# UNDERWATER PHOTOGRAPHY IN FISHERIES RESEARCH

By

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Underwater photography is reviewed with particular respect to the recording of fish in relation to fishing gear by unmanned cameras. The attenuation of natural and artificial light are discussed. Object contrast and its attenuation through the medium are the main problems of underwater photography. Increase of photographic contrast has only limited scope, but other ways of improving image-recording are suggested. The mounting of cameras is related to the amount of information required which can be obtained from each photograph. Stereo photography and some motion analysis greatly increase the amount of information. Diver-operated cameras should be used in shallow water before constructing elaborate unmanned camera systems.

## INTRODUCTION

Underwater photography has been available and in use as a tool in fisheries research for twenty-five years, yet information about the action of fishing gear and the behaviour of fish has tended to come from acoustic instrumentation rather than cameras. The two main purposes of this paper are firstly to review some of the recent contributions to the field and secondly, hopefully to suggest ways in which existing and developing techniques can be used to overcome these difficulties and provide more information. MERTENS' (1970) book was published during the final stages of preparation of this paper. It provides the most exhaustive treatment of the subject, especially the more theoretical aspects, although the main emphasis is upon hand-held cameras. Readers seeking more information upon light penetration, contrast photographic technique and film types are referred to this book.

A single black and white photograph provides a permanent record of the light transmitted by a lens during the exposure time, as an angular distribution pattern of varying optical densities in a flat photographic emulsion, *i.e.* the typical negative. This density distribution pattern contains all the information that can be analysed from a photograph. The arrangement of this paper tries to follow this sequence by considering firstly the problems involved in recording the image, and secondly indicating how it may be interpreted to obtain quantitative information.

Photography in scientific research has three main functions:

1. To provide a permanent record of what the human eye sees at any point in time, or during any period of time.

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2. To replace the human eye in environmental conditions where it is inconvenient or impossible for an eye to be.

3. To investigate phenomena which the eye is ill-adapted to see.

These three cagetories have been purposely chosen to indicate the close relationship between vision and photography. The reasons for this are, firstly the optical and functional similarity between the eye and the camera (WALD, 1950); and secondly the fact that in practice, the vast majority of photographs are analysed visually.

In the underwater environment the first function includes photography by divers and from submersibles, and is considered in this paper only when the lessons from manned photography can be applied in unmanned camera operation. The second application covers all uses of underwater still or ciné cameras in which they are operated remotely or automatically. In this paper particular attention is given to methods of photographing fish and fishing gear. The final application, in which the camera and film can be thought of as optical transducers, covers the use of infra-red or ultra-violet radiation recording, and the analysis of motion by time-lapse or high-speed photography. Of these only motion analysis is really feasible underwater due to the high absorption of non-visible radiation by water.

## ILLUMINATION AND FILM SENSITIVITY

The fundamental requirement is that the radiation reaching the sensitive film emulsion from the object being photographed is of such a spectral nature and intensity as to give an adequate range of optical density on the film after processing. Optical density is defined below in the section on contrast.

The processes of absorption and scattering attenuate the intensity of the sun's radiation with depth. The attenuation is exponential for each wavelength and varies greatly, due in particular to the variation of absorption with wavelength. It is for this reason that semi-log plots of broad band radiation with depth are not straight (DUNTLEY, 1963; JERLOV, 1968). Natural light photography is virtually impossible at depths much below 30 m in most water, although the possible use of image intensifiers may allow the extension of indirect photography to greater depths. Much underwater photography involves the use of artificial light, and because the intensity can be varied within quite wide limits, absolute intensity is much less important than the spectral and spatial distribution of light.

It is commonly stated that the distribution of radiation around a source obeys an inverse square law, but although the law is used in exposure calculations, it should be remembered that it applies strictly only to a uniform point source. A reflector to direct light in the required direction is always used, so that no underwater light distribution truly follows the law. However, for roughly estimating light intensity at different distances, the law can be assumed to operate at distances greater than about 1·0 m for small and moderate sources. WALSH (1958) discusses the departure from the inverse square law of large area sources. It is usually more convenient to measure the effect of a particular light source at a convenient known distance than to calculate on the basis of the power output and efficiency of the source. The most useful formula for calculating intensities in this way is:

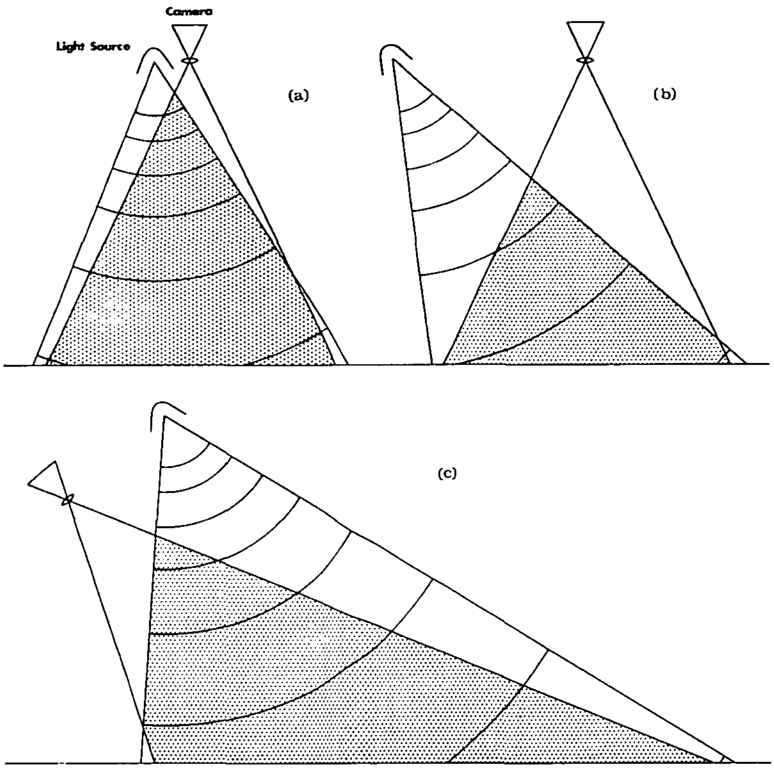


Figure 1. The inverse square law and backscatter in relation to the orientation of camera and lights. The curved lines represent illuminations each half the preceeding one, outwards from the source. The shaded areas indicate where backscatter will reduce picture quality.

$$H_{r2} = H_{r1}/(r_2/r_1)^2$$

where $H_{r1}$ = Intensity at distance $r_1$, $H_{r2}$ = Intensity at distance $r_2$ and $r_2 > r_1$.

The effect of the inverse square law is shown diagrammatically in Figure 1, in which levels of illumination are shown, each half the preceding one, corresponding to one f-stop. It is important to realise that the light from an artificial source is subject to the processes of absorption and scattering, and that the former in particular will alter the spectral nature of the light. These problems are discussed, for continuously running underwater lights, by HATCHETT (1966). Exactly the same principles apply in the case of brief flash sources, and EDGERTON (1966) describes simple methods for calculating exposures with electronic flash.

It is the custom of the film manufacturers to publish information about the sensitivity of films as curves in which log sensitivity is plotted against wavelength. Figure 2a shows such a curve for a typical panchromatic film. This tends to mask one of the deficiencies of panchromatic films which are very commonly used underwater, namely their relatively low sensitivity to blue-green and green light which penetrates into water most effectively. In Figure 2b the sensitivity of the same panchromatic film is replotted on a linear scale along with the transmission of coastal type 3 seawater (JERLOV, 1968). The transmission curve is plotted as percentage transmission per metre, and its effect on the relative film sensitivity is shown for a 5 m pathlength. The longer the water path the more restricted is the spectrum (TYLER, 1959), so that the deficiencies of the film will be greatly exaggerated with increasing range.

## CONTRAST

Contrast is a term so widely used that one definition cannot meet all applications. Its use in different fields of visual and optical investigation requires that it be defined in each context. In general terms, contrast can be

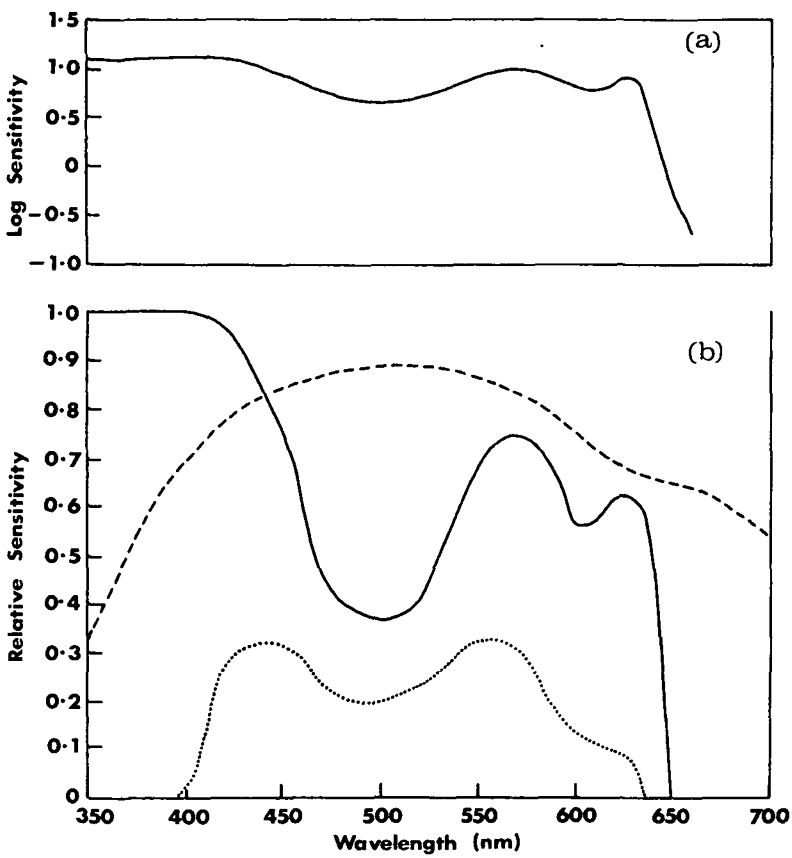


Figure 2. Spectral sensitivity of a panchromatic film (speed ASA 400). a) Logarithmic plot. b) Relative linear plot. Film sensitivity – continuous line. Transmission of coastal type 3 seawater – broken line. Resultant film sensitivity at 5 m distance – dotted line.

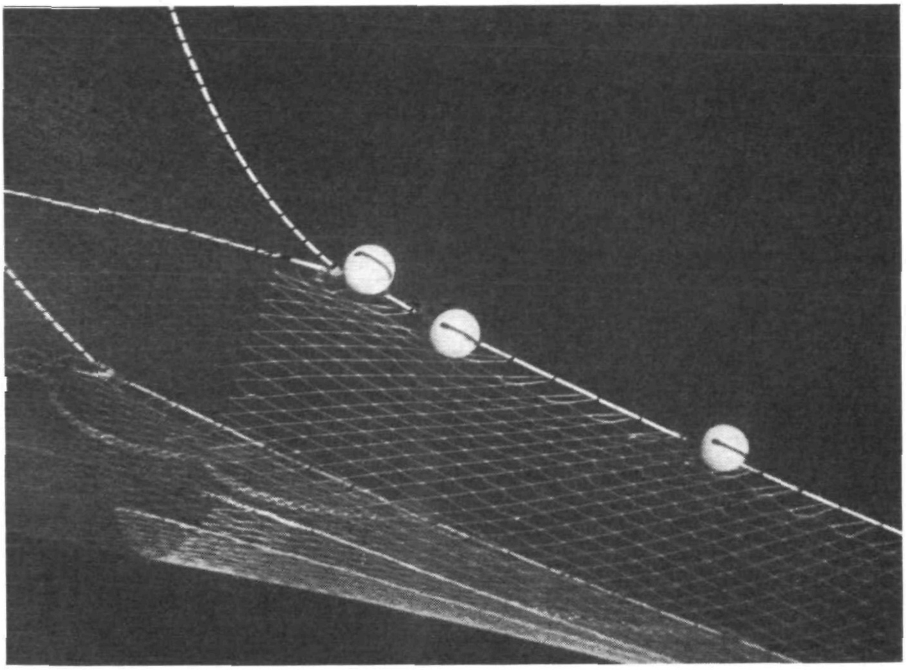

Figure 3. Model net with wings made of white netting and the body of orange netting photographed against oceanic-type blue water.

regarded as the degree of optical dissimilarity of two areas that usually are adjacent to each other. Therefore an object can be seen by eye or on a photograph only if it differs sufficiently from its surroundings in brightness, or colour, or both. This introduces two concepts, brightness or luminance contrast, and colour contrast. Luminance contrast is the more important in underwater photography, partly because the selective absorption by water of certain wavelengths tends to restrict the bandwidth of the usable spectrum, and partly because monochrome emulsions are much more frequently used in research than colour emulsions. An example of an object poorly recorded by monochrome emulsion but of high colour contrast is given in Figure 3, in which a model net made of orange and white netting was photographed in monochrome against a background of blue Mediterranean water. The contrast between the orange and blue was so low that the netting was almost invisible.

Three aspects of contrast are important in underwater monochrome photography:

1. The contrast of an object, either extrinsic against its background, *e.g.* a black cat running on snow, or intrinsic, *e.g.* a zebra.

2. The attenuation of contrast with increasing distance of the object from the camera, due to scattering and absorption.

3. The recording of contrast on the photographic film emulsion.

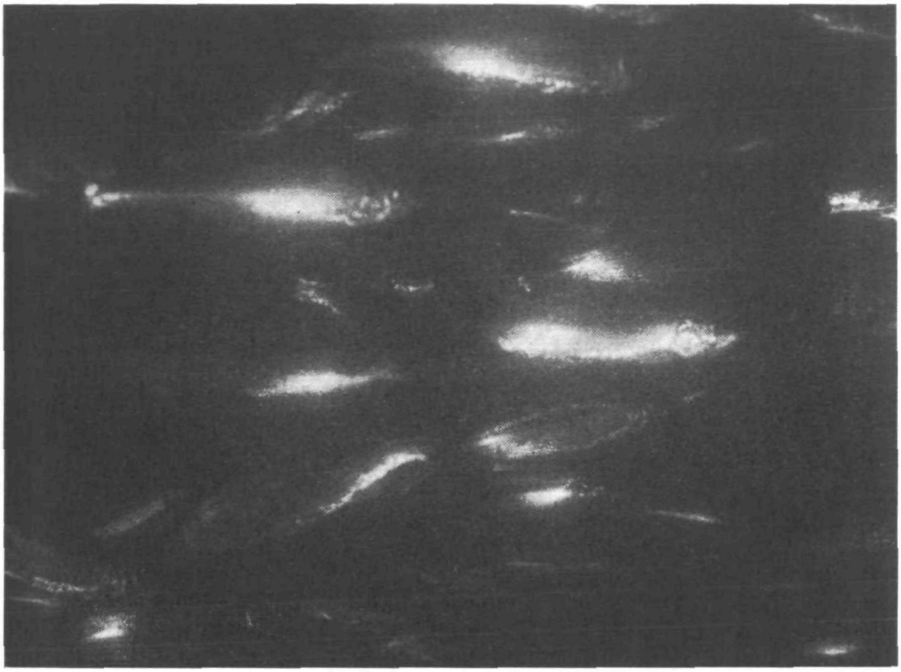

Figure 4. Herring in turbid water, showing evidence of forward scatter and backscatter

OBJECT CONTRAST

In some respects object contrast is the most intractible problem as there can be little control over the nature of the objects being photographed. It is possible to divide most underwater photographs of fish and fishing gear into two broad groups:

1. Objects photographed more or less horizontally against a water background.
2. Objects seen from directly or obliquely above, against the seabed.

If a photograph is taken horizontally in natural light, then the water background will remain of constant intensity irrespective of the distance of the object from the camera, but the contrast of the object against the water will decrease with increasing distance as described in the next section. In horizontal photographs using artificial light the water background tends to be dark (Fig. 4).

The typical fish is well camouflaged with counter-shading or sometimes silvery sides. This coloration is most effective as camouflage when the fish is illuminated from directly above which is obviously the situation with natural light (Denton and Nicol, 1965a and b). If photographs are taken from above, as for example fish in the mouth of a trawl taken from the headline, they tend to be particularly inconspicuous because the fish's dorsal surface is of similar intensity to the seabed. Only when artificial light is used and the fish are further off the bottom, and closer to the light source, do they appear lighter. However, on many photographs, the shadow is more conspicuous than the fish. Some species have lateral markings of high intrinsic contrast which may render them more conspicuous from oblique angles, *e.g.* the white lateral stripe of cod and the pectoral black spot of haddock, or even on the dorsal surface, *e.g.* mackerel. Artificial light photography of fish taken horizontally can result in very high contrasts, due to the silvery reflectance of some species, which reflect light back towards the camera, as shown in Figure 4.

## THE ATTENUATION OF CONTRAST

The reduction of contrast with increasing optical distance is due to a progressive change in the apparent brightness of objects in the field of view. This is brought about mainly by scattering and partly by absorption within the convergent beam of light rays from the object to the lens, shown diagrammatically in Figure 5. Scattering, or the redirection of photons of light can be broadly divided into forward scatter and backscatter. In the case of forward scatter, the angle between the new photon direction and the original path had scattering not occurred, is less than 90°, whereas backscatter involves angles greater than 90°. In pure water backscatter and forward scatter are equal, but in natural waters forward scattering greatly predominates, due to the inevitable presence of particles large in comparison with water molecules (DUNTLEY 1963). As shown in Figure 5 absorption and scattering out of the beam result in the attenuation of light originating at the object. In addition light having its origin outside the beam is redirected by scattering and is added to the beam. The result of these scattering and absorption processes between the object and camera lens is that with increasing distance, dark objects become

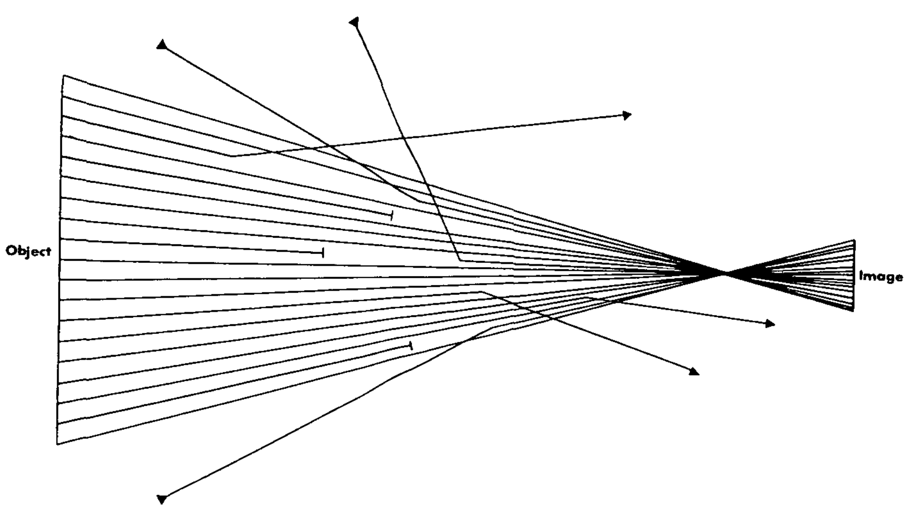


Figure 5. Schematic representation of image degradation in water.
▶———— light rays from outside added to image by scattering.
————▶ light rays from image lost from beam by scattering.
————| light rays absorbed in the medium.

lighter and light objects darker, converging towards the intensity and colour of the background. The contrast sensitivity of the camera optical system and the film therefore define a maximum range for recording the image in any particular condition of water transparency and object brightness and illumination.

In the simplest case of horizontal orientation of the optic axis, the attenuation of contrast is described by the following formula:

$$C_r = C_0 \cdot e^{-\alpha r}$$

where $C_r$ = Contrast at range $r$; $C_0$ = Contrast at range zero; $\alpha$ = Beam attenuation coefficient and $r$ = range.

Contrast in the above equation is given by:

$$C = (t^L - b^L)b^L$$

where $C$ = Contrast at any given range; $t^L$ = Target luminance at the same range; and $b^L$ = Background luminance at the same range.

Target and background in this equation refer to a uniform object seen against a background, but can equally well refer to different elements of a single object. It is important to note that contrast attenuation is dependent solely upon the beam attenuation coefficient, and is independent of the intensity of illumination. The intensity of illumination only affects the recording capacity of the optical system and film.

The majority of underwater photographs are taken with artificial light which involves more complex conditions (Duntley, 1966). The shaded areas in Figure 1 represent volumes where backscatter occurs in such a way as to influence the recording of the image. The ratio between light transmitted and light scattered at any specific angle is constant throughout the light path, assuming a uniform water mass, and this ratio is also independent of source intensity. It thus follows that there is more light scattered close to the source than at some distance from it, hence the advantage of separating the camera and light source as in Figure 1b and 1c. The above principles are quite well illustrated in Figure 4. In such a photograph in clear water the water background would be quite black, but in the turbid conditions in which the picture was taken, backscatter from the electronic flash light source has caused an overall haze of light over the picture. The silvery flanks of the herring in this case act as secondary light sources within the camera's field of view. Forward scattering from them shows as a halo fringing each bright spot. No improvement in the transmission of contrast can be achieved merely by increasing illumination.

## PHOTOGRAPHIC CONTRAST

The contrast recording properties of a photographic film emulsion are expressed by a characteristic, $D/\mathrm{Log}E$ curve. This curve is usually contained in film manufacturer's data sheets. The characteristic curve relates the optical density of the developed emulsion to the exposure received, as shown in Figure 6.

Optical density ($D$) is defined as follows:

$$D = \mathrm{Log}_{10}\, P_0/P_x$$

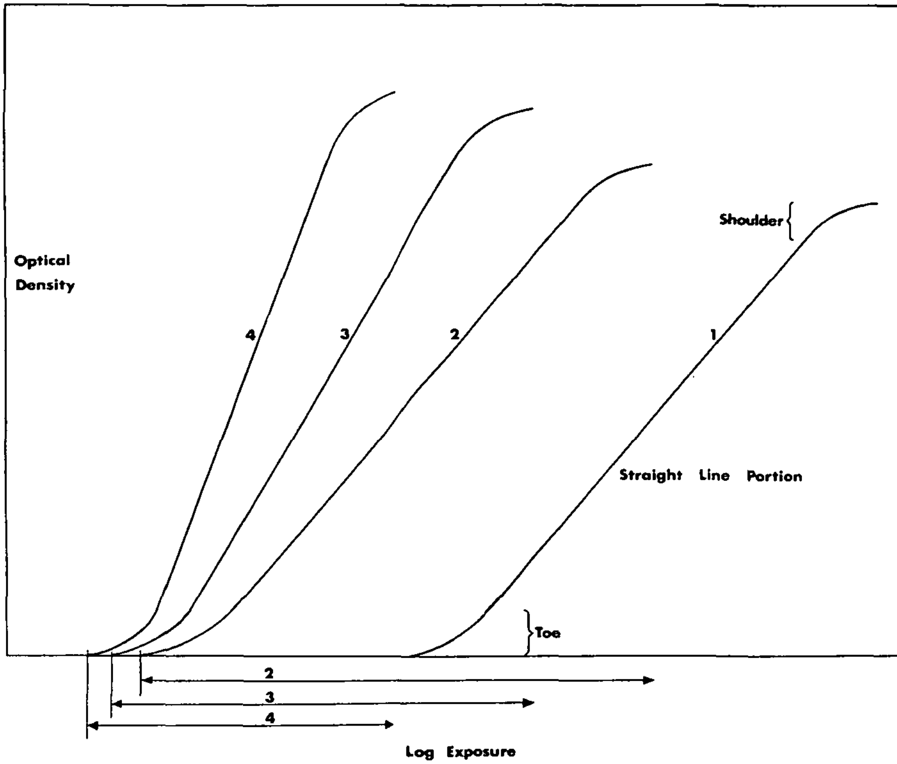


Figure 6. Characteristic or $D$/Log $E$ curve for two hypothetical films. Curve 1 is for a slower film than 2, 3 and 4 which represent one film developed to increasing degrees of contrast respectively.

where $P_0$ = Radiant flux incident on the film and $P_x$ = Radiant flux transmitted through the film.

In practice curves for any one emulsion are influenced by the nature of the radiation during the exposure, the developer and the time, temperature and agitation during development. Curve number 1 in Figure 6 is for a slower film requiring a longer exposure for a given density. The rendering of contrast by any particular film is in terms of the rate of change of density with exposure, *i.e.* the slope of the characteristic curve, a function usually referred to as 'gamma'. Curves 2, 3 and 4 in Figure 6 represent one film developed to give different contrasts, but at the expense of exposure latitude as shown by the arrows along the abscissa. Owing to the tendency of modern film and processing techniques to make considerable use of the densities on the toe of the curve, an alternative contrast index has been devised (NIEDERPRUEM *et al.*, 1966). This contrast index is derived from a line joining specific points on the toe and straight line portions of the curve.

It is outside the scope of this paper to discuss the additional area where contrast can be lost, namely within the lens and camera. The surest way of ensuring that the lens is adequate for the purpose is to test it with known targets under conditions similar to those in which it is to be used. Also, unless the lens is quite clean, the resulting scattering will very considerably reduce definition and contrast.

## OPTICAL DISTORTION

An introduction to the problems of photography using lenses designed for use in air inside flat windows is given by SCHENK and KENDALL (1954), and discussed in more detail in the appendices of the paper by CRAIG and PRIESTLEY (1963), and by MERTENS (1970). THORNDIKE (1950, 1955) describes lenses specially designed for underwater use, and fully corrected water immersion lenses are now manufactured (MANDLER, 1968). In the majority of cases the effects of chromatic aberration and distortion are less than those of contrast attenuation and scattering within the water mass, although all the effects are complementary in degrading the image. It is essential if measurements are to be made from photographs that the lens performance be assessed. Perhaps the simplest way of doing this is to photograph a rectangular grid at a known distance, and to use this to calculate angular dependent correction factors.

## PRACTICAL PROBLEMS

### ILLUMINATION AND CONTRAST

The optical problems of illumination and contrast described above, impose limitations on underwater photography which cannot entirely be avoided. It is desirable to achieve the compromise that will give the best quality and information content of the film and photographs.

Little can be done about the inherent contrast of the seabed and naturally occurring objects, such as fish, apart from the use of colour film, but unless it interferes with an experiment it is clearly advantageous to use apparatus such as fishing gear coloured so as to give maximum contrast on the film record, as illustrated in Figure 3. The colour would normally be white, except in the case of objects photographed against a light sand seabed, when a dark shade would be better.

As indicated above, the effects of absorption can be reduced by increasing the intensity of illumination. This can be done selectively within the spectrum, if it is required either to reinforce those wavelengths that are strongly absorbed, or to maximise output in wavelengths where absorption is lowest (HATCHETT, 1966). The former is most common in colour photography, the latter in monochrome. The problem of backscatter is more difficult to solve. The main aim is to reduce the volume of overlap common to the fields of light source and camera. It is often convenient to maintain the optic axis of the camera lens at right angles to the object or surface being photographed. Clearly if the light source is placed close to the camera position, as in Figure 1 a, the overlap is considerable, and the backscatter is severe. This arrangement is only successful when photographs are taken in clear water against the seabed as a background. The alternative is to place the light so that it illuminates the area being photographed obliquely as seen in Figure 1 b. Not only does this reduce the common volume, but also has the advantage that object contrast is increased if any textural irregularities exist in the object being photographed; this is sometimes termed the 'modelling effect'. The disadvantage is that the variation of illumination can be considerable over the area photographed, and this is accentuated if it is required to put the camera axis at an angle oblique to the object being photographed as in Figure 1c. The normal exposure range of a black and white film is about $10^3$, *i.e.* it will record a thousandfold increase between the minimum and maximum areas of object brightness. Recent development in multilayer film with emulsions of widely different speed, for example the E E and G 'Extended Range' film, (BOQUIST, 1964), allow photographs to be obtained from subjects with an exposure range of about $10^8$. Because even in the clearest water backscatter will reduce the practical exposure range if the light source is mounted anywhere near the camera, the use of such a film would allow the light to be placed at a large angle to the camera lens axis, with the film covering the wide range of exposures that would result. However, practical difficulties of film processing and printing are such that this film is not immediately suitable for underwater work (HARWOOD, personal communication).

Two alternative ways of overcoming the backscatter problem are by the use of polarisers, or range gating with pulsed laser sources. The use of polarisers is based on the fact that the scattering process, the redirection of a photon, does not alter its plane of vibration or polarisation (DUNTLEY, 1966; GILBERT and PERNICKA, 1966). In conditions of natural illumination the use of polaroid analysers can improve contrast perception by the human observer and by the camera (LYTHGOE and HEMMINGS, 1967). An artificial light source could be fitted with a linear or circular polariser and the camera with the appropriate analyser, set to exclude the maximum backscattered light. It must be remembered that at best a polaroid filter absorbs at least half of the light incident upon it, and therefore when using filters a light source of up to four times the power might be necessary. MERTENS (1970) publishes examples of backscatter reduction by the use of circular polarisers.

Pulsed laser light sources and range-gated receivers used in conjunction with them allow images to be received through turbid water along total light paths (illuminator to object to receiver) much longer than would be possible with eye, television or photographic camera (HECKMAN, 1966; WALL and COLEMAN, 1968; KEIL and IMMARCO, 1968). The principle of the system is that a brief pulse of light is emitted from the laser which travels to the object. A proportion is reflected back in the direction of the receiver which remains inactive until the calculated time of arrival of this reflected light from the object at known range. By this system of range-gating all light from the original path reflected by scattering particles in the water between the receiver and the gated range is eliminated because of its shorter path length.

## CAMERA MOUNTING

The design and mounting of a camera system is usually a matter of compromise between opposing requirements. Examples of two rather different solutions to the problem of designing a trawl camera are provided by CRAIG and PRIESTLEY (1963) and CARROTHERS (1967). The former authors put a conventional recording camera and flash unit mounted together into a cylindrical housing with camera and flash windows on the cylindrical wall. The single flash-plus-camera housing was fastened to a frame and attached firmly to the net. CARROTHERS used a commercial underwater camera and flash unit connected by a cable, each operating through windows on the ends of their cylindrical housings. In order to mount the camera conveniently on a trawl headline, an ingenious mirror system was fixed to the end of the camera to turn the optic axis through 90°. The flash was provided with a reflector to achieve the same result. The flash and camera were mounted parallel with the business end of each at opposite ends of their tubular housings to reduce the backscatter. Great care was taken in mounting the whole unit in a low drag fairing to cause minimum distortion of the net and to achieve maximum stabilisation of the camera.

For a camera attached to a trawl, four degrees of movement can occur: tilting in two planes normal to the optic axis, rotation about, and movement along the optic axis. Clearly the first two movements will affect the area of interest photographed, the third will affect the orientation of objects within the frame of the photographic negative, and the fourth, the change in camera object distance, will certainly affect the image size, and may also influence the exposure, sharpness and resolution of objects in the field of view. In the package devised by Carrothers, the most likely tilting movement is neatly limited by the hydrodynamics of the aerofoil fairing. The other movements are subject to changes in shape of the trawl during the fishing operation. Perhaps the most

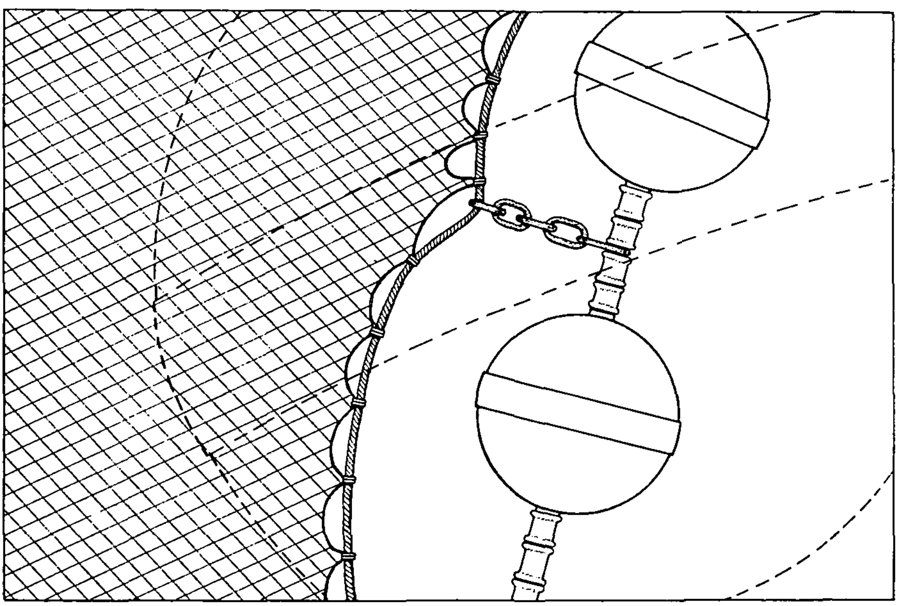

Figure 7. Change in field of view resulting from variation in headline height. The camera is mounted on the headline of the trawl and is facing down towards the footrope. Headline height is calculated by reference to objects of known size within the field of view. Drawing made from projected negatives taken 7 minutes apart. Dotted outline of one bobbin with headline height calculated at 1·50 m, and continuous outline of net, footrope, and two bobbins with headline height calculated at 6·55 m.

inconvenient movement from the point of view of analysis is rotation about the optic axis, especially if this varies within any one series of pictures. In the most common camera orientation, looking downwards from the headline, this would cause some inaccuracy in the determination of the direction of movement, and the alignment of the fish. It would be a simple matter to mount a streamer or stabilised marker in such a position that it aligned to the flow direction and appeared on each frame. A compass could be used to provide known bearings, provided precautions were taken with respect to the presence of ferrous metal interference. If a high degree of precision is required in the positioning of cameras, then instrumentation could be incorporated to monitor camera position when each exposure is made.

There are a number of ways in which the underwater camera has been arranged to take photographs at a standard distance, allowing calculations of size to be made. The simplest is with the camera mounted on a frame that maintains the "object", usually the seabed, a fixed distance from the camera lens. An alternative which is more convenient for moving cameras is the use of a hanging trip-wire which triggers the camera when it comes in contact with the bottom. Neither of these techniques is really suited for a trawl camera, although an acoustic rangefinder could be used. The first of the acoustic methods was developed in 1942 (EWING, WORZELL and VINE, 1967) and a slightly different system used by BLACKER and WOODHEAD (1965). In the case of the trawl camera considerable variation of headline height can occur as shown in Figure 7. An acoustic trigger could be used either to ensure that the camera was only operated within a certain range of headline heights, or to record headline height when the exposure was made.

## INFORMATION CONTENT

### SINGLE PHOTOGRAPHS

The photograph provides a spatial distribution of images representative of the angular distance apart of objects seen by the camera lens, irrespective of their actual distance from the camera. The fundamental limitation of the single photograph is that it gives no direct information about the relative distances of objects from the camera and from each other unless the image of one overlaps that of another. The fact that most photographs are interpreted visually demands consideration of the problems of human visual perception. This topic is simply discussed by ITTELSON and KIRKPATRICK (1951). Because underwater photographs are taken in an unfamiliar environment, the perceptual problem becomes somewhat greater, especially as neutrally buoyant objects such as fish appear suspended in the field of view. No information about the absolute size of an object can be calculated or inferred unless its actual distance from the camera is known, and vice-versa. The problem is complicated further by the fact that one of the cues to distance estimation is object contrast, and not only is this strongly affected in water, but is even more affected by proximity to artificial light sources than distance from the camera. Therefore visual estimation of sizes and distances in an underwater photograph, particularly one taken with artificial light, can be very misleading.

If, as shown in Figure 7, there is an object of known size within the frame, this can be used as a scale for unknown distances and sizes that are more or

TABLE 1. Basic data available in each photograph and additional information required for numerical analysis.

| *Data available in single photographs* | *Additional information* |
|---|---|
| 1. Shape and markings of fish – identification. | Nil. |
| 2. Evidence of swimming pattern and activity from tail and fin positions. | Nil. |
| 3. Number of fish in the frame. | Nil. |
| 4. Size of fish in the frame. | Scale mark in frame. |
| 5. Position of fish in the frame. | Orientation of optic axis. |
| 6. Height of fish above the bottom. | Scale mark and artificial light. |
| 7. Orientation of fish in the frame. | Orientation of frame to movement. |
| 8. Orientation of fish to each other. | Nil. |
| 9. Speed and direction of movement. | Exposure time or double flash exposure. |

less in the same plane. The calculating error involved for lengths out of the plane containing the known object will be inversely related to the focal length of the camera lens employed.

The information potentially available in a single photograph, that is assumed to be a vertical shot of fish in front of a net, is given in Table 1. The column lists additional items of information required for making numerical measurements from the photographs. Most of these have been mentioned in previous sections. Item (6) refers to the fact that if photographs are taken of fish from above using artificial light at a known distance from the camera lens, then the projected shadows of fish on the bottom can be used to calculate their heights above it. CULLEN, SHAW and BALDWIN (1965) describe a method of analysing the three-dimensional structure of fish schools using direct sunlight. They were therefore able to assume parallelism of the projected shadows, so their formulae would need considerable modification if a light source close to the camera were to be used.

## STEREO-PHOTOGRAPHY

Stereo-photography was developed as a means of increasing the realism of pictures by providing the sensation of depth to the observer. The stereo-pair is in this case related to man's binocular vision and the usual camera separation is approximately 60 mm, the mean interocular distance. If photographs are required for geometrical analysis and not for viewing, then there is some advantage in employing a wider separation. However, CULLEN, SHAW and BALDWIN (1965) used a stereo-attachment for a standard camera giving a 59 mm separation, in their study of fish school structure. The appendices to their paper contain the mathematical background to the method. THOMPSON and CLANCY (1959) used twin cameras with an obviously wide, but unstated separation between them to obtain length measurements of migrating salmon. A pointer in the field of both cameras served to eliminate inaccuracies arising from camera alignment, and in conjunction with calibration photographs of a scale, allowed measurement accuracy of better than 1·4%. Some of the techniques of photogrammetry developed for aerial survey work have been applied to seabed studies (SCHULDT, COOK and HALE, 1967), but there does not seem to have been any use yet of this method in fisheries research.

There is no doubt that the provision of 'third dimension' information would be immensely valuable in the analysis of reactions between individual fish and

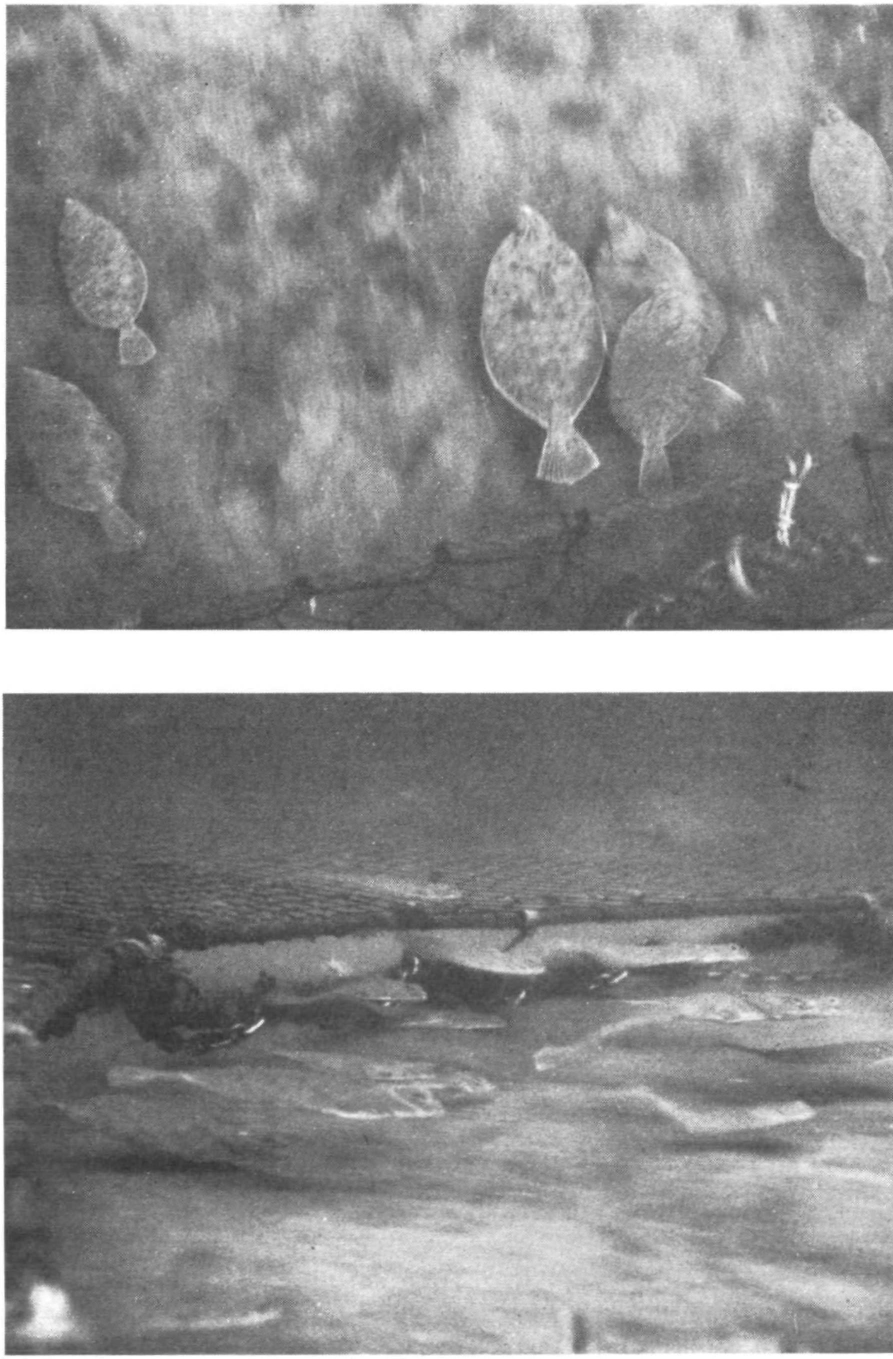

Figure 8. Flatfish in front of groundline of demersal seine net; a, from headline at a height of about 3 m; b, from groundline.

between fish and fishing gear. Although the photographs in Figure 8 were taken by a diver on a seine net, Figure 8a is entirely similar to those obtained from unmanned headline cameras. The impression given is of flatfish swimming in front of the groundline. One fish is shown swimming above another with its tail slightly under the groundline, indicating some variation in height. Figure 8b taken on a similar haul with the same gear shows that nearly all the flatfish were in fact swimming at or below the level of the groundline. Stereo-photography by an unmanned camera on the headline could yield this information, assuming that it is unlikely that anyone would wish to mount a camera on the groundline of a trawl!

Most sets of photographs are taken looking straight downwards in order that information such as the angles of orientation can be directly measured from the photograph. The use of stereo-photography allowing these angles to be obtained accurately by calculation from photographs taken obliquely, would have a number of advantages, such as the easier identification of fish species. It is usually unnecessary to produce an optical reconstruction for viewing the three-dimensional image. Because the main interest is in discrete points, *i.e.* the head and tail positions of a fish, such digital information can be calculated directly from the stereo-pair. If analogue information such as profiles or contours is required, then methods for the reconstruction of the projected image can be used to trace them. It is obvious that one essential aspect of working with stereo-photographs is that the identical point is picked in each photograph for determining range information. It may well be necessary to obtain higher photographic quality than would be required in a single picture, in order that there is no ambiguity in fixing equivalent points on the two photographs.

## MOTION ANALYSIS

A still photograph obviously can only provide information about the position of objects during the brief period of time comprising the shutter speed, or flash duration. If this time is long in relation to the speed of movement of objects within the field of view, as happens with shutter speeds of greater than about 10·0 msec in natural light, then the resulting blurring or streaking of parts of the image can be used directly (item 9 in Table 1). In Figure 8a the shutter speed was a nominal 1/60, measured as 19·0 msec. By using a sample of mesh sizes as scale the ground speed of the gear was calculated as 77 cm $sec^{-1}$. In cases where artificial light is necessary, a similar technique is to use a double flash falling within a relatively slow shutter speed. A knowledge of the changes in the other items in Table 1 depends upon the chosen framing frequency of the camera in relation to the rate of change of the event concerned. Photographs at one minute intervals of the wing end of a seine net would be adequate to describe its change in curvature, but quite inadequate to describe the activity of fish, for which a ciné film frequency of several frames per second is required.

One of the most studied components of the behaviour of fish in the mouth of the net is their orientation to the direction of movement of the net determined by vertical shots from the headline (Beamish, 1967; Parrish, *et al.*, 1967). It is obvious that assumptions have to be made in the interpretation of this sort of photograph, and perhaps one of the most tempting is that fish facing forwards are swimming with the net. However, just by looking at the photographs in PARRISH *et al.* (1967) there is no clear difference between the cod which were caught, and the mackerel which were not. Fish dropping back tail first, or keeping station with the net or accelerating out of it appear exactly similar in single photographs. It is essential for the precise analysis of motion that a sufficiently high frame frequency is chosen so that individual fish can be positively identified in successive frames.

A severe drawback of ciné film is the exposure problem, in that except in shallow water where natural light is sufficient, artificial illumination is essential during filming. This light must disturb the fish to some extent, whereas the brief electronic flash can be assumed not to influence the fish actually appearing in the photograph taken by that flash. The effect of a repetitive flash may be to influence the behaviour of fish especially if the frequency is higher than about 6 per minute. Personal direct observation from the headline of a seine net suggests that at least in conditions of attenuated daylight, the effect of an automatic electronic flash at a frequency of 2 per minute is quite negligible.

## DISCUSSION

When contemplating the use of an unmanned camera system for any specific task, it is perhaps best to start with questions that anticipate the solution of the practical problems; "What precise information is required? With what accuracy? With what frequency?" and finally, "How are the photographs to be analysed?". The practical difficulties are frequently inversely related to each other, as for example, lens focal length and depth of field; film speed and grain size or resolution; backscatter reduction by oblique lighting and evenness of lighting. It is clear therefore that in the absence of an ideal solution the answer will be a compromise. As much flexibility as possible should be built in at the design stage of the camera system to allow changes to be made in its operation, but this often involves difficult decisions being made. For example, if a single housing is built to accommodate flash and camera, this clearly fixes the separation between them. Under the conditions in which Figure 4 was taken this is a major disadvantage, but it is simpler and cheaper to make one housing with two windows and a lid than to make two housings each with a window, a lid and a cable break-through.

Most tasks involving the use of underwater photography can be undertaken first in water shallow enough for divers to operate hand-held cameras. In this way a few trial photographs could be analysed in order to discover practical problems such as flash positioning, fields of view and camera orientation some of which might only become apparent when the photographs are analysed. The final unmanned camera design will be more likely to perform the job intended if such trials are conducted first.

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