Initial Trials to Increase Acoustic Detectability of Drift Nets used in the Albacore Tuna Fishery

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Seafish Technology

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SUMMARY

The drift net fishery for albacore tuna *(Thunnus alalunga)* in the North East Atlantic has received much criticism over the previous two years for its alleged by-catches of small odontocetes which include dolphins. Most of the criticism has come from conservationist organisations who do not appear to have a full understanding of the fishery, but have much public influence. The fishery is currently worked by some 45 vessels, mostly French, but with pioneering Irish and British vessels which have recently joined the fishery.

The EC has decided that this fishery will close at the end of 1993 unless it can be shown that the fishery "does not present ecological risks" (MAFF press release, October 1991). This decision was made in response to public pressure and to a United Nations resolution which called for a halt to the expansion of large scale, high seas drift netting.

Dolphins belong to the group of cetaceans that can echo-locate (use high frequency acoustic pulses for foraging for food underwater). It follows that if it is possible to make a tuna drift net acoustically very detectable to a dolphin then the risk of it becoming entangled in the net is likely to be much reduced.

At the request of UK fishermen's organisations, Seafish and Loughborough University have jointly conducted a sea trial off the Cornwall coast to examine the acoustic detectability of nylon drift nets as used in the albacore tuna fishery. The trial was funded by Seafish but based on the research results of an EC funded project undertaken by a team from Loughborough and Cambridge Universities. Small plastic acoustic reflectors were attached to the face of tuna nets and were deployed at sea, together with unmodified nets for comparison. In addition, 10m gaps were left between the nets to provide spaces for evaluation as potential 'crossing points' for dolphins. The nets were then examined acoustically using a 100kHz sidescan sonar, and the results recorded on a paper trace.

The trial was carried out on the 15.25m (overall length) fishing vessel *Britannia V (FH 121).* The objectives were to establish whether the reflectors enhanced net detectability and whether the presence of reflectors affected the deployment of the gear.

It was found that the reflectors functioned as expected and significantly increased the acoustic detectability of the mesh of these nets. However, the means by which the reflectors were attached to the net still needs refinement as the attachments tended to interfere with the deployment of the nets and would hinder a commercial fishing operation. The position of the 10m gaps was detectable independently from the additional reflectors, and will cost a negligible amount for fishermen to incorporate within their existing gear.

Submerging the headline of the nets underwater is a technique which may reduce the risk of dolphin captures, but many skippers do not have the space on board their vessels for stowing the many buoys required for this operation.

This trial demonstrated that attaching reflectors to a tuna drift net increased the acoustic detectability of the mesh. If better means of attaching these reflectors to the nets can be found, it is probable that the risk of dolphin captures may be significantly reduced. Further sea trials are necessary to determine any effect the reflectors may have on commercial catch rates of tuna.

Grateful acknowledgement is given to Leach and Turner Fishing Gear Suppliers and to skipper Freddie Turner and the crew of *Britannia V* who freely made their vessel, time and facilities available.

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1. INTRODUCTION

During the summer of 1991, three U.K. vessels based in Cornwall joined the North East Atlantic albacore tuna *(Thunnus alalunga)* drift net fishery for the first time. The skippers of these three vessels were anxious to relieve some of the fishing pressure on other local fixed net fisheries and saw the tuna fishery as an ideal opportunity for diversifying their fishing effort. The three vessels involved were the *Britannia V (FH121)* based in Mevagissey, the *Sowenna (PZ14)* and the *Ar-Bageergan (PZ287)* - both based in Newlyn. None of the skippers of these vessels had prior experience of this fishery, and all had to make large financial outlays for fishing gear and vessel modifications.

Their initiative was met with considerable opposition from numerous conservationist organisations who believed that this type of fishing was not "environmentally friendly" due to alleged by-catches of non-target species. These by-catches were said to include birds, sharks and small odontocetes which is the group of cetaceans that include dolphins and porpoises. Much of the conservationists' data was derived from the Pacific tuna drift net fisheries. It is unreasonable to assume that their data applies in the same way to the Atlantic albacore tuna drift net fishery.

Drift netting for albacore tuna was pioneered by the French Research Institute for the Exploitation of the Sea (IFREMER) during the early 1980s as a replacement method for the dwindling French tuna longline fleet (Bonnemains, 1990).

In 1990, the United Nations passed a resolution (44/225) which stated that "further expansion of large scale drift net fishing on the high seas......should cease immediately". This was why the 'new' U.K. drift net fishery a year later in 1991 was greeted with such public outrage.

In the Autumn of 1991 the European Community Fisheries Council set out fishery conservation technical measures (Amendments to Regulation 3094/86), some of which directly involved the drift net tuna fishery. It was proposed that:

> "Drift nets will be limited to 2.5 km except, until 31st December 1993, vessels with at least a two year track record in the tuna fishery in the North East Atlantic; these may use nets of 5km or less provided such nets are submerged at least two metres below the surface of the water. This fishery will cease at the end of 1993 unless it is scientifically demonstrated that its continuation does not carry ecological risks." (MAFF, 1991).

Considerable scientific effort has already been put into attempting to understand how echo-locating dolphins perceive their environment by the University of Loughborough and the University of Cambridge in joint research. Observations of both wild and captive dolphins established certain fundamental principles which govern the acoustic abilities of these animals with respect to detection of barriers such as a net. Seafish was jointly approached by these two institutions, and by fishing industry representatives, with the objective of establishing a viable means of making tuna nets acoustically more detectable to approaching dolphins and therefore to reduce the chances of these animals becoming entangled in this type of fishing gear. In a joint Seafish funded project, Seafish and Loughborough University carried out a sea trial off Mevagissey in Cornwall during June 1992. Appendix I contains the Loughborough University account of the trial, together with background information to their research in this field and detailed bio-acoustic technical information.

2. THE FISHERY

2.1 Background

Drift netting is a traditional method of fishing that has been used throughout Europe since the 10th century. Fish species caught by drift nets are almost exclusively pelagic (midwater) species which include herring, mackerel, pilchards and migratory salmonids. Drift netting is an effective method of catching individual high value fish that are distributed over a wide area and not easily exploited by trawl, Scottish seine or purse seine (Karlsen & Bjarnason 1987). Albacore tuna fall into this category. Drift nets can be set singly but it is more usual to join them together into 'fleets' or 'tiers'. These fleets then drift freely, influenced only by the wind and tide - unlike fixed nets (also referred to as 'set nets' and 'static nets') which remain fixed to the seabed. Drift nets belong to the category of gill nets which are passive fishing gears by their nature. Gill nets are highly size selective; the selectivity of a net is defined as "that proportion of fish of a particular size encountering a net which will be held" (Potter & Pawson, 1991). For gill nets, the selection curve is usually assumed to resemble a classic normal distribution; the probability of fish being held by the net falls rapidly for individuals progressively larger or smaller than the optimum length. However, the shape of the selectivity curve will vary for different species and for different net rigging methods (Potter & Pawson, 1991).

Drift nets were introduced into the North East Atlantic albacore tuna fishery - formerly a longline fishery - by the French research institute IFREMER (see Introduction). Being essentially a French fishery innovation, the majority of vessels working the fishery are French and number about 35. Ireland has about 10 vessels working the fishery, and Britain currently has one vessel working in this fishery (1992). Vessels range in size from about 15m to 24m in length and may be monohull or catamaran configuration.

2.2 Season

The fishing season for tuna is dependant upon the movements of tuna populations. The season generally starts during mid June and finishes when the fish move out of the operating range of the fishing vessels, usually in late September (Bonnemains, 1990). A typical early season fishing trip for tuna would involve the vessel steaming to a location 400-600 nautical miles southwest of Lands End. The French have their own Producer Organisation, which may arrange that fuel and water are taken to member vessels whilst at sea.

3. DOLPHIN INTERACTIONS

U.K. work on dolphin-net interactions has been carried out during a series of joint research projects by Goodson, Loughborough University of Technology (Bioacoustics & Sonar, Electronic & Electrical Engineering Department) and Klinowska, University of Cambridge (Research Group in Mammalian Ecology and Reproduction). Research into how dolphins forage for fish, how they perceive small targets and how they differentiate between a fish and an inert target is reported by Goodson *et al.*, (1992). This analytical work has been based on extensive fieldwork with wild dolphins and tests with captive animals in dolphinaria.

The mesh of a drift net, or indeed any type of set net, is both visually and acoustically difficult for a dolphin to detect without somehow enhancing the mesh (Goodson & Datta, 1991; Klinowska 1992). Acoustic enhancement of the net can be achieved by attaching acoustic reflectors to the net mesh itself, but the type of reflector and the distribution of these reflectors across the face of the net needs to be optimised with respect to detection by echo-locating dolphins and deployment of the net from a fishing vessel. Each reflector functions to return sound directly to the echo-locating dolphin. This is analogous to the way in which cat's eyes reflect light emitted from the headlamps of a vehicle back to the driver (Goodson *et al.*, 1992). An important point is that, having established a type of reflector that meets theoretical criteria, it must be capable of being put into a commercial fishing situation without having any adverse effects on either the deployment of the fishing gear or the fish catching capabilities of the gear. If the performance of the fishing gear is reduced when these reflectors are attached, it is most unlikely that fishermen will voluntarily adopt their use. The use of active noise makers in the vicinity of the nets is another option, but devices of this type have not yet been shown to deter dolphins from net entanglement.

Enhancing the net by chemical means is another possible method, but little is known about the senses of taste and smell in cetaceans. It is known that fish utilise 'chemo-reception' as a means of communication; they can produce chemical alarm signals when threatened (Klinowska 1992). How important chemo-reception is to cetaceans as a means of communication is not as yet known and therefore it is difficult to exploit a chemical approach to this particular problem without extensive basic research.

It is apparent from the above that the most practical approach to enhancing the detectability of a net is to devise some form of acoustic target reflectors that can be attached across the face of the net in some manner.

4. TARGET REFLECTORS

Any acoustic reflector that is to be attached to a net must not compromise the handling and deployment characteristics of that net. In addition, the type of reflector chosen must not appear to a dolphin to be a fish target when ensonified; this could give the reverse effect of attracting the echo-locating dolphin rather than warning the dolphin of the presence of an otherwise undetectable net. Unfortunately, the three dimensional shape that constitutes a good reflector will usually cause tangling when attached directly to the face of a net. The Loughborough/Cambridge research has established the requirement for a reflector of specific dimensions and construction that will give the desired acoustic characteristics. Consultation with Seafish established that there was a commercially available elliptical deepwater net float, having dimensions and construction that satisfy many (but not all) of the minimum acoustic requirements of a good reflector, whilst having been proven rugged and reliable in fishing situations. These floats used as reflectors (designated type X2577.1) have an overall length of 67mm, a maximum diameter of 33.5mm and an internal bore of 10mm along the major axis (see photographs in Appendix III). They are internally braced with webs to improve their strength - an important point as they have to pass through a net hauler in a commercial fishing situation. They weigh approximately 20g and give 20g of lift in seawater. It must be noted that it is the specific curvature of the air film inside the float that provides a good acoustic return back towards the echo-locating animal. As reflectors, these floats have a nominal target strength of -35dB (ref. 2m diameter sphere) - (Goodson, 1992; see also Appendix I for a detailed description). As these floats are essentially elliptical in section and resemble a large bead, the problem of snagging in the net when attached to the net mesh is therefore greatly reduced. The elliptical shape also provides an acoustic advantage. The simplest shape for an omni-directional reflector is a sphere, but a spherical reflector that satisfies the minimum required acoustic criteria was considered to be too bulky by the fishermen. For a given target strength, an elliptical reflector will be smaller than an equivalent spherical reflector. To give the most efficient reflection, it is important that the longer axis of the elliptical reflector is vertical. Figure 1 shows two photographs of the reflectors.

These reflectors were tested at sea in the Moray Firth for the first time in 1991 (Mayo & Goodson, 1992). The reflectors were arranged in grid formation on a horizontal series of vertical ropes, but with no net mesh involved. This arrangement simulated a gill net equipped with reflectors but without the risks presented to approaching dolphins by the presence of net mesh.

5. SEA TRIALS

5.1 Trials Objectives

Three main requirements of the modified gear required testing:

(1) Do the reflectors significantly increase the acoustic detectability of the net mesh between the headrope and footrope of the gear?

(2) Is handling of the net during hauling, shooting, deployment and routine transfer operations adversely affected so as to be unacceptable to the fishermen? There must be no unacceptable increase in the volume required for the stowage of the nets on board a fishing vessel.

(3) Is there an unacceptable change in the geometry of the nets that can be attributed to the reflectors and method of attachment?

5.2 Fishing Gear

For trials purposes, four individual nets of 55m set length were rigged into a single fleet. Two of the 55m nets were equipped with the reflectors and joined together with a 10m gap between them. The other two nets used were unmodified and also joined with a 10m gap between them. The joint between the two modified and the two unmodified nets was a direct butt joint (i.e. no 10m gap - see Appendix I, Figure 9). This configuration allowed the acoustic properties of each of the gear types to be compared and also showed how the ends of a net appear acoustically. Appendix I, Figure 1 shows a diagrammatic representation of this experimental fleet of nets. It was considered important for a drift net deployed directly from the surface to incorporate clear, safe crossing points at intervals along the gear. The acoustic contrast between modified and unmodified nets and the 10m gap was monitored using a 100kHz Waverley 3000 sidescan sonar unit.

5.3 Rigging the Reflectors

Based on data from the moored barrier interaction experiments carried out in 1991 in the Moray Firth (Mayo & Goodson, 1992), reflectors were spaced along strings in a 2m (horizontal) x 3m (vertical) grid. Each string was attached at either end to the headrope and leadline of the net. The nets were nominally 18m deep when deployed (set depth) and nominally 55m long when deployed (set length). In the Moray Firth exercise (Section 4) the reflectors were attached by passing a light rope through the centre hole of the reflector (see photographs in Appendix III) - no actual net sheet was used for this trial (Mayo, 1992). It was decided that attaching the reflectors in this manner would present risks of the reflectors becoming tangled in the net panel (buttoning effect). Instead, for the Cornwall exercise, the reflectors were incorporated within a specially made braided sheath (supplied by Jackson Twines of Glossop, Derbyshire). The sheath material was manufactured with a combination of polypropylene and polyethylene fibres and some worsted material to help lock the twine construction together. The final weight per unit length of the sheath material was about 35.3 grams per metre. It was hoped that by having the reflectors inside a braided sheath, any 'buttoning effect' would be minimised. Each string of reflectors was attached vertically to the headrope and footrope of the net, in such a way that the length of the string was about 30cm less than the theoretical set depth of the net panel. (The term 'set depth' refers to the actual fishing depth of the net panel and not the stretched mesh depth often referred to by fishing gear manufacturers).

5.3.1 Net Specification

Mesh:

* Twine size: 210/18[1] (420 tex) red nylon multifilament
* Mesh size: 168mm stretched, 6.625in

Panel:

* Mesh long: 588
* Mesh deep: 125.5
* Stretched panel length: 100m

Rigging:

* Hanging Ratio (E): 0.55
* Staple settings: 2 full meshes onto the staple length
* Staple length: 187mm, 7.375 in
* Set Depth: 17.8m
* Set Length: 55m
* Flotation: One polyurethane 350g buoyant float every 1.1m, 44in
* Leadline: No. 4 reinforced, runnage = 11kg/100m

Acoustic Reflectors:

* Target strength: nominal -35dB (ref. 2m radius sphere).
* Rigged in a 2m (horizontal) x 3m (vertical) grid across the face of the net.
* Reflectors: plastic, elliptical, air-filled, 20g weight in air, 20g lift in seawater (nominal); length 67mm, maximum diameter 33.5mm, axial hole 10mm internal diameter.
* Attachment sheath: braided polyethylene/polypropylene/worsted twine composition; runnage 35.3g/m.
* Reflector vertical spacings (from headrope downwards): 3m, 6m, 9m, 12m, 15m.
* Reflector string horizontal spacings: every 2m along the net.

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[1] 210/18 is a Denier notation for twines. An explanation of the Denier system and its conversion to European standards is given in Appendix II.

5.4 Trials Procedures

In order to test the prototype acoustic reflector (type X2577.1) it was decided to rig an array of these reflectors on a commercial tuna drift net and deploy them at sea. As a control, an equal amount of unmodified tuna net was also deployed for comparative purposes. The vessel chosen for the trial was the *Britannia V FH121*, which works the albacore tuna fishery during the main part of the summer. The handling characteristics of the nets, when rigged with the acoustic reflectors, were easily monitored during the shooting and hauling operations. Once the nets were deployed they were examined acoustically by a 100kHz sidescan sonar from the vessel. The sidescan sonar equipment used (a Waverley 3000 unit) had nominally similar resolution to that of a bottlenose dolphin *(Tursiops truncatus)* (Goodson, 1992; see Appendix I for a full comparison of sidescan sonar and dolphin sonar characteristics). Once the nets had been shot and settled, the sidescan sonar towfish was deployed from the stern of the vessel on a 50m length of cable. The towfish ran at a depth of about 15m-25m (Goodson, 1992; see also Appendix I). The vessel made repeated runs at different ranges up and down the fleet of nets; runs at an angle past the end of the fleet were also made. The acoustic image of the nets was made on a thermal imaging printer and retained for later inspection. The sidescan sonar traces obtained gave a (rough) dolphin's sonar impression of the gear taken over about three minutes. At any instant, a dolphin would only perceive a small section of the gear (Au, W.W.L., 1980). These trials were carried out in June 1992 from the Cornish port of Mevagissey.

After about 90 minutes immersion time the nets were hauled through a Tarbenson 750/500 drum-belt type hauler. The hauling process was a smooth operation; none of the reflectors or nets was damaged and all of the reflectors remained in place within the braided tube.

6. RESULTS AND DISCUSSION

The fleet of nets was deployed in 54m of water about 6km southeast of Dodman Point in ideal conditions on the afternoon of 13th June 1992, with calm seas and no wind. The fleet was shot with no difficulty; the nets passing cleanly from the net pound and out over the stern rail. It was clear that those nets with the reflector strings attached were not deploying in the water in the same manner as the unmodified nets. The control nets appeared to unfurl immediately to full depth, but it took about 15 minutes before the modified nets began to deploy in a fishing manner.

The reflectors performed as expected, and the sidescan traces showed that detectability of the zone of mesh between the headrope and the footrope was much enhanced by the presence of the reflectors. The headline itself gave an unusually strong reflection, due partly to the calm sea state and partly because the sidescan towfish was operating at a depth of about 15m. If the towfish was operating at the surface, the reflection from the headline would be much reduced (Goodson, 1992; see also Appendix I).

The reflector strings appeared to considerably hinder the deployment of the net in the water once the net had been shot. This was due to entrapped air within the sheath material, and due to the rough texture of the component fibres of the reflector retaining sheath (see also Section 5.2) preventing the net mesh from sliding over them. The skipper of the vessel was of the opinion that it was very unlikely that the net would 'fish' as it should because of these effects.

The reflector string itself trapped large quantities of air on the initial shot; this had the effect of increasing the buoyancy of the gear and allowing large loose bights of braided reflector string to float untidily on the sea surface. Once the net began to sink, however, this air began to disperse. The trapped air also had the effect of increasing the acoustic detectability of the reflector string and took about 30 minutes to dissipate (see Appendix I).

It was noted that the strings of reflectors had a tendency to form into loose bights as the headrope and footrope of the nets were hauled together as is normal practice, and these bights presented a potential snagging problem. When stowing the wet nets, the modified nets occupied 30% more volume than the unmodified nets, which would be an unacceptable volume penalty for the skipper.

Once hauled, the process of transferring the nets fitted with reflectors into net bins ('turning the nets over') was more difficult than transferring the control nets. The crew handling the gear noticed that there was some buttoning effect of the reflectors between successive layers of net.

The 10m gap between the modified net types was detectable by the side scan sonar as expected, but the 10m gap between the unmodified net types was less obvious (see Appendix I).

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 The chosen reflectors significantly increase the acoustic detectability of the nylon nets used in this fishery. The reflectors performed as predicted by Goodson (see Appendix I for explanation of sidescan traces).

7.2 The handling of the nets during shooting and hauling was unaffected by the presence of the reflector strings. However, transferring the nets from bin to pound was made more difficult due to the occasional 'buttoning effect' of the reflectors within the rough sheath.

7.3 The deployment of the nets once they had been shot was disrupted due to the presence of the reflector strings. The rough fibre used for their construction became caught in the nylon mesh of the net and restricted the net from unfurling to its full depth in the water.

7.4 During stowage, the modified nets occupied about 30% more volume than the unmodified nets, primarily due to the braided sheath containing the reflectors. To fishermen, this is an unacceptable attribute.

7.5 The loose, tubular construction of the reflector sheaths allowed air to become trapped when submerged, which was very slow to dissipate and caused increases in net buoyancy and consequent deployment problems. The inherent buoyancy of the sheath material together with the 20g buoyancy from each reflector exacerbated this effect.

7.6 The increase in buoyancy due to the presence of the reflectors alone was not responsible for the net deployment problems encountered in 7.3 and 7.5.

7.7 The 10m gap between the nets when they were equipped with reflectors was easily detected by the sidescan sonar. The 10m gap between the unmodified nets was less obvious.

7.8 Reducing the friction between the reflector strings and the net mesh could be done by utilising a small diameter braid of slippery fibre (nylon) construction. This may also reduce the stowage bulk.

7.9 If a means of attaching the reflector directly to the net mesh should be found and is snag-free, then the need for numerous attachment ropes is eliminated.

7.10 The effect of these reflectors in the tuna fishery should be investigated, provided that the reflector rigging can be suitable modified. An independent observer on board the fishing vessel deploying the nets could then monitor the performance of the gear in a commercial situation.

8. ACKNOWLEDGEMENTS

The assistance and support to this trial by the skipper and crew of the *MFV Britannia V*, by Leach and Turner Fishing Gear, by Jackson Twines of Glossop, Derbyshire and by A. D. Goodson of Loughborough University and M. Klinowska of Cambridge University are most gratefully acknowledged. The loan of the sidescan sonar equipment by the Defence Research Agency at Bincleaves, Weymouth, is also acknowledged, with thanks.

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APPENDIX I

ENHANCING GILL NET ACOUSTIC DETACTABILITY
INITIAL HANDLING TRIALS AT SEA

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Photographs courtesty of Sea Fish Industry Authority, Hull.

ENHANCING GILL NET ACOUSTIC DETECTABILITY
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ABSTRACT

Internationally the incidental mortality of cetaceans in passive fishing nets and traps is a matter of concern both to fishermen and to conservationists. Unfortunately the root causes of the cetacean/fishing net interaction problem are complex and frequently misrepresented in the media. Practical attempts to solve or at least mitigate these problems have been made in a number of countries in recent years but so far the benefits achieved have not been statistically significant, (Dawson 1990).

An alternative approach, employing echo-enhancing devices optimised to match the dolphin's sonar signal parameters, was recently tested in a closely monitored tracking experiment in the Moray Firth with groups of wild bottlenose dolphins, *Tursiops truncatus*. The reactions of these animals demonstrated that they could detect a barrier of these devices by using echo-location at quite long ranges and that, after detection, they altered course to avoid close contact. However, the transfer of this technology into a commercial fishery has still to be achieved and a number of practical problems still need to be resolved.

This paper discusses the observations made during a short sea trial in which both modified and unmodified panels of gill-net were shot and hauled in order to evaluate handling problems. Additionally, the acoustic detectability of echo-enhanced net panels was compared with equivalent unmodified sections at different ranges and angles using a 100kHz sidescan sonar.

1. INTRODUCTION

Even the large whales are at risk when they collide with a fishing net but the major kills in commercial fisheries tend to occur in the phocoenid and delphinid families. These small odontocetes all possess a well developed echo-location sense and normally forage by targeting and intercepting individual fish and cephalopods while swimming at speed. They tend to select food which they can swallow whole and most of their ingestion takes place underwater. However, they are air-breathing mammals, and if restrained from returning to the surface to breathe they suffocate and die.

Since a small, but in some areas very significant, percentage of these echo-locating mammals become entangled in gill-nets, it is normally assumed that the occasional failure to avoid a net must result from problems of detection, i.e. the relative acoustic transparency of modern polymer net materials reflecting insufficient sound to be perceived. Conventionally the Target Strength (TS) or acoustic reflectance of an underwater target is assessed in dB (reference a 2m radius rigid reflecting sphere). However large distributed targets with variable geometry, such as fishing nets, are very difficult to assess in simple numeric terms. The measured TS of a net changes as the area ensonified by the transmitted beam width alters as a function of range. TS is also modified by the net's orientation with respect to the angle of incidence of the sonar signal, by acoustic resolution limits imposed by the net structure (most of which comprises components of sub-wavelength dimensions when assessed in terms of the dolphin's sonar spectrum) and by the ρc of the net material (ρc is the product of density and sound velocity in the material).

In a recent assessment of fishing net materials (Au & Jones 1991) it has been suggested that the bottlenose dolphin and other small cetaceans possess both the Source Level capability and the receive sensitivity necessary to perceive echoes from many types of net webbing at ranges perhaps as great as 9m.

The characteristics of echoes returning from nets are very different from those from swimming fish or from solid objects. Simple detection of weak diffused net echoes which are returning from an area or volume of water ahead of these echo-locating animals may not be easy to classify as an identifiable hazard to be avoided. Similar zones of raised volume reverberation are a common penetrable phenomenon which occurs naturally with bubbles and algae in open water.

An additional complicating factor results from the animal's intermittent usage of it's active sonar sense. This sense seems only to be employed continuously while foraging for food, e.g. an average usage of active sonar for a solitary bottlenose dolphin, which was closely observed during five 24 hour study (winter and summer) periods, was 46%, during which specific acoustic activity classified as chasing fish accounted for some 2.8% (Bloom, 1992a). Dolphins have been observed to travel silently over considerable distances presumably well able to navigate by passive acoustic features, salinity variations, water depth, temperature, geomagnetic variations and other environmental clues.

Based on acoustic parameters determined during a series of studies of the sonar behaviour of a wild bottlenose dolphin, (Goodson *et al.*, 1990; Bloom 1992b), a series of physically small passive reflectors have been engineered. These are designed with a nominal TS of -35 dB to provide a detection criteria equivalent to, or slightly in excess of, that of the largest fish normally sought by the animal. The devices are intended to return a relatively constant

TS regardless of the angle of approach and are matched to the high frequency end of the dolphin's audiogram (Johnson, 1966). These reflectors are intended to be distributed in a uniform pattern over the face of a gill-net between the headline and footrope, spaced so that an approaching echo-locating animal is deterred from attempting to pass between them.

2. DOLPHIN INTERACTIONS WITH A REFLECTING BARRIER

In a preliminary field trial in the Moray Firth, prototype reflectors were deployed to form a floating barrier and placed to obstruct the passage of a number of wild bottlenose dolphins (Mayo & Goodson 1992, Goodson *et al.*, 1992). That experiment, in good acoustic conditions, demonstrated that some dolphins detected the barrier at a maximum range of 170m. Avoidance reactions, typically initiated at ranges greater than 100m, were also noted in those dolphins approaching on a potential collision course.

The simple 'Hukilau' type barrier employed (the term derives from an artisanal Hawaiian fishing device) was constructed from a floating headrope which supported thin weighted strings at 2m intervals carrying reflectors spaced 2m apart vertically. There was no net webbing (mesh) employed in this structure as we wished to avoid any risk to the approaching animals.

This experiment, which tracked the surfacing positions of animals from a high cliff using a theodolite whilst simultaneously monitoring their underwater acoustic emissions, also demonstrated that large numbers of dolphins repeatedly followed quite narrow travel 'paths' with some identifiable turn or 'way' points.

3. INVESTIGATING NET HANDLING AT SEA

The application of any such acoustic device to a commercial fishing net creates additional practical problems. For example:

(i) There is a predictable increase in the volume of the modified net which may overfill a standard net storage bin.

(ii) The handling of the net during deployment, recovery and during transfer between net pounds on board ship may be impaired to a point where the technique could be unacceptable.

(iii) The change in buoyancy caused by the reflectors may affect the deployment of the net once in the water.

To investigate the significance of these anticipated effects, a short sea trial was arranged on board a U.K. gill-net fishing vessel and a test net was prepared from four 54m long by 18m deep net panels. The net mesh (webbing) was constructed from 210/18 red nylon twine with a 170mm stretched mesh. These four nets were rigged as a single fleet from a supporting buoyant headrope and were weighted with a No. 4 reinforced leadline (runnage 11 kg/100 m) together with a backing rope, as in Figure 1. The sections were arranged as a modified net panel (including reflectors), a gap of 10m, a second modified panel (with reflectors) butt-jointed to an unmodified panel, a gap of 10m and a final unmodified panel, as in Figure 9.

The reflectors had been prepared, at short notice by a commercial twine manufacturer, within a mixed fibre flat braid and were spaced apart at 3m intervals. This technique had been chosen to ease handling and to reduce the likelihood of 'buttoning' which might cause adjacent layers of netting to catch together while being shot. The braiding technique also avoids the torque effects that occur in a conventional rope when under tension.

The fishing vessel deployed this experimental net in a depth of 54m, some 6km offshore in calm sea conditions. Shooting the net from the stern, Figure 3, created no apparent difficulties and the flaked net, together with the reflector enhanced hanging lines (spaced at 2m intervals along the headrope), appeared to run out quite smoothly. The unmodified net panels deployed correctly and settled into the water without problems. However, one modified section appeared to be partially 'hung up' with the reflector support lines clearly visible on the surface laid across the headrope. It seemed likely that once wetted, the mixed-fibre tightly woven braid remained very buoyant with trapped air; the lead cored footrope had insufficient weight to drag these (rough surfaced) hanging lines off the headrope. This condition did improve somewhat during the short trial. For most of the observation period the second modified net remained with the head rope and foot rope held close together and with the net webbing hanging below it in a loose 'tube'.

Recovery of the net, Figure 2, appeared to run fairly smoothly through the drum hauler (Tarbenson 750/500) but it was noted that a potential for entanglement existed with the hanging reflector support lines. As the hauler pulls both head rope and foot rope together, this leaves the hanging lines to form into loose bights as these were not attached to the net webbing.

'Turning the net over' (transferring the net between containers and removing any debris) proved a more difficult operation with the modified panels as there was a tendency for some reflectors to drop through into an adjoining layer of mesh and snag, dragging this layer across as the net was transferred. With the existing (rough braid) supporting lines this problem was regarded as a liability and improvements are needed.

4. DOLPHIN v SIDESCAN SONAR CHARACTERISTICS

The sidescan sonar equipment, Figure 4, employed in the net evaluation test was selected for its nominally similar signal characteristics to those of the bottlenose dolphin. The Waverley 3000 sonar transmits a source level (SL) of some 227 dB re 1 μPa at 1m, which is the same SL as the maximum recorded for a bottlenose dolphin. The side scan 100kHz operating frequency is also close to the high frequency peak (120kHz) normally present in the dolphin's wideband 'click' spectrum (Au, 1980). The side scan sonar transmits two fan-shaped, sonar beams, one on each side of the 'tow-fish' track, each with a horizontal beam width of 1.5 degrees. In the vertical plane both beam widths are 50 degrees although the transmission centre line is depressed approximately 10 degrees below the horizontal in order to favour bottom search operations. (Note: some sidelobe sensitivity exists outside these angles for strong target echoes.) The sidescan sonar images the seabed and midwater targets on each side of the towing ship's track and progressively builds up a two dimensional picture on a thermal printer due to the vessels forward movement. The tow-fish is fin stabilised and should run horizontally, without a significant roll angle, at a depth defined by the towing speed and length of towing cable.

In contrast, the dolphin's biological sonar has evolved as a highly directional forward looking sonar. This system appears optimised to search for targets within a 10 degree conical 'spotlight' beam projected ahead of the animal along its swimming axis. The sonar is unlikely to detect small targets (assessed in wavelength terms) unless the animal points its head towards them within this angle. The transmitted broadband 'click' when emitted at a high SL (typically 210-220 dB re 1 μPa at 1m) contains a spectrum which extends above 130kHz with an energy peak in the spectrum normally occurring near 120kHz. This frequency corresponds to a wavelength (λ) of 12.5mm in seawater and targets with sub-wavelength dimensions reflect little of the incident energy. The dolphin's audiogram demonstrates that it is sensitive to sound pressures at frequencies extending to about 140kHz and significant peaks in this audiogram occur near 80kHz and 120kHz.

While travelling, most small cetaceans 'porpoise' briefly to breathe and are believed to stay relatively close to the surface. However when actively searching for food they may dive much deeper while employing slow sonar transmission repetition rates indicative of a long range (in the order of 60m-90m). The bottlenose dolphin appears to adapt its search radius to the propagation conditions and in shallow water its sonar appears to function as a reverberation limited system. From the size of the larger prey seen taken and the choice of search range an approximate detection capability of -35dB TS at 70m is believed possible in the wild (Goodson *et al.*, 1990) which matches the detection abilities measured in laboratory tests, (Au, 1980). The dolphin's maximum detection range is actually determined by its choice of pulse repetition frequency (PRF) as the succeeding transmission can be assumed to terminate reception of longer range small target echoes which arrive later. The animal increases its PRF as it locks on to a fish target during interception and during the chase period is effectively deaf to alternative target echoes.

5. INTERPRETING THE ACOUSTIC IMAGES OF THE GILL-NET

While the net was in the water, a 100kHz (Waverley 3000) side scan sonar was streamed astern and a series of 13 runs were made past the net at different distances and orientations. These sonar scans of the net were made by towing the side scan tow-fish at a speed of about 4 knots with 50m of cable between it and the vessel. This combination of forward speed and short cable length resulted in the tow-fish running at about 15m depth.

For most of the runs some evidence exists that the tow-fish was running with a slight tilt (roll angle) so that one side favoured the bottom and the other the surface. When the towing vessel turns between scanning runs, the forward speed of the tow-fish falls, causing the device to run deeper. The short towcable (needed to avoid scanning too deep) unfortunately resulted in more wake disturbance appearing within the images. These echo 'clouds' are a result of propeller induced turbulence and entrained (very fine) air bubbles which generate a significant volume scattering echo.

Since a drifting gill net is expected to hang vertically from the surface, and the side scan sonar traces displaying slant ranges give little height information, it is apparent that a tow-fish view from the footrope depth should make this lead cored rope the first target detected, with the floating head rope echoes arriving a little later. Likewise, if the tow-fish is run at a depth equivalent to the middle of the net then both floatline and leadline echoes will arrive together. The problem is compounded in practice as the wake of the towing vessel applies a variable side thrust which tends to tilt the net curtain from the vertical.

The (very light) breeze during the trial also tended to drift the head rope's position relative to the bottom of the net. In any event, the 18m deep net appears compressed in these images with respect to its distance from the tow-fish, and some care is needed when identifying specific net components.

That said, the side scan images of the experimental net are quite informative. In an initial scan the net position was clearly detectable at 120m. At this distance however, the net's component structure cannot be resolved. Closer scans made at 45m distance delineate both the headline and leadline, but, even at 20m (the closest point of approach), do not yield any detection of the supported gill-net mesh. The acoustically modified panels showed as an in-filled structure due to the presence of the reflectors. The gap between the modified panels is also clearly detectable in most scans.

Fig. 5 (150m max range - 15m scale lines) shows a run made at 45° passing the nearest end of the net at about 70m. Note that the 10m gap inserted as a potential escape aperture between the first two panels can be detected. The bulk of this echo trace originates from the headrope and the echo-enhanced panels are out of range.

Fig. 6 (75m range - 15m scale lines) shows a run parallel to the net passing at 25m to 35m distance. The dahn buoy and bridle rope leading to the first modified panel is on the left, contrasting with the returns from the unmodified panels on the right. The second modified panel is partially 'hung-up', and 50% of the reflector line length is trapped at the surface. Even so, the escape aperture is detectable and, rather surprisingly, can also be perceived at the RH end. Note the lack of any detectable echoes returned from the unmodified net webbing at the RH end.

Fig. 7 (75m range - 15m scale lines) is very similar to Fig. 5. However, the increased reverberation due to the traces of air entrained by the wake and by turbulence seen at the RH end are clearly stronger returns than any trace echo that might be generated by the net webbing.

Note: At the LH end, the even stronger wake disturbance (probably caused as the fishing vessel started to turn) does not mask the echo enhanced net panels and the 10m gap between these two panels remains detectable. The first few metres of the net panel at the LH end had started to drift together. The second panel shows the transition from the partially 'hung-up' modified panel to the correctly deployed unmodified section very clearly. Good detection of the headrope and (weaker) leadline being maintained out to about 50m range.

Fig. 8 (75m range - 15m scale lines) shows an incomplete trace which delineates the reflector enhancement of the last panel very clearly between 30m and 45m range. (This run was aborted early as the vessel was running too close to the net end for safety!)

6. DISCUSSION

Detection of the (drifting) gill-net in this trial by the side scan sonar was aided by the flat, calm sea conditions and by the depth at which the scans were made. These factors, together with a slight roll angle on the tow-fish, may have exaggerated the detectability of the headline component which is clearly the strongest component in all of these images. In any sea state other than zero, and especially if the dolphin sonar is operated much nearer the surface, the detection of the headline component may be more in question. Wave trough masking effects and the lack of submerged depth of the head line floats will ensure that negligible echoes return in the horizontal plane.

A diurnal refraction effect can exist due to steep temperature gradients in upper surface layers. This effect builds up as the sun warms the surface during the day and results in strong refraction of a horizontally projected sonar signal away from the surface. The thermal gradient effect reverses during night cooling, and as a result, the headline components may become rather more detectable during the night.

In high seastates the headline pulls from the surface, bridging between wavecrests, and it is probable that this repeating exit/re-entry action will entrain fine air bubbles which tend to be driven down, making a detectable bubble cloud in the vicinity of the surface near the net. (Moored buoys produce this aeration effect which is very visible on a 300kHz scanning sonar). However, in still rougher (unfishable?) weather, 'white caps' on the breaking wave crests aerate the water column to considerable depths below the surface layer and any fishing net generated aeration will be masked.

Acoustic net enhancement to make the gill-net webbing appear as a 'wall' is needed if cetacean passage through the large gap apparent between headline and leadline is to be deterred. However, if used in isolation, acoustic enhancement may not be very efficient as the question of how far a cetacean having detected a barrier is prepared to be deflected off its course must be considered. It now seems self evident that the provision of safe and identifiable passage positions, either over the net (employing sub-surface head ropes) or, by inserting significant gaps at the joins between fleets of nets should be considered (10m gaps at 250m intervals are proposed for initial test purposes). Gaps can be added at the joints in existing gill-nets without apparent disadvantage to the fishing operation, and do not alter the active length of net being fished.

The mechanical problems of attaching the reflectors at regular intervals to a gill-net in a way that minimises the gear handling problems requires some refinement. Essentially this is a problem for fishing gear technologists and fishermen to resolve, and will necessitate experimentation in the actual fishery at sea. The prototype reflector tested to date is a cheap, commercially available component which meets many (but not all) of the design criteria. With experience and feedback from a commercial fishing operation, some redesign of this device (whilst maintaining the acoustic characteristics) to improve mechanical handling and net attachment characteristics, can be considered. However, with only slight modifications to the existing method of attachment, the technique can be taken to sea for more a thorough assessment in the fishery.

7. ALTERNATIVE AND ADDITIONAL MODIFICATIONS

Lowering a drift net headline below the surface by at least 2m is a beneficial technique for which some experimental evidence (Hayase & Watanabe, 1990; Robin des Bois, 1991) suggests that this may reduce the cetacean by-catch rate by as much as 50% (and that of diving birds at risk in inshore drift net fisheries by greater amounts). However, the statistical significance of this figure still has to be established. Lowering the headline below the surface has several benefits as this makes the top edge of the net acoustically very detectable by placing the floats below any wave-trough masking effects. Providing a clear zone of water above the net does offers a safe cross-over position although a dolphin may regard the 2m depth as barely passable! Lowering headropes can result in an uneconomic loss of some target species. Implementing lowered headropes necessitates the vessel carrying large numbers of surface support buoys which, with their attendant bulk take up unacceptable stowage volume within the smaller European fishing vessels. There is also a perceived increase in risk to the crew during the attachment of the buoy strops to the headline while shooting the net. These also have to be removed during hauling as the net cannot be stowed with them still attached.

Active sound emitters may also have a place in attracting attention. The experimental use of noise sources (e.g. Hatakeyama *et al.*, 1990) has been evaluated only as a deterrent device and, whilst some avoidance action is reported, this was only noted in close proximity to the source. Unfortunately, most animals subjected to noise makers seem to habituate to the sound as they approach and they have no means of associating the noise with a hazard. The dolphin has very few threats, other than those created by man, so playing back the sounds of a predatory animal (such as a killer whale) fails, as those killer whales that do predate on mammals do so very quietly. The vocally active killer whales tend to be fish eaters, something that dolphin have probably learned through the millennia! A side effect of this approach may be to encourage the dolphin to 'run silently' to avoid attracting attention and in turn this increases their vulnerability to a net.

The problem of attracting the attention of non-echo-locating cetaceans may also be addressed by a non-acoustic method, (Klinowska 1990, 1991 & 1992). Small cetaceans have an excellent sense of taste, possibly needed to detect and track shoals of fish by their excreta trails in the sea. Traditional net materials were treated to preserve them from rotting with a variety of substances including alum, tree bark extracts and light tar oils, and as a result, may well have produced identifiable zones in the seawater around them. Anecdotal evidence suggests that an 'alarm' substance may be secreted in the water by severely stressed animals; late arrivals into the same area have been observed to be startled and to move away. Such a material if isolated and synthesised could have potential as a net marker, but this approach will need considerable long-term research efforts to investigate. Incidental by-catch reductions can be achieved by imposing 'time and area' closures on a fishery, with all the associated problems of monitoring. In many third world countries, the protein component provided by local fisheries is a critical dietary component for the human population, and any proposals to close such fisheries to protect cetaceans are unrealistic.

There is a clear need for an effective technique which will work in a variety of fisheries. Bonnemains & Kanas (1990), Woodley & Earle (1991) and Collet *et al* (1992) describe the by-catch observed in short studies of the French North Atlantic Albacore fishery, and Coffe & Grace, (1990) report a gillnet study made in the Tasman sea. However, cetacean by-catch is not simply a problem of 'Tuna' drift net fisheries; it occurs in almost every part of the world and in every type of fishing net and trap (IWC, 1990; Klinowska, 1991).

8. CONCLUSIONS

This handling trial demonstrated that the acoustic modifications under test performed as intended, and in-filled the apparent space between headrope and footrope effectively. Detection of the supporting lines between each reflector was a predictable effect as the large cross-section braided lines employed also retained traces of air. The duration of this trial provided insufficient soak time to remove this effect. The buoyant headrope and lead-cored footrope were easily detected. The headrope echo component could be easily lost to a sonar near the surface when the sea state increases. The effect of aeration in the water (in this case entrained by the towing ship's propeller) clearly illustrates the volume scattering masking effects to be expected in higher seastates.

The marked detectability of the 10m gaps placed between the modified panels was anticipated, but it was interesting to note that in some of the scans, the equivalent gap between unmodified panels was just perceptible. The panel ends at each side of the gap were reinforced with a 4mm hanging line.

The experimental method of fastening the reflectors to the face of the net needs further refinement, but the problems observed during this first net trial were primarily caused by an inappropriate choice of braiding material, which remained too buoyant with trapped air and failed to slide easily off the headrope. Alternative materials and attachment techniques are being examined which should overcome this difficulty.

The addition of these acoustic reflectors, distributed as a 2m x 3m grid across the net face, does not imply an unacceptable increase in capital net costs when incorporated during construction.

Whilst some small cetaceans will inevitably continue to be caught in fishing nets, regardless of whether acoustic modifications such as these described are employed, this acoustic engineering approach based on detailed consideration of small cetacean sonar behaviour is designed to avoid the pitfalls identified in earlier attempts. Although further modifications may be anticipated in order to satisfy operational requirements, the potential of this technique to mitigate small cetacean by-catch in a commercial fishery now needs to be assessed. To be fully effective it is likely that some additional mechanisms will be required, which are designed to raise cetacean awareness, together with the provision of 'safe passage' crossing points.

9. ACKNOWLEDGEMENTS

The support of this trial by the Sea Fish Industry Authority, by Leach & Turner Fishing Gear and by the master and crew of the *MFV Britannia V* is gratefully acknowledged. The loan of the side scan sonar equipment by the Defence Research Agency (Bincleaves) is also acknowledged with many thanks. Support for the research programme has been provided by the European Community (Eurogroup for Animal Welfare), the Conservation Society, CWS Ltd and Racal Recorders Ltd, Windsor Safari Park and Flamingoland Dolphin Centres. Thanks are due to very many friends and colleagues who gave their time and effort in the support of earlier field work.

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FIGURES

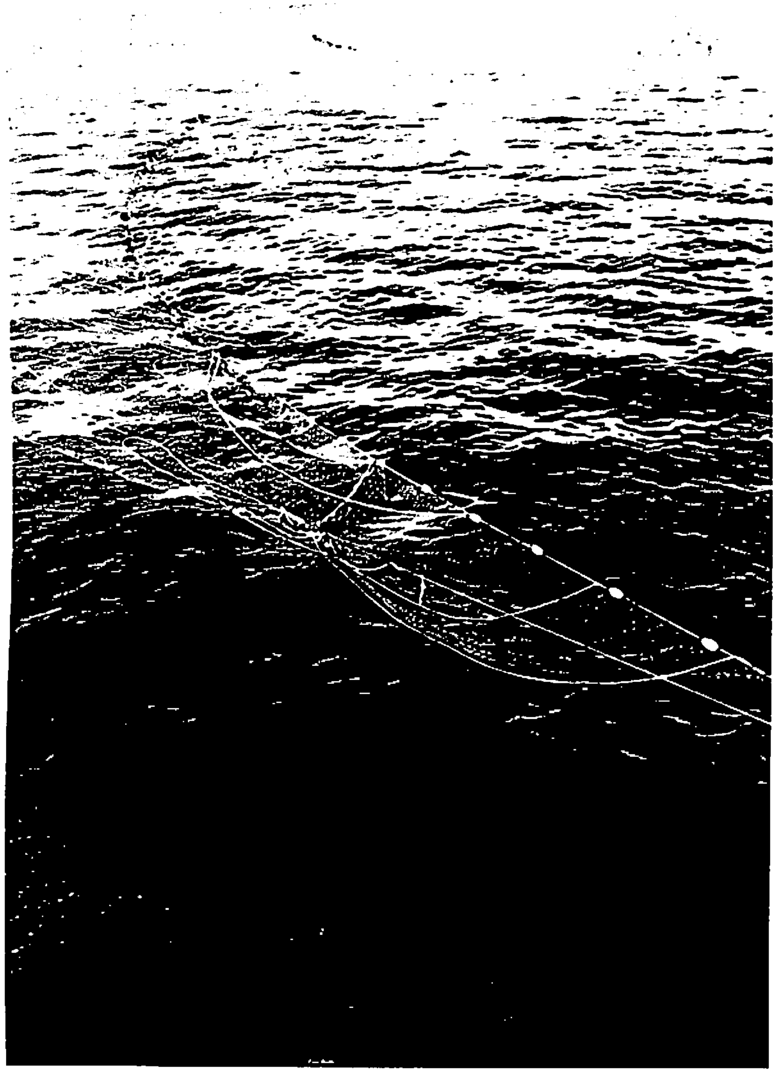


Fig (1): Photograph of net panels - as deployed

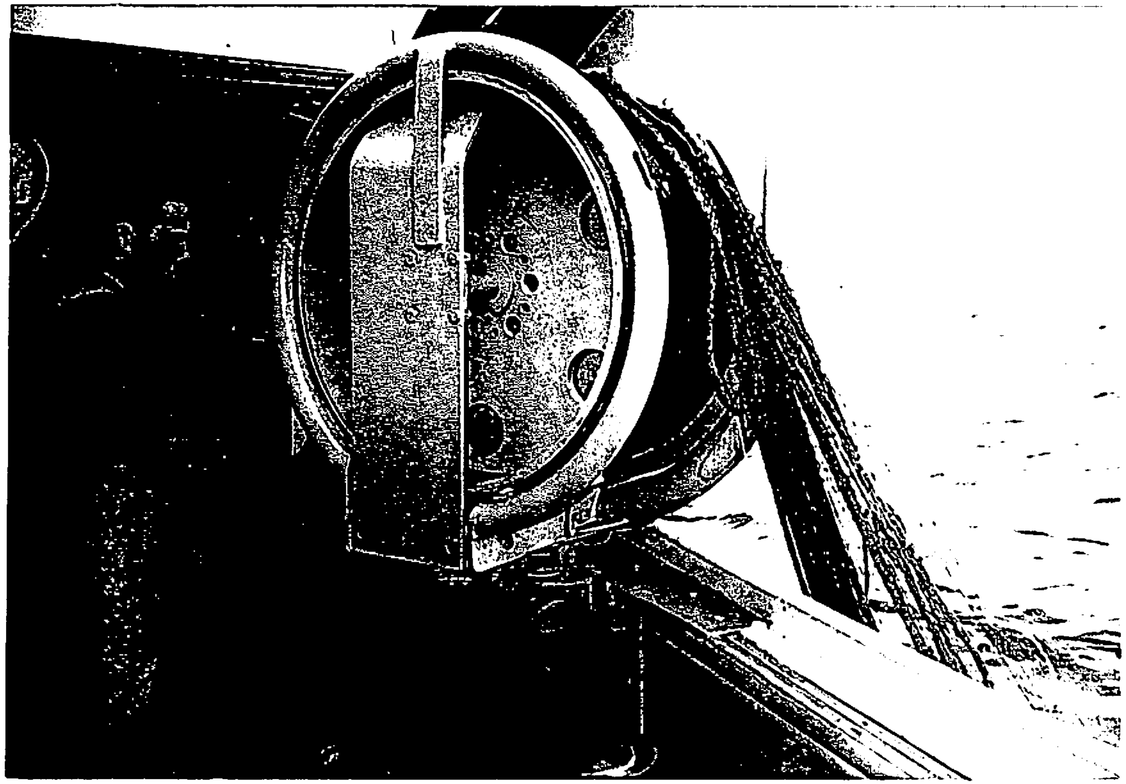


Fig (2): Photograph of net-hauler recovering gill net

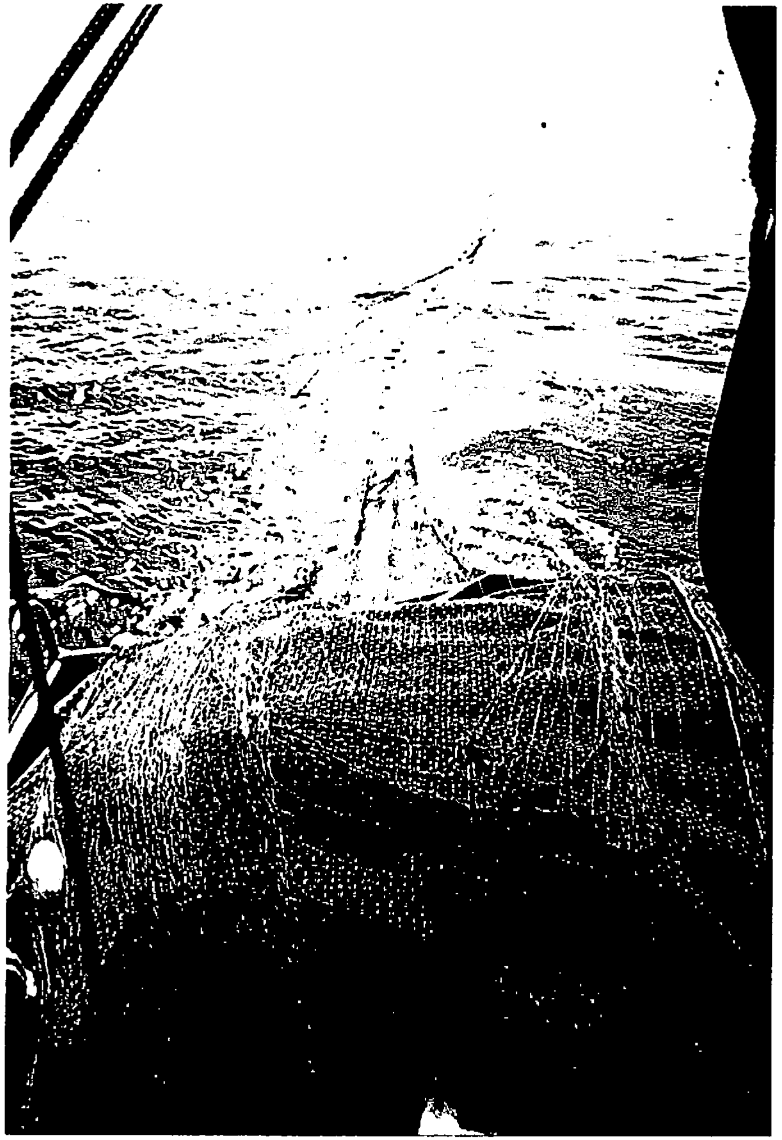


Fig (3): Photograph of gill net shot from MFV Britannia V

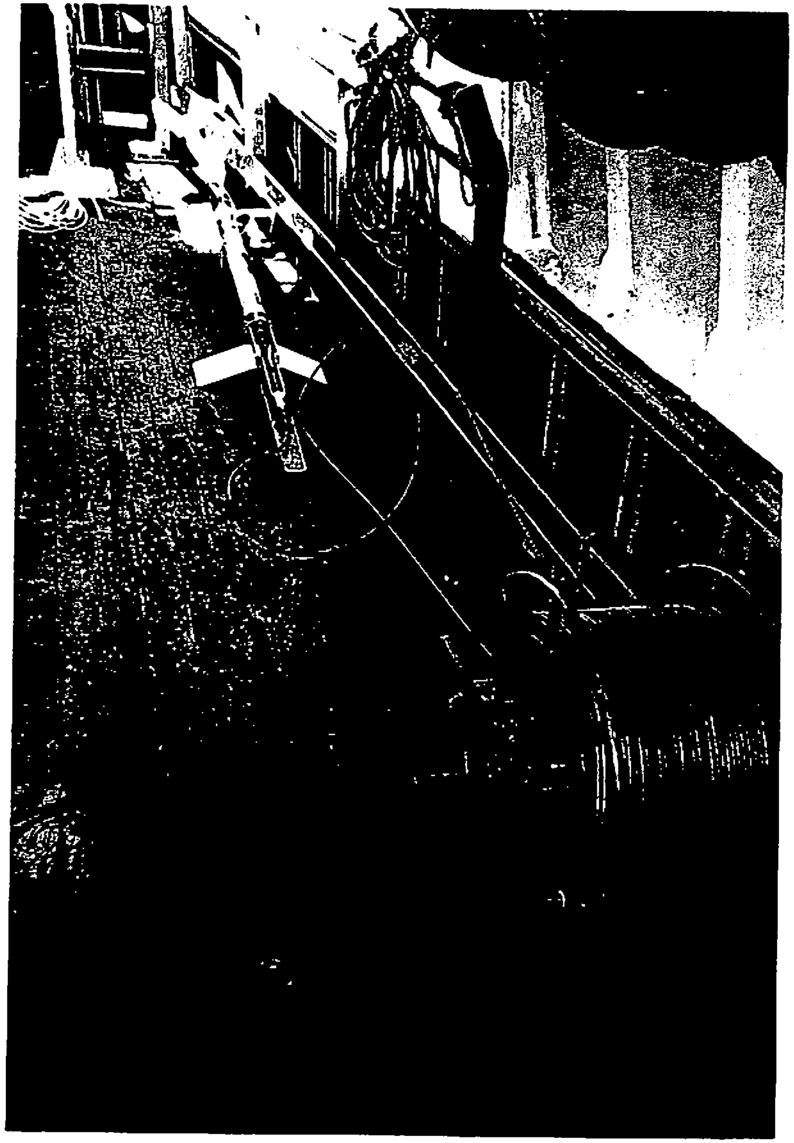


Fig (4): Photograph of sidescan sonar tow-fish

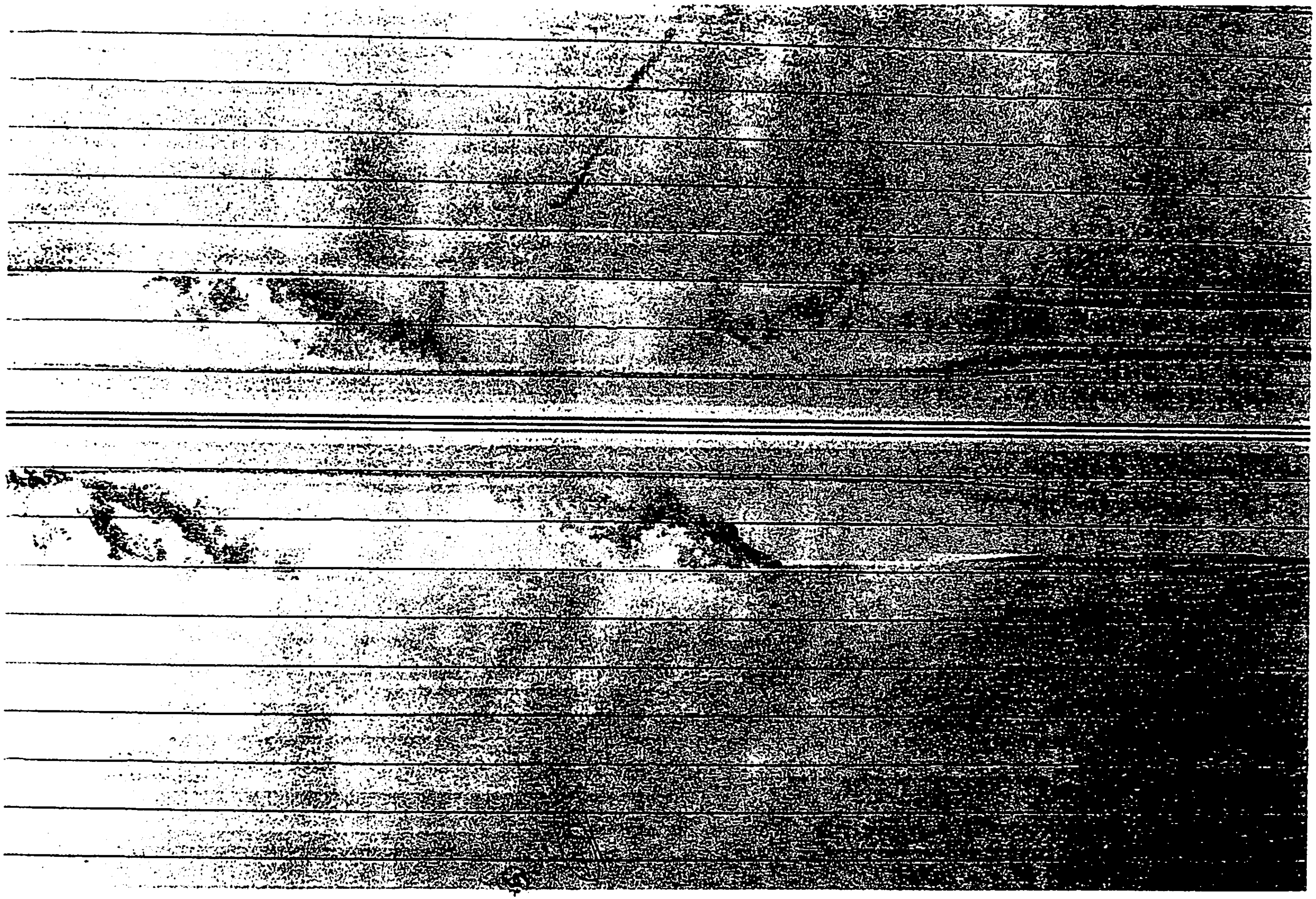


Fig (5): Sidescan - 150m max range, 15m scale lines; 45 degree run

Fig (6): Sidescan - 75m range, 15m scale lines; parallel run

Fig (7): Sidescan - 75m range, 15m scale lines; parallel run

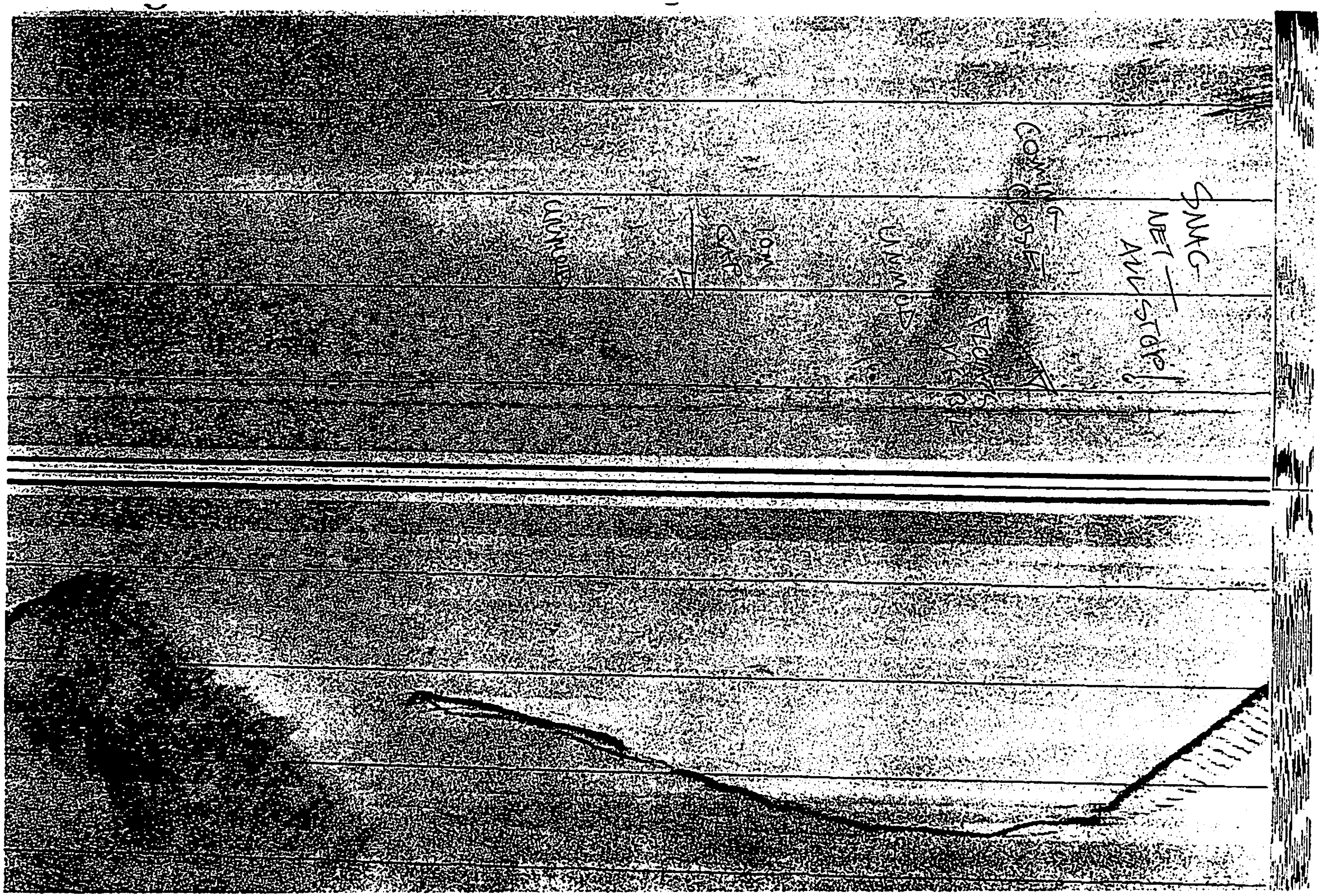


Fig (8): Sidescan - 75m range, 15m scale lines; detailed echoes of strings

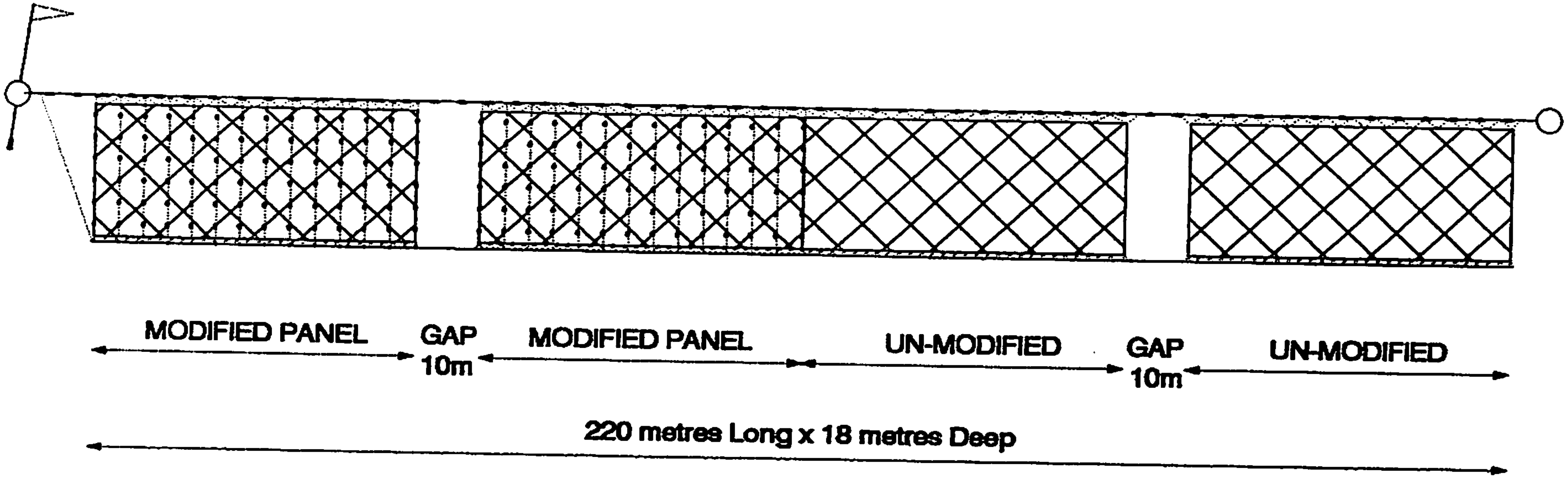


Fig (9): Arrangement of the modified and unmodified nets

APPENDIX II

AN EXPLANATION OF TWINE NOTATION

APPENDIX II

Twine Notation

210/18 is a Denier notation for twines. The first figure (210) refers to the runnage (weight per unit length) in Denier of one individual yarn strand composing the twine. The second figure (18) refers to the construction of the finished twine, and can be factorised into the number of bundles of individual yarns; in this case 3 bundles of 6 yarns (3 x 6 = 18). The Denier system is an old system of notation and can be defined as:

Denier = grams per 9000 metres for an individual yarn

To write a denier notation as 210/18 is not strictly correct, but it is universally used in this form among net suppliers in the U.K. It should be written 210 x 18; the oblique used previously could be mistaken for a division sign (Klust 1982). To describe a twine as being of 210 denier without specifying the twine construction is acceptable (Klust 1982).

The system adopted by the International Organisation for Standardisation (ISO) is the Tex system and is far more common in use than the old Denier notation. The Tex system is also based on runnage and is defined as follows:

1 tex = 1 gram per 1000 metres

It therefore follows that:

1 Denier = 9 x tex

The runnage of a finished twine is usually referred to in terms of Rtex; the letter 'R' to signify a finished twine rather than an individual strand of yarn. This allows for the increase in weight per unit length arising due to the final twisting of the finished twine (Klust 1982).

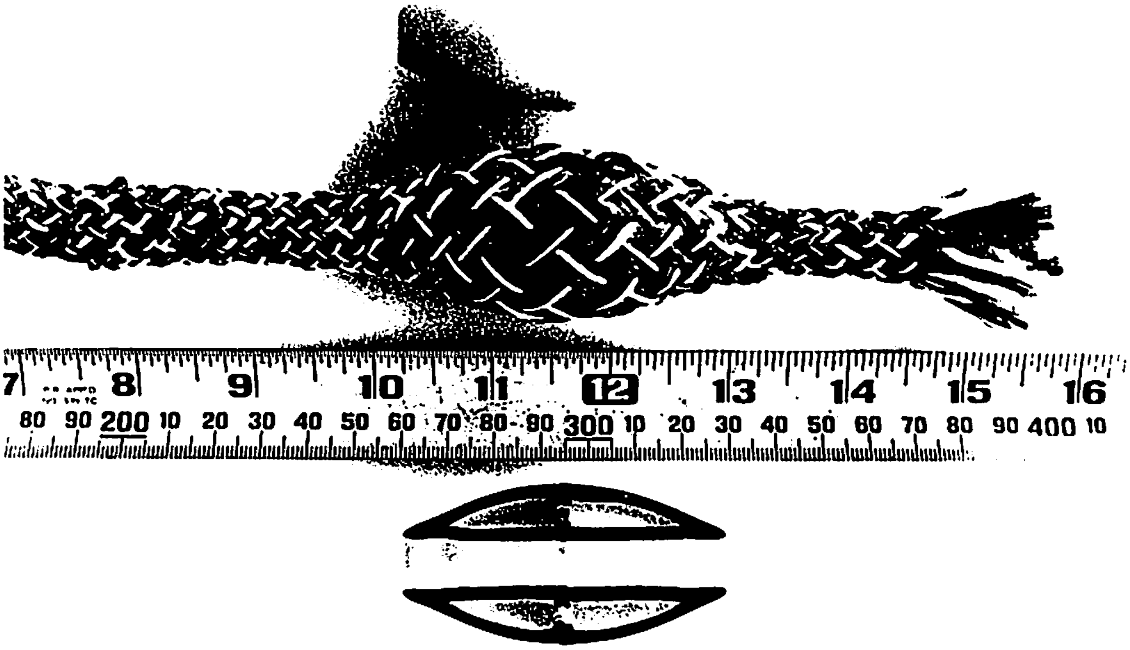
tex x coefficient of final twist = Rtex

It therefore follows that:

'210/18' = 210x18 = 3780 Denier (finished twine) = 420 tex

APPENDIX III

SHOWING THE FLOATS USED AS ACOUSTIC REFLECTORS



Photographs of floats used as acoustic reflectors