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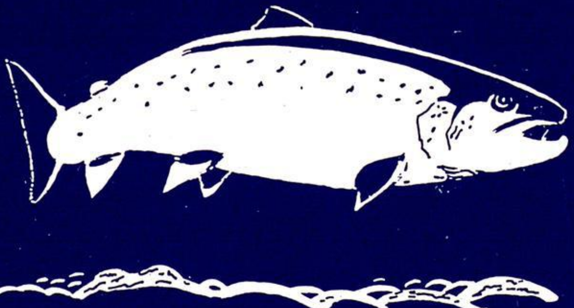
AUTOMATIC SALMON COUNTING TECHNOLOGIES — A CONTEMPORARY REVIEW

Bensinger Liddell Memorial Fellowship 1992/93

G. A. FEWINGS



The Atlantic Salmon Trust
Moulin, Pitlochry, Perthshire PH16 5JQ
Telephone: Pitlochry (0796) 473439

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ATLANTIC SALMON TRUST BENSINGER-LIDDEL FELLOWSHIP

Automatic Salmon Counting Technologies - A Contemporary Review

G.A.Fewings

Atlantic Salmon Trust
Pitlochry, Perthshire

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Foreword

By Derek Mills

Over the years attempts have been made to assess as accurately as possible the numbers of salmon returning to our rivers. The scientist is anxious to have this information in order to estimate spawning escapement and thus the likely future recruitment in terms of smolt production. From these data some attempts can be made to manage the stocks and control exploitation. The salmon proprietor is anxious to know how many fish are in the river so as to gauge the rents he should charge for his fishing at various times of the year. Lastly, the angler is keen to know how many fish, if any, are in the river when he comes to fish. Recently, a dearth of spring fish has left many beats on some rivers unlet, partly as a result of hearsay that no fish are in the river.

Stock size has, with limited exceptions, to be assessed from catch records. We all know how inaccurate these can be, with catches being influenced by weather, river flow, fishing effort and, indeed, fishing season. More reliable data on stock size has been available for those rivers harnessed for hydro power where counters installed in fish passes at the dams have enabled reasonably reliable counts to be made.

The Hunter Committee as long ago as 1965 recommended that salmon stocks should be managed on an in-river basis. It stated that management should be capable of dividing the run between the commercial catch on the one hand and the angling stock and breeding escapement on the other, in such proportions as are required. It should ensure that breeding escapement is sufficient without being excessive. It should provide a way of measuring as accurately as possible the effect of any changes which have occurred naturally or by design. It went on to say that commercial fishing should be permitted only in the river and by methods that allow the catch and escapement to be measured with reasonable accuracy. This latter statement referred to a recommendation that the commercial catch of a river should be made at a single point, preferably by a trap, or failing that, by concentrated net fishing associated wherever possible with a counting device.

The installation of reliable counting devices is a slow and costly business but their value where they have been built, as on the North Esk, has been immense. The Logie Counter on this river, with its associated video equipment, has attracted a great deal of attention with authorities managing other rivers anxious to erect similar devices but constrained by cost. Recent installation of the counter on the Aberdeenshire Dee was only possible through the generosity of a charitable organization. Up-to-date information on automatic fish counting techniques is essential if more such devices are to be installed quickly, efficiently and relatively cheaply. The need to have accurate information on salmon stock size is becoming ever more urgent. We are therefore immensely grateful that Adrian Fewings has produced this valuable up-to-date review on automatic salmon counting devices which hopefully will result in more being installed and some existing ones improved.

Biographical Note

Adrian Fewings gained his first degree in Applied Biological Sciences at Bristol Polytechnic in 1986. Later that year he was accepted to read for a Masters degree in Fisheries Biology and Management at the University of North Wales, Bangor. The research section of this degree was spent in the Lake District working for North West Water on the evaluating various resistivity based fish counters.

After graduation from Bangor he was contracted by North West Water to continue his work for an additional year. In 1988 he was offered a Masters degree at the Cranfield Institute of Technology to read Underwater Technology. On successfully completing this degree, Adrian was appointed in 1989 Fisheries Scientist for the National Rivers Authority, Southern Region. This post is primarily concerned with the operation of fish counting systems to determine the environmental conditions required for "normal" migration of adult salmon in the Hampshire Rivers Itchen and Test.

Adrian was awarded the Bensinger-Liddel Fellowship in 1991 to review the automatic fish counting methods suitable for counting adult salmon in freshwater.

In 1992 he was accepted to read for a part-time doctorate researching the electrical resistive properties and resistive detection of fish, with the Department of Oceanography, Southampton University.

Abstract

The development of automatic fish counters has been driven by the need for accurate, long-term and cost-effective stock assessment of adult Atlantic Salmon (*Salmo salar* L.). These developments have been facilitated by advances in computing and electronics. Non-invasive methods of fish counting are ultimately limited by the properties of the water in which the fish are immersed.

To date, the three main detection and counting methods that have overcome these limitations are based upon acoustic, optical or electrical principles. For each of these methodologies, typical application, siting considerations and use limitations are discussed. Where available, estimates of accuracy and resolution of the methods are described, together with common problems found in the interpretation of fish counter data.

Areas of future development are discussed in relation to their potential for Atlantic Salmon research. Conclusions are drawn on the present capabilities of fish counting systems and key features of these systems are compared to assist fish counter selection.

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1 Introduction

The Atlantic Salmon is considered an important fish species of the north Atlantic due to its economic, symbolic and traditional value at both local and international levels. The presence of Atlantic Salmon populations is often considered to be indicative of high water quality and effective river management. For these reasons Governments and private fisheries interests are prepared to spend hundreds of thousands of pounds to re-instate salmon populations where they have been absent for decades. Two examples of such projects currently underway are the rehabilitation of the River Thames in England and the River Seine in France (Gough, 1989,1990,1991,Euzenat *et al* 1992).

On rivers with populations of Atlantic Salmon, management of both river and salmon resources are essential to prevent over exploitation. Effective management of these resources requires high quality information describing the status of the resource and of resource impacting factors. Whilst the technologies for routine, accurate monitoring of river water quality and quantity are well established, these goals have been difficult to achieve for monitoring salmon populations. Ideally salmon population monitoring should yield high quality data that is non-destructive to the fish, non-invasive to migration and inexpensive to collect. This paper is concerned with the description of monitoring methods that are presently available for the counting of salmon past fixed sites and some methods that are likely to be available in the near future.

All of the methods discussed require significant capital expenditure either for equipment purchase or site installations. Maintenance and operating costs are also significant, so clear benefits must be available to justify this expenditure. Automatic fish counters are presently being used for a number of purposes such as behavioural research, environmental impact assessment and routine stock monitoring.

The earliest uses of automatic fish counters were to determine the environmental impact of physical barriers to migratory fish movement such as hydro-electric dams (Lethlean, 1953). They are still used for this purpose (Harte, 1993). A more recent use requiring new approaches to fish counting is the determination of environmental impact due to the building of tidal barrages (Euzenat and Larinier, 1993, *pers. comm.*). In this case optical counters are required due to the large range in water conductivity at barrage sites, high acoustic noise and the need for a high degree of species discrimination. In some cases barriers to fish movement are a behavioural response to environmental stimuli such as water velocity, temperature or light. Such environmental effects can be caused by water abstraction schemes and therefore counters have been used in such circumstances to determine operational limits for water abstraction (Fewings, 1993, Gregory, 1987).

Other programmes of investigation are concerned with furthering the understanding of in-river migration process so that migratory fish populations may be safeguarded. A spin-off of this type of investigation is the enumeration of total returning stock size, the calculation of exploitation rate and spawning escapement (Solomon and Potter, 1992). Where sufficient resolution of sensing and recording systems allow, it is possible for independent estimates of open sea survival to be calculated if tagged fish can be identified by external features such as adipose fin removal (Solomon and Potter,1992).

Consideration must also be given to the problems of interpretation of fish counter data. Welton *et al* (1989) emphasised the difficulties in interpretation of resistivity fish count data due to the unknown availability of fish and the unknown period of individual fish migration observed in response to a stimulus. In order to evaluate these parameters it was suggested that two counters were used in series and individual fish tagged and tracked past each counter. This would enable the estimation of the number of fish in the intervening section of river and therefore yield an indication of proportioned response to environmental stimuli.

The identification of species is especially important where significant populations of other migratory species exist. For example, many of the salmon rivers of England and Wales have significant populations of sea trout (*Salmo trutta* L.). These fish can cause a significant error in the estimation of total returning stock of salmon if the fish counter cannot discriminate between the two species. In barrages with optical fish counters installed it is important for the fish counter to discriminate species such as salmon and bass (*Dicentrarchus labrax* L.), if meaningful conclusions are to be drawn on the behaviour of each species.

Suitable siting of the counting system is also important in order to observe relevant behaviour patterns and to maximise the accuracy of the resultant data. If a counter is sited too far down a river system then significant vacillation effects may be observed as fish that are not committed to a given migration route retreat to the estuary to ascend another channel. Placement of the hydroacoustic counting site on the Moisie River, Canada was not only a matter of selection of good river profile and flow patterns, but also the position upstream from the estuary (Harte, M. *pers. comm.*).

2 Detection and Counting Methods

The techniques in use and under development for automatic fish detection are essentially sensor systems that can detect some difference between the fish and the water in which they are immersed. Freshwater has only a limited number of transmission "windows" through which it is possible to penetrate. These "windows" are confined to the electromagnetic waves of long radio waves (wavelengths > 0.1m), visible light , X-rays and gamma rays. X-ray and gamma ray bands are too expensive or dangerous to place in river counting situations, leaving only the visible and radio bands suitable for use. Water is also transmissive to electric current and sound thus the major groups of methods that can transfer information through water are the transmission categories of light, radio, sound and electric current.

The objects to be detected must also have a characteristic that distinguishes them from other objects and the water, whilst using a given transmission band. Fish are generally more opaque to light than the surrounding water and so light can be used for detection and discrimination. Fish also conduct electricity better than the freshwater they displace and generate electric fields from muscle activity, which enable passive and active methods of electrical detection. Passive detection methods sense electrical activity generated by the fish and are analogous to insect predators listening for the sound of a flying insect. Active electrical methods detect a change in the conductivity, or some other parameter within a field generated by the sensing system, an analogy being a bat generating sound and listening to the reflections of that sound off prey such as a flying insect.

Whilst fish have an overall density very similar to the water that surrounds them, the tissues of the body may have markedly different densities, for example, the density of muscle tissue is greater than freshwater, but the density of the swim bladder is much less than that of water. This characteristic enables fish detection using sound, as it is reflected from regions of sudden change in density. Unfortunately, fish appear to be almost transparent to radio waves and therefore such a system is unlikely to have adequate discrimination between fish and water.

Generally, the resolution and accuracy of a counting system decreases as the volume of water to be sampled increases.Virtually all of the automatic fish counting systems presently available use light, electric effects or sound to sense the fish. The properties of the fish, freshwater and the detection method place limits on the resolution and accuracy of the counting system and usually constrain the siting and operation of the counting systems. It will become apparent from the following sections that different methods have conditions under which they can yield high quality data. It is therefore important to be aware of the requirements and limits of operation of each technique in order that the correct counting system is selected to provide data of appropriate accuracy and type.

Which ever counting system is chosen it is essential for quality control information to be collected on the data produced. There are often significant difficulties with this requirement since it is necessary to have a more reliable system to test another. In practice, such a method may not be available and the best that can be achieved is frequent calibrations with something as representative of the real target as possible.

2.1 Acoustic methods

2.1.1 Introduction

Mechanical compression waves of frequencies between a few cycles per second (Hertz or Hz) and 500,000 Hz are used by fish for communication, passive location of prey and short range active location for shoaling and object avoidance. Juvenile salmonids are known to communicate in narrow frequency bands and avoid particular sound sources (Knudsen *et al*, 1992). Fish also use low frequency compression waves to locate prey using the lateral line, an organ present in almost all fish, highly specialised for the reception of low frequency sound (Bleckmann, 1986). Low frequency pressure waves are produced by tail movement and these pressure waves are reflected off nearby fish or inanimate objects. The lateral line detects the reflected pressure waves and the fish can therefore avoid obstacles in darkness.

Since salmonids are streamlined and move through water efficiently, little of the propulsive energy of a swimming fish is converted into acoustic energy that could be detected passively. Therefore all the effort to detect migrating salmonids using the acoustic band have employed "active" methods. The term "active" refers to the release of acoustic energy into water and measurement of the acoustic energy reflected off objects in the water. The first active acoustic devices for fish detection were developed in the 1930's. Sund (1935) reports the use of a very early echo sounder for the detection of Cod (*Gadus morhua* L.). Obviously the technologies available for the development of hydroacoustic systems are now far more advanced and can now be applied to the difficult technical task of individual fish detection, sizing and positioning. To discuss the relative merits of the counting systems presently available and the difficulties involved in fish detection, some of the basic theory of hydroacoustics must be explained.

2.1.2 Basic hydroacoustic principles

Oscillations of a submerged surface displace the adjacent water molecules which in turn displace their neighbouring water molecules. In this way sound is transmitted through water as series of compression waves that radiate from the source in a wave front. This spreading of the sound over the area of the wave front leads to a reduction in the intensity of the sound which is therefore proportional to the area over which the sound is spread. Since the area of the wave front is related to the square of the range from the source then the intensity decreases in inverse proportion to the square of the range.

Intensity of sound at a distance is further reduced by absorption losses which are dependent on factors such as temperature, pressure and frequency. Acoustic absorption increases linearly with range but the effects in freshwater are generally considered to be small except for frequency related absorption.

Sound reflects off objects of differing density than the propagation medium, and it is this reflected sound that is required for fish detection. Not all targets reflect sound in the same manner. The technical term for the ability of an object to reflect sound is called the backscattering cross section and equates to the acoustic size of an object. With bony fish most sound reflection is due to the presence of the swim bladder as this organ has a low density.

Intensity of sound can normally vary over several orders of magnitude and is cumbersome to relate in linear units. For this reason sound intensity is measured on a logarithmic scale called the decibel. A further advantage of using decibel units is the ease of manipulation. To multiply values just add their decibel equivalents and to divide values, subtract their decibel values.

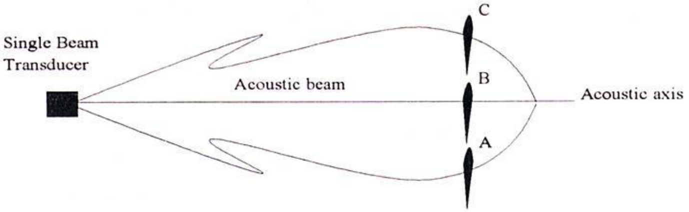
$$X\ \mathrm{dB} = 10.\mathrm{Log}\left(\frac{\text{measurement}}{\text{reference}} \right) \qquad -(1)$$

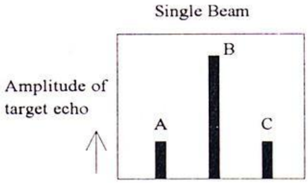
The reference is usually sound intensity measured at a standard range of 1m from the source

In order for sound to be reflected off a target it must first be generated. Since the direction of a target from the sound source is desirable information, it is important that the sound source is directional. Ideally sound would be projected from the source or transducer along a single axis. In practice it has proven difficult to achieve this and so transducers are available with a single primary axis but with smaller secondary axes as shown in Figure 1. These secondary axes are usually referred to as side lobes. Transducers are classified in their directionality, the angle off-axis at which the acoustic energy is reduced by half (-3dB point) is usually the beam angle quoted. This is important since the angle off-axis of the target will affect the apparent size of the acoustic target.

3

Figure 1 Acoustic coverage of a single beam transducer





With a single beam system it is not possible to correct for off axis targets.

A sound transducer converts electrical pulses into acoustic pulses and also generates electrical impulses when excited by incedent reflected sound. Beam angles typically range from 2° to 45° and are usually circular in cross-section. When used in shallow water elliptical beams are sometimes used to "view" horizontally.

Acoustic pulses consist of short bursts of sound at the operating frequency of the transducer. Since these pulses have a finite duration and travel at about 1480 mS^{-1} the resolution of separate targets at similar ranges will be limited by this pulse duration. The greater the pulse duration the lower the range resolution. A typical pulse width for a scientific sonar is 0.2 mS (pulse length =1480 x 0.0002 or 0.296 m). Targets could be theoretically resolved at a range separation of half this distance or 0.148 m.

Acoustic energy spreads spherically and is absorbed on transmission through water, this transmission loss is predictable and quantifiable. On both the projection and reflection path the acoustic intensity decreases by approximately 20 x Log Range due to spreading. Therefore the total loss is

$$40 \times \text{Log } R \qquad -(2)$$

where R is the range to the target

The losses due to absorption are also known and quantified by

$$2\alpha R \qquad -(3)$$

where α is the coefficient of absorption

The range to target can be determined by timing the interval between release of the sound energy and the detection of its reflected image as the speed of sound in water is known. With this information it is possible to compensate for the effects of range to the target and calculate a size estimate for a given target. Scientific sonar has this compensation scheme built in as a feature called Time Varied Gain (TVG).

The observed Target Strength (TS) can be related to the acoustic size or back-scattering cross section by the following equation.

$$TS = 10 \text{ Log } \sigma_{bs} \qquad -(4)$$

where σ_{bs} is the back scattering cross section

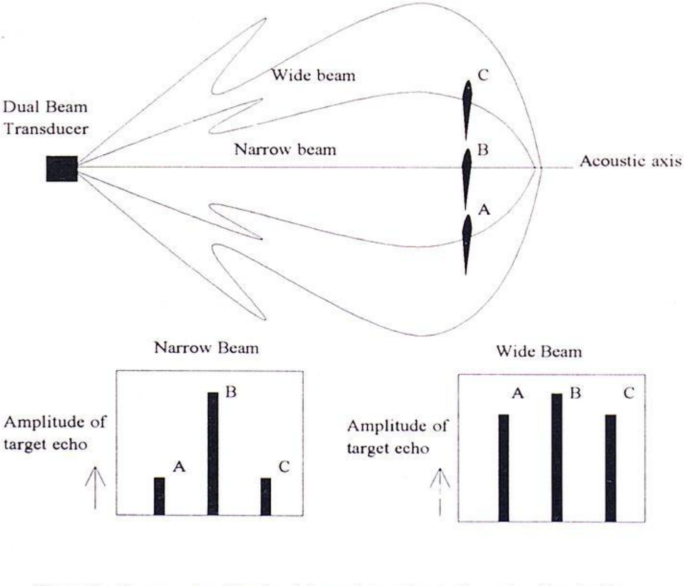
The target strength estimate is dependent on the shape, size and orientation of the acoustic target relative to the acoustic beam. For a given orientation of fish, the target strength is negative and proportional to the length of the fish, ie. -20dB for large fish targets and -65dB for small fish targets. Most of the back scattered acoustic energy is reflected from the swim bladder. Since the swim bladders of most fish have a large side aspect and small end aspect, the largest target strengths are derived from side aspect views of fish targets. For this reason it is important that fish behaviour is taken into consideration for site selection, ie, that fish should swim past the site presenting a side aspect normal to the beam axis.

The axial position of the target in the acoustic beam must also be estimated to successfully detect and size fish targets. The further off-axis the target is, the smaller the target will appear. Two methods are presently in use to determine this axial position of a target.

The dual beam method uses two acoustic transducers on the same axis but with different beam angles. As target strengths from each transducer are processed separately but in a short time span, the off-axis angle can be determined and therefore used to compensate target strengths (Figure 2). The second method uses a single transducer that is divided into four discrete reception units (Figure 3). The four units are combined for the transmission of the acoustic pulse, on reception of reflected energy data from each unit is processed separately. Acoustic energy reflected from an on-axis target is received simultaneously in each of the four quadrants. As the target moves off-axis the sound energy is received at slightly different times in each quadrant leading to phase shifts between adjacent quadrants. These phase shifts can resolve the off-axis angle and therefore allow axial position compensation.

Single beam systems cannot determine the off-axis angle and are therefore limited in their usefulness for salmon counting applications since accurate target strengths cannot be calculated.

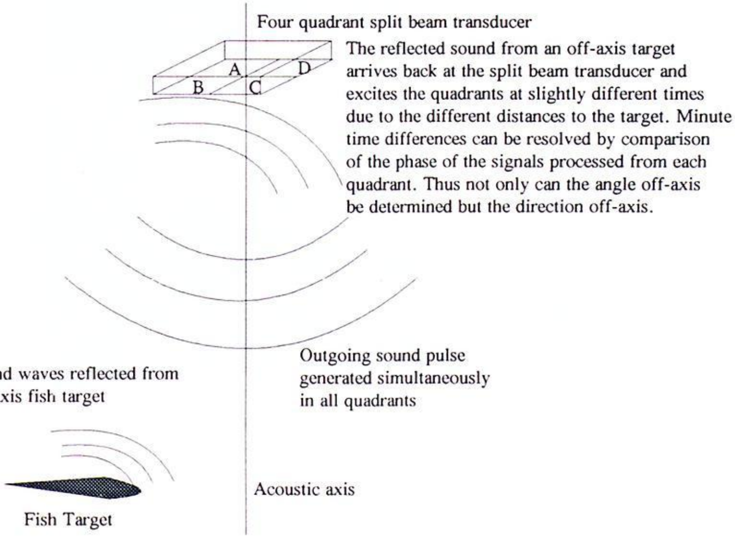
Figure 2 Acoustic coverage of a dual beam transducer



The ratio of narrow to wide signals is used to estimate the angle off-axis of targets.
The location of targets A to C cannot be determined, only the angle off-axis.

One other factor important for the success of acoustic salmon counting operations is that the site must have a low background noise level so that small fish targets are not obscured. Noise is generally derived from three major sources, ambient acoustic energy, electronic noise in the equipment and from reverberation or unwanted targets. The accepted methods for minimising these undesirable effects are good site selection and planning, extensive electronic and digital filtering and the use of thresholding. Thresholding is used extensively in sonar applications whereby acoustic limits are set below which signals are rejected. If ambient noise is very high it may be possible to shift to another frequency band to avoid the noise.

Figure 3 Principle of operation of split beam acoustic system



Target strength (TS) measurements should be accurate and repeatable between years and between sites, calibrations must be made at regular intervals to maintain data quality. This is normally accomplished with standard acoustic targets such as a competition ping pong ball or tethered live fish of similar size and species to that required for monitoring. For ultimate analogy to the natural passage, fish can be trapped upstream of the counting site and released downstream of the site at low activity times. Individual targets can then be tracked and used for calibration as they swim upstream through the counting site. This technique was used at the counting site on the Moisie River, Quebec Province, Canada, by Groupe Environment

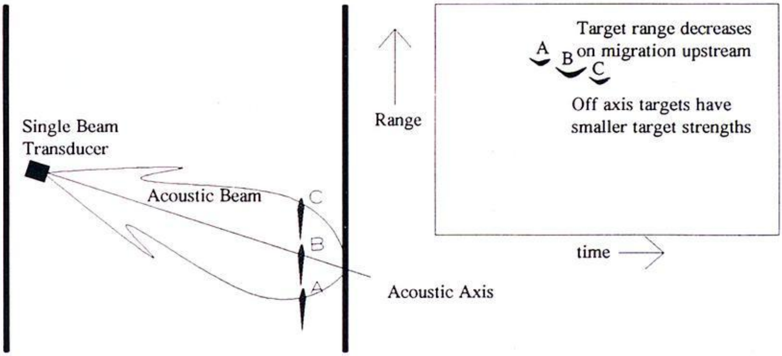
Schooner Inc. Plate 1 shows a salmon that has been trapped upstream of the counting site and which was about to be transported downstream and released for target strength estimation. The tethered fish technique was used by Hydroacoustic Technology Inc. on the Yukon River, Alaska (Johnston *et al* 1993).

Plate 1 A salmon about to be released and tracked through an acoustic counting zone on the Moisie River, Quebec, Canada

Positioning of the standard acoustic target at alternate ranges and angles off-axis enables calibration of the TVG, off-axis determination and mapping of the effective counting zone. The latter calibration allows the estimation of the river cross section not covered by the counting zone and therefore the scaling required to give overall fish passage numbers.

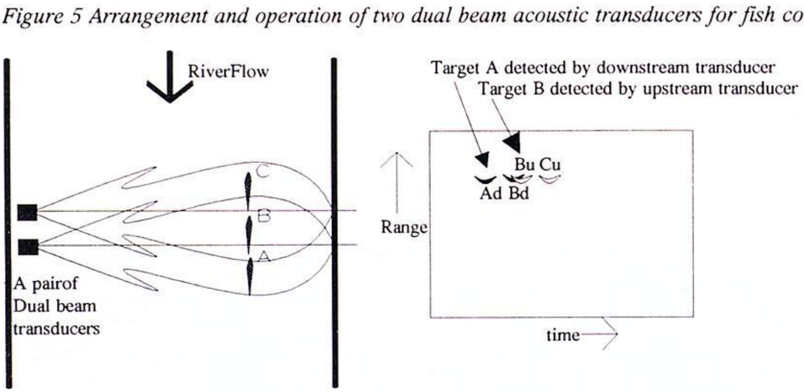
For salmon counting applications it is also important to determine the direction of travel of the acoustic targets. Such determinations can help discriminate fish and non-fish targets since debris rarely move against river currents. Target tracking is an important feature of modern sonar counting systems although the methodologies vary dependent on the type of sonar being used. It is possible to track targets with a single beam system by arranging the acoustic axis to view slightly downstream (Figure 4). Fish swimming upstream through the counting zone are detected at progressively reduced range with an initially small target strength, increasing to a peak and then reducing again as compensation cannot be made for off-axis error. This technique can also be used with a dual beam system with improved accuracy because of axial compensation. The problem with this approach is that most upstream moving targets will present a sub-maximal target strength due to their non-normal orientation relative to the acoustic axis.

Figure 4 Change in range method of target tracking with a single beam acoustic system



The favoured method of operation with dual beam systems uses two dual beam transducers mounted alongside each other and normal to the flow of the river, sometimes referred to as a quad or paired system (Figure 5). Targets are detected and tracked with both acoustic beams although there will be a time delay between detection in one beam relative to another. The order in which the targets are detected indicates the direction of travel. Since none of the transducers can be active simultaneously they must be activated sequentially in order that they do not interfere with each other, this is termed multiplex operation. Two quad systems can be used at the same site, one pair on each bank viewing across to the other which ensures maximum coverage of the river cross section. In these configurations different beam angles are chosen for each bank dependent on channel slope.

Figure 5 Arrangement and operation of two dual beam acoustic transducers for fish counting



2.1.3 Single beam sonar

Single beam sonar systems have been used for individual fish counting but due to their inability to estimate the off-axis angle of a target, TS estimates are less reliable than either the dual beam or split beam system types. Direction information can be derived from angling of the transducer slightly downstream and using the change in range principle as previously described. Unfortunately this requires that many of the fish targets then expose a non perpendicular side aspect to the beam thereby reducing target strength.

By pairing single beam systems with overlap of the beams it is possible to determine the direction of travel of targets with the acoustic beams arranged perpendicular to the river flow. Without axial position information it is generally thought that target strength estimates will not be as robust as that from dual and split beam systems.

2.1.4 Dual beam sonar

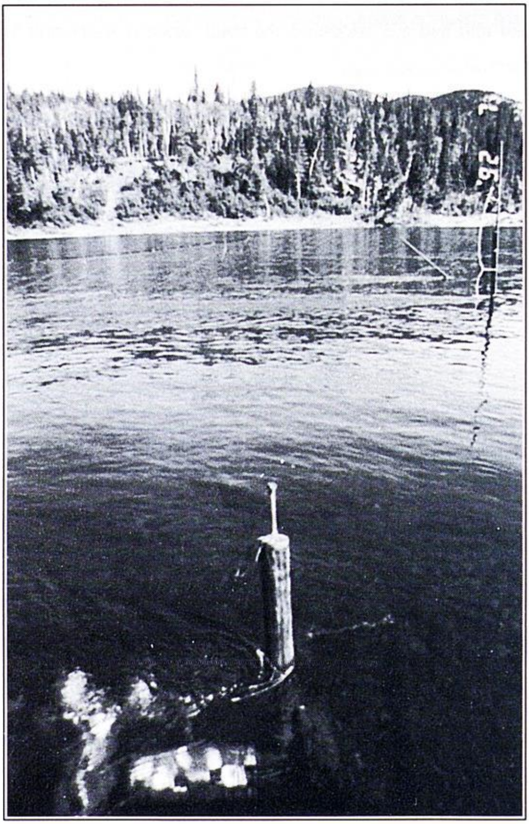
Two major manufacturers can supply dual beam fish counting systems for use in rivers, Biosonics Inc. and Hydroacoustic Technology Inc. of Seattle Washington, USA. As an example of dual beam system operation and the level of effort required, the hydroacoustic study site on the river Moisie, Quebec, Canada was visited as part of the research for this paper.

The site was selected in 1990 due to a combination of desirable features which included a gently shelving bottom profile, laminar flow and sufficient distance from the estuary to ensure consistent upstream movement of salmon. The river was 140 m wide at the study site, flowed from northeast to south west and had a 3° slope on the south eastern shore and an 8° slope on the north western shore (Plate 2).

Plate 2 Aerial view of the acoustic counting site on the Moisie River, Quebec, Canada.

Four dual beam sonar units were used in multiplex fashion, with a three degree narrow beam angle on the gently sloping shore and a six degree narrow beam angle on the steeply sloping shore. This arrangement was to maximise the coverage of the river profile. All transducers operated at a frequency of 420 KHz with the adjacent transducers aligned to overlap their respective beams. By overlapping the acoustic beams, targets could be tracked through the counting zone as described earlier. An ES2000 echo-sounder was used which combined the functions of echo-sounder and multiplexer. Received data were then processed with an Echo Signal Processor (ESP) and data stored on optical disk.

Plate 3 View across Moisie River, Canada, from the transducer



Acoustic calibrations of the equipment were carried out in the laboratory prior to field operation and then standard acoustic targets were used to calibrate the equipment during the study period. In addition to this calibration, live salmon were trapped upstream of the counting site and transported downstream of the acoustic arrays; the fish's progress was then monitored, where possible, through the counting zone. Video cameras were mounted at the end of each deflecting fence and recordings were made of fish passage during daylight hours.

Since limitations of the equipment permitted the use of only one dual beam pair at one time, a larger proportion of each hour was spent recording activity on the gently shelving shore. This decision was made based on experience gained in previous years at the site which indicated more fish passage on this shore. It was also known that the spatial coverage was not complete from standard target tests and released fish target experiments. Expansion of the number of fish detected due to spatial and temporal limit coverage was carried out by incorporation of the data from released fish passages and the known proportion of time each area was sampled. This revealed a detection rate of 71% of the released fish passing through the detection area. A statistically significant correlation was also observed between the hydroacoustic upstream counts and the daily trap catch upstream (r critical=0.497; d.f.=14; $\alpha.=0.05$; r=0.67) (Harte, 1993). The major conclusion drawn from this study was that between 4556 and 4862 salmon passed the study site in 1992 and that these estimates were as accurate as was achievable given the conditions of study.

2.1.5 Split beam sonar

Split beam sonar systems are available from a number of manufacturers (HTI, Biosonics, Simrad). The method offers the possibility of fish counting at minimum ranges of 2-3 m and a maximum of over 150 m. Elliptical beams transducers are available that are suitable for in-river applications. The split beam technique enables the position fixing of individual targets off beam axis and therefore target tracking can be implemented for the counting of individual fish. All of the available systems include sophisticated data archiving and post-processing features that allow three dimensional tracking, individual fish counting and sizing. Such analysis can yield a large amount of information on the behaviour of fish at the counting site such as horizontal and vertical stratification of fish passage as well as speed and direction of passage in relation to target strength (Johnston *et al,* 1993).

Whilst operation of the equipment is automatic, it should be supervised to accommodate changes in water depth and to allow frequent calibrations. Side aspect hydroacoustic counters can suffer from obstructions in the acoustic "view" across a river, and from a reduction in the sensitivity of a transducer at increasing angles off the acoustic axis. Therefore it is usually necessary to scale up the count to redress this error and to account for any gaps in the monitoring schedule. Where other species are likely to migrate through the counting zone it can be difficult to distinguish species on a size basis especially if there is significant background noise.

Due to the simplicity of operation and deployment, many users are looking toward the application of split beam systems for salmon counting in rivers much smaller than those already monitored in North America. Counting accuracies are thought to be similar to that of dual beam systems but noise estimates for the equipment are slightly better with the split beam systems (A.Butterworth *pers. comm.*).

2.2 Optical methods

2.2.1 Introduction

Light has been widely utilised by man and other predators to detect fish. Natural systems possess the ability not only to recognise objects but estimate size, range, texture and colour. Optical methods applied to fish counting have the advantage of potentially high resolution and accuracy for both detection and counting. The disadvantage of the method is its susceptibility to the transmission losses that occur when rivers are in spate. It is precisely in these high turbidity periods that many salmon migrate upstream therefore potentially leading to substantial inaccuracies in counting systems. Successful fish counting systems have specifically addressed this problem of high transmission loss.

Many rivers that support populations of migratory salmonids have normally low water turbidities and would therefore be suitable for optical counting methods. Some attempts have been made to use machine vision systems for the identification and sizing of fish (Johnson *et al*,1988) but these have been limited in their success by the speed of computers to process the visual images. The system developed by Johnson *et al,* processed slowed video tapes of fish passing through a fish counting area.

Visual images contain vast amounts of information that the human system processes extremely quickly. Serial computers process one instruction after another and therefore have to be very fast to process the great deal of information present in a single image. In practice, only a very small proportion of the information from an image is required for counting and sizing. Therefore many of the procedures involved with machine vision processing are merely for searching simple, but large, data sets.

For these reasons, the methods that show greatest promise have incorporated powerful methods for the reduction of the amount of data to be searched for a fish pattern. Two methods have been used to acquire visual data from a counting area. The first uses a video camera to convert light to an electronic signal that can be processed by computer. Data reduction has been achieved with the design of specialist illumination systems to provide very clear, high contrast images (silhouette imaging, Plate 4). The second method uses linear arrays of light emitters and detectors to determine the presence or absence of an opaque object between them (linear array imaging). Data reduction is achieved by the sampling of relatively few detectors that are favourably arranged and only provide the information that an object is in the light path or not.

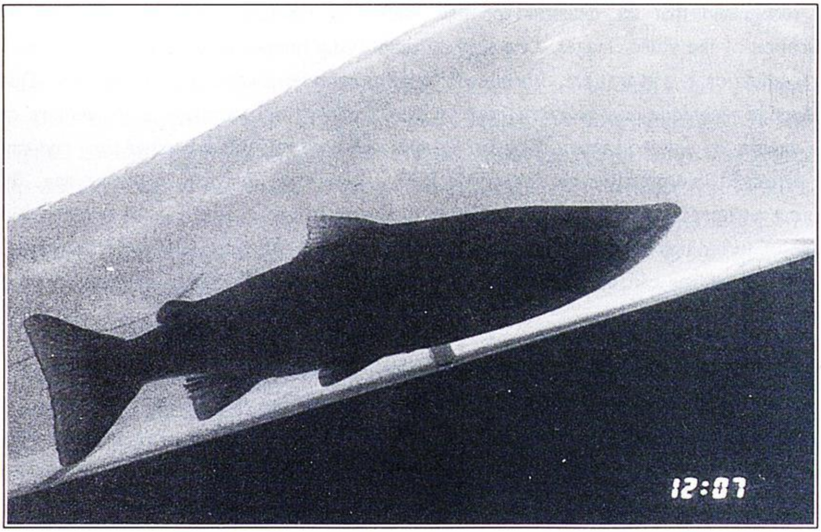
2.2.2 Silhouette imaging

It was recognised that the detection of fish shapes by machine could be enhanced by simplification of the video images. One way of simplifying images is to represent them as a series of points on a grid that are either black or white with no shades of grey between. This data reduction technique may be carried out by the computer once an image is in memory or prior to capture by a video camera. The former approach uses valuable computer time and can lead to errors in interpretation on conversion from a grey scale image to a binary one. By simplifying an image *prior* to capture, variation in the quality of images can be reduced and the range of turbidities under which a machine vision system can operate may be increased. These two advantages can be achieved with an increase in the contrast of subjects to their background.

Pippy (*pers. comm.*) achieved very significant contrast enhancements by employing a highly structured arrangement of lighting, camera and reflective backing (Figure 6). This system is based around the properties of the retro-reflective material frequently used on road signs. This material has the useful characteristic that it reflects incident light almost directly back toward the source so very little light is reflected off this axis. If a video camera is mounted on the same axis, extraneous light sources contribute little to the light entering the camera. The net effect is that the background appears very light and objects obscuring this path appear very dark.

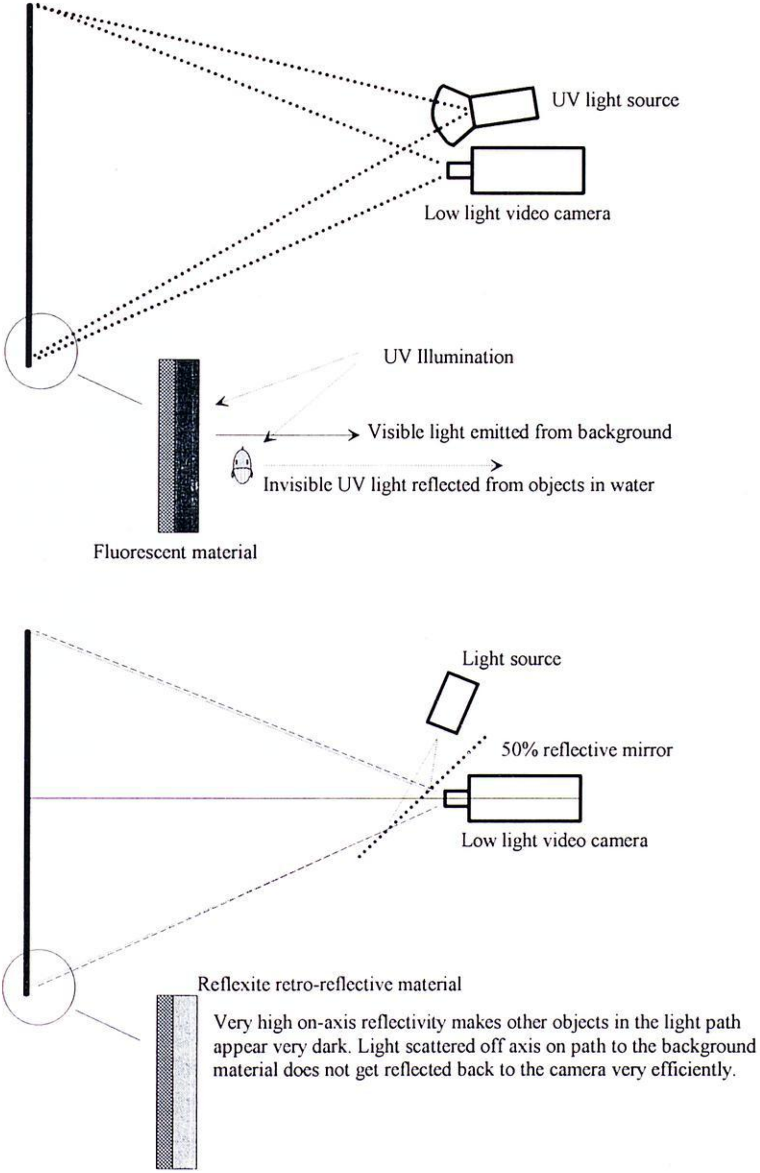
Pippy (*pers. comm.*) arranged an illumination system that supplied light from the axis of the camera using 50% reflective mirrors (Figure 6). A salmon has a reflective underside but does not reflect light as efficiently as the retro-reflective material background. Therefore the fish appears dark against a very bright white background. The technique was further refined by the construction of a counting tube with background surfaces at precise angles to the camera/light source axis and a mirror so that the video image showed fish targets both in plan and side elevation.

Plate 4 Silhouette image of a salmon ascending a resistivity counting site on the River Itchen, Southern England. (Fewings, 1992)



The simplified video image was processed using a motion detector unit which triggered a time-lapse video recorder on detection of an object moving in the field of view. Such units are readily available for security applications and merely search the video image for areas of darkness, over a preset size, that change position on subsequent images. The system produces a series of time-lapse images with the periods of low activity removed. This processing massively simplifies the task of viewing time-lapse video records since only suspect events are included.

Figure 6 Ultra violet and retro-reflective silhouette imaging systems



Very high on-axis reflectivity makes other objects in the light path appear very dark. Light scattered off axis on path to the background material does not get reflected back to the camera very efficiently.

These video records were used by Pippy (*pers. comm.*) to supply the input of a machine vision system which was constructed around a standard video digitiser card for a personal computer. Video images were digitised in real-time and small areas of the images checked for movement of objects into the counting area. The downstream area was searched first, at right angles to the movement of the water.

If an object was detected, then similar searches were carried out at a lateral displacement to the first on subsequent images to determine the direction of movement of the object. Once an object was determined to be fully in the counting area then a search was carried out to determine the length of the object. Certain logical criteria had to be met in order that a count was given and a length attributed to that count. For example, an object must have cleanly traversed the counting area in a preset time and exited from the opposite end of the counting area to the entry point.

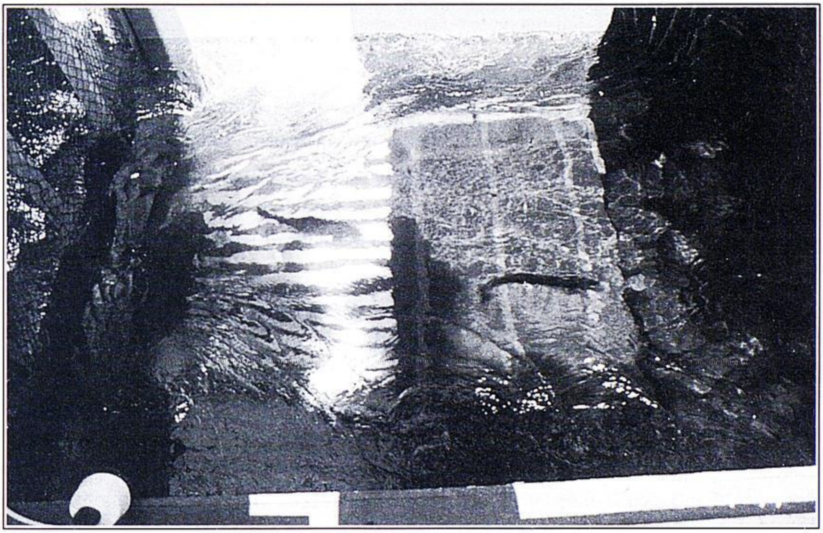
In 1992 the system was used for counting the ascending salmon in a Biscay Bay River of Newfoundland by collecting the motion detector directed video and by subsequent processing by the machine vision system and human interpreter. More recently the machine vision system has been made fast enough to operate on site without intermediate recordings. An accuracy of over 95% for detection of fish has been achieved under conditions of less than 3 fish present simultaneously in view (Pippy *pers. comm.*). The lengthing accuracy of the system is currently under evaluation and therefore no data have been released on this statistic. The system can discriminate between salmonids and eels (*Anguilla anguilla* L.) but significant difficulties exist in the discrimination of salmon from sea trout on anything other than a length basis.

The limitations of such systems are due to the low volume of water that can be sampled with the counting tube described. Clear, high contrast images are required for the successful identification and sizing of fish. This condition cannot be met if the turbidity of the water is too high although Pippy reports that such conditions have not limited counting in the Newfoundland rivers to date. As the field of view is increased to sample greater volumes of water, the relative size of the subject fish become smaller. This increases the search task and reduces the spatial resolution of the output results.

The custom software for the fish counting system on the personal computer was under development by Pippy during 1992 but significant improvements in performance were still being made. These improvements comprised optimisation of the search algorithms for speed and reliability with variable fish behaviour. Such technical limitations will recede as the host computers become faster and the software development programmes become more efficient.

Future developments are expected to integrate the plan and side elevation information to compute the weight and species of the fish passing the counting zone. An installation on the River Gander, Newfoundland was in preparation in 1992 for use in counting fish from side elevation with a counting zone 2.5 m wide and a water depth of approximately 1 m. The results of this project are not known at present, but if successful, the application of the technique will increase considerably (Plate 5). The equipment and software development have been funded by the Department of Fisheries and Oceans, Canada and as such, are not presently available as a commercial item.

Plate 5 A resistivity and optical counting site on the Gander River, Newfoundland, Canada.



Two salmon can be seen ascending the counter, one in the visual counting area to the left of the picture and one in the resistivity counting section to the right. (source Fewings 1992)

Based on the success of silhouette imaging in Canada, investigations were made by Fewings (1993) into alternative methods of silhouette imaging. An effective system was devised that was very simple. The viewing system comprised an ultra-violet (UV) light source, a luminescent background material and a low-light sensitive video camera (Figure 6). Normally image contrast is reduced by particles in the water backscattering light into the camera view and absorption of light by organic compounds dissolved in the water.

If UV illumination is used then backscattered light cannot degrade the image since the camera is not sensitive to it. Background illumination is provided by the luminescent material as it has the property of converting UV into light within the visible spectrum. Emitted light from the background falls within the range of wavelengths to which the camera is sensitive. Light reflected from even shiny objects was not detected by the camera making the objects appear black on the video image. As the majority of the incedent light to the camera is from the background the camera adjusts its sensitivity to make the background very light. For optimum performance visible light intrusion should be limited.

Such systems can be used in conjunction with resistivity counters to improve image quality for validation or may be considered the primary processing of a machine vision system.

Travade (1990) used a video motion detector unit to switch a time-lapse video recorder from a long play (480 hour) mode to a normal play (3 hour) mode when an object was detected moving in a preset direction. Evaluation of these machine edited tapes compared with continuous time-lapse recordings showed that high counting accuracies of 90-100% were possible under favourable conditions. Additionally the analysis system had the ability to discriminate species using shape factors. Images were collected using a side viewing window with illumination by halogen lamps. Highly reflective background made the fish appear in silhouette to enhance contrast. Good results were obtained with channel widths of 0.3 to 1 m, dependent on the turbidity of the water.

An image analysis system is now under development by Larinier (*pers. comm.*) to incorporate a fast digital image processor on a unit to be used within a personal computer host. Target identification, tracking and sizing are achieved within the unit and the processed information is transferred to the host computer for additional processing and archiving. The target rate that images are analysed is 25 images per second to ensure that even the fastest fish past the counting zone are analysed in more than one image. The desired system specification requires that many freshwater and estuarine fish are recognised, although most effort has been directed to the migratory species such as salmon, sea trout, European eel, Sea lamprey (*Petromyzon marinus* L.) and Shad (*Alosa alosa* Lacépéde).

Fish targets are tracked and constituent features of the fish target are combined to construct a composite target image for further analysis. This target tracking allows account to be made of the direction of travel for counting statistics. Shape parameters are extracted from this composite and used in a discriminant analysis process to determine species. Larinier (*pers. comm.*) reports 90%-100% of fish targets are correctly recognised for fish of greater length than 25 cm although the most difficult discrimination is that of salmon from sea trout. Problems are noted in the discrimination of multiple targets that appear to overlap on the image since silhouette images contain little or no texture information.

Reson System A/S of Denmark have developed a fish counting and sizing system based on similar principles to that of the Pippy and Larinier systems called the Sealook 9000 submersible weighing system. Silhouette images were generated with structured lighting in an enclosed sensing zone of approximately 0.3 m^3 through which fish swam. The images were digitised and processed using fast microprocessors and software optimised for speed and resolution (Reson System *pers. comm.*). The system has been designed to be accurate and flexible since it is field programmable and portable. The precision of the unit is claimed by the manufacturers to be within 5% for weight of single fish, 2% for total biomass calculation and counting error is said to be less than 1%. The analysis method is designed for salmon and trout in the size range 0.3 to 8 kg. Since the view of the fish silhouette is restricted to the width of the counting zone (0.3 m) the system must calculate the mass of passing fish from a combination of width and length measurements. To establish the length of an individual fish the speed of passage must be determined from the movement of shape markers past the camera. Mass is calculated using trout and salmon shape relationships.

Reson System claim that two fish may be identified by a length axis separation of just 5 cm. Furthermore, two fish can be simultaneously counted and sized even if they are alongside each other, but one slightly higher than the other to expose one of the fish edges. The weight estimate in this instance is a combined mass although two fish are counted.

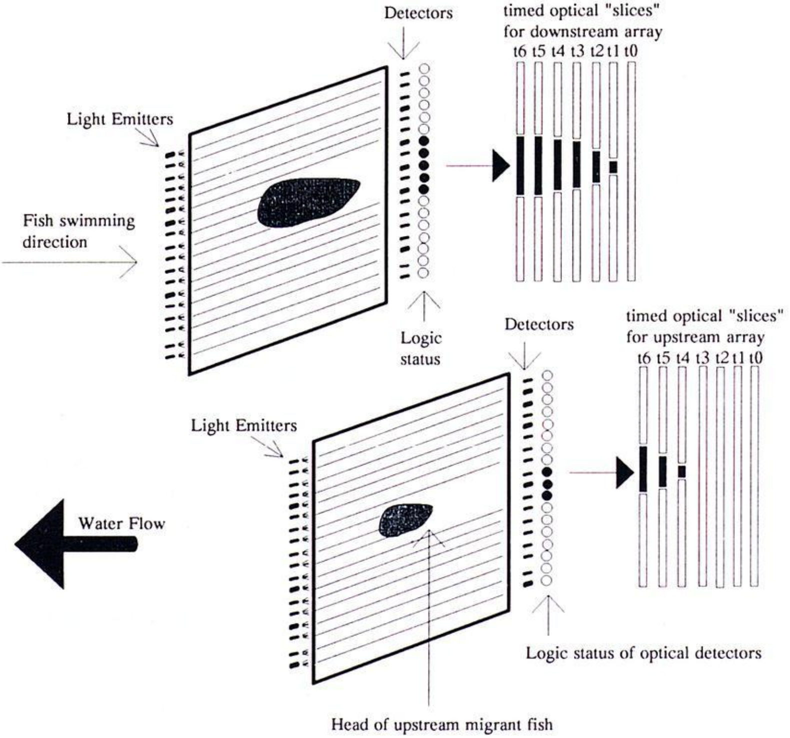
Options with the system include a camera trigger for validation purposes, mounting for fish pass operation and extended software for the control of a grader. This last option was developed for the fish farming industry to allow the grading of fish without removal from water.

Although the system has been used successfully in fish farm situations its overall accuracy will depend upon the turbidity of the water sampled. No figures have been supplied regarding the counting of non-fish objects or turbidity ranges applicable to the device. This system has advanced capabilities compared to other silhouette imaging systems but until such devices can be tested alongside each other then they will be difficult to compare.

2.2.3 Linear sensor array

Two groups, Vaki Aquaculture Systems of Iceland (*pers. comm.*) and Mr Karl Kilvik of Norway (*pers. comm.*) have developed almost identical solutions to machine vision fish counting. A series of light emitting diodes (LED) were arranged in a vertical line at 5 mm centres (Figure 7) on one side of a rectangular cross section channel. A sensitive light detector was arranged opposite each LED at 5mm centres. This arrangement was repeated 100 mm upstream of the first array. Each emitter/detector pair was activated in succession to determine if there was an object between. Since these pairs can be sampled at a high rate, a line of 200 pairs can be sampled in a fraction of a second.

Figure 7 Description of the linear array method of optical fish counting



These two optical arrays are placed one upstream of the other, separated by approximately 100mm.

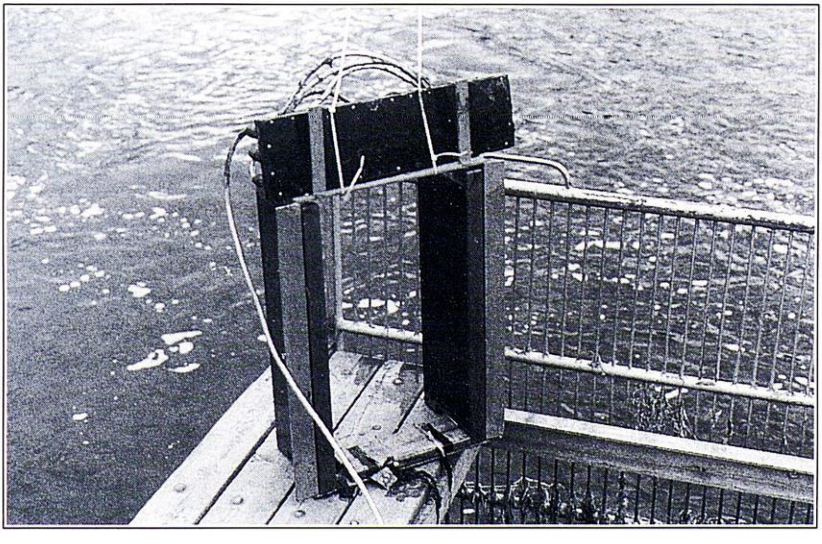
Time delays between corresponding features of the passing objects allow reconstruction of velocity profiles and therefore the spatial separation between adjacent optical "slices" of the object.

Subsequent processing enables the calculation of individual fish length and weight in addition to population biomass and length frequency statistics.

As a fish moves upstream through the counting, area the sensor pairs whose light path is obscured, map out the vertical height of the fish body. To transform this information into the outline of the fish, the rate of fish movement past the array is required. This is obtained by the determination of the time delay between coincident points on the fish as they pass the second upstream array. With this rate data, a complete outline of the fish is calculated. The resolution of fish lengthing is dependent upon the reliability of the algorithm searching for coincident points on the fish. The direction of fish passage may be determined from the order in which the vertical arrays are traversed.

Both of the systems under development use infra-red emitter/detector pairs that transmit coded pulses of light. The transmission of coded signals allows screening of signals to reject extraneous light thus improving the signal to noise ratio. This not only reduces the likelihood of false positive signals but enables transmission of signals through turbid water or over greater range than simple light transmissions. Although the two groups have developed the technique independently, the problem and the technology available have contributed to this convergent development.

Plate 6 Prototype linear array fish counter by Vaki Aquaculture Systems on test in Reykjavik, Iceland



The Norwegian system, the FL60, is smaller than the Vaki system shown in Figure 9 and therefore cannot presently sample as large a volume of water. Data from the FL60 array are transmitted as digital information in serial form to a logic unit that may be tens of metres from the array. The logic unit performs the function of fish recognition, determination of direction, length and swimming height. All of these parameters are recorded along with the time in digital form and are output to either a small display or printer. Power can be supplied by battery which may be recharged using a solar cell or from alternating current power supplies. The device has an endurance of approximately seven weeks from one battery. Installation is a simple matter and can be achieved in under ten minutes.

Under test conditions the counter has shown a minimum accuracy of 93% for counts but this was achieved in less than ideal conditions. Where debris and air bubble entrainment are kept to a minimum, the counting accuracy was increased to 100%. The developer assures that current developments in the fish recognition software will increase the counter's reliability under such unfavourable, but realistic conditions.

The Vaki system has the additional capability to reconstruct fish outlines using a number of coincident points on the fish shape, thus it can cope with variation in fish traversal speed therefore giving a more robust estimate of fish length. Plate 7 describes the outline of a fish reconstructed from a real fish passage in the field. It is possible for the Vaki system to output the actual shapes of passing objects for validation purposes where quality assurance data is required. This device is somewhat larger than the FL60 and can therefore sample more water. At present the information is not available to determine if the size difference between couning units is due to the design ranges of turbidity under which the devices are expected to operate.

Tests on the Vaki counter by the Institute of Freshwater Fisheries on the River Blanda, northern Iceland show a high correlation of manual and automatic counts (Figure 8) (*pers. comm.*). For the data shown the minimum accuracy was 55% but the accuracy of counts over a month was 98.9%. Detailed recording of fish outlines indicated the major sources of error. The manufacturers are confident that modifications to the present system software can remove most of this error. Such statistics must be considered in the context that trapping above the counter under test may influence fish behaviour and increase the number of fish that fall downstream on encountering the trap inscales. This factor may decrease counter accuracy by increasing the number of complex passages of fish past the counter.

Figure 8 Observed accuracy of the Vaki linear array fish counter

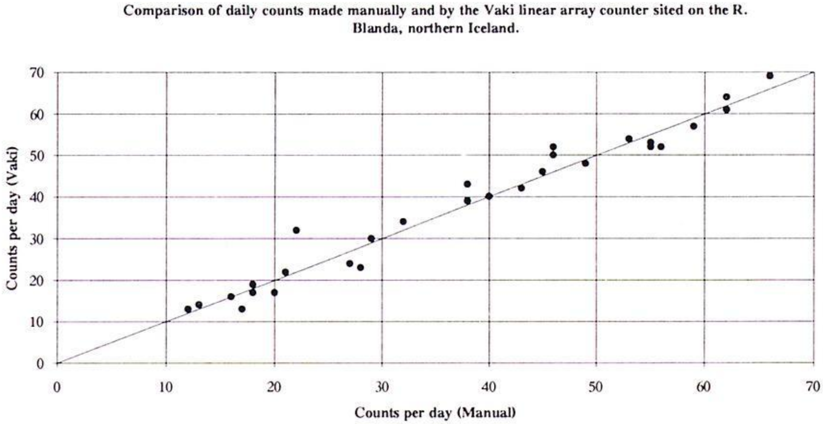
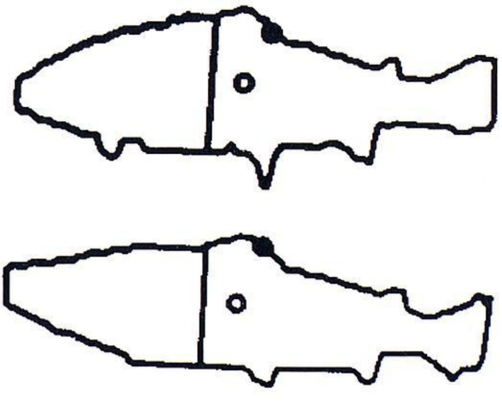


Plate 7 Reconstructed fish outlines from the passage of a fish through the Vaki linear array counter



The two images above are constructed from the upstream and downstream arrays with one set of velocity information. Note the visibility of the adipose fin.

At present both systems only sample opposite emitter/detector pairs, further resolution will be possible in the future by the sampling of non adjacent pairs and three dimensional reconstruction. Some work has been carried out by Vaki to build a dual axis device which can view the fish from plan and side elevation. This development has been found to provide a very good correlation between actual and sensed length and weight of fish.

2.3 Electrical methods

2.3.1 Introduction

Freshwater is an electrical conductor, this property enables electric fields to penetrate the medium and for electric current to flow between points of different electrical potential. Aquatic predators have used this characteristic to locate prey that are otherwise camouflaged or apparently invisible. Some cartilaginous fish have sensor systems that are able to passively detect the minute electric fields generated by nervous and muscular tissue (Kalmijn, A.J. 1982). This natural sensory system has feedback mechanisms to inhibit the sensors when the predator's tissues near the sensors are active (Montgomery, 1984). This is required to prevent swamping of prey signals by the signals generated from surrounding tissues.

Detection ranges are usually short since the field strength of such signals diminish very rapidly as the range increases (Denny, 1990). Sharkey proposed a method in the 1970's for the detection of salmon action potentials as they swam over counting structures. Unfortunately, the electronic sophistication available to filter extraneous noise and admit the desired signal was not sufficient to ensure reliable operation and the method did not win wide acceptance. Modern methods of signal processing are now far superior and so there may be potential in a re-appraisal of this technique. It has found application in the monitoring of river quality and is presently used for measuring the stress reaction of rainbow trout (*Oncorhyncus mykiss* Walbaum) and Bluegill Sunfish (*Lepomis macrochirus* Rafinesque) (Cairns *et al* 1980).

Another method used in nature is that of active electrical detection. The weakly electric fish (*Apteronotus albifrons* L.) generate a high frequency electric field from specialised organs along their bodies. When prey enter the field this presence is sensed by specialised detectors on the body surface. The alteration in the electric field is caused by the prey having a higher electrical conductivity than the water they displace. This ability is very important to these Gymnotiform fish since they live in very turbid rivers where light based vision is of limited use.

Most of the species that use this type of detection system swim backward slowly in order to "scan" resistive objects. Prey is thereby near the mouth when the decision on whether the object is prey or not has been made (Lannoo & Lannoo 1993).

It is uncertain whether the frequency changes observed during prey detection have a data acquisition function or are for communication (Hagedorn 1986). Multiple frequencies may be used to increase the resolution of the detection system but it is also known that the frequency changes are used during courtship for mate attraction.

The platypus (*Ornithorhynchus anatinus*), an Australian nocturnal diving monotreme, also uses an active electrical detection system that enables it to locate prey and avoid objects in the zero visibility habitat in which it lives (Scheich *et al*, 1986). This monotreme has sensors arranged around its bill and is insulated from the water by its air entrained fur coat. Electrical pulses are believed to be produced in the bill and take the form of direct current pulses at low frequency. It appears that using these pulses the animal can detect and avoid rocks underwater, although the full extent of this sense is not known at present.

Many automatic salmon counters have been built on the basis of this type of active method. The first (Lethlean 1953), was built around the resistance bridge principle which offered high sensitivity to resistance change but had the unfortunate inability to distinguish fish moving upstream from volumes of high resistance such as air entrained debris moving downstream.

Currently almost all systems used operate on a similar principle. Three electrodes are mounted across the flow of a channel each separated by approximately 450 mm (Figure 9). An oscillating electrical signal, either a square or sine wave, is applied to the centre electrode. This signal can be arranged to provide a constant current or a constant voltage to the electrode. Ohm's law can then be used to determine the resistance between the centre electrode and the other two electrodes. This law states that the electrical current that flows through a conductor is determined by the voltage difference across the conductor and the resistance of the conductor.

Ohm's Law:

$$V = I \times R \qquad -(5)$$

where

V = voltage difference across conductor

I = current flowing in the conductor

R = resistance of the conductor

or

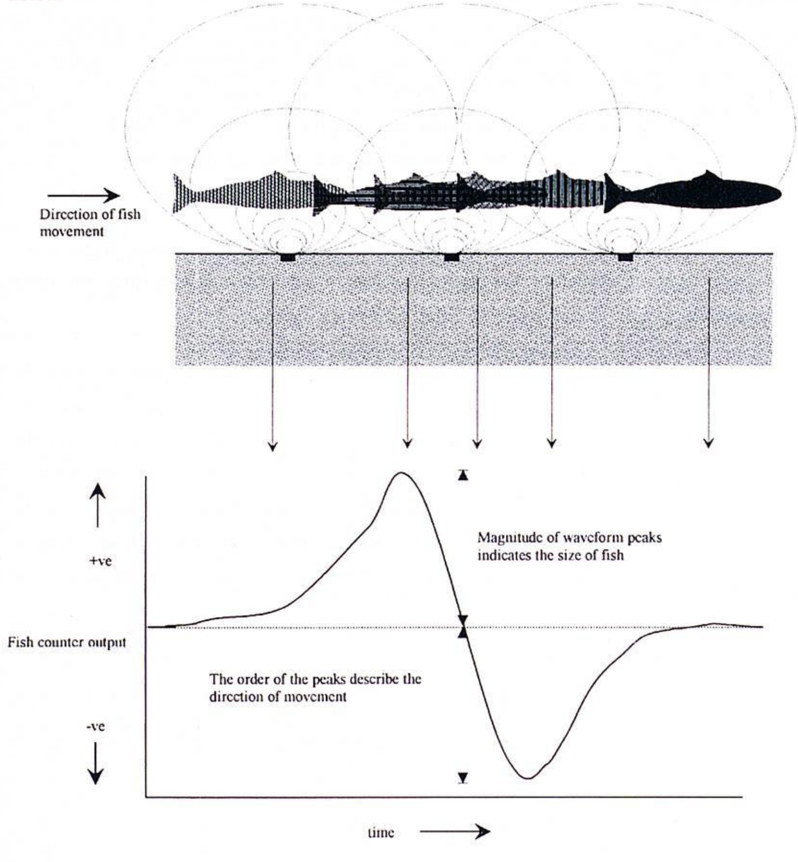
$$R = V / I$$

If a constant voltage is applied to the centre electrode then by measuring the current in the other arms of the array, the resistance between the electrodes can be determined. Similarly if a constant current is applied to the outer two electrodes then the voltage required to drive this current will enable the determination of resistance between the electrodes. By division of the sensing area into two regions it is possible to determine the order in which the regions are traversed and therefore the direction of fish travel.

Fish have a lower electrical resistivity than the water they displace, unlike plastic bags, wood and rafts of weed, and are therefore are distinguishable from other objects that are often carried over weirs.

As a fish swims over a counting weir it forms a low resistivity path in parallel with the background water resistance (Equation 6). Since there is always a serial resistance in addition to this parallel resistance (it is unusual for fish to touch both electrodes simultaneously) the overall change in resistance is necessarily small. This change in resistance is transient and may vary in size by several orders of magnitude especially with fish targets that are longer than the separation of the electrodes. The observed change in resistance for a given size fish is dependent on a number of variables some related to the sensing zone conditions and some related to the behaviour of the fish.

Figure 9 The passage of fish over fish counting electrodes with the resistance change waveform below



The background water resistance determines the resistivity change that occurs when a fish passes by providing an alternate conduction path for the sensing electrical signal. Normally the background resistance is smaller than the fish resistance therefore the absolute change in resistance when a fish is present is not very large.

Parallel resistances combine in the following manner

$$R_{total} = 1/\left((1/R_{Fish}) + (1/R_{Background})\right) \qquad -(6)$$

If the difference between the background resistance and the fish resistance is small ie. short electrodes, low conductivity water with shallow depth, then the presence of a fish resistance provides a relatively large change in the combined resistance. If the background resistance is very small in comparison to the fish resistance ie. long electrodes, high conductivity water of significant depth, then the addition of the fish resistance provides a small change in the combined resistance.

Therefore in a typical case of background resistance 100 ohms and an apparent fish resistance of 2500 ohms the peak signal would be

$$= (R_{Background}) - (1/((1/R_{Fish}) + (1/R_{Background}))) \qquad -(7)$$

$$= 100-(1/((1/2500)+(1/100)))$$

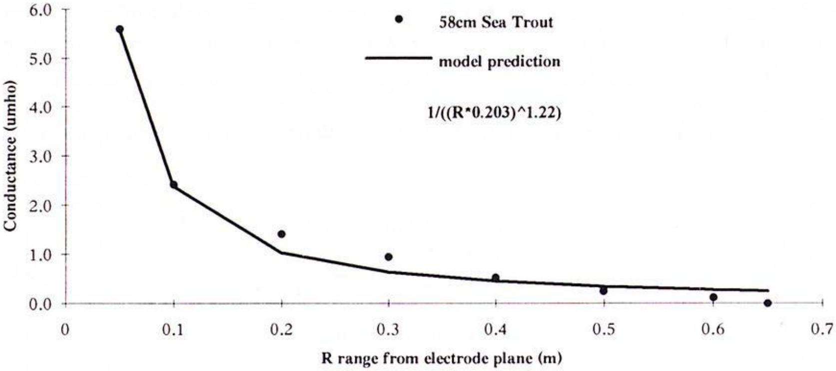
$$= 3.85 \text{ ohms change in resistance or maximum fish signal}$$

If $R_{Background}$ were 20 ohms the change in resistance for a similar fish resistance is calculated as only 0.16 ohms. This demonstrates that this type of counting system must include environmental compensation if reliable long term results are required.

The background resistance can be modified by many factors such as electrode surface area, water depth, water conductivity and electrode separation. Modern resistivity fish counters attempt to compensate for these variations to maintain a near constant response to a standard fish passage at a given range from the counting electrodes.

Whilst modern counters can attempt to compensate for environmental variation in the counting zone it is much more difficult to compensate for variations in fish swimming behaviour. The magnitude of resistance change also depends on the range of the fish to the electrodes for a given size fish. The greater the range the smaller the resistance change with a fish present. This reduction in apparent size is not linear but is reciprocal, where each increase in range of 50 mm can halve the signal produced by the presence of the target. Figure 10 shows the change in conductance due to a centrally placed 58 cm sea trout target at multiple ranges from point electrodes separated by 0.9 m. This experiment was carried out with a freshly killed fish suspended in a large test tank of 400 μS.cm water (Fewings, 1994).

Figure 10 The electrical conductance change caused by a sea trout positioned at increasing range from two point electrodes



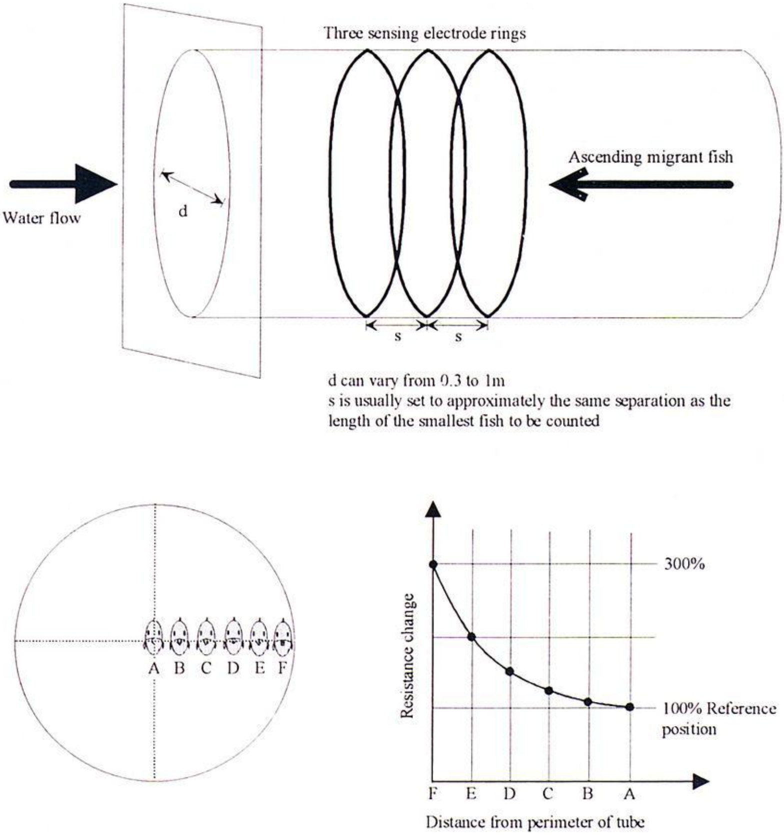
Normally, for reliable counting of fish larger than 50 cm at short range, signal amplification or gain is set which excludes such fish at ranges greater than half the separation of the electrodes or 225 mm. It is possible to set count thresholds and gain to count fish at greater range but this can cause inaccuracies by inclusion of small fish such as young sea trout that pass close to the electrodes. Inclusion of such small fish can dramatically increase the error count since these fish are often present in much higher numbers than the larger target species.

Where adult salmon are the only fish likely to pass the counting station, gain for counting can be set high with little risk of counting undesired species but yields increased detection of salmon at larger range. No methods exist at present to compensate for range to the fish target and therefore methods have been developed to encourage fish to swim close to the electrodes.

These methods exploit the energy saving behaviour patterns of anadromous fish. When challenged with a region of fast flowing water with a distinct velocity profile, fish often swim in the lowest velocity paths (Dunkley and Shearer 1989, Hellawell 1974, Beaumont *et al* 1986). These conditions must be met whilst maintaining a relatively constant water volume over the counting zone. If this water volume is allowed to fluctuate with a similar period to that of a fish passing, it is difficult to remove this resistivity noise from the fish signals (fish signals have a period of 0.5 to 4 seconds and large ripples and waves fall into this noise generating category).

It is possible to create favourable counting conditions using a number of tried and tested techniques. The first method employed was used by Lethlean in 1953 and involves forcing fish to swim through a submerged tube. Three ring electrodes are set in the tube at approximately 450 mm separations as shown in Figure 11. Since the tube is submerged there is no opportunity for the volume of water to change in the tube and a high signal to noise ratio is maintained.

Figure 11 Typical tube type resistivity counting installation



d can vary from 0.3 to 1m
s is usually set to approximately the same separation as the length of the smallest fish to be counted

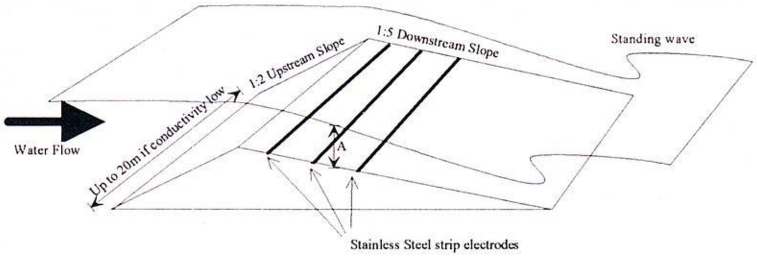
Although the fish travelling through the tube are surrounded by electrodes significant range effects remain. This effect, described by Lethlean, is due to the variation in field density as the distance from the electrodes increases ie. as a fish traverses closer to the central axis of the tube. Lethlean showed that a given size fish longer than the separation of the electrodes that passes through the centre of the tube could give an arbitrary output signal of 100 units. The same length fish that passes very close to the electrodes would then give an output signal of 300 units; clearly range is still important even in tube counting systems. Where laminar flow is presented to the ascending salmon it is thought that most will seek the lower velocity paths. In a tube counter situation the lowest velocities can be found closest to the tube walls which also correspond to the positions of largest signal response.

Relationships have been determined for the correlation of fish body weight and resistivity change (Gosset, *pers. comm.*) when the position of the fish in the tube is known. Unfortunately, this information is rather difficult to collect and therefore is generally unavailable for other models of resistivity change fish counter. If the information was available it could be possible to set confidence limits for the size of each fish passage detected.

The major problem with tube type counting systems remains the potential for blockage and that fish must be guided to the counter or prevented from using alternate routes by fish screens. This usually involves costly maintenance checks and detracts from the advantages of high signal to noise ratio.

An alternative to tube counting uses open crested weirs with the electrodes set into the downstream face of the weir. Figure 12 shows a standard arrangement for this type of weir and includes design considerations for installation of new weirs. Advantages with this method include its immunity to blockage and the visibility of the objects that swim or float past. Disadvantages include increased problems of environmental compensation due to variable water depth, low signal to noise ratios, low sensitivity on wide weirs and construction problems.

Figure 12 Crump type fish counting weir with resistivity counter electrodes incorporated



Open Channel Fish Counting Weir Design Considerations

1 Water depth at point A should not be less than half the electrode separation.
2 Approach slope should not be truncated to less than twice the electrode separation from the downstream electrode.
3 Care should be taken on the design of the weir crest height to ensure the downstream standing wave cannot encroach on the electrode area. Normally at least 0.5m head loss is required for such installations. It is also important to ensure realistic water velocities for the passage of smaller migratory fish such as sea trout and Dace (Leuciscus leuciscus L.). Water velocities of 2-2.5m/sec appear satisfactory.
4 The substrate for the electrodes and the side walls of the counting section should be made of a good insulator. Concrete, epoxy concrete and some plastics have been found to become poor insulators after prolonged immersion in freshwater. Low water uptake plastics, resin impregnated plywood and Glass Reinforced Plastic appear to have good long term characteristics for fish counting applications.
5 Algal fouling can be prevented on small weirs with installation of light excluding covers, this also aids photographic checks of counting performance by restricting the dynamic range of light intensity.

The Crump gauging weir (Crump, 1952) is the most commonly used type of weir for open channel fish counting. It is triangular in cross section with an upstream face of slope 2:1 and downstream slope of 5:1. It is particularly suitable for this purpose due to the laminar flow conditions and range of velocities that can be achieved.

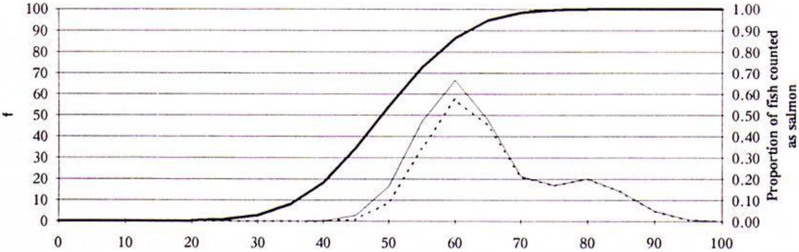
Low signal to noise ratios are due to the open nature of weirs which make them susceptible to wind induced waves over the counting zone and entrainment of bubbles due to the proximity of channel partitions and other obstructions. Signal to noise ratio is also highly dependent on the depth of water over the electrode set. Successful designs of this type of weir ensure that a minimal depth of half the separation of the electrodes is maintained (225 mm). It is also desirable that the water depth does not exceed the separation of the electrodes for more than a modest proportion of the year as unnecessary water depth provides more opportunity for fish to ascend the weir at significant ranges from the electrodes.

Approach slopes should not be truncated since ascending fish may not have sufficient distance to align near the bottom of the water column before entering the electrode array. This may lead to fish ascending the weir at markedly different heights in the water column for each of the two halves of the electrode array. This will reduce the symmetry of the processed fish passage waveform. If the amplitudes of the upstream and downstream portions of the waveform are too dissimilar the counting logic may not be satisfied and the count may not be made.

Fewings (1987) quotes 95% confidence limits for length estimation of ascending salmon at two open channel counting sites using two resistivity fish counters. These estimates vary from ± 8 cm to ± 21 cm and appear to depend on water depth. Aprahamian *et al,* (1993) also suggests lengthing accuracies of ± 20 cm are normal over significant changes in background resistance. Greater water depth tends to provide poorer lengthing accuracy possibly as there is the opportunity for more variability in fish swimming depth. More recent evaluations by Aprahamian (*pers. comm.*) suggests the extra variation is due to changed field shape and alternate fish behaviour.

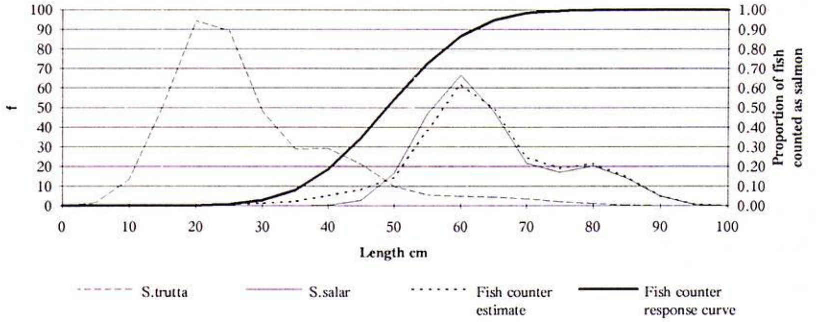
These lengthing limitations are obviously a major cause of inaccuracy if migratory fish are present that have lengths within the error bands of the species that are desired to be counted. For example, if a counting system is established to count salmon on a river that has no significant population of sea trout and almost all of the salmon are ≥55 cm, then thresholds can be set low and very good counting accuracy can be achieved (Figure 13). In the example given the thresholds are set with the 50% count at 49 cm. There is some undercount of the smaller fish leading to an overall undercount of 13 % for salmon.

Figure 13 Simulation of counting performance with a single population of Salmon size fish (counter lengthing accuracy ± 20 cm [α0.05])



If however there is a significant sea trout population with a year class of median length 35 cm and larger then some of these trout may be counted as salmon. If the threshold were set centrally between the two species year classes then some salmon will not be counted. Of course one error will partially offset, the other but the true accuracy of the counter must take each of these error types into account to show how the counter has really performed. The threshold used is the best compromise for uncertain presence of sea trout. As stated in the above conditions, with no sea trout present, the salmon count is 13% less than the real figure. If the conditions below prevailed then the error would be 3% overcount. With some experience of a given counting site, thresholds can be set to minimise the errors induced by poor length discrimination and the presence of species not required in the count.

Figure 14 Simulation of counting performance with a dual population of Salmon and Sea Trout size fish (counter lengthing accuracy ± 20 cm [α 0.05])



2.3.2 Logie fish counter

The Logie fish counter has been evaluated and refined for several years by collaboration between the manufacturers, Aquantic of Dingwall, Scotland, and many scientific users in Europe and North America.

This counter is significantly different from previous fish counters since it incorporates a number of features which are designed to decrease the inaccuracies caused by changes in the conductivity and quantity of water over the electrodes. The most significant features of the counter are the environmental compensation techniques employed, the relatively sophisticated fish discrimination algorithm and the data archiving of a size index for the fish detected.

Environmental compensation is achieved by a combination of techniques. The background water resistance is determined by automatic insertion of a known test resistance with automatic gain adjustment to give a constant response. This test procedure is carried out every 30 minutes. Water conductivity is measured with an external probe and the length of the electrodes is input at the system keypad. With this combination of measured and manually input information, the Logie constructs internal lookup tables for signal gain adjustment. Testing (Aprahamian *et al*, 1993), has shown that much of the variation in performance due to environmental fluctuations are compensated for with this system.

The fish discrimination algorithm is one of the most important features of the Logie fish counter and has proven to be robust in its application to distinguish fish and non-fish passage events. It was known from earlier experience of fish counters by the Scottish Office Agriculture and Fisheries Department (SOAFD), who co-developed the Logie counter, that wind induced ripples, ice and various items of river borne debris could seriously degrade counter performance by causing false counts. The Logie counter applies rather more discriminant rules to the event waveforms than previous resistivity fish counters. Most counters have preset thresholds for each of the upstream and downstream pairs of electrodes. A count would normally be given if both thresholds are met or exceeded within a given time period of approximately three seconds. The sequence of threshold attainment indicating the direction of travel. In the Logie counter additional rules are applied to the waveform requiring both waveform peaks to be broadly similar in size and significantly larger than the noise in the sample.

This approach has worked well at most sites but care must be taken when this method is used at sites with a rectangular cross section, since some fish were not counted because of dissimilar peak estimates in the upstream and downstream sections (Plate 5). Dissimilar waveform peaks can be caused by fish ascending or descending in the water column during passage over the counting electrodes. Modifications have been made to the fish discrimination algorithm that relax this criterion. As a result this problem has been solved but it illustrates the importance of optimum site conditions. It is unlikely that such sites will be able to achieve as high count accuracies as purpose built sites that minimise behavioural variation of passing salmon.

Another feature of the Logie counter that distinguishes it from the other resistivity counters is the storage of event time and a size index estimate for the event. Events that satisfy the count criteria are given a size estimate based on the amplitude of the largest waveform peak observed. These sizes are values from 0 to 127, the larger the value, the larger the size estimate for the fish. Comparison of observed fish length and fish counter size estimates by North West Region NRA has yielded relationships between the size index and the real length of the migrant salmon (Aprahamian *et al*, 1993).

Additional testing of the counter by Aprahamian *et al* (*pers. comm.*) has determined the lengthing capabilities of the system and established increased lengthing error with increased water depth. It is postulated that this may be due to increased opportunity for fish to swim far from the electrodes and from altered electric field shape during high water conditions.

The 'Logie' fish counter may can be operated from a battery power supply and controlled remotely using a personal computer, modem and a telephone link.

2.3.3 MkX Fish counter

The MkX fish counter from Scottish Hydro-Electric was first available in 1987 and has since been refined by continuous development and extensive field testing. This resistivity based fish counter was primarily developed for use in Scottish rivers to monitor the passage of salmon past barriers imposed by hydro-electric schemes. To this end it was optimised for use in smaller channels, with low conductivity water and low power consumption for remote use. Many of the counting sites were positioned at the upstream exit of Borland fish lifts where fish exit is highly sporadic and therefore the maximum counting rate was important.

The Mk X design had to achieve count accuracies of 80% or better to meet the specification set by the Government's Fisheries Committee for its monitoring role in Scottish hydro-electric schemes. Johnson and Clarke (1987) report that this specification has been met at various sites in Scotland. The counter is microprocessor based and is designed to be flexible in use. Core plug-in modules can be augmented by ancillary modules for tasks such as data logging, external switching of cameras or data recorders and output of analogue resistivity change data. Internal batteries provide enough power for three days of stand alone operation but provision is made for extended operation from external batteries. Few controls are available on the unit as gain is set by digital push button settings. Recent versions have 32 gain settings which can be tested *in-situ* by momentarily switching in preset resistances.

Resistance measurement is made in an unusual manner that has some advantages over other methods. In the standard three electrode configuration the centre electrode is excited with a constant voltage waveform whilst the current in each of the other electrode circuits is measured. This arrangement allows direct determination of the type of change in resistance of each section in the counting zone, ie. it is explicitly known if a resistance change is due to a high or low conductivity object. Measurement techniques based on the bridge principle of resistance measurement could not directly determine if a change in resistance was due to a high resistivity volume in one section or a low resistivity volume in the other section.

This counter can be configured to use five electrodes instead of the more usual three. The purpose of the alternate configuration is to improve fish size estimation by provision of two size groups in both the upstream and downstream sections. This is possible since the resistance change detected is relatively large when an object spans two of the electrodes. For example, if a fish is large enough to span both pairs of electrodes in one section then large signals will be detected on both pairs. If a fish can only span one and a half electrode pairs then a large signal will only be detected on the pair of electrodes with the small separation. This feature is most useful for categorisation of large and small fish such as small sea trout and salmon.

2.3.4 Fron fish counter

The Fron counter has been developed by collaboration between the Institut National de la Researche Agronomique, Centre National du Mechanisme Agricole, du Genie Rural, des Eaux et des Forets and Establissment Fron of France (CEMAGREF). It uses the standard three electrode configuration to detect the resistance change when fish swim over the electrodes. The counter automatically compensates for changes in resistance between the two pairs of electrodes but does not directly test the water conductivity or the water depth. It was initially designed for use in counting tubes but has been successfully used on open channel weirs in France. Sensitivity is set manually and test resistors can be switched into place to check counter sensitivity whilst attached to the counting electrodes. Evaluations on the Eaulne and Nivelle rivers show high correlation of counted salmon with either trapped numbers or salmon viewed on video records (Gosset, *pers. comm.*).

The team evaluating and developing the counter have shown that there is a high correlation of detected resistance change with *weight* of fish if the position of the fish is compensated for. Work is also being undertaken to estimate the body resistivity of various species using laboratory experiments.

2.3.5 Multi electrode fish counter

A radically different approach to fish counting and sizing has been proposed by Shaw of the NRA North West Region. Under development is a sophisticated multi-electrode impedance detection system that is intended not only to detect but accurately size the fish swimming over the electrode array. Although in the early stages of development, tests indicate that this is a very promising line of development.

In essence, thin strip electrodes are fixed across the face of a suitable weir in a similar fashion to the present counters but with up to 100 electrodes rather than the three currently used. These electrodes will be much thinner than existing types and will be separated by approximately 10 mm of insulator.

Resistance measurements will be made using an alternating polarity square wave of approximately 0.1 mS duration. Such a known voltage pulse will be applied to a designated electrode and the current flowing through the water to another designated electrode will be measured. With this information the resistance between the electrodes of interest may be determined.

Since there is a large number of electrodes in the array these may be scanned at a high rate to determine which exhibit background impedance and which exhibit a lower impedance indicative of fish presence. Conductive targets, such as fish, that are near to the electrode plane will cause a large change in resistance measured between electrodes immediately below the target. Electrodes pairs with significant distances between either electrode and the nearest part of target indicate a poor match to fish position with only minor reduction in resistance. This methodology could therefore yield significantly enhanced count quality and size information compared to existing types of resistance change fish counter. This scanning multi electrode principle is similar to the natural active electric senses described by Lannoo & Lannoo (1993) in the weakly electric fish (*Apteronotus albifrons L.*). It appears that prey are scanned by the predator swimming backwards past the prey. This ensures that the mouth is near the prey after the "scan" for ingestion if the prey is of suitable size.

Compensation for changes in water depth and conductivity will be made by varying the magnitude of excitation pulse or varying the threshold level for fish detected status. With knowledge of the spatial position of these electrodes, the water conductivity and the water depth, it should be possible to obtain good estimates of the longitudinal position and also the length of the fish. Only the electrode drive and thresholding are achieved with analogue electronic methods. Target position and length is determined using an iterative digital process where each pair of electrodes tested yields either a presence or absence of target result. This contrasts with present resistance change fish counters which interpret the magnitude of resistance change to determine length and the phase of the resultant waveform to estimate longitudinal position.

It should be possible to retro-fit the electrode array required to suitable structures and the cost of the electronics should be comparatively low. Such a system will, however, require siting on the type of structure found to be necessary for existing impedance counting techniques due to the restricted depth range over which it can operate. Fish are required to swim within approximately 200 mm of the weir surface in order to be detected and sized. With correct siting it appears that is achievable in most cases due to the energy saving behaviour of migratory salmonids already described.

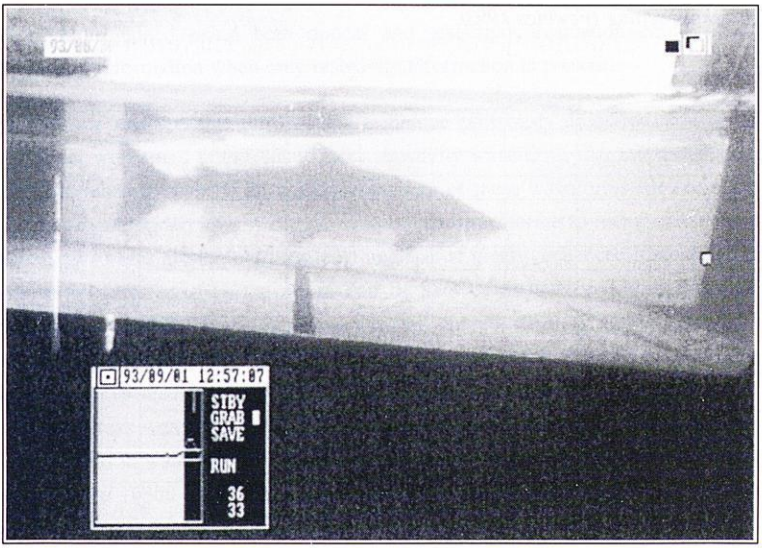
The major benefits of the system are that it will be self calibrating and should display good lengthing accuracy within the parameters described.

2.3.6 Retrospective thresholding

Each of these counters previously discussed are designed to do the task of fish discrimination *in-situ* and store the number of fish in each size class. This method has its drawbacks, the main one being the inability to review the data on each event based on subsequent knowledge. Methods are available to record in digital form the target waveforms from existing resistance change fish counters and to review them in the office (Beaumont *et al*, 1986, Aquantic proprietary software) but counts were given by the counter on-site and verified by human interpreter.

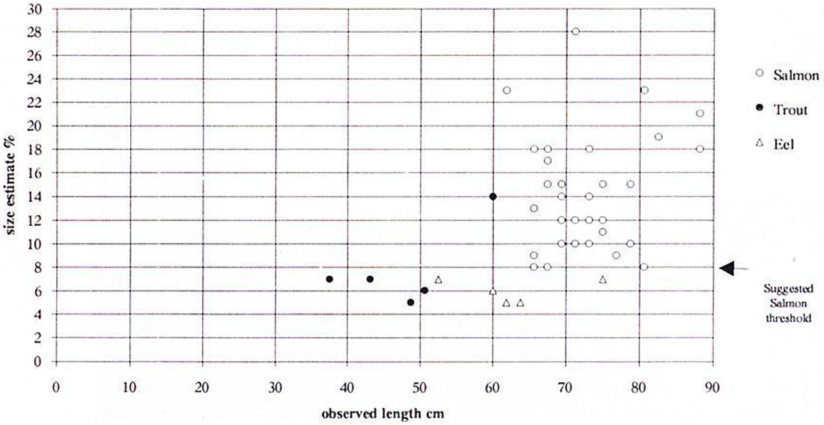
To simplify this process a system was developed by Fewings (1992) to record the fish resistivity traces as they occurred and to subsequently evaluate them on an office based computer using custom analysis software. It is this office based software that actually carries out the task of fish discrimination, counting and sizing. Thresholds on the recording system for the storage of an event are set very small to ensure that even the smallest fish events are recorded. Using this method more powerful processing can be employed, documentation and reporting of each event can be accomplished routinely and retrospective thresholds can be set for discrimination of salmon and non-salmon events.

Plate 8 Video print of a Salmon ascending a resistivity counting weir on the River Itchen in Southern England (Fewings 1993)



It is the latter capability of retrospective thresholding that is most significant. Video still prints such as that shown in Plate 8 can be used to sample the waveform sizes ascribed to particular species and sizes of fish. Using this information thresholds can be retrospectively set to give optimum discrimination between the fish size groups required. An example of such a data set is displayed in Figure 15. Validation of the system has determined an overall accuracy of over 88% for salmon and 100% for fish of salmon size ie. large sea trout and salmon although this is dependent on the size classes of alternate species present.

Figure 15 Scatter plot of fish size and species against resistivity change size estimate for retrospective threshold setting (Fewings 1993)



2.3.7 Combined sensor fish counting

Optical counting methods have the advantage of high spatial resolution but are confined to use in low turbidity circumstances. Resistivity counting methods can operate under much wider circumstances and have very good detection capabilities but lack the sizing resolution of optical methods. Video has been used for years to verify counts made by resistivity fish counters. It is now possible to combine these two approaches to enhance the overall quality and reliability of the detection system.

Such systems should be applicable to weirs of similar type to that used for resistance change fish counting but, initally, of widths up to approximately 3 m. It is intended that resistance change information is always recorded, but that under favourable viewing conditions, additional optical information is included automatically.

With effective data compression techniques it is possible to reduce the data storage requirement for one fish event to only a few hundred bytes. Such data could then be expanded and evaluated at a later date without the requirement for high speed on site computation.

Therefore documentation of each event could not only include the evaluation of the resistivity information but also display a picture of the counting area leading to optically based sizing. Information gained using both optical and resistivity evaluation could then be used as calibration information when only resistivity information is present.

As with the retrospective thresholding technique previously described, digital data recorders can be set with small thresholds to store resistivity waveforms that are much smaller than that normally made by fish. With real time analysis of these waveforms for critical points in fish passage, digital video images can be triggered and transferred to memory. Since relatively low resolution images are required for lengthing fish at greatly enhanced resolution, the amount of data to be transferred in the image can be kept as images of 320 x 270 x 256 levels of greyscale or 86400 bytes. Reductions in the amount of data storage can be achieved by selection of an appropriate greyscale threshold to distinguish black from white. The image can then be represented by 1 bit per pixel instead of the 8 required for 256 levels of grey. If reference areas were included in the counting area then the threshold can be adaptive to cope with changes in water depth and turbidity. Such data reduction reduces the storage requirement per image to 10800 bytes. Images represented in this manner can be further compressed using run length coding techniques. After run length coding images are typically reduced to approximately 400 bytes, an overall compression ratio of 216:1. Not all information of the original image is retained but such images can yield lengthing accuracies of better than ± 5 cm at the 95% confidence limit, a significant improvement on the lengthing accuracy of the resistivity method alone.

By using hardware designed for use in the ubiquitous personal computer, the technique will become faster by updating host processors as mainstream developments in processor speed become available. Decisions on the species and sizing of fish will not be required on site as the compressed data can be evaluated in the laboratory. Counting fish by image analysis alone is a difficult task because of the data processing speeds required and the large amount of optically opaque material that flows within rivers. Inclusion of the resistivity data reduces the volume of data processing required and increases the discriminant capabilities of the technique (Fewings, 1993).

The techniques required to achieve this are currently under investigation (Fewings, 1993). Once fully investigated they will be incorporated into the fish counting systems operated on the Rivers Test and Itchen in Southern England.

3 Future developments

Many of the techniques previously described have components that rely, in part, on processing by the personal computer. There is good reason for this dependence since there is significant commercial drive to enhance personal computer performance through advances in hardware and software. Hardware advances have particular relevance to computation intensive techniques such as silhouette imaging and hydroacoustics where high data processing rates are required.

In the silhouette imaging field a major limitation to performance is the data transfer rate achievable through the standard interface of the personal computer. Through the advent of multimedia, computer manufacturers have developed new interfaces such as peripheral component interconnect (PCI) that should be able to achieve the high data transfer rates required. The existing standard interface can transfer data at approximately 1 megabyte per second, the new standard is specified to transfer data at approximately 100 times this rate. Further generations of central processing units in these computers should enable both resolution and speed enhancements.

It is routine in hydroacoustics to collect partially processed data, store it on some non volatile medium and post-process it at some later date. To date this storage has been accomplished with media such as digital audio tape (DAT) and rewritable optical disc. As new generations of data storage media become available it will be possible to collect more data but process it off river under supervision.

Butterworth (1993) suggests that it may be possible to digitise acoustic receptions at the transducer and therefore receive data at the processing site without the noise and degradation that long cables from the transducer to the echo processor can introduce. Another area that is under intense development is that of the hydroacoustic interpretation software. Significant improvements are likely in software capabilities to determine target aspect ratio by improved target tracking and therefore enhance target strength estimates. Whilst it is unlikely that field data gathering will become much less labour intensive, the data processing component both on, and off, site is likely to become more automated and therefore more cost effective.

Optical linear array counters are likely to be improved by a number of developments. Their application will be enhanced by an increase in the transmission range of the emitter detector pairs. This increase in performance could also allow operation in a greater range of water turbidities. Transmission range can be increased with higher output power emitters and higher sensitivity detectors. These hardware developments come from progression in solid state physics and electronic engineering.

Greater information regarding the shape of objects could be obtained from the sampling of non opposite emitters and detectors. With three dimensional reconstruction techniques much better weight estimates may be achievable, perhaps leading to high reliability of species identification and even virtual images of the objects passing through the sensor units.

Some optical counter manufacturers are now incorporating passive integrated transponder (PIT) tag detector units to increase the applications of their products. This can allow concurrent monitoring of populations of fish and non invasive long term monitoring of the size and condition of individual fish. PIT tags are now small enough to be inserted into large smolts trapped on emigration from freshwater (Prentice *et al,* 1987). Routine monitoring for these tags could yield higher resolution in-river information than that possible at present from microtag studies since each tag has a unique identification number instead of the batch numbers used for microtags. Incorporation into counting programmes can therefore reduce overall costs and provide stock size estimates as benchmarks.

Silhouette imaging techniques are likely to benefit from further developments in the field of data compression algorithms. Numerous standards and techniques are emerging for compression of the vast amounts of data generated in image processing approaches to fish counting. It is not uncommon for optimised data compression algorithms to reduce the storage capacity required for a digital image by more than 100 times without perceptible loss of picture quality. As it becomes possible to record and archive more optical data from detected fish events additional post processing will be possible. Thus re-evaluation of archived data could be carried out later in the course of an investigation with obvious potential for improved accuracy of evaluations.

High image evaluation rates due to the hardware developments outlined could also allow target tracking capabilities for machine vision fish counters. Alternatively, recognition and evaluation programs could be augmented by output from dedicated sub-processors that signal the presence of fish like tracks. Such separate modules are available as stand alone units or could be constructed on sub-processor cards such as described by Lubinski *et al*, (1977).

High spatial resolution images of detected targets could allow greater accuracy in species determination. A number of groups have worked on image analysis techniques for species discrimination (Strachen, 1993) and some work has even been carried out on stock discrimination of using image analysis (Metruzals, INRA, France, *pers. comm.*). It is possible that far more information on each fish passage may be available in the future.

Fast digital signal processing techniques are now able to discriminate specific signals from data that contains a great deal of noise. These capabilities were not available when passive electrical detection techniques were first tried in the 1970's. Whilst passive detection is likely to have very good fish discrimination potential, its ability to size fish would be limited since activity information would be required in addition to the range of the fish from the electrode set. The technique may however prove a good sensor for combination with other sensor types.

By modelling the series and parallel resistances considered important in the measurement of resistance as fish pass over resistivity counter electrodes, it should be possible to predict the theoretical response of a standard fish target under varied conditions of water conductivity and background water resistance. Once such a relationship is available, it should be possible to incorporate this information into an environmental compensation scheme to minimise environmental influence of counting performance.

The Multi-Electrode Resistivity fish counter is expected to increase lengthing accuracy of fish on purpose built weirs and therefore is likely to provide better weight estimation data than presently available from the other active electrical detection methods. This development should also lead to an improvement in species discrimination on a size basis.

The makers of the Logie resistivity fish counter have plans to build a new generation of fish counter still based on the resistivity change principle but thought to incorporate many more electrodes to improve fish lengthing capabilities. Further information is not available due to commercial considerations.

Electrical impedance tomography (EIT) techniques currently under development both in the medical and geological field may have application in fish counting (Webster, 1990). The basic technique involves the placement of a large number of electrodes around a conductive body. Alternating current is injected via one pair of electrodes and voltage measured on all of the other pairs of electrodes. This process is then repeated using another pair of electrodes for current injection. Powerful reconstruction algorithms then process the data to estimate the impedance distribution that could have caused the observed potential distribution. If such a system were constructed around the circumference of a fish counting tube and repeated slightly upstream of the first array, it may be possible to image cross-sections of fish as they swim through the tube. The length of the fish could be estimated using similar velocity construction method to that of linear array fish counting. This system could exhibit high fish discrimination capabilities and may yield information on biological condition such as fat content etc. as is possible with EIT used in medicine.

4 Conclusions

The pressing need for ever more accurate stock assessment information due to perceived pressures on resources has driven the development of pre-existing and new fish counters. Each of the major methods has significantly benefitted from the rapid progression of computer technologies both for data gathering and for the processing of collected data. Resolution and accuracy of the counting systems varies widely and are roughly dependent on the volume of water that must be searched for fish targets.

The selection of a fish counting system must take into account the capabilities of the system relative to the aims and objectives of the counting programme. A lower accuracy of counting is tolerable if the timing of migratory behaviour is required, as opposed to a requirement for the absolute number of fish counted in a given period. Most automatic fish counting systems are designed for fish counting, not salmon counting, therefore the accuracy of resultant data may depend on the presence of other fish species of similar size to the target species.

This review has emphasised the importance of site selection for a given counting system. Great care must be taken in this respect as whichever method is chosen, site selection and detailed application of the method will largely dictate data quality.

On large rivers where there are no fish crowding, or weir structures, only acoustic counting systems can realistically provide count estimates. The accuracy of these counts depends largely on the siting of the counting area and correct interpretation of target aspect ratios since these factors dictate the volume searched and the acoustic "size" of fish targets respectively. Species discrimination is only possible on a size basis therefore large trout could provide a significant error to stock estimates. Most acoustic counting stations are temporary and are only operated during the most active migration periods due to the high manpower costs of equipment operation and the need for frequent calibrations. A general level of accuracy of total counts is thought to be better than 70% where trapping and checks with live fish have been carried out.

Medium sized rivers with weirs can be suitable for counting using resistivity change based fish counters. Counting weirs of up to 17 m width have been operated with high correlation rates between observed and counted fish targets. Multiples of these counting weirs can be used to span a river but sensitivity of detection is reduced as weir width is increased. Fish sizing capabilities are poor due to the dependence of target strength on range. Environmental influences on fish counter sensitivity have been reduced by recent changes in fish counter design enabling count accuracies of >90% to be achieved on suitable weir designs for fish of salmon size. Species discrimination is based on size estimates and therefore large trout can again introduce significant errors. Although installation costs are generally high due to the cost of weir construction, manpower and maintenance costs are low, enabling continuous year round monitoring. Routine calibration checks using visual recording methods are recommended.

Linear array optical fish counters represent a new class of fish counter that enables high resolution and accuracy of fish detection and recording but with a reduced volume of water sampled. Installation is relatively simple and operation can be continuous, limited only by the turbidity of the water and the susceptibility of the site to obstruction by debris. Species discrimination is not presently built into the counting system software but the system is capable of storing digital fish shape outlines with a resolution of 5 mm. This information could be viewed by human operator for species identification or discriminant analysis methods could be used by computer. This type of counter is particularly suitable for operation in fish passes and is not limited to freshwater use, it could also be used on tidal barrage fish passes.

Machine vision optical fish counters are in use in a number of configurations with differing capabilities. The simplest form is a motion detector connected to a time lapse video recorder programmed to record short sequences of video on detection of a moving object in the field of view. An operator or computer can then inspect the machine edited sequences. Such methods allow species discrimination when fish targets are viewed in side aspect and can provide mark and "virtual" recapture data when external visual markers are used such as adipose removal. The only commercially available machine vision fish counter (Reson System counter) has a restricted size orifice for fish entry but such orifices (0.25m x 0.3m of the Pippy system) have proven adequate for use in rivers of Newfoundland. Performance claims for this fish counter are for higher accuracy and resolution than other counters. A machine vision fish counter under development in France has been designed and tested for fish pass and barrage use with the ability to discriminate over ten fish species, track and count multiple simultaneous targets. This fish counter is not yet commercially available.

The strengths of some techniques have been found to be complementary, enabling overall enhanced system performance. A combination of resistivity detection with visual sizing and species identification has been tested *in situ* with success (Fewings, 1992). Such combinations of sensors can increase fish/non-fish discrimination of overhead optical viewing methods and allows continued counting at lower resolution during high turbidity conditions. View widths of up to 3 m have been tested with overhead viewing and distances of 0.8 m in side view. Systems are in development to combine automated image processing with the combined sensor recording system, these should provide a reliable long term means for stock assessment in salmon rivers of suitable size with suitable weir structures in place.

The relative merits of the available fish counting systems are summarised in Figure 16 below.

Figure 16 Comparison of some key features of automatic fish counters

	Acoustic Counter	Video Counter	Optical Linear Array Counter	Resistivity Counter (3 electrode)	Multi-Electrode Resistivity Counter	Combined Sensor Counter
Max Width Of Channel (m)	200	0.5	0.5	20	3	3
Min Width Of Channel (m)	5	0.3	0.3	< 1	< 1*	< 1
Max Depth Of Channel (m)	20**	0.5	0.5	0.5	0.5*	0.5
Min Depth Of Channel (m)	1**	0.3	0.3	0.3	0.3*	0.3
Relative Fish Sizing Capability	●●●••	●●●●●	●●●●●	●●•••	●●●●•	●●●●●
Relative Cost Of Equipment	●●●●●	●●●••	●●●••	●••••	●●•••	●●•••
Sensitivity To Water Turbidity	•••••	●●●●●	●●●●•	•••••	•••••	●●•••
Sensitivity To Entrained Air	●●●●●	●●●••	●●●●•	●●●●•	●●●●•	●●●●•
Species Discrimination	●●•••	●●●●•	●●●••	●●•••	●●•••	●●●••

Key

*	Predicted Estimate
**	Dependent On Transducer Used
●●●●●	High Relative Score
•••••	Low Relative Score

Automatic fish counting will become an increasingly important tool in migratory fish biology and fishery management. The reliability and resolution of data is likely to increase progressively for the foreseeable future due to continued development and availability of ever increasing computing power at low cost. Greater availability of high quality stock assessment data is likely to help drive the development of population models to raise our understanding of salmonid population dynamics and thus aid stock management. It remains to be seen whether the availability of this stock assessment data will enable effective long term management of Atlantic salmon resources.

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6 Glossary

Absorption	The loss of energy that occurs when energy passes through a medium and interacts with it. Example: Loss of light intensity as light travels through pigmented water.
Accuracy	The smallest unit of a measurement that can be repeatedly established or correctness.
Anadromous	The collective term given to the fish that spawn in freshwater and mature in the sea.
Backscattering	The reflection of energy from an object at many angles. Example: sound reflection from a fish swimbladder.
Borland fish lift	A method of allowing upstream or downstream migrating fish to pass a dam or obstruction using a large tube that is continuously filled from the top and periodically blocked at the bottom to allow fish to rise or descend in the tube.
Biomass	The mass of a given biological material.
CCD	Charge coupled device, usually a description of a type of modern video camera that can be robust, small and cheap.
Conductance	A measurement describing the ability of a given object to conduct electric current. (mho). The inverse of resistance.
Conductivity	A measurement describing the ability of a given material to conduct electric current. The inverse of resistivity.
Density	The mass of an object divided by its volume. Units: Kg/m^3
Digitise	The description of a continuous signal using whole number values.
Digitiser	An electronic device that converts an analogue or continuous signal into a digital signal. Example: video digitiser converts an electrical waveform of the video signal into a picture of discrete points whose coulour or darkness is represented by a number.
Discriminant analysis	A statistical method for identification of species or items using multiple criteria.
EIT	Electrical Impedance Tomography; A medical technique for imaging layered parts of the body by detection of differing regions of electrical impedance.
Entrainment	To transport one substance within another eg. air bubbles in moving water.
Feedback	The sampling of an output to modify an input.
Greyscale	The representation of light intensity from light to dark using whole numbers.

Impedance	The opposition offered to an alternating electric current by resistance, inductance or capacitance.
Laminar	Ordered thin layers. In water flow means non turbulent.
LED	Light Emitting Diode, a solid state electronic device that emits light when supplied with electric current.
Lookup table	A table of values used to translate data. Often used for image analysis.
Monotreme	A member of the lowest order of mammals Monotremata having only one opening for the genitals and digestive tract.
Microprocessor	An integrated circuit on a silicon chip, a number of these may combine to form the central processing unit of a computer.
mS	The unit of time millisecond, one thousandth of one second.
Programmable	Possesses the ability to store and execute a sequence of instructions.
Resistance	Opposition offered by a circuit to passage of current through it. Unit (ohm). The inverse of conductance.
Resistivity	The opposition offered by a material to the passage of current.
Resolution	The smallest distinguishable difference of a measurement.
Salmonids	Species of the family Salmonidae Example: Atlantic Salmon (*Salmo salar*), Sea Trout (*Salmo trutta*).
Thresholding	A data filtering method that rejects data values less than a preset threshold.
Tomography	A computer reconstruction technique to allow visualisation of layers or virtual cuts in objects often using X-rays or electrical impedance.
Transducer	A device that converts one form of energy to another. Example: video camera converts an optical signal to an electrical one.
Transmissive	The property of a medium to allow an object or energy to pass through it. Example: light through clear water.
Transponding	Ability of a device to transmit a message in response to reception of a trigger signal.
Turbidity	A description of the opacity of a liquid.
Vacillation	Repeated movement past a fixed point.
Waveform	A description of a signal that alternates in direction.

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National Rivers Authority

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