
18	Cru	*Dromia personata*	1C	78	Ech	*Brissopsis*	3A
19	Cru	*Ebalia deshayesi*	3C	79	Ech	*Centrostephanus longispinus*	1C
20	Cru	*Ebalia nux*	3C	80	Ech	*Cidaris cidaris*	1C
21	Cru	*Ebalia sp.*	3C	81	Ech	*Echinaster sepositus*	1C
22	Cru	*Ebalia tuberosa*	3C	82	Ech	*Luida ciliaris*	1C
23	Cru	*Engystenopus sp.*	1C	83	Ech	*Luidia sarsi*	1C
24	Cru	*Epimeria cornigera*	1C	84	Ech	*Marthasterias glacialis*	1C
25	Cru	*Ethusa mascarone*	1C	85	Ech	*Ophiacantha setosa*	1C
26	Cru	*Eurynome aspera*	1C	86	Ech	*Ophiothrix fragilis*	1C
27	Cru	*Galathea intermedia*	2C	87	Ech	*Ophiura ophiura*	1C
28	Cru	*Galathea sp.*	2C	88	Ech	*Sphaerochinus granularis*	1C
29	Cru	*Goneplax rhomboides*	1C	89	Ech	*Sphaerodiscus placenta*	1C
30	Cru	*Heterocrypta maltzani*	1C	90	Ech	*Stichopus regalis*	3C
31	Cru	*Hippolytidae*	1C	91	Ech	*Tethyaster subinermis*	1C
32	Cru	*Inachus parvirostris*	1C	92	Ech	*Thalassema gigas*	3B
33	Cru	*Isopoda*	1C	93	Fish	*Arnoglossus laterna*	1C
34	Cru	*Latreillia elegans*	1C	94	Fish	*Arnoglossus thorri*	1C
35	Cru	*Liocarcinus maculatus*	1C	95	Fish	*Blennius occelaris*	1C
36	Cru	*Lysianassidae*	1C	96	Fish	*Callionymus phaeton*	1C
37	Cru	*Macropodia linaresi*	1C	97	Fish	*Cepola rubescens*	1C
38	Cru	*Macropodia longipes*	1C	98	Fish	*Citharus linguatula*	1C
39	Cru	*Macropodia longirostris*	1C	99	Fish	*Flatfish diafanes*	1C
40	Cru	*Macropodia rostrata*	1C	100	Fish	*Gobiosocidae*	1C
41	Cru	*Maja crispata*	1C	101	Fish	*Gobius gasteveni*	1C
42	Cru	*Maja squinado*	1C	102	Fish	*Gobius geniporus*	1C
43	Cru	*Monodaeus couchii*	1C	103	Fish	*Gobius sp.*	1C
44	Cru	*Paguristes eremita*	1C	104	Fish	*Lappanela fasciata*	1C
45	Cru	*Pagurus cuanensis*	1C	105	Fish	*Lepidotrigla cavillone*	1C
46	Cru	*Pagurus sp.*	1C	106	Fish	*Lepidotrigla deudezei*	1C
47	Cru	*Pagurus excavatus*	1C	107	Fish	*Leuseurigobius friescii*	1C
48	Cru	*Pagurus prideaux*	1C	108	Fish	*Lophius budegasa*	1C
49	Cru	*Palicus caronii*	1C	109	Fish	*Microchirus variegatus*	1C
50	Cru	*Palinurus elephas*	1C	110	Fish	*Mullus barbatus*	1C
51	Cru	*Parthenope macrochelos*	1C	111	Fish	*Ophidion rockei*	1C
52	Cru	*Parthenope massena*	1C	112	Fish	*Scorpaena notata*	1C
53	Cru	*Parthenope miersi*	1C	113	Fish	*Scorpaena scrofa*	1C
54	Cru	*Parthenope sp.*	1C	114	Fish	*Serranus cabrilla*	1C
55	Cru	*Periclimenes sp.*	1C	115	Fish	*Serranus hepatus*	1C
56	Cru	*Philocheras bispinosus*	1C	116	Fish	*Symphurus nigrescens*	1C
57	Cru	*Philocheras sculptus*	1C	117	Fish	*Trigloporus lastoviza*	1C
58	Cru	*Pilumnus hirtellus*	1C	118	Fish	*Uranoscopus scaber*	1C
59	Cru	*Pisa armata*	1C	119	Mol	*Acanthocardia echinata*	2B
60	Cru	*Plesionika heterocarpus*	1C	120	Mol	*Acanthocardia paucicostata*	2B

..continued ….

Appendix III-C continued

No.	Cat.	Species	F.G.
121	Mol	*Aequipecten opercularis*	2B
122	Mol	*Anomia ephippium*	2B
123	Mol	*Aporrhais pespelecani*	2B
124	Mol	*Arca tetragona*	2B
125	Mol	*Barbatia barbata*	2B
126	Mol	*Calliostoma sp.*	1C
127	Mol	*Callista chione*	2B
128	Mol	*Caloplocamus ramosus*	1C
129	Mol	*Cardita aculeata*	2B
130	Mol	*Chiton sp.*	1C
131	Mol	*Pseudamussium septeradiatum*	2B
132	Mol	*Chlamys varia*	2B
133	Mol	*Clausinella brongiarti*	2B
134	Mol	*Clausinella fasciata*	2B
135	Mol	*Corbula gibba*	2B
136	Mol	*Cuspidaria rostrata*	2B
137	Mol	*Dentalium sp.*	3B
138	Mol	*Eledone cirrhosa*	1C
139	Mol	*Fissurella gibba*	1C
140	Mol	*Fusinus pulchelus*	1C
141	Mol	*Fusinus rostratus*	1C
142	Mol	*Gibbula sp.*	3B
143	Mol	*Opisthobranchia*	1C
144	Mol	*Hiatella arctica*	2B
145	Mol	*Jujubinus sp.*	2B
146	Mol	*Laevicardium oblongum*	2B
147	Mol	*Limatulla subauriculata*	2B
148	Mol	*Modiodula phaseolina*	2B
149	Mol	*Murex trunculus*	1C
150	Mol	*Natica milepunctata*	1C
151	Mol	*Octopus vulgaris*	1C
152	Mol	*Pleurobranchia meckeli*	1C
153	Mol	*Palliolum hyalinum*	2B
154	Mol	*Papillicardium papillosum*	2B
155	Mol	*Parvicardium ovale*	2B
156	Mol	*Pecten maximus*	2B
157	Mol	*Philine sp.*	1C
158	Mol	*Rossia macrosoma*	1C
159	Mol	*Scaphander lignarius*	1C
160	Mol	*Sepia elegans*	1C
161	Mol	*Sepia officinalis*	1C
162	Mol	*Sepietta oweniana*	IC
163	Mol	*Sepiola sp.*	1C
164	Mol	*Striarca lactea*	2B
165	Mol	*Tellina balaustina*	3B
166	Mol	*Tethys fimbria*	1C
167	Mol	*Turridae*	1C
168	Mol	*Turritella triplicata*	2B
169	Mol	*Umbraculum mediterraneum*	1C
170	Pol	*Chloeia sp.*	1C
171	Pol	*Hermione hystrix*	1C
172	Pol	*Hyalinoecia tubicola*	1C
173	Var	*Cerianthus sp.*	2B

For Appendix III-B & C, Asc = ascidians, Cru = crustaceans, Ech = echionoderms, Mol = molluscs, Pol = polychaetes, Var = various other groups.

APPENDIX IV

Population density of epibenthic megafauna from six sites in the Clyde representing three nominal levels of fishing impact (H = high, M = moderate, L = low). Common-name headings (e.g. Round-fish) define ecologically / taxonomically significant groups used when summarising the data (Section 4.4.3, Figure 67).

	Density by weight (g · 1000 m^2)						Density by number (no · 1000 m^2)					
Taxon	**H1**	**H2**	**M1**	**M2**	**L1**	**L2**	**H1**	**H2**	**M1**	**M2**	**L1**	**L2**
Round-Fish												
Agonus cataphractus					6.2						0.2	
Callionymus lyra	5.6	3.6		12.1		0.5	0.2	0.2		0.5		0.1
Callionymus maculatus		3.1		0.8	17.9			0.3		0.1	2.4	
Cepola rubescens					8.2						0.1	
Enchelyopus cimbrius	33.9	33.4	27.5	13.3		14.4	2.3	3.3	2.0	0.7		0.6
Eutrigla gurnardus					3.5						0.3	
Lumpenus lampretaeformis	20.9	16.5	334.0	19.3			1.2	2.1	43.9	1.3		
Pholis gunnellus					13.6						0.6	
Pomatoschistus grp 1			52.7		1.2				14.3		0.7	
Pomatoschistus grp 2	0.2			0.1			0.1			0.1		
Scyliorhinus canicula				0.5	62.5					0.1	0.2	
Taurulus bubalis					8.6						0.1	
Zoarces viviparus					1.1						0.1	
Flat-Fish												
Glyptocephalus cynoglossus	58.1	23.9	4.8	7.8	3.6	28.4	2.5	2.0	1.1	0.5	0.1	0.6
Hippoglossoides platessoides	4.6	6.4	21.4	16.1	85.1		0.1	0.2	1.7	0.6	8.5	
Limanda limanda					17.7	2.6					0.9	0.2
Microchirus variegatus					1.5						0.1	
Microstomus kitt	1.9						0.1					
Phrynorhombus norvegicus					6.8						0.8	
Pleuronectes platessa	0.2			27.4	31.2	77.1	0.1			1.3	0.6	0.7
Cephalopods												
Rossia macrosoma		9.9	12.1					0.5	0.3			
Bivalves												
Aequipecten opercularis		3.5	6.1	9.5	532.2	25.4		0.2	0.2	0.3	13.9	1.3
Pseudamussium septemradiatum	1.2	1.1	0.8	9.3		67.5	0.1	0.1	0.1	1.1		8.3
Mesogastropods												
Aporrhais pespelecani	1285.5	1970.9	484.1	824.7	38.4	335.5	194.9	326.1	71.0	143.0	5.8	55.6
Aporrhais serresianus	30.4	2.7	1.0			0.8	6.1	0.7	0.2			0.1
Turritella communis	4.4	2.8	191.7		69.8		3.5	2.1	159.8		82.9	
Neogastropods												
Buccinium undatum	63.5	175.7	65.9	13.9	311.4	112.0	1.0	4.8	1.0	0.1	5.0	2.3
Colus gracilis		3.3			10.1	7.5		0.1			0.4	0.2
Neptunea antiqua	65.2	70.0	97.7	74.2	300.5	43.6	0.7	0.7	0.8	0.9	4.2	0.8
Nephrops												
Nephrops norvegicus	177.3	299.2	366.1	69.5	36.0	133.8	14.8	27.9	33.3	4.7	0.7	2.9
Squat lobsters												
Galathea dispersa				0.3		0.1				0.1		0.1
Galathea squamifera					0.5						0.3	
Munida rugosa	26.2	12.3	46.3	961.7	499.7	2079.1	1.7	1.5	4.0	81.3	28.7	159.6
Munida sarsi					0.1						0.1	0.7

	Density by weight (g . 1000 m^2)						Density by number (no . 1000 m^2)					
Taxon	**H1**	**H2**	**M1**	**M2**	**L1**	**L2**	**H1**	**H2**	**M1**	**M2**	**L1**	**L2**
Crabs												
Carcinus maenas				84.4		28.4				2.7		1.3
Goneplax rhomboides			2.4						0.2			
Liocarcinus depurator	25.3	60.9	100.1	454.1	136.1	189.2	1.1	3.5	4.5	21.1	8.2	9.2
Liocarcinus holsatus	0.5	1.8		12.6		3.2	0.1	0.2		0.8		0.3
Necora puber					22.4						0.2	
Pisidia longicornis					0.1						0.1	
Hermit crabs												
Pagurus bernhardus	2.7	111.9	56.1	27.0	251.2	49.4	0.5	10.5	8.6	6.6	25.3	12.1
Pagurus cuanensis		2.9			0.5			0.3			0.5	
Pagurus prideauxi		3.5	0.4		4.4			0.5	0.2		1.5	
Spider crabs												
Hyas araneus		0.4		37.3	13.3	25.5		0.1		0.6	0.2	0.4
Hyas coarctatus		3.4			9.7			0.2			0.3	
Inachus dorsettensis		0.3			0.5			0.1			0.2	
Macropodia tenuirostris			0.3		0.2				0.2		0.3	
Burrowing shrimp												
Calocaris macandreae	5.5	6.4		1.9		18.3	4.3	4.2		1.3		10.3
Errant shrimp & prawns												
Dichelopandalus bonnieri	97.7	23.6	0.5	44.6	0.1	97.7	35.1	10.1	0.3	14.9	0.1	23.9
Palaemon serratus	2.1		0.7			2.8	0.2		0.1			0.3
Pandalus montagui	3.5	0.6	6.7	10.1	0.2	8.5	2.6	0.3	4.2	5.3	0.1	3.3
Processa sp.	2.8	0.5	0.3	0.5		3.0	3.6	0.7	0.2	0.3		1.8
Spirontocaris lilljeborgi	0.1	6.6	0.4	0.1		1.0	0.1	0.1	0.3	0.1		0.5
Starfish												
Asterias rubens	5.2	200.1	93.7	660.2	178.7	521.2	0.2	9.1	2.6	20.6	22.2	35.1
Astropecten irregularis		5.3	2.0		24.5			0.2	0.1		7.4	
Marthasterias glacialis		14.8			13.0			0.2			0.1	
Porania pulvillus					5.9						0.1	
Brittle-stars												
Amphiura brachiata					0.4						0.2	
Amphiura chiajei	0.5	1.9	0.4	0.1		0.4	1.7	6.6	1.4	0.2		1.7
Ophiocomina nigra					1.2						0.6	
Ophiopholis aculeata					1.0						0.7	
Ophiothrix fragilis					6.2						3.5	
Ophiura albida		0.2		0.1	54.0			0.8		0.1	197.7	
Ophiura ophiura	3.7	548.1	27.5	266.3	451.2	332.7	0.8	137.4	5.5	60.7	152.9	92.6
Urchins												
Brissopsis lyrifera	13.3	8.2					0.5	0.4				
Echinocardium cordatum	2.3		0.1		0.2		0.2		0.1		0.1	
Echinus acutus					13.9						0.3	
Echinus esculentus				12.8	52.1					0.1	0.3	
Psammechinus miliaris		0.1	0.1	1.1	26.4	4.9		0.1	0.2	0.3	4.4	0.7
Polychaets												
Aphrodita aculeata	48.6	49.2	27.9	14.5	123.4	150.5	2.5	2.5	1.7	2.9	4.5	24.2
Sea pens												
Virgularia mirabilis			0.1	0.2	0.3				0.3	0.1	0.7	