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A SHORT RETROSPECTIVE ON PERSONAL RESEARCH CARRIED OUT IN EASTERN CANADA IN THE PERIOD 1966-'75 RELEVANT TO IMPACTS OF FISHING GEAR ON THE BENTHIC ENVIRONMENT, AND SOME PERSPECTIVES FOR FURTHER RESEARCH

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RIASSUNTO

Una breve retrospettiva su ricerche personali condotte nel Canada orientale, nel periodo 1966-75, riguardanti l'impatto degli attrezzi da pesca sull'ambiente bentonico, e linee per future ricerche.

Questo sommario delle ricerche condotte dall'autore sulle attrezzature subacquee e della pesca negli anni '60 e '70 fornisce lo spunto per futuri indirizzi di ricerca riguardanti l'impatto degli attrezzi di pesca sul benthos, la selettività delle reti, e per esperimenti sul campo tesi a valutare l'impatto che la pesca provoca indirettamente sull'ambiente.

ABSTRACT

A summary of underwater and fishing gear research conducted by the author in the 1960's and 1970's provides the context for some suggested directions for future research on the impacts of fishing gear on the benthos, gear selectivity, and field experimentation on the indirect impacts of fishing on the environment.

INTRODUCTION

In retrospect, it is clear that the environment was optimal for marine research in Canada during the 1960's and early 1970's, with abundant funds made available to the Fisheries Research Board of Canada, and later, Fisheries and Oceans Canada; i.e. this was a period of enthusiasm on the part of the government of Pierre Trudeau for underwater technology and exploration. Funding became more restrictive later on, with the urgent need to assess the resources of the newly declared Exclusive Economic Zone, and became more focussed on more standard approaches to stock assessment. The early 1970's then, was an environment where underwater research and the application of SCUBA and submersibles to fisheries, was an open field, seen as a possible way to catalogue the resources of national waters. There was an enchantment with new technology, and new exploration by SCUBA and submersibles was seen as paralleling, underwater, what was going on in space through NASA's lunar landing programme. Interest in underwater exploration was also driven by the publicity raised by Cousteau and Piccard, and the new results then emerging from the Woods Hole programme with the submersible Alvin.

In consequence, for a series of years the St Andrews laboratory was able to hire submersibles for underwater fishery research. The Cubmarine and Shelf Diver from Perry Cubmarine, Florida were in Canada in 1968 and 1969 respectively, and in 1970, the Pisces submersible from Vancouver, built at Barrow-in-Furnace, England.

In retrospect, the use of underwater technology was found to be inappropriate for visually surveying the enormous areas of the Canadian EEZ, but it did provide a useful perspective and more convenient platform for study of underwater phenomena than SCUBA at the depths of the continental shelf. Since some of the papers where these results are reported are difficult to obtain, some imagery is given in the Annex of Illustrations at the end, that refers the reader to some research results that may prove difficult to find nowadays.

As noted, from the 1970's onward, Canadian fishery research priorities began to focus more closely on support to the setting of quotas through the ICNAF, and later NAFO Commissions, in the Northwest Atlantic, including trawl and acoustic surveys of fisheries resources. Government laboratories began to dedicate more efforts to surveys and stock assessment, and much less to basic biological research.

This situation is now changing in Canada and elsewhere, but the papers presented at the recent ICES/SCOR Symposium "Ecosystem effects of fishing" (13-14/03/99, Montpellier) do not show the progress we would have expected in 1970 if the 1960's research priorities had continued uninterrupted.

The principal fisheries research focus since the 1960's has been on estimating sustainable yield of fish populations (under the assumption that environmental impacts are of minimal importance compared with fishing), and in providing advice to management (e.g.) on quotas. This has led fisheries science to focus almost exclusively on modelling and methods of deducing the state of resources from indirect evidence obtained through trawl surveys and analysis of commercial landings. In fact, it has been the serious decline in many fishable stocks, and the inability of conventional stock assessment to forecast these declines, that has revived interest in the status of marine ecosystems and what actually happens during the fishing process. The difficult questions now being raised are whether we are simply observing a reversible change in stock size as a simple function of fishing effort, or as seems increasingly likely, that habitats and environmental characteristics have changed under the combined impact of fishing (and for coastal waters) other anthropogenic effects.

The programme I was involved in for at least 8 years revolved around the fishery for *Placopecten magellanicus*, especially the scallop fishery on Georges Bank, which was (and probably still is) the biggest single scallop concentration in the world (see Fig. 16). The gear used (Fig. 17) is large and heavy (Fig. 18a), designed for use from large offshore dredgers in relatively deep water, strong currents, and on usually hard gravel and sand bottoms (Bourne, 1966). A sweep chain takes the place of the teeth used in European dredges for *Pecten*, and the gear in fact resembles a heavy beam trawl. Small dredges used inshore (drags in N. American parlance), may or may not be toothed, and arc fished in gangs of 3-8 (Fig. 9).

The objectives of the scallop research programme in 1969-'72 were mainly to:

a) Estimate biomasses and new recruitment, monitor the fishery, and determine growth and mortality rates in the population.
b) Study population distribution and patchiness.
c) Determine drag performance and behaviour of scallops in response to fishing.

Objective a) is less relevant to the present paper, and is more or less outlined in the chapter on scallops included in the shellfish case studies edited by Caddy (1988).

Objective b) is of interest here, since it is fundamental to understand the contagious nature of marine organisms in deciding on experimental areas and controls. The results for scallops described in Caddy (1968, `70) used SCUBA, and later submersibles. These latter allowed relatively large areas to be covered (see Fig. 21), and showed a population structure of `beds' of 0.24-0.53 km (in the Northumberland Strait) in size: often elongated in dimension. The existence of such population `subunits' was the basis for an early fishery model with spatial components (Caddy, 1975), later elaborated as a generalised spatial fishery model software (Seijo *et.al.*, 1994).

Objective c) involved underwater observation (SCUBA and submersibles), photography, and experimental work. In the course of this work, the effects of scallop gear in producing incidental mortality was measured underwater, perhaps for the first time (Caddy, 1973), and the relevance of swimming (Figs 1-4 incl.), recessing (Fig. 5) and byssal attachment to the capture process was described (Caddy, 1968,1973).

Three aspects can be retrieved from these earlier studies on scallop drags, as well as work on other clam dredges (Medcof and Caddy, 1974), that may still have broad relevance to studies of the effects of gear on benthic biocoenoses, subsequent aggregation of predators, calibration of underwater observations, and the experimental design approach. Some illustrations from this early experimental work are shown in the photo annex to this paper with references to the relevant literature.

The use of direct observation data on fauna as a means of establishing interspecific interactions of different species on a scallop ground was also reported on by Caddy and Carter (1984).

EFFECTS OF DRAGGING ON THE BOTTOM

This was shown to vary with type of bottom. On bottoms with boulders and epifauna, displacement of rocks and removal of epifauna (Caddy, 1959) are the more obvious aspects, which lead to bulldozing and `piling up' of rocks and scallops at intervals along the dredge track, especially with Digby dredges (figs. 9-12). On the inshore scallop grounds in the Bay of Fundy, Caddy (1989) illustrated the cumulative effect of dredging on the grounds under a strong tidal regime, in causing shell debris to be deposited upstream and downstream of the main beds.

On sand, individual scallops may be buried by dredge action (Fig. 13), while on mud, recessed individuals (Fig. 5) may be buried or their mantle cavities choked with silt. On mud, loose fines are displaced by dredging and in tidal areas, may wash in layers close to bottom, potentially smothering young scallops. Fig. 18b shows another feature of dredged scallops, namely the formation of `shock marks' on the shell after damage but survival on passing through the gear. As noted by Caddy (1989), the frequency of these per age, and the size distribution of marks, are indices of the intensity of fishing and of size selectivity respectively, and could be very useful in comparing impacts of fishing and its past distribution in different areas.

On anoxic bottom (Caddy, in press), all types of bottom gear may lead to release of hydrogen sulphide and recycling of phosphorus from the bottom, with algal blooms, direct toxic effects and hypoxia as potential consequences. All of these effects may injure benthic fauna and demersal fish; in the extreme, they can lead to local mass mortalities.

CONGREGATION OF PREDATORS

Accumulation of predators occurs from 5-10 minutes to half an hour after dredging (Fig. 14), in order to feed on damaged individuals in the track (e.g. Caddy, 1973). Such feeding aggregations occur naturally wherever surplus food is available, as was observed over herring spawning grounds (e.g. Caddy and lies, 1973).

In order to make quantitative observations by SCUBA or submersibles, systematic calibration of underwater observations was necessary, and in the photo annex, some indications of the approaches used for this are given in figs. 19-24.

SOME BROADER PERSPECTIVES

Three perspectives seem worthy of interest in the current research environment:

I) Indirect impacts of fishing are not ascertainable from standard population dynamics involving analysis of catch, effort and trawl surveys.

2) The experimental approach is possible, and involves underwater observations, and can reveal aspects of the fishing process not available to conventional analysis.

One such approach is detailed in the Annex. Underwater observations by either divers, or from underwater vehicles such as submersibles, or automatic cameras, require quire careful calibration of the area of visual field in order to quantify observations (e. g. Caddy, 1976) and allow for the dynamics of the observational platform and its varying distance from bottom. An example is shown in Fig. 14 of an approach to quantifying diver observations: an odometer tor quantifying distance travelled by the gear is shown in Fig. 19, while figs. 21-24 illustrate observational techniques and calibration from a submersible. The advantage of these latter vehicles for studying medium-large scale metapopulation structure is illustrated in Fig. 25, which would be difficult or time consuming to achieve by diver observation.

3) Scallop dredges or beam trawls arc also useful `platforms' for observation and monitoring.

They can be used for photography (figs. 20 a and b), and environmental sampling. (In relation to environmental monitoring for example, concentrations of oxygen, hydrogen sulphide, suspended organics etc, could all be sampled from equipment mounted on dredging gear. In environments prone to hypoxia such as the Adriatic Sea, this approach could provide data useful for deciding on fishery closures when these concentrations reach critical levels).

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ANNEX: A GEAR SELECTION EXPERIMENT, MODIFIED TO DETERMINE IMPACTS OF DREDGING ON ORGANISMS ENTERING BOTTOM GEAR

THE DENSITY-DEPENDENT MORTALITY PROBLEM

An experiment on scallop dispersal carried out in 1966 off the laboratory wharf at St Andrews, placed some 50 scallops at the centre of a rope `target' to determine dispersal capabilities (see summary in Caddy, 1989).

The experiment was discontinued when it was determined that before dispersal, within 48 hours of initiation, those scallops still immobile at the centre of the target were being consumed by a feeding congregation of whelks and crabs! The moral of this observation is that a logical experiment on survival of discards we had attempted, by placing such discards on bottom in a cage to determine survival, may lead to an excessively high predation rate if access to predators is possible.

High densities of discards in the cage may produce metabolites if damaged in capture, which can attract excessive number of predators, as undoubtedly is also the case in dredge tracks in response to damaged organisms. In other words, an indirect approach is needed to this kind of experimentation, which takes predator behaviour into account.

STUDYING GEAR SELECTIVITY AND IMPACTS IN DETAIL

Following and extending the approach used by Caddy (1971,'89) (Fig. 18b), the following research framework is proposed for investigating experimentally damage to benthic resources by dredges, beam trawls or 'rapidos'. Undamaged organisms of known size are tagged or marked, and tied inside the dredge in plastic bags or other containers designed to break and release them into the dredge when this reaches the bottom (Fig. 18b).

Various simple devices can be used to ensure this release, which places a known number of tagged individuals with measured characteristics inside the fishing gear during operation. (One approach is to make multiple perforations of the bag to weaken it: other more elaborate devices are easily imaginable: unfortunately, similar approaches are less feasible for fish!).

Since a fine mesh cover may be placed over the top of the dredge to catch those leaving by this (less damaging) route, the number leaving through the bottom of the dredge can be obtained by subtraction:

i.e. suppose that the number of organisms released into the dredge of size

$N(1)^* = R(1)^* + C(1)^* + B(1)$

where $R(1)$ is the number of organisms retained in the gear;

$C(1)$ is the number exiting through the back of the dredge into a fine mesh cover;

$B(1)$ is the number passing out through the belly of dredge.

In the case discussed, where tagged animals of known size (1) are released into the dredge, the quantities asterisked (*) are known. Hence the proportion passing out through belly of shell length (1) can be deduced from:

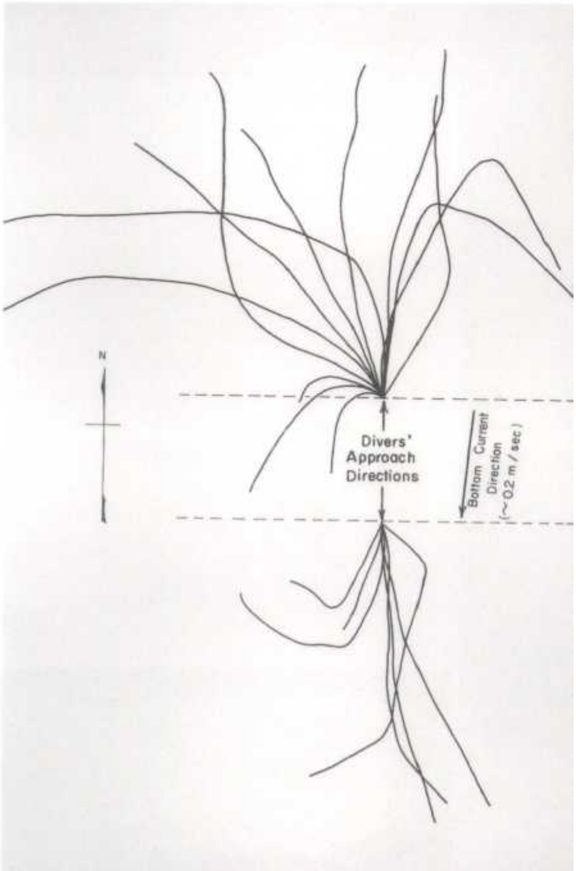
[N (1) - R(1) - C(1)] / N(1)

And through the back of the dredge can be counted directly in the cover as B (1) expressed as probabilities, $p_R + p_C + p_B = 1$

Hence the above partial probabilities can be assessed.

This experiment is easily modified to determine the proportion of organisms that escaped from dredging after entering the dredge, by determining the recapture rate (assuming an award for return of tagged scallop shells returned alive or dead to fishermen) compared to a control group of the same size composition tagged and released in the same area without having passed through the dredge. (In both cases, it would be ideal to use previously captured organisms that have either survived in mesh cages for at least 24 hrs, or were collected by divers, in order to eliminate the impact of this previous capture on the results).

Preliminary tag and release experiments would be needed to establish the probability of recapture, and hence the numbers that would have to be released to obtain statistically significant results.



A/ Behaviour of scallops and performance of the dredge
A/ Comportamento dei Pettinidi e rendimento della draga

Fig. I: Illustrating the flight behaviour of the giant scallop *Placopecten magellanicus* (from Caddy, 1968)
Fig. 1: Esempio di comportamento di fuga del Placopecten magellanicus *(da Caddy, 1968)*

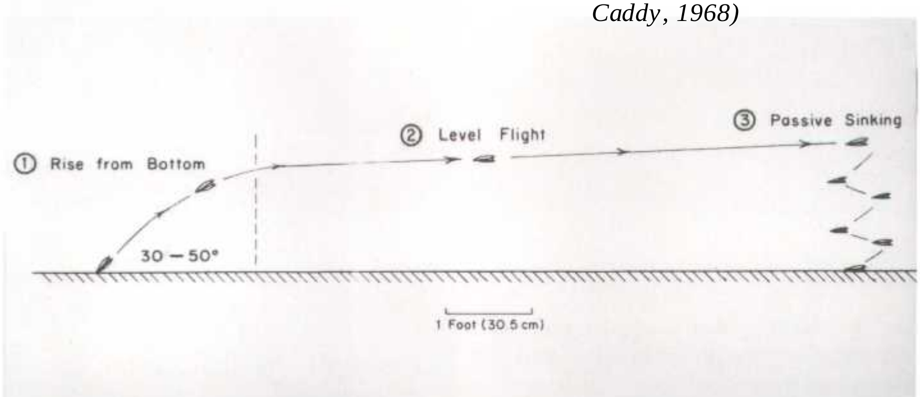


Fig. 2: Vertical and horizontal flight pattern (from Caddy, 1968)
Fig. 2: Modelli di fuga verticale e orizzontale (da Caddy, 1968)

Fig. 3: Younger scallops (2-3+ yrs) reacting to presence of a diver
Fig. 3: Pettinidi giovani (2-3 + anni) che reagiscono alla presenza di un subacqueo

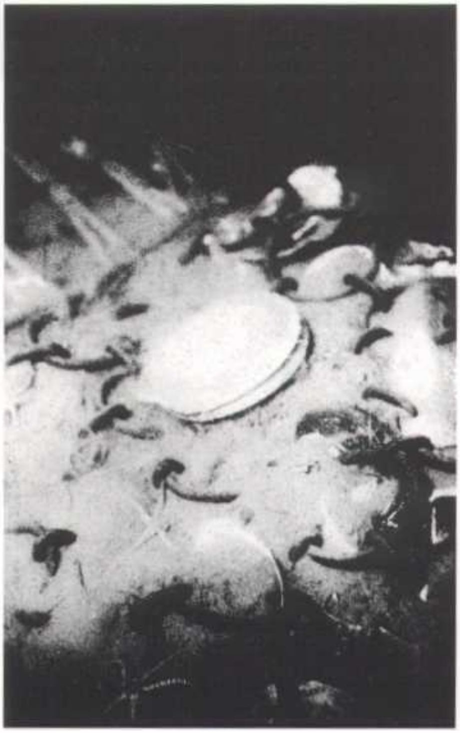


Fig. 4: A scallop that escaped capture by swimming over the dredge mouth to land on the back of the dredge
Fig. 4: Un pettinide sfuggito alla cattura nuotando sopra la bocca dell'attrezzo per posarsi sulla parte superiore della rete

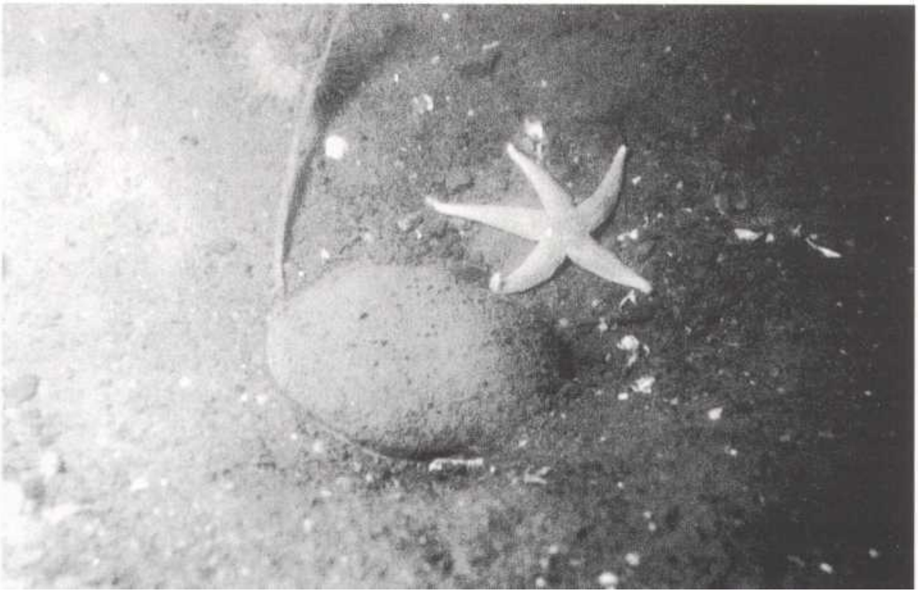


Fig. 5: Showing 'recessing behaviour' of older specimens on soli bottom. Repeated dredging to 'develop' the ground is needed to dislodge these individuals and make them vulnerable to capture

Fig. 5: Esempio di 'comportamento di scavo di una nicchia' di esemplari vecchi su un fondale molle. Sono necessari ripetuti dragaggi per 'trasformare' il fondo in modo da rimuovere questi individui e renderli vulnerabili alla cattura

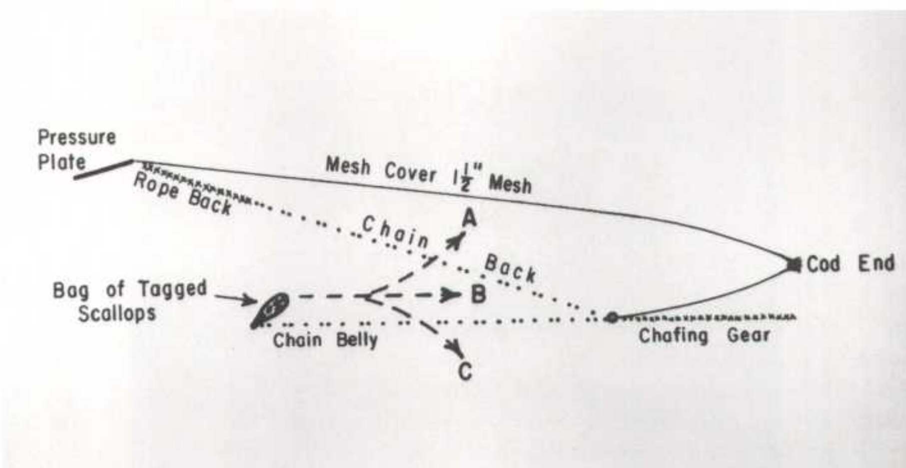


Fig. 6: Illustrating experimental design to determine selectivity of back and belly of the dredge (see Annex)

Fig. 6: Esempio di design sperimentale per determinare la selettività della parte superiore e del ventre della rete (vedere Allegato)

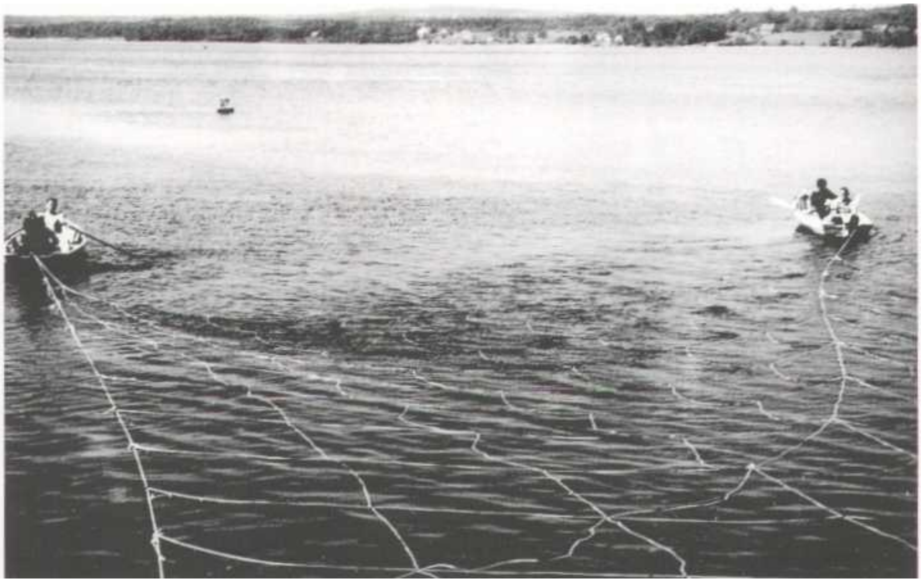


Fig. 7: Setting a grid of lead-cored rope squares for behavioural studies on scallop mobility
Fig. 7: Messa a punto di una griglia di quadrati realizzata con corde (dall'interno di piombo) utilizzata per studi sulla mobilità dei Pettinidi

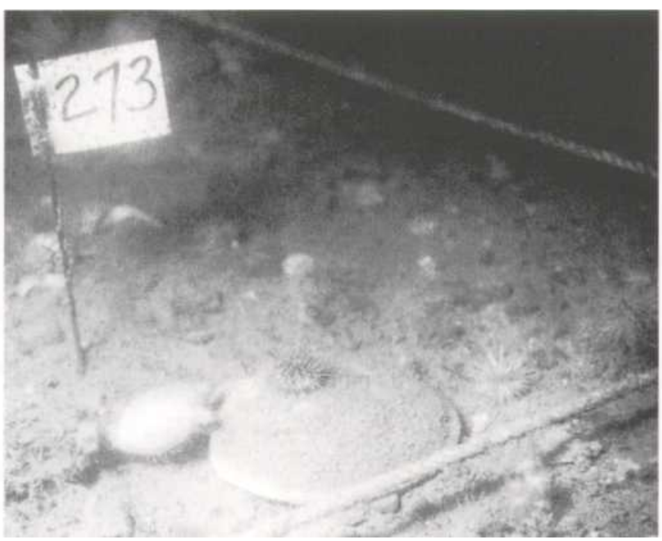
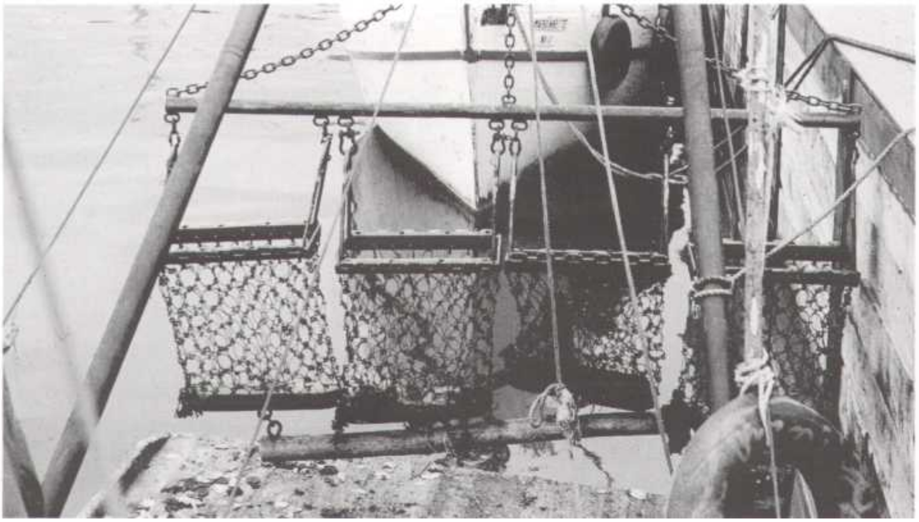


Fig. 8: Marking individual scallops during a behavioural experiment to determine frequency of movement and distance travelled over a rope grid
Fig. 8: Marcatura di esemplari di Pettinidi durante un esperimento teso a determinare la frequenza del movimento e della distanza percorsa su una griglia di corde



B/ Impact of scallop dredges on the bottom

B/ Impatto della draga per Pettinidi sul fondale

Fig. 9: The 'Digby' or 'rock dredge' used on hard gravel bottoms

Fig. 9: 'Draga Digby' o 'per rocce' utilizzata sui fondali ghiaiosi duri

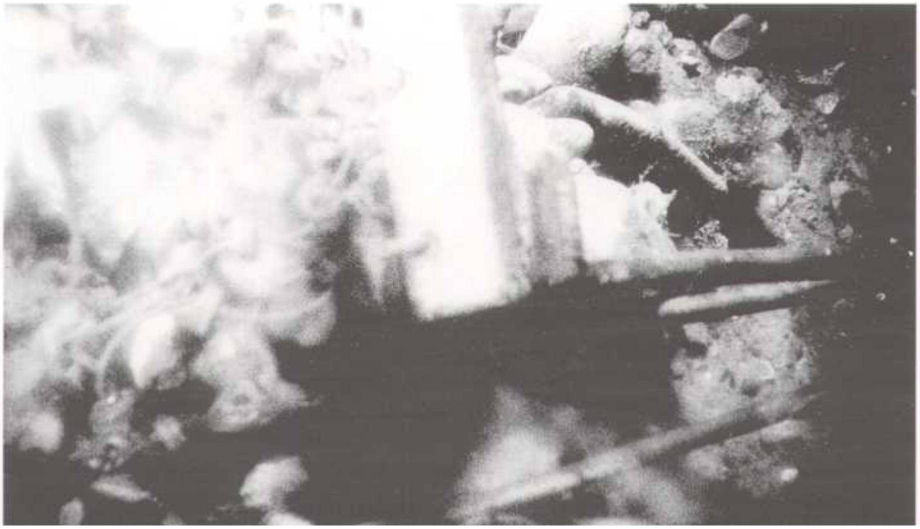


Fig. 10: `Bulldozing' effect of the Digby dredge, pushing rocks ahead of the dredge mouth. Intermittent filling of the dredge is followed by `rocking' and deposit of accumulated material along the dredge track

Fig. I0: Effetto 'spianatore' della Draga Digby', che spinge le rocce davanti all'imboccatura dell'attrezzo. Quando l'attrezzo si ottura, a intervalli più o meno regolari, provoca 'scossoni' e deposito del materiale accumulato lungo il solco scavato dalla draga

Fig. 11: Large boulders accumulated and deposited by a Digby dredge
Fig. 11: Grossi ciottoli accumulati e depositati da una draga Digby

Fig. 12: Large scallops accumulated and deposited by a filled Digby dredge
Fig. 12: Grossi esemplari di Pettinidi accumulati e depositati da una draga Digby colma

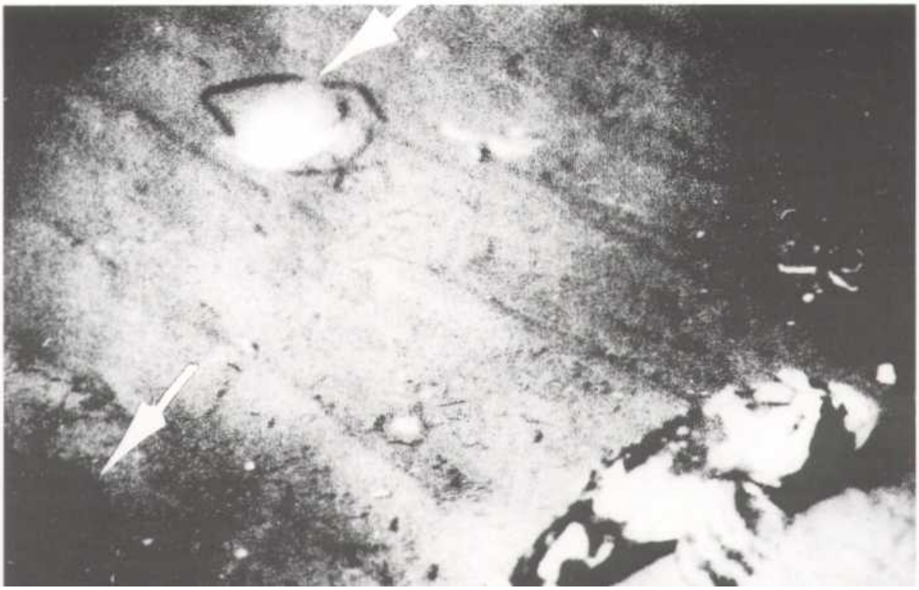


Fig. 13: Dredging on sand bottom pushing a recessed scallop into the bottom
Fig. 13. L'azione di dragaggio sul fondale sabbioso spinge un Pettinide che si era scavato una nicchia ad infossarsi

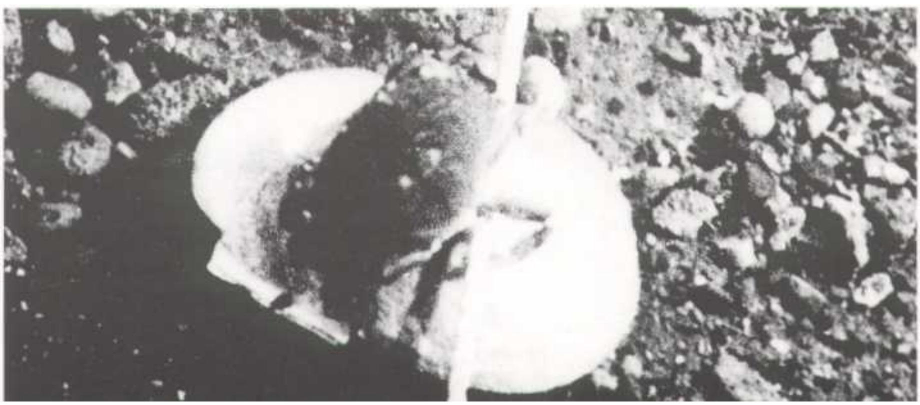


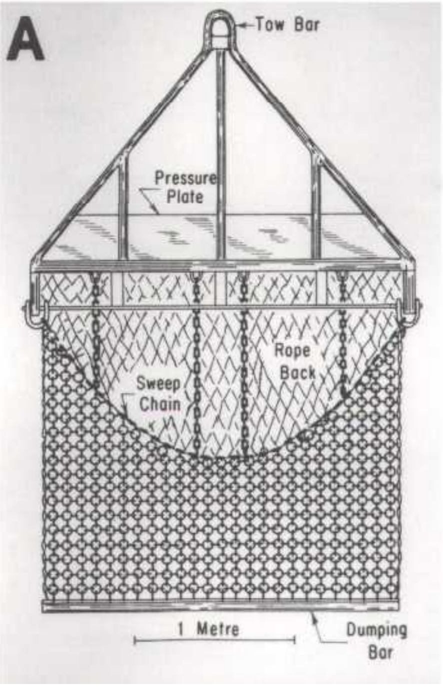
Fig. 14: Cancer crab feeding on broken scallop in the dredge track. Photo also illustrates method of quantification by diver inspection of dredged populations: a 50 m lead core rope marked at I m intervals is tied to the back of the dredge. Divers swim back down the track, holding a 2-m bar marked at 10 cm intervals (shown), perpendicular to the rope, counting individual organisms expressed per m^2.
Fig. 14: Un crostaceo Carcinide che mangia un Pettinide danneggiato all'interno di un solco scavato dalla draga. La foto illustra anche il metodo di quantificazione delle popolazioni utilizzato dai sub: una corda con l'interno di piombo, lunga 50 m, contrassegnata da intervalli di 1 m ciascuno viene legata sul dorso della draga. I sub nuotano lungo il solco in senso inverso, tenendo una barra di 2 m marcata con intervalli di 10 cm ciascuno, perpendicolarmente alla corda, contando il numero di organismi per m^2

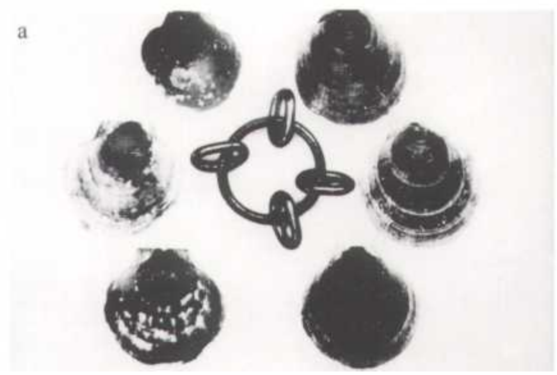
Fig. 15: Hydraulic dredging of an *Arctica islandica* population showing broken shells
Fig. 15: Conchiglie rotte di una popolazione di Arctica islandica *dopo il passaggio della draga idraulica*

C/ Offshore scallop dredging on Georges Bank, Gulf of Maine
C/ Pesca al largo di Pettinidi con lu draga nella zona di Georges Bank, Golfo del Maine
Fig. 16: A large offshore scallop catch from the 1960's
Fig. 16: Abbondante pescata di Pettinidi compiuta al largo (anni '60)

Fig. 17: Design of offshore dredge showing rope diamonds on back and rings held by metaI links

Fig. 17: Design di una draga per la pesca al largo dove sono evidenziati la maglia a losanga e gli anelli tenuti da ganci di metallo





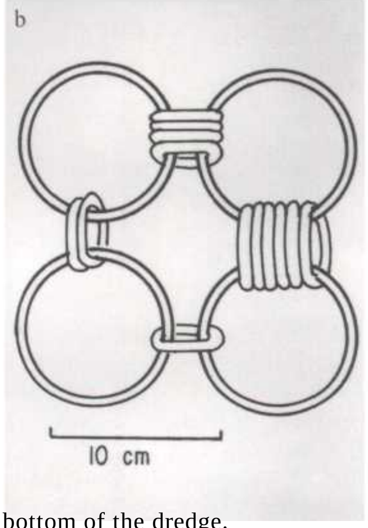


Fig. 18: a) `Shock marks' provoked by scallops damaged during passage through dredge rings and through interring spaces (See Chapter on scallops in Caddy 1989).
b) Different numbers of links affect dredge selectivity, especially multiple links are used on the bottom of the dredge.

Fig. 18: a) 'Segni di urto' subiti dai Pettinidi danneggiati durante il passaggio attraverso gli anelli e gli spazi presenti fra gli anelli (vedere il capitolo sui Pettinidi in Caddy, 1989). b) Diverse quantità di ganci influenzano la selettività della draga; i ganci multipli vengono usati soprattutto sulla parte inferiore dell'attrezzo.

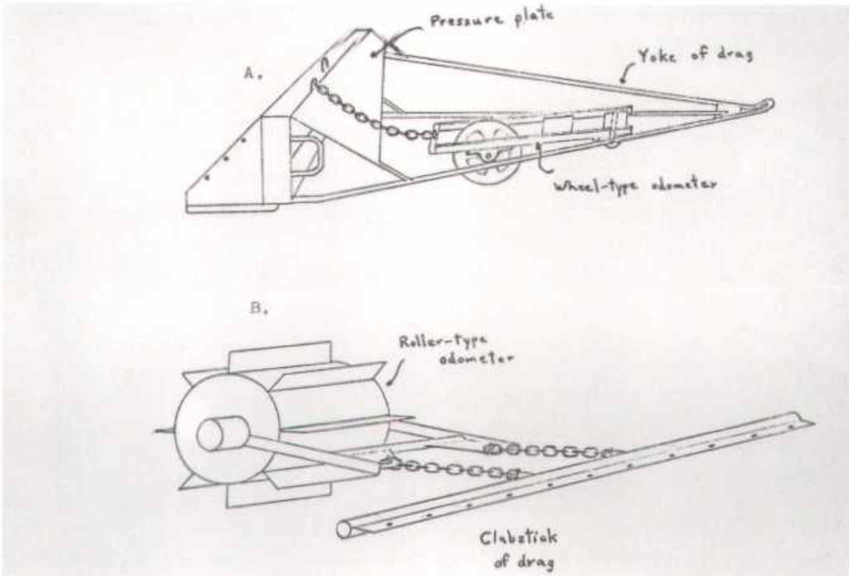


Fig. 19: Design of odometer for measuring distance travelled by the dredge
Fig. 19: Design di un odometro per misurare la distanza percorsa dalla draga

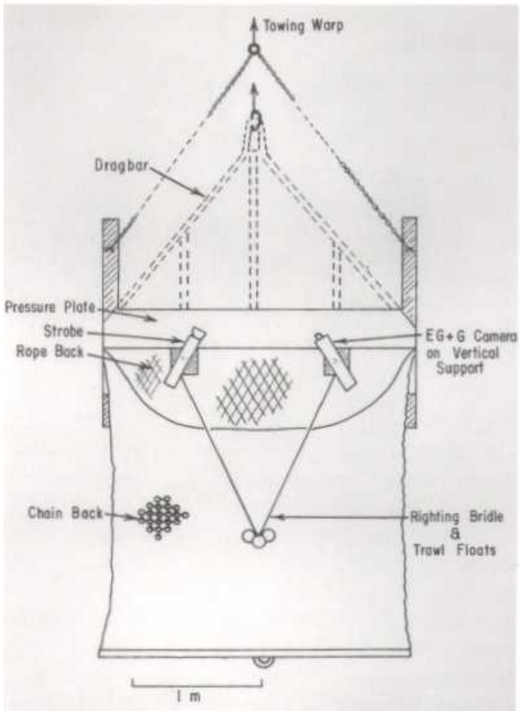
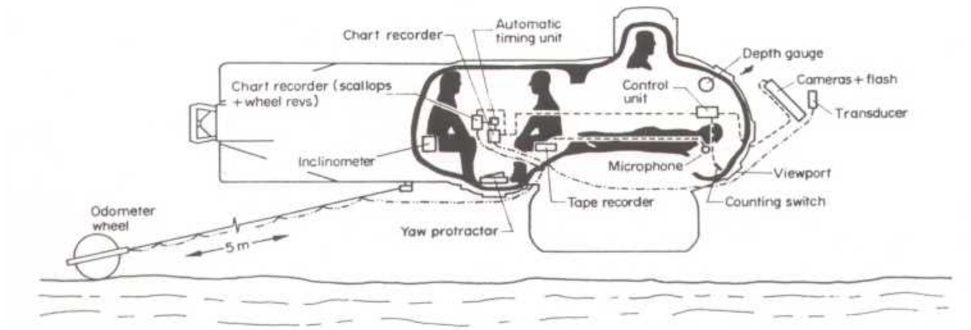


Fig. 20: Offshore dredge modified to take photos in front of dredge path allows catch efficiency to be derived by comparing numbers in the dredge path with the catch
Fig. 20: Draga per la pesca al largo, modificata per fare fotografie in corrispondenza del solco tracciato dall'attrezzo, che permette di calcolare l'efficienza di pesca della draga, mettendo a confronto i dati relativi al solco con il pescato



D/ Use of submersibles to determine population density and medium scale ecosystem structure

D/ Utilizzo di sommergibili per determinare la densità delle popolazioni e la struttura di un ecosistema su scala media

Fig. 21: Instrumentation for measuring vehicle performance and quantitative observation procedure for quantitative benthic estimation (from Caddy, 1976)

Fig. 21: Strumentazione utilizzata per valutare il rendimento del veicolo e procedimenti per effettuare osservazioni di tipo quantitativo per una stima del benthos (da Caddy, 1976)

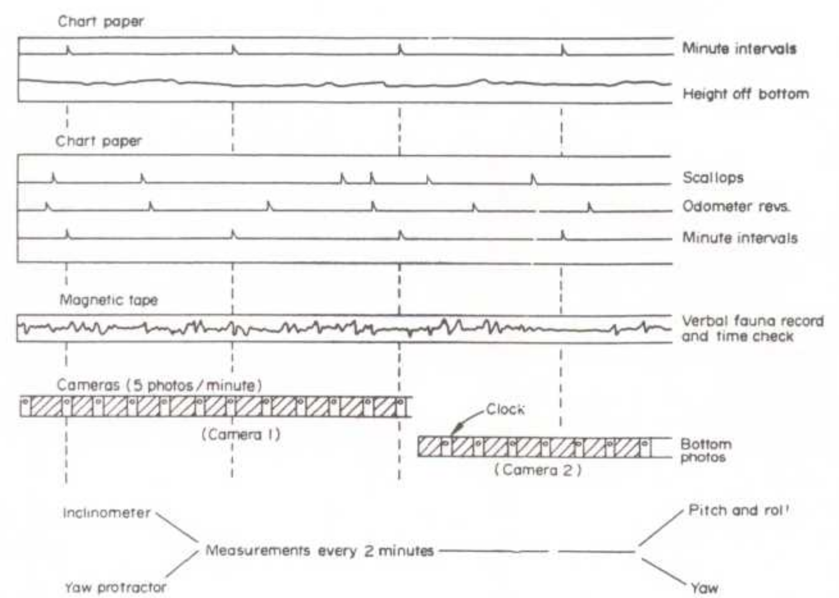


Fig. 22: Intercalibrating faunal observational data (recorded on magnetic tape) and photo data, and measuring vehicle speed and distance off bottom (from Caddy, 1976).

Fig. 22: Intercalibrazione dei dati di osservazione della, fauna (registrati su un nastro magnetico) e delle foto; misura della velocità del veicolo e della distanza dal fondo (da Caddy, 1976).

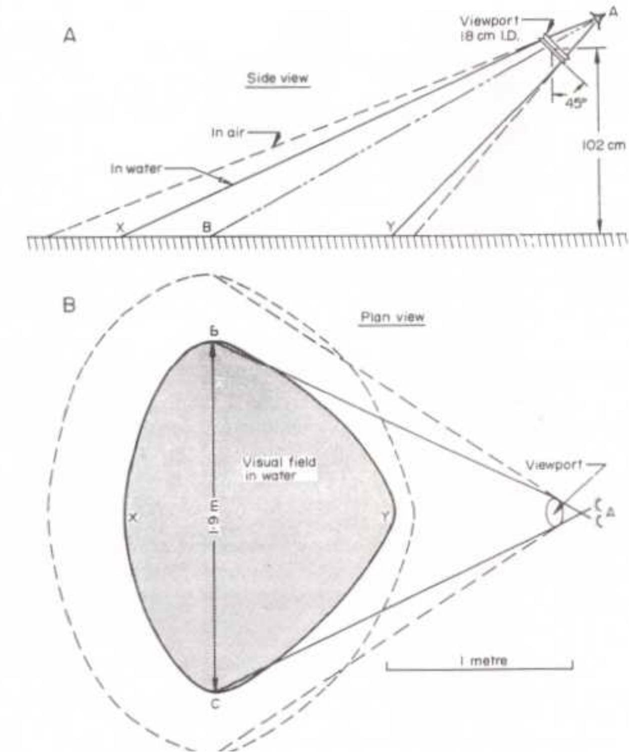


Fig. 23: Calibrating the area of view of portholes for quantitative observation (from Caddy 1976)

Fig. 23: Calibrazione dell'area di vista degli oblò per osservazioni di tipo quantitativo (da Caddy, 1976)

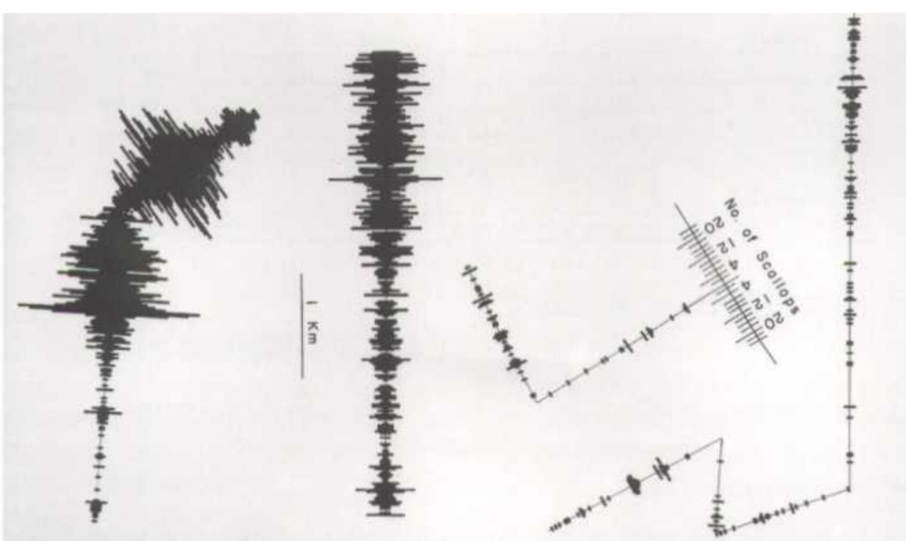


Fig. 24: Example of medium-scale meta-population distribution patterns of scallops in 'beds'

Fig. 24: Esempio di modelli di distribuzione su scala media di meta-popolazioni di Pettinidi sul fondale (nei 'banchi')