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ALTERNATIVE STIMULATION IN FISHERIES

FINAL REPORT
for the period 1.09.1994 - 31.12.1996

STRICTLY CONFIDENTIAL - FOR COMMISSION USE ONLY
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TABLE OF CONTENTS

Pre-script

This report contains contributions by the various participants in this Concerted Action, and was edited to one document by B. van Marlen, acting as coordinator of the project. The introduction was written by B. van Marlen. Chapter 2 "Visual stimulus of fishing gears and fish reaction" was written by Dr. C.S. Wardle with help of Dr. C.W. Glass. Chapter 3 on "Visual stimulation of fish, including artificial lights" was written by Dr. I. Huse. Chapter 4 on "Reactions to Sound" was written by Dr. A. Engås. Chapter 5 "Olfactory and gustatory stimulation in fish" was assembled by Dr. I Huse. Chapter 6 was written by a number of different authors. The part on work on electric fishing in The Netherlands by B. van Marlen, based on a report by RIVO in 1988. The section on "Work done in Belgium and France" was written by H. Polet. The contents of the section about the Work done in the UK was taken from Confidential Report No. 96 written by W.J. Lart and R. Horton. The section on the work done in Germany was written by Ing. K. Lange. Chapter 7 dealing with "Other stimuli" *i.e.* water flow was delivered by E. Lehtonen and M. Kiviniemi. Information on alternative stimuli in general was also retrieved by visits to scientists in Japan by Dr. C.S. Wardle and B. van Marlen and in Russia by B. van Marlen with the aid of Dr. O. Gabriel. Additional sections were written by B. van Marlen on light stimulation and electro-fishing based on the information collected. Chapter 8 about mobility under this project was edited by B. van Marlen with input from D. de Haan, Dr. C.S. Wardle and K. Lange. Chapter 9 "Summary and conclusions" was drafted during the last project meeting and re-written by Dr. C.S. Wardle and B. van Marlen.

1. INTRODUCTION

1.1 Objectives of the study

The objective of this concerted action is to review current knowledge of fish behaviour and the stimuli to which they react. One aim of the review is to reveal where improvements might be made to current practice in fisheries. Question might be: is there an alternative to heavy ground gears that are thought to damage the sea bed perhaps using sound pulses, electric fields, laser beams or water jets? Why do not all fish small enough pass out through grids and square mesh windows built into codend extentions? It is widely recognised that there is a fund of knowledge about fish behaviour as well as the properties of physical and natural stimuli that is not made use of in applied fishing gear technology. With the present surge of environmental awareness, responsible fishing has become an increasingly important discussion point among fisheries managers and politicians. Knowledge can equally be used to frustrate the action of or improve a selective device used in a fishing gear and it is clear that local management incentives can stimulate use or misuse of scientific knowledge. The processes used by man to harvest food from the sea have generated issues such as how to reduce overfishing, discards, seabed damage, introduction of humane slaughter methods and emotive issues of avoiding unwanted bycatches such as turtles, seals and dolphins. There are examples where biological study and the resulting awareness of the interaction of fishing mechanisms and the fish behaviour have been made use of. Large efforts have for example been made by scientific teams to reduce the capture of unwanted juveniles of commercial fish that occur in the shrimp fisheries around the world. In only some of these areas appropriate small changes to the details of the fishing gear used have shown large benifits in conservation. Such studies have shown us how important it is to understand the mechanisms both biological, physical and mechanical that come together during the particular local harvesting process. Many of the problems like the bycatch in shrimp fisheries are international and knowledge from one group can be sensibly adapted by other groups to improve their local fisheries but not without appropriate knowledge. A good idea can be easily destroyed by inappropriate applications. Coordination of ideas and scientific approaches worldwide is important in the development of suitable answers.

List of tasks for the year 1994-1995.

P	1994-1995 Task	Month											
		S	O	N	D	J	F	M	A	M	J	J	A
1	1.1 *Meeting 1, IJmuiden*	X											
	1.2 Retrieval of information						X	X					
	1.3 Report							X	X				
	1.4 Making bibliography	X		X		X		X		X		X	
	1.5 Review sound studies	X		X		X		X		X		X	
	1.6 Review light studies	X		X		X		X		X		X	
	1.7 Review electric stimulation	X		X		X		X		X		X	
	1.8 Review other stimuli	X		X		X		X		X		X	
	1.9 *Meeting 2, Hamburg*									X			
	1.10 **Periodic Report No 1**											X	X
2	2.1 Mobility sea trials on sound	X											
	2.2 Cruise report		X										
	2.3 Mobility sea trials on light										X		
	2.4 Cruise report											X	
	2.5 Mobility trials other stimuli												
	2.6 Cruise report												
	2.7 *Meeting 3, IJmuiden*												
	2.8 **Periodic Report No 2**												

List of tasks for the year 1995-1996.

P	1995-1996 Task	Month												Ext.			
		S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
1	1.1 *Meeting 1, IJmuiden*																
	1.2 Retrieval of information		X	X									X				
	1.3 Report				X			X						x	x		
	1.4 Making bibliography	X		X		X		X		X		X		x	x	x	
	1.5 Review sound studies	X		X		X		X		X		X		x	x	x	
	1.6 Review light studies	X		X		X		X		X		X		x	x	x	
	1.7 Review electric stimulation	X		X		X		X		X		X		x	x	x	
	1.8 Review other stimuli	X		X		X		X		X		X		x	x	x	
	1.9 *Meeting 2, Hamburg*							X									
	1.10 **Periodic Report No 1**			X													
2	2.1 Mobility sea trials on sound	X												x			
	2.2 Cruise report		X											x	x		
	2.3 Mobility sea trials on light		X	X				X			X						
	2.4 Cruise report				X				X			X					
	2.5 Mobility trials other stimuli										X						
	2.6 Cruise report											X					
	2.7 *Meeting 3, IJmuiden*												X				
	2.8 **Periodic Report No 2**													x	x	x	x
3	3.1 **Draft Final Report**												X	x	x	x	x
	3.2 Reaction DG-XIV																x
	3.3 **Revised Final Report**																x

1.2 Outline of the project

The outline of the project is given in the two tables above with the various tasks for the two years involved.

Three project coordination meetings were organised at which it was agreed to search literature by accumulating a large bibliography and bring together as much as was known about the reaction behaviour of fish observed over the past 30 years as possible. Two visits were made to distant fishing areas of China and Japan and Russia in search of alternative applications, as will be further explained in the next Chapter. It was agreed that there were areas where incentives to apply valuable knowledge in the harvesting techniques were very low, yet potential was high. It was decided to split up tasks between participants working by correspondance and attend each others cruises and make visits.

List of project meetings.

Meeting	Dates	Host	Town	Duration	Persons
1	1-2 Nov 1994	RIVO-DLO	IJmuiden NL	2 days	11
2	18-19 Mar 1996	BFAFi	Hamburg D	2 days	7
3	28-29 Aug 1996	RIVO-DLO	IJmuiden NL	2 days	9

1.3 References to introduction

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BEON, 1992. Effects of beam trawl fishery on the bottom fauna in the North Sea III - The 1991 studies. BEON-report No 16.

Enger, P.S., Karlsen, H.E., Knudsen, F.R. and Sand, O., 1993. Detection and reaction of fish to infrasound, ICES mar. Sci. Symp., 196: 108-112.

Glass C.W. and Wardle C.S., 1989. Comparison of the reactions of fish to a trawl gear, at high and low light intensities. Fisheries Research, 7: 249-266, and J. Fish. Biol. 29: 71-81.

Løkkeborg, S. and Soldal, A.V., 1993. The influence of seismic exploration with airguns on cod *(Gadus morhua)* behaviour and catch rates, ICES mar. Sci. Symp., 196: 62-67.

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Walsh, S.J. and Hickey, M.H., 1993. Behavioural reactions of demersal fish to bottom trawls at various light conditions, ICES mar. Sci. Symp., 196: 68-76.

2. VISUAL STIMULUS CAUSED BY FISHING GEARS AND FISH REACTION

2.1 Introduction

The work summarised here was inspired by the aims of the alternative stimulation project and includes a review of the visual stimulus as a fish capture stimulus as well as experiments checking the basic science of the underwater view. It was carried out by Mr Kim (Yong-Hae) as a visitor from South Korea working with Dr C.S.Wardle at the Marine Laboratory Aberdeen. Mr Kim was aiming for a comprehensive predictive model of fish behaviour in towed fishing gears and has by this process investigated the rules that predict those variables currently thought to be involved in the capture process and further details can be found by refering to Kim (1996).

2.2 The visual stimulus of the fishing gear

The basic components of the visual stimulus of the towed gear are considered as the visibility (*i.e.* maximum detection distance (range) of an object by the fish) and the intensity of the visual stimulus (i.e brightness contrast of an object). The visibility is affected by light transmission properties of the water, the brightness contrast of an object, the contrast threshold of the fish (Duntley, 1963) and by acuity (*i.e.* the minimum separable angle of the fish eye, Zhang and Arimoto, 1993). Human visibility range and object brightness contrast have been investigated and principles defined in both atmosphere studies and in underwater studies (Sasaki *et al.*, 1952, Wells, 1973, and Hodara, 1973), with the secchi disc (Hojerslev, 1986) and for effects on object detection (Hemmings and Lythgoe, 1965, Kinney *et al.*, 1967, Jerlov, 1976, Leach and Morris, 1993).

The visibility of netting twine has been studied mainly by measuring the maximum distance it can be detected in a horizontal view by the human eye. The visibility for grey and buff Polyamide (PA) netting twines under different turbidity and horizontal light beams was studied in tank experiments by human eye (Inoue *et al.*, 1958). The visibilities of nets were observed in the sea in the downward direction for samples using meshes of dyed twine, and in the tank for meshes of monofilament twine (Yajima *et al.*, 1962, Tsuda, 1975a). It was also demonstrated that the vertical and horizontal visibility of the netting twine and meshes decreased exponentially with increasing turbidity in the tank and in the sea (Kajihara *et al.*, 1968).

The horizontal visibility of black twine in tank studies increased with the twine diameter (Tsuda and Inoue, 1972) and the visibility of the knot was greater than that of the twine under the green filtered light (Tsuda and Inoue, 1973a). Tsuda and Inoue (1973b) have analysed the relationships between luminous reflectance and visual range using modified equations for atmosphere visibility (Tsuda, 1975b). However, the above measurements showed limited results for visibility and only related to human vision and these studies may have involved some attenuation factors and problems of limited viewing geometry in relation to the background light and they are inadequate as basic data for predicting the intensity of the visual stimuli of fishing gear.

An underwater video camera (Kobayashi *et al.*, 1987) has been used to observe nets down to 30*m* depth pointing the camera upward, horizontal and downwards, but they had problems due to the light sensitivity and range of the vidicon camera. The luminances of the nylon and the wire branch lines in tuna long lines were directly measured by a luminance meter in a water tank under bright illuminance and the inherent contrast and the visibility were calculated by Duntley's formula (Morinaga *et al.*, 1990).

Wardle *et al.* (1991) observed the effects of depth on the colour of monofilament nylon mesh in the sea and demonstrated the visual effect of changing the zenith angle up to a depth of 25 m on the human eye image and the film camera image. The bright colours of twines when viewed at depth become different shades of greeny grey and when viewed against the graded water background luminance, their brightness contrasts vary with the viewing zenith angle (Wardle *et al.*, 1991). Their related study has confirmed in behaviour studies of mackerel in aquaria experiments, the effects of different colours of monofilament and twisted nylon on the brightness contrast threshold of mackerel (Cui *et al.*, 1991). Unfortunately, in these studies there were no quantitative physical analysis on the contrast change with viewing angle and background luminance.

None of the studies include sufficient quantitative investigation of the contrast and visibility of the twine or the mesh under similar practical underwater light conditions such as known illuminance and angular distribution with precise zenith and azimuth viewing angles *etc.* All these are needed in order to predict the practical visual stimulus of the gear for fish behaviour. Therefore it was considered important that visual stimulus is examined systematically as brightness contrast or visibility for the various components of the towed fishing gear in order to define reference factors for the stimulus intensity in a gear and fish behaviour model as well as for behavioural experiments with fish.

2.3 Fish behaviour in towed fishing gear

The complexities of fish vision could be simplified in the context of the fishing gear and considered in relation to the three variables, brightness contrast and spatial resolution. The brightness threshold for vision demonstrates a lower light level limit for visual reaction. The brightness contrast threshold and minimum separable angle of a fish's eye varied with body length, background light level and water temperature within the range of photopic spectral sensitivity between 400 and 600nm (Douglas and Hawryshyn, 1990).

The brightness contrast threshold of cod (*Gadus morhua*) by Anthony (1981) and sunfish (*Lepomis macrochirus*) by Hawryshyn *et al.* (1988), was measured with changing background illuminance. The minimum brightness contrast thresholds have been measured as 0.003 for red colour wavelength to 0.007 for green light for blue gill sunfish by Hawryshyn *et al.* (1988), 0.006 for squid (*Todarodes pacificus*) by Siriraksophon *et al.* (1995) and 0.018 for goldfish (*Carassius auratus*) by Bilotta and Abramov (1989). However, most of the valuable fish species in fisheries have not been examined for contrast threshold and no studies relate threshold abilities to actual visual stimulus of the gear components.

Acuity or spatial resolution decides whether a fish can see or not see objects from a distance and is determined by the minimum separable angle and becomes important in visibility of fine objects such as twines or knots. The minimum separable angle for herring was related to eye size which was proportional to the body length (Blaxter and Jones, 1967). A study of tuna species showed acuity changing with background light intensity (Nakamura, 1969). The calculated angular acuities of fish by the focal length and the density of retinal cell are 2-7 arc min for mackerel or tuna (Tamura, 1957, Tamura and Wisby, 1963). Otherwise, behaviourally measured acuities are 4-8 arc min for tuna fishes (Nakamura, 1969) and minimum 3 arc min for herring (Blaxter and Jones, 1967).

However, the above measurements of minimum separable angle for fish were carried out using relatively bright light conditions. The visual sensitivity of fish by behavioural measurements may be influenced by the optical property of an object in particular underwater light conditions as well as experimental factors of behavioural conditioning (Douglas and Hawryshyn, 1990). These findings suggest that in general to estimate visual sensitivity of fish to the fishing gear, factors such as body length, background light level as well as factors determining visual contrast and size of the object must be considered.

Aquarium experiments investigating reactions of fish to the specific stimuli of fishing gear were performed for moving net by Nambiar *et al.* (1970a,b,c), Kushnarenko (1975), Arimoto *et al.* (1984), to moving chain by Park and Arimoto (1985), and to model towed gear by Blaxter *et al.* (1963) and Matuda *et al.* (1988). Most of these results however, showed limited and adapted response of fish behaviour within the particular experimental conditions.

Some basic concepts of fish behaviour such as optomotor response (Lyon 1904, 1909, Harden Jones, 1963) and escape (or defensive) response to fishing gear were suggested by Livingstone (1962), Hemmings (1969), Pavlov (1969) and Wardle (1983). Optomotor response was fully reviewed as rheotropism by Arnold (1974) and studied using mesh patterns in relation to fishing methods (Inoue and Kondo, 1972, Inoue and Arimoto, 1976). These two main responses were considered as fundamental behaviour of fish in the towed gear. However, these two simple concepts do not allow a full explanation of the more specific and complex responses of fish seen in their detailed swimming movements.

TV observations of trawls during fishing operations, form the foundation for most of our understanding of the behaviour of fish in trawls. They were mainly carried out at the Marine Laboratory, Aberdeen using the SIT TV camera used from ether a towed underwater diver operated vehicle vehicle (Main and Sangster, 1981, 1982a,b, 1983) or the Magnus rotor remote controlled (Wardle and Hall, 1994). By repeated collection of observations of fish reacting to fishing gears at sea, the behaviour of the fish in the towed fishing gear was analysed.

The ordered fish reaction behaviour patterns cease at light levels lower than 10^{-6} lux indicating that visual stimuli initiate and maintain the behaviour patterns (Glass and Wardle, 1989, Walsh and Hickey, 1993). The observed visually driven behaviour patterns are a combination of keeping clear of approaching objects (herding reactions), holding position relative to the gear maintaining a clear "safe" swimming space (optomotor response) or actively keeping clear of passing walls of netting (risk taking behaviour) while choosing the clearest path through the net (Glass *et al.*, 1995). The time spent reacting in these different ways is constrained by other factors such as locomotion abilities that limit the reaction behaviour and are known to depend on species, fish size and temperature (Videler and Wardle, 1991).

However the relationship between stimulus and response are changed by many external and internal variables which show as more complicated individual behaviour. Other valuable results have been obtained from field observations of swimming speed and endurance of fishes escaping from trawls by Korotkov (1970). Light level thresholds for behavioural response have been demonstrated for schooling fish such as described by Glass *et al.* (1986). The effects on fish behaviour of lowering light levels have been described by Glass and Wardle (1989). The schooling behaviour of fish when in the big meshes of a towed net are reported by Kawamura and Tabata (1990). Recent experiments to stimulate fish escapes from codends made use of controlled black and white contrasting patterns in the netting forming the appearance of an approaching preditory mouth and made use of the knowledge that the underwater view may be controlled when understood to form desired illusions (Glass and Wardle, 1995).

However such studies in general reveal changeable and complex behaviour of fish some results show linear change of response of the behaviour of fish to linear change of the stimulus of the fishing gear while other results point to no significant relationship between fish response and stimulus of the net.

The catch of a fishing gear is the result of the individual movements of each responding fish. There are many variables which alter these responses and they are a combination of internal factors of the fish and external factors of environment and gear (Wardle, 1995). Most of the published work as in the above experiments lacks quantitative definition of stimulus intensity of the fishing gear components as well as having limited analysis of quantitative behavioural responses such as the swimming speed or direction and these general findings were suitable only as guidelines towards a mathematical model of fish behaviour. A model soon reveals understanding of the principles of any mechanism and was considered to be a good test of any review of our relevant understanding.

2.4 A study of the visual stimulus of towed fishing gear

The fish reaction distances can vary enormously with factors such as light level visibility range, and physical properties that determine the visible contrast of objects against their background. In other words to predict the visual stimulus generated by a trawl the factors affecting the underwater view must be thoroughly understood.

At depths greater than 20-30m, objects become monochromatic and the main source of natural light (illuminance) is from directly above. Luminance is a measure of the amount of light reflected from the surface of an object in the direction of the observer (Arnold, 1976). Whether an object is seen or not is determined by its brightness contrast which is the difference between the luminance of the object and the luminance of its background. In some objects, like knots or floats large differences in luminance between two parts of the structure can generate high brightness contrast. The eyes of fish are as good as or better than those of humans in detecting small differences in brightness contrast. The brightness contrast threshold has been measured for cod (Anthony, 1981) and for squid (Siriraksophon *et al.*, 1995).

Under the sea, objects are viewed against a water background the luminance of which varies in an orderly fashion. The observer can be imagined as being within a sphere where the walls of the sphere show a symmetrical distribution from bright luminance above grading to dark below. The direction of observation within this sphere can be described by Zenith and Azimuth angles where zenith angle 0° is looking vertically up and zenith 180° is vertically down. The Azimuth is the compass bearing of the viewing direction. The symmetry of this spherical underwater luminance distribution may be tilted due to the zenith and azimuth of the sun and the geometry of the luminance distribution has been measured using a narrow angle photomultiplier in studies such as Jerlov (1976). The importance of this spherical symmetry is inherent in the evolution of vertical mirrors in fish scales which make pelagic fish invisible to predators from all viewing angles except from directly below and even more so in the bioluminescent lanterns of lantern fish that even eliminate their silhouette by an automatically graded light source that matches the background light from all angles (Denton *et al.*, 1985). The bright colours of twines when viewed at depth become different shades of greeny grey and when viewed against the graded water background luminance, their brightness contrasts vary with the viewing zenith angle (Wardle*et al.*, 1991). For example a white twine is more visible when seen against the dark background when looking downwards and less visible against the light background looking upwards.

Mainly in the context of making gill nets less visible there have been a number of studies investigating the visibility of nets to the human eye in horizontal sighting ranges in tanks (Inoue *et al.*, 1958, Mitsugi, *et al.*, 1964, Kajihara *et al.*, 1968, Tsuda and Inoue, 1972, 1973a, 1973b) as well as in the sea (Yajima *et al.*, 1962, Tsuda, 1975a,b) or using a video camera (Kobayashi *et al.*, 1987). These studies have had limited application in predicting the visual stimulus of the towed fishing gear to the fish in the sea, as they ignore the changing background luminance with zenith angle.

The present study reports development of a technique to make direct measurement of luminance from the surface of an object in one case in tank experiments and in another in towed fishing gears. The first is achieved by pointing a narrow beam photomultiplier at the component in tank experiments (Morinaga *et al.*, 1990, Nakamura *et al.*, 1991). Such measurements are not practical from positions inside a towed fishing gear but images of objects made by a camera are used after calibration of the image grey levels in tank experiments with both the camera and the photomultiplier measuring the same surfaces. By combining these techniques we were able to investigate the rules that determine the luminance of components of a fishing gear when towed in the fishing ground as well as the luminance of the backgrounds against which a fish would observe the same items. This then allows prediction of the brightness contrast of the components in any gear specification as seen by a fish from any defined position, and in any underwater light level and underwater quality. This work was concurrent with the ALTSTIM project supervised by Dr. C.S. Wardle. The work was directed very much in line with the project and reviewed the subjects of the stimulus to fish in trawl capture in order to find the rules that would allow a predictive model. The relevant terms for description of underwater light and their meaning are discussed and defined with diagrams in Arnold (1976).

2.4.1 Materials and methods

2.4.1.1 Principle of contrast estimation by image processing

The optical contrast has been defined generally as the ratio of object luminance (Lo), which is a measure of light level, to background luminance (Lb) as in the following two equations (Duntley, 1963, Hecht, 1988):

$$C_1=(Lo-Lb)/Lb \qquad (2.1)$$

$$C_2=(Lo-Lb)/(Lo+Lb) \qquad (2.2)$$

The difference between the above two equations is the limit of the contrast values, which is $-1<C_1<\infty$ or $-1<C_2<1$. The equation (2.1) has been mostly adopted in optical visibility and underwater contrast as well as in this study.

There is a potential equation for the underwater contrast formulated by Duntley (1963) on the assumption of which daylight radiance underwater has a relatively homogeneous optical property within a sighting range. The apparent contrast (Cr) was decreased by the distance SA between object and observer, the beam attenuation coefficient c and the vertical attenuation coefficient k where zenith angle ZA, azimuth angle AZ, depth at observer yo and depth at target yd (Refer to Fig. 39 in Jerlov, 1976).

$$Cr(yo, ZA, AZ)=C0(yd, ZA, AZ)* \exp\{-c*SA+k*\cos(ZA)*SA\} \quad (2.3)$$

C0 is called inherent contrast when zero distance SA=0 or c=k*cos(ZA) theoretically. It is also possible to estimate the visibility as a distance SA when Cr is the contrast threshold of the observer if an object has nearly Lambert reflectance (Ditchburn, 1976).

If the fishing gear could be detected visually by fish in relative darkness during fishing operations, it must differ photometrically from its background luminance in the direction of view. The minimum value of detectable difference of luminance between an object and background was the so-called contrast threshold of fish vision. It must be noted that direct measurement of luminance of nets in deeper fishing grounds is very difficult and impractical at the moment. In addition to that, the measurements of luminance in a water tank also have shortcomings of differences in the distribution of background luminance and in viewing angle.

The "Silicon Intensified Tube" (abbreviated SIT) underwater video camera is the most useful equipment for visual observation even in darker conditions or deeper water with the light sensitivity down to 5×10^{-3} lux. It has automatic iris control and gamma correction using mean video signal within certain limit of light intensity. That means the contrast and the brightness of an image can be represented as constant values although the surrounding light is changed. However, if video signal per unit area in a video image is varied linearly with the change of light intensity, luminance distribution of the target must also be related to the video signal intensity. The video signal intensity can be converted to grey level by computer image processing. It has already been proved that the grey level represented luminance in human vision studies (Kingdom *et al.*, 1987).

The estimation of luminance for nets and their surroundings can be achieved by the linear relationship between the grey levels of the video image and the luminance of the target within a certain range of light intensity. Similarity of image condition between the field and the calibration tank is also required in luminance distribution and optical property of the water.

2.4.1.2 Calibration of photomultiplier

A larger photomultiplier with cosine collector (Thorn EMI Electron Tube 9804B, sensor diameter 52mm) and two identical smaller photomultipliers (Thorn EMI Electron Tube 9124B, sensor diameter 30mm) with sensing angle about 80° were calibrated using the standard NPL light source with neutral density filters in the dark room. The smaller photomultipliers were converted to micro-luminance meters. This was done by mounting a reflex Angenieux 12-120mm type 10x12A zoom-lens set at 120mm and f2.8 so that it focussed the image of a small area of the test object onto a slit in a black disc fitted to the sensitive window of the photomultiplier. The use of the switchable reflex viewer in the Angenieux zoom lens allowed the operator to fill the sensitive area with the image sample. A slit of 3x5mm gave an acceptance angle of 1.3x2.3° and was used in the glass aquarium experiments and a 3x3 mm slit gave an angle of 0.9x0.9° and was used in the concrete tank experiments. Using the micro-luminance meter the measured relative incident luminance and relative object luminance can be presented as calibrated illuminance (lux) when divided by π (steradian) (Arnold, 1976).

The relationship between the light intensity I (log lux) and output voltage V (volt) of the photomultiplier are as follows:

Larger photomultiplier:

$$I_1=13.466-15.9397*V+7.2698*V^2-1.7308*V^3+0.1645*V^4 \qquad (2.4)$$

Micro-photomultiplier A:

$$I_2=6.7137-0.02729*V+3.3056E\text{-}3*V^2-1.9837E\text{-}6*V^3+4.4316E\text{-}10*V^4$$

(without slit and zoom-lens)

$$I_3=7.0610-0.01627*V+1.1171E\text{-}3*V^2-2.9338E\text{-}7*V^3 \qquad (2.5)$$

(with slit and zoom-lens), where E-10 means: $* 10^{-10}$

Micro-photomultiplier B:

$$I_4=9.5067-10.0836*V+3.2796*V^2-0.3954*V^3$$

(without slit and zoom-lens)

$$I_5=8.3141-6.1808*V+1.6159*V^2-0.1771*V^3 \qquad (2.6)$$

(with slit and zoom-lens)

2.4.1.3 Calibration of SIT camera

All video images were made using an underwater SIT TV camera (OE 1321, Osprey Electronics Ltd) with the angle of view 100x75° and were recorded on SVHS format tape using a Panasonic AG-6720 video recorder (Matsushita Communication Ind. Co. Ltd). Views of towed fishing gear were achieved with the camera mounted on a pan and tilt slung under the towed underwater Magnus rotor vehicle as described by Wardle and Hall (1994).

In order to calibrate the SIT TV camera, images of a 9 steps standard grey chart (27.0 x 5.5cm (reflectance 2.2, Vertex Video Systems) were recorded at 7 light levels and simultaneously luminance was measured from the 9 grey levels. The standard grey chart was fixed vertically in front of a screen of green fabric immersed in a glass aquarium. The aquarium tank (length 1.8m, width 0.6m, depth 0.6m) was positioned in a dark room. The TV camera and the micro-luminance meter A were positioned as in Fig. 2.1, and the other three tank sides were screened by sheets of dark grey paper.

Illumination from a spotlight (Prelude, 240V, 650W) 1.5m above and 1.5m in front of the object target (*i.e.* in a direction 45°) and two bulbs (240V, 25W) were positioned to evenly illuminate the background screens. All the lamps were fitted with dark green filters (Strand, Chromoid 124, peak wave length 521nm, >50% transmission wave length between 495 and 550nm). The arrangement is seen in Fig. 2.1. The lighting intensity was controlled in 7 steps within the range of 0.004 to 9.456 lux and was measured by a calibrated larger photomultiplier. The beam attenuation coefficient of filtered sea water in the glass tank was 0.37/m, measured using a 25cm Transmissometer (Sea Teck Inc.).

2.4.1.4 Measurement of luminance of trawl components in a water tank

The experiments were carried out in a light proofed concrete water tank (L =1.6m, B=1.5m, D=1.5m) with glass observation window 1.3x1.0m in the front wall. The sample objects were set in the centre of the tank 75cm from the window glass and at a distance of 70cm from the tank bottom. Heavier test objects were hung from a beam and floats were held in position by a 9kg iron weight as shown in Fig. 2.2.

The underwater light source (120V, 500W) was mounted in an adjustable aluminum frame, so that it was always at a distance of 50cm from the test object but the direction of illumination (B, Fig. 2.2) could be adjusted through 5 steps, 0, 45, 90, 135 and 180°. The light was filtered in order to match sea water colours, using dark green (Chromoid 124) or peacock blue (Chromoid 115, peak wave length 480nm with 62%

transmission). The micro-luminance meter B with a slit of 3x3mm was positioned outside the window of the tank set to view horizontally. The intensity of incident light at 1.5m from the light source could be controlled from 0.025 to 94.248lux (position B=0°, without object, Fig. 2.2). The beam attenuation coefficient of the sea water in the tank measured by the 25 cm transmissometer was 0.48/m.

White Polyamide (PA) twisted netting twines were dyed with seven colours of fabric dyes (Dylon multipurpose, Dylon International Ltd). The diameters of the Polyamide (Nylon, PA) twisted twines after dying and the Polyethylene (PE) twines both twisted and braided forms were measured using optical thickness equipment (Ferro, 1989) and the twine specifications are detailed in Table 2.1.

The twisted rope samples were made 2cm in diameter using the same colours of twisted PA twines (see Nos 41-48, Table 2.1) and PE twines (Nos 55 and 57, Table 2.1). The 10 samples of ropes (length 10cm) were packed close together on a flat aluminium plate (10x10x20cm) and mounted vertically. The four colours of floats with diameter 19- 20 cmwere white, yellow, orange and silver. The two black rubber bobbins were one disc type (24.6x6.4 *cm* diameter and height) and one cylinder type (12.5x16.5cm) as well as a rusty iron beam (7x7x27cm). The standard grey chart (Vertex Video System) was used to calibrate these measurements. Luminance was measured from small sample areas of each rope, float, bobbin, iron beam and reference areas of the standard grey chart for each light level and illumination angle.

2.4.1.5 Recording TV images of netting panels in the sea

The sample netting panels were constructed with 10cm meshes, each sample comprising one Weaver's knot and four bars for each colour and twine diameter by melting end to end. Four sample panels each with 4x3 or 4x2 meshes were stretched with the hanging ratio 0.71 onto steel wire (5mm) frames (50x40cm) as shown in Fig. 2.3. Each frame was fixed in turn at a distance of 25cm in front of the SIT TV camera as shown in Fig. 2.4.

The SIT TV camera was mounted on the shaft of a 12V DC motor so that it could be swept to point in directions from zenith zero to 180° at 0.12rad/sec. The zenith angle indicator, made of a steel strip, notched at each 10°, was fixed in order to be seen at the right side of the video image. The camera and other apparatus were all mounted in a steel frame with a stabilizing rudder and 10kg weight.

Recordings were made at each 10m depth from 30 to 80m by sweeping the camera from upward to downward and to upward again (*i.e.* zenith angle 0-180-0°). At the same time, the illuminance (by photomultiplier with cosine collector) and the beam attenuation coefficient (by Transmissometer) were recorded by time synchronised data logger (Chelsea Instruments CTD, ICL 7109). The background luminances were measured as directional illuminance by a smaller photomultiplier A (without cosine collector, about 80° acceptance) mounted in place of the camera and swept through 45° zenith steps from upward to downwards with reference to an electric-resistance inclinometer.

The experiments were carried out between the Orkney Islands and north of the mainland of Scotland on the FRV Clupea during 1-9 February and 8-24 July 1994 and the main features of the experimental conditions are shown in Table 2.2.

The trawl chosen for these tests was the BT 130 C North sea bottom trawl as described in Corrigall and Watson (1977). The video images of the BT 130C bottom trawl, with the backgrounds of water, sand cloud or sea bed, were recorded on the FRV Clupea during 8 to 24 July 1994 and 30 January to 13 February 1995. The SIT camera was carried by the remote controlled Magnus rotor vehicle as described by Wardle and Hall (1994). During filming light data was collected every 1 second into a time synchronised Aqua-data logger (Chelsea). The light level from the same directions was measured by the smaller photomultiplier B fixed parallel and on top of the SIT TV camera and the water turbidity was measured by the Transmissometer on the towed TV vehicle. The brightness contrasts of the trawl components were estimated by the same image processing technique and pixel grey level evaluation and were corrected for the observing distance and beam attenuation coefficients at the different locations.

2.4.1.6 The estimation of brightness contrast by video image processing.

All TV images were analysed by DT 3851a-8 Image Grabber Board and GL LAB Image ver. 2.2 Image Processing Software (Data Translation Inc.) with a PC (DEC 466 D2 DT). TV frames recorded on SVHS Tape were selected, transferred and analysed as single frames. The optimum format for image input was selected as gain 1.0, offset 10, reference 505, frame average 1 (refer to the manual by Data Translation Inc., 1993). The median filtering method of the software was used in order to reduce the unnecessary "noise" of the image and to achieve a more uniform grey level of the underwater background (Sidiropoulos *et al.*, 1994).

Under this set up, every grey level in all of the netting images fell within the scale range of 0-255. One image consisted of 640 (horizontal) by 480 (vertical) pixels. The actual length resolution of the image was 0.94-0.98mm/pixel (horizontal) by 0.78-0.81mm/pixel (vertical) when the twine was at a distance of 26.5-28.0cm from the camera window. The relative luminance value L (*i.e.* illuminance lux/π steradian) and grey level GL in an image of the 9 steps grey chart with 7 steps of horizontal illuminance (Ih) are shown in Table 2.3. The relationship between luminance L and mean grey level GL can be expressed linearly as the following 3-order polynomial equation with No. of data 9 and correlation coefficient $r > 0.999$:

$$L(GL)=E_0+E_1*GL+E_2*GL^2+E_3*GL^3 \quad (2.7)$$

The coefficients E_0-E_3 as shown in Table 2.4 change according to the horizontal illuminance Ih (lux) as in the following equation:

$$E_0\text{-}E_3(Ih)=i_0+i_1*Ih+i_2*Ih^2+i_3*Ih^3 \quad (2.8)$$

The coefficients i_0, i_1, $_2$ and i_3 of equation (2.8) are shown in Table 2.5.

The grey level data was collected from the images of the twine and knot samples near the centre of the TV frame. More exactly all pixels positioned between 300 and 350 pixels from the left side edge and 150 and 200 pixels from the top edge of the TV frame were sampled including object areas and background. The background luminance was corrected to the value measured by the photomultiplier at the same zenith angle. Pixel grey values within the knot or twine images deviate from the grey level of the background. The maximum value of this deviation was taken to calculate the relative luminance values.

In equation (2.3), a luminance correction factor (CB) allows for the difference of beam attenuation coefficients in the tank (cw) and in the sea (c) and the target distances in tank (S1) and sea (S2) as follows:

$$CB=\exp^{(cw*S1)-(c*S2)} \quad (2.9)$$

The luminance (L) values are converted to the relative luminance at the position of the SIT TV camera window by L*CB using a developed FORTRAN programme.

2.4.2 Results

2.4.2.1 The contrast of the trawl parts by video image processing

The relative luminance Lr of the ropes, floats, bobbins or grey chart increased with the relative incident luminance of the light source Ls as described by the following power equation with the reflectance factor (Pr) and power np equal to the relative luminance (Lr) when Ls=1:

$$Lr=Pr*Ls^{np} \tag{2.10}$$

2.4.2.2 The contrast of the floats

Values for Pr measured from the brighter zone of 4 colours of floats in the tank experiment (refer Fig. 2.2) using dark green filter are related to relative viewing angle B in Fig. 2.5. The values of Pr and power n which were calculated by the least square method with light levels and correlation coefficient r>0.95 were little different between dark green and blue filter. The relationship between Pr and B can be represented as follows:

$$Pr=a_0 * \sin^{a_1}(B/2) \tag{2.11}$$

The mean value of power n of equation (2.10) and coefficients a_0 and a_1 of equation (2.11) are shown in Table 2.6 with colour of the floats and light filters.

The reflectance p defined as the ratio of the reflected luminance Lr to the incident luminance Ls (Arnold, 1976, Wyszecki and Stiles, 1982) can be applied to unify these light measurements of the trawl components as follows:

$$p=Pr*Ls^{(np-1)} \tag{2.12}$$

When Ls is equal to or greater than 100, the estimated reflectances of the grey reference panels (Vertex Video System) closely approached the values of the manufacturer confirming the practicality of estimating the reflectance values of the trawl components. The inherent contrast C0 of an object with a known reflectance factor p can therefore be deduced from the equation (2.1) as follows where Lb is background luminance and Ls is underwater downwelling luminance and Ls=Lb when relative viewing angle B=0:

$$C0=(p*Ls/Lb)-1 \tag{2.13}$$

The luminance distribution of the spherical float varied with the relative viewing angle. For example with illuminance from above, increasing the zenith viewing direction from 0° (looking up at the float) to 180° (looking down at the float), the brighter zone of the float moves from one edge towards the centre, while the darker zone moves from centre to one edge. The reflectance factor Pr of the white and silver floats increased with the viewing angle. Whereas, yellow and orange floats show a slight decrease as the viewing angle passes 90° also found by Duntley *et al.* (1964).

The apparent contrasts Cr (see equation (2.3)) of the images of floats, bobbins and otter board taken from TV film of the BT130C trawl gear are estimated at known observation distances (S) by the image processing technique and are shown in Fig. 2.6.

The yellow and the orange floats (diameter 20cm) at the head rope of the BT130C trawl were observed with the range of estimated zenith 30° to 150° at the depth 50 to 75m.

The inherent contrast (C0) was approximately calculated as a 1st order regression line using only the observed distance against the apparent contrast. The yellow float gave a positive inherent contrast value of 2.4 (within the range of zenith angle 140-160°) and a negative value -0.6 (30-40°), and for the orange float values of 0.95 (130-150°) and -0.75 (40-50°) as from Fig. 2.6. These calculated positive inherent contrast values for the floats are only slightly higher than the values estimated by the reflectance in the tank measurements.

2.4.2.3 The contrast of the bobbins

The tank measurement of reflectance factor Pr of the black rubber bobbins and dark brown rusty iron are plotted against relative viewing angle in Fig. 2.5. They show a lower range of Pr 0.01-0.03 (with a mean power n=1.065) than floats and are close to the reflectance of similar colours of enamel paints (Wyszecki and Stiles, 1982).

In the field observation, the black rubber bobbins (diameter 15cm and 38cm) were viewed near the quarters and in the centre of the ground rope of the trawl, both were recorded from a position dead ahead in its towing path while viewing in the direction of the codend. Using the image processing method, the apparent contrast (Cr) of the black bobbin in the ground rope was calculated when seen against either the sand cloud or sea bed background. The negative values of the 6 inch and 15 inch tyre bobbins were observed at around 100-130° of zenith angle as shown in Fig. 2.6.

The sand cloud background luminance is brighter than the sea bed background luminance. Consequently, the values for apparent contrast (Cr) of the bobbin seen against the sand cloud is greater than that seen against the sea bed. The inherent contrast (C0) of the bobbin at viewing zenith angle 100-130° can be estimated from the value for apparent contrast (Cr) against sand cloud background at the same viewing distance with a negative value of -0.92 for the small bobbin and -0.99 for the large bobbin. The contrast of the bobbin viewed from directly above, *i.e.* zenith 180°, can be expected to display little variance from the result when viewed horizontally because the reflectance of the black rubber was very low regardless of the relative angle of the light beam and observer. Also, the luminance of the sand cloud and sea bed showed little change from downwards to horizontal view.

2.4.2.4 Otter board

The V-shaped rectangular brown otter board (2.7x1.35m) used with bottom trawl BT 130C was filmed horizontally in a starboard direction from a point between the towing track of the two otter boards. The apparent contrast of the brown otter board was estimated by image processing both for the case where the brighter zone of the board image is seen against its own darker zone as well as where the board is seen against the sand cloud or sea bed backgrounds. The latter 2 cases are shown in Fig. 2.6. The maximum apparent contrast is found as a negative contrast between the darker zone of the otter board and brighter background of its own sand cloud while a minimum apparent contrast value can be derived from the darker zone of the otter board viewed against the sea bed.

The inherent contrast of the darker zone of the brown otter board viewed nearly horizontally gave a negative value of -0.42 against the sea bed and -0.89 against the sand cloud. The above values for inherent contrast of the otter board were close to the estimated value by reflectance of brown paint when the otter board is in an upright posture.

2.4.2.5 The contrast of the ropes

The reflected light values from the coloured rope samples were measured in the concrete tank (refer Fig. 2.2) using the special micro-luminance meter B. The values for Pr and np in equation (2.10) of 10 samples of rope at the viewing zenith angle 180° are greater than those at 135° as shown in Table 2.7

Most of the values for Pr of the ropes under green filtered light are similar or slightly larger than those under the blue filtered light. The estimated values for inherent contrast of the rope sample derived by equation (2.13) showed values lower than those for the knots measured by the video image processing techniques. The reason is that an object area of 1.5x1.5cm is sampled by the 120mm lens of the micro-luminance meter B with a 3x3mm slit so that the sampled image of a rope of 2cm diameter includes both light and dark zones of its rough surface structure.

2.4.2.6 The contrast of the sand cloud

TV images of the sand cloud thrown up by the otter board were recorded at points near the wing tip and at other points nearer and at the otter board and with the same horizontal viewing direction as for the otter board. Images of the otter board sand cloud show 2 extremes of luminance with a shadow zone at the base of the cloud and a bright scattering zone at the upper edge of the cloud. The sea bed was always brighter than the shadow zone of the sand cloud. The relationship between the apparent contrast of the sand cloud CSr and horizontal background illuminance Ih (*lux*) can be represented in the following equation:

$$CSr = CS_0 + n_1 * \ln(Ih) \qquad (2.14)$$

The coefficient CS_0 was approximated as -0.416 within the sand cloud and as -0.452 for sea bed to sand cloud, and slope n_1 as 0.108 and 0.085 respectively. This apparent contrast is considered as varying with an irregular period due to the sand cloud swirling movement. The inherent contrast of the sand cloud could be approximated from linear change of the apparent contrast against estimated observation distance of about 3-4m.

2.4.2.7 The contrast of the net by video image processing

The image processing technique picks the pixel grey values with the greatest deviation from the water background value. The relative luminance of the different coloured PA and PE twines were measured by the video image processing technique from recordings made at different water depths, light intensities and zenith angles (refer Fig. 2.3, 2.4). In general the coloured twines viewed in underwater, monochromatic light against the underwater background were seen as darker (*i.e.* as silhouettes) when viewed from below (*i.e.* zenith angle 0) and when viewed from above all but the darker colours become brighter than the background. The black, red and dark green twines (Table 2.1) do not become lighter when seen from above.

2.4.2.8 The luminance distribution by the pixel of the netting image

In pale coloured knots, viewed against the water background, there is a small threshold range of zenith angles where both negative and positive contrast can be sampled within one image (zenith angles 70-100° in PA white and PE glow white, 80-110° in PA and PE green, 110-130° in PA yellow and blue, 120-140° in PA and PE dark blue and 140-180° in PE orange and braided blue) whereas there is only negative contrast in black, red and dark green regardless of zenith angles. An example of a white PA knot viewed in a direction of 80° zenith is shown in Plate 2.1 as video image and Fig. 2.7 as converted luminance. In twines the range of viewing angles, for the coexistence of negative and positive contrast, was relatively narrower than that of the knot and decreased with thinner twine.

Downwelling light is reflected as a highlight at certain points where strands of a twine pass through a horizontal position or where twines of a knot bend through the horizontal, whereas shaded zones can occur at the underside of the same point. There is a higher contrast between highlight, high luminance zones and shaded, low luminance zones in pale coloured twines. A twine placed diagonally or vertically shows a lower range of luminance values with less self contrast and is therefore less visible than a twine placed horizontally with greater self contrast. The knot with its more complex surfaces has more glint or higher self contrast with increasing zenith angle.

2.4.2.9 The contrast variation of the netting image with zenith angle

The inherent contrasts (C0) of the netting twine and knot were estimated for each 10° of zenith angle (ZA) from upwards 0° to downwards 180° by the equations (2.1) and (2.3) as converted relative luminance of the net and background. Fig. 2.8 shows an example of the effect of zenith angle change on the inherent contrast of a knot. The values are calculated from both the maximum and minimum luminance of the pixels in a knot image and the mean luminances of background between 2 meshes. The relationships between the inherent contrast C0 and zenith ZA can be expressed as follows:

$$C0 = b_0 * \sin^{b1}\{(ZA - Z_0)/2\} \qquad (2.15)$$

where Z_0 is zero zenith angle such as $Z_0(+)$ when $C0 \geq 0$ and $ZA > Z_0(+)$ as positive contrast or $Z_0 = Z_0(-)-360°$ when $C0<0$ and $ZA+Z_0(-) \leq 180°$ as negative contrast as shown in Table 2.8. The above equation could represent two forms of contrast such as negative and positive contrast according to the definition of equation (2.1). The range of zenith angle in equation (2.15) is valid only either when the negative contrast is between -1 and 0 or when the positive contrast is greater than 0.

A comparison of the viewed contrast of different materials and the effect of light intensity is shown in Fig. 2.9 as an example of the relationship between the white PA knot luminance (Lk) and the background luminance (Lb) plotted for 5 steps of the zenith angle 0°, 45°, 90°, 135° and 180°, and represented as a power equation as follows:

$$Lk=L_1*Lb^n \quad (2.16)$$

where L_1 is knot reflectance factor, n is power and $Lk=L_1$ when Lb=1. The L_1 and power n of equation (2.16) were calculated for combination of 8 colours and 4 twine thicknesses with each No. of data between 12 and 24 and r>0.99. It was notable that the values of L1 were changed by the twine diameter Dt (mm) as shown in the example of PA white twine in Fig. 2.10 and can be represented with slope Ld and power m as the following equation:

$$L_1=Ld*Dt^m \quad (2.17)$$

The mean value of power n of the equation (2.16) and the coefficients Ld and m of the equation (2.17) with colour and zenith are as shown in Table 2.9.

The apparent contrast of the knot in equation (2.1) can be converted from equation (2.9) and (2.16) as follows:

$$Cr=L_1*Lb^{(n-1)}-1 \quad (2.18)$$

In equation (2.18), negative contrast is represented as n<1 and $L_1<1$, and positive contrast as n>1 and $L_1>1$. The inherent contrast (C0) of the knot with 5 steps of zenith angle can be transformed by the equation (2.3) and equations (2.16 -18) substituted by the attenuation value of BA=exp(-c+k*cos(ZA))*SA at underwater light observation as given in Table 2.10. Then, the inherent contrast of the knot can be expressed as follows:

$$C0=\{L1*(Lb^{n-1})-1\}/BA=(Ld*Dt^m*Lb^{n-1}-1)/BA \quad (2.19)$$

The inherent contrast can be predicted from C0 in equation (2.19) for every 45° of zenith angle and also allowing for the variation of the C0 in equation (2.15). Another form of the contrast equation (2.15) can be established with zenith angle by replacement of C0 in the equation (2.19) at certain zenith angles with the coefficients b0 and b1 which can be calculated by at least two equations (2.15) by substituting 2 or more steps of zenith angle in a positive or a negative contrast range by Table 2.8.

2.4.3 Discussion

An indirect method of luminance measurement was developed by Smith *et al.*, (1970) using a film camera with fish eye lens underwater. They showed that the density of an area in a developed film negative, which was related to the exposure of that area, was also related to the field radiance, after comparison with measurement by photo-multiplier. With the development of computer image processing, Williams and Cogan (1991) have defined the contrast in the atmosphere as a ratio of reference pixel luminance of an object to background from a satellite image. This method also finally yielded the possibility of visibility estimation using the contrast of a reference image pixel. Both the above methods could provide a clue to the estimation of luminance and contrast of nets underwater, using the video image processing.

The reflectance factor Pr of the floats in equation (2.10) recorded with the green filter are similar or slightly larger than those using the blue filter. Most of the reflectance factor (p) values calculated by equation (2.12) with relative luminance of Ls=100 are quite close to those measured for enamel paint with similar colours by standard optical methods (Wyszecki and Stiles, 1982). The slight differences in the calculated values of p might arise from the different light intensity, beam angle, surface state of the sample, sensing area and viewing geometry.

The inherent contrast Co of the float estimated by using the Duntley's equation (2.3) with apparent contrast Cr derived from the image processing, does not fit well with the results from the observations in the concrete tank. The assumption in equation (2.3) is that underwater light has a relatively homogeneous optical property within a sighting range in a stable midwater situation. This is no longer suitable due to the proximity of the sea bed and sand cloud since coefficients c and k could be varied within the sighting range and these were adapted in another equation by Hojerslev (1986). Also, the viewing distance is only 27 cm in the image calibration experiments and much longer viewing distances are involved in the field observation. There are also complex effects caused by attenuation coefficients and automatic video signal correction of the camera.

Above all these equations include no conceptions of area and luminance variation in an object and background. For these reasons, Hodara (1973) has pointed out that the definition of optical contrast is an ill-defined quantity. Many authors proposed other definitions of contrast for the complex analysis in vision research such as local contrast (Reid and Shapley, 1988), motion contrast (Zhang *et al.*, 1993). However, the contrast value in this study can be simply expressed as a function of viewing geometry as well as of water properties. Future studies on the light scattering of the sand cloud during trawling operations should involved precise field measurements and include theoretical approaches such as those in the theory of light scattering by particles (Barber and Hill, 1990).

The unevenness of the water-background-luminance distribution was also observed in the experiments observing a zinc-plated wire snood placed vertically and viewed horizontally in a tank by Nakamura *et al.* (1991) and also illustrated by Wardle *et al.* (1991) for monofilament nylon and a silvered cylinder. The brightness contrast determines the strength of the visual stimulus and the contrast can be either a luminance difference within an object or between an object and background. An uneven structure within an object may generate high self contrast allowing it to be more easily detected than a smooth object (Reid and Shapley, 1988, Bowen and Wilson, 1994). It is desirable that the knot contrast in the threshold range of viewing zenith angles is represented by both maximum and minimum luminance values of the object.

The zenith angles at which there is coexistence of negative and positive contrast could also be changed by the sun's altitude and azimuth angle, by the radiance polarization and by Snell's circle. However, these effects are small and are decreased with increasing depth and cloud cover (Tyler and Shaules, 1964). In addition, the values of contrast for the four twine bars of a netting mesh are significantly different as also pointed out by the result of Tsuda (1975b). A knot is usually more visible than twine when looking upwards and downwards (Mitsugi *et al.*, 1964, Tsuda and Inoue, 1973a, Tsuda, 1975b).

The luminance values of knot L_1 in Equation (2.15) varied with the projective area or the surface area of the Weaver's knot which is assumed proportional to the twine diameter by the measurements of Imai (1983, 1984a,b). The inherent contrast of the knot is changed linearly with the diameter just as found for the luminance in nylon monofilament (Nakamura *et al.*, 1991).

There are some published reports of inherent contrast measurement made when viewing horizontally with bright downwelling light in tank experiments. These showed a value of 0.7 for 0.5mm blue monofilament nylon (Tsuda, 1975a), 1.1 for 2mm nylon monofilament and 6.3 for 1.7mm wire snood (Morinaga *et al.*, 1990). Those results are however difficult to compare with the present experiments because of different materials and lighting conditions and background.

The visibility to a fish of the brightly reflective areas in the net would seem to be related to the size of the objects, and spatial acuity of fish vision (Douglas and Hawryshin, 1990, Cui *et al.*, 1991). The visibility of an object is increased with the zenith angle and light intensity as well as diameter of the twine and even more so when involving strong positive contrast. On the other hand, a resolvable image of visible net components is decreased by lowering contrast. Due to these effects, the apparent size of the images of net components as interpreted by the eye are less than the actual measured size of the twine or knot at lower contrast and may be more than the actual size at higher positive contrast. This must be considered when estimating the maximum range at which a fish using the spatial acuity of its eye might detect the object (Zhang and Arimoto, 1993). The results of published measurements of human eye visibility threshold for twines and knots in the sea (Yajima *et al.*, 1962, Tsuda, 1975a,b) roughly agree with the calculated visibility threshold from equation (2.18) and (2.19) with the similar zenith angle and the brightness contrast threshold of the human eye.

2.4.4 Summary and conclusions

The brightness contrast of the netting and other components of the trawl gear are studied in different conditions by comparing their luminance to that of their visual background of water, sand-cloud or sea bed. Luminance of each component was measured directly with a micro-luminance meter in controlled tank experiments and by computer processing of TV images of twines and whole gears recorded in the sea with precise calibration of light intensity and grey levels. The brightness contrast of 3 dimensional components can involve self contrast between bright (+ve contrast) and dark zones (-ve contrast) of the structure. The brightness contrasts of floats, bobbins and otter board are increased with light level and relative viewing angle in both tank and the sea observations and can be defined by their self reflectance ratio.

The brightness contrast of pale coloured twines and their knots was negative when viewed upwards while positive when viewed downwards and at some intermediate angle they match the underwater background and are least visible. The positive contrast of the knot was linearly increased with increasing diameter of the twine, background luminance and zenith angle whereas the negative contrast was decreased with background luminance and zenith angle. The contrast of sand cloud between its own darker and brighter portions was decreased with light intensity and density of particles. This study shows that the visibility or intensity of the visual stimulus of any part of the gear can be predicted by defining an equation with its reflectance coefficients in the underwater light field. These results may be applied in modelling the relative intensities of the visual stimuli that surround a fish swimming at any position within the towed fishing gear. It is recommended to carry out further investigations into the practical control of colours and materials used in nets etc. as visual stimuli possibly in conjunction with water flow, which at the moment is very much left to chance by fishermen.

2.4.5 Acknowledgements

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6.4.2 Electrical Stimulation

6.4.2.1 Marine Teleosts

McK.Bary (1956) describes reactions of fish to increasing electric stimuli. He classifies them as follows:

i. minimum response,
ii. electrotaxis,
iii. electronarcosis.

The minimum response consists of a jerk of the musculature at the make or break of the current. The DC field strength required to elicit this response varies with the orientation of the fish to the electric field; the voltage required for fish held with their heads pointing towards the anode was double that required for fish pointing towards the cathode. It was also found that the required stimulus for fish held with the longitudinal axis of the body varied between species. For the mullet (*Mugil auratus*) the field strength required was greater than for flounder (*Platichthys flesus*). This was considered to be due to the longer length of the segmented nerves in the flatfish (flounder) resulting in increased sensitivity in this orientation.

Electrotaxis (or 'forced swimming') is a reaction of fish to increased DC electric field strength. The fish swim in a direction relative to the electric field direction; the fish swim towards the anode and away from the cathode. Fish orientated at right angles to the current may curve towards the anode (Lamarque 1967). Studies cited in Lamarque (1967) suggest that flatfish do not exhibit this reaction - they simply flatten themselves against the bottom of the tank.

The state of electronarcosis is described by McK.Bary (1956) as *"......... respiratory movements cease, the opercula flare widely and the fish becomes rigid and then sinks"*. Lamarque (1967) describes further subdivisions of the response of fish to electrical stimuli and discusses the physiological explanations for these observations.

The characteristics of the electric field has an important bearing upon the magnitude and type of the response observed. Pulsed DC was found to elicit responses at lower field strengths; thus this is considered to be the best stimulus for electric fishing. However, Lamarque (1967) points out that certain reactions are missing for interrupted current, and suggests that interrupted current affects spinal or medullary structures only.

However, with the present strong interest to reduce any adverse environmental impact of fishing gears, the concept of electric fishing has new potential. New research activities should focus on reducing the physical impact of trawled fishing gear on the sea bed. This could be achieved in beam trawls particularly when the heavy tickler chains or chain mats can be replaced with electrodes, which are lighter in construction. But also the design of the whole trawl could be reconsidered. A better length and species selectivity might be obtained for target species with considerable reduction in by-catch.

6.3.4 Work done in france

In France, already in the early sixties, studies were carried out to find methods for alternative stimulation to catch fish. Most of the effort was put into a system where fish were attracted by light and forced to move towards a pump by means of an electric field. At some stage in the development a co-operation was established with Poland. Most studies included a lot of basic research into the behaviour of fish in electric fields. Based on this knowledge the specifications of a system which could be commercially used for pelagic fish were defined. The advantages of this method would be a high catchability and a sharp length selectivity.

More details are given in the abstracts of the French reports on electric fishing.

6.4 Work done in the UK

6.4.1 Introduction

This review presents background information on the physiological responses of fish and crustacea to electric fields. It describes the studies predominantly carried out by White Fish Authority (WFA) and the Sea Fish Industry Authority on the use of electrical stimulation in marine fisheries and discusses them in terms of environmental effects of fishing. The studies predominantly took place between 1976 and ended in 1986, included investigations into the use of electric fishing on beam and otter trawlers. Refer Tables 6.5-6.11 and Figures 16-22.

The aim of most of these studies was to reduce fuel consumption per unit catch of fish which was considered to be of importance during a time of high inflation in energy costs.

This review was carried out under European Community concerted action project Alternative Stimulation in Fisheries co-ordinated by RIVO-DLO.

6.3.2.2 Electro otter trawls

A basic study was made on the reaction of Norway lobster towards electric pulses. Different pulses, pulse lengths, frequencies and tensions were tried out. The trials were done in an aquarium where the environmental conditions of Norway lobster grounds were imitated as close as possible. It seemed quite easy to stimulate the prawns and it was clear that larger prawns reacted sooner to the pulses than smaller ones. The most efficient stimulation pattern was determined with the aim to apply electric pulses to a commercial otter trawl (Figure 15). The system applying electrified ticklers, already often tried out on beam trawls, was now tested on an otter trawl on a commercial vessel. The electrified otter trawl has a higher catchability for sole. It also had improved selection characteristics, with smaller ctaches of undersized fish and larger ones of fish with lengths above the minimum landing size. Alternating positive and negative pulses were used in order to reduce the electrolysis effect. The results indicate that in this case catches are higher compared to the pulses derived from direct current. As previous studies indicated, the system had a serious drawback: the extra cable needed to connect the electrodes with the energy source. Extra manpower is necessary for hauling the cable and damage to the cable causes loss of fishing time.

6.3.3 Discussion

The main aims in the study of the use of electric stimuli in trawl fisheries in Belgium were:

- A reduction of gear drag and consequently a reduction of fuel costs.
- An increase in marketable catch.
- A better length selectivity for the target species.

The system showed, however, serious drawbacks:

- The need of an extra cable between the vessel and the fishing gear.
- Problems with safety of the crew in contact with electrified parts of the system.
- Losses in fishing time in the case of a system breakdown.
- Rather high investment and maintenance costs.

Although promising, the use of electric stimulation in trawl fisheries met a range of practical problems, which in Belgium, during a 15 year period of research were never really overcome. Consequently, when in the Netherlands electric fishing was stopped, the experiments in Belgium also ceased.

In 1976 experiments were carried out on electric fishing for sole with a beam trawl. A refined pulse system was introduced. A frequency between 5 and 10 pulses per second and a voltage between 60 and 100V could be chosen. In order to reduce damage to the fish, a short pulse length of 1ms was applied. The results indicated that the heavy tickler chains rigged in traditional beam trawls could be replaced by lighter ones using the electrical stimulation, without loss of catch. The pulse length of seemed to play an important role in stimulating sole.

The experiments with electric fishing for shrimp with beam trawls were continued in 1977, with an improved system. The electric beam trawl showed higher catches for shrimp, but reduced catches for cod and whiting. Contrary to the traditional shrimp fishery, the difference between day and night catches was very low with the electric trawl. For sole the results were less promising. However, due to a lower trawl weight, the electric beam trawl could be towed at higher speeds and with larger beam lengths.

During the experiments, different numbers of electrodes were tried out. The main conclusion was that a distance between the electrodes of 0.75m was the better choice. If closer, the electrodes often collided causing short circuits. A larger spacing resulted in a too weak electric field. The catches of the electric gear were mostly higher for sole, especially for the night hauls.

In the early eighties the trials were continued with a study of the electric field between the electrodes of an electric beam trawl, both in the laboratory and in commercial conditions. The study aimed at a configurations with an optimal electric field within the trawl mouth, without causing stimulation outside of the trawl which could result in negative effects on the catchability of the trawl and which could cause damage to fish outside of the trawl path.

In the following years continuous effort was put in improving the system, with tests with an electric otter trawl, an electric beam trawl with altered cutting rate and an electric beam trawl with an altered groundrope. Trials with an otter trawl demonstrated possibilities towards higher catchability in this fishery too. International co-operation between the North-Sea states lead to promising results. The development of a pulse-generator which could be fixed on the gear, however, was never completed in Belgium.

6.3 Work done in Belgium and France

6.3.1 Introduction

In this review the work carried out in Belgium, by the Fisheries Research Station in Ostend, on electric fishing is described. The earliest experiments started in 1972 on a beam trawl and with shrimp as the main target species. In a second stage the target species were expanded to shrimp and flatfish. Beside the beam trawl, also otter trawls equipped with an electric stimulation system were tried out. In this case, Nephrops norvegicus was the main target species. Experiments continued until 1988. By then the commercial application of electrified gears was legally forbidden in the Netherlands and following this example, also in Belgium no more effort was put into this fishery.

6.3.2 Electrical stimulation

6.3.2.1 Electro beam trawls

The main aims of the research were to reduce fuel costs, to increase the marketable catch, and to obtain a better length selectivity.

In 1972 the first trials with a shrimp beam trawl, equipped with electrodes were started. The principle idea was that shrimp and flatfish, which are startled from the bottom by mechanical stimulation could now be disturbed with a higher efficiency and by means of less heavy equipment. The main intention of this first series of sea-trips was to evaluate the rigging of the electrodes and the catch composition. Figure 13 shows the general lay-out of a electric fishing system. The voltage used for the pulse generator was 220V. Since the electricity produced by the dynamo on board of the vessels in that time was 24V, a transformator was necessary. The use of 220V was one of the weak points of the system because of the safety of the crew. The pulse generator produced the electric pulse to stimulate the fish. The frequency and the amplitude of the pulses could be altered by a control unit. The electrodes, rigged to the fishing gear were connected by a cable to the pulse-generator aboard the vessel. This cable was a second serious drawback of the system. It caused problems with safety on board and extra labour. Different lay-outs of the electro beam trawl are shown in Figure 14.

The second series of experiments in 1973 again gave higher catches for shrimp as well as for the by-catch species sole. Although the distance between the electrodes and the pulse frequency was different, the results were comparable to the ones in 1972.

technical solutions found over the years and to exchange ideas and experience. As most workers had developed prototypes according to different design phylosofies it was not technically possible to merge all these designs into one generally applicable system. Further research was done into the effect of towing speed in the course of 1985 and was reported by Kraaijenoord. Lower speeds produced a higher percentage of sole in the catches of the electrified trawl. Size selectivity was not improved by the electric stimulus. Comparative fishing trials in the end of 1985 on RV "Isis" with the RIVO system and one developed by BFA-Fi in Hamburg, Germany showed the RIVO system catching more sole, but also breaking down more often.

6.2.4 Phase C: Commercialisation attempts from 1986 until 1988

This phase is characterised by attempts to create a commercially applicable system. A thorough analysis of reasons of failure of RIVO's system was carried out and design improvements given. A comparison was also made between RIVO's system and one based on a Rhumkorff solenoid principle (System "Van der Vis") after a request from the Dutch Fishermen Federation resulting in higher catches of sole and plaice for RIVO's system (refer Table 6.3). Additional software engineering and performance measurements were carried out in 1987 to improve the design of RIVO's system and enhance its reliability. A private electronic company developed a system based on the knowledge built up at RIVO which was transferred. Extensive collaboration emerged between RIVO and this company in order to commercialise the system. The company developed a prototype with two capacitor containers that were mounted on the shoes of the beam trawl. The power unit also differed from RIVO's system with a three phase current. The design was based on requirements concerning robustness and quick interchange of components. Tests of the commercial prototype were done on the beamer GO-65 at the end of 1987 resulting in higher sole and lower plaice catches than the conventional beam trawl (Table 6.4). No improvement in size selectivity was found. Further research was advocated but the project stopped with a ban on electric fishing by the Dutch Ministry of Agriculture and Fisheries out of fear of further increasing fishing effort in the beam trawling fleet which was under severe international criticism at the time. Curiously the research in other nations stopped around the same time, partly for unknown reasons, in other cases due to untimely death of scientific workers involved. Recently new development work was done by a private company in The Netherlands without any cooperation with RIVO. The current status of this work is presently unknown.

were conducted in 1978 on the GO-4 in the southern North Sea. The equipment did not function satisfactory and the catch results were not sufficient.

6.2.3 Phase B: The flatfish (sole) period from 1979 until 1985

In this period more manpower was allocated to this project with the important distinction that electric equipment was designed and built by RIVO-staff and not by outside companies (Fig. 6-9). Three generations of pulse generators were developed over the period, one in 1979, one in 1982 and one in 1984. The main principle did not change, the pulses were generated by capacitor discharge. Field trials were conducted on the UK-141. An underwater camera was also used in attempts to observe fish reactions. Variables under investigation were: frequency, voltage on electrodes and length of electrodes. It appeared that the catches on the electrified side increased with rising frequency and voltage. Ratios of over 1.0 could be obtained. No difference was found as a result of changes in electrode length, nor between various gear designs. Extensive trials were also done in 1981 on the UK-141. Four different electrode arrangements were studied with best results with 4m electrodes (central position). Differences in catchability were found between day and night with higher effectivity at night. Experiments on electrical fish barriers resulted in the idea to decrease the pulse width. The amplitude of the pulser was again increased in a new design, now to 1000V. This design featured also: higher voltage of the power supply generator, safety circuits for current and voltage, sequential discharge of pairs of electrodes by an electronic ringcounter, discharge through thyristors. Trials were continued in 1982 on the UK-141, with better catches at night (+50%) for the electrified net, but lower during the day (-10%). Claims were given of a higher selectivity for the electrified gear. Especially small soles did not appear in the catches. The electrodes showed a large degree of corrosion, and the pulse unit was not reliable at high capacitor voltages. Catches increased with higher voltages, but the maximum appeared not be have been achieved with this machine. A new design followed with a maximum capacitor voltage of 2000V. A large watertight container to carry these capacitors was incorporated into the beam of the trawl. Better designs were made for electronic circuitry, and in addition a new design of gear was made which enabled fitting electrodes of equal length. Extended sea trials were carried out in 1984 first on RV "Isis", later on the UK-141. A new gear design appeared to be successful +45% more sole during the day and +65% more sole during the night (Fig. 10-12). The optimum voltage with this net was around 700V, at 20Hz frequency. Sole catches with the electric gear were relatively higher at lower towing speed as can be read off Table 6.2. All leading scientists were brought together in a one day seminar held at RIVO in IJmuiden in January 1985. It was an excellent opportunity to compare the various

6.2.2 Phase A: The shrimp period from 1966 until 1979

De Groot and Boonstra started to study literature about electric stimulation around 1966. In shrimp trawling the major aims were to increase the efficiency of the gear and to reduce discards of juvenile fish. In flatfish trawling the major objective became to replace the array of tickler chains bny a lighter stimulator thus reducing the drag of the gear when towed over the sea bed and consequently its fuel consumption The energy crises of 1973 and 1979 resulted in emphasizing this aspect. Interesting is to note that the impact of relatively heavy groundgear as used in beam trawling on Benthic organisms was already mentioned as a point of concern and with it the possible advantages of the electrified beam trawl (See Table 6.1, and Fig. 1-5).

In the early phase of the project the development hinges on two separate lines of research, one on shrimps and one on sole. Until 1969 some behaviour experiments were carried out in aquaria at RIVO and oyster bassins both on shrimps and sole subjected to electric fields. The potential for using this kind of stimulus for catching the animals was clearly identified, leading to an increase in effort in the development of a commercially applicable system. From these bassin trials the following specifications arose: optimum pulse width for shrimps 0.2 ms, and for sole 0.7ms. The generator was placed onboard with cables running to the electrodes in the gear, a construction leading to a significant loss in voltage between the electrodes.

In 1971 a second pulse generator was developed. It was mounted directly on the beam of the trawl and used an internal power unit, but apparently its specifications in amplitude (≤10V) were too low. Field tests were carried out in 1972 with the first pulse unit on 3m beam trawls. Results were discouraging and led to new spec's defined for a follow-up pulse unit, that was built in 1973 and used in field trials in 1973 and 1974 on trawls with 9m beams on vessel TH-6 at speeds of 3 to 3.5 kn. Reports describe an improvement in catches of shrimps ranging from 8 to 35%, but also malfunctioning of the equipment in 20% of the time. Again a new pulse generator was built with higher amplitude (65V). In 1975 this machine was tested on vessel WR-87. It showed many malfunctions. Research on electrified shrimp trawling stopped in 1976 after a series of experiments on vessel WR-17 which led to catch ratio of 1 to 1. From then on priority was given to flatfish. On the WR-87 trials were conducted on a 9m beam trawl. Catch ratio was 1 to 1, and no difference was reported on the length distribution of fish caught. Similar experiments were done in 1977 on WR-17 with some modifications on the equipment. Catches were almost equal and the scientists reported a higher selectivity for the electrified beam trawl. Further trials that is used commercially. In many cases the fishing industry expressed great interest in the developments, and cooperation with fishermen took place on a wide scale. Nevertheless, the large investments involved combined with the vulnerability of any electro-fishing device hempered its introduction. In retrospect one can state that the development was mainly driven by scientific workers and marketing attempts were only made towards the end of the project. It is still questionable whether such a complicated device as an electrified fishing gear may work in commercial conditions over a long period at all, and pay its investment back. The similarity of conditions found in all these countries is striking. The principle has been proven to work, the problem consisted of making a cheap, robust version of a prototype, that could proof its feasibility and convince fishermen of its usefulness and profitability.

6.2 Research done in The Netherlands

6.2.1 General

The work done in The Netherlands covers a long period from 1966 to 1988 with various phases. The various design specifications for the electrical systems and results are given in Table 6.1. Report TO 88-06 of RIVO explains the whole history of the project. Three phases are distinguished as follows:

Phase A: The shrimp period from 1966 until 1979
Phase B: The flatfish (sole) period from 1979 until 1985
Phase C: Commercialisation attempts from 1985 until 1988

Most of the work is published in internal RIVO-reports written in the Dutch language. Only in the beginning some publications were made as ICES-papers or in fisheries science magasines. In the commercialisation phase most work was laid down in memoranda and remained unpublished to protect commercial interests.

The objective for the whole project is:

> *to create better chances of survival of discards, to improve the quality of the catch and the selectivity of the gear, and to reduce the fuel consumption.*

It is interesting to note that the aims shifted in attention throughout the project. The energy consumption issue is at present not regarded as high priority, most emphasis is laid on the environmental aspects.

6. ELECTRICAL STIMULATION

6.1 Introduction

The idea to use electricity in fishing is indeed very old. De Groot (1974) mentioned a reference to Job Baster stating as early as 1765 that electricity might affect shrimps, and that this should be investigated. Experiments with electricity on fish were conducted in the middle of the nineteenth century. In the 1930s Holzer and Scheminsky investigated the effects of direct, alternate and intermittent currents on fish and introduced quantitative analyses. Many scientists quote the work done by Mck. Bary (1956) who studied the behaviour of round fish in electric fields, and found profound differences for fish in sea water, compared to studies related to fresh water species.

Physiological studies done by Danyulite and Malyukina (1967) revealed that reactions to electric fields could not be contributed to skin receptors or the fishes brain, but cutting the spinal cord caused reactions to stop. Locomotory activity and swimming are apparently controlled by the spinal cord.

Holt (1992) describes developments in the United States on electrified shrimp trawls. It is interesting to note that a special design was made (so-called 'frame trawl') that could more easily be stored on the deck of fishing vessels by using hinges on the beam. The gear was of similar dimensions (30' or 9.14m width) as its European counterparts. The beam construction offered a more rigid platform to install electrical equipment than a flexible ottertrawl maintaining its geometry by dynamic equilibrium when towed. Power supply was initially led through cables, later by placing batteries on the beam. Total energy requirement of the system was as low as 100W. Five electrodes ran perpendicular to the towing direction, covering a total distance of about 4.5m in towing direction. Shrimp catches for the electrical gear were recorded up to twice of that of the standard gear. Similar to the situation in Europe this technology was not taken over by the fishing industry. Reasons were not given.

The work in Europe was mainly done in The Netherlands (RIVO-DLO), Belgium (RvZ), the U.K. (SEAFISH), Germany (BFAFI), and France (IFREMER) sometimes in combination with private companies. In many cases ideas were copied and very similar problems occurred. The technologies developed along similar lines, with The Netherlands producing devices with the highest energy input. Reading through the literature one can easily wonder why in all these countries not any system emerged

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complicated and premeditated by earlier experience (Dawkins 1971; Krebs 1973; Hart 1986). "Search images" are established with experience, and may obtain as well as olfactory, and tactile components.

Several reviews on the role of specific chemical components for different fish species exist (Atema 1980; Mackie 1982; Carr and Derby 1986). They all conclude that different species generally respond to different substances in food extracts. It is therefore a promising avenue in species-selective bait fishing to utilize this difference in preference. Reviews of attractants and applications are given by e.g. Hara (1975), Atema (1980), Carr 1982) and Mackie (1982). Carr and Derby (1986) claim that the main stimulatory effect from tissue extracts which induce feeding behaviour in fish and crustaceans are common metabolites of low molecular weight, particularly ammino acids.

Longlining and potfishing are considered at length by Svein Løkkeborg and Dag M. Furevik in a book edited by Fernö and Olsen (1994), which is suggested for further reading on this subject.

5.3 Conclusion

The use of olfactory and gustatory attractants in fisheries has a long history, but is presently of relatively limited interest as the bulk of the landed quantities in fisheries are caught with active fishing gear. In view of the future energy situation and also of the species specificity of new attractants it is recommended to stimulate more research in this direction.

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5. OLFACTORY AND GUSTATORY STIMULATION IN FISH

5.1 Introduction

Olfactory and gustatory stimulation of fish fall beyond the scope of the present project, but since such stimulation is certainly important, particularly in the use of passive fishing gear, a short abstract and a general bibliography on the subject will be presented.

5.2 Abstract

In passive fishing gear like hand lines, long lines and traps, olfactory stimulation and attraction of target species has been used as long as man has fished with such gear. Bardach and Villars (1974) have shown that feeding behaviour in fish shows a stereotyped sequence of behaviour components, and Atema (1971) has classified the response of fish into four phases: arousal, location (search), food uptake, and food ingestion. A similarly simple behavioural reportoire in response to baited hooks is also described in Huse and Fernö (1983) and Løkkeborg et al. (1989).

Arousal by the presence of food is the initial step in the feeding behaviour (Bardach and Villars 1974; Hara 1993). Most fish use the olfactory sense to detect distant prey (Atema 1980). The arousal distance is therefore determined by the attractant release concentration and the detection threshold of the fish. This has been termed the active space (Wilson and Bossert 1963).

Location of the olfactory source involves orientation in a turbulent odour field where gradients and firective indications are distorted by currents and diffusion. This is resolved in different ways for different species, both mophologically, with barbels in catfish and a wide head in hammerhead shark, and locomotory, with different searching patterns in many fishes. Generally, arousal is followed by rheotactic orientation to locate the source of the odour (Atema 1980). Chemically stimulated rheotaxis is well documented in *e.g.* salmonid homing migrationg (Hasler and Scholz 1983). Cod and haddock also are ashown to swim against the current to find food (Pawson 1977a; Løkkeborg *et al.*, 1989), as other species (Wilson and Smith 1984; Bjordal 1986; Fernö *et al.*, 1986).

Food uptake and food ingestion involve a wide diversity of sensory application. Vision as well as gustatory sense and tactile sensing are all involved in the food acceptance algorithm (Bardach and Vilars 1974; Atema 1980). This phase is

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fish (cod) to sound from an approaching vessel are very variable, due to areal, seasonal, biological or hydrographical conditions.

Recent studies of the effects of seismic surveys on fisheries indicate that the availability of the species in open sea areas is changed and this is both species and size related. The different zones of the survey can show increased or decreased catches and this has been interpreted as detailed changes in distribution. This is a difficult subject to study where large sea areas can be affected by the varying components of the mobile, powerful and continuous pulsing sounds. The Norwegian studies indicate that effects are noticeable over distances up to 18 nautical miles from the sound source. It was advocated to keep clear of spawning grounds at least this distance during spawing periods. It was also stated that injuries of fish eggs, larvae, and fry caused by seismic investigations were only found very close to the air-guns, at a distance of 5m and less. A recent critical review of the recent research points out the need to plot carefully the sound levels at the different points in the survey area and use a great many different techniques to sample the fish distributions. It suggests more detailed studies of the effects of such sounds on a range of marked individual fish might be more productive in explaining the changes in vulnerability and reduce the speculation. If the interpretations are true these sound may have potential to guide particular sizes and species of fish into or out of large areas, diverting migrations etc.

Infra sound (0.1-10 Hz) has been shown to block the passage of some species on migration in rivers. This is a new area where applications of infrasound fields as barriers are being researched for both aquaculture and protection of industrial water inlets etc. Infra sound may well become valuable in specific fishing gears although at present high power is needed to generate local sound fields at low frequencies and this may make it less attractive. There is limited knowledge on fish sensitivity and in only a few fish species.

4.8 References on reactions to sound

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wires and netting when flash photos record them in darkness. Details of the fish's sound receptors for both pressure and displacement are documented, however, many of the details needed for commercial species are lacking and should receive support for further investigation. There is potential here to discover practical species specific differences. For example anatomy suggest that mackerel, horse mackerel and herring have quite different sets of mechanisms for hearing. Herring is well studied the others not so. There is a gap in knowledge on fish reaction on sounds. It is not known why reactions are variable and which sound characteristic causes not only detection, but also reaction. Possibilities to use sound to reduce the by-catch in trawling are hempered by the lack of equipment (loudspeakers) that can replay sound in the frequency band between 0 and 2000Hz at a level well above the ambient noise level.

Japanese fishing cooperatives use sound signals to condition and regularly recall to feed points cultured but freely roaming red sea-bream at many successful ranching sites around their coast. A system that suites a policy of maintaining and managing fisheries as exclusive zones with all the added incentives to improve the productivity.

Sounds are traditionally used in surface fishing where gaps in ring nets and beach seines etc are observed and filled, before they close, by the operators splashing stones etc in order to retain the herded fish. Conversely it is sometimes important to avoid sounds when fishing! Reports indicate that although sounds are an integral part of most gears they have not been consciously designed as part of remote fishing gears. The many sounds produced by fishing gears have been recorded and are very variable and depend on detailed arrangements of the structures of the gear or the nature of bottom contact and the sea bed composition particularly in towed bottom trawls. Tests have pointed towards sound having major effects on catch particularly in pelagic fishing where fish near the surface may dive away from the sounds emanating from an approaching vessel. Demersal catches may be increased by fish moving to the sea bed as the sound of the towing ship passes. The sound of a ship and trawl passing may attract surrounding fish into the harrowed track where they have learnt that food is more easily found. Some parts of gear such as warps and sweeps consistently vibrate with characteristic frequencies and Russian scientists believe strongly in their herding role. In contrast despite rope vibrations, single boat Danish seines were only economically fished in daylight hours and have more recently given way to pair seiners which work effectively day and night. Detailed investigations into these fishing techniques, with these questions, might sort out the mechanisms of the different herding mechanisms of boat noise, vibrating sweeps, otter boards, their turbulence or their visual stimulus. Work done in Norway indicates that responses of

4.6.1 Conditioned approach

In principle, there is no reason why fish should not be trained to respond to sounds (or other stimuli) that would either draw them into a trap, bring them to turn into the path of an approaching trawl, or herd them more closely together to enable a purse seine to be drawn around them. In practice, the usefulness of the concept will be limited by the difficulties of training large numbers of fish and by the economics of the training operation. Conditioning would probably have to be done on fry of cultivated populations before release to the wild, and on species in which the conditioned response was stable for long periods (several months). Only species whose schools stay together for long periods, and which stay in the same place, would present realistic opportunities for capture - the classical sea-ranching problem.

These considerations suggest that it would usually be more feasible to try to exploit natural reactions of fish species to naturally occurring sounds, particularly those that cause them to aggregate. Maniwa (1976) tested several sounds, including those of feeding, splashing, pure tones and fishing boat noise, all of which were successful in attracting one or more commercial species. At the same symposium, Chapman (1976) reported what he regarded as a learned attraction to the sound of divers' breathing apparatus, suggesting that the unconditioned stimulus was the availability of food disturbed by the divers.

Knoph (1987) described the use of sound signals to train cod fry to approach a food source. When this had been done, the same signal was used to gather the fish into a trap for vaccination, sorting and/or transport purposes. Knoph suggested that such a method (which might also employ other conditioned stimuli than sounds) would be useful in sea-ranching of salmon or halibut, mentioning successful trials with cod in a fjord and Japanese studies using Red Sea Bream. Scientists involved in the sea ranching programme of Oita Prefecture in Japan were visited in October 1995 by Wardle and Van Marlen, as well as an automatic feeding buoy with a telemetry link to a shore base. Claims were given of enhanced catches in the area by attracting fish condioned with a tone to return to this buoy (Kudo, personal communication 1995, Kamijyo et al., 1993)

4.7 Conclusions

There is no doubt that many fish species react to sounds and like other vertebrates a sound can act as a warning, attracting attention and requiring visual checks to assess danger. Where vision is absent, fish seem unable to react in an orderly manner and often collide with noisy fast moving components of towed gears such as bobbin-rigs,

4.6 Attraction effects

Although many types of noise have a repellent effect on individual species of fish, other sounds are neutral or positive in their effects. These may include the feeding sounds of the species concerned. Takemura *et al.* (1988), for example, found that real and synthesized feeding sounds attracted both carp and yellow tail. Knoph (1987) listed courtship, shoaling and alarm sounds as playing a part in the social life of fish, in addition to feeding sounds. Aggression is also mentioned by Hawkins (1993) as a reason for males to produce sounds.

Hawkins (1993) reviews sources of fish sounds, and suggests that most sounds are produced in a social context. For example, they may serve to alert conspecifics or as a warning to potential predators. Some species, including gadoids (haddock), appear to demonstrate territorial behaviour, one component of which is the production of a characteristic series of sounds.

Chapman (1976) reported that gadoid species were attracted by pure sounds (40, 60 and 100 Hz) but avoided low-frequency narrow-band noise. Chapman cites Gray and Denton (1991) to the effect that pressure pulses generated by fish can be detected by other fish at a number of body-lengths distance, and that sufficient information is provided by such pulses to enable individuals to determine the approximate position of its neighbours, though there is no evidence that this information is used. Pitcher and Parrish (1993) review the phenomenon and functions of shoaling, and suggest that it may be facilitated by sounds, but otherwise pay little attention to this aspect. In fact, little seems to have been done to identify the role of auditory communication in shoaling or aggregation

A study by Ona and Beltestad (1986) looked at the reactions of saithe held in a 90 x 10 x 7 m deep seawater pen to a 160 Hz pulsed underwater sound. The positions of acoustically tagged fish in terms of "cells" within the pen were monitored by means of receiving hydrophones, which showed a very rapid increase in fish density in the cell containing the sound stimulus. The aggregation started soon after the sound was switched on, but fell off gradually as no further stimulus was given and the fish lost interest.

Sound stimuli are also used to repel fish as reported by Arimoto (personal comminication, 1995) and Sreekrishna, 1995. Fish is driven into encircling gill nets by noise made by fishermen of the Malabar coast. Fishermen along the coast of Travancore listen to sounds produced by fish to locate them (Gopinath, 1953).

after a series of shoots on the North Cape Bank in the Barents Sea in May 1992. The shooting area of 3 x 10 nautical miles was in the centre of a study area of about 40 x 40 nautical miles, and an array of 3 x 6 guns with a total volume of 82,132 cm^3 and a pressure of 13784 kPa was towed at a depth of 6 m and fired every 10 s during 26 x 10-mile transects over a period of five days.

The results were clear (Engås *et al.*, 1993). Trawl catches of cod and haddock fell by as much as 70% up to18 nm from the seismic area both during and after the shoots. Long-line catches fell by 44% in the seismic area, a reduction that gradually fell as distance increased, until there was no effect 16-18 nm from the seismic area. There was a 50% drop in catches of haddock throughout the study area. The effects lasted at least as long as five days post-shoot (when the experiment terminated), and seemed to be due primarily to the fish fleeing the area, rather than moving vertically in the water column out of the reach of trawls or simply not responding to baited lines. In operational terms, the result was that the highly localized, high-intensity, low-frequency sound of seismic airguns greatly reduced catches.

Acoustic abundance estimates were made at the same time, using another trawler that made systematic transects of the study area. This part of the study also found a clear reduction in the quantities of cod and haddock in the study area, particularly within about 5 nm of the central shooting area. Quantities of fish measured continued to fall after shooting ceased, while the distribution of fish throughout the study area tended to become more even.

A study by Løkkeborg and Soldal (1993) complemented the experimental investigation by analysing catch rates of cod in long-line and trawl fisheries within seismic survey areas. Analyses of catch data from fishing vessels that happened to be operating in areas where shooting was taking place showed drops of 55 - 85% in long-line and trawl catches of cod during seismic shooting. The effects lasted for 24 hours and were at least 6 nm in extent.

On the other hand, there was a three-fold increase in by-catches of cod in saithe trawls, with a return to normal levels immediately after shooting ceased. This was probably due to the short duration of the particular series of shoots, which may have caused the fish to start their avoidance routines by moving diagonally downwards in the water column, temporarily increasing the density of fish available to the demersal saithe trawl.

individually tagged common bream to avoid a series of trawl hauls in a reservoir, finding that in mature fish, vulnerability to the gear decreased dramatically after very few trials. In practice, of course, the point of trawling is to catch the fish on the first occasion they encounter a trawl, but these studies do illustrate the learning capacity of fish. Like the series of studies carried out by the Institute of Marine Research in Bergen (*e.g.* Misund and Aglen, 1992; Engås and Godø, 1989; Ona, 1988) and others on the behaviour of fish in front of trawling gear, they may also provide pointers as to how trawling operations can be modified in order to exploit innate and/or learned responses to sound and light (*e.g.* Van Marlen *et al.*, 1990; Watson *et al.*, 1992).

4.5 Seismic shooting

Seismic shooting in connection with offshore hydrocarbon exploration is the other main source of anthropogenic noise in fishing grounds at any distance from coasts and harbours. Seismic shooting employs air-guns to produce high-intensity, low-frequency noise that penetrates the seabed and is differentially reflected by layers of the substrate.

As early as 1984, the Institute of Marine Research in Bergen, Norway was studying the effects of seismic shooting on fish behaviour. Dalen and Raknes (1985) showed that air-guns affected the distribution and behaviour of pelagic and ground living species. The latter either moved to the bottom or out of the area, while there were small non-systematic reductions in the number of pelagic fish observed in the are for up to six days after shooting.

An early study by Malme *et al.* (1986) provided two searches that summarized the literature on the effects of sound on fish behaviour and on the characteristics of sound from offshore geophysical surveys.

The literature on the effects of air-guns on marine organisms has again been summarised in a report (Knudsen and Enger, no date, but post 1991) that focused on possible physical effects (injuries) on fish and whales, but which also looked at effects on fish behaviour. Among other things, it concluded that fish are scared by seismic shooting and that catches in densely populated regions may fall as a result of seismic shoots.

In response to continued fishing industry concern about the effects of offshore industry seismic activity on catch rates, the Institute of Marine Research carried out a systematic study of trawl and autoline catch rates on several days before, during and

Knudsen *et al.* (1994) also played high-intensity 10 Hz and 150 Hz sounds to Atlantic salmon smolts in a small river, with the idea of using sound as an acoustic barrier. While the 150 Hz stimuli had no observable effects on the smolts, 10 Hz was an effective deterrent, causing them to detour out of the main channel of the river, where the transducer was located, and into a side channel.

At the other end of the sensitivity spectrum, indeed well beyond what has been regarded as the range of auditory sensitivity of fish, Ross *et al.* (1993) tested a full-scale deterrent system intended to exclude alewives (Alosa pseudoharengus) from the cooling-water intake of a nuclear power plant in New York State. High-frequency broadband sound (122 - 128 kHz) at an intensity of 190 dB (relative to 1 Pa) reduced fish density near the intake by 96% and the number of fish "impinged" on the intake screens by 87%.

Similar effects of high-frequency sounds were observed by Nestler *et al.* (1992) on another clupeid, the blueback herring (Alosa astivalis), in a series of open-water and confined-area experiments. Using frequencies and intensities roughly comparable to those employed by Ross *et al.* (1993), they observed avoidance responses in open water lasting as long as one hour, in fish up to 60 m from the sound source.

At these frequency and energy levels, however, it is possible that we are not dealing with audition in any conventional sense of the term, but rather with the effects (possibly even including heating) of high energy inputs to the body tissues in general.

In the echosounder experiments cited above, Bercy and Bordeau (n.d.) observed a breakdown in schooling patterns and a sharp rise in activity, including spasmodic movements and "disordered up and down movements showing a great excitation", presumably in response to the 500 Hz frequency components. The fish took several hours to adapt to the continuous sound of the echosounder. These authors claim that it is likely that such low-frequency components are typical of echosounders, since the design and conception are essentially similar.

4.4.1 Conditioned avoidance

Fish can also be trained to avoid trawls. P'yanov and Zhujkov (1993) performed hauling experiments in an aquarium in order to study the ability of *Hemigrammus caudovittatus* and *Puntius conchonius* to form defensive conditioned reflexes. After only 1 - 2 hauls the fish began to avoid the fishing gear well in advance, presumably on the basis of the noise it produced. P'yanov (1993) also tracked the ability of avoidance behaviour in response to vessel noise (usually research vessels) results in a change in the natural distribution pattern of fish, "around, and/or below a noisy vessel" when the radiated noise levels exceed their threshold of hearing by 30 dB or more. This effect may occur at distances as great as 400 m, and the aim should be to reduce these to approximately 10 - 20 m, so that the fish can be detected and/or measured by sonar or taken by fishing gear before they themselves detect the presence of the research vessel and take avoiding action.

The Study Group efficiently summarizes the findings of a very large number of studies, and other recent references generally confirm these findings. Huse (1994), for example, studied the effects of synthesized trawler sounds, on which spike frequencies filtered out from sound measurements of individual trawlers had been superimposed. The spikes had frequencies of between 90 and 239 Hz. Some of the spikes were processed to provide a continuous tone over time. She played these sounds through hydrophones to cod in sea-cages and showed that they affected swimming, schooling and polarization activities. Adding frequency spikes to the synthetic noise generally increased response intensity or lowered response thresholds.

A related study using both cod and herring by Engås *et al.* (1995) started by recording the sounds of a large factory trawler during trawling. Hydrophones were positioned near the surface and the vessel passed at a minimum distance of 45 m. Adapted to net pens in sheltered waters and exposed to underwater loudspeakers, both species showed avoidance (but not alarm) reactions to playbacks of the original noise and to 60 - 300 Hz and 300 - 3000 Hz filtered spectra, but little response to a 20 - 60 Hz filtered spectrum. The reactions, which consisted for the most part of diving and schooling, were longer to the original sounds than to time-smoothed versions of the original noise. Engås et al. suggest that avoidance reactions are primarily determined by vessel sound level, although temporal structure (as modified by the time-smoothing process) also seems to be of importance.

4.4 Reactions to other sounds

Enger *et al.* (1993) compared the effects of 150 Hz and 10 Hz sound stimuli on juvenile salmon in a large tank and on migrating salmon smolt in a river. In both situations, only the infrasound stimulus produced an avoidance response, (inferred, in the river situation, by the fact that very few fish passed the 10 Hz sound source compared with the no-stimulus situation).

1988; Ona and Chruickshank, 1986), demonstrated vigorous vertical and horizontal avoidance responses of cod, haddock and herring during trawling operations, when heavy loadś on propellers greatly increase cavitation noise, whose spectrum tends to match the range of maximum sensitivity of fish hearing.

The ICES report points out, however, that the avoidance response may be influenced by other factors such as feeding behaviour, migration, water temperature, prevailing light levels or vessel lights (Halldorsson, 1983), not to mention the species of the fish concerned and its physiological condition. Avoidance is the attempt of a fish to move to a lower intensity noise field as quickly as possible. Pelagic species may dive away from the source while schools swimming near the surface may avoid it by splitting and swimming on either side. Demersal fish may dive and/or spread out laterally out of the path of the vessel. For example, Olsen et al. (1983) found that hibernating herring, spawning cod, polar cod and capelin moved sideways out of the track of a vessel running at 15 knots. There was a reduced reaction on the part of schools swimming at greater depths, and when the vessel was running at reduced speed (decrease in sound signature). Misund has found both both horizontal avoidance (Misund, 1990) and diving reactions of herring (Misund and Aglen, 1992) to approaching fishing or research vessels .

Gear designs which exploit the tendency of pelagic species to avoid noise-generating vessels by lateral avoidance movements were studied by De Jong and Van Marlen (1991). This new design of trawl gear, originating from the University of Rostock Germany, featured a single door on one side only and was towed outside the trawler's wake in order to catch fish close to the sea surface. They reported success in a mechanical sense with single- and two-door variants of the gear at a scale of 1:7, but actual fishing trials were never conducted, so the claim for better catchability was never proven.

With the advent of omni-directional sonar, a number of research groups have been able to measure swimming speed as well as direction of avoidance reaction, and have shown that this may increase as a vessel approaches (e.g. Olsen et al, 1983; Misund and Aglen, 1992; Goncharov et al., 1989). Avoidance reactions may be initiated at distances of up to several hundred metres. Determining reaction distances relative to vessel noise intensity is complicated by the fact that the noise field of the vessel concerned, i.e. the three-dimensional pattern in the water column of sound intensity at various frequencies, radiated from the hull, is seldom known. However, the conclusion of the many experiments discussed by the 1994 ICES report is that high energy levels at 500 Hz as well as a number of other frequency components below 1 kHz. It thus seems likely that at the high energy levels used in operational conditions, fish can perceive, and are likely to be adversely affected by, "stray" sounds emitted by echosoounders and sonar gear.

4.2.5 Fishing gear

The noise of fishing gear such as a trawl follows that of the towing vessel itself. In his review of fishing behaviour and fishing gear, Wardle (1993) describes how "as the sounds of the towing ship begin to fade, a new sound from the otter boards will start to grow". The noise of the boards scraping the seabed is soon augmented by that of the ground gear and fishing line at the open end of the trawl also bumping the seabed, and by turbulence noise as the net is pulled through the water. Escape reactions to such sounds are likely.

Engås (1994) reviewed material on the reactions of fish to trawling operations, mentioning specifically the sounds generated by trawl warps and doors, particularly on hard seabeds, but pointing out that there is still a lack of literature on these potential sources of alarm. In the same volume, Misund (1994) suggests that high levels of background noise plus the noise of the vessel itself probably mask the noise generated by fishing gear.

4.3 Reactions of fish to vessel noise

The age-old claim of fishermen that vessel noise can affect the behaviour of fish has been recognised at least since 1969, with the report of the Norwegian Directorate of Fisheries' Vessel Noise Committee on "noise problems in fisheries" (Anon, 1969). Most recently, de Haan (1992) has concluded that sudden changes in propeller r.p.m. and pitch can scare off fish. A recent review by Wardle (1993) points out that the sound of an approaching vessel can be heard by fish long before the trawl gear becomes visible to them.

The 1994 ICES report suggests that tones, wide-band pressure levels or pressure gradients are capable of causing avoidance reactions, but that the principal determinant of the response is the amount of noise energy contained within the most sensitive auditory bandwidth of a given species. It appears that a large proportion of the sound energy radiated from ship hulls through the water is in the "right" frequency range to be perceived by fish. In a number of studies, Ona and colleagues (e.g. Ona, Mitson (1991) points out that there are many potential sources of both low- and high-frequency noise on board vessels. He cites Kay et al. (1991) who recorded a low-frequency noise (strangely enough described as a "piercing squeal") during trials of a new research vessel. This turned out to be emitted by the polyamide (nylon) bearings of the rudder. Sources of high-frequency noise include flow noise due to rough hull surface or hull projections, and pumps.

A typical combination of diesel engine, fixed- or two-speed gearbox and CPP "is most unsatisfactory when underwater radiated noise is considered". However, diesel-electric systems, in which diesel engines drive electrical generators, which in turn power electric motors driving fixed-pitch propellers, have "the potential to achieve much better noise reduction". This is partly because the prime mover can be partially physically isolated from the hull by flexible mountings, and because there is no gearbox.

Both propulsion systems offer adequate operational flexibility, but in view of the advantages of diesel-electric propulsion in noise terms, it is reasonable to ask why this system is not more widely used by research vessels. The ICES report concludes (p. 14) simply that there are two reasons; the first is that the initial cost of a diesel-electric system is about 1.2 times that of a diesel/gearbox/CPP installation, and in the second place, the problem of underwater irradiated noise has been ignored (until now).

A further finding of the ICES report is that very little information is actually available regarding actual noise signatures of vessels, especially research vessels, under typical operational conditions. Systems have been developed, e.g. by Geco Fjord Instruments in Norway, that record and/or synthesize individual vessel signatures in order to play them back at sea with the aim of detonating mines. Since these systems have been developed on behalf of the military, however, they tend to be very expensive. A more practical method of acquiring information on vessel signatures would probably be to build up a library of fishing and research vessel noises under standardized conditions.

4.2.4 Fish-locating equipment

A separate but related question is whether echo-sounders and sonars generate noise within the sensitivity range of fish. Although the standard frequency is 38 kHz, it has been pointed out (e.g. Bercy and Bordeau, no date, but post-1985) that "most pulsed ultrasonic transmitters and sounders are perfectly audible to [the] human ear". These authors cite observations of Terhune (1976), who measured substantial energy at 1 kHz from a pulsed 200 kHz depth sounder. Their own measurements demonstrated

However, ambient noise is relevant in the context of this review because its level determines the ultimate limit to detection of a wanted signal, whether by the fish themselves (Buerkle, 1968), or researchers. It may thus be a confounding factor in studies of fish reactions to anthropogenic noise.

In addition, two classes of anthropogenic sound sources are likely to provoke avoidance reactions in target fish.

4.2.2 Vessel noise

The fishing (or research) vessel itself and its gear produce a wide range of sounds which, precisely because the vessel is targeting specific localities at specific points in time, are bound to be experienced as unfamiliar and intense, and therefore probably repellent. There are close similarities between the fishing situation and the activities of research vessels, which tend to follow schools closely and often deploy trawling gear, and the effects of research vessel and gear noise on population estimates and the validity of catch statistics have become a source of concern. For this reason, this field was recently and very comprehensively reviewed by an ICES Study Group on Research Vessel Noise Measurement, which reported back to the ICES in April 1994 (ICES: C.M. 1994/B:5).

In brief, the ICES report identifies three principal sources of underwater noise radiated by vessels; engines, gearboxes and propellers.

Engine noise levels have risen over the years as installed power has increased. Virtually all vessel propulsion systems are diesel, and most of their radiated noise energy is within the frequency range to which fish are most sensitive. Altering the speed of a vessel does not have much effect on noise level, as this is usually controlled nowadays via changeable (or variable) pitch (CPP) propellers.

Like the engine, the gearbox is rigidly mounted to the hull, and sound is radiated through the hull. Most gearbox noise is below 1 kHz.

Propeller-hull interactions are responsible for much low-frequency noise below 1 kHz, and changes in pitch and speed can drastically alter the sound signature of a given propeller. Even minor mechanical damage to the edges of propeller blades may affect noise levels, while heavy propeller loading, which occurs for example during trawling and which may result in cavitation, also causes great changes in noise characteristics.

Schuijf and Hawkins and others (*e.g.* Schuijf 1975; Schuijf and Hawkins 1982) suggest that cod are capable of discriminating both the direction and distance of sound sources. Such an ability is of course essential if avoidance responses are to be better than random reactions to sounds.

4.2 Effects of sound on fish behaviour

Sounds may have either attractant or repellent effects, and a combination of these two roles might conceivably be exploited to improve the selectivity of fishing gear, i.e. it may be possible to employ specific sounds to attract a target species while other species are deterred from approaching the gear by the same sounds.

In any given catch situation, there are as many as three main sources of water-borne sound or low-frequency vibration that may affect the behaviour of a catch "target":

4.2.1 Ambient noise

The general ambient or "background" noise of the ocean, both near- and far-field, emanating from such diverse sources as the swimming movements of the target fish and its fellows, the activity of other species in the vicinity, other biogenic sounds such as fish, whale and dolphin calls, noise generated by physical factors such as rain, wind and wave action, currents and other sources of turbulence, iceberg movements, natural seismic disturbances, and anthropogenic noise such as harbour and offshore industry operations, propeller and other noises from distant vessels, and seismic shooting (ICES: C.M. 1994/B:5; Hawkins, 1993).

Some of these sources of ambient noise are of potential adaptive relevance when they emerge into the "foreground" and demand a specific response. A problem is that increases in marine traffic levels, propulsion power and the number of auxiliary power sources carried by all types of vessels have led to a steady rise in ambient noise levels during the past few decades. Ross (1993) claims that ambient sound levels in the ocean have risen by more than10dB over 1950 levels in some areas, particularly in the East and West Atlantic.

Ambient noise is all-pervasive, continuous and continuously (and presumably randomly) variable in spectral composition and intensity, depending as it does on propagation conditions and the absorption of sound by the water (Francois and Garrison, 1982), and we must assume that fish are generally adapted to it. Unless it has a local or particularly intense source, reactions to background noise are likely to be weak and relatively unpredictable.

4. REACTIONS TO SOUND

4.1 Hearing in fish

The sensory systems of individual fish species are adapted to their biotopes, "life styles" and the likelihood of encountering particular situations (Hawkins, 1981; Hawkins and Myrberg, 1983), particularly in terms of food, sexual partners or threats. Audition is particularly important for fish because underwater visual range is limited although most fish have well-developed visual systems and make extensive use of vision (Guthrie and Muntz, 1993), and olfactory stimulation carries little information (and then only over a relatively short range), while sound is transmitted efficiently for long distances through water. A recent review of the physics of underwater sound transmission and of how fish respond to sounds is provided by Hawkins (1993).

Generally speaking, the auditory frequency range of fish seems to be much lower than that of most mammals, with sensitivity peaking below 2 kHz in most species measured, although it may extend to about 5 kHZ in some "specialists" (reviewed by Chapman, 1976). Cod seem to be most sensitive to sounds between 40 - 300 Hz, with a peak at around 160 Hz (Buerkle, 1968; Hawkins and Chapman, 1969). Sensitivity (in herring) decreases sharply at higher frequencies (Enger, 1967). Sand and Karlsen (1986) have shown that cod can hear "infrasound" with frequencies well below 10 Hz. An up-to-date brief review of sensitivity to infrasound is provided by ICES: C.M. 1994/B:5. The same report also discusses the question of fish sensitivity to ultrasound, citing a number of reports of avoidance reactions to echo-sounders, which emit pulses that are decades higher than the known range of sensitivity of fish auditory systems. The sensory system involved in detecting high-frequency sounds does not seem to have been identified, but one of the papers cited in the report (Astrup and Møhl, 1993) points out that there are good adaptive reasons for fish to have developed the ability to respond to the presence of echo-locating odontocetes.

Sound detection is via the otoliths of the inner ear (Sand, 1974), rather than the lateral line organ (Karlsen, 1992), though this system does detect local low-frequency water movements within a few body-lengths of the fish (Denton and Gray, 1983), *i.e.* it is probably most concerned with position maintenance in schooling.

Although directional discrimination of sounds is probably not as good as that provided by vision, it will often be sufficient to indicate the most efficient direction of flight, or to bring the fish within visual range of an attractive stimulus. A number of studies by

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used are jiggers and dip nets. Successful areas are: South-West Atlantic, Patagonian Shelf, George Bank, Japanese Sea, and the Caspian Sea. Links with the physiological state of the fish are reported. Apparently the presence of vitamin A in the fishes eyes play a role in the attraction effect. Discontinuous light sources were not applied and reported to have a low effect.

3.11 Work done in India

Sreekrishna (1995) points out the effect of colour of fishing gear components on their behaviour. A study by Aboobaker and Noble (1994) on Indian white prawns (*Penaeus indicus*) indicated preference to bright colours red, green and yellow for this species. Light stimulation is also mentioned by Sreekrishna for the waters of India. A scoop net fishing exists for Sardinella albella and Sardinella jussieu with torches as attractant Also the use of lanterns is reported to be successful.

3.12 Conclusions

There are strong indications that visual stimuli play a dominant role in fish reactions towards fishing gear. The absence of light causes fish to be taken by surprise by a moving gear. Articial light stimuli are used in many places in the world, *e.g.* in Japanese waters, with success. In these fisheries a combination of surface and underwater lamps attract fish to be caught by purse seines or dip nets. The effect seems to be restricted to certain pelagic and squid fisheries. These techniques are not applied in northern European waters for reasons not very well understood. Attempts to use artificial lights mounted on a trawl to manipulate fish behaviour did not result in clear responses. These studies were however only scarcely carried out, and may not give a final verdict. Manipulation of behaviour by using visual stimuli can be quite successful as is shown in Chapter 2. The full potential is not exhausted and more work needed to find effective ways to influence fish behaviour to improve species and size selectivity of fishing gears.

3.13 References to visual stimulation of fish including artificial lights

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Japanese light fishery is the largest light fishing industry in the world. Species targetted in with light stimulation are: *Cololabis saura, Sardinops melanostictus, Engraulis japonica, Etrumeus teres, Trachurus japonicus, Decapterus muroadsi, Scomber japonicus, Scomber australasicus, Ammodytes personatus, Spratelloides gracilis, Clupanodon punctuatus, Parapristipoma trileneatum, Auxis thazrd, Seriola quinqueradiata*. Gears used in Japanese light fishery are: stick-held dip nets, lift nets, small set nets (Hari-ami), surrounding nets, squid jigging, gill nets, scoop nets, harpoon and spears, beach seine, bag nets, and eight angle nets. The characteristics of light radiated by two underwater lamps and fish behaviour towards this stimulus is given by Hasegawa and Kobayashi (1989) for *Pneumatopholus japonicus* . The effectiveness of light stimulation was found to be dependent on time. An experiment described by Hasegawa, et. al (1991) shows the hightest concentrations of *Scomber japonicus, Scomber australasicus*, and the flying squid *Eucleoteuthis luminosa* to be attracted to an underwater lamp between 02:00 and 03:00 am. Studies on changes in the retinas of chub mackerel and sardines show differences in reaction before and after midnight for both species (Hasegawa et. al, 1991).

Work on light stimulation was also done in Russia, (Shekhovtsev, 1996, personal communication, Kaliningrad). Experiments commenced in the early 1960's and were aimed at finding whether fish can be attracted by light sources placed above and below the sea surface. Other countries working on this topic that were mentioned are Japan, Poland, Bulgaria and Eastern Germany. Most work was carried out between 1966 and 1989. First practical results were obtained on *Scomber Saurus* L. in the North-West Atlantic in the beginning of the 1960's. It appears that only a limited number of species react in a way that can be utilised in commercial fishery.

Species mentioned are:
- *Clupeonella Kessler* (Kilka's)
- *Trachurus mediterraneus ponticus* (Mediterranean scad)
- *Scomberesox saurus saurus* (Saury)
- *Sardinella aurita Valenciennes* (Atlantic saury)
- some squid species
- some flying fish

The light sources developed imitate the spectrum of the sun, being the most effective. Squid could be caught at commercially applicable rates. Mercury was used as filler gas for the lamps. Other gases were investigated to avoid pollution of the sea in case of lamps breaking. The research was terminated in 1989 due to loss of funding. Gears

Watson *et al.* (1992) also suggest that the primary reaction of fish to trawling gear is a visual reaction when visual conditions are adequate. They point out that not all fish exhibit the optomotor response, swimming in such a way as to keep a constant orientation and distance to a visual stimulus, and that the lack of an optomotor response increases the chances of escape. They add that flow-rate within the net also affects the way in which fish react visually to the net, underlining the idea that visual stimuli need to be studied in the context of a realistic capture situation. During a EU-project described by Van Marlen *et al.* (1994), which concentrated on species and size selectivity in midwater trawling, it was observed that netting panels with high visual contrast were avoided by mackerel, horse mackerel and herring. A black tunnel, which also offered high contrast to its background in a tank, was also avoided by the three species (Glass and Wardle, 1995, Glass *et al.*, 1995).

3.9 Increasing attractiveness of gear and baits

Wardle (1993) considered the role of fishing gear as a set of visual stimuli, and pointed out the low contrast of most visual stimuli even at moderate water depths. He suggests constructing trawl nets of materials with high-contrast patterns whose high visibility would guide the fish into the net.

Very few studies seem to have been done on realistic stimuli that might attract fish. One by Løkkeborg (1990), on artificial baits, compared the reactions of cod to rectangular vs. fish-shaped baits, but found no difference in response. Løkkeborg explained this by the omnivorous habits of cod. However, the same author (Løkkeborg *et al.*, 1993) did find that bait size is a reliable determinant of fish behaviour. According to He and Cai (1994), nets actually attract fish (two species of carp), and the degree of effect is related to mesh shape.

3.10 The use of lights in Japan and Russia

The use of light stimulation is widespread in Japan. Hasegawa (1993) describes the development of light fisheries in Japan. Topics reviewed are: the origin of fishing with light, historical changes of fishing light and its features, fishing with light in foreign countries, light fishing in Japan and in Mie Prefecture. As soon as men knew how to make fires, it was discovered that some kind of fish are attracted to light. Fishing with torches was eventually improved by using fuel oil, kerosene, gas and electricity. Throughout the centuries, the light fishery have used fires, torches, acetylene, kerosene, gas and electric incandescent and fluorescent lamps, as attractants. Some methods of fishing with light are applied in many countries in the world, but the

On the other hand, Beltestad and Misund (1989) conducted a series of experiments that showed how scattered herring may be concentrated by lights switched on **under** a school. The effect was to drive the fish towards the surface, an avoidance response which seems to be in agreement with the homeostatic tendency to avoid extremes of light levels, referred to above.

Taken together, these studies suggest that a dynamic programme of light stimuli might be one way of increasing the efficiency of purse seining gear. For example, a ring of weak lights might be switched on at or under the surface in order to attract scattered schools. This might be followed by a powerful light below schooling depth which would drive them upwards into a concentration for seining.

3.8 Stimuli produced by fishing gears in actual conditions

On the other hand, there are a number of studies of how fish actually react to the sight of fishing gear and/or approaching vessels. Wardle (1989) suggests that the sounds of fishing gear draw the attention of the fish long before they can see the gear, but only when the gear is seen can precise reactions be stimulated and the fish herded to the codend. This interpretation is confirmed by Walsh (1988, 1991), who found that bottom-living fish such as plaice and flounder were taken more efficiently at night by a survey trawl, whereas there were no differences in catch rates for cod. The difficulty of determining whether a particular species can actually see gear in the water even during daylight is brought out in a study by Zhang *et al.* (1993) of retinal adaptation in wall-eye pollock, which showed that at typical mid-water trawl depths, some retinas showed a tendency towards dark adaptation. The authors suggested that the lack of response of this species to trawl gear was due to reduced visual acuity and colour vision.

Walsh and Hickey (1993) compared the responses of demersal roundfish and flatfish to a bottom trawl under light and dark conditions, as well as in the dark with a constant artificial light, finding that the ordered pattern of reaction behaviour seen in roundfish during high light intensities disappears at low light intensities. In contrast to the increased catches reported by Clarke and Pascoe (1985), mentioned above, Walsh and Hickey found that attaching a strong light to the footgear was not enough to stimulate fish to respond in the ordered way.

stimuli are of no use in fish capture, as herding may require no more than a relatively straightforward approach or avoidance reaction to e.g. a strobe light.

3.7 Artificial lights and other artificial stimuli

Nemeth and Anderson (1992) found that coho and chinook salmon, for example, avoided strobe and high-intensity mercury lights, but were attracted to dim lights. Their work was done in the context of designing bypass systems for smolts to enable/encourage them to avoid water intakes, but has obvious relevance to the capture situation. A study by An and Arimoto (1994) suggests that there is a stress component in the avoidance reaction. Various rates and intensities of strobe lights produced both avoidance reactions and rises in heart rate in jack mackerel. Heart rate decreased once again when the fish passed the strobe light barrier.

Sager (1987) and Sager et al. (1987) also examined the potential of combinations of strobe lights and bubble curtains as behavioural guidance systems for estuarine fish. They concluded that while bubble curtains alone had little effect on avoidance behaviour, strobe lights were effective alone and even more so in combination with bubble curtains. The latter presumably provide a primarily visual stimulus. Sager and his colleagues were primarily interested in fixed systems designed to prevent impingement of fish on water intakes, but the technology raises the interesting prospect of incorporating a bubble curtain into fishing gear, establishing a virtual wall whose effect might be increased if it were illuminated.

Many fish species do react positively to bright lights, a response that has been exploited in fisheries all over the world for many years (*e.g.* Mubamba, 1992, Enderlein and Wickström, 1991). As far as is known, more or less constant (non-flashing) lights are always used. Clarke and Pascoe (1985) utilized a very modest 70 W light in conjunction with midwater trawling gear in the Bay of Biscay and off Madeira at depths of 800 m, where ambient light levels are negligible. They found significant increases in numbers and total volume of fish taken, as well as in the size of the biggest fish. At the same time, catches of crustaceans, mainly decapods, dropped significantly. Larinier and Boyer-Bernard (1991) actually used underwater mercury lights to encourage fish migration past a by-pass, finding that three to eight times as many fish were bypassed with the lights on, significantly increasing the rate of passage.

salmon, well below the dangerous upper reaches of the water column (visual predation) but giving sufficient light for feeding. This type of behaviour is found in both marine and freshwater species (Wandera, 1993).

The startle response has the effect of activating the animal as the first stage in distancing it from a potential source of danger before the degree of risk has been fully evaluated. Nakamura and Ishida (1983) found that individually tagged yellowtail rapidly escaped vertically downwards from sudden sound or light stimuli. Batty (1989) elicited a startle response in herring larvae to bright flashes of light and to dark looming stimuli, and found a more consistent directional escape response from these visual stimuli than that brought about by sound or touch. This suggests that some sort of evaluation of the stimulus had taken place.

In catch/survey situations, the startle response will often already have occurred to sound stimuli, as vessel noise usually precedes the onset of visual stimuli such as trawl doors, sand clouds, etc. (Engås, 1994). This leaves the fish free to investigate the source of the sound, which at some point will be supplemented by the visible approach of the gear. This appears to be the case, for example, in the study reported by Engås et al. (1991), one of whose figures shows acoustically tagged cod first swimming **towards** an approaching trawler, then parallel to but ahead of it, until it veers off at burst speed as the vessel overtakes it. Main and Sangster (1983) also found that roundfish swam slowly towards the approaching gear, equidistant between the doors. Such results appear to confirm the common-sense idea that reactions to unfamiliar sensory stimuli will usually be a balance of investigation and avoidance.

3.6 Visual stimuli

Real-life stimuli that may have exerted selection pressure on the species in the past are more likely to elicit an adaptive response from an individual than an artificial stimulus, but are correspondingly more difficult to investigate systematically, due to their very complexity. This is especially true of visual stimuli, where the number of dimensions that can be varied is so much greater than in olfaction or audition. These dimensions include size, shape, brightness, chromaticity, contrast, polarization, movement, periodicity, orientation, complexity, etc., as well as the dynamic functions (in time and/or space) of many of them. Only some of these have been investigated, and very few in meaningful combination. This is not to say that highly artificial signals intercepted by predators, citing studies by Endler (*e.g.* 1987) that demonstrated how differences in pigmentation depend on the pattern of visual sensitivity of particular predators.

3.5 Fish vision and fish capture

Vision is but one aspect of a whole complex of sensory inputs, processing mechanisms and types of behaviour that must be taken into accout when considering how fish rect to different types of fishing gear. This field was comprehensively reviewed by Wardle (1993), who emphasizes the importance of the blind zone in the visual field of the typical roundfish in determining how it swims in relation to an approaching trawl. He suggests that the tendency of the fish to maintain a constant visual angle to the trawl board, while it is moving at a greater speed than their swimming speed, results in them automatically gathering behind the board - the fountain effect. This places them in a position to be guided towards the trawl opening by the sand clouds swept up by the boards. The strong visual stimuli provided by the netting, ropes, floats and bobbins of the trawl itself are perceived only much later.

As Douglas and Hawryshyn (1990) point out, there is a wide range of innate responses to visual stimuli. These include the optomotor response, pursuit eye movements, dorsal light reactions and phototactic behaviour, as well as more complex behaviours such as feeding, barrier avoidance, schooling, the light shock reaction and aggression. Douglas and Hawryshyn provide extensive lists of references for each of these types of behaviour as means of evaluating the visual capabilities of individual species, but they have little to say about the role of vision in real-life situations.

As far as the capture situation is concerned, the main areas of interest are probably attraction to, and avoidance of, visual stimuli, as well as the possibility of conditioning approach or avoidance responses to such stimuli.

The two most basic reactions are probably the tendency to avoid bright ambient light levels as well as complete darkness by changing swimming depth, and the startle response to any unanticipated movement in the visual field, particularly overhead (*e.g.* Eaton and Bombardieri, 1978). Appenzeller and Leggett (1995) and Fernö et al. (1995) are among the most recent of many workers who have found evidence of diel vertical migration, which seems to serve the dual purpose of keeping fish, in this case

Of course, the presence of particular combinations of pigments says little about how cone or rod signals are processed by the retina or the rest of the visual system. However, these CNS stages appear to possess neural feature-extraction mechanisms that resemble those of the more familiar mammalian systems. These processes are reviewed in further chapters in the volume edited by Douglas & Djamgoz (1990).

3.4 Vision and behaviour

Likewise, the ability of the visual system to process external information provides by itself no indication of how fish perceive their visual environment or react to it. However, as Guthrie and Muntz point out, the variety of colour patterns and specific movements that they display invite comparison between them and the most visually oriented species among birds and mammals. Indeed, it is likely that the extreme vividness of the defensive and/or sexual displays of many fish species, as well as complementing the characteristics of the visual systems they are designed to attract or repel, has evolved to compensate for the inadequacies of the underwater visual environment as outlined in the above paragraphs. Theoretical treatments of the relationship between the physical surroundings and the biology of the visual system, with emphasis on the predatory behaviour of fish, are provided by Aksnes and Giske (1993 a and b).

Vision plays a role in feeding and orientation (Blaxter, 1980; Huse, 1993, 1994; Giske and Salvanes, 1995), schooling (Blaxter and Batty, 1990), territorial and sexual behaviour (*e.g.* Tinbergen, 1951) and in predator avoidance (Fernö *et al.*, 1995). Blaxter & Batty, in fact, point out that in darkness, herring schools disperse and the level of activity of individuals falls, while Huse *et al.* (1994) found that fish were significantly less polarized by night than during the day, i.e. that the schools became less structured. Similar results for two species of salmon are reported by Nemeth and Anderson (1992). Huse (1994) emphasizes the wide differences in light level preferences shown by the three species whose larval feeding patterns he studied, with plaice being the most versatile, the surface-feeding turbot preferring high light levels, and cod feeding in near dark.

Studies from all these areas of natural behaviour can provide information that is also relevant to the capture situation. These different facets of behaviour interact in many ways. For example, Guthrie and Muntz (1993) point out that there is a balance of selective forces between signalling effectively to conspecifics, and having these

Other factors have more subtle effects. Scatter, for example, due to particles in the water column, not only decreases light penetration, but also decreases its directionality so that beyond a certain depth photons enter a volume of water equally from all directions. Consequently objects cast no shadows and all directional cues from the light field are lost (Loew & McFarland, 1990). Image brightness is reduced, two-dimensional image information is destroyed and contrast is lessened. All of these factors are likely to have negative effects on the ability of individual fish to locate, identify and avoid threats by visual means (Lythgoe, 1972).

Pelagic species may be affected by fluctuations in light intensity caused by interference patterns of surface waves and ripples. Above a certain frequency, the critical fusion frequency, the light is experienced as constant, but below it, flicker may provide fish with extra visual information or alternatively, reduce the contrast needed to discriminate an object from its background.

3.3 Sensory and perceptual systems

Once again, these have been thoroughly reviewed by the writers of chapters in a single recent volume. Fernald (1990) discusses the optical system of fish in physical terms, and points out that the optical resolution of the fish lens is very good, and in fact appears to be about ten times better than the retinal resolution would predict. According to Fernald, this may have the effect of improving contrast detection.

Bowmaker (1990), reviewing receptor types, points out that most species contain rods and cones, and thus have the ability both to make use of low light levels and probably to make wavelength discriminations. (At least two spectrally distinct types of cones with overlapping spectral sensitivities are required for polychromatic vision). Given the restricted spectral range of many underwater habitats, a dichromatic visual system may well be sufficient to extract most of the useful information provided by the visual environment. An interesting finding (Bowmaker *et al.*, 1988) is of the presence of two classes of rod with different spectral sensitivities in the same (deep-sea) species, suggesting that such fish may possess rod-based (*i.e.* highly sensitive) dichromatic vision. Similar results have been reported by Partridge et al, 1988). Bowmaker also refers to unpublished work on cod by himself and Djamgoz, showing the presence of two types of cones with maximum sensititivies at 517 nm and 446 nm, ideally located for dichromatic vision in the blue-green light of coastal marine waters.

3. VISUAL STIMULATION OF FISH, INCLUDING ARTIFICIAL LIGHTS

3.1 Introduction

The role of fish vision in capture situations is a function of three interrelated factors: the light irradiance of the physical underwater environment of the species concerned, the evolution and immediate adaptation of its sensory and perceptual systems to that environment; and the interference of the visibility of catch gear and related anthropogenic inputs on the first two factors.

3.2 The physical environment

The underwater physical environment has recently been well reviewed by Guthrie and Muntz (1993) and Loew and McFarland (1990). Guthrie and Muntz also refer to a number of earlier reviews. While most aspects of their discussions are beyond the scope of this short review, certain points should be kept in mind. For instance, Loew & McFarland point out that due to the effects of water composition, depth and turbidity, the range of intensities of irradiance available to individual species at different times and locations is much wider than that available to land-dwelling species. A comprehensive list of physical parameters was also given by Sreekrishna, 1995, among which temperature, oxygen content, salinity, turbidity, turbulance, tides, upwelling, the presence of mud banks, wind, sun light and also lunar periodicity.

The spectral composition of light underwater also differs from that in air at sea level, and it also varies more from place to place and at different depths. However, it is generally true to say that the range of wavelengths available to marine species is narrower than on dry land, with the peak irradiance wavelength around 460 nm in "pure" water (Dartnall, 1975). In practice, most natural waters contain a wide range of scattering and absorbing agents, which both increase attenuation and alter the spectral composition of the light that is available to fish. Although UV-A light can penetrate the surface layers of water in potentially useful amounts, marine species with UV-sensitive receptors have not been identified, while several freshwater species have such receptors (e.g.: young brown trout, yellow perch, bluegill sunfish). Loew and McFarland suggest that useful spatial information mediated by UV light would be limited to short distances at shallow depths. We may therefore expect to find a wider range of adaptations to local and temporal conditions among fish than in mammals, for example.

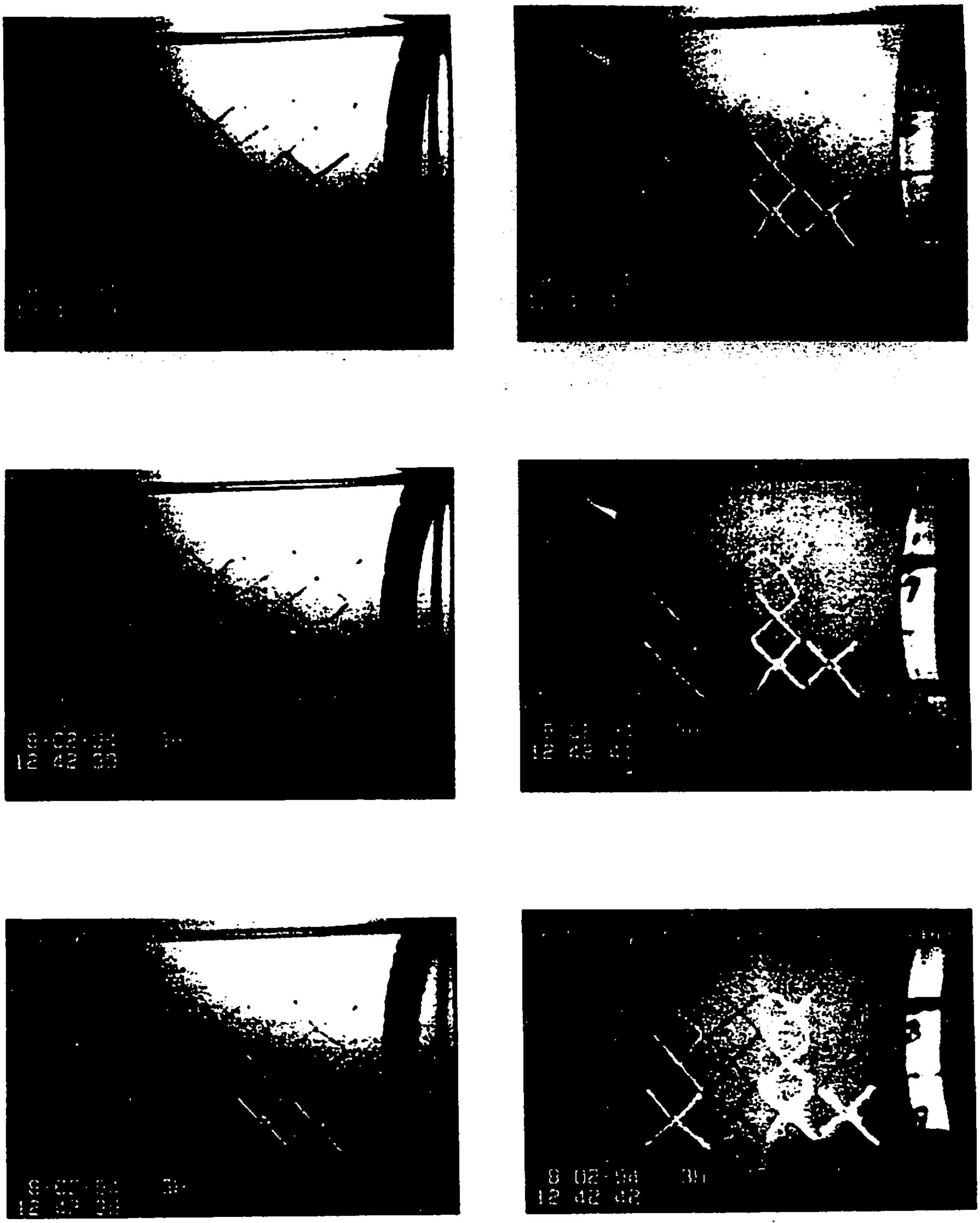

Plate 2.1 Examples of the video image of netting (frame 1 in Fig.2.3)changing with zenith angle. From left row (top) 70 *deg*, (middle) 90 *deg*, and (bottom) 110 *deg*, and from right row (top) 130 *deg*, (middle) 150 *deg*, and (bottom) 170 *deg*.

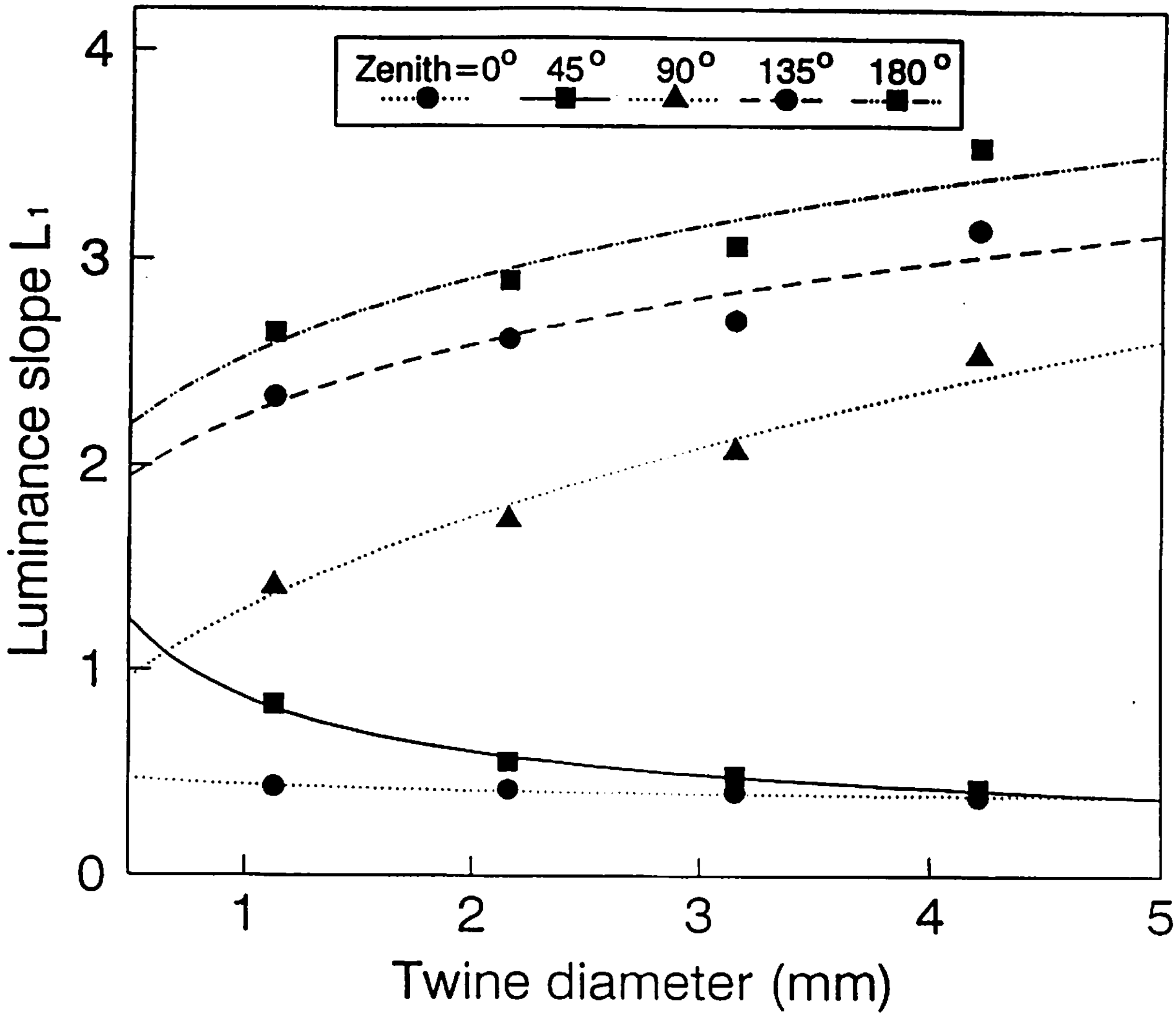

Fig. 2.10 An example of the relationship between the luminance slope L_1 and PA white twine diameter Dt for different zenith angles.

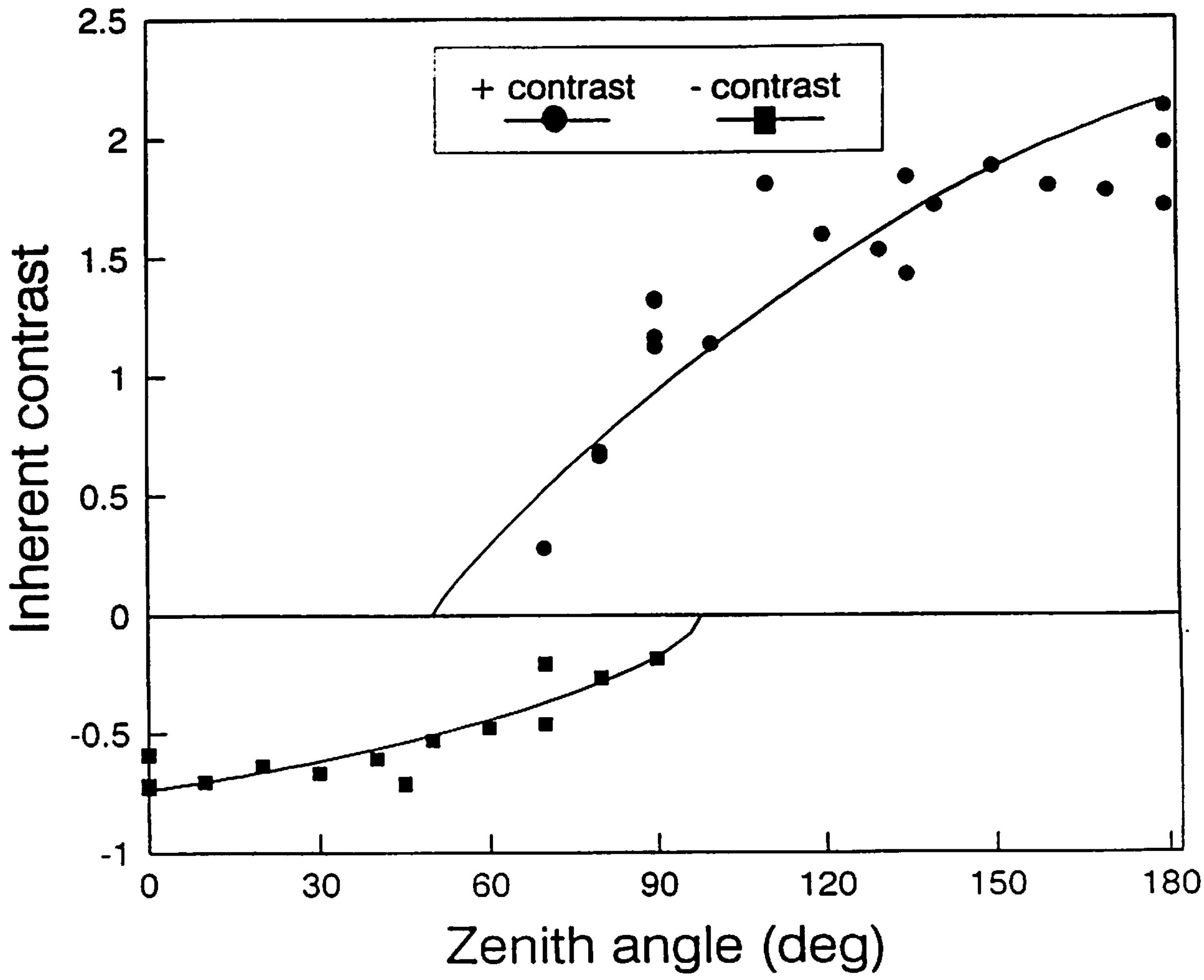

Fig. 2.8 An example of the inherent contrast of the white knot made from 3 mm diameter (twine serial No 31) twine changing with the zenith angle at depth 50 m. The fit curves are represented with the coefficients b_0=2.351, b_1 =0.859 and $Z_0(+)$=49 *deg* (N=20, r=0.88) as +ve contrast and b_0=-0.876, b_1=0.607 and $Z_0(-)$=98 *deg* (N=15, r=0.86) as -ve contrast.

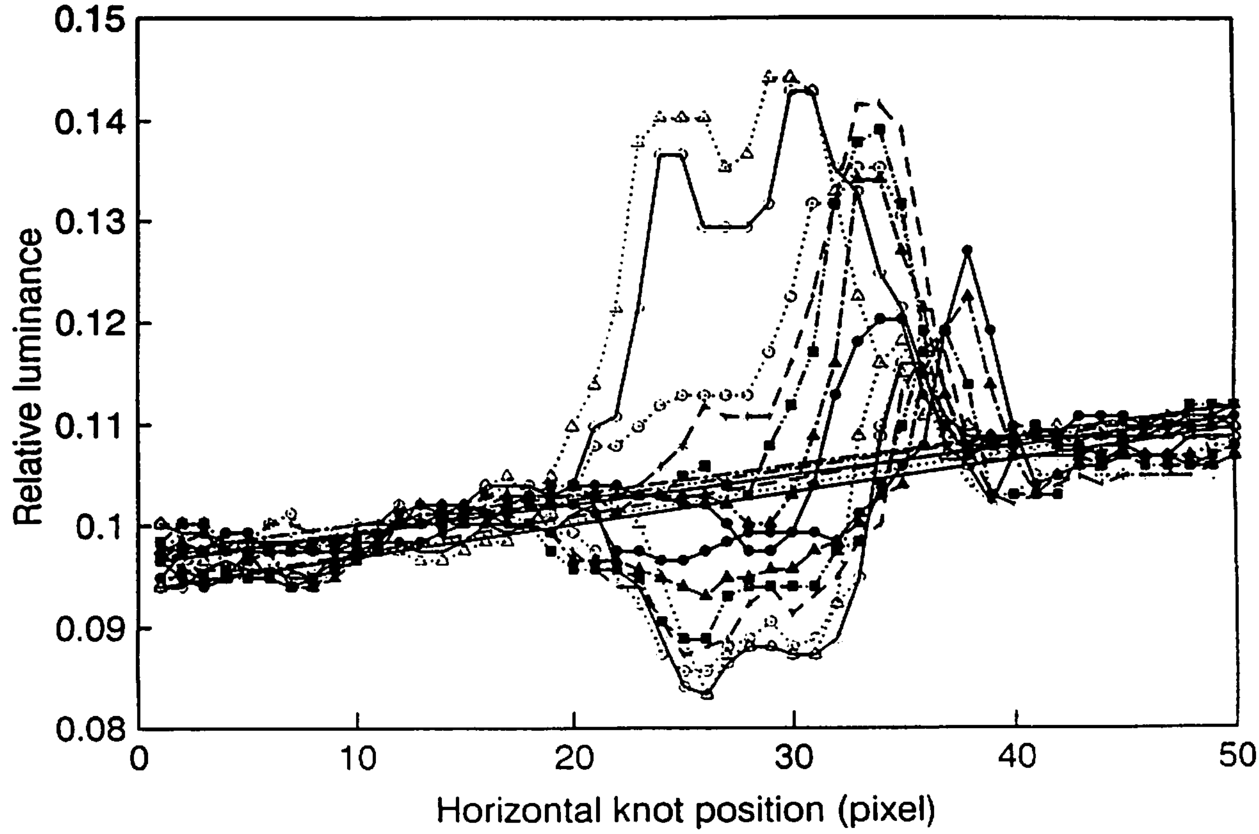

Fig. 2.7 One example of the relative luminance distribution in a white knot of twine diameter 3 *mm* along the horizontal pixel lines and viewed at 80 *deg* zenith and 50 *m* depth.

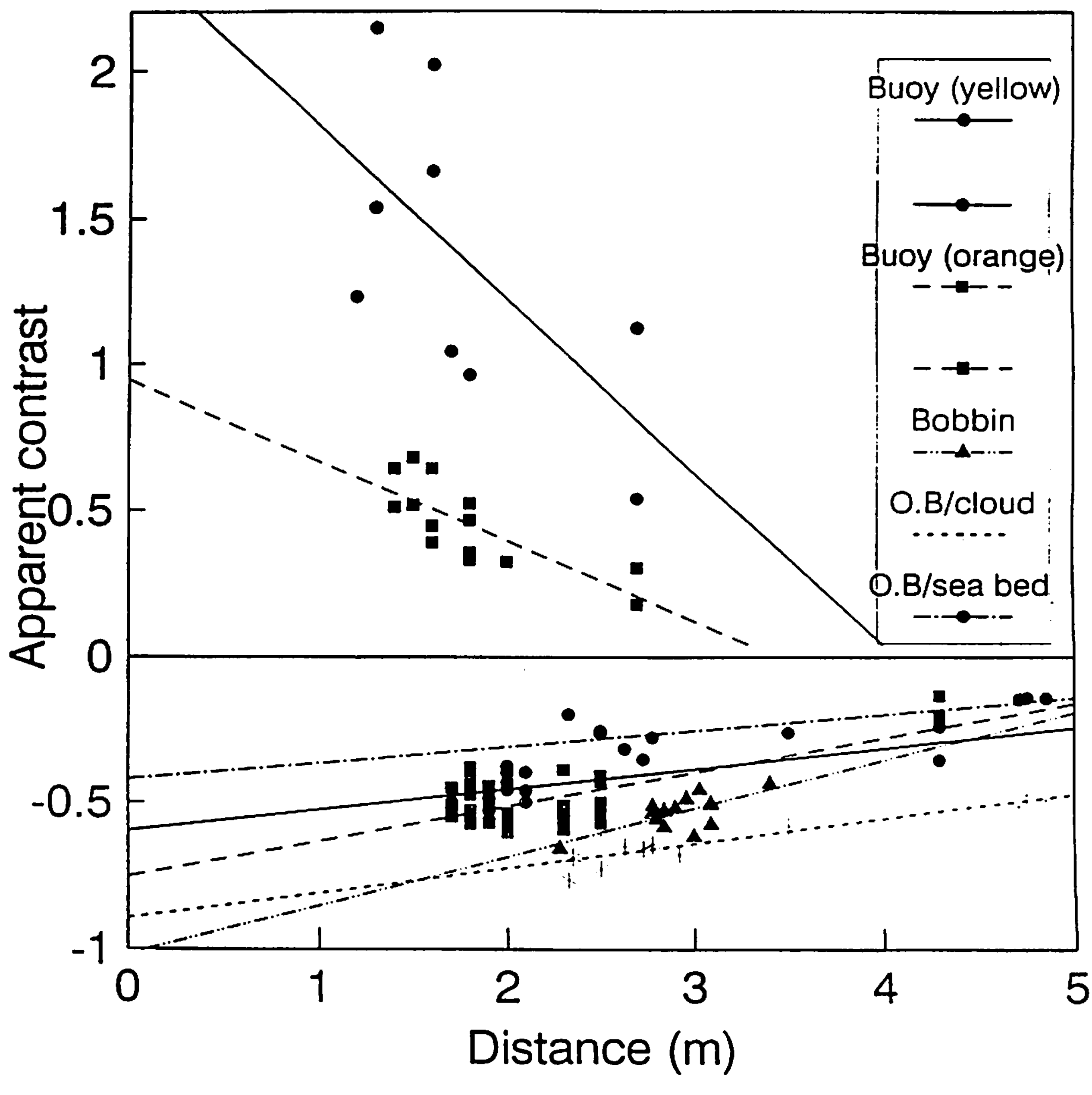

Fig. 2.6 The apparent contrast (Cr) of floats, bobbins and otter board from the image processing of TV film of towed trawl gear.

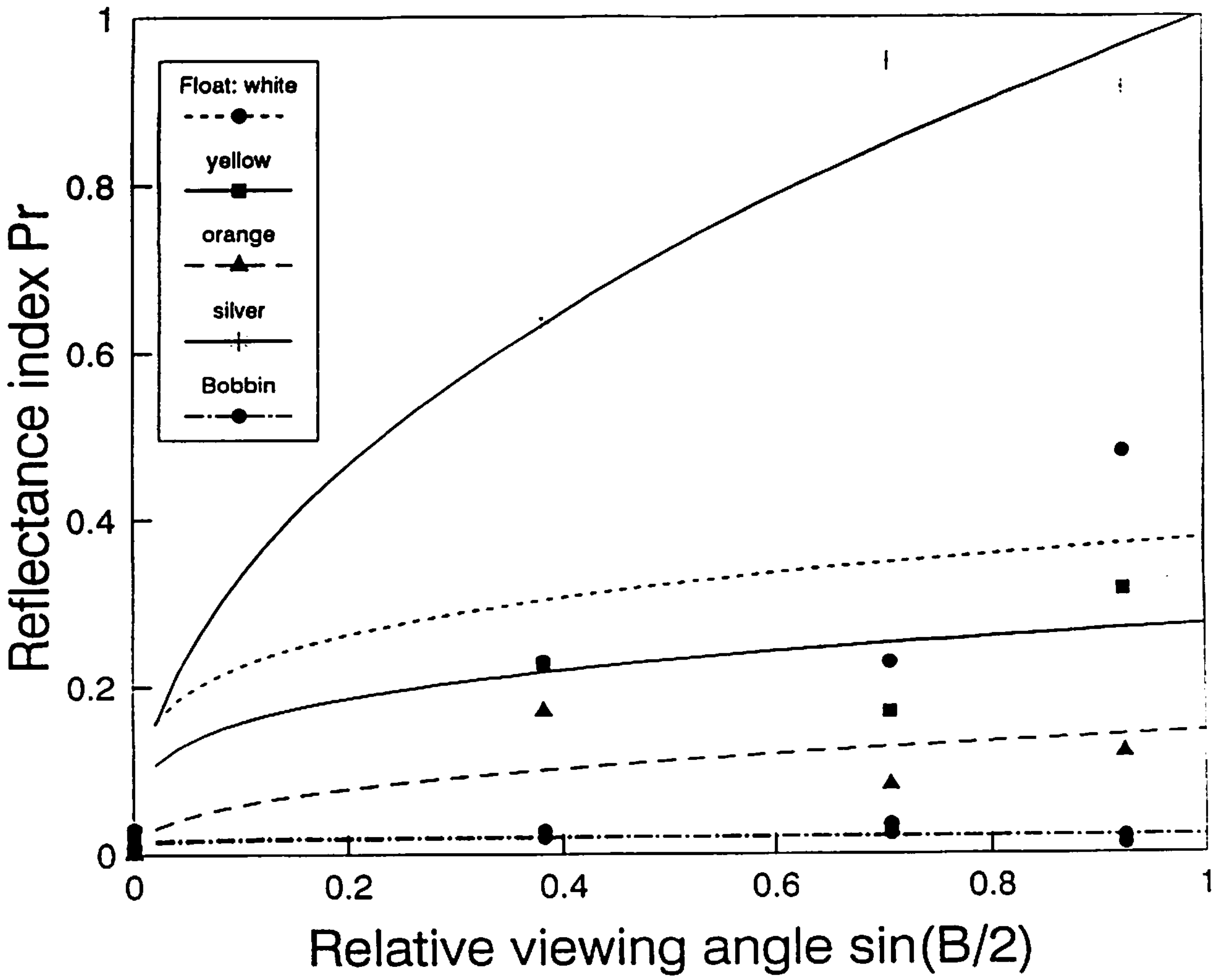

Fig. 2.5 The reflectance factor Pr related to relative viewing angle (B) of the floats and bobbins from equation (2.10) illuminated through dark green filter.

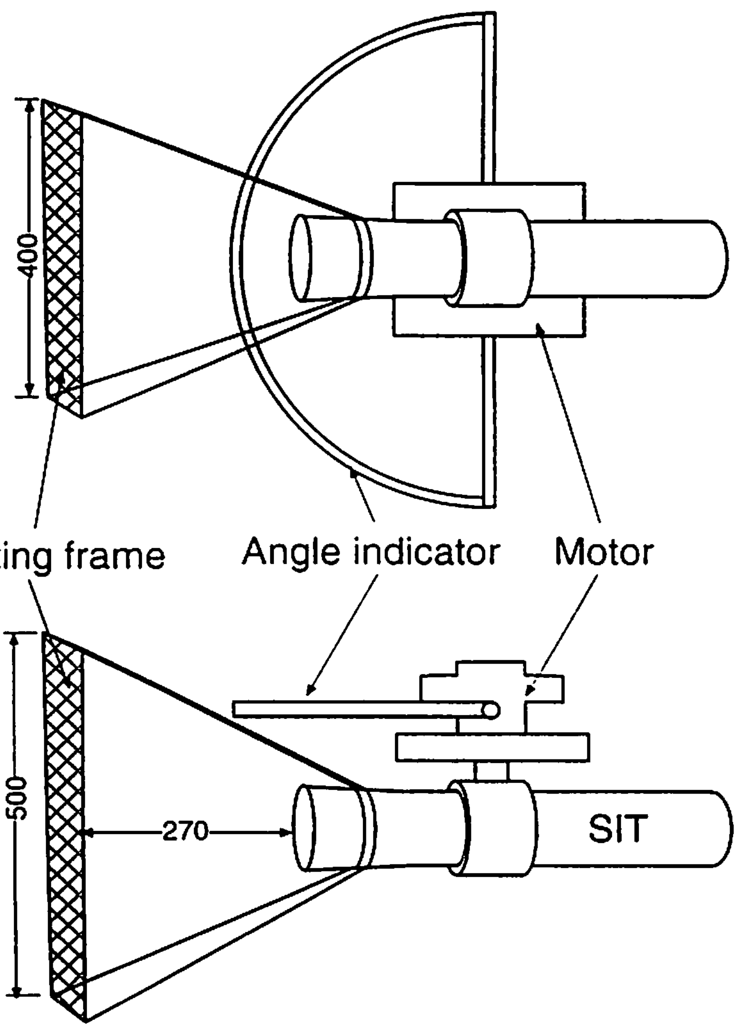

Fig. 2.4 Side (upper) and top (lower) viewing of self-contained apparatus for recording the TV images of twine and knot samples viewed at different zenith angles and depths in the sea.

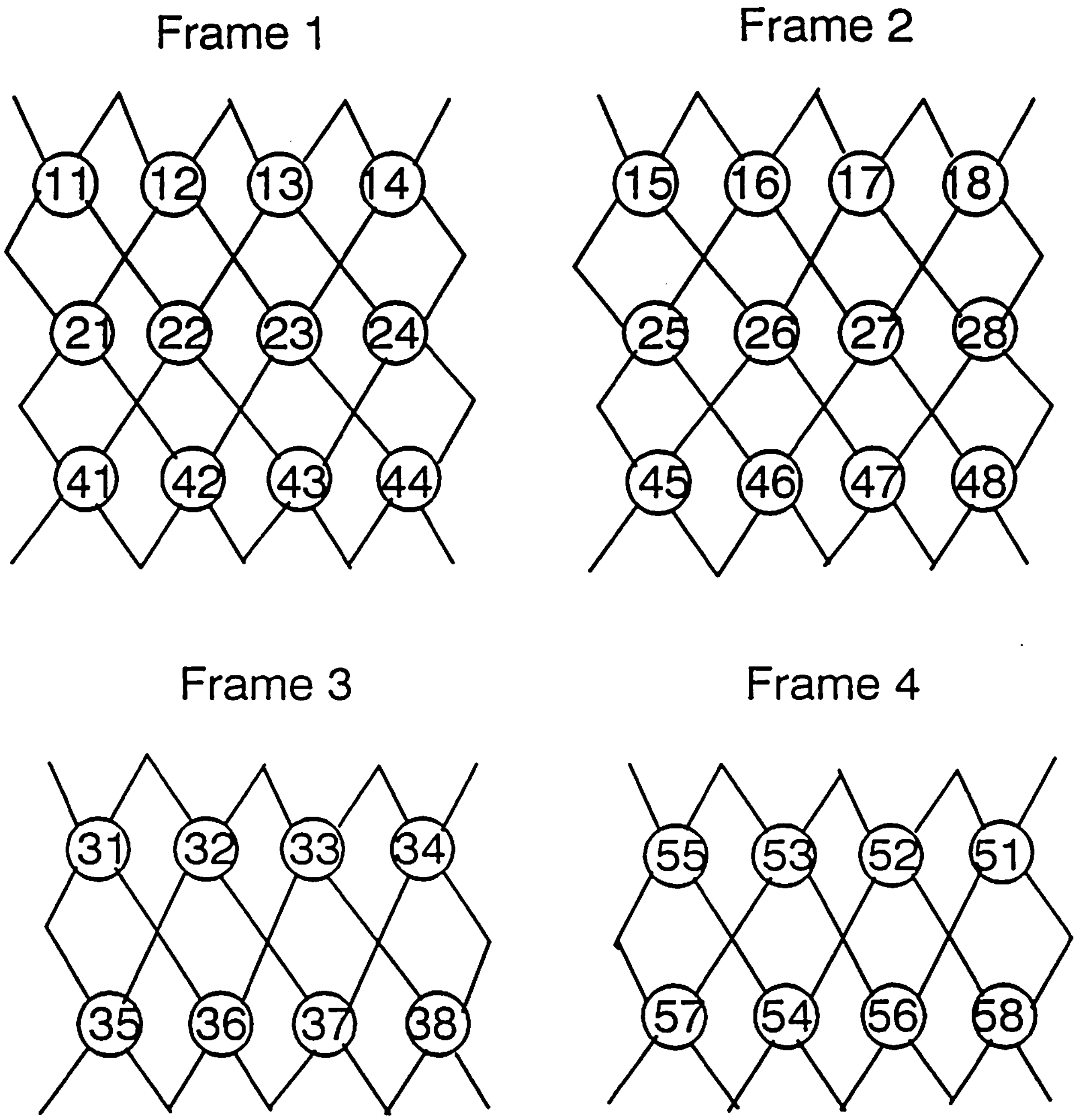

Fig. 2.3 The arrays of 4 netting frames with sequence No of the twine.

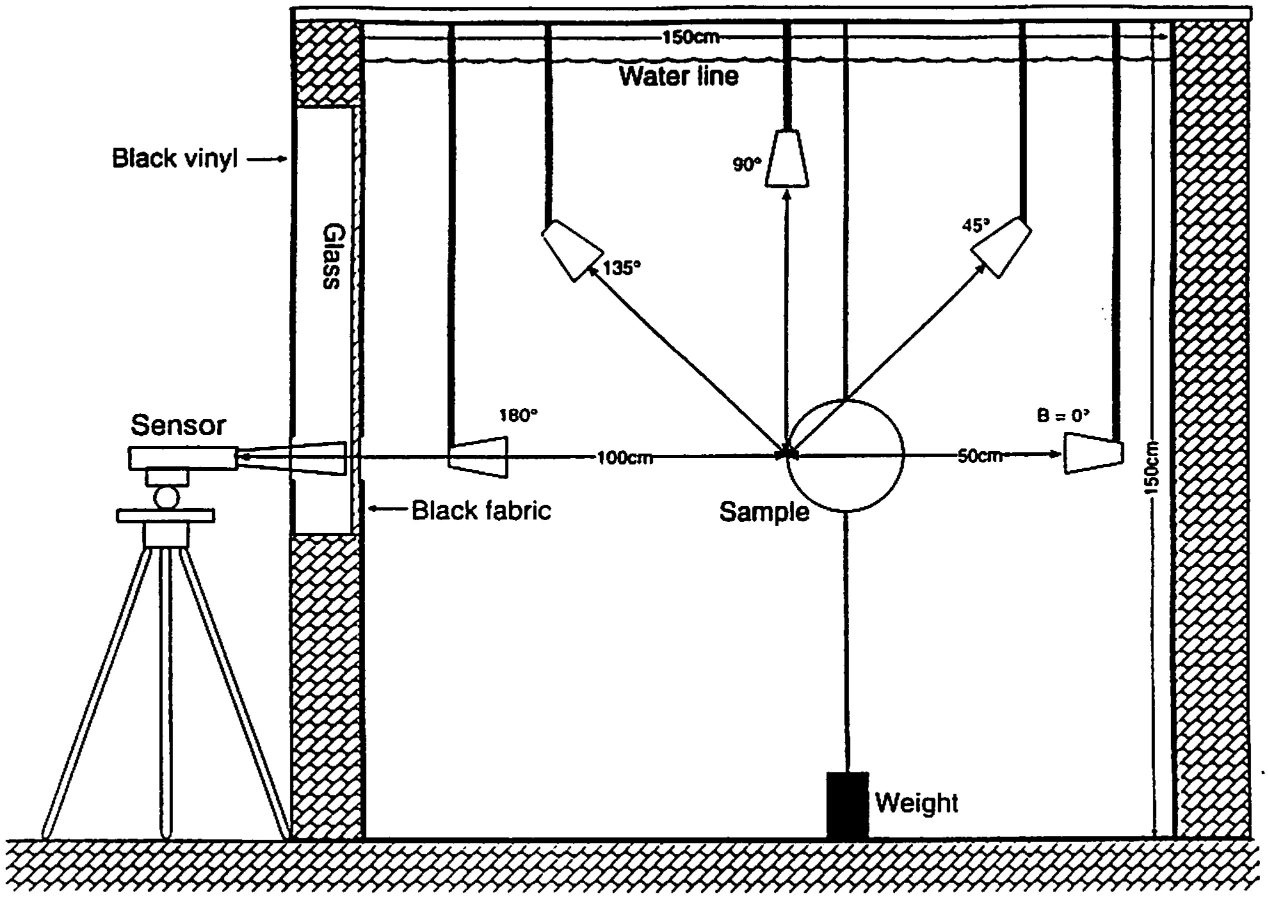

Fig. 2.2 The experimental setup for luminance measurements of the trawl components within a concrete and glass light proofed aquarium tank.

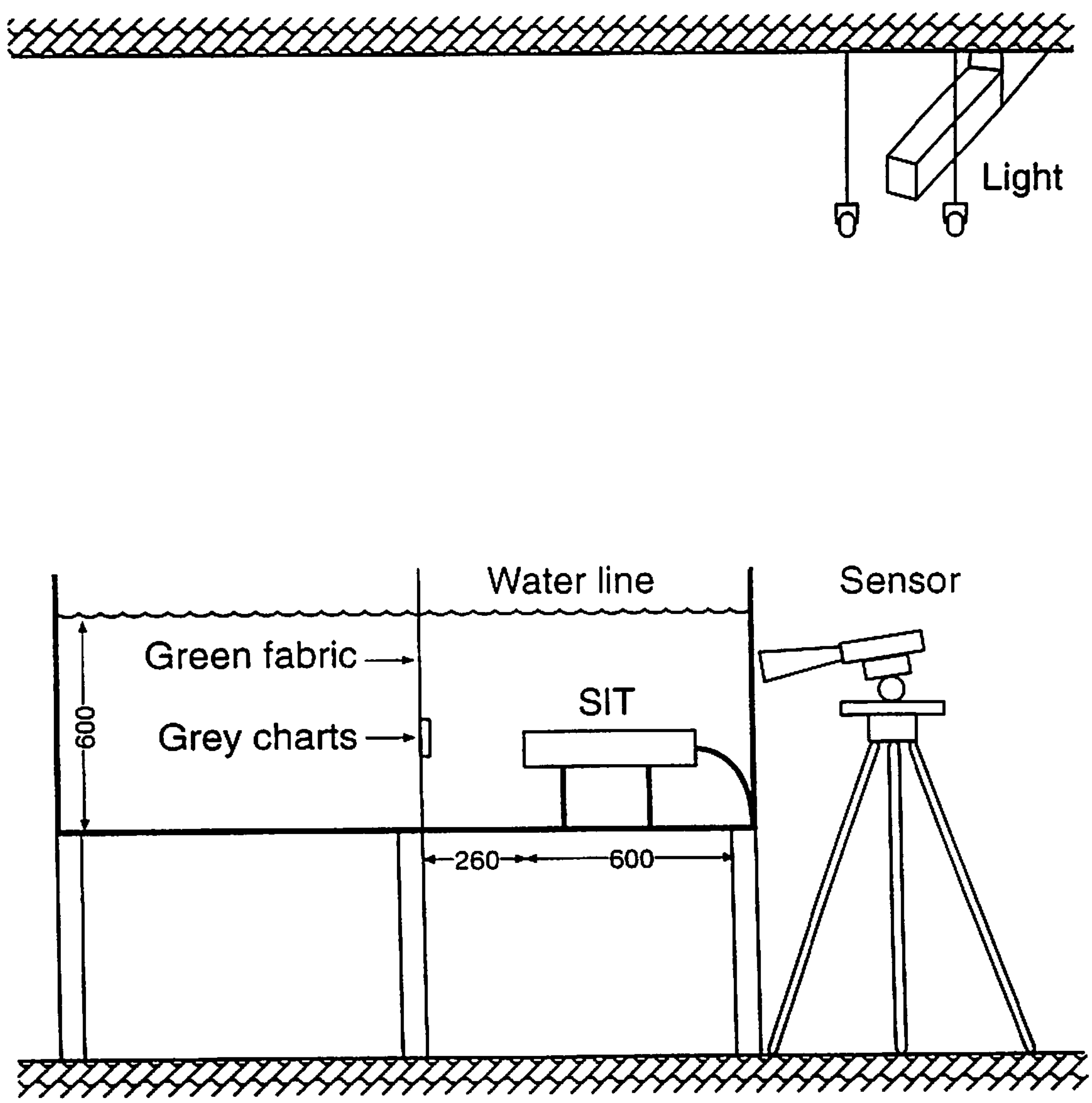

Fig. 2.1 Experimental setup for video image calibration using standard grey charts.

Table 2.10 The attenuation function BA=exp{(-c+k*cos(ZA)}*SA during underwater observation

Date (Feb/94)	Depth (m)	BA ZA=0°	45°	90°	135°	180°
2	30	0.7530	0.7442	0.7232	0.7029	0.6946
	40	0.7485	0.7397	0.7188	0.6986	0.6904
	50	0.7439	0.7352	0.7145	0.6943	0.6862
	60	0.7394	0.7307	0.7101	0.6901	0.6820
6	30	0.7597	0.7526	0.7357	0.7192	0.7125
	40	0.7597	0.7526	0.7357	0.7192	0.7125
8	30	0.7239	0.7178	0.7030	0.6886	0.6827
	40	0.7208	0.7147	0.7000	0.6856	0.6797
	50	0.7185	0.7122	0.6976	0.6833	0.6774
	60	0.7167	0.7105	0.6959	0.6816	0.6758
	70	0.7156	0.7095	0.6949	0.6806	0.6748
	80	0.7152	0.7091	0.6945	0.6803	0.6745
Mean		0.7346	0.7274	0.7103	0.6937	0.6869
SD		0.0179	0.0170	0.0152	0.0139	0.0134

Table 2.9 The mean value of power n of equation (2.16) and coefficients Ld and power m of equation (2.17) with colour and zenith for knots

Colour	Zenith	Ld*	m*	n**	Colour	Ld*	m*	n**
White,	0	0.445	-0.091	0.947	Blue,	0.652	-0.625	0.947
PA	45	0.871	-0.514	0.972	PA	0.688	-0.545	0.940
	90	1.297	0.434	1.032		0.807	-0.352	0.962
	135	2.241	0.207	1.025		1.478	0.290	1.010
	180	2.524	0.205	1.030		1.543	0.279	1.010
Black,	0	0.604	-0.534	0.955	Dark	0.510	-0.601	0.912
PA	45	0.622	-0.461	0.973	blue,	0.727	-0.647	0.940
	90	0.634	-0.380	0.947	PA	0.823	-0.536	0.951
	135	0.632	-0.359	0.960		1.069	0.312	1.008
	180	0.694	-0.362	0.965		1.091	0.408	1.013
Green,	0	0.636	-0.664	0.947	Yellow,	0.523	-0.506	0.906
PA	45	0.733	-0.661	0.950	PA	0.573	-0.394	0.920
	90	0.879	-0.450	0.978		0.732	-0.382	0.945
	135	1.219	0.379	1.012		1.065	0.403	1.040
	180	1.616	0.295	1.033		1.117	0.448	1.039
Dark	0	0.482	-0.679	0.956	Red,	0.558	-0.489	0.944
green,	45	0.502	-0.552	0.942	PA	0.586	-0.418	0.954
PA	90	0.567	-0.450	0.956		0.592	-0.350	0.952
	135	0.615	-0.369	0.960		0.614	-0.336	0.950
	180	0.628	-0.295	0.960		0.637	-0.293	0.960

* each No. of data is 4 as 4 kinds of diameter and each correlation coefficient is $r > 0.95$

** mean values of 4 data

Table 2.8 continued

Colour	Con-trast (+ or -)	Dt (mm)	zenith=0° knot	twine	dif*	Twine contrast ratio(%) Cmax/Ckt**	Cmin/Cmax***
Yellow	-	2.36	135.1	135.1-10.0		86.4	96.0
	+	2.36	85.4	110.010.0		90.0	96.0
	-	3.46	140.0	135.0-10.0		95.1	96.0
	+	3.46	85.4	110.510.0		89.1	96.0
	-	4.80	156.3	165.2-25.0		95.8	95.8
	+	4.80	97.4	111.0	15.0	55.1	95.8
Blue	-	2.53	144.3	144.3	30.0	63.0	89.0
	+	2.53	92.0	91.7	20.0	92.3	89.0
	-	3.48	141.7105.7		10.0	82.7	89.6
	+	3.48	99.0	90.0	10.0	90.0	89.0
	-	4.85	141.1152.7		-45.7	87.0	89.3
	+	4.85	57.3	89.9	20.0	89.0	89.3
Dark blue	-	2.27	177.0	177.0	10.0	75.0	95.0
	+	2.27	57.6	110.0	10.0	85.0	95.0
	-	3.44	148.4	124.4	10.0	89.0	95.0
	+	3.44	57.6	90.6	10.0	90.6	95.0
	-	4.87	150.9	129.0	10.0	94.9	95.0
	+	4.87	88.1	91.4	10.0	93.6	95.0
Black	-	2.31	78.7	92.5		48.1	70.0
	-	3.40	100.0	95.0		62.1	80.0
	-	4.96	100.0	100.0		76.8	89.0
Dark green	-	2.27	72.2	87.2		57.0	46.7
	-	3.49	93.8	97.5		37.6	77.8
	-	4.76	96.5	97.3		75.2	100.0
Red	-	1.99	84.9	97.6		71.3	92.6
	-	3.53	85.8	87.6		77.9	99.0
	-	4.97	93.0	96.6		83.0	88.1

* dif: Zenith angle difference between Cmax and Cmin at zero contrast

** Ckt: Contrast of the knot

*** Cmax: Maximum contrast of twine

Cmin: minimum contrast of twine

Table 2.7 continued

Filter	Colour	Relative viewing angle (deg) 135				180			
		Pr	np	No	r	Pr	np	No	r
Blue	Red	0.010	1.078	18	0.998	0.020	1.078	22	0.996
	White	0.100	1.029	24	0.995	0.251	1.004	26	0.998
	Dark blue	0.045	1.141	22	0.997	0.076	1.069	22	0.993
	Green	0.036	1.001	22	0.998	0.070	1.029	22	0.993
	Dark green	0.012	1.127	18	0.996	0.024	1.007	22	0.999
	Blue	0.063	1.235	22	0.990	0.101	1.028	24	0.998
	Black	0.009	1.045	18	0.998	0.014	1.063	20	0.999
	Yellow	0.033	1.132	20	0.989	0.046	1.001	24	0.998
	PE green	0.097	1.048	24	0.995	0.113	1.012	24	0.998
	PE orange	0.018	1.001	20	0.994	0.062	1.004	22	0.996

Table 2.8 The approximated zenith angle when the inherent contrast C0=0 and the calculated contrast ratio of twine to knot

Colour	Con-trast (+ or -)	Dt (mm)	zenith=0° knot	twine	Twine contrast ratio(%) dif*	Cmax/Ckt**	Cmin/Cmax***
White	-	2.16	78.1	78.1	2.2	81.2	96.7
	+	2.16	69.3	69.3	2.2	77.2	96.7
	-	3.15	98.3	98.1	2.2	92.1	96.7
	+	3.15	48.8	71.6	2.2	76.8	96.7
	-	4.21	93.0	98.3	2.2	93.4	96.7
	+	4.21	55.3	69.5	2.2	93.3	96.7
Green	-	2.33	162.9	162.9	5.0	71.8	70.0
	+	2.33	105.4	105.4	5.0	81.6	70.0
	-	3.54	136.6	119.1	5.0	78.4	94.2
	+	3.54	85.9	101.4	5.0	60.3	94.2
	-	4.96	151.9	136.3	1.0	85.5	89.1
	+	4.96	82.5	110.1	1.0	69.3	89.1

Table 2.6 The mean values of power np in equation (2.10) and coefficients a_0 and a_1 in equation (2.11) for 4 coloured floats

Filter	Coefficients	Colour of float			
		White	Yellow	Orange	Silver
	np	1.1112	1.0938	1.1184	1.0162
	a_0	0.3772	0.2748	0.1449	1.0000
Green	a_1	0.2240	0.2434	0.3943	0.4795
	r	0.955	0.982	0.983	0.999
	np	1.0381	1.0044	1.0129	1.0377
	a_0	0.3254	0.2418	0.1469	1.0000
Blue	a_1	0.3369	0.2034	0.2621	0.5252
	r	0.958	0.976	0.970	0.999

* each No. of data is 5 as viewing angle 0, 45, 90, 135 and 180°.

r: correlation coefficient

Table 2.7 Results of light measurement for ropes with the slopes Pr and power np in equation (2.10)

Filter	Colour	Relative viewing angle (deg)							
		135				180			
		Pr	np	No	r	Pr	np	No	r
Green	Red	0.008	1.166	14	0.978	0.021	1.149	18	0.994
	White	0.138	1.143	22	0.995	0.308	1.079	24	0.998
	Dark blue	0.051	1.120	20	0.991	0.074	1.140	20	0.993
	Green	0.058	1.118	20	0.995	0.088	1.160	20	0.993
	Dark green	0.013	1.248	14	0.979	0.032	1.218	18	0.984
	Blue	0.091	1.248	20	0.994	0.123	1.111	22	0.991
	Black	0.009	1.123	14	0.992	0.023	1.242	16	0.984
	Yellow	0.064	1.109	20	0.988	0.092	1.119	20	0.993
	PE green	0.112	1.177	20	0.990	0.158	1.098	22	0.996
	PE orange	0.020	1.195	18	0.992	0.063	1.108	20	0.995

Table 2.3 continued

Illuminance (lux)	Grey steps	No. of data	Grey level mean	(SD)	Relative luminance
0.0039	5	31	21.58	1.15	0.0010
	6	30	23.97	1.63	0.0017
	7	30	25.90	0.66	0.0021
	8	30	27.53	1.22	0.0027
	9	30	28.67	0.96	0.0033

Table 2.4 The coefficients E_0-E_3 of the equation (2.7) with light intensity

Illuminance			Coefficients	
(lux)	E_0	E_1	E_2	E_3
9.4563	-0.3865E-01	0.1894E-01	-0.6301E-04	0.3312E-06
4.7205	-0.6960E-02	0.7861E-02	-0.2283E-04	0.1648E-06
0.8127	-0.3476E-02	0.1627E-02	-0.5603E-05	0.3095E-07
0.1182	-0.4331E-03	0.2322E-03	-0.1214E-05	0.5539E-08
0.0366	-0.2655E-03	0.1130E-03	-0.5253E-06	0.3155E-08
0.0106	-0.6757E-05	0.1516E-04	-0.1732E-05	0.1129E-07
0.0039	-0.1963E-06	0.6700E-04	-0.8245E-05	0.3427E-06

Table 2.5 The coefficients i_0, i_1, i_2 and i_3 of equation (2.8)

Coefficients	E_0	E_1	E_2	E_3
i_0	5.391E-05	1.195E-05	-3.118E-07	1.535E-09
i_1	-5.477E-03	2.117E-03	-7.257E-06	3.667E-08
i_2	1.542E-03	-1.799E-04	9.857E-07	-6.922E-10
i_3	-1.476E-04	1.774E-05	-9.723E-08	5.296E-11

* each No. of data is 7 and each correlation coefficients is $r > 0.999$

Table 2.3 continued

Illuminance (lux)	Grey steps	No. of data	Grey level mean	(SD)	Relative luminance
0.8127	1	30	40.13	1.68	0.0511
	2	30	50.73	2.33	0.0668
	3	30	71.93	4.72	0.0922
	4	30	118.33	5.03	0.1656
	5	34	146.18	5.41	0.2148
	6	34	174.47	5.08	0.2827
	7	37	207.97	5.98	0.3657
	8	36	237.31	3.79	0.4524
	9	35	249.51	1.67	0.5577
0.1182	1	30	57.60	2.31	0.0092
	2	28	72.43	2.89	0.0117
	3	31	95.71	5.85	0.0153
	4	31	139.26	6.54	0.0241
	5	34	164.65	5.15	0.0319
	6	33	193.06	5.29	0.0388
	7	36	223.75	6.24	0.0490
	8	30	243.90	4.54	0.0603
	9	31	246.42	2.60	0.0721
0.0366	1	30	33.73	2.27	0.0023
	2	28	40.71	1.67	0.0037
	3	32	55.38	3.63	0.0051
	4	33	86.00	6.19	0.0081
	5	32	107.34	4.43	0.0100
	6	34	136.03	6.64	0.0128
	7	35	151.71	2.82	0.0156
	8	39	168.31	2.73	0.0180
	9	30	169.97	4.85	0.0204
0.0106	4	31	27.26	1.15	0.0018
	5	33	33.33	1.74	0.0030
	6	33	40.33	1.29	0.0043
	7	38	47.37	1.28	0.0054
	8	35	50.69	1.73	0.0062
	9	29	51.03	1.82	0.0075

Table 2.2 Underwater conditions at the time of TV recording of knot and twine images and background luminance

Date	GMT	Weather	Lat(N)	long(W)	Depth(yd:m)	k	c
2/Feb	12.5-13.8	clear	58:56	2:34	30-65	0.144	1.092+0.0022*yd (r=0.826, N=107)
6/Feb	13.3-14.0	cloud	59:16	2:45	30-40	0.119	1.369Å0.0059 (N=117)
8/Feb	10.8-13.1	clear	57:45	2:11	30-80	0.111	1.300+0.0011*yd (r=0.869, N=156)
9/Feb	10.0-10.6	cloud	57:45	2:06	30-70	0.133	1.256+0.0019*yd (r=0.908, N=126)

k: Vertical attenuation coefficient

c: Beam attenuation coefficient

r: correlation coefficient, N: No. of data

Table 2.3 Grey levels and relative luminances of the standard grey charts.

Illuminance (lux)	Grey steps	No. of data	Grey level mean	(SD)	Relative luminance
9.4563	1	30	40.27	1.68	0.5644
	2	30	50.37	3.13	0.8044
	3	30	74.13	6.08	1.1553
	4	30	123.40	5.68	1.9521
	5	33	150.52	5.80	2.5755
	6	35	179.20	6.46	3.3292
	7	33	211.06	6.07	4.2049
	8	40	238.20	6.99	5.0931
	9	31	250.58	2.06	6.1959
4.7205	1	28	39.18	2.10	0.2602
	2	31	49.39	2.75	0.3539
	3	32	74.09	5.43	0.5077
	4	30	120.93	6.46	0.9017
	5	35	150.26	5.62	1.2351
	6	33	179.21	3.91	1.6243
	7	34	207.97	4.65	2.1283
	8	36	235.42	6.93	2.6533
	9	30	248.97	3.95	3.1317

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2.6 Tables

Table 2.1 Specification of the PA and PE twisted netting twines

Colour	Dylon	PA Twine diameter Dt (mm)								PE twine		
		*: Sequence No. of netting twine										
	No	No*	Dt	No*	Dt	No*	Dt	No*	Dt	No*	Dt	
white	undyed	11	1.13	21	2.16	31	3.15	41	4.21	51	2.70	(glow white)
black	8	12	1.16	22	2.31	32	3.40	42	4.96	52	2.79	
green	25	13	1.20	23	2.33	33	3.54	43	4.96	53	2.75	
dark green	26	14	1.14	24	2.27	34	3.49	44	4.76	54	2.2x4	(braided)
yellow	2	15	1.17	25	2.36	35	3.46	45	4.80	55	2.77	(orange)
scarlet red	32	16	1.15	26	1.99	36	3.53	46	4.97	56	2.8x6	(green,braid.)
blue	33	17	1.22	27	2.53	37	3.48	47	4.85	57	3.93	(navy blue)
dark blue	16	18	1.17	28	2.27	38	3.44	48	4.87	58	3.9x6	(braided)

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McK. Bary (1956) found that larger fish required increased potential differences along their bodies to induce responses to electrical stimuli. However, for the different types of responses the gradient of response with length was sloped differently. The gradient for the potential required for minimum response with length was considerably less steep than for electrotaxis or electronarcosis.

Stewart (1975) using McK. Bary's results showed that for a given field strength larger fish showed a greater potential difference from snout to tail. Thus larger fish are likely to exhibit an increased response to a given electric field. However, because the gradient of potential difference with length required to elicit a response differs for the three types of responses; it is minimal for the minimum response, increasing for electrotaxis and electronarcosis, the effects of the length of fish are likely to be different dependent upon the type of response being induced. This has implications for changes in selectivity during electrofishing; potential gradients sufficient for inducing 'minimum responses' may not affect the selectivity of the gear, as much as the higher potential gradients which induce electrotaxis or electronarcosis.

6.4.2.2 Crustacea

Stewart (1972) describes a number of laboratory experiments where *Nephrops norvegicus* were induced to emerge from their burrows under laboratory conditions as a result of the application of pulsed DC. He considers that the field strength used in the experiment could be realistically induced in the mouth of the trawl. However, field observations did not elicit the same response (Baker 1973).

6.4.3 White Fish Authority and Seafish Experiments 1976-1986

Tables 6.5-6.8 show in chronological order, outlines of the date, location, aim, method, including electrical characteristics and target species, results, discussion and further work of all the investigations carried out by WFA/Seafish over the period 1976-1986. Catch results are given in Tables 6.9-6.11.

The initial experiments were carried out on beam trawls (Figs 16 and 17); these results indicated that towing speeds should be reduced from 4-5 knots to 3-3.5 knots (Field Reports FR 556 and 557). Investigations were initiated into the use of electrical arrays on otter trawls (FR 945), refer Fig. 21.

The next set of experiments were designed to establish the optimum electrode and electrical characteristics (Fig. 22). They consisted of field observations of resistivity in order to establish field strength, and laboratory observations of the effect of pulsed electric fields at 4Hz, an impulse of 1ms and an estimated field strength of 150V/m on flatfish (Dover sole and turbot). These parameters proved adequate to elicit minimum response from Dover sole causing them to lift upwards off the seabed.

These electric field characteristics were achieved in experiments carried out from 1979 onwards. Later experiments on beam trawls solved a number of technical problems and tested various electrode configurations and materials. By late 1980 the system was developed to the point where long term trials were contemplated. The main benefit was found to be in fuel saving for a similar catch per effort due to the reduced towing speeds and in reduced towing load required for electric fishing (see Figs 19 and 20). However the reduction in the relative cost of fuel during the early 1980's rendered these savings less attractive than at the time when the research project was initiated so the work was discontinued circa 1983.

The work on otter trawls (FR 945 and 1004) carried out in parallel with the beam trawl experiments proved more difficult because of the difficulty of maintaining the gear in a consistent geometry. The fuel savings were less and a number of handling problems were encountered so the otter trawl investigations were not considered to be as promising as the beam trawling studies.

Finally, there were investigations into inducing electronarcosis in roundfish (IR 1167) captured in otter trawls. This was based upon the observation that roundfish catches were increased in electrified beam trawls with catches from conventionally rigged beam trawls. In this case it was intended to electrify the trawl floats in otter trawls (Table 6.8) in order to induce electronarcosis in the mouth of the trawl. The experiments carried out on a test rig were curtailed before consistent results were obtained.

6.4.4 Environmental Effects

The potential environmental effects of demersal fishing operations fall into a number of categories:

i. Removal of target and non target organisms through contact with and capture by the gear.
ii. Effects of the gear on the substratum and benthos.
iii. Consumption of fuel and discharge of waste.
iv. Effect of lost gear and other litter.
v. Effect of noise, light and other vessel activities.

In electric fishing there may also be the release of free ions of toxic metals from the electrodes. Electrode materials are discussed by Stewart (1972).

Since the experiments on electric fishing carried out by WFA and Seafish were orientated towards a reduction in the consumption of fuel per fish captured they only address this issue directly. However the results of the work may show some promise in reducing the extent of seabed contact and hence effect on the gear because a greater yield of fish is obtained per unit area. The intensity of environment effects on the benthos may also be reduced because tickler chains are removed.

No fish length measurements were made in any of the WFA/Seafish studies, so these results cannot confirm other experimental and theoretical studies (McK.Bary 1956 and Stewart 1975) which indicate that larger fish are more susceptible to the effects of electric fields. However characteristics of the electric fields were adjusted to elicit a 'minimum response' from the target species. This response is the least influenced by the length of the fish (section 6.4.2.1) compared with electrotaxis and electronarcosis, which would require greater field strength. Thus at the field strengths used in these studies, benefits in terms of selectivity may be minimal.

6.4.5 Discussion

Electric fishing may hold the expectation of:

i. Reducing the optimum speed and weight of trawling gear if this increases the yield per area fished. Then it could reduce the extent and intensity of fishing impact on the benthic environment per unit catch.

ii. Reducing the fuel consumption per unit catch.

iii. Possibly changing the selectivity of the gear by making the larger individuals more vulnerable to the gear, this would require close examination of the physiological response of fish to electrical stimuli, in particular at the level of minimum response.

However before these benefits can be realised there must be a clear view taken in the management of the fishery to take theses factors into account when making policy decisions. The research requirements; in terms of describing the impact of the gear and its selectivity could then be derived from this policy decision.

6.4.6 Further Work

There is potential for further work in:

i. A better analysis of yield changes available and optimisation of towing speeds.

ii. Some indication of the selectivity changes induced by electric trawling.

6.5 Work done in Germany

The Institut für Fangtechnik, Hamburg, startet first activities in the field of electrical fishing in 1965 when an electrified bottom trawl was tested on FRV "Walther Herwig". The results of these investigations were not sufficient to justify further development in the application of electrical fishing in the distant water fishery and during the following years the institute concentrated on electrified small bottom trawls for the eel fishery in German fresh water lakes.

To decrease the electric power consumption a pulse generator was developed using condensator discharge pulses instead of continuous DC voltage for the electrified gear. Fishing trials in three small fresh water lakes in northern Germany (Wittensee, Ratzeburger See and Steinhuder Meer) proved the efficiency of the electrified bottom trawls compared to the traditional bottom trawl gear. Catches of eel could be increased by a factor 10 - 20. Nevertheless commercial application of the system failed due to the fact that there were no boats available with sufficient engine power for trawling, and the local fishermen preferred to stick to their traditional fishing gear *e.g.* baited pots and long lines.

Based on the know-how obtained in the fresh water fishery the institute started the development of an electrified beam trawl for the German inshore sole fishery in 1975 to replace the heavy tickler chains by electrodes with the aim of reducing the fuel consumption of the fishing vessels and to decrease the destructive impact of the gear to the sea bottom. The pulse generator designed for this purpose delivered pulses of a peak voltage of 82V, and a peak current of 1.95A at a frequency of 25Hz.

Comparative fishing trials with electrified and traditional beam trawls resulted in higher catches and improved selectivity of the electrified gear not only with sole but also with plaice and cod.

During the following tests of the equipment the electric characteristics of the pulse generator were varied to find the optimum of the configuration. A voltage of 110V and a current of 1.31A at every pair of electrodes with a pulse length of 0.51ms at a frequency of 25Hz proved to be most effective. An increase of catch (sole) in weight of 114% was obtained. At the same time the by-catch of benthic organisms and sand was reduced to almost 50%.

In 1985 a modified arrangement of electrodes and lower panel of the beam trawl was investigated to get an uniform electrical field in front of the groundrope.

Research and development in the field of electrified beam trawls were terminated in 1987 when the German authorities were not prepared to allow electrical fishing on a commercial basis. Since then environmental aspects have become much more important in the sea fishery. Especially the destruction of the benthos by heavy tickler chains of beam trawls is considered as a major disadvantage of this type of gear. From this point of view a revival of electrified beam trawls seems possible.

6.6 Work done in Klaipeda (Lithunia)

Electrical stimulation was mainly investigated in the institute in Klaipeda, Lithunia (Masimov and Toliusis, personal communication, 1996). Species under investigation were: Baltic cod, herring, flounder, rainbow trout, shrimps (Crangon crangon) and Japanese scallop. Anode electrotaxis was studied intensively in pulsed electric fields and under direct current (Daniulyte *et al.*, 1987; Simonaviciene, 1987; Daniulyte and Petrauskiene, 1987), as well as the effect of electric current on physiological parameters (Vosyline, 1987), and on electrocardiogrammes and the heart rhythm of fish (Kazlauskiene and Daniulyte, 1987; Kazlauskiene, 1987). The three basic types of reaction: first reaction, electro-taxis, electro-narcosis mentioned in the report of Lart and Horton were also identified by these workers. Species under investigation were *Gadus morhua* L. (cod), *Clupea harengus* L. (herring), and *Pleuronectes platessa* L. (plaice). The work started with observations on behaviour in dependence of field characteristics. Prototype electrical equipment was built and tested on experimental sea trips, including *in situ* observations on fish. Applications in gears followed both in midwater (Malkevicius and Toliusis, 1987), and in bottom trawls, but not in beam trawls that are unknown in these parts of the Baltic Sea. Crangon were observed to jump off-bottom, as reported by many other workers (Burba, 1987). In addition, anode attraction was used in sardinella fishery in combination with light attraction. In this application fish is pumped onboard. The effect on other benthic marine life was also extensively studied and reported as being negligible, due to the smaller sizes involved.

It was also found that electric currents do not affect reproductive qualities. Plaice was observed to jump out of the seabed and rise 1.5-2.0 m off bottom under the influence of the electric field. The critical frequency for electro-narcosis was found to be around 80-100Hz. The reaction occurs mainly 3-4 sec after exposure. Other frequencies lead to slower responses. Sinusoidal pulse shapes were found to be most effective, and ways were found to optimise the energy efficiency of the pulser unit (Malkevicius and Malkevicius, 1987). It was also found that fish length determine reaction, as larger fish experience a larger potential difference in an electric field (Maksimov *et al.*, 1987). The product of fish length * voltage for a given reaction was found to be constant, which means that larger animals are more strongly affected. Selective properties of the electrified gear were observed during experiments on the Jamaican Shelf on grounds unsuitable for trawling by using direct observation techniques. The pulse generators were placed onboard the vessel with cables running to the net as in most applications in Western Europe. Various electrode arrangements were tested with the anode placed in the lower panel and the cathode in the upper panel, an arrangement not tried out in beamtrawls. The optomotor reflex mentioned by Wardle was also observed by direct observation in a pelagic trawl. A regime of 7s exposure to the electric field followed by a 60s unexposed interval at 100Hz resulted in all fish appearing in the codend. When a school enters the trawl, the fish start to react when the height of the section is about 4-6m. Then they begin to swim along with the trawl, which can be maintained for lengths of time depending on the towing speed. The electrode arrangement was chosen to elicite an upward movement of the fish, with the anode placed above the cathode attached to the ground rope. The workers believe that the trawl can be fished off-bottom thus avoiding any bottom contact and related by-catch and mortality of bentic organisms. This idea deserves more study.

Introduction into commercial fisheries did not take place, as in other countries, because of the following reasons:

- Fishermen showed lack of interest.

- The robustness of the system was not adequate, leading to loss of fishing time.

6.7 Work done in India

Sreekrishna (1995) reports on studies with electrical stimulation in India. In India, electrical fishing has been successfully applied on an experimental basis. Namboodiri *et al.* (1969) studied the effect of impulse current on certain fresh water fishes. Mitra and Biswas (1968) studied the threshold current densities required for narcosis of Indian carps in captivity. Higher catch rates of prawns and fish were reported for an electrified trawl by Namboodiri *et al.* (1970).

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Report No	Date Author(s) Vessel	Subject	Method						Results			Further Work
			Fishing Gear and Electrode Configuration	Target species	Impulse		Electrical Characteristics					
					Shape	Dura-tion (ms)	Voltage (V)	Freq (Hz)	Fish Catches	Physical Parameters	Comment	
ICES C.M. 1970/ B:4	1970, S.J. de Groot G.P. Boonstra laboratory WR-213	Bassin tests	parallel electrodes, spacing 30-35cm	Sole, plaice, flounde r dab, brill	Capacitor discharge	1	2.5-60	1-50	3-4 fishes used in each experiment	Optimum for shrimps 0.2msec, for sole 0.7msec	OMEGA jump only seen in sole, no effect from temperature	Incorporation in a trawl
ICES C.M. 1970/ B:5	1970, S.J. de Groot G.P. Boonstra laboratory	Oyster bassin tests and sea trials	3m beam trawl	Crangon	Capacitor discharge	1	2.5-60	1-50	Total catch could be raised by 50%		Interrupted pulse cycle tried	Development of electrified flatfish trawl
J. Cons. int. Explo. Mer 35 (2) 1974	1974 S.J. de Groot G.P. Boonstra TH-6	Electric shrimp fishery	9m beam trawl	Crangon	Capacitor discharge	0.5	10	5, 7 - 50	E caught 116% more commercial and 81% more discard shrimps		Day trials only. Burrowed shrimps jump out	Trials at night
ICES C.M. 1974/ B:5	1974 S.J. de Groot G.P. Boonstra TH-6	Electric shrimp fishery	9m beam trawl	Crangon plaice	Capacitor discharge	0.5	60	1-50	E caught 33% more commercial shrimps			Further work on flatfish suggested.
Paper presen ted in 1976 in ICES WG	1976 G.P. Boonstra WR-17, WR-87	Electric shrimp & flatfish fishery	9m beam trawl	Crangon plaice	Capacitor discharge	0.5	35, 65	5, 30	Similar catches for plaice, higher cathces for sole.		Stimulation only works better at daytime, water should be clear for shrimp fishing.	Further work on flatfish suggested, termination of work on shrimps.
TO 81-03	1981 J.B. Agricola UK-141	Electric flatfish fishery	10m beam trawl	Solea solea	Capacitor discharge	0.7	70-180	5, 10, 11, 12, 18, 22	With 75V, 18Hz catch rate > 1.0		Video shots taken show reactions	Optimisation V, Hz and electrode length
TO 81-06	1981 J.B. Agricola UK-141	Electric flatfish fishery	10m beam trawl	Solea solea	Capacitor discharge	1.0	100-300	5-25	Catch rate 0.6 at day, >1.0 at night		No video shots due to bad weather	Improving endurance of electrodes, integration of capacitors in beam
ICES C.M. 1985/ B:36	1985 J.B. Agricola ISIS, UK-141	Electric flatfish fishery	10m beam trawl	Solea solea	Capacitor discharge	1.0	200 - 2000 (1400 eff.)	0-25	>700V higher sole catches for all lengths	Optimum V, Hz: day: 600-700, 20, E-catch 1.45*stn night: 700, 20, E-catch 1.65*stn	Capacitors built in beam. Electrodes of equal length work better	Improvement of system endurance, and reduction of electrolytic corrosion of electrodes. Electrodes made of RVS.

Report No	Date Author(s) Vessel	Subject	Method: Fishing Gear and Electrode Configuration	Method: Target species	Method: Impulse: Shape	Method: Impulse: Dura-tion (ms)	Method: Electrical Characteristics: Voltage (V)	Method: Electrical Characteristics: Freq (Hz)	Results: Fish Catches	Results: Physical Parameters	Results: Comment	Further Work
TO 85-09	1985 A. Kraayenoord ISIS	Electric flatfish fishery	10m beam trawl	Solea solea	Capacitor discharge		700	20	E caught 171% more sole		Best results for speeds 3.0-3.5 kn, lower for higher speeds.	
not publis hed	1985 ISIS	Comparison of RIVO -system and system built by BFAFi Hamburg	9m beam trawl	Solea solea	Capacitor discharge Transfor mers on beam		RIVO:: 700	RIVO: 20	Higher catches for RIVO-system		Many breakdowns for RIVO-system. System BFAFi runs well.	Further development and commercialisation of Dutch system
not publis hed	1986 ISIS & GO-65	Comparison of RIVO -system and "V.d. Vis"-system	10m beam trawl	Sole, plaice	Capacitor discharge Ruhm - korff solenoid		400 - 600 - 800 - 1000 RIVO	20 RIVO	Higher catches for RIVO-system		+22% sole & -68% plaice for RIVO, -46% sole & -153% plaice for "V.d.Vis"	Commercialisation of RIVO system
not publis hed	1987 ISIS	Comparison between RIVO - system and system built by OKAY B.V.	10m beam trawl	Sole, plaice	Capacitor discharge		RIVO:: 700	RIVO: 20	Catches system OKAY almost equal		System OKAY based on two pulser units built on the beam trawl shoes	Commercial trials and further development of system OKAY on UK-141
TO 88-06	1988 B. v. Marlen D. de Haan	Review report of whole project	N/A	Crangon Solea solea	Capacitor discharge	N/A	N/A	N/A	N/A	N/A	System banned by Dutch Law, research terminated	Commercial application

Table 6.1 Overview of the major Dutch experiments and reports 1970-1988.

Table 6.2: Effect of towing speed on 1984 catch results.

Towing speed range (kn)	Percentage higher sole catch for the electrified trawl
3.0-3.5	171
3.5-4.0	95
4.0-4.5	77
4.5-5.3	62.5

Table 6.3: Catch results in weight of experiments on GO-65 & ISIS, Mar 1986.

System	Plaice E	Plaice T	% Difference	Sole E	Sole T	% Difference
Van de Vis	347.5	879.5	-153.09%	483.5	707	-46.23%
RIVO	611	1111	-81.83%	845	662	21.66%

Table 6.4: Catch results in weight of experiments on GO-65, Nov-Dec 1987.

	Plaice E	Plaice T	% Difference	Sole E	Sole T	% Difference
Week 1	497	742	-49.30%	182	166	8.79%
Week 2	723	2318	-220.61%	293	297	-1.37%
Week 3	1141	2045	-79.23%	584	427	26.88%
Week 4	766	1795	-134.33%	409	307	24.94%
Average	**782**	**1725**	**-120.66%**	**367**	**299**	**18.46%**

Report No	Date Author(s) Vessel	Aim	Method						Results			Further Work
			Fishing Gear and Electrode Configuration	Target species	Impulse		Electrical Characteristics					
					Shape	Dura-tion (ms)	Field strength (V/m)	Freq (Hz)	Fish Catches	Physical Parameters	Comment	
FR556	10/77 R.S. Horton H. Wright MFV PG Islander	Capture flatfish using electrical impulses discharged into the seabed, via a trailing electrode array (using 4m beam trawls as the primary platform).	4m beam trawls; 5 longitudinal electrodes were deployed. These were constructed from 32mm diameter nylon rope with a copper wire inlay and separated by a lateral distance of 65cm. Figs 1&2	Dover sole	Exponential decay	0.2	20	4	Fish catches were very low at approximately 1/3 of chain mat rigged gear.	The towing speed of 4-5 knots was considered too high to produce an effective period of stimulation.	The ground effectiveness of the electrical field was unknown, more power may possibly be required.	To examine the possibilities of holding the electrodes closer to the seabed and preventing lifting. Increase pulse frequency so that buried fish experience more impulses.
FR567	12/77 P. Neve R. S. Horton MFV Chandelle	Improvement of the ground holding characteristics of the array. Include an experiment with pulse frequency of 6Hz. Compare with non electrified control array.	Electrodes as above. A rope was connected between the beam shoes in order to hold down the front end of the electrodes.	Dover sole	Exponential decay	0.2	20	4 and 6	Catch rates of Dover sole 26% by weight more than control electrode array. No difference in the catch level at 6Hz compared with 4Hz.	Towing speeds 3-3.5 knots. Electrodes showing signs of good contact with the seabed.	These results are not conclusive because: Comparison was not made with a chain-mat rig; There were uncertainties as to the power requirements.	There is a need to perform several controlled experiments in order to determine the following: The electric field strength at the array compared to fully charged pulser capacitance and to plot its physical distribution (test stainless steel electrodes). To observe fish reactions at SOAFD (P. Stewart) using the electrical stimuli developed by Seafish electric-fishing system. Also to perform these tests with higher capacitance value (in pulser unit). Also to examine the poss. of adapting electrode arrays to flatfish otter trawls.
FR945	4/81 J. E. Tumilty	To review the feasibility of applying an electrode array to an otter trawl and to examine its characteristics onboard.	C3 Otter trawl 53ft headline rigged with an electrode array comprising of the following: Seven electrodes each of length 4.3m separated by a lateral distance of 1m., the front ends of which were supported by a floated combination rope.	Plaice	N/A	N/A	N/A	N/A	N/A	Towing array at speeds up to 4 knots. A certain amount of difficulty was experienced in shooting due to the net hanging-up on the array. However, it is felt that these problems will be overcome in time for a semi-commercial assessment voyage on a stern trawler.	Diver obs on the array: The array performed well on the seabed, with the electrodes running more or less parallel on the bottom. However there was a tendency to lift at the front end at higher towing speeds, so added was weight needed. The cross-wire appeared to keep 1-2 ft clear of the bottom, which should be sufficient to clear most obstacles. The dimensions of the net in the water did not appear to be substantially altered by the attachment of the array.	There are a few minor modifications to be done to the array in order to prevent the array from 'snagging-up'. These present no difficulty and it was felt that the gear can be used with confidence on a semi-commercial trip later this year.

Report No	Date Author(s) Vessel	Aim	Method						Results			Further Work
			Fishing Gear and Electrode Configuration	Target species	Impulse: Shape	Impulse: Dura-tion (ms)	Electrical Characteristics: Field strength (V/m)	Electrical Characteristics: Freq (Hz)	Fish Catches	Physical Parameters	Comment	
Not publish-ed	2/78 R. S. Horton Location: Stonehaven harbour/ SOAFD Marine Laboratory, Aberdeen.	To measure electrode array resistances for rope and stainless steel elec-trodes. Deduce a relationship between the overall array resistance and electrode length, diameter, lateral separation and number of electrodes comprising the array in an infinitely bounded medium of seawater. To plot the electric field strength between the rope/stainless steel.	A number of rope and stainless steel electrodes of various lengths. Starting with two adjacent to each other at a measured distance apart. Applied A.C. source at one end and measured accurately (on an oscilloscope) the current drawn by the electrodes : thus resis-tance was computed. Measurement of current for the subsequent addition of electrodes up to max of 9.							Resistance Ro=p(sw).Log e(d/r) /L(n-1) p(sw)=resistivity of seawater d=lateral separation of electrodes(m) r=electrode ra-dius(m) L=electrode length(m) n=number of electrodes	This formula was modified to take into account the conductivity of (K) to give: Ro=((1+K)/K)*p(sw) log e (d/r)/L(n-1) The establishment of these criteria enables the design of electrode arrays to cover finite boundaries of both beam and otter trawls. The array resistance forms the basic parame-ter on which the total input power can be deduced.	
Not publish-ed	SOAFD Marine Laboratory, Aberdeen.	To observe the effects of the pulsing stimulus used by Seafish on Dover sole and turbot, in a controlled experimental environment.	A group of 1.5m length stainless steel electrodes separated by a horizontal distance of 70cm were arranged in the bottom of a GRP tank.	Dover sole and turbot	Exponential decay	1	150	4	N/A		Upon switch on of power the pectoral and dorsal fins of the Dover sole oscillated in concert with the output frequency of the pulser (4Hz). After 2-3 seconds the fish took to an upward flight. Response known as involuntary flight or minimum response.	Carry forward these parameters onto the 4m beam trawling trials for a full scale commercial evalua-tion.

Table 6.5. Electro fishing experiments carried out by White Fish Authority 1977-1978.

Report No	Date Author(s) Vessel	Aim	Method: Fishing Gear and Electrode Configuration	Method: Target species	Method: Impulse: Shape	Method: Impulse: Dura-tion (ms)	Method: Electrical Characteristics: Field strength (V/m)	Method: Electrical Characteristics: Freq (Hz)	Results: Fish Catches	Results: Physical Parameters	Results: Comment	Further Work
FR678	11/78 P. Neve R. S. Horton MFV Chandelle	To continue a commercial assessment of electro-fishing on 4m beam trawls. To utilise and in-corporate the knowledge recently acquired from laboratory experiments into improving the performance of the current system.	An improved rope array with holding rope between beam shoes (for closer front-end adhesion of the electrodes). Later in the trials an electrified bunt chain was added to which the trailing ends of the electrodes were tied via nylon rope. Tests on aluminium rod electrodes.	Dover sole	Exponentia l decay	0.3	100	6	Catches of Dover sole improved. Now catching ~60% of that caught by full chain mat rig. Later in the trial added electrified bunt chain - catch rates further in-creased to 85%. Noted that fre-quently 10% more round fish in the electrified beam trawl.	Whilst towing a full chain mat rig both sides a fuel consumption of 14 gal/hr was recorded compared to 8.5 gal/ hr for beams rigged with electrode arrays. Handling problems with the aluminium electrodes. Finally usage discontinued. Rope electrodes suffer from excessive wear, i.e. loss of copper con-ductor. For long-term commercial operations the electrodes must be able to sustain harsh seabed conditions. Investigate other electrode materials i.e. stainless steel.	Both chain mat rigged gears and electrode arrays have different towing speeds at which their optimum catch effectiveness occurs. Considerable amounts of heat being generated in the supply line cable to the pulsers. (Consider reducing pulser frequency back to 4Hz).	Assess the relative catch rates of electrified trawls and chain rigged trawls at their respective optimum towing speeds. Assess quantitively the power and fuel savings to be obtained by towing electrified trawls in pref-erence to normal chain rigs. Equate the relative catch rates with fuel consump-tion figures for the tow gears and compare the economic returns for the two methods of fishing. To investigate the use of stainless steel electrodes and any other modifications to the electric fishing equipment considered to be beneficial.
FR793	8/79 R. S. Horton/ P. Neve MFV Homewaters	To perform a full technical and economical appraisal of electro-fishing applied to a 4m beam trawl.	Five trailing 20mm diameter stainless steel wire electrodes and one transverse electrified bunt chain (Fig 18).	Dover sole	Exponentia l decay	1	150	4	Catch rates were low (suspected to be due to a pollution incident) for all classes of beam trawls during the period of the study; thus results from this study should be considered with caution. However, no significant differences in catch rates were observed be-tween the electrified and non electrified beam trawl.	The highest catch rates in the electric beam trawl occurred at 3-3.5 kts at which there was a drag reduction of 29%. (Figs 19&20). By tow-ing electrified trawls at an op-timum speed of 3.5 kts compared to 5 kts for heavy chain rigged gears, fuel savings of at least 18% were shown. Annual gear savings of up to 12% were also demonstrated. A fi-nancial analysis of this class of vessel showed that a fuel and gear saving of 10% with no change in catch rate would increase operational profit by approx. 12%.	The addition of the electrified bunt chain has almost certainly closed off the escape route for the soles which had been el-evated by electrical stimulus by the electrode array. The electrodes could be an expensive item in a future commercial environment. Stainless steel wire is not cheap. It is also not easily accessible and its wearing characteristics are not good on the more abrasive hard ground. Supply line cable problems of over-heating. This problem must be surmounted.	A period of further beam trawling trials under commercial fishing conditions is considered necessary. Realistic catch com-parisons can only be made on commercial quantities of fish. Several modifications to the electrode array; we shall investigate the viability of other electrode materials, possibly steel wire warps. In order to alleviate overheating problems associated with the supply cable on the self-tensioning winches we are inves-tigating the possible use of the seawater path between electrodes and vessel as the alternative return charging line.

Report No	Date Author(s) Vessel	Aim	Method: Fishing Gear and Electrode Configuration	Method: Target species	Method: Impulse: Shape	Method: Impulse: Dura-tion (ms)	Method: Electrical Characteristics: Field strength (V/m)	Method: Electrical Characteristics: Freq (Hz)	Results: Fish Catches	Results: Physical Parameters	Results: Comment	Further Work
FR808	11/79 R. S. Horton P. Neve MFV C.K.Amber	Assess the commercial viability of electric fishing, the use of galvanised steel wire electrodes and the feasibility of utilising seawater as a return electrical charging path from the trawl to the ship. Further examine the viability of electrification of an otter trawl.	4m beam trawls fitted with five electrodes separated by a horizontal distance of 65cm (galvanised steel wire electrodes).	Dover sole	Exponential decay	1	150	4	Catch rates of Dover sole are at least as high as those taken by other vessels using chain mats.	Fuel saving of up to 58% during the towing of electrode arrays. Max towing speed for array must not exceed 3.5 kts. Tests on the seawater return theory are successfully carried out. The self-tensioning winches to be integrated into the vessels' own hydraulic system, this will streamline the installation in readiness for a full period of commercial assessment.		Preparations to modify cable winches for integration into vessel' hydraulic system. Pilot commercial full scale trial next year over a seasonal period. Replace the deck mounted portable generator with an auxiliary engine-room mounted set.
FR881	8/80 R. S. Horton P. Neve Zhou Yingi (Shanghai Fisheries College) MFV C.K.Amber	Use the seawater return system commercially. Continue assessment of the steel wire electrodes.	As above.	Dover sole	Exponential decay	1	150	4	The results in terms of catch rates are considered sufficiently encouraging to arrange a long-term commercial assessment.	Towing at 3.5 kts appears to be the optimum for flatfish with electrified gears. Fuel reduction circa 45% compared to chain mat rigged trawls.	The success of the seawater return system means: An overall reduction in cable costs. A reduction in heating effects on remaining cable left on the winch during the electric fishing periods.	A period of one year's commercial assessment of the electrified beams to be carried out. This period would also allow initial trials of an electrified otter trawl system to be carried out.

Table 6.6. Electro fishing experiments carried out by White Fish Authority 1978-1980.

Report No	Date Author(s) Vessel	Aim	Method						Results			Further Work
			Fishing Gear and Electrode Configuration	Target species	Impulse		Electrical Characteristics					
					Shape	Dura-tion (ms)	Field strength (V/m)	Freq (Hz)	Fish Catches	Physical Parameters	Comment	
FR 1003	11/81 J. E.Tumilty R. S. Horton	Full commercial assessment of 4m electrified beam trawls.	Five steel wire trailing electrodes separated by a lateral distance of 65cm plus a bunt chain into which the ends of the electrodes were connected via insulated strops. (see Fig 18).	Dover sole	Exponential decay	1	150	4	(See Tables 6.9-6.10). Over a period of 129 paired tows (214hrs) the catch rates varied considerablyThe average daily catch for the whole period was 288kgs or £780 in value. Another vessel of similar HP caught 244kgs - £508 in value.	The fuel consumption was less by 40% even when taking into account of the 35kVA. Generator now fitted into the engine room. Heat generated in the charging line ballast resistance units created excessive/ unacceptable temperature rises in the engine room.	Since the first trials began in 1977 the underlying objective has been to produce an electric array capable of giving catch rates equal to or better than those by conventional gears and to sustain them over a commercial period. This has been achieved through subjecting the equipment to the normal fishing environment and monitoring its performance for a full season. This trials period revealed, as expected, some weak areas in the system.	Apart from minor improvements to the system it is considered that the system designed for 4m beam trawls is now worthy of commercialisation.
Not published		Pilot trials of electrified C4 otter trawl.	C4 otter trawl 82ft headline normally fishing with chain ticklers, fitted with an electrode array comprising: 11 longitudinal steel wire electrodes separated by a lateral distance of 73cm, 9 supported by a floated combination rope at the forward ends of the electrodes and tied into a bunt chain at the rear.	Mainly Plaice	N/A	N/A	N/A	N/A	Handling trial only.	Judging from the area of coverage required, the size of the electrode array will be considerable. The estimated array resistance 50 million ohms (55 million ohms actual measurement) will require a major increase in the value of the pulser capacitance in order to maintain a pulse duration of 1ms into the array.	It has been decided to proceed with the electrification of flatfish otter trawls. This work involves totally rebuilding the electric fishing control system, virtually doubling the pulser capacitance banks and redesigning the electrode array. This total redesign is hoped to be also, later, directed on the much larger 8-10 beam trawls operating from the port of Brixham.	Develop a new electric fishing system which will be universally adaptable to both the otter trawl and the 8-10m beam trawls.

Report No	Date Author(s) Vessel	Aim	Method						Results			Further Work
			Fishing Gear and Electrode Configuration	Target species	Impulse		Electrical Characteristics		Fish Catches	Physical Parameters	Comment	
					Shape	Dura-tion (ms)	Field strength (V/m)	Freq (Hz)				
FR 1004	11/81 R. S. Horton J. E.Tumilty MT Boltby Queen	Development/fishing trials of an electrified otter trawl for flatfish.	As above.	Plaice	Exponentia l decay	1	150	4	Very low fish catch rates. During the voyage the vessel completed 176hrs actual fishing time; of this 52hrs was spent electro-trawling, the remainder was spent using the vessel's traditional chain rig.	At the optimum towing speed of 4.5kts for the chain rig, the gear drag force was 7.7 tonnes compared to 7.5tonnes with the electrode array . Both were towed at the same speed. At 3.5 kts the drag of the electro trawl was 7.3 tonnes representing a drag reduction of 0.4 tonnes (5.2%) comparing the two gears at their respective optimum towing speeds.	The trials were beset with many technical breakdowns which is evident from the amount of time spent fishing with the traditional chain rig. Removal of the otterboard chains prior to electro fishing actually increased the drag on the gear by increasing the angle of attack of the otterboards.	All the problems which were encountered on these trials have been closely examined. Some of these are extremely large, relatively unsurmountable, without the outlay of prohibitive costs. The advantages in fuel savings were negligible whilst catches were extremely poor. Therefore it has been decided to concentrate efforts on the 8-10m beam trawling fleet.
IR 1180 TR206	6/83 R. S. Horton J. E.Tumilty MFV Zuiderkruis	Evaluate the performance of 8m electrified beam trawls, i.e. transfer electrical stimuli parameters from the successful 4m beams to cater for 8m.	Seven steel wire electrodes separated by a lateral distance of 1m and an electrified bunt chain.	Dover sole	Exponentia l decay	0.9	150	4	See Table 6.22 for a complete breakdown of catches. The results in essence reiterate the catch performance achieved on previous electro beam trawling trials.	Fig 20 shows the variation of fishing gear drag with engine RPM for both a chain rigged gear and electrode arrays. At the optimum towing speed of the two types of fishing gear there is a drag reduction of 2.6 tonnes.	There has been little doubt that the trials have created interest from both the vessel owners and other beam trawling operators in Brixham. These trials have been met with such success that the Zuiderkruis owners have been prepared to invest in an engine room mounted alternator specifically for electric fishing.	Except for the latter stages of these trials when cable failures created the need to curtail the exercise, electro-beam trawling has shown that it is a viable alternative to the traditional method of chain mats. It is now necessary to replace those few cosmetic weak links in the present system, which have been identified, and repeat a commercial assessment thus increasing skipper/owner confidence in the techno-economical viability of this relatively new technique.

Table 6.7. Electro fishing experiments carried out by White Fish Authority/Seafish 1981-1983.

Report No	Date Author(s) Vessel	Aim	Method: Fishing Gear and Electrode Configuration	Method: Target species	Method: Impulse: Shape	Method: Impulse: Dura-tion (ms)	Method: Electrical Characteristics: Field strength (V/m)	Method: Electrical Characteristics: Freq (Hz)	Results: Fish Catches	Results: Physical Parameters	Further Work
IR 1167	1984 R. S. Horton A practical study into the application of electro-narcosis for otter trawling.	During the development of the electro-beam trawling system, particularly on the Lowestoft fishing grounds, catch rates on species other than flatfish were observed to be higher than those caught with conventional chain gears. Having gathered sufficient statistical data to support this, an investigation into the phenomenon was deemed necessary, since these possible effects could bear some useful relevance to the capture of fish in otter trawls.	Fig 21 shows the zone coverage by the electric field created from the use of alternately excited Siamese floats. By applying the controlled output voltage from a variac isolated by a double wound transformer the electric field strengths were measured over the zone of coverage by the trawl. The power demands to produce this field energy were closely scrutinised for future adaptation to practical volumes swept by commercial fishing gears.	Round fish Cod Haddock Whiting etc.	Sinusoidal (halfwave & fullwave). 10.5 V/m was the max electric field strength which could be produced for a practically achievable power input at 50Hz full sine wave and at half rectified sine wave.	10	6.3	50	A simplistic approach was adopted based on some of the electro-narcosis experiments performed by R. le Men (1971) F.I.F. Having studied the electric field strengths/pulse widths and frequencies deduced by le Men to induce electro-narcosis in a number of round fishes, it was decided that sine pulses of 10ms duration and frequency 50Hz formed a median of the parameters of those used by le Men.	It was hypothesised that a very mild form of electronarcosis was being induced on whitefish, just forward of the beam trawl, due to the effects produced by the charge cycle of the pulser unit. The electric field could have induced fatigue in the roundfish herded by the beams quicker than would normally be expected by conventional rigged gears. Electric field strength measurements were made over the volumetric zone coverage of a commercially used otter trawl-Goshawk (Fig 21 . The measured coordinates were staked out in the fish farm estuary and , using Siamese aluminium floats as electrodes alternately excited, electric field strength measurements were computed for a variety of applied voltages.	Having deduced that the electric field strength at 50Hz could be economically produced and were within the band width of le Men's experimental parameters to produced narcosis a series of experiments were performed on codling and coley.
		To observe the effects of the electrical field previously measured in the zones defined in the estuary through controlled tank experiments.	Two 1m_ steel plates separated by a distance of 7m (Fig 22).	Cod Coley	Half wave rectified sine waves of amplitude 80 volts.	10	10.5	50	Experiment was started 12 hours after the fish were introduced to the tank. At the instant of switch-on the normal swimming of codling was to undulate sluggishly, until after 30 seconds they became almost motionless. Power off: the codling resumed normal activity after 1 minute. Repeated experiment after 1 hour: reaction was that the fish swam in an undulating fashion for only 10 seconds and then slowed down to be motionless. During this experiment, in an adjoining section of the tank, was a group of large halibut. At the point of current switch-on these halibut reacted violently to what could only be residual electric field leakage. The backs of the halibuts were considerably bruised laterally indicating that the fish arched their backs in a concave manner upwards. Herein lies the implication that large fish react much more violently to lower levels of stimulus than smaller fish (simply because more voltage is dropped across its body length). The reaction for coley was very similar.		
					Full sine wave	10	6.3	100 one pos sine wave foll by one neg	Slow increase of voltage up to a maximum of 6.3 v/m. No reaction before this value of field strength. Swimming slows down and fish tilts over to 30 degrees to the vertical plane, remaining motionless with opercula flare wide open. Fish recovered back to normal swimming after 10 minutes. Repeated the experiment after 12 hours. Same reactions observed.		

Table 6.8. Electro fishing experiments carried out by Seafish 1984.

Vessel	Installed HP	Number of Days at Sea	Mean Daily Landings (kg)	%Sole of Total Landings
A	160	27	209	80
B	300	18	265	66
C	250	28	244	66
D	300	33	281	72
CK Amber	240	13	288	82

Table 6.9. Comparative fish landings for five Lowestoft beam trawlers April-May 1981. Gear - vessels A-D conventional beam trawls, CK Amber : Electric fishing.

No of Tows	Time				Landings		Landings/hr			
	Fishing (hrs)	Steaming (hrs)	Repairs/ Handling (hrs)	Total Port-Port (hrs)	Total Weight (kg)	Soles Weight (kg)	Total Weight (kg/hr)		Dover soles (kg/hr)	
							Port-Port	Fishing	Port-Port	Fishing
11	15.5	3	4	22.5	235	200	10.44	12.90	8.89	12.90
26	54	4	9.5	67.5	986	671	14.61	12.43	9.94	12.43
31	49.25	8.2	23.5	81	861	692	10.63	14.05	8.54	14.05
36	55	9.5	14	78.5	1166	1132	14.85	20.58	14.42	20.58
25	40.6	9.5	9.2	63	484	372	7.68	9.16	5.90	9.16
						Means=	11.64	13.82	9.54	13.82

Table 6.10. Summary of electric fishing results: MFV CK Amber April-May 1981. Gear - 4m beam trawl.

No of Tows	Time				Landings		Fuel		Landings/hr and Landings/ltr					
	Fishing (hrs)	Steaming (hrs)	Repairs/ Handling (hrs)	Total Port-Port (hrs)	Total Weight (kg)	Soles Weight (kg)	Litres	Litres/ hr Port-Port	Total Fish			Dover soles		
									Port-Port (kg/hr)	Fishing (kg/hr)	Port-Port (kg/ltr)	Port-Port (kg/hr)	Fishing (kg/hr)	Port-Port (kg/ltr)
63	114.7	4	20.3	139	3702	1015			26.63	32.28		7.30	32.28	
54	85.7	5.5	26.3	117.5	2683	749	6230	53.02	22.83	31.31	0.43	6.37	31.31	0.12
72	108.3	9	34.7	152	3266	889	6497	42.74	21.49	30.16	0.50	5.85	30.16	0.14
41	61.7	5	18.3	85	1873	400	4450	52.35	22.04	30.36	0.42	4.71	30.36	0.09
80	128.7	6.8	35	170.5	4464	851	8455	49.59	26.18	34.69	0.53	4.99	34.69	0.10
77	144.5	5.5	30.5	180.5	5118	1048	8900	49.31	28.35	35.42	0.58	5.81	35.42	0.12
56	96.2	8.8	29.5	134	3822	635	7102	53.00	28.52	39.73	0.54	4.74	39.73	0.09
							Means=	**50.00**	**25.15**	**33.42**	**0.50**	**5.68**	**33.42**	**0.11**

Table 6.11. Summary of electric fishing results: MFV Zuiderkruis July-September 1983. Gear - 8m beam trawl, normal fuel consumption steaming and towing = 85litres/hr.

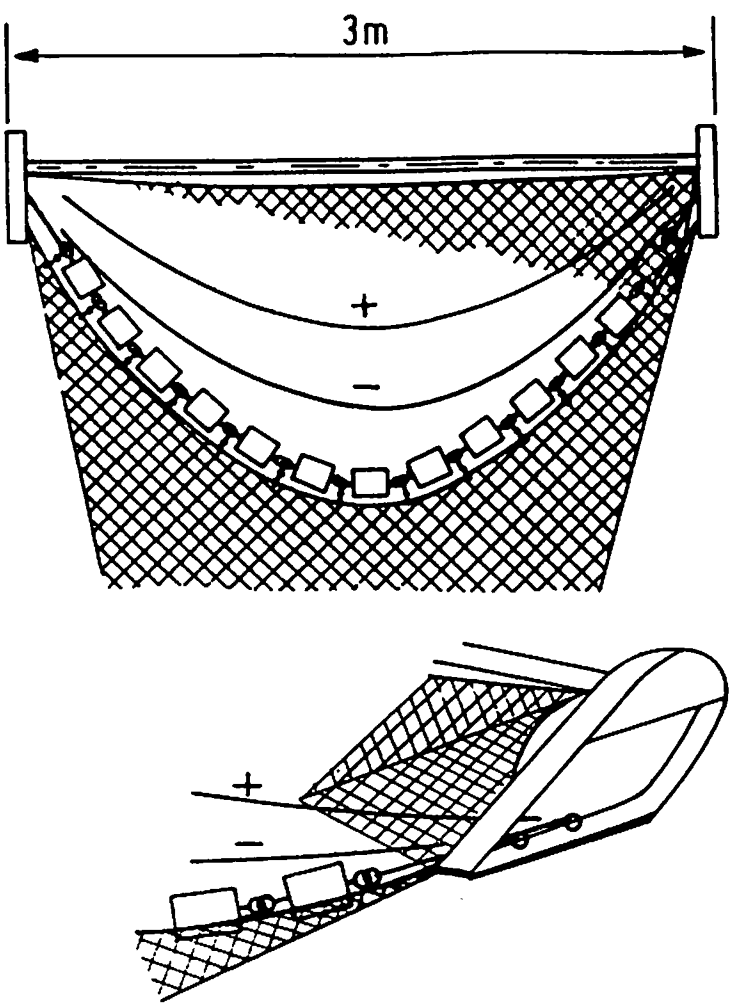


Figure 1. The rig of the shrimp beam trawl with electrodes parallel with the groundrope.

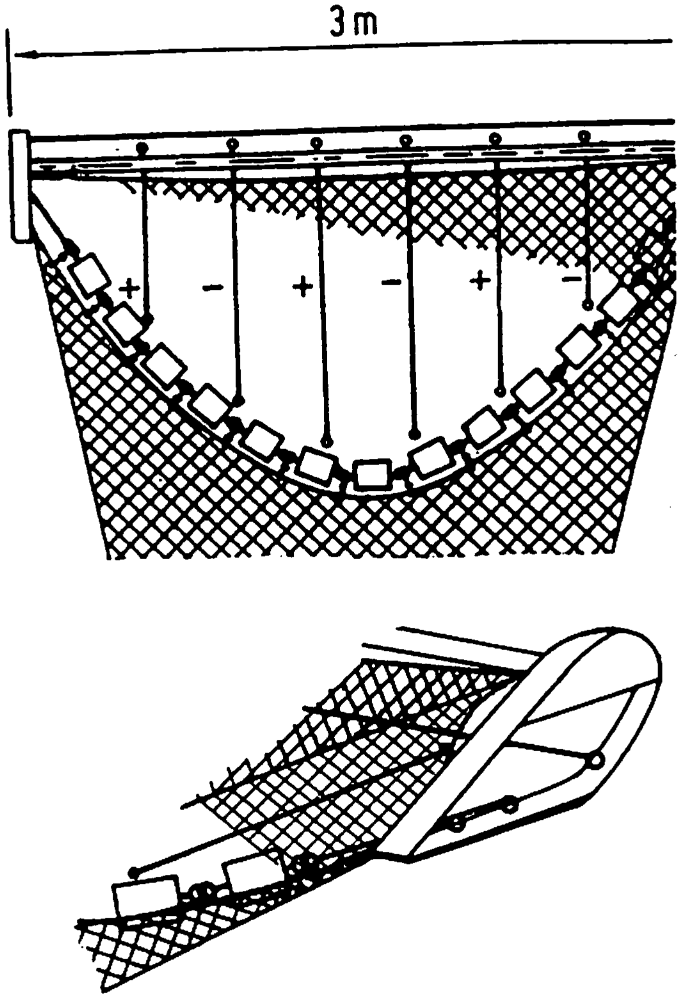


Figure 2. The rig of the shrimp beam trawl with trodes in line with the direction of tow.

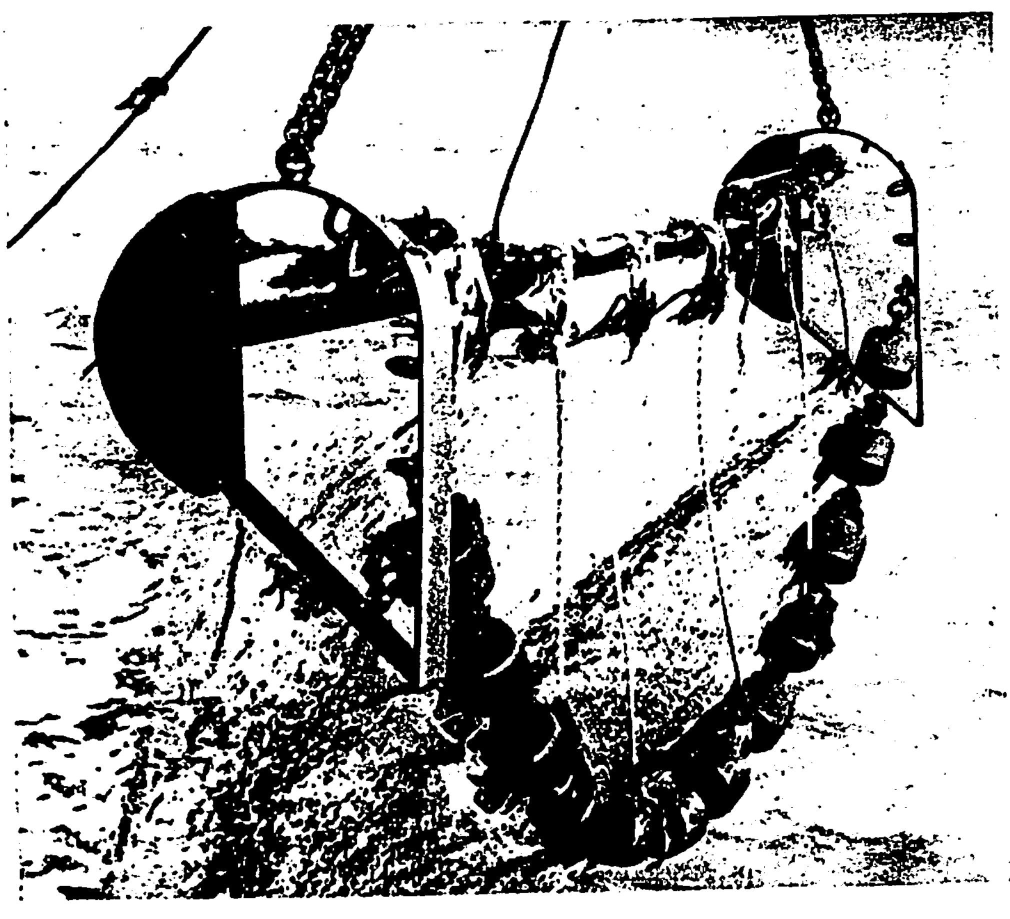
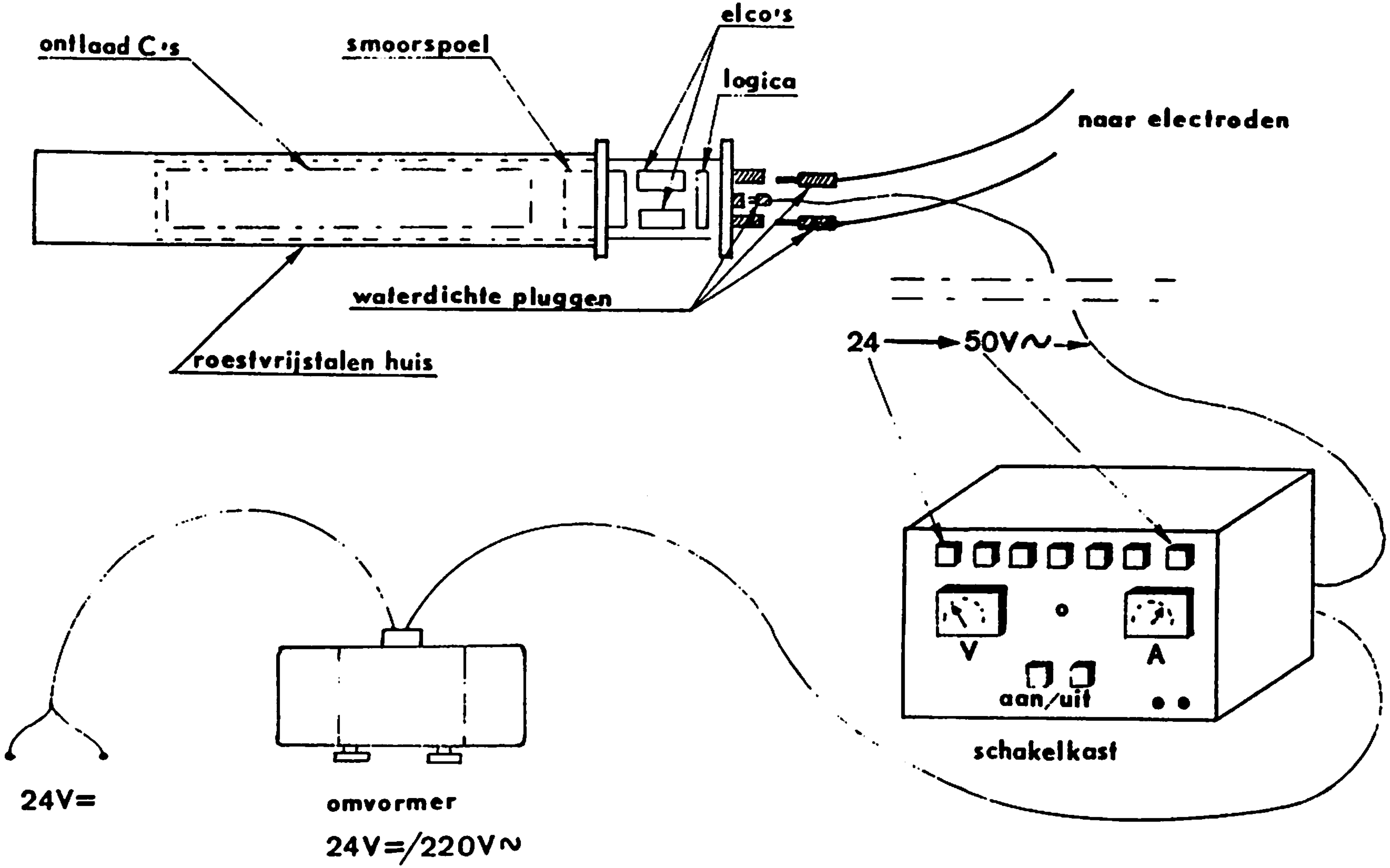


Figure 3. A 3 m shrimp beam rigged for electrical fishing. tograph, S. J. de Groot.)

Benaming

PULS GENERATOR PG 7317

FIG. 4



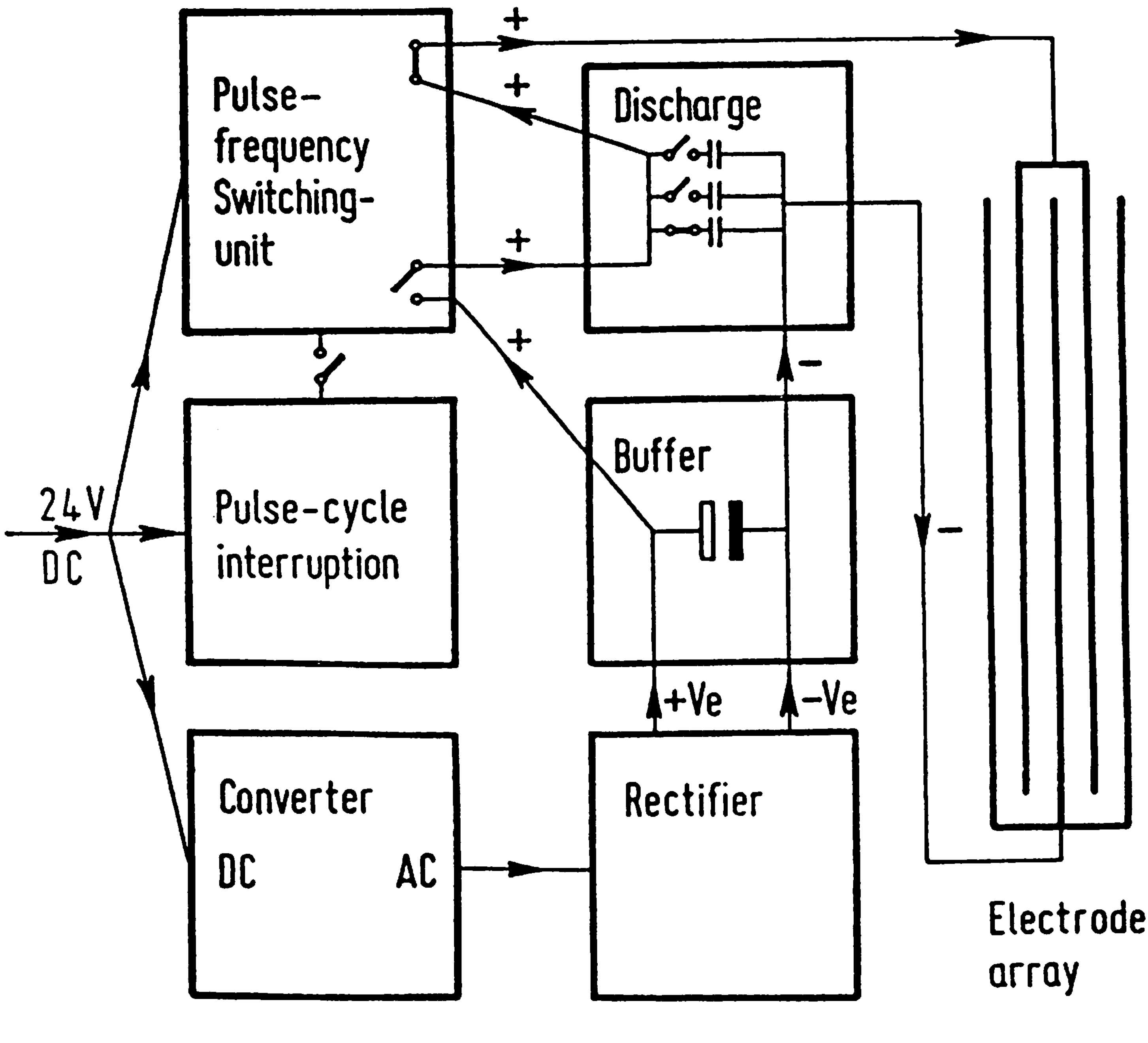


Figure 5 Block diagram of pulse-generator PG 6820.

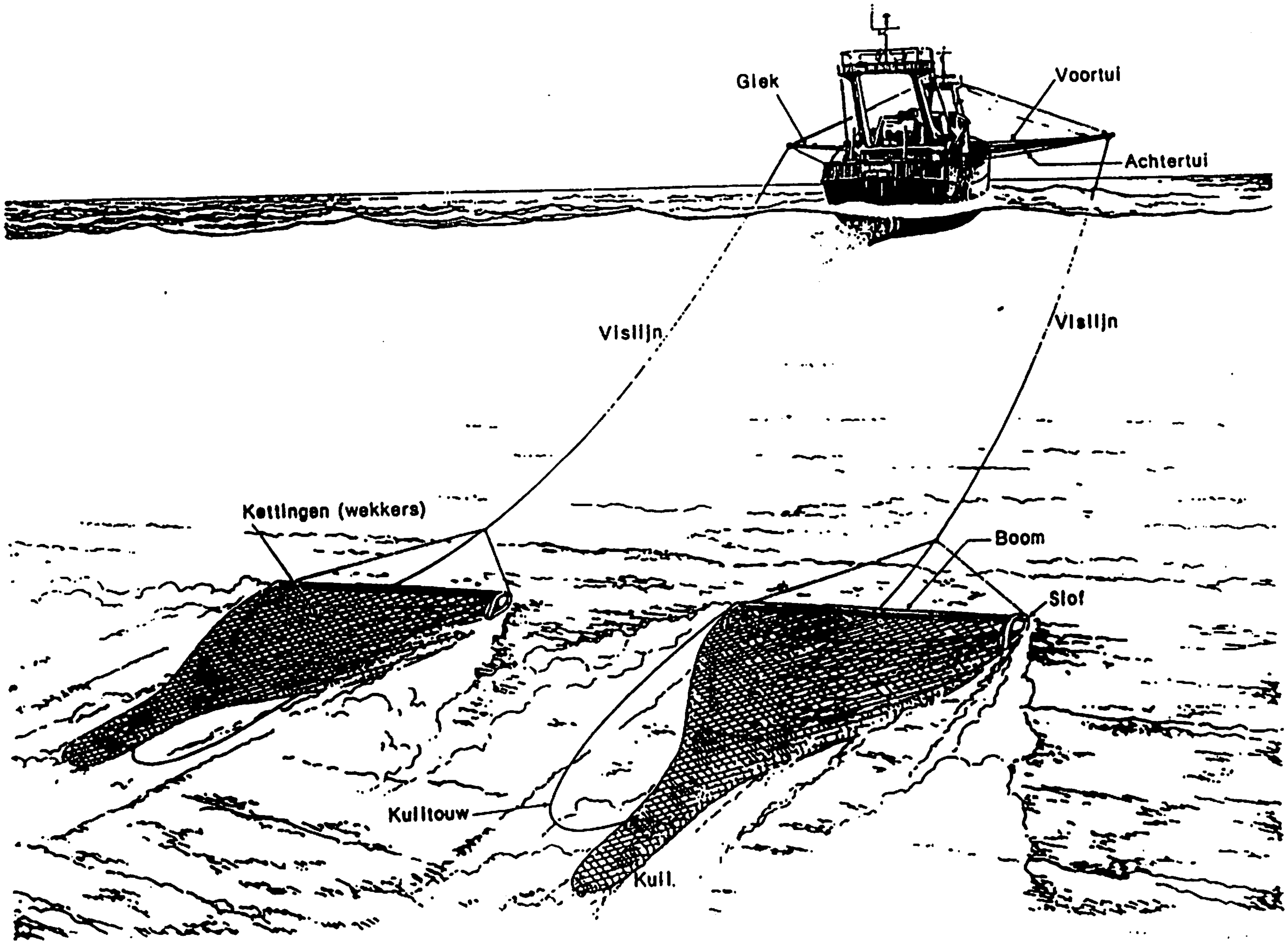

Giek
Voortui
Achtertui
Vislijn
Vislijn
Kettingen (wekkers)
Boom
Slof
Kuiltouw
Kuil.

FIG. 6

opslingering van de generatorspanning

Onderstaand schema toont het hoofdstroomcircuit van de installatie.

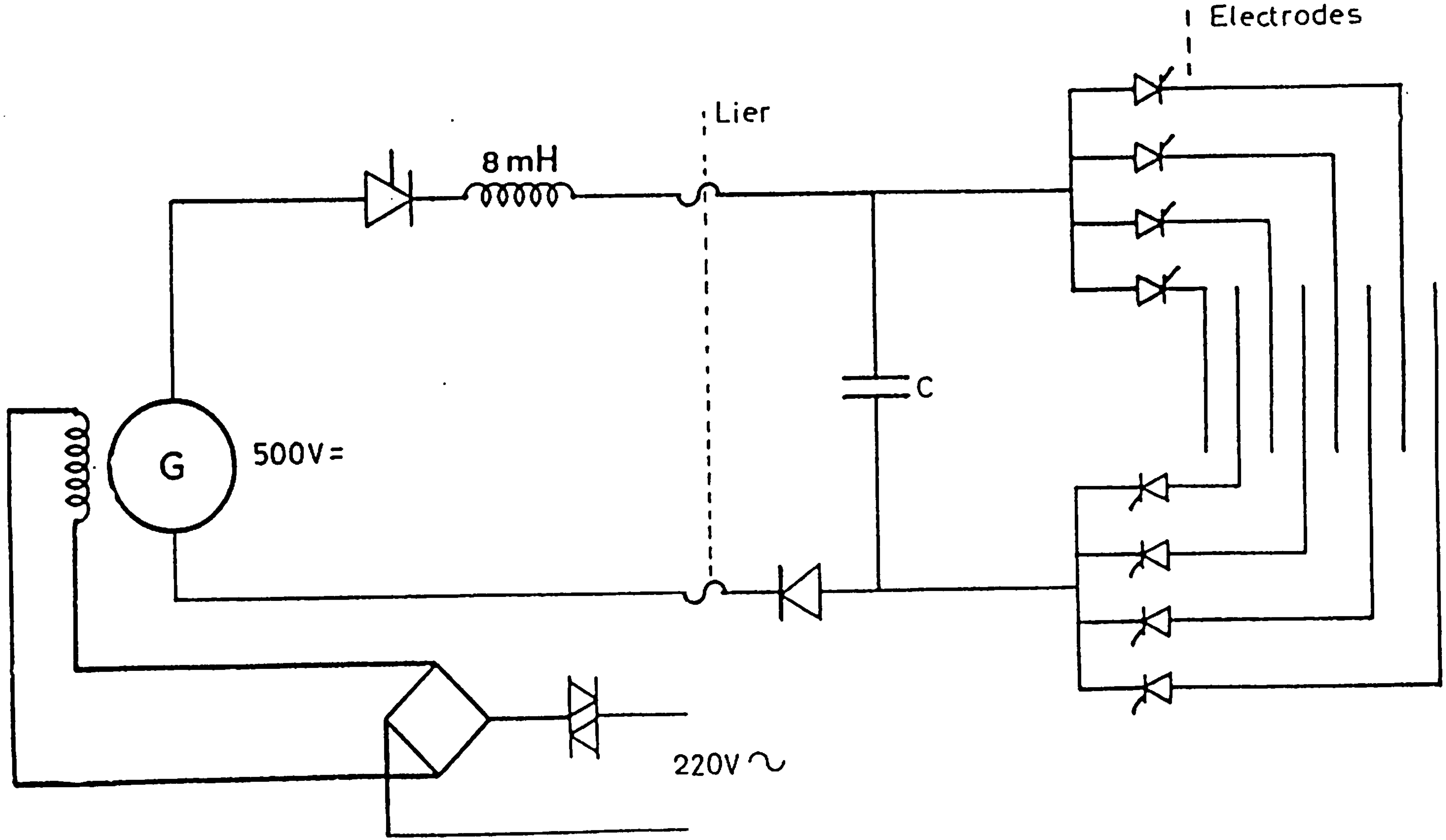


FIG. 7

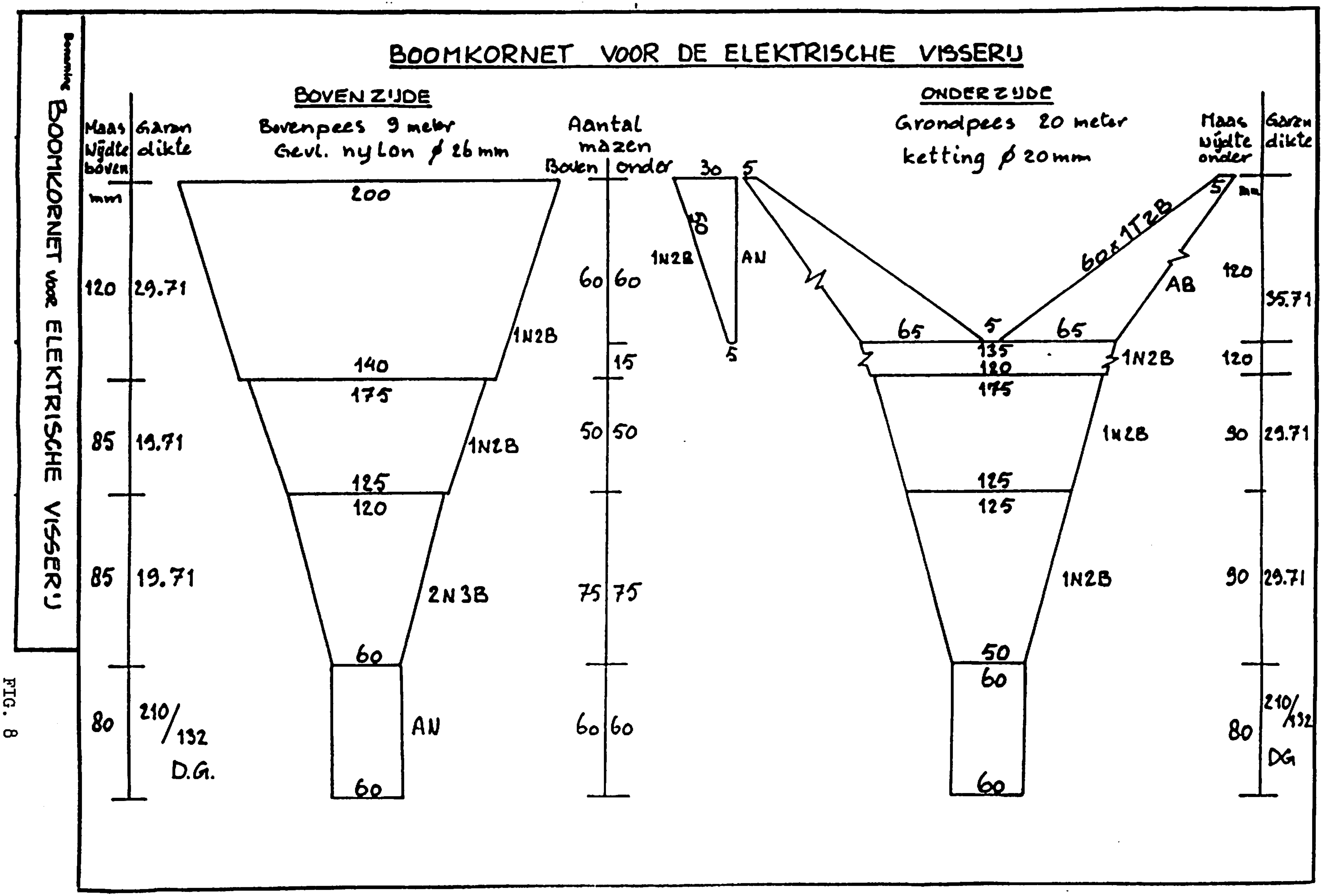
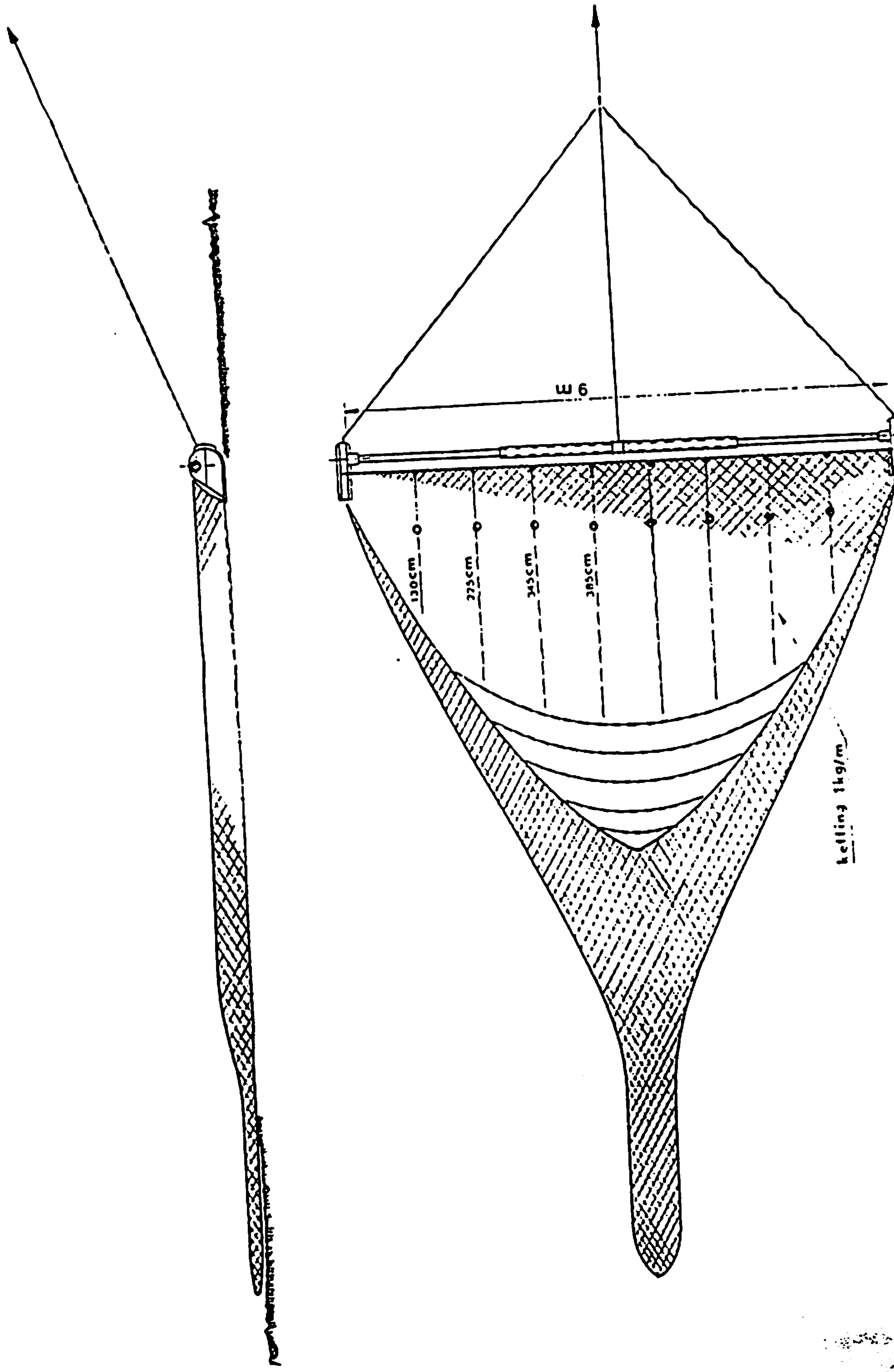

BOOMKORNET VOOR DE ELEKTRISCHE VISSERIJ
BOOMKORNET voor ELEKTRISCHE VISSERIJ
BOVENZIJDE
Bovenpees 9 meter
Gevl. nylon ø 26 mm
ONDERZIJDE
Grondpees 20 meter
ketting ø 20 mm
Maas wijdte boven mm
Garen dikte
Aantal mazen
Boven | onder
Maas wijdte onder mm
Garen dikte
200
140
175
125
120
60
60
1N2B
1N2B
2N3B
AN
120 29.71
85 19.71
85 19.71
80 210/132 D.G.
60 60
15
50 50
75 75
60 60
30
5
1N2B
AN
5
5
60 x 1T2B
AB
65
5
65
135
120
175
125
125
50
60
60
1N2B
1N2B
1N2B
120 35.71
120
90 29.71
90 29.71
80 210/132 DG

FIG. 8



FIG; 9

HAKTANDENNET I. (809C)
ELEKTRISCHE STIMULERING VAN PLATVIS 1984.

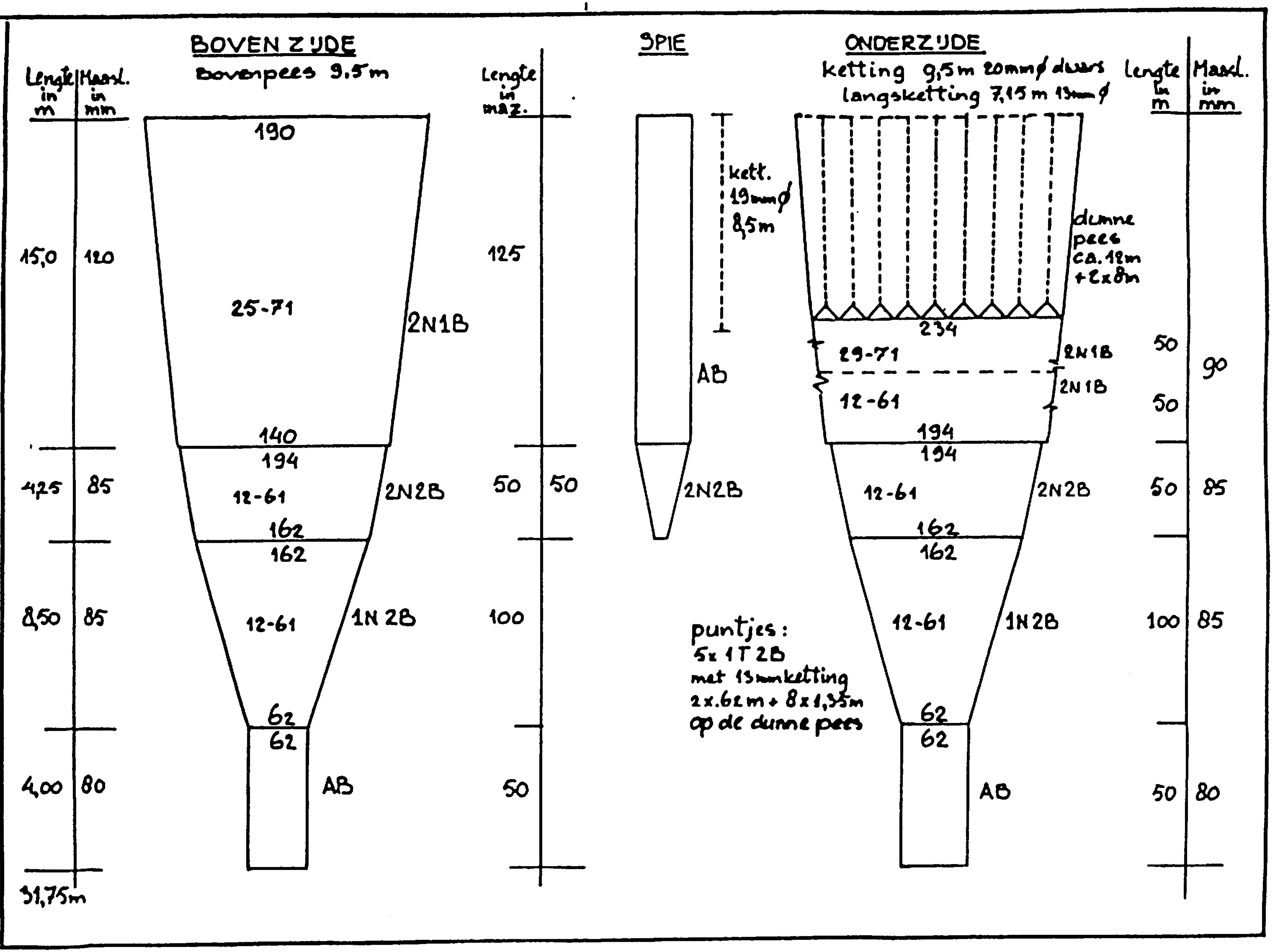
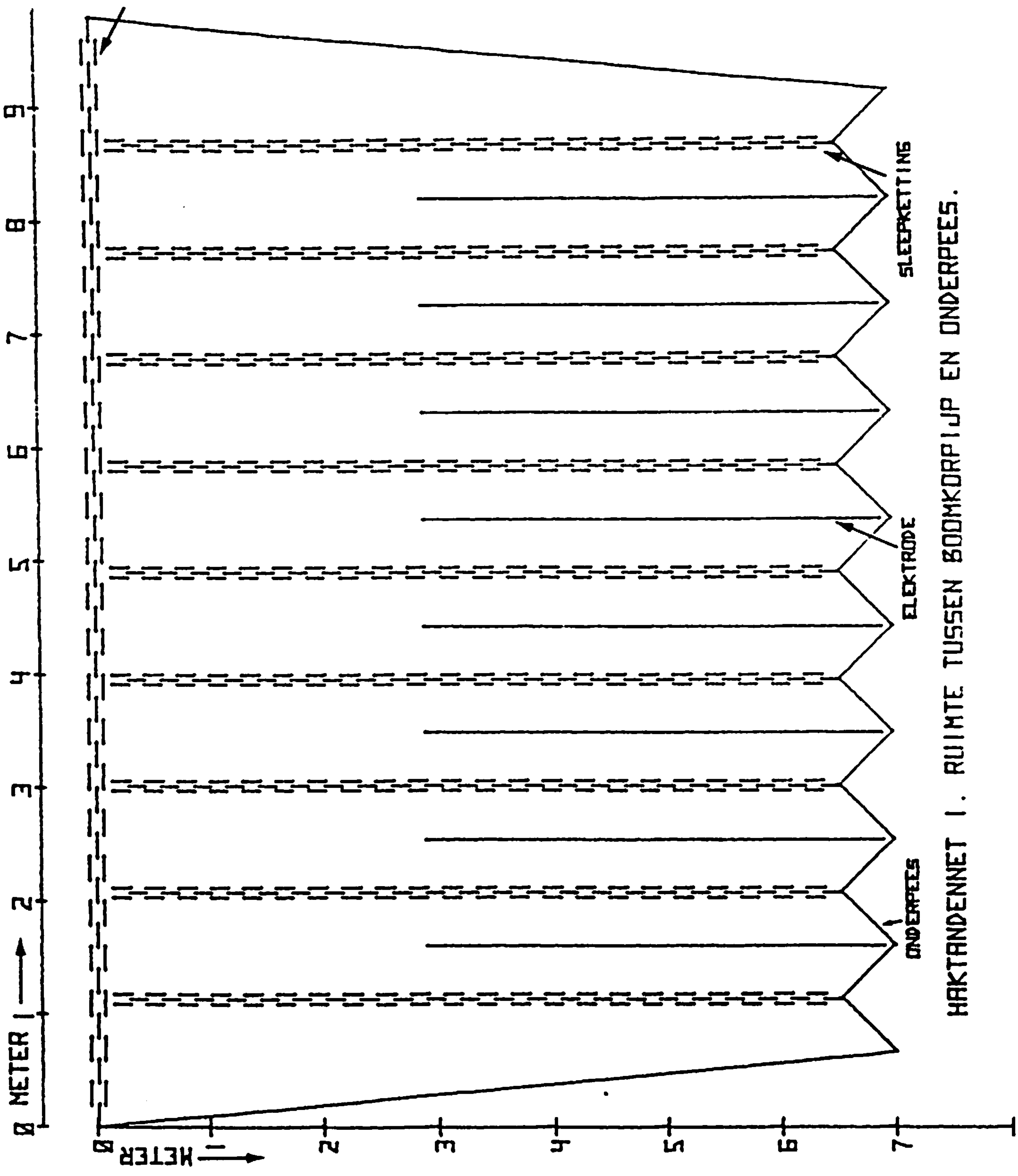
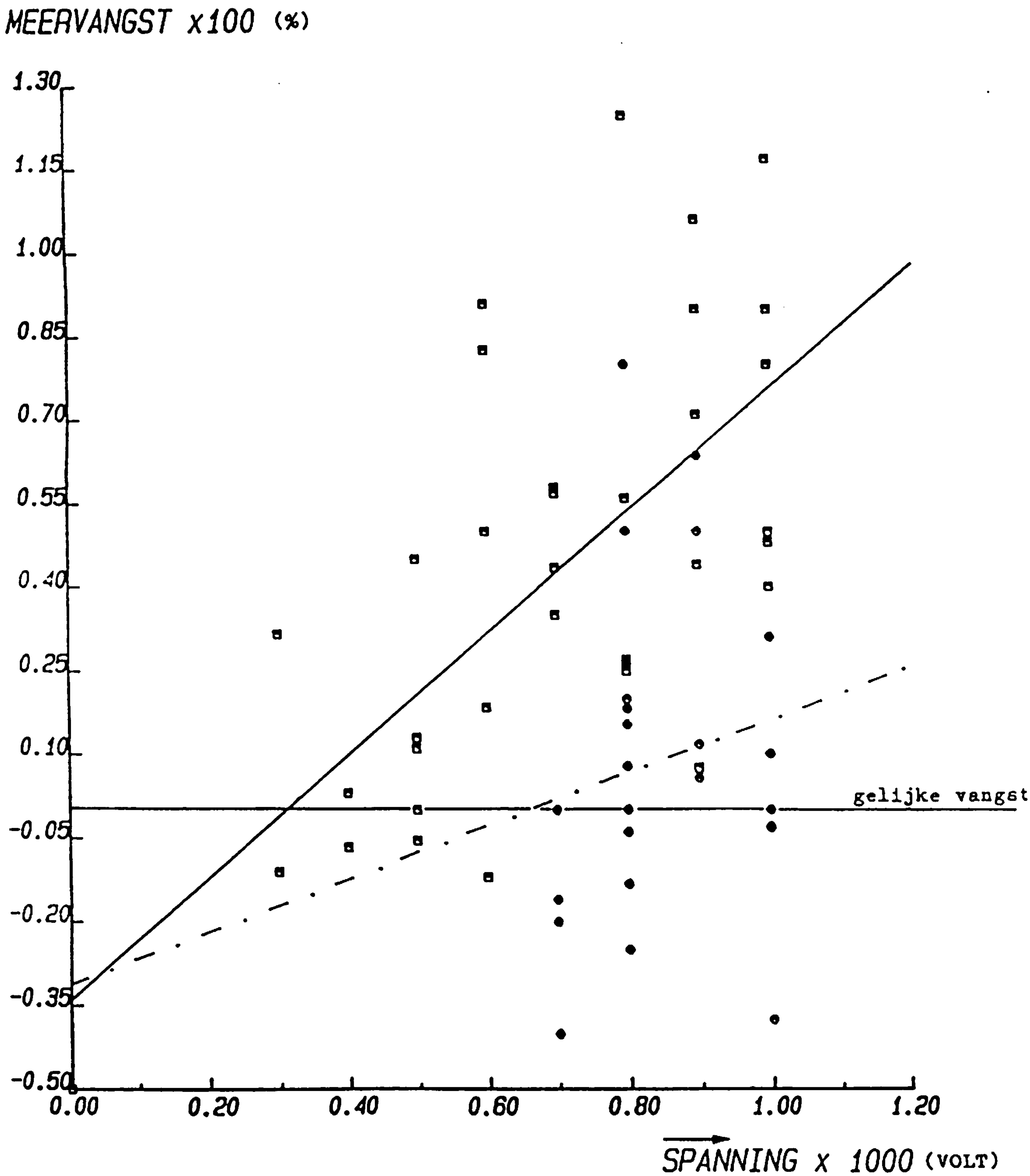


FIG. 10



HAKTANDENNET I. RUIMTE TUSSEN BOOMKORPIJP EN ONDERPEES.
SLEEPKETTING
ELEKTRODE
ONDERPEES
Ø METER 1 2 3 4 5 6 7 8 9
Ø METER 1 2 3 4 5 6 7

FIG. 11



PROCENTUELE MEERVANGST (KG) ELEKTRISCH VISTUIG T.O.V.
BOOMKORTUIG MET WEKKERS.
———————— HAKTANDENNET I.
—·—·—·— ROND NET.
STIMULERINGSFREQUENTIE 20 HERZ.
DAGTREKKEN.

FIG. 12

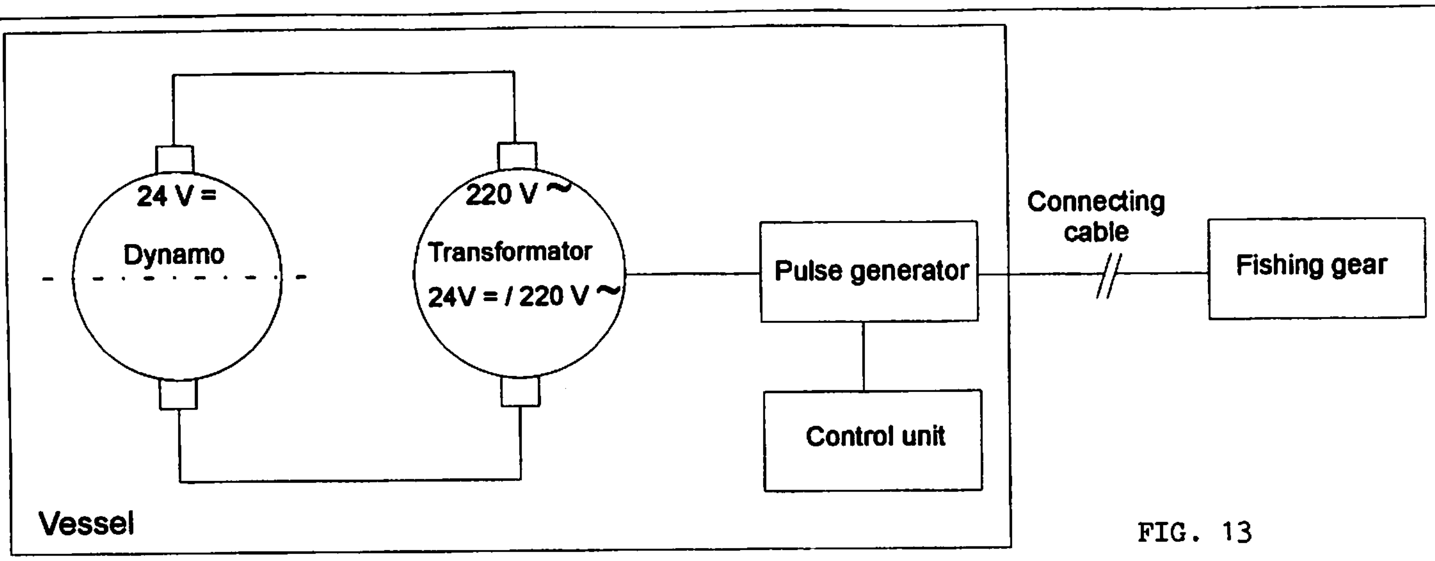


FIG. 13

General lay-out of an electric fishing system

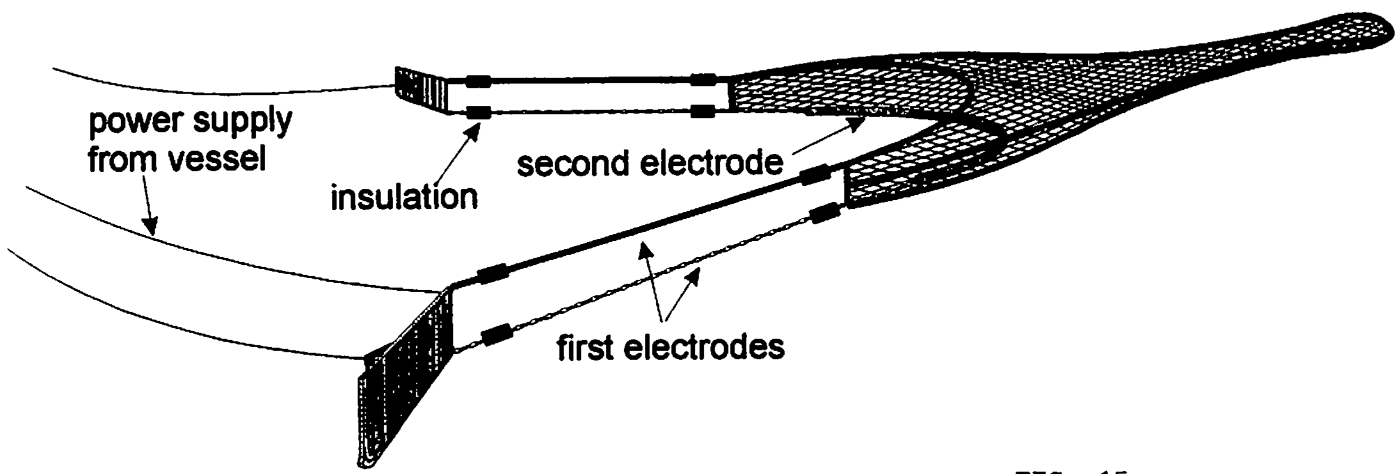


FIG. 15

Shrimp otter trawl rigged for electric fishing

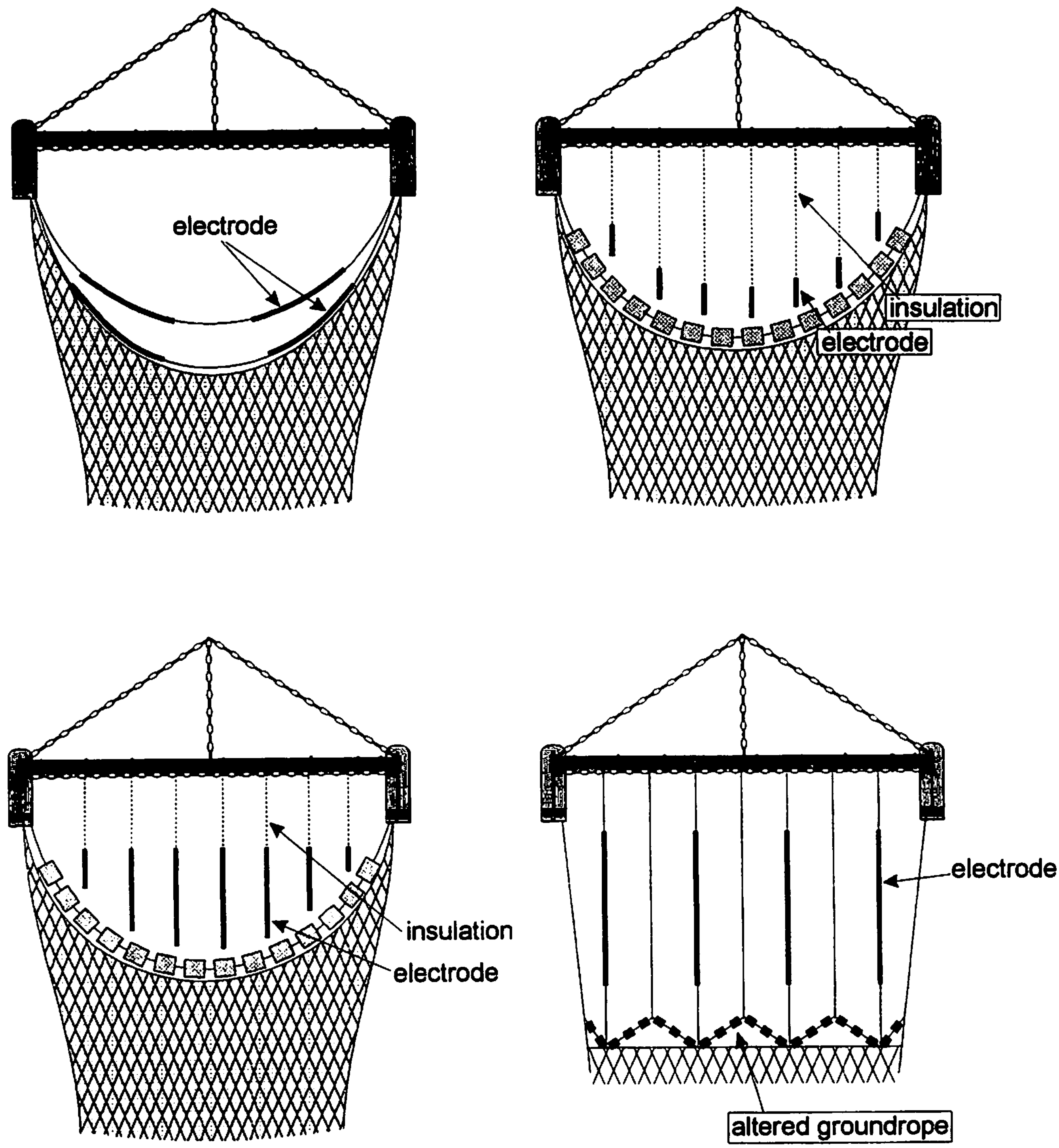
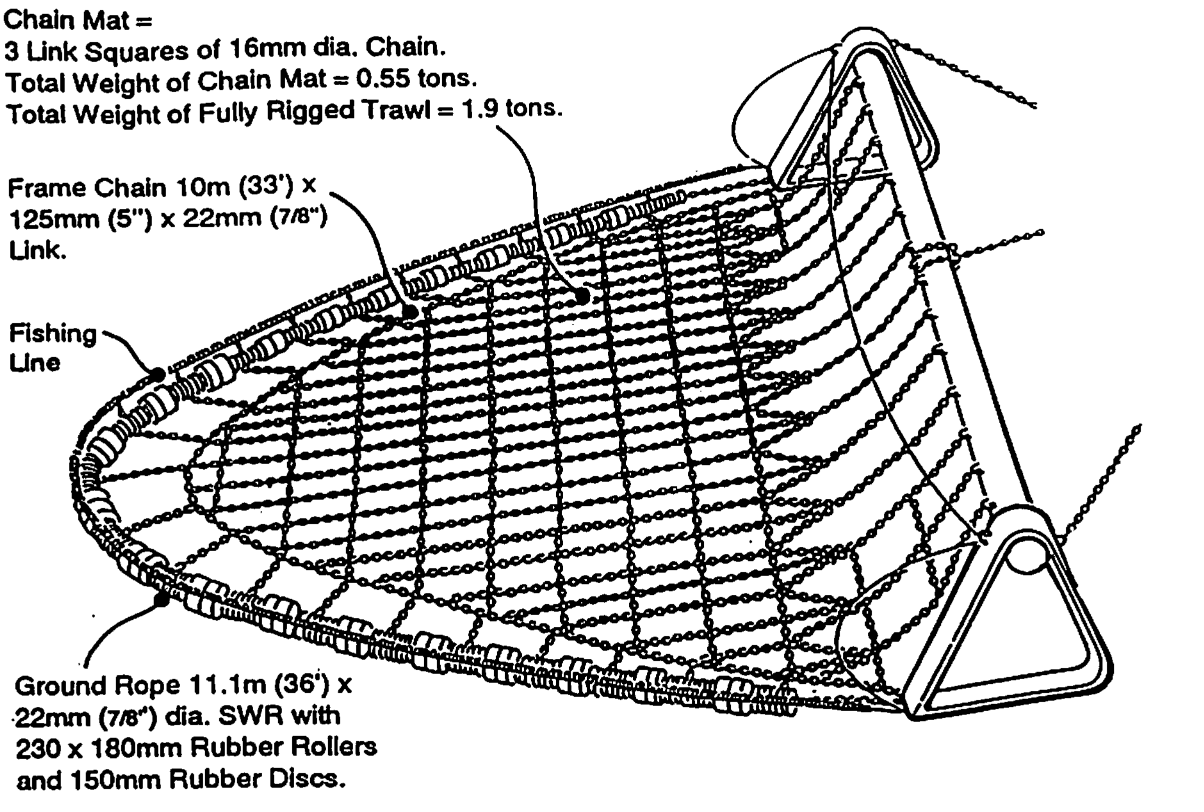
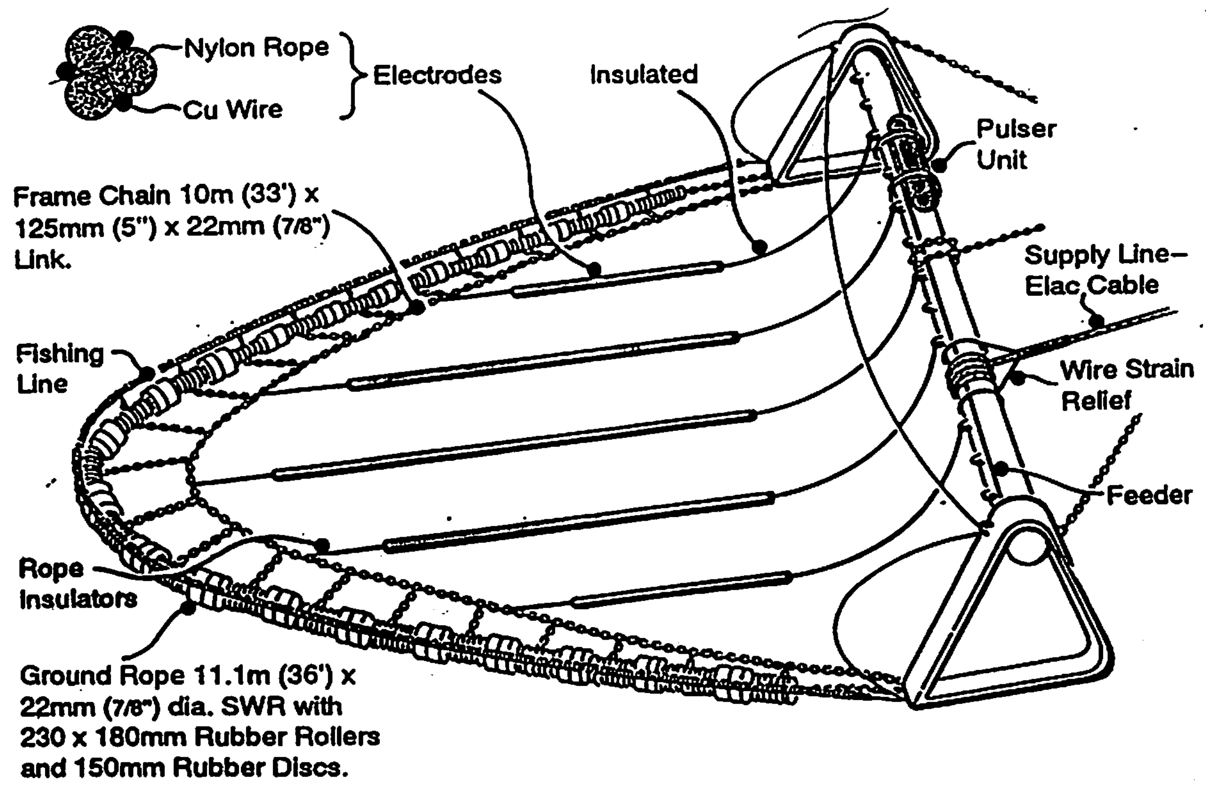


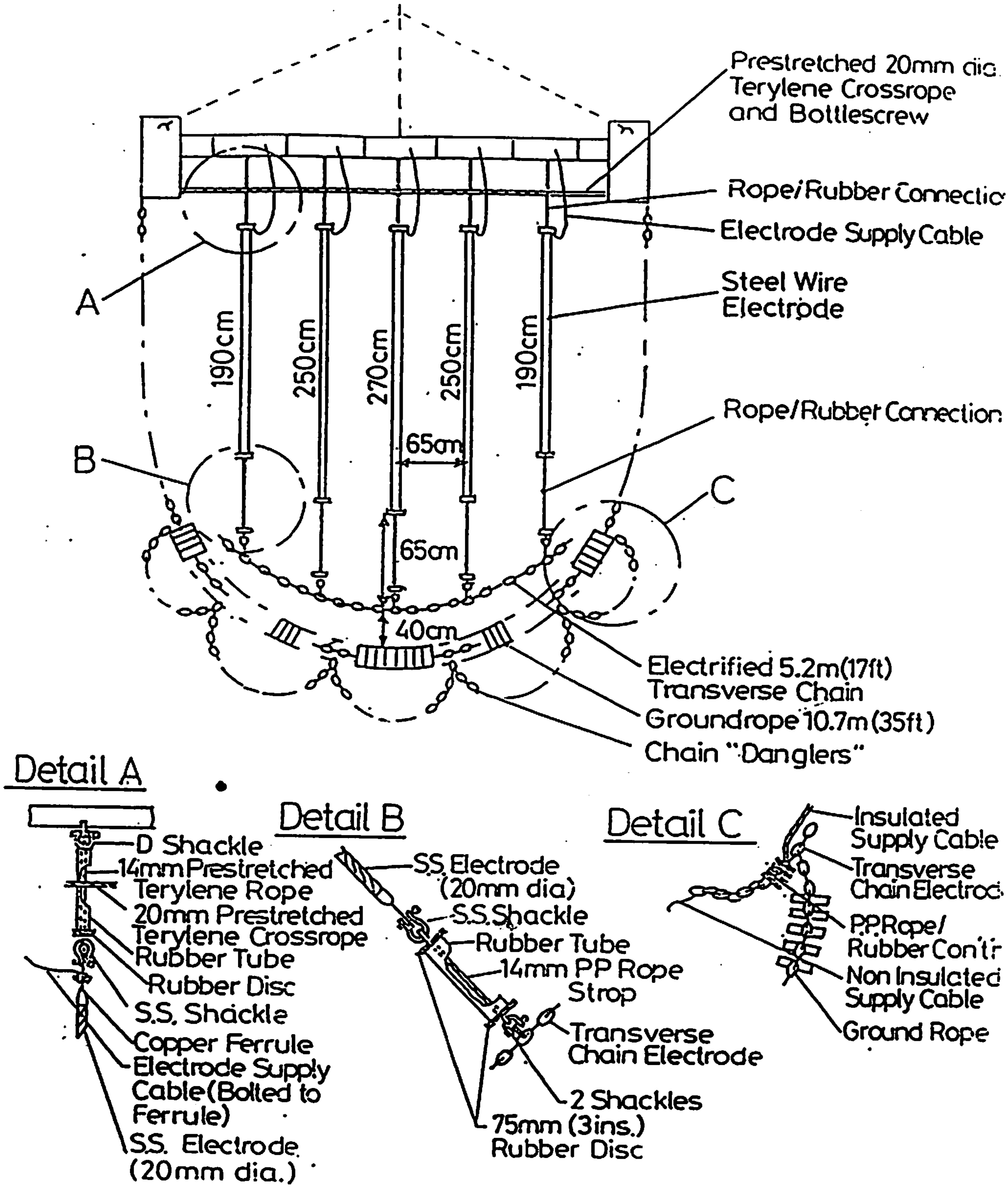
Figure14 - Different designs of electro beam trawls



4 Metre Beam Trawl Rigged with Chain Mat. Fig. 16

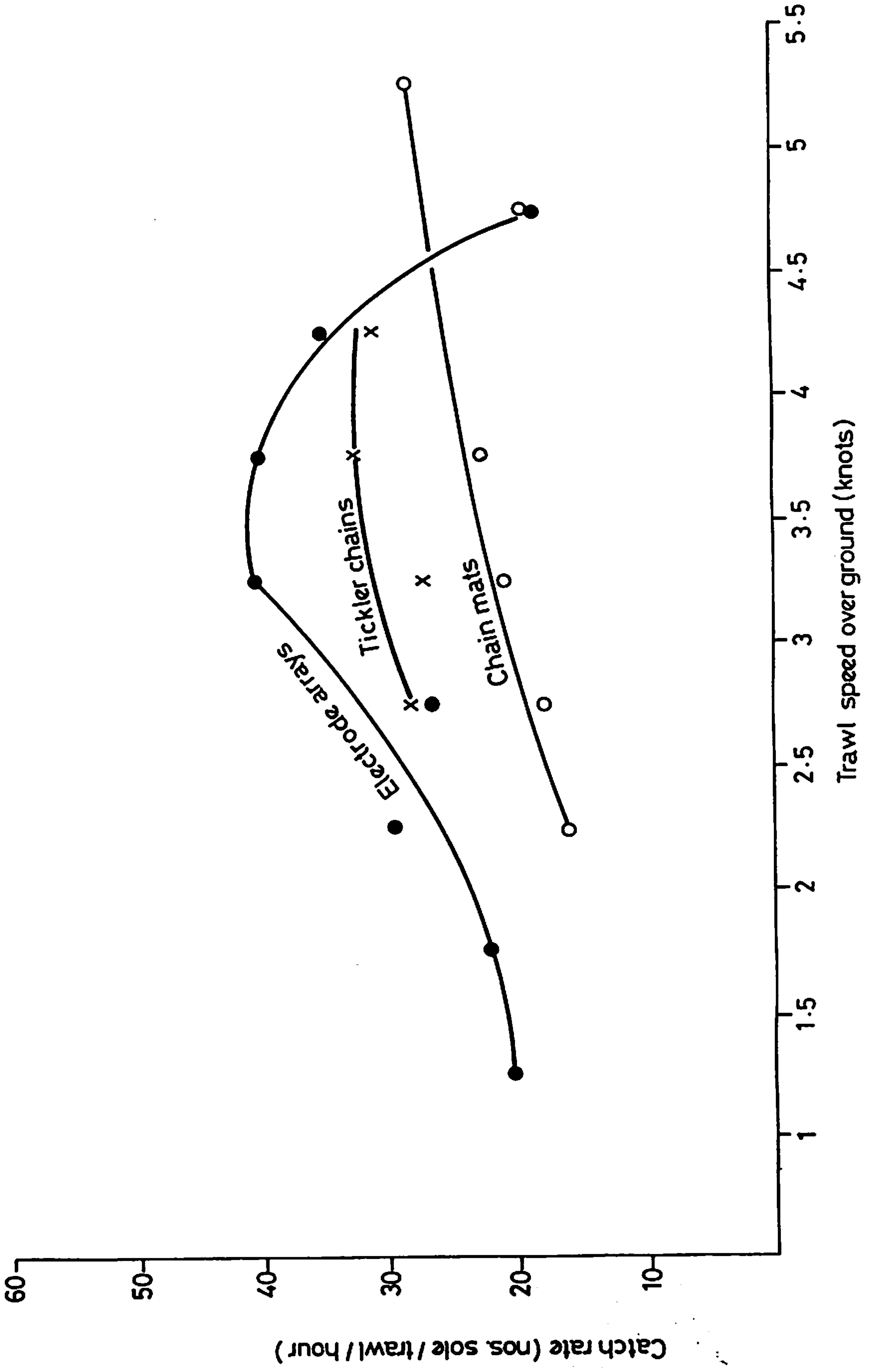


4 Metre Beam Trawl Rigged with Electrode Arrary Mk I Fig. 17



Trailing Wire/ Transverse Chain Electrode Array — Arrangement

Fig. 18



Variation of Catch Rate with Trawl Speed mv. Homewaters
Fishing Gear Beam Trawl 4m, Rigged as indicated

Fig. 1

M.F.V. ZUIDER KRUIS
Variation of Gear Drag Force with Engine r.p.m.

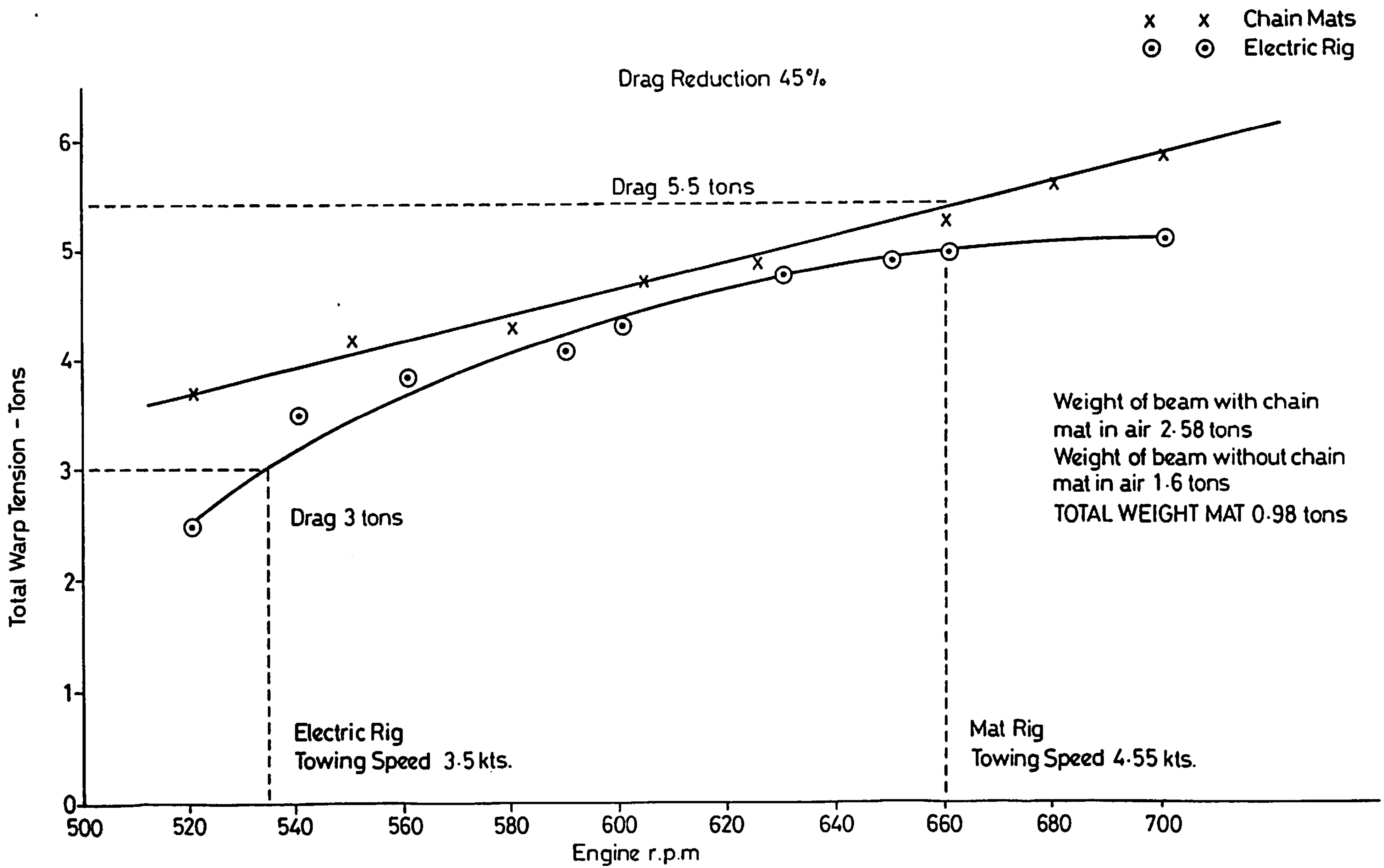
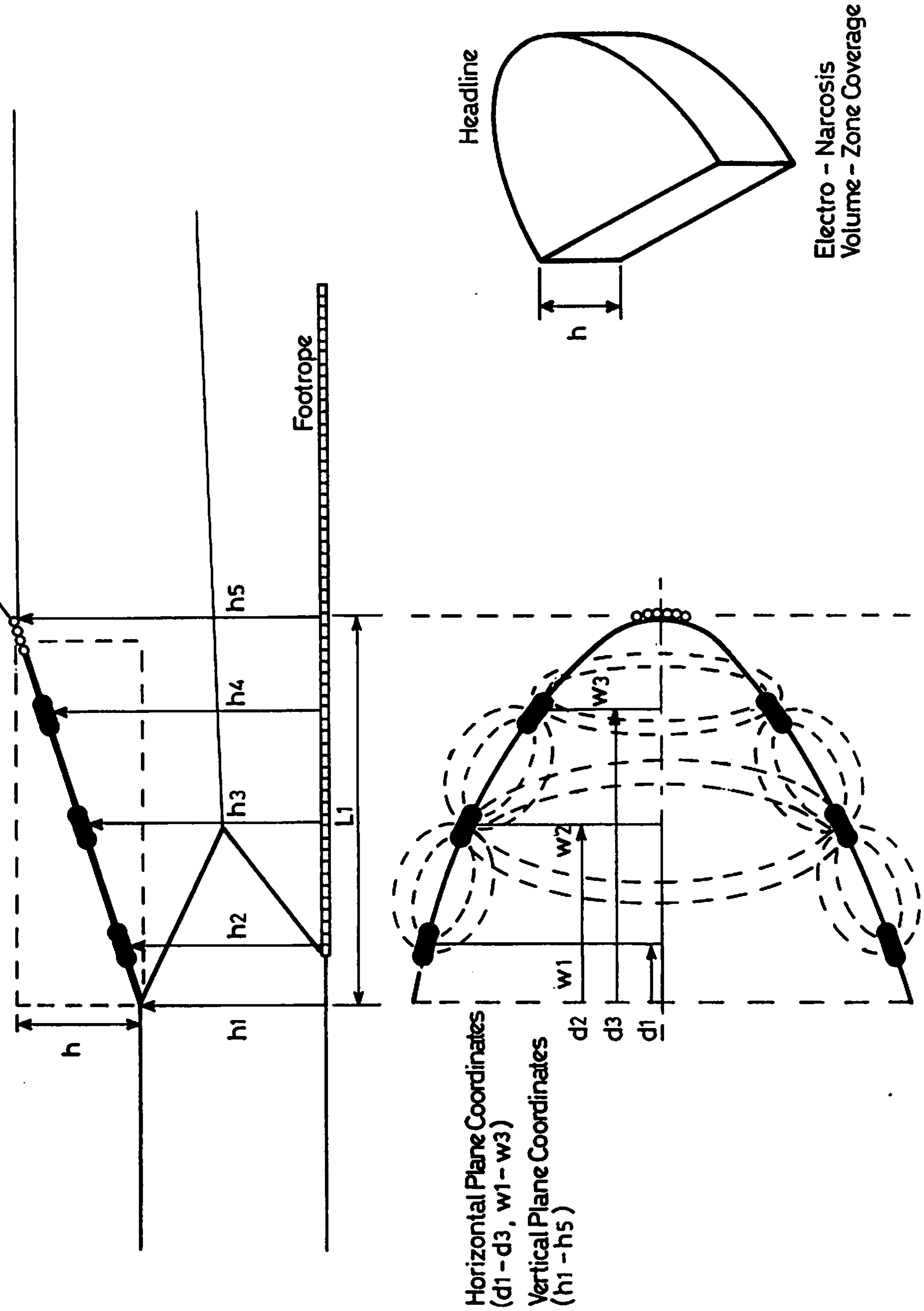
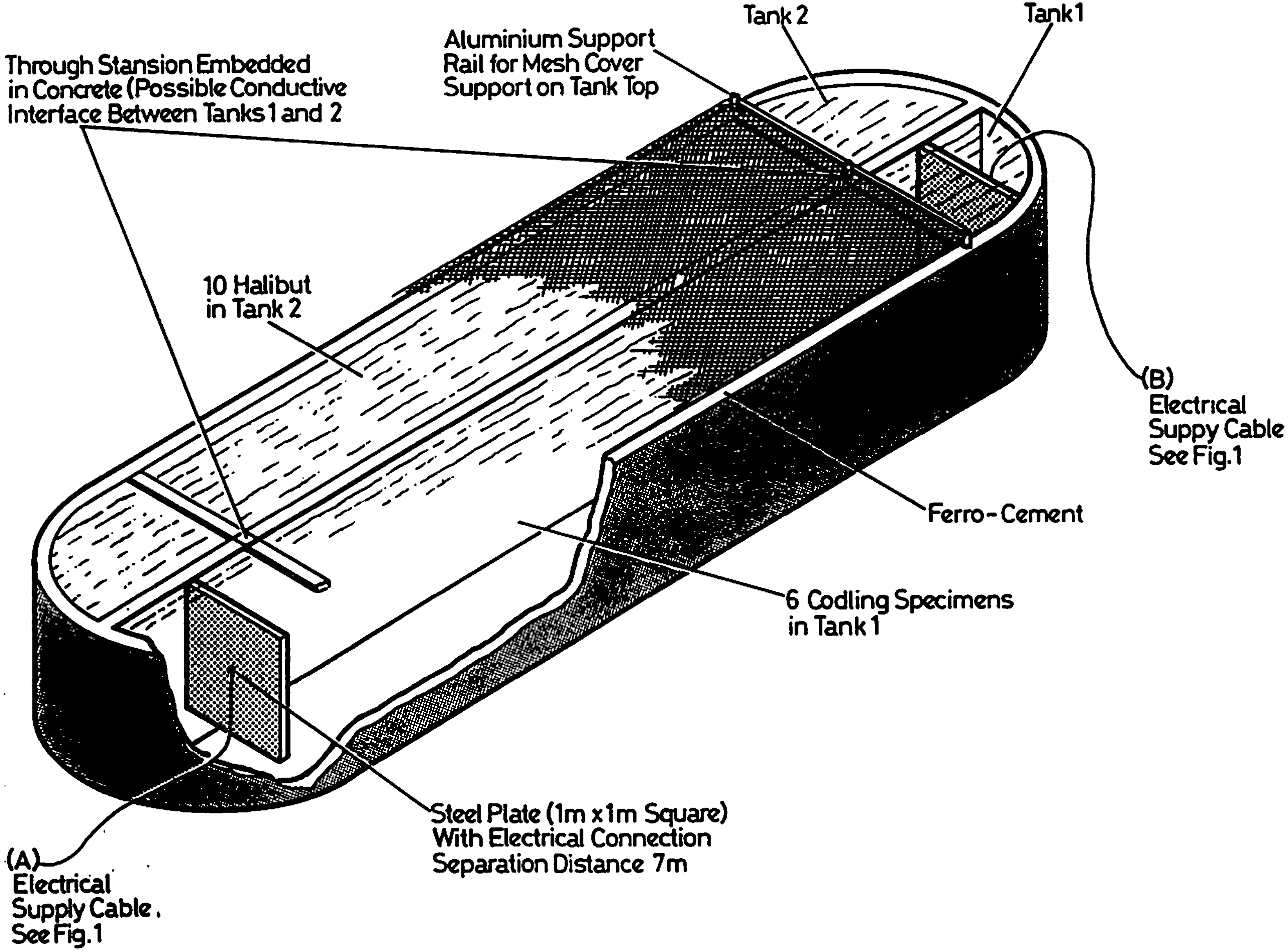


Fig. 20



Electro - Float Arrangement

FIG. 21



Experimental Tank Test Arrangement

FIG. 22

7. OTHER WAYS TO INFLUENCE FISH BEHAVIOUR

7.1 Introduction to water flow

It is well known among the fishermen and the scientists that the water flow (speed, direction and period) plays an important role in the fishing process. Fishermen know that the catch will be poor, if a net or a poundnet is rigged wrong in relation to the water flow. In spite of the fishermens valuable empirical and practical experiences very little interest have been manifested in scientific research of that area.

Water flow affecting the behaviour of fish before and during the catching process has two main sources:

natural - sea currents, winds, rivers (estuaries) and channels

man-made - structure and speed of gears (seine/trawl), guides, propellers, fishpumps

Natural currents play a significant role on fisheries. The velocity of natural water flows is usually low, only few centimeters per second. However, migrations and aggregations of fishes are greatly influenced by direction, speed and duration of currents. Hence they determine where, when, what and how to fish.

Man-made water flows act mostly on a gear scale. Their speeds depend on those of gears and are rarely more than 1-2 m/s. Those flows participate in herding fishes into the catching device and through it too, for example the trawl. Flows are influenced and produced by constructions of the gear, since technical measures could be used to get desirable results.

7.2 Review of investigations

7.2.1 Pelagic herring trawl

Several selectivity and survival studies have been conducted in pelagic herring trawling in the Northern Baltic Sea. Selectivity properties of different kinds of mesh sizes, mesh shapes and sorting grids as well as survival of escapees were studied in Finland (Suuronen 1990, Suuronen 1991, Suuronen et al. 1991a and 1991b, Suuronen & Millar 1992, Suuronen et al. 1992 and Suuronen 1993). The behaviour of herring escaping from a codend and through a sorting grid were observed with the underwater TV camera.

Sorting grids were mounted at the front upper panel of the codend extension and small-meshed lifting panels were used. Tests with different grid and lifting panel modifications indicated that the selection performance is connected to rigging and the water flow through it (Suuronen et al. 1993a and b). Controlling of the water flow around and through the grid, however, turned out to be complex and difficult task. The water flow patterns and the optimal performance of a grid seemed to be sensitive even to small changes in the rigging of the grid and the lifting panel construction. On the basis of these experiments it can be concluded that arrangements which could guide the water flow through the grid and minimize the turbulent water flow around the grid would likely be helpful in developing an optimal grid construction. Pilot tests have been made with a special "flow booster", that increases the water flow through the sorting devices and minimizes the turbulence.

7.2.2 Herring poundnet

The herring poundnet is used in the herring fishery during the spawning season in spring. The herring catch fished by poundnets was 15.8 % of the total herring catch in Finland in 1993. The fishing trials were conducted in the autumns of 1989-1991 in a traditional poundnet fishing area in the central part of the Archipelago Sea of Baltic (ICES Subdivision 29N) (Tschernij *et al.* 1993). The aim of the study was to clarify the possibilities to extend the herring poundnet season also to autumn, when the herring schools are rear and the catches are poor. Water movements and the swimming patterns of herring in relation to an typical poundnet were monitored with a current meter, echo sounder and experimental gillnets around the poundnet.

There was a dominant southwesterly water flow during the experiments and its velocity varied from 1.5 to 13.0 cm/s. The higher fish densities on the current side of the poundnet indicated that herring were at least to some extent guided into the poundnet by water currents during dark period. It was further noticed that the relation between changes in water surface level and experimental gillnet catches was clear. The water movement seemed to have an important effect on swimming patterns of herring. The main problem in capture process was connected to behaviour of herring in relation to the leader net. In these experiments the guiding function of the leader net was not satisfactory, even when the netting was made up of very small meshes (bar length 13 mm).

7.3 Further works

The effects of water flow in the trawl codend is possible to maintain in two different ways. The one alternative is to increase the flow through the sorting devices. This construction guides the fishes passively through the sorting grids or mesh window panels etc. The other solution is to create areas with lowered speed of water flow, where fish can actively search out of the trawl codend. The knowledge about swimming patterns and behaviour of fish is essential, when developing the different sorting constructions.

7.3.1 Trawling of herring in the Baltic Sea

The smallest individuals of Baltic herring (< 15 cm) are not capable to swim actively through the sorting devices. The maintaining of the passive guiding effect is found out to be the only way to sort the smallest herring out of the codend. The mounting and rigging angle of sorting panels, the use of guiding funnels and flow boosters can be further developed to enable the higher selectivity performance.

7.3.2 Trawling of Baltic cod

The cod, even the smallest individuals, can swim actively through the sorting devices in the codend. The optimal position of sorting panels (mesh window panels) is essential to attain high selectivity in bottom trawling. Experiments of codend selectivity with different type of mesh sizes and mesh configurations are currently under way in Baltic to find the optimal codend construction.

7.4 Other stimuli than water flow

Sreekrishna (1995) gives an extended overview of fishing techniques and strategies used in India. Factors affecting fish behaviour are listed such as biological factors, environmental factors, meteorological factors, light, sound and electric fields. Of meteorological factors it is interesting to note that lunar periodicity was found to affect especially crusteceans. Many techniques use fish behaviour to enhance catches. Some fishermen use the sound produced by fish to locate them, others use place where fish tend to seek shelter such as bushes. Gears used are traps, pound nets, scoop nets, gill nets. The paper ends with an interesting list of references of which the most relevant are given here.

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8. MOBILITY AMONG SCIENTISTS

8.1 General

The table below shows the mobility organised under this project.

List of mobility

Host	Topic	Timing	Duration	Visitor	Vessel
IMR	Tagged fish reactions to sound	Sep 1994	5d	D. de Haan	FJORD-FANGST
IMR	Tagged fish reactions to sound	Sep 1995	5d	D. de Haan	FJORD-FANGST
IMR	Tagged fish reactions to sound	Sep-Oct 1996	5d	D. de Haan	OSCAR SUND
SOAEFD	Stimuli for escape	Jan-Feb 95	10 days	K. Lange	CLUPEA
SOAEFD	Stimuli for escape by flow manipulation	Jun 96	10 days	K. Lange	CLUPEA

Centres of excellence were visited to retrieve information from outside the European Community, as indicated in the table below.

List of visits

Institutes	Topic	Timing	Contact	Duration	Places
RIVO/SOAEFD	Sound, light, others	Oct-Nov 95	prof. Dr. T. Arimoto	15 days	Bejing, Tokyo
RIVO/BFAFi	Sound, light, electricity	Aug 96	MARINPO	5 days	Kalinin-grad

8.2 Visits to Norway

8.2.1 Introduction

Three trips were undertaken by staff of RIVO-DLO under the heading of mobility, one in 1994, one in 1995 and the last one in 1996. Dick de Haan from RIVO-DLO joined experiments done in Norway with acoustically tagged plaice and cod on RV "Fjordfangst" in the Ramfjord in Northern Norway in the first two years. The objective was to monitor fish reactions to sound produced by air-guns. The experiments in 1996 were aimed at analysing the output characteristics of an acoustic fish concentrator produced by Skipper Electronics A/S of Oslo. These were carried out from RV "Oscar Sund" of Bodø College in Norway in the Balsen Fjord.

8.2.2 Methods and materials.

The 1994 experiments.

The positioning system used is of type Vemko VR-20. The deck station is controlled through an IBM-AT computer with positionering software and a micro-processor controlled timer interface and radio-modem. This station is connected to three or more buoys with a radio-modem, a 12V battery, and a hydrophone underneath. Signals are picked up by radio telemetry. The basis station calculates the position of each pinger in relation to the three buoys. Each pinger transmits a pulse train every 40 seconds with a frequency between 50 and 60 kHz, and a period of ~1300 msec. It contains a battery that can last for 20 days. Its dimensions are 16mm in diameter and 48mm in length. A mini current meter type SD-6000 was used. It is programmable with three channels measuring flow strength, direction and water temperature with an update every 5 minutes. Its capacity is 6000 measurements. It is made by Sensordata, Bergen, Norway.

The 1995 experiments.

The air-gun used is a pneumatic sound source type 600B made by Bolt Associates Inc., Norwalk USA, who are representated by GECO, Norway. Pressure is delivered by an air bottle of 1 liter volume of which two are available. Starting pressure is 90 bar maximal. The minimum air pressure during the experiments is 23 bar. The air-gun is fired by an acoustic link made by Scanmar, at an automatic firing frequency of 0.1 Hz. Firing was also done by hand with a 30V power supply during the last experiment. Four pingers of type Vemco V16-4H were used with the following specifications:

Serial no	Freq.	Pulswidth	Pulse period	Pulses per min
1918	60	10	1000	60
1919	65.54	10	1031	58
1920	69	10	1043	57
1921	73.50	10	1051	57

Calibrated Brüel & Kjaer (B&K) hydrophones of type 8104 (with 30 m cable) were used in combination with a Brüel & Kjaer Charge Amplifier 2635. The recorder was a Sony Datrecorder type TCD-D10 PRO. The current meter was made by Simtronix, Sandnes Noorwegen, type UCM-60, and able to record horizontal and vertical water speed, compass direction, temparature, depth, and tilt angle. Underwater and surface light levels were measured and recorded with a LI-1000 datalogger, made by LI-COR Inc., of Lincoln, Nebraska USA. The changes in position of the tagged animals were plotted in an X-Y graph, as well as its speed and its heading as a function of time.

The 1996 experiments.

The 1996 measurements were conducted south of Tromsø in the Balsen Fjord. The prototype Skipper ABC-100 is designed to emit a pattern of several layers in a horizontal plane (90° horizontal and 20° vertical) to prevent the fish from escaping upwards. Two center frequencies of 12.5 kHz and 30 kHz (optional) are available. The device is powered by a rechargeable battery of 12 V/42 Ahr and one cycle of approx. 5 hrs. The weight of the device is approx. 65 kg. Ambient noise was recorded prior to the actual measurements. During these measurements the ship was anchored at the bow and stern. The main engines were switched off and power was generated by the ship's auxiliary engine. The acoustic source has a weight of approx. 15 kg and was launched vertically with the active side upwards. It was lowered to a depth of 23 m below the water surface. The exact depth value was checked with the ship's echo-sounder EK-500. At the start a hydrophone B&K type 8104 was connected to the recording/analysing equipment. The other equipment was used to check repeatability of the results.

The following set of FTFI instrumentation was used to record the characteristics:

Hydrophone	B&K types 8103, 8104 and 8106.
Conditioning Amplifier	B&K type 2635
Portable signal analyser	B&K type 2143
DAT recorder	Sony type TCD-D10PRO

8.2.3 Results

Cod reacted clearly to the air-gun sound, whereas plaice did not seem to be affected at all. Further observations were deemed necessary. It was recommended to investigate whether fish can be diverted by sound when swimming.

In the 1995 experiments three plaice of 41, 50 and 60cm were tagged, of which two were monitored. The third one was out of range and could not be followed. One of the tags was spit out by a plaice and swallowed by a fish of unknown species. This unidentified fish showed strong reactions to the sound stimulus, indicating it to be a cod fish. The air-gun did not function optimally. Air pressure was lost with time leading to reduced capacity. Flatfish reactions were only observed in one case at night. A passive animal was activated. The data are insufficient to draw any conclusions with confidence.

8.3 Visits to Scotland

8.3.1 FRV Clupea trip report, Cruise 0295C

Programme

Timing: 30 January to 13 February 1995

Ports:	Loading Fraserburgh 30 Jan
	Unloading Fraserburgh 13 Feb

Personnel

C.S. Wardle	SPSO
C.W. Glass	SSO
C.D. Hall	SSO
Y-Y. Kim	Visitor
K. Lange	Visitor Hamburg BFAFi

Fishing gear and equipment

Bottom trawls BT 130C with 7' V-Boards (V33/34) and Heavy Rock hopper Ground gear. Spare BT 130F (Black and white). Bobbin ground gear and 7' V-boards (V35/36) to be kept ready in Aberdeen as spares. Experimental black codends and white codends.

Objectives

1. To measure light distribution in and around the trawl for modelling the visual stimulus (Mr. Kim).
2. To observe behaviour of fish in experimental extensions in order to quantify escape behaviour and encounter rate.
3. To observe the behaviour of fish in the same extension arrangements in dark conditions using the TUV fitted with the SIMRAD scanning sonar and a new low light level flash TV system.
3. To assess small fish escape routes at night using small mesh pocket covers.
4. To assess the potential of flow guidance devices in aiding the passage of fish attempting to swim through meshes.

Procedure

Staff will travel by minibus to join *Clupea* on the morning of monday 30th January. The fishing gear towed vehicle and scientific equipment will be loaded and assembled during the morning. *Clupea* will sail for Moray Firth or the Orkney Islands, Copinsay area depending on weather forecasts. The working day will be arranged so that underwater light measurements can be made soon after midday followed by the first daylight haul and the last haul will be in darkness ending before midnight. *Clupea* will return to Fraserburgh for unloading on the morning of monday 13 Feb 1995.

Results

The cruise suffered from winter conditions and bad weather. No observations could be made.

8.3.2 FRV Clupea trip report. Cruise 0996 C

Programme

Timing: 17 June to 01 July 1996

Ports: Loading Fraserburgh 17 June
Unloading Fraserburgh 01 July

Personnel

C.S. Wardle	SPSO
C.W. Glass	SSO
P. Barkel	PTO
K. Hall (miss)	Visitor
H. Ozbiligin	Visitor (PT)
K. Lange	Visitor Hamburg BFAFi

Fishing gear and equipment

Bottom trawls BT 130C with 7' V Boards (V33/34) and with RCTV. Spare BT 130 to be ready in Aberdeen as spare. Experimental black codends and white codends.

Objectives

1. To determine range of tail beat frequencies of escaping fish and determine relationship between encounter rate and escape rate.

2. To asses the potential of flow guidance devices in aiding the passage of fish attempting to swim through the meshes.

Procedure

Staff will travel by minibus to join *Clupea* on the morning of 17 June. The fishing gear, RCTV and scientific equipment will be loaded and Clupea will sail to the Orkney Area. *Clupea* will return to Fraserburgh for unloading on the morning of 01 July 1996. Normal contacts will be maintained with the laboratory.

Results

Attempts were made to create a Karmann vortex sheet in front of a square mesh panel. No final conclusion could be drawn from the work.

8.4 Visit to Japan

8.4.1 Introduction

B. van Marlen and Dr. C.S. Wardle visited China and Japan between 14 October and 4 November 1995, under the heading "Retrieval of information". The first week was allocated to attend sessions in the Fourth Asian Fisheries Forum in Beijing, the FAO Expert Consultation and the CRAFT "Cooperative Research in Asia for Fishing Technology" workshop. Van Marlen gave a "Keynote address" in workshop CRAFT titled: *"International Cooperation in Fishing Technology and Fish Behaviour - The ICES - EU model"* by invitation of prof. Dr. T. Arimoto of Tokyo University of Fisheries (TUF). Dr. Wardle spoke about "Research trends in fish behaviour" also as keynote speaker.

8.4.2 FAO expert consultation and CRAFT workshop Beijing CHINA, October 1995

During the FAO expert consultation on 16 and 17 October 1995 and the workshop CRAFT "Cooperative Research in Asia for Fishing Technology" on 18 October 1995 a great deal of information about fishing methods used in Asia was given. Many details related to fish behaviour and alternative stimulation were revealed.

8.4.3 Facilities visited in Japan

After the Asian Fisheries Forum the trip continued to Japan, where two weeks were spent in travelling and visiting laboratories, and facilities, chosen to be of relevance to this project, namely the use of alternative stimuli in fisheries, particularly light and sound.

8.4.3.1 Tokyo University of Fisheries

Tokyo University of Fisheries (TUF) was founded in 1949, but its predecessor the "Fisheries Institute" or "Suisan Denshujo" originated as early as 1888. The university has a master programme since 1964, and a doctoral programme since 1987. The visit was limited to The Department of Marine Science and Technology. Outside the main campus ground there are also a number of Research and Training Stations of which a few were visited later on.

These are:

- Banda Marine Laboratory.
- Tateyama Research and Training Station.
- Yoshida Research and Training Station.
- Oizumi Research and Training Station.

The university runs three research and training vessels:

- Umitaka-Maru (Loa= 79.0m)
- Shinyo-Maru (Loa= 53.0m)
- Seiyo-Maru (Loa= 35.5m)

The Department of Marine Science and Technology covers the following subjects:

- Physical and chemical aspects of marine environmental variation and influences of pollutants on the marine eco-system.
- Variations and forecasting of fisheries environment.
- The influence of environmental conditions on fish behaviour and dynamics in capture process.
- Fishing technology in relation to behaviour.
- Fishing vessel and gear engineering topics, including onboard working conditions and safety.
- Navigation and fishing equipment.
- Seamanship apprentices, if requested.

The department has four laboratories:

- Laboratory of Marine Environmental Studies.
- Laboratory of Fisheries Oceanography
- Laboratory of Fishing Science and Technology
- Laboratory of Fishing Technology and Engineering

TUF hosted the following numbers of students in 1994:

Undergraduate programme	1362
Graduate programme	267
Other programmes	92
Foreign students	106

The Laboratory of Fishing Science and Technology was visited on 23 October 1995. After a short introduction by prof. T. Arimoto several test facilities were visited and work explained by various students.

Ari Purbayanto talked about behaviour of fish in trammel nets, which is studied as part of his thesis-work. The nets are used in the daytime mostly. The construction is multi-monfilament. Target species are: Japanese whiting of lengthrange 15-25cm. Meshsizes used in the trammel net are 3cm for the inner net and 30cm for the outer net. Tests are done in the laboratory to determine the visual recognition of multi-monofilament netting yarns, and the effects of learning. Fish are studied by taking ECG's.

Nana Kasai showed a test tank with different materials. Fish were released from a closed section and subjected to various objects for which the reactions were recorded by ECG. The opto-motor reflex was investigated in a circular basin. A third experiment comprised a two-choice alternative, where food coloured green led to an electrical stimulus as punishment and red coloured food not. Conditioning could thus be studied.

A small flume channel is used to measure oxygen consumption. Its working section is 0.50x0.25x0.25m, and the maximum water speed is 1.7m/s.

Yasushi Shiobata showed work done on measuring the visual field of fish eyes. Fish were placed in a small sphere and measurements taken.

Fishing gear model studies can be carried out with a flume tank situated on the campus grounds. The maximum water speed in this tank is 2 m/s. Student tests involve measurements on the drag of spheres and cylinders, three-dimensional force measurements on trawl boards, and measurements of drag of nets in frames. The tank has no moving conveyor belt to simulate the seabed as many tanks have in Europe.

Prof. Arimoto showed a video about fishing with lights. The lightboats are 10m long, and carry a lamp of 4kW. Two or thee small vessels work with one larger purse seiner.

Species are mackerel, horse mackerel, squid and flying fish. The purse seine has a floatline of 700m length. A catch can be as much as several hundred tons, and fish are pumped onboard, and stored in tanks with ice. Also possible is to land fish alive by storing in seawater tanks. Apparently fish survive the pumping activity. This fishing operation is only carried out during the night. It is not allowed in Tokyp Bay. The reason is that the method is claimed to be too effective in the competition with artisanal fisheries. Apart from a purse seine fish is also caught by the so-called stick-held dip net, a gear operated from the side of the vessel. The lamps are used to lure the fish above the dip net which can than be lifted to catch the fish. This light stimulation is dispersed by using a large array of lamps instead of a single light source. For mackerel (*Scomber Japonicus* L.) sardine bait is added to the water to lure the fish. This species is claimed to exhibit strong reactions to light stimuli.

Other fishing methods were also explained by Arimoto. Automatic squid jigging was shown. The mainline of 1-1.5mm diameter carries no snoods, just the coloured baits at intervals. Squid is lured to the gear with light. The jigging movement is made irregular to be effective.

Various other techniques using alternative herding or scaring devices were shown on the video. An electrified harpoon is used in swordfish fishery to stun the fish and avoid the dangerous struggling period of two-three hours which would occur with normal harpoons. Other methods were shark fishing with a baited wire from small vessels, divers using hand harpoons, small boat encircling gillnet operated by two or three men. Fish is scared into the net by hitting the water surface or throwing stones in the water to frighten them. Another herding method shown were sticks with vanes moved through the water by divers. In other fisheries fires lit above the surface are used as attracting devices. In a shore-based dipnet fishery the fish were herded to the net by poles carrying a line and a feather, and the net operated by a single person. An application of olfaction is the use of the smell of sea otters to scare off fish in certain directions. Many artisinal methods were shown such as bamboo eel pots, cast nets operated by a single man, bamboo screens, bundles of twines as FAD's for crayfish, FAD's made of junk, a salmon lift net, bamboo set nets. Fish were scared off hiding places in winter by hitting rocks above with a hammer. Other methods are octopuss fishing with handgrips, floating mats made of rice straw and sea weed operated by two men per boat. Many fishing methods make use of particular behaviour patterns or behaviour to various stimuli.

8.4.3.2 Tokyo Central Wholesale Market

Observations during the visit:

- Packing units are usually small polystyrene boxes in which fish is stored on ice.
- Many fish are landed alive and kept alive in circulating water tanks ensuring maximum quality.
- Products are sent all over the world (e.g. Denmark, Canada, etc.)
- A very large variety of products can be seen from crusteceans to sea weed, and of course many fish species.
- Shops for the daily market are located inside the area or very close to it.
- Categories are: fresh fish, alive fish, frozen fish, salted and dried fish and others (See leaflet), with a total of some 2500 tons a day.
- Trucks are mostly small, transportation also takes place on mopeds and bicycles to local markets and restaurants in Tokyo.
- Small diesel powered carts are used for transportation of boxes on the market area.

8.4.3.3 OITA Prefectural Fisheries Experimental Station

The visit took place on 26 Octber 1995 after a short boat trip to a fish feeding buoy, explained further. We were welcomed by Mr. Rikichi Sato, the general director of the OITA Prefectural Fisheries Experimental Station (OPFES).

OPFES was founded in 1900. The organisation consists of five divisions, the Administrative Division, the Fish Breeding Division, the Fishing Ground and Environment Division, the Fish Desease Guidance Center, and the Fishery Product Processing Center. The total staff counted 28 persons, including administrative and technical staff in 1991. Among services rendered to the industry are: fisheries research and technical guidance, culture of aquatic animals and plants, improvement and dessimination of fishing techniques, prevention of fish deseases, fish processing guidance, and others. The institute has laboratories, a research vessel and experimental ponds.

Research topics are:

- Fish distribution and hydrographical conditions.
- Stock assessment and larvae studies for the offshore fishery.
- Studies on natural and artificial fishing banks including production of sea maps.

- Management of resources by hatching fish and conditioning using sound stimuli, after which they are released in the open sea and can be manipulated to return to the feeding point.
- Pelagic fish resource management studies.
- Marine ranching demonstration tests on five different locations.
- Development of fish releasing methods including studies of seed production, intermediate breeding and appraisal of efficiency.
- Monitoring of environmentally protected areas.
- Research on algae blooms ('red tides') and effects on shellfish.
- Sea water aquaculture research, including accelerants for rearing and new feeds.
- Tests of new aquaculture species, *ie* amberjacks and common basses.
- Prevention activities of fish deseases in aquaculture.
- Development of new fish products and quality aspects.

The Marine Ranching Programme is subsidized by the New Mechanical Systems Propagation and Promotion Project of the Mechanical Social Systems Foundation, which is a part of a project called Marinopolis Project. The idea is to increase natural fish stocks and improve the availability of fish to fishermen by introducing hatched and conditioned specimen into the live stocks, that can be called back to feeding stations placed in the sea. This project started in 1983 with research activities. Cooperating companies are: Mitsui Engineering and Shipbuilding Co., Ltd., Japan Radio Co., Ltd., Matsushita Electrical Industrial Co., Ltd., Penta Ocean Construction Co., Ltd., Santo Engineering Co., Ltd., Shimizu Construction Co., Ltd., and Zeni Light Buoy Co., Ltd. In Oita the first buoy was placed in 1990. The facilities for controlling fish resources by acoustic conditioning feeding process were visited.

Finance was given by local governmental, municipal governmental and national governmental authorities, according to the following percentages.

Structure of finance

Contributor	%
National government	50
Local government	40
City government	5
Fishermen's Association	5

Mr. Kudo explained the following distribution of costs.

Project cost items

Item	MYen
Feeding buoy	60.0
Fry	2.5
Nursury	4.0
Artificial reefs	60.0
Placing reefs	110.0
Total costs	**336.5**

The yearly income from one buoy is estimated at **8.5** Myen. A buoy has a life span of 15 years. It appears that capital recovery of this investment is rather low.

The system consists of an automatic feeding buoy with telemetry link to a shore-based computer and echosounder. In addition artificial reefs (fish aggregating devices) are placed in the sea area. The species involved is red sea bream (*Pagus major* L.). Eggs are withdrawn from fish older than three years and hatched for 35 days until the fish are 12mm in length. Then the fish is transported to a sea basin and reared for another 20 days until they reach a length of 30mm. Whilst growing from 30mm to 100mm the fish are conditioned for 80 days during feeding with a tone of 300Hz (150dB). This stimulus was found from basic studies using frequencies between 200 and 800Hz, which turned out to be acceptable for conditioning these fish. The fish is then released in the bay and fed 5 to 7 times a day with the same acoustic stimulus attracting the animals to the feeding buoy. The sound is played for a period of three minutes, after which feed is released for three minutes, and this is repeated once. At any time afterwards the fish can be aggregated in the vicinity of the buoy by playing the sound and become available for commercial fishing. At the time of the visit (26.10.95) it was mentioned that a total of 70000 fish were released in September. It is expected that harvesting will occur next April when the fish reach a length of 20cm, which appeared to be the minimum landing size. Harvesting is done by jigging. Around 15% of the released fish is expected to be caught. The catches comprise of both hatched fish and fish from the natural stock. It is prohibited for sportfishers to operate within a 200m radius around the feeding buoy to avoid poaching. Placing such a buoy must be permitted by coastal authorities. A demonstration of the telemetry system was given in the office after visiting the buoy by boat. The feeding mechanism is controlled from the shore base and the echogram showed aggregations of fish a short while after start of feeding. It was mentioned later that the fish conditioning system was copied in other places in Japan, and that some twenty units are now operational.

Some data given:

Recaptured rates of fish from one group

Year	1	2	3	4	5
% recaptured	12.5	14.6	7.8	3.9	2.3

The rates of recapture are generally between 10-12% in the year after release, which comprises 13-14% of the market of red sea bream. As can be seen from the table above, the recapture rate drops with time for the same group as might be expected. These data were derived from studies on tagged fish. Crucial for success of this programme is to work with a non-migrating species. Red sea bream is known to stay in Oita bay. It was also recorded that these fish live in the 15 to 20m depth strata. The water depth of the bay is around 40m. Other species observed in the area are: Chilken Grunt, Japanese Parrot fish, Scorpion fish and Thread Sail File fish. The behaviour is temperature dependent. When the water temperature drops below 13 °C in the winter time feeding is stopped.

8.4.3.4 Kamiara Branch of the Japan Sea Farming Fishery Association (JASFA)

Kamiara Branch of the Japan Sea Farming Fishery Association (JASFA) was visited straight after the visit to he OITA Prefectural Fisheries Experimental Station (OPFES). The station is led by Dr. Keinosuke Imaizumi, who guided us around the facilities consiting of several land-based hatching tanks and floating net pens.

8.4.3.5 Light-fishing vessel in Nishiki

The little fishing port of Nishiki in the Mie Prefecture was visited on 28 October 1995. Adverse weather conditions hempered witnessing the complete fishing operation during the night. Instead a short demonstration was given at sea aboard the "Daido-Maru" (No. 18) by her skipper Mr. Kyoji Itokawa with more elaborate explanation of the fishing method afterwards. Skipper Kyoki Itokawa demonstrated the use of lamps to attract fish at sea, and explained the technique of light stimulation in combination with purse seining afterwards. Two or three small boats carrying lamps lure the fish upwards to be caught by a purse seine vessel also carrying lamps. Technical details and specifications of the lamps were given by the skipper.

The operation is carried out with three light boats (L.o.a = 12m, B = 2.7m, hp = 630hp, V = 30kn), and one catching unit, which is a purse seiner (L.o.a = 28m, B = 6m, hp = 800hp). Lights are used both above the surface (10 kW) and below the surface on an electric wire (3 kW). The purse seine consists of 34 pieces of nylon (Teteron) netting over a total length of 1020m, and reaches a stretched depth of 220m. The mesh size is 30mm.

Two underwater lamps are used of 3 kW each, plus one so-called "small-shade" lamp of 2kW, and five "large-shade" lamps of 2 kW above the surface. All of type halogene on 220V. The generator delivers 20 kW, which is limited by legislation, as well as the number of light boats in one operation, i. e. 3 at maximum.

One of the light boats carries a fish-finder and a doppler sonar to measure the deepsea water speed. The species fished are: Japanese mackerel (*Scomber Japonicus* L.), and Japanese horse mackerel, which always seem to get mixed in a haul. The light boats lure the fish up to the surface while the purse seiner shoots his net around encircling the light boats. Fishing is done at night only. One shot takes about 45 minutes, and a total of five hauls can be done in one night. No baits are used, only the light stimulation. The catch can be as large as 135 tons and is pumped onboard and stored in tanks with ice. These holding tanks can take 50 tons. A transporter vessel can come alongside and take 35 tons. The fish is not gutted onboard but stored on ice only.

Vessel noise seem to affect particularly horse mackerel. When the lamps are carried on the port side, other vessels always approach from the other side. No sound stimuli are used in the operation.

8.4.3.6 Banda Marine Laboratory

Banda Marine Laboratory was visited on 01 November 1996 under guidance of Dr. Yasuyuki Koike of the hydrographical-chemical research section. Aquaculture facilities and laboratories were shown. New techniques are under research for the culture of fishes, moluscus and crusteceans. An example is the hatchery of the crayfish *Palyneurus Japonicus* L., and three abalone species among which *Haliotis Discus* L. *Haliotis* are released at sea at suitable locations by divers after 1 to 1.5 years breeding and hatchery at a length of 2.5-3cm. Harvesting is done three years after release. Experiments are conducted on the design and water flow of breeding cages. Other examples of hatchery are "Gruppa"-fish, cultured to full size in sea cages, and "Rockfish".

Dr. Koike showed us around the Chemical and Physical Laboratory were a demonstration was given on hydrographical data acquisition from remote buoys in the vicinity and one sensor on the top of the building. Data transmitted were: surface and bottom water temperature, direction and strength of water current, atmospheric pressure, wind speed and direction, solar radiation and sea water salinity. The water temperature at the surface ranges between 12°-26°C, and on the bottom at a depth of 29m between 13-24°C. The data is exchanged between coastal stations and dessiminated to the fishing industry.

8.4.3.7 Fishing vessel using light stimulation in the port of Tateyama

The vessel is the type fishing with a stick-held dip net and light stimulation. The following information was given by one of the crew members onboard. Fish is located with sonar, and guided to the vessel with lights. Lamps are used on the starboard side to begin with and to attract the fish from the deep. A fibreglass pole on which the net is attached is floated outward from the portside at a distance of some 30m. The net is lowered hanging down thus leaving room for the fish to swim into the volume above it. The net has meshsizes of 80mm and 22mm in the center. Species caught are Sanma Japanese, Saury (*Cololobis Saira* L.), and Saba (*Scomber Japonicus* L.). The species are not mixed at sea. A total of 16 lamps are used above the net. The lamps are placed in rows of 18 and 21. They are 500W lamps at 100V. Catches can be as high as 12 tons, for which three shots are used per night. The fish is pumped onboard.

8.4.3.8 Department of Mechanical Engineering and Science of the Tokyo Institute of Technology

A meeting was arranged with Dr. Motomu Nakashima on 31 October 1995 of the Department of Mechanical Engineering and Science, who is working on a mechanical simulation model of the swimming motion of fishes. He explaned the experimental set-up, consisting of a small model with two joints (e.g. one at about 1/3 from the tail and one at the beginning of the tail) and with the middle section driven by small stepmotors. The model is hung in a small flume tank and with dynamometers the force components in the direction of motion and lateral direction can be measured. The model is a three dimensional fish model representing a yellow-tail tuna. Earlier studies on a two-dimensional model with three joints did not give results comparable with the 3-D case. The propulsion efficiency measured was approximately 0.30. Calculations suggested a value of about 0.65. The maximum speed in the tank is 25cm/s. Further extensions of the work are sought in a bigger model with more joints to simulate a more flexible fish body.

8.4.3.9 National Research Institute of Fisheries Engineering (NRIFE) in Hasaki

NRIFE was established in Hasaki, Ibaraki Pref. close to the fishing port of Choshi, in 1979 by reorganising several different institutes. It consists of three divisions: Aquaculture and Fishing Port Engineering, Fishing Boat and Instrumentation, Fishing Gear and Methods. The latter division promotes scientific and industrial R&D on a national and local basis for advanced harvesting conservation technology. Dr. Yoshihiro Inoue guided us around the various research facilities of NRIFE, after a short visit to the port of Choshi. The institute comprises of 17 facilities called: Main Office, Research Office, Marine Dynamics Basin, Towing Tank, Circulating Water Channel, Engine and Machinery Lab, Optics and Radio Wave Lab, Fish Behaviour Lab., Aquacultural Hydraulics Lab., Aquacultural Environment Lab., Tide and Wave Test Basin, Fishery Material Lab., Acoustic Experiment Tank, Fishing Port Hydraulics Lab., Coastal Wave Test Basin, Soils and Foundations Lab., Structure Expriment Lab. A few of these were visited:

The Towing Tank can be used to carry out experiments on ship models. The dimensions are 143.0m x 6.0m x 3.5m. The tank has a wave generator installed. The maximum speed to be obtained is 5.0 m/s. Work has been done on bulbous bows for fishing vessels. The tank is run by two scientists and the major client is the government.

The Marine Dynamics Basin was established in 1993 and offers facilities for model experiments of fishing vessels and moored structures subject to directional irregular waves. Work is done on safety criteria to avoid capsizing of fishing vessels, reduction of vessel motions and ways to avoid damage in floating aquaculture facilities. Model between 1.0m and 2.5m in length can be used in the tank.

The Seawater Arena Tank of dimensions length: 17m, width 7.5m and depth: 2.5m has a controlled water temperature and light intensity. Top and side view observations with remote VTR systems and an image analyser are used to study environmental factors in schooling behaviour of fish. During the visit a model of a set net for Red Sea Bream could be observed.

The Seawater Flume Tank with a working section of length: 6m, width 2m and depth: 1.1m has a controlled water temperature in the range between 0-10°C and 20-38°C, and a water filtering system. The water speed in the test section can reach a speed of 3 knots at maximum. Observation windows allow a view from the side of the tank. This facility is unique in the sense that fish behaviour studies and hydromechanical studies can be both carried out, unlike most flume tanks that work with fresh water. This enables for instance work on escapement and survival of fish from fishing gear components.

8.5 Visit to Russia

8.5.1 Introduction

The visit to Kaliningrad Russia took place from 17-24 August 1996 together with Dr. O. Gabriel, Director of BFAFI-IFH, Hamburg. Various scientists working at MARINPO were interviewed and laboratories visited and a great deal of interesting information collected about work done in the former USSR. In addition scientists working in Lithuania (Klaipeda) visited MARINPO for one day and were interviewed. Here is a list of scientists and the topics discussed:

Dr. Vladimir Belov	The effect of sound generated by vibrating components of fishing gears.
Mr. Victor Kuznetsov	Acoustic research at MARINPO. Effect of sounds generated by vibrating wires.
Mr. Leonid Shekhovtsev	The use of light stimulation in fisheries.
Dr. Leonid Meyler	Hydrodynamics of fishing gears and components. Possibilities of MARINPO flume tank and research facilities. Rotating warp system replacing otterboards.
Dr. Jury Maksimov & Mr. Sarinas Toliusis	Research and application of electrical stimulation at the Klaipeda station (Lithuania).
Dr. J. Kadilnikov	Mathematical modelling of capture process and gear selection, stock development.

8.5.2 Discussions on sound stimulation

Dr. Belov reports about fish reactions to sound caused by vibrating gear components. These vibrations are generated by the water flow. This sound pressure field propagates mainly in directions perpendicular to the cross section of the wire elements, contrary to the vortices shed in its wake. Belov's view is that fish behaviour is determined by such stimuli, contrary to the views of other scientists (eg Wardle). Warps and trawl doors also cause detectable vibrations and were shown to herd fish away from the path of the trawl. Fish were also observed to maintain a distance of about 0.5m away from gear components and netting. It appeared that fish accumulate badly to sounds with frequencies between 2-200 Hz. Very low frequencies cause schools to disperse. Measurements were made of underwater sound emitted by fishing vessels in free sailing and towing condition. Peaks in sound pressure around 80dB were found at the moment of passage of the vessel. Sound emitted by vibrating ropes were measured experimentally. Twined yarns generate sounds in the range of 40dB, braided yarns show lower values around 30dB. Experiments with sounds on caged fish were carried out and different reactions to sounds were observed, sometimes attraction (eg in herring), sometimes scaring.

Kuznetsov explained work on sound carried out at MARINPO, Kaliningrad. Sounds were measured in the range between 100-3000Hz in proximity of a bottom trawl and a pelagic trawl using a manned underwater vehicle equipped with hydrophones. Maximum values were found between the sweeps and behind the trawl boards, and not inside the net itself. Behaviour experiments were done on Corigonidae (*Corigonus Lavaretus* L.) at sea. A wire element placed horizontally under tension was exited and fish reactions in the vicinity at a depth of 12.5m were observed. The observations were recorded with a camera looking downward. The bottom was fitted with a grid of lines to be able to quantify fish movements. Most reactions were shown to occur in the area between 45° and 135° inrelation to the wire direction. Even when pointed away from the wire, the fish reacted to the sound, which indicated that vision is not the only stimulus determining behaviour. The main conclusions of the work are:
- Fish can detect sound sources and determine their position in three dimensions.
- The irregular character of sound emitted by towed gears hemper adaption by fish, continuous monotonous sounds lead to quick adaption.

A comparison between a pelagic trawl type "Gloria" and a conventional design with more net distortion, carried out by scientists in Rostock, resulted in a drop in catch of about 20%, which could have been caused by a decrease in sound level for the "Gloria"-trawl. This net design is based on equalising the tension in all bars, whereas conventional nets are usually not. This effect was also reported by Wileman in 1988 when discussing the catchability of fishing gears with the highly distorted Danish design philosophy. Apparently ideally shaped trawls do not have maximum catch-ability.

8.5.3 Discussions on light stimulation

Shekhovtsev reports on light stimulation work done in Russia. Experiments commenced in the early 1960's and were aimed at finding whether fish can be attracted by light sources placed above and below the sea surface. Other countries working on this topic were Japan, Poland, Bulgaria and Eastern Germany. Most work was carried out between 1966 and 1989. First practical results were obtained on *Scomber Saurus* L. in the North-West Atlantic in the beginning of the 1960's. It appears that only a limited number of species react in a way that can be utilised in commercial fishery.

These are:

- *Clupeonella Kessler* (Kilka's)
- *Trachurus mediterraneus ponticus* (Mediterranean scad)
- *Scomberesox saurus saurus* (Saury)
- *Sardinella aurita Valenciennes* (Atlantic saury)
- some squid species
- some flying fish

The light sources developed imitate the spectrum of the sun, being the most effective. Squid could be caught at commercially applicable rates. Mercury was used as filler gas for the lamps. Other gases were investigated to avoid pollution of the sea in case of lamps breaking. The research was termintated in 1989 with the loss of financial sources. Gears used are jiggers and dip nets. Successful areas are: South-West Atlantic, Patagonian Shelf, George Bank, Japanese Sea, and the Caspian Sea. Links with the physiological state of the fish are reported. Apparently the presence of vitamin A in the fishes eyes play a role in the attraction effect. Discontinuous light sources were not applied and reported to have a low effect.

8.5.4 Discussions on electrical stimulation

Electrical stimulation was mainly investigated in the institute in Klaipeda, Lithunia. The three basic types of reaction: first reaction, electro-taxis, electro-narcosis mentioned in the report of Lart and Horton were also identified by these workers. Species under investigation were *Gadus morhua* L. (cod), *Clupea harengus* L. (herring), and *Pleuronectes platessa* L. (plaice). It was also found that fish length determine reaction, as larger fish experience a larger potential difference in an electric field. The work started with observations on behaviour in dependence of field characteristics. Prototype electrical equipment was built and tested on experimental sea trips, including *in situ* observations on fish. Applications in gears followed both in midwater and in bottom trawls, but not in beam trawls that are unknown in these parts of the Baltic Sea. In addition, anode attraction was used in sardinella fishery in combination with light attraction. In this fishery fish is pumped onboard. The effect on other benthic marine life was also extensively studied and reported as being negligible, due to the smaller sizes involved. It was also found that electric currents do not affect reproductive qualities. Plaice was observed to jump out of the seabed and rise 1.5-2.0 m off bottom under the influence of the electric field. The critical frequency for electro-narcosis was found to be around 80-100Hz. The reaction occurs mainly 3-4 sec after exposure. Other frequencies lead to slower responses. Sinusoidal pulse shapes were found to be most effective. The product of fish length * voltage for a given reaction was found to be constant, which means that larger animals are more strongly affected. Selective properties of the electrified gear were observed during experiments on the Jamaican Shelf on grounds unsuitable for trawling by using direct observation techniques. The pulse generators were placed onboard the vessel with cables running to the net as in most applications in Western Europe. Various electrode arrangements were tested with the anode placed in the lower panel and the cathode in the upper panel, an arrangement not tried out in beamtrawls. The optomotor reflex mentioned by Wardle was also observed by direct observation in a pelagic trawl. A regime of 7s exposure to the electric field followed by a 60s unexposed interval at 100Hz resulted in all fish appearing in the codend. When a school enters the trawl, the fish stratrs to react when the height of the section is about 4-6m. Then they begin to swim along with the trawl, which can be maintained for lengths of time depending on the towing speed. The reactions in a bottom trawl are as described by Wardle. The electrode arrangement was chosen to elicite an upward movement of the fish, with the anode placed above the cathode attached to the ground rope. The workers believe that the trawl can be fished off-bottom thus avoiding any bottom contact and related by-catch and mortality of bentic organisms. This idea deserve more study. Introduction into commercial fisheries did not take place, as in other countries, because of the following reasons:

- Fishermen showed lack of interest.
- The robustness of the system was not good enough, leading to loss of fishing time.

8.5.5 Discussions of mathematical modelling and software

Dr. J. Kadilnikov of ATLANT-NIRO explains a suit of computer programmes he developed based on probability models of fish behaviour. Selection parameters can be calculated by onde of the programmes. Swimming abilities of fish and length/girth-weight relationships are given in quantitative expressions and stored in files. The calculations are based on swimming abilities and fish dimensions, operational quantities such as vessels characteristics, gear dimensions, and fishing ground characteristics. Another programme can be used to calculate the catchability of fishing gears, based on a stochastic model of the catching process. It works with data concerning the size and behaviour of fish schools including species involved, the dimensions and materials of the trawl, the towing speed used and calculates the catch size and composition, and the fraction of fish caught related to fish entering the trawl. Survival of escapees is estimated to be nihil. Theoretically calculated catches were compared to those observed in commercial practice with good correspondance. A third programme describes the catching process in more detail, based on a series of probabilities of fish appearing in certain parts of the gear and being caught or escaped. The arrival process of fish schools is described based on the analysis of existing echogrammes. The assumptions and probabilities can be varied to produce realistic forecasts by the model.

8.5.6 Flume tank and hydro-dynamical studies

Dr. Leonid Meyler explains the possibilities of the Kaliningrad flume tank. Most interesting are the low price for rent ($ 500/day) compared to the flume tanks in Western-Europe, and the high maximum water speed of the tank at 3.5m/s, and also a wave generator absent in other facilities. The flow field is quite uniform, the tank has a diffusor leading the flow to the working section. Disadvantageous is that the working section is rather limited in size, and that the bottom cannot move along with the flow (no conveyor belt). Meyler has produced two monographs: "Flow speed investigations on schematic net constructions" (IFREMER Sep 95 Project No 94/721, report DITI/NPA 95.016), and a survey of Russian literature called: "Flow through three-dimensional net structures", coordinated by MARINTEK (contact Geir Løland) and published in 1996. He expresses interest in further cooperation with scientists in the EU, possibly through financial cooperation programmes, such as INTAS. The tank may offer possibilities of studying phenomena outside the reach of the conventional tanks. Further cooperation possibilities will be explored.

8.5.7 Protocol

The visit was rounded off by a protocol expressing various views and lines of action for the future. This document was signed between the three parties involved, namely: AG MariNPO, BFAFI and RIVO-DLO. The contents of the exchange of information were mentioned as well as interest to search for further ways of co-operation. The idea was expressed to use the meeting in April 1997 of the ICES Working Group on Fishing Technology and Fish Behaviour in Hamburg to extend contacts and suggest projects of cooperation. The EU-Programme INTAS, the International Association for the promotion of co-operation with scientists from the New Independant States of the former Soviet Union could offer further possibilities for such co-operation.

8.6 Conclusions

The mobility organised within the framework of this project was deemed very satisfactory by the various participants. In many cases detailed and specific information was exchanged that can not easily be found in the literature. Also new relationships and contacts were establisehed that can serve the scientists involved in the personal career. In addition it should be stated that a great deal of hospitality and friendship was met during these visits. Particularly the visits to China, Japan and Russia were very interesting. Access to literature frome these countries is limited by nature of the differences between our languages, and in many cases explanations were given to work undertaken that written articles do not always contain. It was also stimulating to learn about the differences in culture in these countries. In the case of Russia it can be feared that a great deal of information will get lost due to extreme cuts in research funding leading to closure of institutes and scientists involved losing their jobs. Attempts should be made to safe this cultural heritence, possibly through aid programmes established recently within the European Community.

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9. SUMMARY OF CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

Our studies reveal that there is enormous potential for the appropriate development of the various behavioural stimuli in applied technologies for improving the control of the movements and selection for consumption of wild fish species. Incentives to do so among those involved in fisheries are generally lacking and as well as educating those involved in fisheries those in the politics of management should deal with this major problem of increasing the incentive to use appropriate methods.

9.1 Use of sound

Many fish species react to sound which attracts attention requiring visual checks to assess danger. Some species show distinct differences in hearing ability *e.g.* herring vs. mackerel. Reactions to sounds are variable. It is not known why and which characteristic causes not only detection but also a reaction. Sound can be used to attract or to dispel fish. Vessels and gears produce sounds which can evoke avoidance reactions. Very strong stimuli such as air-gun explosions were shown to scare fish away over large areas. Some artisinal fisheries use sound to lure fish to a gear. There is a gap in knowledge about the effect on infra-sound. In some cases sounds are used to condition fish to be attracted at a later age, such as in the Japanese sea ranching programme. More knowledge is needed to be able to use active sound stimuli to affect fishing gear selectivity.

9.2 Use of lights

It is not clear why it is that many fisheries around the world use bright light sources to concentrate and control the distribution of fish schools, particularly pelagic fish species and squid, whereas there is little application in traditional purse seine and other fisheries in northern European waters. Species specific effects are very evident in major commercial fisheries in Pacific waters in the saury and mackerel fisheries as well as squid jigging and it is not clear why these effects have not been tried with Atlantic and North Sea species. Russian researchers explained that trials done on these species did not show a great potential for these areas. As with intermittant sound, light flashing has been used as a signal to condition fish to feeding stations in fish ranching but with less effective range; max may be 40-100m in clearest waters. Some experiments were carried out with flashlights in beam trawling and constant lights in otter trawling, but they indicated minor effectivity. Nevertheless it is felt that the full potential is not exhausted and more work is needed to find effective ways to influence fish behaviour to improve species and size selectivity of fishing gears.

9.3 Making more precise use of vision

Recent conclusions are that the visual stimulus is under utilised in the design of fishing gears. Most fish species have excellent vision and use this as the overriding stimulus in their decision making. Many reports indicate the presence of other well developed and specialised sensory systems including taste, touch, flow, displacement of water, pressure, sound etc. but none of these sensors are fast enough to give the quick reactions needed to avoid the fast moving components which generate the herding functions of mobile gears. In proved dark conditions fish bounce from one part of the gear to another probably responding by touch reactions (observations are rare!). There are now an abundance of details that indicate how to make unambiguous the visual stimulus generated by the structures making up the gear. This knowledge has not been made use of in the design of gears. Studies such as that outlined in detail here of the underwater visual properties of objects and materials indicate that the visual stimulus of the gear can be made more relevant. For example a panel of netting, as viewed by the fish from within the net, can be made to be maximally visible or least visible simply by appropriate use of colour or shade of the twine. A panel below the fish needs to be white, whereas one above the fish must be black to achieve the same visual effect. This suggests that appropriate innovative designs incorporating these ideas still need to be tested thoroughly. The aim of these designs should be to make the functions of nets more predictable and eliminate the random component. Incentive to improve gear function and education in the necessary awareness is needed to bring this approach about.

9.4 Electrical stimulation

The method recently received new attention in Belgium, where individual fishermen made visits to China where a form of electric fishing for shrimps exists. The method was deemed to be too complicated and no further work is foreseen in the United Kingdom. In Germany and in The Netherlands the developments have stopped until recently. The authorities rejected the idea out of fear of increased catch rates, in spite of claims for improved size selection. A private company in The Netherlands is now developing a commercial system with consensus from the Ministry of Agriculture, Nature Management and Fisheries.

An important argument to take up the development is the possibility to diminish sea-bed interaction. Research shows that most mortality of benthic organisms is caused by the passage of the trawl and not by actual capture. When an electrode arrangement can be designed which generates an electric field that penetrates into the sea-bed, fish can be stimulated to jump off bottom into the path of the trawl passing above. Bottom contact might then be avoided completely.

Although electrical stimulation was tested very thoroughly in many countries the research did not lead to a commercially applied system in any of them. Nevertheless it was concluded that electrical stimulation as an option should not be ignored. It seemed to work effectively on shrimps and soles, but fishermen found it too complex and vulnerable, and possibly could not afford the high investment costs involved. Particularly its potential in creating gears with less bottom contact can become an important motive for further development. Research in Lithunia did not reveal harmful effects to other marine life, but some reports mention adverse effects that need further consideration. New developments in high-energy electronics ("sparker"-technology) might be used to create a more robust system without complex underwater components.

9.5 Water flow

There are many observations showing the lack of effectiveness of selection panel windows with what seem to be major areas of open mesh presented to fish for escape from the gear. Fish are seen dropping back past the windows and are trapped in the codend. How can we make every fish test itself for size at these panels? Recent experiments have demonstrated that highly contrasting coloured panels built into the net will make the fish try to swim out through the open meshes of the window panel because they are reluctant to drop back through the open tube of the extension to the codend (for example the black mouth illusion experiments already published and referred to here). There are however problems with the fishe's ability to cope with net penetrating manoeuvres through fast cross flow. Seasonal studies are showing, as well as observations in cold and warm areas of the world, that differences in the abilities of fish to pass through selection devices even when properly stimulated are frustrated in cold conditions. The flush fitted netting window-panels in extensions can have fast flow speeds along both inside and outside the panel surfaces that are close to towing speeds. Serious attention should be paid to research developing practical controlled flow conditions in those areas where small sizes of a species are required to manoeuvre through meshes in the selection process. In trawls and towed seines fish falling back to these positions are usually already partially exhausted. Flow control at these panels can be developed to aid the complex manoeuvre so that exhaustion and poor seasonal condition and low temperature do not frustrate the intention of the design.

Waterflow manipulation also offers further potential to enhance selectivity. Trials were conducted with a conical flapper inserted in a codend of a shrimp trawl and a square mesh window fitted above it. Fish tend to seek spots with reduced water flow and can find escape opportunities from that position. On the other hand fish do not seem to have a concept of being inside or outside a net, or that they escape from being captured. Underwater observations have illustrated this in many cases.

A prototype experimental waterjet system was tried out in Germany as a possible replacement of tickler chains to scare flatfish off-bottom in beam trawls. Trials conducted in may 1997 on RV TRIDENS showed that flat fish can be caught with this technique, but it is still unknown what the extent of impact is on benthic organisms. Further experiments with this type of gear are therefore advocated.

9.6 Olfaction

Olfaction has potential in traps, pots and longlines as fish attractant, although by nature its scope and duration are limited. Selection can be improved by choosing the right bait. Some promising techniques are developed in Norway. A baited collapsable two-stage trap was developed for cod. Additionally experiments were carried out with baited gillnets. Here a problem is to get bait attraction to work after the setting operation of the nets. These gears require a low energy input, which is an advantage. Equipment is under development in Norway with which mackerel attractants can be released at sea at a constant rate. The idea is to use this on traps, gillnets and longlines. A first prototype will be tested in January 1997.

9.7 Resource management incentives

Incentives are needed to develop and use conservational devices for harvesting and improving the fishery resource. The visit to the Sea Ranching Project in Oita Prefecture, Japan made it clear that improvements in local fisheries is not just an ideal but an active and achievable goal when exclusive rights are held by local cooperatives. In Europe scientific research has developed a clear understanding of most aspects of fishing and fish stocks including many well founded conservation devices, *e.g.* square mesh windows, separator panels, and selection grids. If we were to establish a matching framework of management, with positive incentives and benefits for fishermen using these devices, they would volunteer development and use of this resource of knowledge to optimise and maintain productivity. None of the players are interested if their is only a small chance of reaping the return for their efforts. Research into alternative management strategies is therefore advocated to stimulate the use of this neglected knowledge resource.

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APPENDIX 1:
TITLES AND ABSTRACTS OF PAPERS

Papers on electrical stimulation

H. Kruuk, Diurnal periodicity in the activity of the common sole, Solea Vulgaris Quensel, Journal of Sea Research 2, 1, 1963, p.1-28

Various behavioural observations are reported on sole placed in tanks and subject to differing light regimes. The results are related to diurnal fluctuations in catches reported by fishermen with positive correlation. The periodicity in the food intake of sole in its natural habitat was studied by analysis of the contents of the intestines of fish caught at sea. Food intake appears to have a maximum during the night and a minimum during the day. It was argued that this reflected a diurnal periodicity in the locomotory activity. In a aquarium, periodicity in the activity of the sole was measured directly by an array of lead balls suspended in the tank with which contacts were recorded automatically. Activity levels appeared to be zero during the day and maximal during the night confirming the findings of the food intake study. The diurnal cycle has an active and an inactive phase. Behaviour from the inactive phase into the active phase is mostly characterised by the so-called Omega jump, releasing the animal from its sand cover. Digging-in preceeds the inactive phase. The diurnal activity cycle of sole is adjusted to changes in natural light. Experiments conducted with continuous light, continuous darknes and a twelve hours light cycle show the correlation between light level and activity, but also that other stimuli (e.g. hunger) may evoke active behaviour patterns. Interesting are the notes by the author about the difficulty in chasing sole from the bottom when dug in by mechanical stimuli. Even a rake with vertical pertubations of 2cm did not cause the animals to leave the sea bed.

S.J. de Groot & G.P. Boonstra, Preliminary notes on the development of an electrical tickler chain for sole (Solea solea L.), ICES C.M. 1970/B:4

In the sole fishery in The Netherlands beam trawls are used with relatively heavy tickler chains to chase the fish off bottom. Vessels at the time were fitted with engines of some 800hp. The tickler chains may damage immature fish. The research aimed at replacing these chains by light electrical ticklers, without reducing the catch of the target species (Solea solea L.). Experiments on live fish in tanks and in an oyster bassin were conducted. Electrode arrays were used with 30cm spacing and with 35cm spacing. Variables under investigation were: peak voltage (2.5-60V), pulse frequency (1-50 Hz), distance between electrodes (30-35cm), and water temperature (6-20 °C). The fish ranged in length from 15-30 cm. Only three to four individuals were used in each experiment and one per day. Learning and adaption was avoided by replacing the animals after four trials. The soles were covered with sand prior to the experiments. A typical behaviour pattern of the sole is the "writhing or Omega jump" with which a searching activity for food is often started. It was found that by using electric stimulation these jumps can be evoked with the result that the fish leave their borrowed position. Specifications of the stimulus are given: voltage $\leq$ 8V, pulse repetition rate 40-50Hz, interruption of pulse cycle 0.5Hz, pulse length of 0.7ms. The shape of the pulse was of the capacitor discharge type in the tank experiments. The oyster bassin trials confirmed the results found in tanks, even with a pulse shape (quarter sine) affected by longer cables between the pulse generator and the electrodes. No effect was found of the temperature. Interesting to note is that the authors also report on behaviour of other flatfish species (plaice, flounder, dab, brill) subjected to the same stimulus. These fish did not show a similar jumping behaviour, but were merely paralysed. A possible explanation of this difference is the difference in musculature of these other species, not allowing the fish to curl easily as in soles. The authors also give constructional ideas. Primarily they think of an electrode array parallel to the ground rope of the trawl, but the possibility of an array in the direction of tow is also mentioned.

S.J. de Groot & G.P. Boonstra. Report on the development of an electrified shrimp-trawl in The Netherlands. ICES C.M. 1970/B:5

A report is given of behaviour experiments on shrimp subjected to electric fields undertaken in an oyster bassin. The project aimed at increasing the efficiency and improving the selectivity of shrimp trawls. The work was based on reports from the United States. Interesting is the remark that an electrified shrimp trawl might reduce the destruction of immature flat fish, sole and plaice. Observation of behaviour showed that burrowed shrimps jumped off bottom at the third pulse given. The authors found the optimal pulse length to be 0.2 ms. Jumps are mostly ranging in height from 10 to 20 cm, sometimes even higher. In addition field tests on the commercial beam trawler WR-213 of 150 hp are described. Three electrodes were used parallel to the ground rope with 50cm spacing. Claims are given of an increase in catches of 50% for the electrified gear, but in turbid water catches for the elcetrified net feel short. Possibly the electric stimulus helps the shrimp to escape whilst jumping when they are not burrowed.

S.J. de Groot & G.P. Boonstra. Notes on the further development of an electrified shrimp trawl in The Netherlands. ICES C.M. 1974/B:5

Experiments on an electrified shrimp beam trawl on the TH-6 conducted in 1973 and 1974 are described. Gear width was 8m. An array of eight electrodes with lengths ranging from 1 to 3m was towed in front of the roller gear in two experiments, and two electrodes parallel to the groundrope in another experiment. The system consisted of a pulse generator placed on the beam of the electrified net connected by a cable with a power supply on the vessel operated by a self-tensioning winch. From the pulse generator cables ran to the electrodes in the net. Pulse form was capacitor discharge, peak voltage 60V, frequency variable between 1-50Hz. The authors claim an improvement in commercial shrimp catches of 33% on average for the electrified trawl. They also comment on the fluctuation found in catches which were deemed due to variability in water turbidity affecting shrimp behaviour.

S.J. de Groot & G.P. Boonstra. The development of an electrified shrimp-trawl in The Netherlands. J. Cons. int. Explor. Mer. 35 (2): 165-170. Feb 1974

This paper is a more elaborated version of earlier published work in ICES, including unpublished data. The preliminary experiments done in an oyster bassin and the first results of field trials with an electrified Dutch beam trawl for shrimp (*Crangon crangon* L.) fishing are reported. An electrified beam trawl catches about 116% more commercial shrimp and 81% more undersized shrimp. By using this type of gear it is hoped that the destruction of immature fish, especially flatfish, by the shrimp fishing fleet will be reduced. From the bassin trials the authors claim the optimum pulse length for shrimp to be 0.2ms, and the pulse frequency should not exceed 5Hz, but the field trials onboard suggested that better results can even be obtained with higher repetition rates up to 50Hz. Reflections are given on the construction of the device with a separate power unit onboard or with a power supply mounted on the gear.

P.A.M. Stewart. A study of the response of flatfish (Pleuronectidae) to electrical stimulation. J. Cons. int. Explor. Mer., 37(2): 123-129. Feb 1997.

Direct observation on the reactions of flatfish of the Pleuronectidae to electrical stimulation were made by towing a manned sledge supporting an energised electrode array over the sea bed. The electrical stimulus was pulsed DC, ranging infrequency from 4 to 40 Hz. Involuntary muscular contractions were induced by this stimulus which caused the majority of fish to flee from the electrified zone. Reactions were classified into a few broad categories and the approximate fish size in each observed event was recorded. The results suggested that the most efficient frequency for inducing flatfish to leave the bottom is around 20 Hz, and that large fish are more strongly stimulated by an electric field than small fish; the latter being a significant demonstration under natural conditions of a theory based on aquarium experiments.

Observations were made on the reaction of flatfish to a towed chain to assess its comparative efficiency in forcing the fish to leave the sea bed.

P.A.M. Stewart. Comparative Fishing for Flatfish using a Beam Trawl fitted with ElectricTicklers. Scottish Fisheries Research Report No 11. 1978. ISSN 0308-8022
Flatfish respond to an electric stimulus by moving away from the electrified zone. Experiment has demonstrated that this reaction is induced most effectively by a pulsed DC field at 20 Hz and that large fish react more strongly than small fish. This behaviour suggested that electric ticklers could usefully replace chain ticklers on flatfish trawls. To investigate this idea two comparative fishing experiments were conducted using a vertically divided beam trawl of 9m width at trawling speeds from 2 to 3 knots. The voltage between the electrodes was monitored continuously at 50-60V. Trawling was carried out on RV "Clupea" in the Moray Firth in June 1974, October 1975 and October 1976. In the first experiment one side if the gear was electrified during each haul and it was found that the electric stimulus significantly increased the catch. However, the best results were obtained in 1974 (increase of +54%), whereas even a small drop in catch rates (- 3-10%) was found in the trials in 1975 and 1976. Species under investigation were lemon sole, plaice, and common dab. In the second experiment the non-electrified side of the gear was rigged with a chain tickler, and no significant difference was found between the total catches. The author also states that the electrified trawl has the advantage of reducing the catch of juvenile fish.

Le Men, R., 1971. Pêche électrique en mer. Science et Pêche. Bull. Inst. Pêches marit., 200, 1971: 1-14.
The author describes the outline of a system to catch fish by means of light, electricity and a pump. The reactions of pelagic fish towards these type of stimuli are described in detail and are backed up by some practical experience. The results demonstrate that the system could have a profitable use in commercial fisheries. Within certain limits, the destructive impact on the environment should very limited and length selectivity should be quite sharp.

Blancheteau, M., 1971. Choix du stimulus approprié à la pêche à l'électricité en mer. Rev. Trav. Inst. Pêches marit., 35 (1), 1971: 13-20.
This paper contains basic information on the behaviour of fish in an electric field. The effect of electricity on the nerval system of the fish, the dependency of the orientation of the fish towards anode and cathode and the effect of different types of electric fields are explained in detail.

Kurc, G., 1971. Pêche à l'électricité avec lumière artificielle et pompe. Rev. Trav. Inst. Pêches marit., 35 (1), 1971: 5-12.
This report describes the outlines of a system to catch pelagic fish based on the phototrophic and galvanotrophic stimulation of fish. The author stresses the possibilities of a high catchability and good length selectivity.

Kurc, G., 1972. La pêche électrique, pêche de l'an 2000 ? La Pêche Maritime, December 20, 1972: 1022-1025.
The author makes a review of the application of light and electricity in fisheries and gives his vision on the future use of these techniques.

Vanden Broucke, G., 1972. Eerste resultaten in de electro-visserij. Mededelingen van het Rijksstation voor Zeevisserij, 68-TZ/50/1972.
In 1972 a first series of experiments have been carried out in Belgium on electric stimulation in shrimp beam trawling. The study aimed at a better selectivity and higher catches. The higher catches were significant for shrimp and sole and the amount of undersized sole in the catch were less with the electric gear. A drawback of

the system was the need of an extra cable between the vessel and the gear since the pulse-generator was fixed on board of the vessel.

Chmielewski, A., Cuinat, R., Dembinski, W. and Lamarque, P., 1973. Investigation of a method for comparing the efficiency of electrical fishing machines. Pol. Arch. Hydrobiol. 20 (2), 1973: 319-340.
Five electrical fishing machines, four of which were portable, producing different currents and using several fishing techniques, were tested to determine their efficiencies. There were great differences of efficiency between the machines. In the light of the results, modifications are proposed to improve the experimental method.

Chmielewski, A., Cuinat, R., Dembinski, W. and Lamarque, P., 1973. Fatigue and mortality effects in electrical fishing. Pol. Arch. Hydrobiol. 20 (2), 1973: 341-348.
This report describes experiments where fish were exposed to the current supplied by the machines which had been tried out before for their fishing efficiency. The time elapsed between the start of exposure and the instant at which the fish recovered was taken as the "index of fatigue". Subsequent mortalities were recorded. Indices of fatigue are discussed in relation to the machine under test, distance from anode, fish length and number of exposures to the current.

Vanden Broucke, G., 1973. First results of electro-fishing experiments. Mededelingen van het Rijksstation voor Zeevisserij, 68-TZ/50/1973.
English version of [5].

Vanden Broucke, G., 1973. Verder onderzoek over het electrisch vissen. Mededelingen van het Rijksstation voor Zeevisserij, 85-TZ/56/1973.
This second series of experiments again gave higher catches for shrimp and sole. Although the distance between the electrodes and the pulse frequency was different, the results were comparable to the ones in 1972.

Vanden Broucke, G., 1973. Further investigations on electrical fishing. Mededelingen van het Rijksstation voor Zeevisserij, 90-TZ/58/1973.
English version of [9].

Vanden Broucke, G., 1973. Further investigations on electrical fishing. ICES C.M. 1973/B:14.
Idem [10].

Diner, N. and Le Men, R., 1974. Seuils de taxie et de tétanie de bars, des mulets et des sardines dans un champ électrique impulsionnel uniforme. ICES C.M. 1974/B:16.
The fishery by means of light, an electric field and a pump has been studied for several years. In order to learn more about the fish reactions towards this electric field, experiments were carried out to study the thresholds for movement and cramp for sardine, grey mullet and *Dicentrarchus labrax*. The results are given for different frequencies and pulse lengths in relation with fish length.

Lamarque, P., 1976. Un appareil de pêche à l'électricité pour les eaux de forte conductivité (eaux saumatres et marines). Rev. Trav. Inst. Pêches marit., 40 (3 et 4): 646-647.
The author describes the so called "Albatros", a system developed to stimulate fish by means of electricity in seawater conditions, the same way as in fresh water. It is made for small fishing gears and can be used to sample fish, capture live fish for aquariums and catch fish for small scale commercial purposes.

Vanden Broucke, G. and Van Hee, J., 1976. Electro-visserij op tong. Fisheries Research Station, Ostend, Dep. Note 76/45 (unpubl.).
This reports describes experiments in electric fishing for sole with a beam trawl. A refined pulse system has been introduced. A frequency between 5 and 10 pulses per second and a tension between 60 and 100 volts can be chosen. In order to reduce damage to the fish, a short pulse length of 1 ms was applied. The results indicate that the heavy tickler chains rigged in traditional beam trawls can be replaced by lighter ones if electricity is used, without loss of catch. The stimulation of sole can be improved by applying shorter pulse-lengths.

Le Men, R., 1977. Etude d'un système de pêche par lumière, champ électrique et pômpe pour la capture des sardines, *Sardina pilchardus* (Walbaum). ICES C.M. 1977/B:6.
This paper reviews the possibilities of catching sardine by using artificial light, an electric field and a pump. The catches which could be achieved by this method are assessed. The author states that this type of electric fishing could lead to a better length selectivity.

Namboodiri, K.S., Vijayan, V. and Hridayanathan, C., 1977. Development of electro-trawl system in marine environment. Fish. Technol. Vol. 14 no. 1 1977: pp. 61-65.
The authors describe experiments with an electro-otter trawl. Pulses were generated aboard the trawler and fed to electrodes distributed along the footrope of the trawl. This builds up a homogeneous electrical field around the net mouth. Catch comparison demonstrated an increase in catch for fish and shrimp of 36 and 20 % respectively.

* Vanden Broucke, G. and Van Hee, J., 1977. Onderzoek over de electrische visserij op garnalen. Fisheries Research Station, Ostend, Dep. Note 77/4 (unpubl.).

* Vanden Broucke, G. and Van Hee, J., 1977. Vorderingsverslag over de electrovisserij op tong en garnalen. Fisheries Research Station, Ostend, Dep. Note 77/43 (unpubl.).

* Vanden Broucke, G. and Van Hee, J., 1977. Verder onderzoek over de elektrische visserij op garnalen. Mededelingen van het Rijksstation voor Zeevisserij, 133-TZ/82/1977.
The experiments with electric fishing for shrimp with beam trawls were continued, with an improved system. The electric beam trawl showed higher catches for shrimp, but reduced catches for cod and whiting. Contrary to the traditional shrimp fishery, the difference between day and night catches was very low with the electric trawl. For sole the results were less promising. However, due to a lower trawl weight, the electric beam trawl could be towed a higher speeds and with larger beam lengths.

Delanghe, F. and Vanden Broucke, G., 1978. Studie van het gedragingspatroon van Noorse kreeft (*Nephrops norvegicus L.*) ten aanzien van electrische pulsvelden. Fisheries Research Station, Ostend, Dep. Note 78/8 (unpubl.).
A study was made on the reaction of Norway lobster towards electric pulses. Different pulses, pulse lengths, frequencies and tensions were tried out. The trials were done in an aquarium where the environmental conditions of Norway lobster grounds were imitated as close as possible. It seemed quite easy to stimulate the prawns and it was clear that larger prawns reacted sooner to the pulses than smaller ones. The most efficient stimulation pattern was determined with the aim to apply electric pulses to a commercial otter trawl.

Vanden Broucke, G. and Delanghe, F., 1979. Verdere proeven over het electrisch vissen op tong. Fisheries Research Station, Ostend, Dep. Note 79/11 (unpubl.).
During this study on the electric beam trawl, different numbers of electrodes were tried out. The main conclusion was that a distance between the electrodes of 0.75 m the better choice was. If closer, the electrodes often collided causing short circuits. A larger spacing resulted in a to weak electric field. The catches of the electric gear were mostly higher for sole, especially for the night hauls.

Delanghe, F., 1983. Toepassing van een geëlectrificeerd net in de bordenvisserij. Mededelingen van het Rijksstation voor Zeevisserij, 195, 1983, D/1984/0889/11.
The system applying electrified ticklers, already often tried out on beam trawls, was now tested on an otter trawl. The electrified otter trawl has a higher catchability for sole. It also improved selectivity, catching less undersized and more sized fish. The pulse was alternating positive and negative in order to reduce the electrolysis effect. The results indicate that in this case catches are higher compared to the pulses from direct current. As previous studies indicated, the system has a serious drawback, the extra cable needed to connect the electrodes with the energy source. Extra manpower is necessary for hauling the cable and damage to the cable causes loss of fishing time.

Delanghe, F. and Vanden Broucke, G., 1983. Electrische visserij op garnaal uitgevoerd met bordennet. Mededelingen van het Rijksstation voor Zeevisserij, 199-TZ/106, 1983, D/1984/0889/11.
This paper describes experiments with an electrified otter trawl targeting shrimp. The experimental hauls were not successful due to large amount of by-catch resulting in difficult sorting of the catch. The data were insufficient to draw any conclusions.

Delanghe, F. and Vanden Broucke, G., 1985. Studie over de verdeling van de veldsterkte bij electrisch vissen met een bokkennet. Fisheries Research Station, Ostend, Dep. Note 85/19 (unpubl.).
In order to determine the parameters of the electric field between the electrodes of an electric beam trawl, several measurements were carried out, both in the lab and in commercial conditions. The study aimed at a configurations where the electric field would be optimal within the trawl mouth, without causing stimulation outside of the trawl which could result in negative effects on the catchability of the trawl and which could cause damage to fish outside of the trawl path. No conclusions could be drawn from the lab-study due to problems in the lab-set-up. With the full-scale beam trawl, different configurations were tried out. A detailed description is given of the electric field in the trawl mouth. Catch comparisons were carried out and demonstrated an increase in catch when applying electric pulses.

Delanghe, F., Vanden Broucke, G. and Deschacht, W., 1988. Electrische visserij op garnalen en platvis. Mededelingen van het Rijksstation voor Zeevisserij, 224, 1988, D/1988/0889/3.
This report describes tests with an electric otter trawl, an electric beam trawl with altered cutting rate and an electric beam trawl with an altered groundrope. The results were comparable to the previous ones.

Papers from Russia

Daniulyte, G., Naktinis, J. and Petrauskiene, L. Dependence of anode electrotaxis efficiency of marine fishes on pulse current parameters. Acta Hydrobiologica Litunica, Volume 6, ISSN 0208-2527, 1987, pp 3-11.
Anode electrotaxis of the Baltic fishes, i.e. herring, cod and flounder, has been investigated under the effect of different parameters of the pulse current. Anode electrotaxis has repeatedly proved to be closely related to the body shape of the fishes and their swimming manner. Distinct anode electrotaxis is typical of herring and cod, while that of flounder is very weak. The most effective anode electrotaxis was observed under current frequency somewhat lower than that used for electronarcosis, i.e. ≈ 40 Hz for herring and ≈ 20 Hz for cod, pulse duration being 2-5 ms. Under shorter pulse duration (1 ms) anode electrotaxis obtained was rather effective by the use of 40-120 Hz; in this case, however, the fish underwent electronarcosis more rapidly. Under experimental conditions, maximum of electrotaxis was obtained at the field strength of 10-22 V/m and 6-14 V/m, for herring and cod, respectivily. Locomotory activity of flounder was very limited in the pulsed electric field. Their swimming activity was much greater under continuous pulse current (80 Hz, 1.2 ms, duration of pulse series 0.5 s, with 1 s intervals); however, even under these conditions a more pronounced anode electrotaxis was not observed.

Simonaviciene, B. Efficiency of freshwater fish anode electrotaxis. Acta Hydrobiologica Litunica, Volume 6, ISSN 0208-2527, 1987, pp 12-19.
Four species of freshwater fishes have been investigated under the effect of different parameters of pulse current and DC. Anode electrotaxis was established to be more distinct under DC effect (90-100% of fishes in the anode zone) as compared to that in the pulsed electric field. Pulse current of lower frequencies (f = 31-62 Hz) was found to be more effective. Some specific differences of anode electrotaxis of the above fishes, its dependence on the electric field strength have also been determined.

Daniulyte, G., and Petrauskiene, L. Anode electrotaxis of fishes of various ecological groups with respect to their locomotion mode and its mechanism. Acta Hydrobiologica Litunica, Volume 6, ISSN 0208-2527, 1987, pp 20-27.
On the basis of fish locomotion observations in the electric field, electrophysiological investigations and special literature data analysis, the mechanism of anode electrotaxis of fishes, i.e. their swimming towards anode, has been considered. Anode electrotaxis was found to be characteristic of fishes swimming with undulating motion performed due alternating waves of contraction along the body muscles. Anode electrotaxis was observed to decrease or even completely disappear the fish taking over to propelling themselves by means of fins. Anode electrotaxis is likely to be accounted for by the polarized electric current (DC, unipolar C, pulse C) effect on the fish nerve fibres in the spinal cord responsible for the manifestation of undulatory movements. The fish pursues in the direction of anode, for this is the only direction in the electric field to activate the mechanism of undulatory movements of its body. The fish is incapable of swimming towards cathode because of long descending fibres (Maudmer Müller and other spinal cord cells) excited in this direction and bringing about tetanic body muscle contractions. When in the position of transverse current fluence, the body muscles of the fish always contract on the side of anode, and consequently it turns to that direction because the mechanism of undulatory movements in the spinal cord is activated.

Petrauskiene, L. Neuronal mechanism of electrotaxis. Acta Hydrobiologica Litunica, Volume 6, ISSN 0208-2527, 1987, pp 28-36.
Possible effects of DC on the nervous system of leech and fish when in the electric field are discussed. The leech electrotaxis mechanism may be explained both by the direct excitation influence of current on interneurones - central pattern generators or

swim-initiating cells and by indirect activiation of the latter through inhibition of inhibitory interneurones. Activation of spinal generators is supposed to result in swimming movements of fish towards anode. Possible ways of activation are as follows: (1) direct excitation effect on spinal generators, (2) activation of descending fibres of brain, (3) hyperpolarization of spinal cord inhibitory interneurones.

Simonaviciene, B. Pulse current stress effect on gold-fish feeding conditioned reflexes. Acta Hydrobiologica Litunica, Volume 6, ISSN 0208-2527, 1987, pp 37-46.
The reaction of goldfish exposed to the pulsed electric current (f = 100 Hz, T = 1.6 ms, E = 250 V/m, t = 5 s) for 9 times (once a week) has been investigated. The first four irritations were found to result in strong short term reflex activity disorder (deterioration of sign recognition differentiation, longer reaction time), which recovered within a week. The deep conditioned reflex breakdown has developed after the 5th and successive irritations, which did not recover within a week. After the irritations had been cut off the stress condition still lasted several weeks. Retraining of the fish under similar conditions turned out to be practically impossible. The extent of conditioned reflex damage and restoration time depended solely on the individual properties of the fishes nervous system.

Vosyline, M. Effect of electric current on some physiological parameters of rainbow trout. Acta Hydrobiologica Litunica, Volume 6, ISSN 0208-2527, 1987, pp 47-52.
A rainbow trout stress reaction induced by a 30 s exposure to pulse current at f = 100 Hz, E = 40 V/m, T = 0.8 ms has been studied. The catecholamine (noradrenaline and adrenaline) content in the head-kidney as well as that of blood erythrocytes, lymphocytes, trombocytes and glucose were used as indicators in the fish stress reaction. An increase in the catecholamine content in the head-kidney and that in the blood lymphocytes was observed immediately after the exposure, decreasing later on. A maximum decrease of lymphocytes was observed 12 h after the exposure. The glucose content increased to a maximum value in 4 h. A recovery of physiological parameters was observed within 1-2 days.

Kazlauskiene, N. and Daniulyte, G. Effect of d.c. on ECG of fishes. Acta Hydrobiologica Litunica, Volume 6, ISSN 0208-2527, 1987, pp 53-60.
DC effect on Baltic Sea fishes, i.e. cod, herring and flounder electrocardiogrammes (ECG) has been studied. DC depending on its intensity (low $E < 0.1$ V/m, average $E \approx 0.1$-0.5 V/cm, high $E \approx 0.3$-1.0 V/cm) was found to give rise to the decrease in the QRS complex amplitude and changes in the form of the ECG. The effect of a rising current is greater than of a falling one.

Kazlauskiene, N. D.c. effect on the heart rhythm of fishes. Acta Hydrobiologica Litunica, Volume 6, ISSN 0208-2527, 1987, pp 54-68.
DC effect on the heart rhythm of Baltic Sea fishes, i.e. cod, herring and flounder has been investigated. The changes in the heart rhythm indices were found to be dependent on the current intensity and its direction. Under the effect of falling DC of the intensities employed ($E < 0.1$ V/cm, $E \approx 0.1$-0.5 V/cm, $E \approx 0.3$-1.0 V/cm) the heart rhythm became slower, arrhythmia decreased, while under rising current the rhythm became more intense, arrhythmia increased. The duration of the changes and recovery were dependent on the current intensity; under low and average DC the heart rhythm changes were recorded in the duration of 1 h, while under high DC no recovery occurred.

Maksimov, Yu., Malevicius, S. and Yudin, V. Selective effect of electrified field while fishing by electrotrawl. Acta Hydrobiologica Litunica, Volume 6, ISSN 0208-2527, 1987, pp 54-74.
The analysis of catches of an electrotrawl produced the Klaipeda SMU Department of Commercial Fishery shows, that by using not only the abundance of the fish caught

increased, but also their size. There is a possibility of further improving the selectivity of an electrified trawl by choosing the parameters and regime of pulsed electric current according to fish behaviour.

Maksimov, Yu. and Tamasauskas, P. Reactions of Japanese scallop in homegeneous pulsed electric current field. Acta Hydrobiologica Litunica. Volume 6. ISSN 0208-2527. 1987. pp 75-78.
Locomotory reactions of Japanese scallop (Patinopecten jessoensis) have been investigated in the pulsed electric current field. Scallops subjected to pulsed electric current move towards a cathode. Their highest locimotory activity is observed when scallop is subjected to pulsed electric current with f = 10-4- Hz, E = 20-40 V/m, according to the schedule 1 s current, 1 s interval.

Burba, A. Pulsed electric current effect on the Baltic shrimp feeding behaviour. Acta Hydrobiologica Litunica. Volume 6. ISSN 0208-2527. 1987. pp 79-87.
The dependance of Baltic shrimp (Crangon crangon L.) feeding behaviour on the effect of pulsed electric current has been investigated. Under the effect of pulsed electric current giving rise to electronarcosis, the number of feeding individuald considerably decreased the following day as compared to a blank test (the day in point they did not feed at all), the duration of separate stages of feeding behaviour increased, the structure of the behaviour became somewhat different. After the effect of current giving rise to eletrotaxis the shrimp survival slightly decreased. The number of feeding individuals was the lowest when exposed to the longest duration (60 s) of the stimulus. On the following day the number of feeding shrimps was independent of either the effect or fasting period. A dependence of marked changes in the structure of feeding behaviour on the duration of fasting was not found. Experimental data suggest that electric current is of under-effect character to the shrimp nutrition, not affecting, however, the structure of feeding behaviour.

Burba, A. and Petrauskiene, L. Structure of the Baltic shrimp reactions in d.c. and pulsed current fields. Acta Hydrobiologica Litunica. Volume 6. ISSN 0208-2527. 1987. pp 79-92.
The reactions of the Baltic shrimp Crangon crangon L. in the homogeneous horizontal and vertical fields of d.c. and pulsed (f = 5 Hz, T = 1 ms) electric current were studied. The primary reactions, anode electrotaxis and electronarcosis were observed in the electric field that was gradually increased. The thresholds of these reactions are given in the paper. Swimming towards anode is mainly stimulated by the ascending current in both the horizontal and vertical field. The jumps of shrimps from the bottom induced by electric current are significantly higher in the descending current than in the ascending one (horizontal field), and is case when anode but not catode is placed on the top of the aquarium (vertical field).

Burba, A., Maksimov, Yu. and Plerpa, A. Response of grass shrimp pandalus latirostris rathbun to artificial illumination. Acta Hydrobiologica Litunica. Volume 6. ISSN 0208-2527. 1987. pp 93-100.
The response of grass shrimp Pandalus latirostris rathbun L. to natural light in the day-time and to artificial illumination of different intensity at night has been investigated. In the day-time, under the lighting of 70000 lux, most of the grass shrimps (96-100%) preferred the shadowy part of the test basin where light amounted to 1 lux; after light decreasing to several thousend lux, some 50% of individuals appeared in the open space. At night the response of grass shrimps is dependent on the intensity of artificial light. Under illumination of 30 lux the exploring behaviour of shrimps was well pronounced. This behaviour was especially marked under the light spot of 5-10 lux on the part of the basin wall submerged; the number of individuals there, within 3 min, increased more than twice. Under more intense (several hundred lux) or lower (some decimal parts of lux) illumination the exploring behaviour was either weak or

completely disappeared. Evidently, the illumination from several lux to several tens of lux is optimal for a grass shrimp in accordance with its ecology.

Malkevicius, S. A simplified method of electric field calculation in pelagic electrotrawl. Acta Hydrobiologica Litunica, Volume 6, ISSN 0208-2527, 1987, pp 101-107.
A simplified method for the calculation of the electric field in the space between electrodes of an electrotrawl has been considered. This method allows the module of electric field strength in points symmetrical to the axis between electrodes to be calculated by analytical methods.

Malkevicius, S and Toliusis, S. A behaviour prognosis of fish in pelagic electrotrawl. Acta Hydrobiologica Litunica, Volume 6, ISSN 0208-2527, 1987, pp 108-112.
The behaviour prognosis of fish affected by electric current between electrodes of electrified trawl is considered and the algorithm of calculation by this method is presented.

Malkevicius, S and Malkevicius, R. Charging efficiency improvement of power capacitor used in electrofishing pulse devices. Acta Hydrobiologica Litunica, Volume 6, ISSN 0208-2527, 1987, pp 113-118.
In order to decrease energy losses an energy source with step-by-step growing voltage formed from sinusoidal pulses in offered. In this case no current restrictors are necessary in the charging circuit when the abovementioned charging method is used, and the charging efficiency coefficient is not lower than in the charging circuits containing reactive current restrictors.

Papers from Japan

Akiyama, S., Baskoro, M.S. and Arimoto, T. Entrapping time of fish into the small scale set net. Nippon Suisan Gakkaishi, 61(5) 1995, pp 738-743.
In order to identify the entrapping time of fish into the set-net, experimental operations were conducted at a small scale set-net fishing area in Tateyama Bay, Chiba prefecture. The bag net was hauled up six times per day at 03:00, 07:00, 11:00, 15:00, 19:00 and 23:00 hours at 4 hour intervals. A total of 60 hauls at 6 different times a day were made and the catch was recorded for each species for studying the entrapping time of fish. Total catch was increased at the twilight time and the catch patterns of the main species were classified as the diurnal, nocturnal, crepuscular and aperiodic types. For example, the diurnal type included frigate mackerel *Auxis thazard*, the nocturnal type bottom perch *Apogon semilineatis* and flying fish Prognichthys agoo, and the crepuscular type round herring *Etruneus teres* and jack mackerel *Trachurus japonicus*.

Akiyama, S., Yasuda, K., Arimoto, T., and Tawara, Y. Underwater observation of fish behaviour to trolling line. Nippon Suisan Gakkaishi, 61(5) 1995, pp 713-716.
In order to understand the capture process of trolling gear, the fish response towards a trolling line was observed by a towed underwater video camera. Fishing tackle consisted of a main line, a depressor board, a leader line, and a lure. The underwtaer video camera was mounted on the depressor board to observe and record the sequence of responses towards the lure. Fish species that could be identified, were yellowtail *Seriola Quinqueradiata*, frigate mackerel *Auxis rochei*, amberjack *Seriola dumerilli*, and mackerel *Scomber japonicus*. Behaviour patterns were classified as follows: appearance into the camera view, approach to the lure, attack on the lure, touching the lure, being hooked, and captured. The total number of appearances in the camera view was 1361, in which the catch was only 18 due to the low attack response frequency to the approaches. A slight difference was also abserved on the proportion of missed

hookings, which was attributed to the difference in struggling escape behaviour between yellowtail and frigate mackerel.

Hasegawa, E. and Kobayashi, H. Estimate of the trace of swimming behaviour of fish around underwater lamps. Nippon Suisan Gakkaishi, 55(10) 1989, pp 1707-1714.
Iso-illuminance lines produced by two underwater lamps hanging on a vertical line were described with relation to the displacement of lights by current, the extinction of lights, the arrangement of lights and the reflection at water surface. Under the condition of this irradiance, the trace of swimming behaviour of fish was estimated by the method of computer simulation, and was described by X-Y plotter. The results suggest that it is a reasonable motion for the fish to swim lazily or zigzag under the fish lamp, and it is necessary to consider the operating area of the fishing gear with relation to the lamp fishing. Species investigated was *Pneumatopholus japonicus* (Houttuyn). A flowchart is presented for the calculation of the direction of detecting an optimal light intensity for the fish around the two underwater lamps.

Hasegawa, E. and Kobayashi, H. Observation of the fish behaviour around the underwater lamps by fish sounder and underwater TV camera. La mer 28: pp 131-138. 1990 Société franco-japonaise d'océanographie, Tokyo.
Changes of fish behaviour around two underwater lamps hanging vertically underneath a research vessel were observed by using a fish sounder and an underwater camera. Both the amount of fish in the beam angle of fish sounder and the amount of fish in the visual field of an underwater video camera changed in synchronizing with turning on and off the lamps. Iso-illuminance line of 1.0 lux had a tendency to become a boundery of fish distribution around the underwater lamps. It seemed that the minimum stimulus which influenced fish reaction to the changes in illuminance was very low. The number of fish concentrated around the underwater lamps was estimated to be 0.47 m^{-3}. Species under investigation were *Scomber japonicus* and *Scomber australasicus.*

Hasegawa, E., Kobayashi, H., and Niwa, H. Retinomotor response of the fish concentrated around an underwater lamp. Nippon Suisan Gakkaishi, 56 (2), pp 367 (1990).
The retinomotor responses of the fish in the dark room, where light illuminance was kept constantly, were observed by Welsh and Osborn, 1937 and Tamura, 1957. They pointed out that the responses have a circadian rhythm. While Kawamura (1979) indicated that the degree of light adaptation of the fish caught around fish lamp was not proportional to the time since its lamp switched on, the fishes retina showed extremely dark adaption. In this experiment, the circadian rhythms of the retinomotor responses of cobaltcap silverside Hypoatherina tsurugae and japanese anchovy Engraulis japonicus were studied in relation to the change in concentration around a 500W underwater lamp. The change of the number of individuals concentrated around the underwater lamp was recorded with an underwater video camera set nearby the floating pier of the Fisheries Research Laboratory of Mie University from sunset to sunrise of 28, 29 and 30 June 1988. The distance from the camera to the lamp was about 3 m horizontally, both of them were set up at 3 m depth from the water surface. Under similar conditions as mentioned above, the fish concentrated around the lamp were caught with a four-arm scoop net at suitable intervals during the night from 28 until 29 July 1988. The catch consisted mainly of cobaltcap silverside and japanese anchovy. Their body lengths were measured and their heads cut off smoothly and fixed with 10% formalin. The eyes were extracted after one night in 70% ethyl alcohol. Tranverse sections (7um) obtained were stained with hematoxyline-eosin and placed under an optical microscope. Some fish caught first by the gear after sunset were put in a darkened tank, some were placed in a tank illuminated by a 100W lamp and accomodated for six hours. Kawamura, 1979 investigated retinas of spotted mackerel caught around a fish lamp and he discovered that the degree of light

adaptation differed in various parts of the retina. In this experiment the retinal fragment was taken from near the eye's bottom. The ratio of movement is the distance from the base of the pigment layer to the tip of pigment (or ellipsoid of cone) divided by the distance from outer limiting membrane to the base of the pigment layer. This method of measurement is quite similar to the one used by Tamura (1957) or Suzuki et al. (1985, 1988). The average movement of cones differed from that of the tips of pigment. In both cones (whether scotopic vision or photopic vision), the value for japanese anchovy was higher than that of cobaltcap silverside, but the tendency of movement was similar. The increase in number of individuals gathering around an underwater lamp depended on the time before or after midnight. Before sunrise the number decreased regardless of light intensity. In light fishery these results sggest that it is necessary to consider the effect of light intensity before midnight (when the fishes eye indicates scotopic vision), and to consider the effect of different light wavelengths after midnight (when the fishes eye indicates photopic vision).

Hasegawa, E. Effect of light upon the behaviour of fish in twilight vision. Nippon Suisan Gakkaishi, 59 (9), pp 1509-1514 (1993).
The present investigation is an attempt to study the effect of light upon the behaviour of fish in twilight condition, in which visual pigments in the outer segments of rods are strongly bleached. The optomotor reaction in albino and pigmented moenkhausia *Moenkhausia sanctaefillomenae* and rose bitterling *Rhodeus ocellatus ocellatus* were examined after light and dark adaption. Photomicrographs of the retina of both species show the differences in structure of light adapted and dark adapted fish. Plots are shown of the rate of reaction versus time for both light adapted and dark adapted fish. Albino individuals were less reactive than pigmented ones when light adapted, but more reactive when dark adapted, and the reaction was inferior in the case of light conditions with similar absorbance to the visibility of individual fish. These results suggest that light, similar to the visibility of fish, may possibly inhibit the onset of visual behaviour. The method of utilization of fish lamps ought to be given all due consideration in light fishing.

Hasegawa, E., Kobayashi, H., and Niwa, H. Comparison of retinal adaption in chub mackerel and sardine attracted to a fishing lamp previous and subsequent to midnight. Nippon Suisan Gakkaishi, 57 (3), pp 425-431 (1991).
In order to investigate the differences in retinomotor responses between pre- and post-midnight phases, the responses in chib mackerel angled under a fishing lamp and those in sardine caught ny nighttime purse seining were examined. The adaptation ratio determined in the cone and pigment layers of chub mackerel indicated no direct relationship to illuminance at the spot of angling, but showed a large variation. Chub mackerel were mostly angled at a light intensity ranging from 10^{-3} to 10^{-1} lux, and were angled more frequently in darker areas post-midnight than pre-midnight. The correlation between cone migration and pigment migration was high before midnight, but low after midnight. This tendency was observed in both species. If these results are due to circadian rhythms corresponding to retinomotor responses, operating time in lamp fishing operations should be considered in commercial endeavors.

Hasegawa, E. History, development and present condition of fishing with light. Bulletin of the Faculty of Bioresources, Mie University, No 10, pp 131-140, Tsu, Japan (1993).
This report reviews the history, development and present condition of fishing with light. Topics discussed are: the origin of fishing with light, historical changes of fishing light and its features, fishing with light in foreign countries, light fishing in Japan and in Mie Prefecture. As soon as men knew how to make fires, it was discovered that some kind of fish are attracted to light. Fishing with torches was eventually improved by using fuel oil, kerosene, gas and electricity. Throughout the centuries, the light fishery have used fires, torches, acetylene, kerosene, gas and

electric incandescent and fluorescent lamps, as attractants. Some methods of fishing with light are applied in many countries in the world, but the Japanese light fishery is the largest light fishing industry in the world. The light fishery is able to economize the energy use and equipment through contriving optimum light intensity, optimum light wave length that matches the visibility of fish. With the present need to review coastal fisheries light fishery ought to be developed in a controlled form to meet the objectives of resource management. Species targetted in light fishing are: *Cololabis saura, Sardinops melanostictus, Engraulis japonica, Etrumeus teres, Trachurus japonicus, Decapterus muroadsi, Scomber japonicus, Scomber australasicus, Ammodytes personatus, Spratelloides gracilis, Clupanodon punctuatus, Parapristipoma trileneatum, Auxis thazrd, Seriola quinqueradiata.* Gears used in Japanese light fishery are: stick-held dip nets, lift nets, small set nets (Hari-ami), surrounding nets, squid jigging, gill nets, scoop nets, harpoon and spears, beach seine, bag nets, and eight angle nets.

Hasegawa, E., Kobayashi, H., Ishikura, I., Uchida, M., and Maekawa, Y. Changes of appearance and disappearance of fish under an underwater lamp. Nippon Guisan Gakkaishi 57 (7), pp 1307-1311, (1991).
In order to investigate the periodicity of the appearance and disappearance of fish attracted around an underwater lamp, the change of volume of fish in the illuminated area was measured by using scanning sonar and fish finder. The biggest volume was recorded between 02:00 and 03:00 am. After that, the volume showed a decreasing tendency at astronomical twilight time before sunrise regardless of the low light intensity (10^{-3} to 10^{-2} lux). The authors think that the preparation of the fish to adapt to light stimulation in that time, when the retinal rhythm of fish shows a distribution intermediate between dark- and light-adaption, caused the approach to the underwater lamp by the fish. The time (astronomical twilight time) of disappearance of fish from the lamp suggests the threshold for retina in the fish attracted around the underwater lamp. Species investigated were: *Scomber japonicus, Scomber australasicus,* and the flying squid *Eucleoteuthis luminosa.*

Hasegawa, E., Yoza, K., and Soeda, H. Experimental study and discussion of Fridman's theory in relation to the behaviour of fish school encountered by the leader-net of a set net. Nippon Guisan Gakkaishi 54 (6), pp 975-982, (1988).
In relation to the behaviour of a fish school encountering a leader-net, Fridman's theory is as follows. The fish school of constant concentration is considered as a liquid stream of density ρ = constant. Let the volume rate of the liquid in the incoming stream to the leader-net be q, the volume rates in the component of the same direction as yet which is parallel with the leader-net and that of the opposite side be q_2 and q_1, and the encounter angle α of the fish, respectively, i.e.

$q_1/q_2 = (1-\cos\alpha)/(1+\cos\alpha)$, also referred to as the hydrodynamic analogy.
The author proposes a new theory on the behaviour of fish passing through the mesh of a leader-net. If v = the swimming speed of fish encountering the leader-net, then v. cos α is the component of the speed parallel with the leader net, and v. sin α the component perpendicular to the leader-net. The volume rate of water passing through the mesh is q_3, i.e.

$q_1 = k_1 . \sin\alpha/2$, $q_2 = k_2 . (\sin\alpha/2 + \cos\alpha)$, $q_3 = k_3 . \sin\alpha$,
with k_1, k_2 , k_3 = constant.
This theory is more in conformity with the experimental data than Fridman's.

Hasegawa, E., and Tsuboi, H. A study on the three dimensional structure of marine fish schools by the stereo method with two cameras. La mer 19. Société franco-japonaise d'océanographie. Tokyo. pp 179-184 (1981).
A stereo method with two cameras was used to determine the three-dimensional position of schools of marine fish in the tank. Photographs of fish schools in the tank were taken with two cameras set above it, and the depth of an individual position from the water surface was determined by the horizontal parallax estimated from two films. The average absolute errors were 1.4 cm in the vertical and 0.4 cm in the horizontal direction. The structure of schools of sardine *Sardinops melanosticta*, parrot bass *Oplegnathus fasciatus*, striped pigfish *Parapristipoma trilineatum* and opaleye *Girella punctata* observed using this method was discussed with respect to the density of the school, the distance between the fish and the angular deviation of the school.

Hasegawa, E., and Kobayashi, H. Mathematical model in relation to the significance of fish schooling. Nippon Guisan Gakkaishi 55 (2), p 371. (1989).
This short paper describes a mathematical model of schooling behaviour of fish. Schooling may provide some protection against predation. An attacking predator may get confused by the movements of prey in a school. Expressions are derived for the number of individuals in a school based on the assumption of an ellipsoidal school shape, and an average distance of the individuals, and the surface area of the school. The probability of detecting a predator by prey in a school depends on the number of fish in the surface of the school, the field of vision of each fish, and the underwater visibility range. The probability of detection of a school by a predator is taken as proportional to the maximum cross-sectional area of the school. The distance between individuals in a school decreases with the number of fish in the school when the probability of detecting the predator by the prey exceeds the probability of detecting the prey by the predator.

Hasegawa, E. Effect of shape of fishing gear on moving behaviour of fish. Bull. Fac. Bioresources. Mie University. Japan. No. 1: pp 39-37. 1988.
This study describes tank experiments with six carps *Cyprinus carpio*, about 11 cm in average total length, to investigate fish distribution in a funnel net and fish movement between two "mountain-shaped" nets (two oblique netting panels with a join in the center) which are set of the upper and lower sides or set on both sides. The funnel net consisted of a wedge shaped net with six partitions. The whole net was set in six different ways and the number of fish in each compartment counted and averaged over ten observations. Most fish were found in the widest lower compartment. Setting the net at an angle (15°) had the most pronounced effect on the distribution of fish in it. A second experiment was to confront fish with netting panels sloping up and down (mountain-shape), and observe the way they pass the funnel as a function of time. Sloping panels of netting set above and below the passage of the fish had a greater effect on fish movement than panels placed at the sides.

Hasegawa, E., Yoza, K. and Soeda, H. Fish behaviour entering the bag net from the playground of set-net. Bull. Coll. Agr. & Vet. Med., Nihon University. No 44 . pp 169-174. (1987).
The authors studied the behaviour of fish entering the bag of a set net in the aquarium. Blue gill *Lepomis Rafinesque* and dace *Tribolodon hakonensis* were used for this experiment. The patterns of fish behaviour passing over the funnel net were classified in two categories, a behaviour following the contours of the netting, and a behaviour following the upward slope and passing horizontally from the edge. The second behaviour pattern emerged more often when the slope angle was increased, but the rate of passing fell as well as the swimming speed both for the ascending as the descending track. The descending track shows a larger distance from the bottom to the fish than the ascending one, a tendency rising with the slope angle. The behaviour patterns were recognised for both species, but with some differences.

Hasegawa, E., Yoza, K. and Soeda, H. Entering and leaving fish behaviour in case of a funnel net with inner funnel net (Uchi-Nobori). Bull. Coll. Agr. & Vet. Med., Nihon University. No 44 , pp 175-179, (1987).
Fish behaviour leaving the bag net with Uchi-Nobori and turning and going back were observed in the aquarium. Dace *Tribolodon hakonensis* were used for this experiment. The number of fish entering or leaving the bag net increased with time. The steeper the slope of the funnel, the smaller the increase in numbers. Most fish enter the bag net and turn at two-third of the funnel. The longer the length of the Uchi-Nobori (apparently the sloped leader net, also called funnel), the more time the fish take to leave the bag net. Both the behaviour of turning and going back both under the Uchi-Nobori and beside the Hantate-ami increase with the slope angle. The influence of the Hantate-ami is notable.

Soeda, H., Yoza, K., Shimamura, T., and Hasegawa, E. On the swimming behaviour of chum salmon in early migratory season off the coast of Hokkaido, Okhotsu Sea. Nippon Guisan Gakkaishi 53 (10), pp 1827-1833, (1987).
This paper deals with the swimming behaviour of chum salmon *Oncorhynchus keta*, the sea condition in the area under study of the 1985 experiment, and a summary of the experiments conducted in and after 1982 in early migratory season at Othotsk Sea off the coast of Shiretoko peninsula on the island of Hokkaido. The fish were pursued and their motions monitored (bio-telemetry). In the '85 experiment it was found that swimming direction was notably east-ward, and the mean horizontal swimming speed was faster than Ichihara's estimated value (1.0 FL/s), the trend of vertical movement showed that the test fish swam comparatively deep before and after noon, just below the sea surface without vertical movement at mid-night, with notable vertical movement at sunrise. The sea condition of the '85 experiment can be considered as a normal condition by oceanographic standards. As the results of the experiment, conducted in and after '82, the migration of chum salmon was assumed to be as follows, chum salmon migrated to Kitamiyamato bank to Cape Notoro or off-shore Monbetsu. Concerning swimming depth, it was recognised that maximum depth is not always reached in a sea area where depth is large enough, and the test fish swam at comparatively shallower depth in the deep sea, and at the bottom layer in a shallow sea.

Soeda, H., Hasegawa, E., Shimamura, T. and Yoza, K. The trend of the fishing effect of chum salmon by the data of set-net. Bull. Coll. Agr. & Vet. Med., Nihon University. No 45 , pp 214-218, (1988).
This paper deals with a study on the swimming behaviour of chum salmon *Oncorhyncus keta* as a result of fishing with set-nets along the coast of Shiretoko, Abashiri, Hokkaido. Catch data were collected for a range of nine positions of set-nets along the North coast of Hokkaido over the years 1982-1986. The average trend in catches was plotted for each station as a function of time for the months September to October. The results were as follows: As the fishing season progresses, the catch of set-nets (Type No 5 and 6) decreased west of Abashiri, and increased east of Abashiri. The center of the fishing ground moved from west to east through the fishing season.

Hasegawa, E., and Soeda, H. Mutual relationship among individuals composing a fish schools. Bulleting of the Japanese Society of Scientific Fisheries, 51 (12), pp 1921-1926, (1985).
In order to consider the mechanism of schooling behaviour of fish and that of maintenance, the stereo method with two cameras was used. Bitterling *Rhodeus ocellatus*, dace *Tribolodon hakonensis* and mackerel *Pneumatophorus japonicus* (Houttuyn) were used in this experiment. The results obtained are as follows: 1) Each individual of the school interacts with each other individual, so that its swimming speed fluctuates with time. 2) Each individual of the school constantly supports the distance and orientation of the others. 3) Orderly movement of the school is produced

when each swimming speed remains steady, and the concentration of the school results in the disorder of that behaviour. 4) When the school is turning, each individual regulates its swimming speed according to its position in the school.

Ishikura, I.,Uchida, M., Hasegawa, E., Nakayama, T. and Kobayashi, H. Investigation on results of test operations by trawl in Northern area of East China Sea. Bull. Fac. Bioresources, Mie University, Japan, No. 2: pp 85-96, 1989.

The results of the catches of test trawl fishing in the northern area of the East China Sea over the years 1981 to 1987 were analysed. Every summer eight or nine test fishing operations were conducted. Length and weight frequency distributions, and weight length relationships are shown for lizard fish *Aulops japonicus*, and abyssal searobin *Lepidotrigla abyssalis*. The results obtained are summarised as follows:

- It was inferred that the change in fishing conditions is reflected in the difference in size and species composition of the catches. The most abundant species in the area is hiratsumegani *Ovalipes punctatus*.
- For the principal ten species a stratification of the fishing grounds can be used: grounds shallower than 100m depth, grounds deeper than 100m, and a combination of both areas. The species caught correlate with the bottom structure.
- Gonads of hime *Aulops japonicus* were very immature and individuals having a mature gonad were not found. Gonads of Sokokanagasira *Lepidotrigla abyssalis* were mostly immature, and individuals having a mature gonad were not found to any great extent. Juvenile fishes of both species were not observed during the summer months.

Hasegawa, E. A study on the three-dimensional structure of fish school of dace by modified stereo method with two cameras. Bull. Coll. Agr. & Vet. Med., Nihon University, No 39 , pp 218-223, (1982).

Since the accuracy of focal length and lens distortion were serious problems in the case of the existing method, the three-dimensional structure of a fish school was measured with a cross striped plate, which is a correcting criterion set behind the aquarium. As a result, the errors were reduced, since the three-dimensional position of a fish school could be calculated without considering the above mentioned accuracy The structure of fish schools of dace, *Tribolodon hakonensis*, was discussed from the viewpoint of the swimming speed and the brightness of the surface of the water by this modofied method. The results obtained are as follows:

- Judging by the changes of swimming speed of individuals which seemed to interact with each other, the reaction of the following fish seemed to be delayed.
- The degree of change of swimming speed was proportional to the distance moved.
- The behaviour of approaching individuals interact with each other, in spite of the fact that brightness of the surface water is low (0.25 lux).
- The parallel orientation of the school was disrupted at sunrise and at sunset.