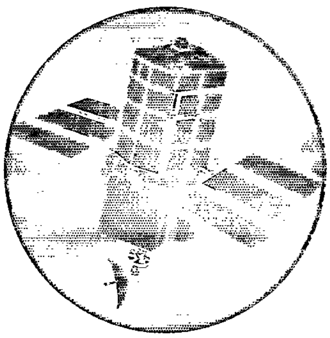
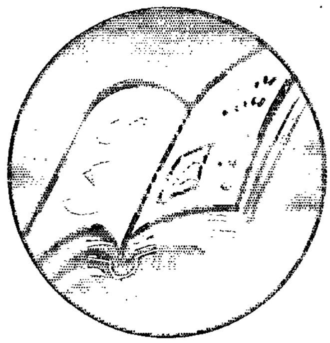
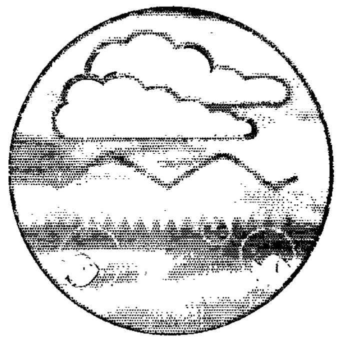
The Use of a Hydroacoustic Counter for Assessing Salmon Stocks

Research and Development

Technical Report
W92

ENVIRONMENT AGENCY

The Use of a Hydroacoustic Counter for Assessing Salmon Stocks

Technical Report W92

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South East Area Environmental Appraisal Unit
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W-10/98-AZVF

Dissemination status
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Statement of use
This Technical Report describes a study to assess the ability of a hydroacoustic counter to enumerate adult salmon passage in a riverine environment. Recommendations for further evaluation work in Phase 2 of the study are given. It will chiefly be of interest to Fisheries staff involved in the management of salmon stocks.

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GLOSSARY

A/D conversion : Analog to digital conversion. A device used to convert a continuous time (analog) signal into digital form.

Absorption : Loss of acoustic signal strength due to conversion of acoustic energy into heat.

Absorption coefficient : The rate of absorption per unit distance. Represented by the letter a, the absorption coefficient gives the attenuation of the sound level in dB/m during the transmission of the signal through water.

Acoustic axis : The centre axis of the acoustic beam. The direction of highest acoustic intensity (i.e. maximum in-phase condition or maximum correlation).

Acoustic calibration : A method of measuring the acoustic transmission and receiving characteristics of the echo sounder and the directivity function of the transducer.

Acoustic signature : Particular reverberation of sound and typical reflections from a target (usually with swim bladder).

Angular resolution : This expresses, in degrees, the echosounder's ability to distinguish between targets at different bearings but at the same distance from the transducer. Transducers with narrow beams have good angular resolution.

Ambient noise : The noise of the medium itself. That part of the total noise background that is 'left over' after all identifiable sources of noise are accounted for.

Attenuation : Decrease in signal strength due to several factors, including geometric spreading, absorption, shading and multiple scattering. Total attenuation is typically a function of range and must be accurately compensated for in quantitative processes.

Backscattering cross-section : A measure of the reflectivity of a target. Target strength (TS) is equal to $10 \log_{10} (\sigma_{bs} / 4\pi)$ of the backscattering cross section σ_{bs}, which is defined by the relationship : $\sigma_{bs} = 4\pi R^2 I_b / I_i$ where R = range to target; I_i = intensity at the midpoint of the incident wave at the target; I_b = intensity at the midpoint of the backscattering pulse.

Bandwidth : The bandwidth of an amplifier is given as a difference between the two frequencies (in Hz) where a drop of dB occurs in the amplification of each side of the centre frequency. Bandwidth of a sounder should be set to approximately 2 / pulse length.

Beam pattern : The beam pattern is shown as a polar plot of the sensitivity of the transducer against direction.

Beam pattern factor : In dual-beam sonar applications, this is the ratio of the received signal intensities from the narrow and wide beams (I_n / I_w). Assuming that the received signals come from one target, the ratio depends on the direction of the target and can be used to estimate the amount of signal intensity lost due to the angle of the target from the acoustic axis.

Beam width : A nominal value in degrees describing the full angular width of the acoustic sound cone.

Bottom tracking : A special circuit or algorithm that predicts the location of the bottom based on previous bottom detections. Bottom tracking is used to terminate processing of the acoustic return just prior to the bottom pulse.

Boundary : The surface, the bottom or other structures, layers or sources of interference that mask the acoustic signal and limit the range of fish detection.

Cross-talk : Interference caused by the acoustic pulse from one transducer being received by another. This occurs during fast multiplexing when transducers are positioned too close together.

Decibel : A logarithmic system for expressing the wide range of values in the sonar equation.

Directivity index : A measure of the degree to which acoustic energy is concentrated along the acoustic axis. The directivity index (DI) increases with decreasing beam width.

Directivity pattern : A map of relative sensitivity or efficiency of a transducer in transmitting or receiving acoustic signals. The highest sensitivity is on axis, and sensitivity falls off (directivity function becomes negative) as angle from the axis increases.

Doppler effect : The alteration of the apparent frequency when the sound source is moving relative to the observer, or when the target is moving relative to the transducer.

Dual-beam sonar : Simultaneous use of wide and narrow beam transducers, allowing in-situ estimation of target strength.

Echo : Returning sound reflected off a target of density differing from the medium in which the sound is travelling.

Echogram : A (paper or electric) display of a time series of received echo pulses.

Echo integration : A signal processing technique that determines the averaged squared echo sounder output voltage for selected range bins and averaging times. The echo integrator output is proportional to fish density or biomass. Echo integration is used in multiple target environments, such as fish schools.

Glossary

Fish trace : A collection of echoes received from a fish passing through the sound field, typically displayed on a paper strip chart or a computerized display. The echoes are spatially correlated in range and time to represent a single object.

Fixed-location hydroacoustics : A hydroacoustic survey technique where the transducer is secured in a fixed position. In contrast to a mobile survey, the fixed location survey samples fish as they move through the acoustic beam.

Frequency : The number of oscillations a sinusoidal signal source makes each second. Usually expressed in Hertz (1Hz = 1cycle/sec). Hydroacoustic systems usually have frequencies in the range of 20-500 kHz.

Gain : Amplification applied by hardware or software to increase signal levels or compensate for some systematic signal loss, such as geometric spreading loss.

Geometrical loss : The loss in the intensity of a propagating acoustic signal caused by geometrical spreading.

Geometrical spreading : The increase in the esonified cross-sectional area with distance travelled by the sound waves.

Hydroacoustics : The study or use of sound in water to remotely obtain information about the physical characteristics of the water body, its bathymetry, or biotic populations.

Hydrophone : A device that receives underwater sound pressure waves and converts them to electric waves.

Incident sound : Sound which impinges on a target.

Insonified volume : Volume of water into which acoustic signals are directed.

Intensity : The acoustic power per unit area of a propagating acoustic wave. Intensity is proportional to pressure squared.

Multiple targets : More than one target within the acoustic beam.

Multiplexers : Switching devices that permit sampling of multiple transducers with a single echosounder. In fast multiplexing mode, multiple transducers can effectively be sampled simultaneously. In slow multiplexing mode, each transducer is sampled for a user-input amount of time before switching to the next transducer.

Near field : This is the region in front of the transducer where the wave fronts produced by the transducer are not parallel and the beam is not properly formed.

Glossary

Noise : Unwanted signals that interfere with the signals to be quantified. Sources include self (internally generated) noise, received noise radiated into the system through the transducer cable, flow noise from water passing across the transducer at high velocity, volume reverberation noise from unwanted particles, bubbles, or animals distributed throughout the sound field or from the sound field grazing a boundary, and false targets (such as rocks, debris and resident fish).

Pulse duration : Length of time a pulse of a given frequency is emitted by the transducer.

Ping : Informal name for the transmission and reception of a single acoustic pulse.

Ping rate : The pulse repetition rate , i.e. the rate of repetitive acoustic pulses, of a given duration and frequency, emitted by the transducer.

Propagation : The process of outward travel of an acoustic pulse through a medium.

Pulse repetition rate : Number of pulses transmitted per unit time.

Pulse width : The width or duration in time of the transmitted acoustic pulse, usually expressed in msec. Also called pulse duration or pulse length.

Range : Distance from the transducer face to the target.

Reflection : The "bouncing" of sound off a target due to the differences in density between medium and target and target orientation.

Refraction : The change of direction of propagation of any wave, such as an electromagnetic or sound wave, when it passes from one medium to another in which the wave velocity is different, or when there is a spatial variation in a medium's wave velocity.

Reverberation : Acoustic interference caused by scattering of objects other than those of interest. The main source of reverberation in fisheries assessment are the bottom, surface, other boundaries, air bubbles and particles in the water.

Sampling cross section : The cross-sectional area sampled by the acoustic beam.

Side lobe : All transmit\receive beams of a transducer except the main beam.

Signal-to-noise ratio (SNR) : Ratio of signal strength to background noise level.

Sound velocity : Velocity of sound through a medium. In water this is approximately 1500 m/sec, dependent upon temperature, salinity and depth.

Sound wave : Pressure maxima and minima moving within a compressible medium.

Glossary

Split-beam : An echo sounder designed to directly measure target strength. The position of a target in the sound field is calculated by accurately measuring the differences in an echo's arrival time to individual elements in the transducer.

Standard target : A target with known acoustic size. Standard targets are designed to be omni-directional and have stable reflective properties with depth and temperature (e.g. tungsten carbide spheres).

Swimbladder resonance : Characteristic "ringing" of air-filled swim bladders when insonified by a hydroacoustic system..

System noise : Interfering signals internally generated by an acoustic system, also called self-noise. This noise is contrasted to signals reflected from transmitted noise..

Target strength (TS) : Acoustic size of target in dB.

Threshold : An amplitude value below which all echoes are rejected. A threshold is applied to reject noise and signals from very small targets which are not of interest.

Time-varied-gain (TVG) : A successive increase in the amplification of the receiver with range during the reception period of each sounding. For single targets, 40 log(R) compensates for geometric spreading loss and absorption.

Transducer : Electro-mechanical device which translates electrical energy to sound energy to produce the hydroacoustic signal, and converts returning echoes back into electrical signals.

Wavelength (λ) : The distance travelled by a sinusoidal acoustic wave in a time equal to the period of the sine wave. The wavelength is important in determining the directivity of transducers and the characteristics of scattering. $\lambda = c/f$, where c = the speed of sound (approx 1500m/sec) and f is the frequency (Hz).

Executive Summary

This R&D report assesses the performance of a split-beam echo sounder for enumerating the passage of migrating adult salmon.

The equipment was manufactured by Hydroacoustic Technology Incorporated (HTI) and the three-year trial was conducted on the River Wye.

Details of the background to the project are given along with basic acoustic theory plus the principles behind system operation. A protocol for site selection is listed using the Wye as an example.

The results of the study show that Atlantic salmon present an acoustic target large enough to be detected above background noise levels typical of potential sites on many UK rivers. Fish targets were detected and enumerated as they passed through the beam over a range of environmental conditions.

Like the alternative methods of salmonid enumeration, the successful application of this tool is dependant on aspects of site selection, riverine characteristics and fish behaviour. In addition, the ability to assess the proportion of fish passing through the ensonified area of the water column over a range of flows is required.

The selection of a site suitable for the application of hydroacoustics is of paramount importance. There will probably be river systems where a suitable site does not naturally exist.

The high debris load of the Wye caused several problems. The automatic "real time" fish tracking and counting facility of the system could not be solely relied upon to obtain robust data on fish passage. Multiple counting of single targets and spurious counts from downstream drifting weed caused the tracking software to over count. Every upstream target had to be verified manually after data collection.

It was not possible to accurately filter out the true fish from the downstream moving targets. No downstream fish counts were attempted on the Wye.

The resource implications for year round production of counts are discussed.

A method of validating the data produced by the acoustic counter using underwater video cameras was trialed. The results from this small scale operation suggested that the counter detected 80% of fish passage under trial conditions.

A by-product of the project was the discovery that twaite shad (*Alosa fallax*) demonstrate a

strong avoidance reaction to sound transmitted at 200kHz, well above the range previously reported for other Clupeid species. They were not repelled by sound transmitted at 420kHz.

Despite the problems discussed, the technique represents a potentially powerful management tool for quantifying salmonid migration in a riverine environment. Further validation work is required and recommendations on suitable techniques are made in this report.

Based on the findings reported here, the commissioning period for an acoustic counter would be two years. This period could be extended if the high degree of technical expertise and experience needed to manage an acoustic system was not available.

Key Words

Acoustic Counter, Fish Counters, Atlantic Salmon, Shad, Verification, Videographics, Video

1.0 Introduction

This report details the Research and Development project, initiated by the Environment Agency's predecessor (the National Rivers Authority), to assess the use of a hydroacoustic counter to enumerate adult salmon passage in a riverine environment. It reports the work carried out during the three year study and brings together information already published in interim reports. It is not intended to be used as a Field Manual but serves to fully illustrate the technique to potential Environment Agency users.

The remit of the Environment Agency includes the management of salmon and sea trout stocks and the regulation of rod and net fisheries. The Agency therefore wishes to be able to predict and monitor the effect of changes to fishery regulations and environmental impacts such as increased water abstraction on fish populations. Quantitative stock assessment is a prerequisite for this.

In England and Wales data on adult migratory salmonid abundance are collected from only a few of the main migratory salmonid rivers. This information is obtained through resistivity counters or trapping programmes. These techniques are appropriate for use in small rivers or where suitable structures exist which can be modified. However, construction of weirs for fishery assessment can be prohibitively expensive. They may also adversely affect salmon migration and the local landscape. Most rivers have an absence of quantitative data and reliance is placed upon rod or net catch return data for stock management. Rod catch data, although very valuable, do not necessarily represent actual stock abundance as they do not present out of season runs of fish, or stocks of fish that run when conditions are not conducive to angling. Angling success can also vary substantially, both within and between years, due to varying environmental conditions and run timing.

1.1 Background to Project

The concept for this project evolved from a requirement to collect reliable data on the abundance and timing of the spring salmon run on the River Wye, one of the most important salmon rivers in England and Wales. This requirement was identified in a review of the status of the spring run on the river (Gough et al, 1992) and subsequently by the Wye Salmon Action Plan (NRA, 1993).

The use of traps and resistivity counters to obtain abundance data on the Wye was precluded mainly by the expense and objections on land drainage and navigation grounds. The labour intensive nature of trapping and the problems of validating resistivity counters in rivers with a highly variable flow also contributed to rule out their use on the Wye.

A hydroacoustic counter was identified as possibly the only technique that could enumerate the migration of adult salmon on the River Wye. Although no long term equipment trial had been attempted before in the UK, the technology is used routinely in North America where it is a successful management tool for assessing the valuable commercial and sport fisheries. The acoustic technique requires little civil engineering work to install, is completely unobtrusive to the salmon and has the potential to offer a relatively cost-effective approach to assessing run size.

In a wider context, the NRA (now The Environment Agency) recognised that a more flexible, reliable and cost-effective method for stock enumeration, particularly on those rivers for which more traditional approaches are inappropriate, was needed. To address this issue, the use of hydroacoustic techniques for stock assessment was proposed as subject of an NRA Research and Development project, to be based on the River Wye, in South East Wales.

The Wye offers an ideal environment in which to assess an acoustic system, having a substantial run of salmon with stock components ascending the river throughout the duration of the calendar year. The Wye has an almost negligible run of sea trout and at the selected site a sparse population of large coarse fish. Species apportionment was therefore not a substantive issue for the Wye counter. It also represented a site at which acoustic techniques would be thoroughly examined because of relatively demanding environmental criteria. A map of the River Wye is shown in Figure 1.1.

The project commenced in April 1994.

1.2 Project Objectives

The following is taken from the original plan and provided the blue print for the project to follow.

Overall Objective

To install, operate and evaluate a hydroacoustic fish counter to produce reliable data for stock management and to provide guidelines for applications of the system in the NRA, and to provide future data on the impact of Water Resources schemes on the abundance and behaviour of salmon.

Specific Objectives

PHASE 1

(a)To evaluate previous work on the use of hydroacoustic fish counters, and consider the potential for riverine applications for the NRA and the selected specific investigation site on the River Wye, Welsh Region.

(b)To carry out a scoping study to appraise the options for the purchase of a hydroacoustic system.

(c)To obtain full technical and practical briefings from equipment suppliers in the USA.

(d)To produce an Interim Project Report containing the results and including a full appraisal of the cost effectiveness of each of the viable options.

PHASE 2

(a)To order and purchase the hydroacoustic counting equipment.

(b)To install the hydroacoustic counter, and to develop the deployment techniques to ensure that optimum target counting in the expected range of river flows is achieved. This will include the development of mounting and deployment equipment, examination of the aspect of the transducers in the river, and the development of control procedures for the equipment.

(c)To ensure acoustic calibration of the equipment at the range of flows used by salmon, using standard targets of known size.

(d)To establish operating procedures.

(e)To examine the acoustic size of target species (salmon, salmon smolts and shad).

(f)To validate the data produced by the equipment at the range of flows used by the fish for migration. This will include the use of existing methods, and development of new ones for the interpretation of acoustic data and fish behaviour. Validation procedures will also include the use of acoustic and radio telemetry techniques (a Regional radio-tracking programme is to commence on the Wye in 1994/5), perhaps including high-resolution tracking of tagged salmon approaching and traversing the ensonified area, and the use of this data to confirm acoustic data.

Other validation techniques including the use of catch-effort indices in adjacent fisheries, and photography would also be assessed.

(g)To investigate the presence of non-target fish species in the vicinity of the counting area. This may include the use of test netting or trapping. It may also include the use of mobile hydroacoustic equipment, and development of techniques to discriminate and eliminate non-target fish from acoustic counts.

(h)To explore the feasibility of differentiating and enumerating the annual migrations of salmon smolts and shad.

(i)To make a judgement on the efficiency and cost effectiveness of the hydroacoustic counting equipment and to make recommendations on the deployment of the equipment at other sites. This should include cost guidelines for the installation and running of the equipment.

(j)To produce an R&D Report containing the findings and recommendations arising from the study.

(k)To produce a manual and guidelines (R&D Note) for assessing the appropriateness of, and installing and operating the system elsewhere. This will include training recommendations.

Phase 1, the appraisal and purchase of equipment, has been reported separately (NRA Interim Report 486/1/W, 1993).

This report details the progress of Phase 2.

1.3 Acoustic Fish Counters

The riverine environment presents the most difficult situation in which to apply a hydroacoustic system. Typically such environments are areas of high background noise where fish are migrating close to the river bed across the full channel width, in relatively shallow water.

There are three types of hydroacoustic systems used for the enumeration of adult salmonid passage; single beam, dual beam and split beam. In riverine applications transducers are aimed horizontally so that the fish are in side aspect as they pass through the beam.

Single beam systems are relatively cheap and simple to operate, but only capable of detecting the presence or absence of objects as they pass through the beam. No information relating to the objects position in the beam can be derived. Therefore no target strength (target strength depends on position in the beam and target size) or direction of travel information is available. All sport fishing echosounders are single beam systems. Single beam systems are used in some fisheries research applications to count smolt passage through hydroelectric turbine intakes on North American Dams.

Dual beam transducers allow the distance of a target off the acoustic axis to be determined and this can be compensated for when calculating target size. No exact target position can be calculated however.

Split beam transducers give a three dimensional position of a target in the beam. A much greater amount of information is available for each echo that considerably improves the ability of an operator to count fish. It is also possible for micro processors to link echoes from the same target together, and to track it as it passes through the beam. For each fish tracked, data on the direction of movement, the range and position in the water column, and the passage speed can be collected. Target sizes are also estimated to an increased level of accuracy.

1.4 It works in the States, why not here?

There are several differences between UK rivers and salmon runs and those of North America that prevent the assumption that the technique and methodology of hydroacoustics will transfer directly to England and Wales.

Fixed location hydroacoustics has been used in North America to provide counts of migrating adult Pacific salmon in rivers since the early 1960's. The Fraser River, British Columbia; Illinois River, Oregon; Kenai River, Alaska; Klamath River, California; Mosie River, Quebec and Susitna River, Alaska have all had extensive acoustic monitoring programmes (Ransom et al, 1996). The first riverine application of split-beam sonar technology was on the main stem of the Yukon River in 1992 (Johnston et al, 1993). Methodology for instalment of equipment, data collection and data handling has therefore undergone modification and has evolved to suit the biological and environmental conditions of the enormous North American rivers and their huge migrations of salmon.

There is a significant difference in the timing of salmon migration for Pacific and Atlantic salmon. Pacific salmon runs tend to be concentrated into short periods of two or three months (this can be as short as four weeks in the north of Alaska). In large UK rivers, fresh-run fish may be present in variable number all year. The concentrated nature of Pacific salmon runs enables relatively high levels of resources to be deployed for intensive monitoring over a short period.

For example, on the Chandalar River, Alaska, the entire 1995 fall chum salmon (*Oncorhynchus keta)* run was enumerated by deploying two hydroacoustic counters between August 8th and September 22nd (Daum and Osborne, 1995). The counters were run continuously during this time, except a short period where high water prevented operation.

In UK rivers, although spring and autumn peaks in run timing are often apparent, it is necessary to monitor almost year round. This could result in several operational difficulties due to seasonal variations in environmental conditions.

The shorter and more concentrated nature of the North American salmon runs suggest that these fish actively migrate upstream throughout this period. This is borne out by the results of split-beam acoustic monitoring. For example, the Chandalar River autumn counts consisted of 98% upstream targets, 1% downstream and 1% not determined (Daum and Osborne, 1995). Spring run salmon in UK rivers remain within the river system until spawning in late November through to January. Therefore, active migration of salmon in UK rivers can be interrupted by periods of quiescence when the fish remain in a pool. These holding or 'milling' fish can lead to an overestimation in acoustic counts if the fish pass downstream and then return up again later.

Weed growth, which can be substantial in many UK rivers, will affect directional counts. Wafting submerged macrophytes and downstream floating debris could prevent the simple subtraction of downstream counts from the total upstream count.

The difference in salmon run sizes in North American and UK rivers also has an effect on hydroacoustic monitoring. Annual salmon escapement in North American rivers can reach several orders of magnitude greater than UK rivers. The Chandalar River chum salmon escapement for 1995 was 280,999 fish with daily counts of over 1,000 fish per day recorded for 39 of the 46 counting days. With such high numbers of fish passing through the acoustic beam daily, a few thousand spurious fish targets are not going to significantly affect the final count.

By contrast, the target for salmon escapement on the River Wye, set out in the Environment Agency's Salmon Action Plan (Environment Agency, In prep.), is 11800.

Many rivers in the UK are highly accessible public areas. Anti-vandalism and equipment security measures may therefore place additional constraints on the selection of an acoustic monitoring site. The remoteness of many North American hydroacoustic sites often provide sufficient security in itself. Due to the shortness of each monitoring period these remote sites are usually constantly staffed.

Species apportionment cannot be addressed by acoustic monitoring techniques alone. To enumerate concurrent runs of two different salmonid species in the same river, an additional technique to apportion species is required. Gill netting is frequently carried out to determine the species composition of acoustic counts in North America (e.g. Chandalar River 1995, Yukon River 1992). From these associated studies the accuracy of acoustic counts can be estimated.

The rivers of the UK often support migratory salmon and sea trout but the relatively low numbers preclude netting a sub-sample of the run and for a mixed stock river. Alternative methods of species differentiation would have to be devised.

These differences, among others, prevented the immediate adoption of the American experience and were part of the reason for the R&D project.

1.5 Equipment Manufacturers

There are currently three companies marketing acoustic systems for the riverine enumeration of salmon; Kongsberg Simrad, Biosonics and HTI (Hydroacoustic Technology Inc.).

Kongsberg Simrad, a Norwegian based company, manufactures split beam echosounders, mainly for mobile marine surveys. Several regions of the Environment Agency have adapted these systems for mobile coarse fish surveys with the transducer aimed horizontally. To date there are no Simrad systems deployed in a fixed location for the enumeration of adult salmon passage.

Biosonics of Seattle in North America produce a dual beam system used for in-river adult salmon counting in a few American rivers. The company is rapidly developing a split beam system in an attempt to catch up with its competitors. The new system may be available towards the end of 1997.

HTI are a relatively new company but have manufactured and operated split beam systems on over 30 riverine projects to quantify salmon abundance. They offer a consultancy service and from these experiences have developed an extensive range of post-processing software.

1.6 Equipment Purchase

Several working groups (Johnson and Clark, 1986, Bussell, 1978) have produced a list of criteria that a fish counter designed for enumerating adult migratory salmonids must satisfy. These include the following:

1. To gather spatial and temporal data for each fish and its direction of travel.
2. To produce output data in a form that can easily be interpreted, manipulated and analysed.
3. To give an estimate of the size of each fish.
4. To be able to filter out false targets from genuine fish.
5. Allow as much automation as possible to provide a low maintenance system.

The initial scoping study (NRA, 1993) considered that of the available acoustic technology only a split beam system could meet the requirements for a fish counter in the rivers of England and Wales.

Hydroacoustic Technology Incorporated (HTI) were able to offer a split-beam product that had proven results in the field and was technically ahead of its rivals. They were also backed by an experienced consultancy team. Furthermore a substantial investment in R&D by the company promised future advances in hardware, software and operations controlled by telemetry. HTI equipment was therefore purchased for the R&D study on the Wye.

2.0 Principles of Acoustic Fish Counting

Decision making on all levels of acoustic survey design, from site selection through to data analysis, is made considerably easier by a good understanding of the physics of sound transmission in water. A basic concept is also helpful in understanding the reasoning behind specific objectives of this R&D project and in the interpretation of the results.

2.1 Basic Theory

2.11 History of Acoustic Fish Counting

Fish were first detected acoustically during an experiment by Kimura (1929) who bounced an acoustic beam off a pond wall and noted that the received sound was disturbed when fish swam through it. Sund (1935), used a 16 kHz echosounder to produce paper traces of the echoes reflected from cod off Norway. After the Second World War commercial development of echosounders for fisheries use continued. Echo integration techniques developed in the 1960s allowed fish abundance to be measured for the first time.

The development of dual beam transducers in the 1970s allowed in situ measurements of target strength to be made. The recent and rapid development of microprocessor technology has allowed the subsequent development of split-beam transducers. This has resulted in improved target strength estimations and enables the tracking of fish targets in time and space.

Acoustic systems have become considerably more powerful. They are now small and "user friendly" enough to be considered as a routine fishery management tool.

2.12 The Concept of Sound Transmission in Water

Sound is transmitted in water by periodic compression and expansion of water molecules resulting in a travelling pressure wave that radiates out from the point source. These pressure waves are subjected to energy scattering, reflection and absorption as they travel through the water medium.

The frequency of sound refers to the number of cycles per unit time and is expressed in hertz (Hz). One hertz is one cycle per second so 1 kilohertz (kHz) is 1000 cycles per second. Human hearing is responsive to frequencies from 20Hz to 20kHz.

Sound in water travels at approximately 1450 - 1500ms^{-1} depending on temperature and salinity. In freshwater at 20°c, the velocity of sound is 1480 ms^{-1}.

The spreading of the wave front causes a reduction in its intensity as the area of the wave front is related to the distance from source. The decrease in sound intensity is inversely proportional to the square of the range from source.

Intensity of sound is also reduced by localised heating of the water molecules as the wave front passes. The degree of this absorption is influenced by water temperature, salinity and sound frequency. Absorption increases linearly with range. In freshwater at frequencies up to 200kHz absorption is negligible at ranges under 50 metres.

Sound reflects off objects of differing density to the surrounding medium. The magnitude of the reflected energy is dependent on the size of the object and its orientation. The swim bladder represents the greatest density difference between the fish and the water medium.

From experiments with gadoids, Foote (1980), found that the swim bladder reflects up to 90% of the back-scattered energy (the reflected sound). However, this depends on swim bladder shape and internal physiology and can therefore be highly variable between species. The ability of a fish to reflect sound is known as the back-scattering cross section. This equates to the acoustic size of the fish.

The acoustic size of a fish is not expressed in units of pressure or intensity but in logarithmic decibels (dB). Due to the large variation of values, the logarithmic decibel greatly simplifies manipulation of data.

For a detailed review of sound transmission in water refer to MacLennan and Simmonds (1992).

2.13 Reverberation and Noise

Transmitting a sound pulse from an acoustic system can produce echoes from the river bottom, the surface and suspended matter besides target echoes. This unwanted additional echo caused by the system is known as reverberation.

Any unwanted signal detected by an acoustic system other than reverberation is described as noise. Noise is caused by a range of factors. Rain and wind on the water surface, movement on the river bed (including animal movement) and even electrical disturbance from the system itself will all contribute to noise.

For a target echo to be detected by a system, it must have a signal strength greater than the total strength of all noise sources.

2.2 How an Acoustic Counter Works

In a hydroacoustic system an electrical input to the transducer causes cyclical movement of a ceramic plate and creates pressure waves that spread radially into the water as a pulse or ping. Some of this sound energy is scattered or absorbed but a proportion is reflected back to the transducer. All objects with a different density to the water medium (such as rocks, the water surface and the swim bladders of fish) can cause reflection.

After transmitting a pulse, the transducer "listens" for any returning echoes. These echoes will cause the ceramic plate to create electrical energy that can be processed and analysed by the acoustic system. For an object of given size, echo magnitude varies with range and distance off beam axis of the target.

To remove the effect of range from the signal the echosounder has a variable gain to compensate for this loss. The gain increases with increasing range. The range of the target is calculated from the time difference between pulse transmission and reception of the resulting echo. This is known as time-varied-gain, or TVG.

Acoustic strength of an echo also depends on its position in the beam. The transducer will produce the greatest voltage output when the source is in the centre of the beam (on the acoustic axis). This voltage strength will decrease as the source moves towards the edge of the beam. In split-beam and dual beam systems, the angular position off the acoustic axis is calculated and the system can compensate for this effect.

2.21 Characteristics of the Acoustic Pulse

An acoustic pulse is initiated by the echosounder, and generated by mechanical vibration of the ceramic element housed within the transducer. The transducer produces a short burst of sound, a pulse or "ping", at its operational frequency. The length of this pulse in metres is expressed as:

$$\mathbf{PL = c\tau}$$

where c = speed of sound in water and τ = pulse duration in seconds.

During typical operating conditions the speed of sound in water is $1480ms^{-1}$ and the pulse duration is set at 0.2msec. The pulse length is therefore 0.296m.

Pulse length determines the spatial resolution of the acoustic system; its ability to resolve multiple targets as individuals rather than one large target. This could apply to separating individual fish targets from each other or separating fish echoes from the bottom. Theoretically the minimum difference in range between two targets to resolve them as separate objects is half the pulse length. Therefore in the example described above, targets can be resolved if they are greater than 14.8cm apart.

It might be expected to set pulse length as short as possible to maximise spatial resolution. Practically this is not desirable. An acoustic systems ability to detect signals in "noisy" environments (such as rivers) is a function of the energy in the pulse or the transmit power, which is proportional to pulse length. The higher the transmit power, the bigger the returning echoes will be compared to the background noise levels. Pulse length selection is a compromise between spatial resolution and the ability to distinguish targets against background noise.

The operational frequency of an acoustic system is also a compromise. Using a high frequency allows more cycles to be transmitted in a short pulse. This therefore maintains the high transmit power and target resolution. However, greater signal loss occurs at high frequencies due to absorption. Most acoustic systems for detecting fish operate between 38 and 420 kHz.

The frequency of the system also has economic implications. The lower the frequency, the larger and more expensive the transducer.

2.22 Variation in Target Strength of Fish

If a system compensates for both time varied gain and position in the beam, the target strength of any fish is still NOT simply a function of fish length or weight. Many factors can combine to either negatively or positively effect target strength. These include the size and shape of the swim bladder, the physiology of the fish, its orientation in the beam and possibly even the swimming speed of the fish (the flexing motion of the fish's body will affect the aspect of the swim bladder to the acoustic beam).

For fish of the same species, in direct side aspect to the beam, target strength varies with swim bladder size and that in turn is proportional to the weight of the fish. Salmonids have a ducted swim bladder and so the actual size of the bladder (and therefore its target strength) for an individual fish may vary over time.

The highest target strengths are obtained from a fish in side aspect, i.e. perpendicular to the acoustic beam and on the acoustic axis. If this angle changes, for example if the fish is viewed head or tail on, then the target strength will drop. Similarly the target strength of an individual fish changes with changing tilt angle. A fish in dorsal aspect will have a lower target strength than in side aspect.

There are two reasons for this effect. As the tilt angle changes, the amount of surface area in the acoustic beam is reduced. Secondly, as the fish aspect changes it effects the echo energy received by the transducer due to interference between wavelets reflected from different parts of the body. When a fish is in side aspect all the reflected sound is in phase and the sound waves reinforce each other, leading to a large echo. A target not in side aspect may cause reflected waves to originate from different parts of the target. These waves can become progressively out of phase and the amplitude of the echo will be reduced. This interference becomes significant where the wavelength of sound is shorter than or equal to the length of the fish.

The size of an echo also varies depending on the position of the fish in the acoustic beam. Detection ability is greatest along the centre of the beam (on axis) and decreases as the angle between target and axis increases. It is possible for a small target on axis to reflect a larger echo than a larger target off axis. This beam pattern effect can be compensated for in dual and split beam systems as the angle off axis is known.

Fish behaviour is therefor an important consideration when planning and siting an acoustic counter (see Section 3).

2.23 Dual-Beam

A dual-beam system uses transducers that have an arrangement of elements to produce two beam patterns, one narrow and one wide, aligned on the same acoustic axis.

In transmit mode all the elements combine to form a narrow beam that transmits a pulse. The central elements, when used independently, form a wide beam. Received signals are processed on both the wide and narrow beam giving two output signals. These two output signals have different intensities that correspond to the narrow and wide beams. If the received signals come from a single target, then the ratio of these two intensities (the beam factor) will depend on the position of the target.

Knowing the position of the target within the beam (i.e. either on axis or off) allows real time in situ determinations of target strength to be made. This development of two beam patterns allows target position to be calculated and is a considerable advance over single beam sonar. Using the single-beam technique, a fish on the edge of the beam will reflect a smaller echo than when it is in the centre of the beam. By comparison, the dual-beam technique can determine the changing position of the fish within the beam (from outside edge to on-axis to outside edge again) allowing compensation factors to be calculated.

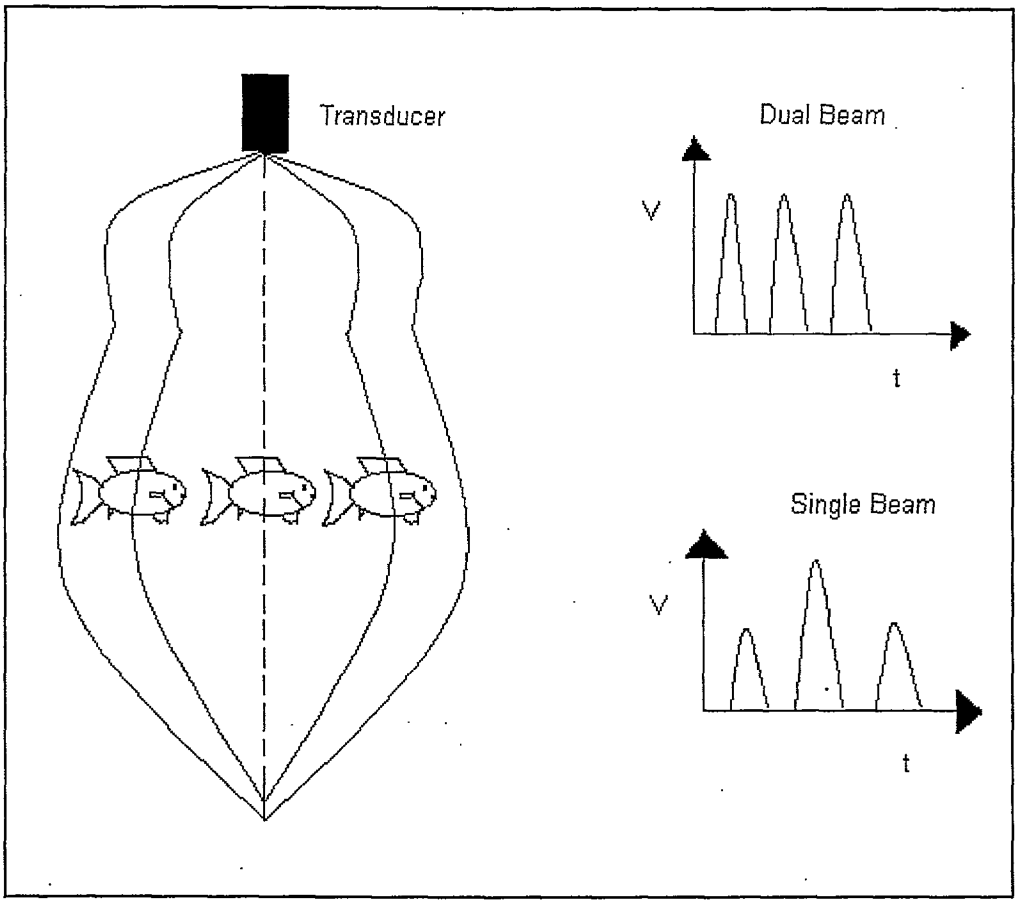


Figure 2.1. The output voltages from an echosounder due to fish swimming through a dual-beam and single-beam acoustic beam.

2.24 Split Beam

A split-beam echosounder uses a transducer divided into four quadrants. The pulse is transmitted from the entire transducer, but the signals received from each quadrant pair (the up/down pair and the left/right pair) are processed separately. The phase differences of the returning echoes determine the angle off the acoustic axis.

Figure 2.2 (after Maclennan and Simmonds (1992)) describes a vertically aimed transducer mounted on a ship but serves to illustrate split-beam operation. The four quadrants are labelled a, b, c and d. The angle θ of the target in one plane can be determined by the phase differences (a-b) and (c-d), which should be the same. The summed signal (a+c) is compared with (b+d). The second angle ϕ, in the plane perpendicular to the first, is similarly calculated by the phase difference between (a+b) and (c+d). These two angles define the target direction uniquely, allowing a trajectory of the target's movement through the beam to be mapped.

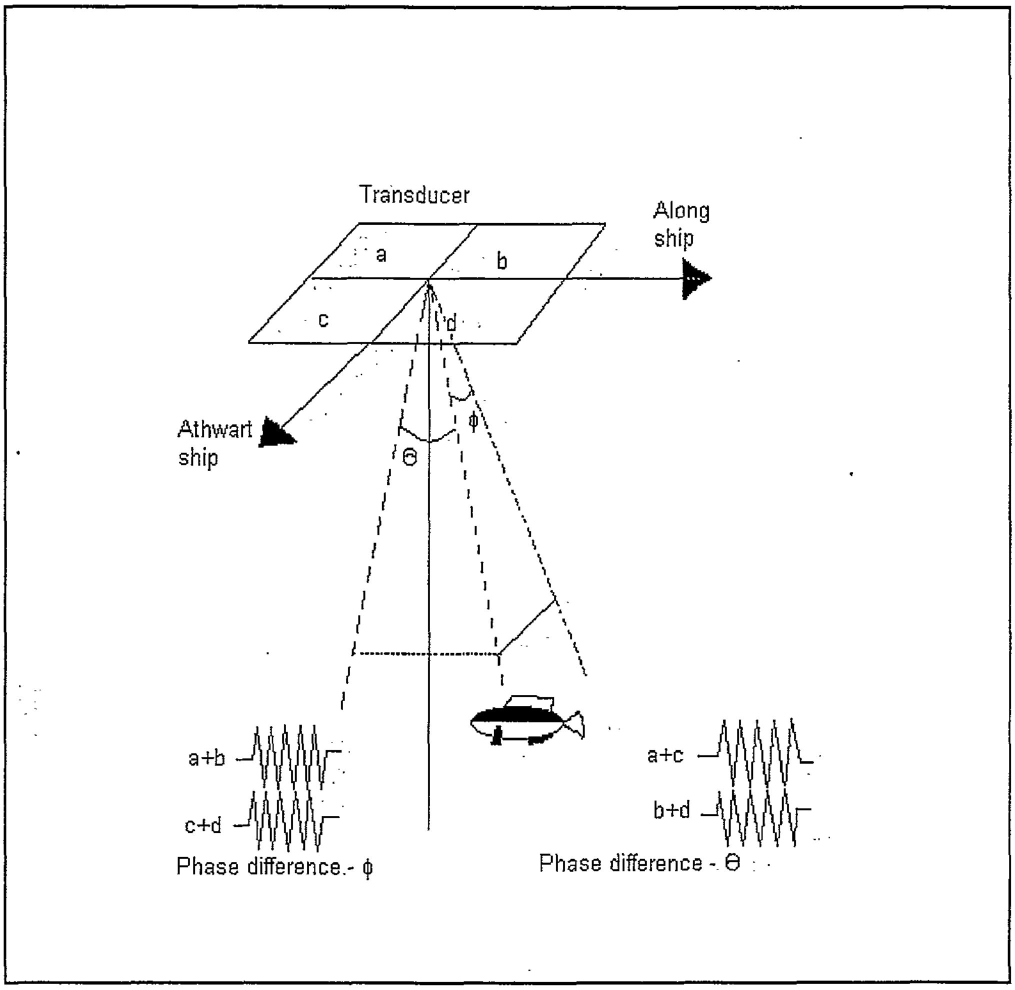


Figure 2.2 Diagram showing the principles of a split-beam echosounder from the perspective of a vertically aimed transducer.

Since the direction of the echo, its range and amplitude can be learned from signals produced by the split-beam echosounder, the appropriate time varied gain (TVG) and transducer sensitivity for distance off axis can be applied to obtain a measure of target strength.

Traynor and Ehrenberg (1990) have shown that the split-beam system has superior performance to the dual-beam in the presence of noise. Using a new echosounding system, which had both dual-beam and split-beam target strength measurement capability, target strength measurements of a standard target sphere of -42.2dB were collected using the dual-beam method. These were seen to be more variable than those obtained using the split-beam technique (see Figure 2.3).

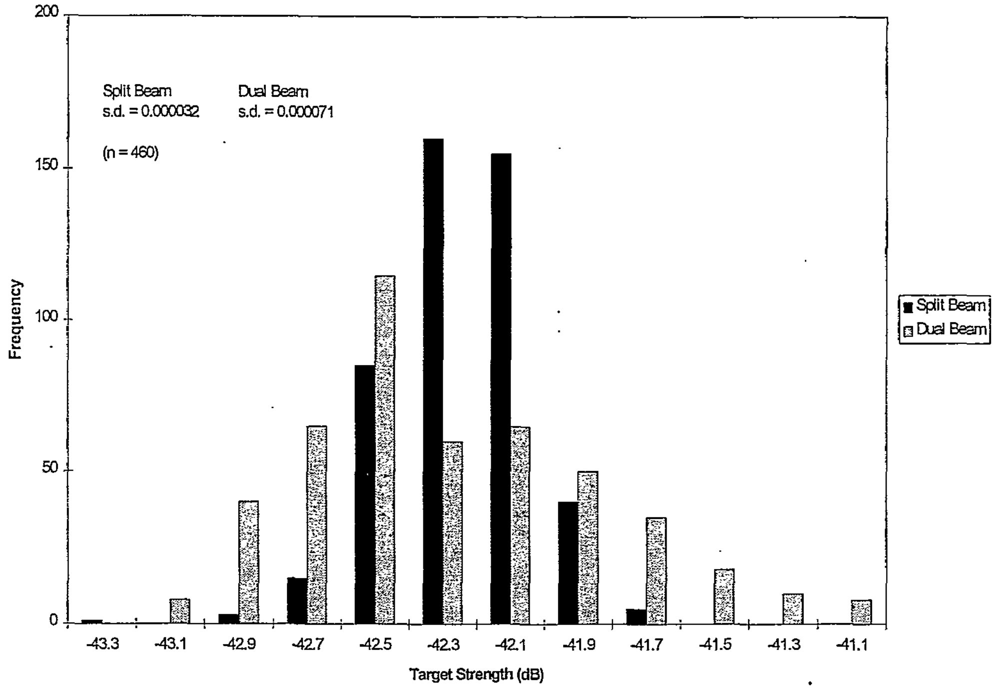


Figure 2.3: Target strength measurements of a tungsten carbide sphere using the dual-beam and split-beam techniques (Traynor and Ehrenberg, 1990).

Burwen, Bosch and Fleischman (1995), deployed a split-beam system side-by-side with an existing dual-beam system to compare several performance attributes of the two. The split-beam system operated at a lower frequency (200 kHz) than the dual-beam system (420 kHz). Results showed that the split-beam yielded more precise measurements of target strength on the standard sphere than the dual-beam system, the split-beam measurements being 4-5 times less variable. The study recommended replacement of an existing dual-beam system with a split-beam system to improve the accuracy of estimating chinook salmon (*Oncorhynchus tshawytscha)* numbers in the Kenai River.

The ability to estimate the three-dimensional position of a target in space allows individual echoes from the same target to be linked together into one track. The trajectory of this track can then be determined. This offers considerable advancements over dual-beam for riverine applications.

The theoretical advantages of a split-beam system over a dual-beam system in riverine applications can be summarised as follows:

- data such as fish velocity, trajectory and horizontal and vertical distributions can be obtained under changing environmental conditions giving in sit fish behavioural information,
- the known trajectory of targets through the beam allows counts to be adjusted to discriminate downstream targets, thus reducing overestimates of migration runs,
- the known spatial position of each target allows accurate mapping and aiming of the beam along the river bottom,
- split-beam has better performance in the presence of noise (noise can limit the accuracy of fish TS measurements),
- split-beam target strength estimates are more accurate and less variable than those for dual-beam,
- the split-beam technique locates targets within the beam with much greater resolution than for dual-beam systems,
- the ease with which field calibrations can be carried out allows more accurate and frequent *in situ* tests, thereby allowing equipment malfunctions or changes in performance to be detected swiftly.

2.3 Specialised Techniques

2.31 Frequency Modulation (FM Slide or Chirp)

Most acoustic systems designed for fisheries and plankton research use continuous wave (CW) pulses. In general, the spatial resolution of a signal is determined by the pulse width and the signal-to-noise ratio is determined by the energy of the signal. For CW pulses, increasing the energy decreases the resolution and vice versa, since spatial resolution is improved with a smaller pulse width and energy is proportional to pulse width.

The spatial resolution of a system can be calculated by multiplying the speed of sound in water by the pulse width and dividing by two. For example a 1msec CW pulse will have a range resolution of 0.75 m and a 0.5 msec pulse will have a resolution of 0.375 m.

To be able to resolve fish travelling close to each other it is therefore necessary to decrease the pulse width, but this also has the effect of reducing the transmit power. Therefore, with a continuous wave pulse there is always a tradeoff between spatial resolution and signal-to-noise ratio. The electronics required to both generate and receive this type of pulse are relatively simple.

In theory, one way to avoid the dilemma of trading signal-to-noise performance with spatial resolution is to use alternate signal waveforms. FM Slide (or Chirp) effectively provides a shorter pulse width resulting in good spatial resolution but maintains a high transmit power and good signal-to-noise.

The FM Slide waveform varies the frequency of the sinusoidal wave within the pulse. The processing gain then measures the increase in signal-to-noise ratio achieved by using the chirp signal with an equivalent spatial resolution. FM slide can potentially improve signal to noise ratios in non-reverberant environments such as lakes by over 15 dB (J. Ehrenberg, pers. com.).

In riverine environments the major source of noise is reverberant (from entrained air, bottom structures, etc.) and this masks the effect of FM Slide. The River Wye system shows little difference between an FM Slide signal and a CW signal although small improvements have been reported from the River Chandalar in Alaska (D. Daum, pers. com.).

2.32 Multiplexing

Multiplexing refers to transmitting and receiving on two or more transducers using one echosounder. This can be done by alternating transducer sampling on a time basis (slow multiplexing) or alternating on a ping by ping basis (fast multiplexing).

When slow multiplexing, a system samples one transducer for a given amount of time before effectively switching it off and sampling on subsequent transducers. Since there is a slight delay between one transducer switching off and another switching on, no interference or crosstalk between transducers occurs.

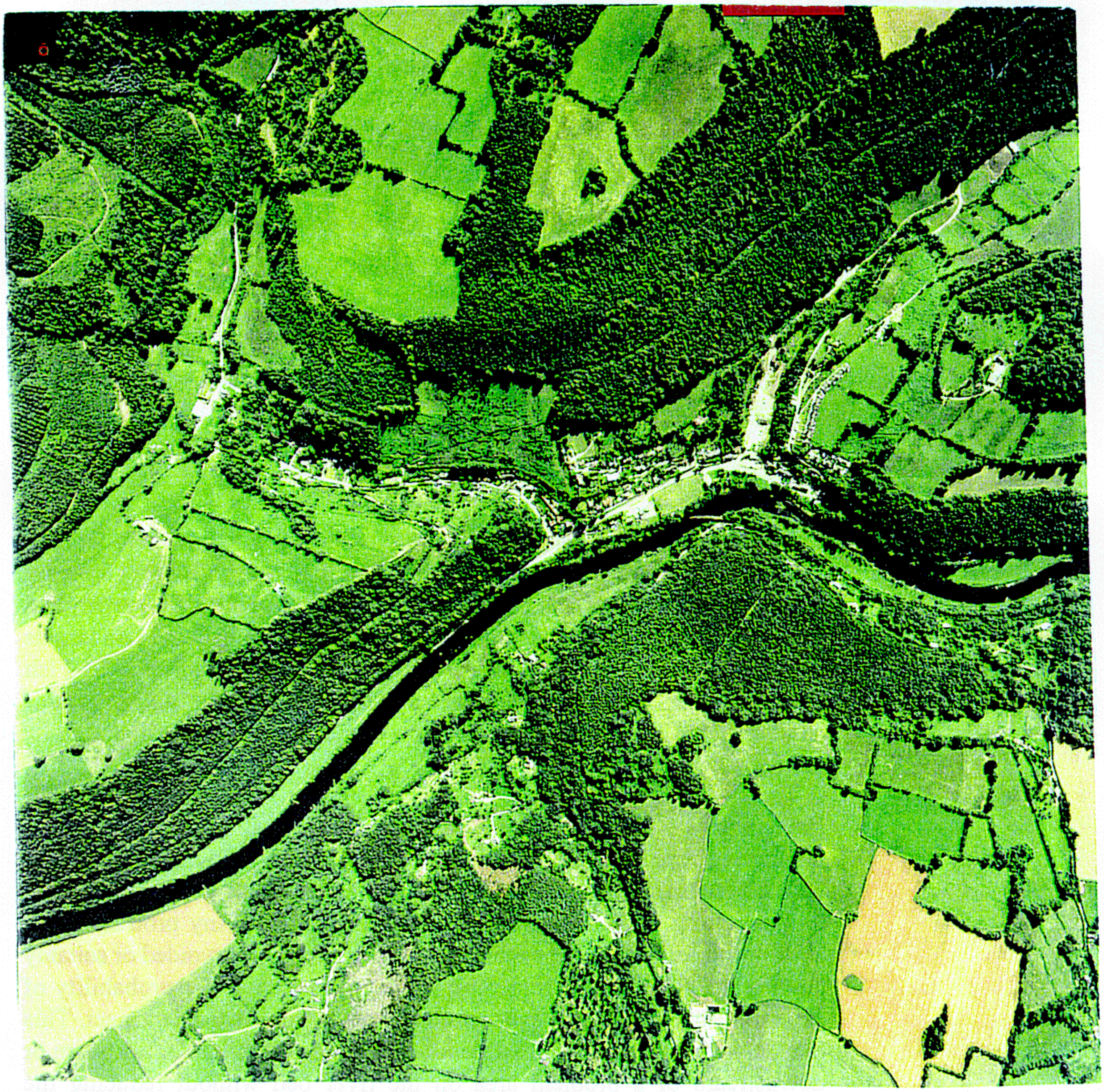
Slow multiplexing sacrifices sample time per transducer in favour of increased sample area. Total counts can be extrapolated from the period sampled.

Fast multiplexing effectively allows two or more transducers to be sampled simultaneously. This is achieved by sampling each transducer on alternate pings. For example, a system fast multiplexing between two transducers with a total ping rate of 40 would be continually transmitting at 20 pings per second on each one.

Theoretically, interference between two fast multiplexing transducers would place restrictions on how close together the two could be placed on the same bank. It may not be possible to place transducers within 50 metres of each other at some sites.

Slow multiplexing has been used on the River Wye system, both for transducers on opposite sides of the river and for transducers deployed side by side.

The River Wye at Redbrook



3.0 The River Wye Site

The selection of a site suitable for acoustic monitoring is the most important single criterion in survey design.The mobility of the equipment makes several site trials possible and it is important to utilise this capability. Rivers are acoustically noisy environments and a key objective of site selection is to maximise the signal-to-noise ratio to discriminate targets from background noise.

Unlike the marine environment, riverine deployments require the transducer to operate in shallow waters, aimed horizontally not vertically. The acoustic beam transmitted by the transducer can be simplistically visualised as a torch beam where the cross sectional area increases with range from the transducer. A site has to be selected that will enable this beam to maximise the coverage in areas of fish passage and reduce the opportunity for fish to migrate undetected.

A list of criteria for selecting an acoustic monitoring site was developed as a result of the experience gained from the Wye.

3.1 Decision Criteria for Site Selection

In looking for a site there are three main areas for consideration. These can be split into physical, biological and logistical variables.

Physical

Flow characteristics: The river profile should be low to moderate laminar flow with no entrained air. Air bubbles (like fish swim bladders) are very good sound reflectors and can look like fish to both acoustic system and operator. They can also mask the reflected sound from genuine fish targets and reduce the systems ability to detect fish at lower thresholds. Fish behaviour is more likely to be consistent when they pass through an area of laminar flow. The absence of good flow conditions at a site will curtail its use for acoustic monitoring.

Bathymetry: It is essential to obtain bottom profiles of all potential monitoring sites. Ideally, the site should have a flat, gently sloping bottom with a triangular cross section. The acoustic beam should be able to fit close to the bottom and cover as much area as possible. Any protrusions or hollows where fish could pass undetected will need to be avoided or suitably engineered. It should be remembered that to maximise the probability of detecting fish it is necessary to ensonify targets in direct side aspect. This means that it is often not possible to aim the transducer either upstream or downstream of a problem area on the river bed without reducing the efficiency of the acoustic system to detect fish. It may be necessary to deploy more than one transducer at a site in order to obtain adequate coverage. This will raise further logistical considerations. The profile must also be deep enough at the furthest ranges from the transducer to an acoustic beam without hitting either the surface or bottom. Experiences on the Rivers Wye and Spey have shown that the effects of wind, rain, hail and snow together with surface borne debris make it desirable to avoid aiming the beam near the water surface.

Bottom Substrate and bedload movement: It is preferable to have a substrate that has as low an acoustic reflectivity as possible. Mud and silt is almost acoustically invisible and so allows the beam to be aimed very close to the bottom. Reflectivity increases with the size of the substrate components so that gravel would make a good acoustic site and large, angular cobbles and boulders would make a very poor, if not impossible site. An artificial substrate has been created on a tributary of the Fraser River in Canada using sandbags. This substantial manipulation of the river bed enabled the acoustic beam to be aimed close to the bottom with a moderate amount of maintenance (Enzenhofer and Olsen, 1996).

It is obviously desirable for the substrate to remain stable throughout the monitoring period.

Tidal Influence: This should be avoided. Where a salt wedge exists the change in density will either act as a barrier to sound or deflect sound waves as they pass through it. Daily changes in water levels can be logistically difficult to compensate for.

Temperature and turbidity: Temperature effects the speed of sound in water and turbidity effects the rate of signal absorption. The degree to which these two have an effect will depend on the frequency of the system but will have an almost negligible impact on ranges under 50 metres.

Debris Load: Sites with a moderate to high debris load should be avoided. Surface borne debris is not usually a problem unless it is a requirement to aim the transducer near the surface. Sub-surface debris however, while being difficult to observe visually can have a large acoustic impact. Even under low flow conditions, downstream drifting macrophytes and submerged logs provide enough of a target to be either mistaken as a fish or mask true fish movements.

Background Noise Levels: This is any noise that is not generated by the acoustic system. This could be from wind or waves on the water surface, animal movement, rocks rolling along the bottom or boat traffic. A site with a signal to noise ratio of less than 7dB should be avoided.

Biological

Species Apportionment: It is currently not possible to separate salmon from sea trout based on the acoustic characteristic of the returning echo. Therefore, in rivers where both species are present, a method of apportioning relative abundance will be necessary.

Horizontal Distribution: Fish passing through the acoustic beam at a range of less than 5 metres from the transducer are very difficult to interpret acoustically and can be very misleading. Situations where a significant proportion of the target species are passing the transducer within 5 metres should be avoided. On a few sites in North America, an artificial weir has been constructed to deflect fish away from the transducer.

Fish Behaviour: Fish must be actively migrating past the sample site. Any fish holding or milling in the beam makes interpretation very difficult and leads to over counting. Spawning areas should be avoided as should close proximity to a confluence. In both cases, fish could move up and down stream several times.

Non-Target species: Sites with resident non-target fish species close to the size of the species of interest will prove problematical as they can pass backwards and forwards through the beam several times a day.

It is advised that the failure to meet the above biological criteria be treated as a fatal flaw in the site and an alternative investigated.

Logistical

An adequate, dependable power supply is essential. The site and equipment needs to be safe from vandalism, attack by rodents and interference from extreme river flow and weather conditions. A telephone line for both voice and modem communications is invaluable.

As with other types of fish counter it is important to be able to independently assess the data obtained from an acoustic site. The data is open to a certain amount of interpretation so the ability to validate the site and equipment is an important consideration.

The physical characteristics are relatively easy to determine. Although a lot can be gleamed from site visits during low flow and high flow conditions (sites may become much less suitable on higher river flows), depth profiles are a must for any potential site. Profiles can be obtained using a boat and plumb line and if care is taken then they can produce accurate results. The river bed needs to be mapped in a band wide enough to fit the transducer beam at its greatest range (a 10° transducer will have a beam width of almost 4 metres at 20 metres range). This takes time to do by plumb line. There are however, a number of companies that will accurately map the river bed using specialised survey equipment. Though expensive, they can cover a much greater number of sites than more conventional methods and offer a cost effective way of surveying a large area.

Certain physical problems can be engineered away. Boulders can be removed, hollows can be filled and even the substrate can be replaced. Such civil works may require an ongoing maintenance program and effect fish behaviour.

The biological characteristics can be the most limiting and the hardest to determine. Information may be available from radio tracking studies or visual observations by local anglers or fishing guides and all such data is invaluable. However, hydroacoustics has the potential to monitor fish behaviour in a way that no other technique is capable of. One of the inherent problems of this is that it can be difficult to tell if a site is good for acoustic monitoring until you have actually deployed it and gathered sufficient data. Therefore, as much as the first year of deployment should be regarded as a trial period before the site is made permanent.

3.2 Selection of the Redbrook Site

The site on the River Wye selected for counter deployment was at Redbrook, 5 km below Monmouth (National Grid Ref. SO 527 112). Initial assessments confirmed that a number of transects with the potential for acoustic monitoring exists in the reach. A gauging station on the river bank was used to house the equipment and this largely resolved the logistical aspects of counter operation, although a generator had to be used to supply power to the site during the initial trials until the hut could be connected to mains electricity.

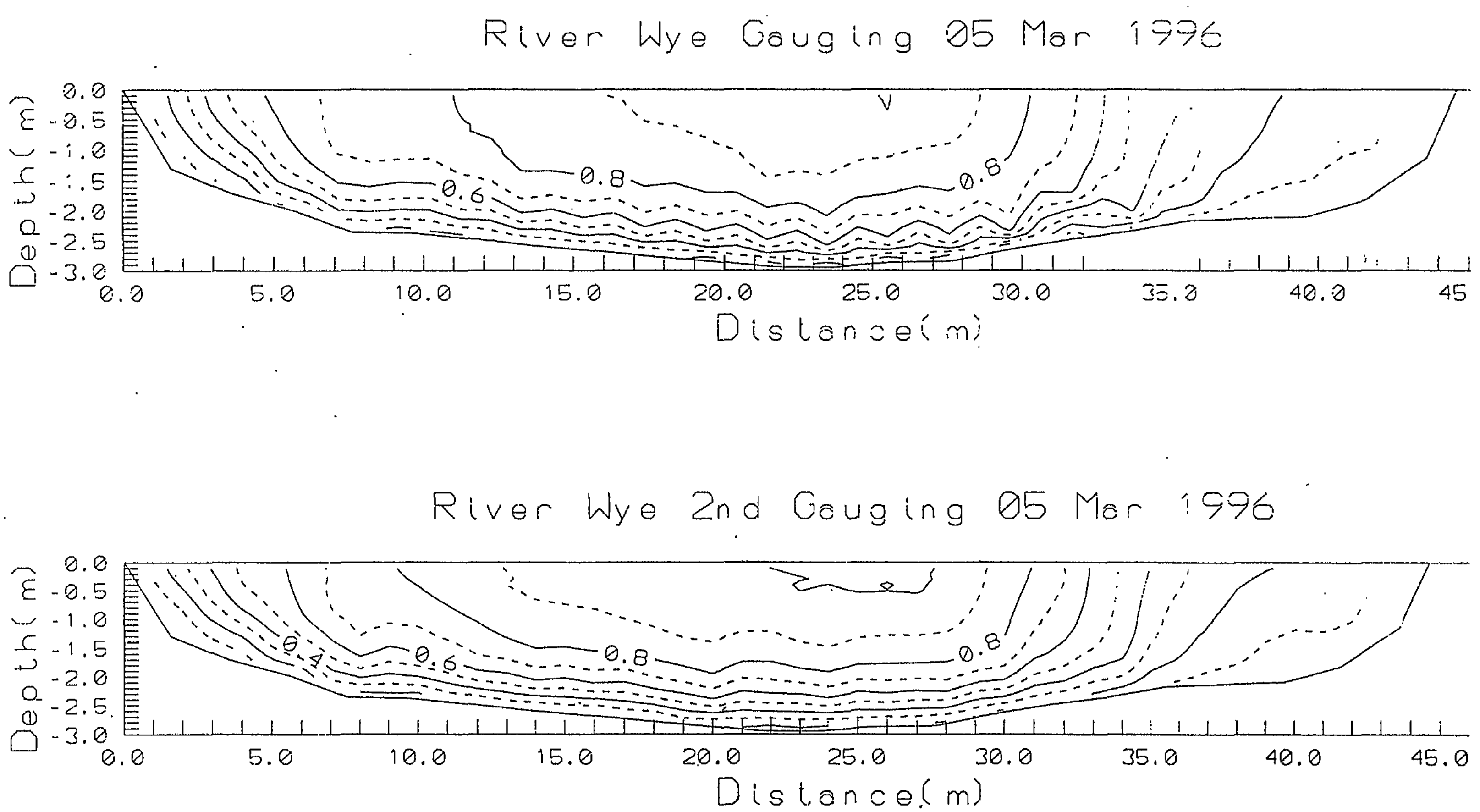
The inherent resistivity of the counter equipment and cables restricted the maximum distance between transducer and power source was 350 metres. Several trials were conducted, commencing from immediately adjacent to the gauging hut and working downstream in order to identify the optimum sites.

Three potential sites were identified; in front of the gauging hut, 200 metres downstream of the hut (opposite a fishing croy) and 250 metres downstream of the hut.

Accurate depth profiles of each potential site were obtained using a conventional depth sounder with a hard copy paper printout. Deployment was carried out at each and evaluated for at least 24 hours.

For each trial the transducer had to be temporarily mounted on a portable mount and secured to the river bed. The transducer was attached to a pan and tilt rotator that could effectively aim in any direction.

The site finally chosen was approximately 250 metres downstream of the gauging hut.



Velocity contours in m/s

Gaugeboard reading 1.4m   Telegen level at start of first gauging 11am GMT 1.375m   Telegen level at end of second gauging 2pmGMT 1.380m

Telegen water temperature at start of first gauging 11am GMT 6.1 deg C   Telegen water temperature at end of second gauging 2pmGMT 6.2 deg C

Figure 3.1 Velocity. Profiles of the Redbrook Acoustic Site.

Further details of the site selection process at Redbrook can be found in the Annual Reports for the project (Gregory (1995); Gregory and Clabburn (1996)).

A summary of the considerations for the choice of site on the Wye are presented below.

Physical Characteristics

Flow: The water velocity of the three sites ranged from approximately 0.2 to 1.0 m/sec, with an average of approximately 0.5 m/sec. The site 200 metres downstream of the gauging station, directly opposite the fishing croy, was identified as unsuitable for hydroacoustic monitoring due to the irregular flows caused by this croy. Turbulence and back flowing eddies were of concern. Local information and visual observations by Agency staff indicated that the chosen Redbrook site experienced moderate, laminar flow across a range of environmental conditions.

Velocity profiles were obtained for the chosen deployment site. These were measured during a period of elevated flows in March 1996 and are presented in Figure 3.1.

Bathymetry: A profile of the river bed was obtained for all the sites. The profile of the preferred site is shown in Figure 3.2.

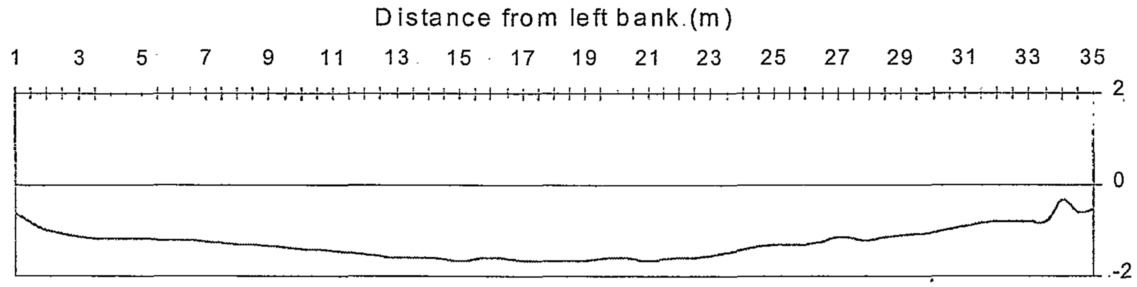


Figure 3.2 Depth profile of preferred site at Redbrook

This profile suggested that an acoustic beam could be aimed from the left bank and achieve coverage of the river bottom to a distance of 23 metres.

Information supplied by local fishermen and the Ghillie for the fishing beat suggested that fish passage on the remaining section of river (i.e. from 23 metres to the right bank) was minimal due to the presence of a croy 50 metres upstream. This area was identified for future investigation.

Unsampled areas also exist at a range of three metres from the transducer. Due to the size of the beam at this point it is probably not feasible to enumerate salmon passage at ranges of less than 5 metres. It was accepted that should fish movements be detected at ranges closer than this, a deflection weir would be considered to force fish away from the bank.

Bottom substrate: The site directly opposite the gauging station was deemed unsuitable for hydroacoustic monitoring due to the presence of several large boulders. This uneven bottom would prevent close aiming of the beam to the river bed and thus provide unsatisfactory monitoring. Artificial smoothing of the river bed was not seen as an acceptable solution. The chosen site has a bottom substrate composed of sand to rounded cobble of 6 cm.

Tidal influence: The Redbrook site is approximately 5 km above Bigsweir and well above tidal influence.

Temperature and turbidity: In the absence of tidal influence, water quality is rarely a significant factor effecting hydroacoustic monitoring at the ranges commonly used in riverine applications. At Redbrook, turbidity ranged from 0.4 to 28.0 FTU (Formazene standard Turbidity Unit), and was generally 1-10 FTU (with a mean of approx. 5 FTU). Water temperatures generally ranged from 3 to 25°C. Particulate solids ranged from 2 to 370 mg/l, but were generally 2-100 mg/l (mean = 19 mg/l).

The primary issue is the potential influence that these characteristics can have on signal attenuation, absorption and/or the speed of sound in water. None of the levels of the hydrochemical characteristics presented above would significantly affect these hydroacoustic parameters.

Debris load: The site directly opposite the gauging station was assessed as unsuitable, not only due to the presence of large boulders, but also due to dense growth of *Ranunculus fluitans* in the summer months. This weed growth both added to the debris load but more importantly, rooted strands of weed continually undulated in and out of the beam. The mass of macrophyte tissue and associated entrained air provides a highly reflective surface for the acoustic beam. This not only creates acoustic targets, but also prevents close aiming of the beam to the river bed. At the chosen site some weed growth during the summer was apparent (*R. fluitans* and *Potamogeton perfoliatus*) but it was determined that regular cutting prevented weed interference with the acoustic monitoring. It has been accepted that the River Wye has a high debris load due in part to excessive macrophyte growth, this being one of the more rigorous challenges to the technique.

Background noise levels: Background noise levels along this stretch of the Wye were initially measured using a dual-beam hydroacoustic system. Acoustic data was collected over two days with high flows and high turbidity levels. This represented a relatively noisy environment. Data from a standard target of -38.5 dB showed background noise levels that were approximately 18 dB below the maximum amplitude of the standard target (i.e. approximately -58 dB). The size of Atlantic salmon on the Wye were expected to be larger than -30 dB. With an ambient background interference level in the river approaching -60 dB it was concluded that acoustic signals received from fish should easily exceed background noise signals.

Biological characteristics

Biological characteristics of the monitored stock can be difficult to assess ahead of acoustic system deployment. Often reliance is placed on local knowledge, expert opinion and assumption. Acoustics can however, reveal information on fish behaviour in a unique way that no other technique can and this may challenge these assumptions.

Species apportionment: As sea trout and salmon are acoustically indistinguishable, non-acoustic methods would have to be used to apportion species should sea trout be present. The Wye has never been a sea trout river. An examination of the catch data from the last 10 years of the Wyesham fishery (of which the Redbrook site is a part) revealed that for each season sea trout constituted less than 1% of the total fish catch, with five of the years reporting no sea trout catch at all. However, as anglers do not fish for sea trout on the Wye, this may not be a true reflection of sea trout stocks.

Horizontal distribution During the initial site visits and discussions with the Wyesham ghillie, it was suggested that salmon tended to actively migrate further out towards the centre of the river and that salmon movement close to the left bank, by the transducer mount, was minimal.

Fish behaviour Local information indicated that fish did not generally hold station or mill in this area. Adult salmon were thought to migrate through the area directly, with no delay. The fishing croy, positioned approximately 50 metres upstream, provides a deep pool intended to cause fish to hold up. It was thought that the distance between this pool and the chosen site was sufficient to prevent these resting fish from interfering with the monitoring of actively migrating salmon at the chosen site. The main salmon spawning area on the Wye is in the upper catchment well above Hereford, which itself is approximately 70 km upstream from the site at Redbrook. However, habitat suitable for spawning occurs as far down as Brockweir, in the tidally influenced reach below Redbrook. Spawning this far down occurs but is uncommon, and as no suitable spawning habitat is present within at least 3 km either side of the Redbrook site, this type of fish behaviour was not expected to affect monitoring.

Examination of rod catch records from the fishery shows that migration occurs throughout the year, but is predominant during March through October, peaking in the period August through to October. The angling season on the Wye is from 26th January to the 17th October, although the season extends to the 26th October on the upper Wye.

Non-Target species

Information from local coarse fish anglers and the ghillie indicated an absence of coarse fish of a size to influence monitoring. However, it was recognised that investigations would be necessary to determine the extent to which non-target species were present within this stretch of river.

Logistical Considerations

The selected site is approximately 250 metres downstream from Redbrook gauging station. Access to this site therefore already existed and the station provided a dry and secure building for the hydroacoustic electronics. Power supply and telephone lines were added.

3.3 Construction of a Transducer Mount

For the collection of accurate and consistent data it is vital to mount the transducer and rotator on a stable platform, robust enough for the range of flows anticipated that would also allow safe access to the transducer.

The transducer mount constructed at Redbrook was designed as a mono rail system running from the top of the river bank to the river bed. A trolley with transducer and rotator attached could be winched up and down the rail and locked into place on the river bed. The overall length of the rail was 14 metres and the weight exceeded 3 tonnes. It was dug into the river bank and fixed with concrete filled sand bags. When locked into position, the transducer was 1.5 metres away from the base of the river bank.

No river bed manipulation was necessary and the total cost of construction and installation was under £3000.

The Wye mount is shown as a diagram in Figure 3.3. Photographs of both the trolley and slide are shown in Figure 3.4.

Temporary transducer mounts were also deployed on the Wye. These consisted of two upright scaffold poles of 1 metre in length, joined by a cross piece. A rotator and transducer could be attached to the cross piece and hung underneath. Joined at right angles from the bottom of the uprights were two more metre lengths of scaffold on which sandbags could be placed to stabilise the structure. Photographs of temporary transducer mounts are shown in Figure 3.5.

Cross - section view of the transducer mount

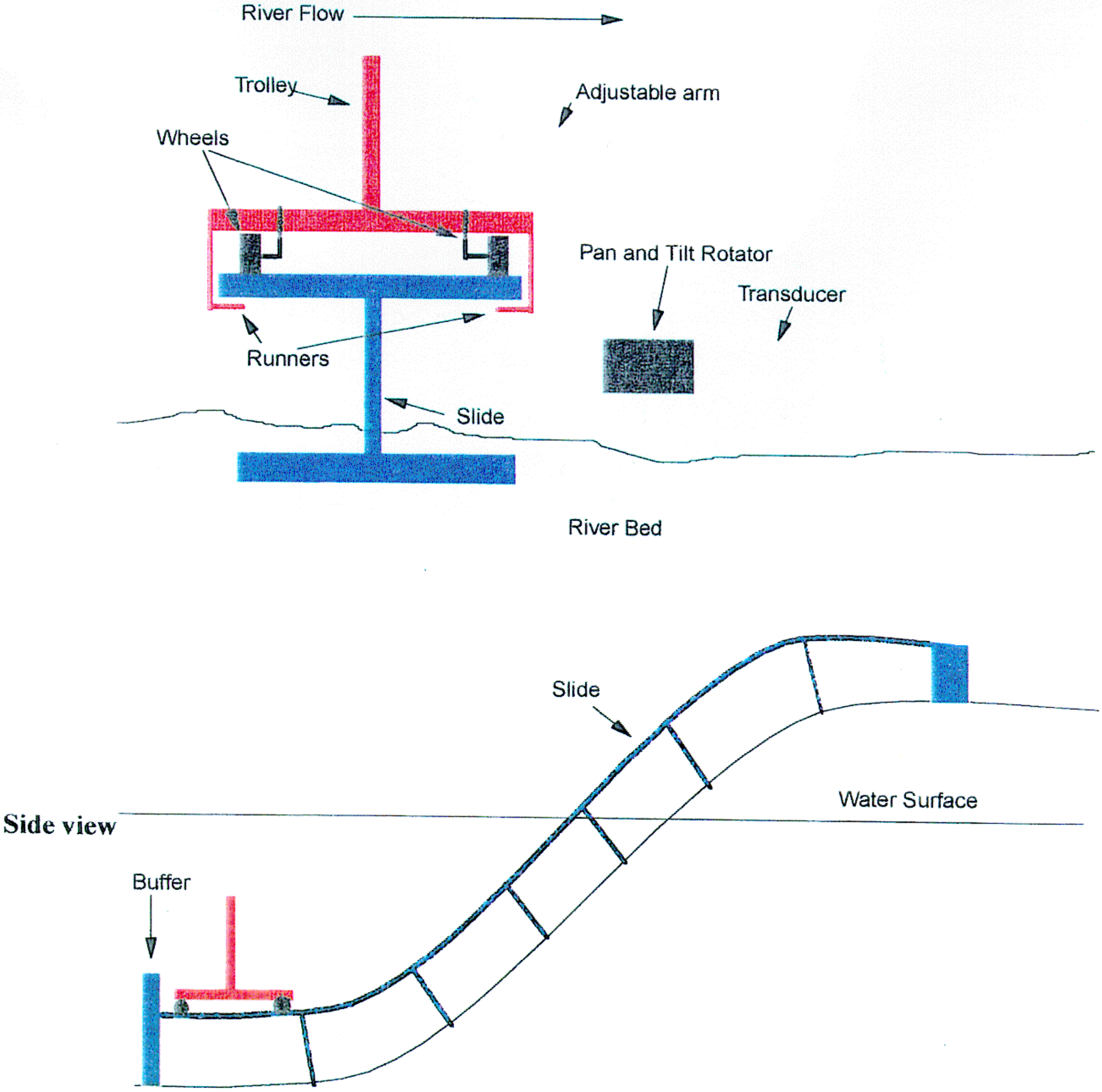
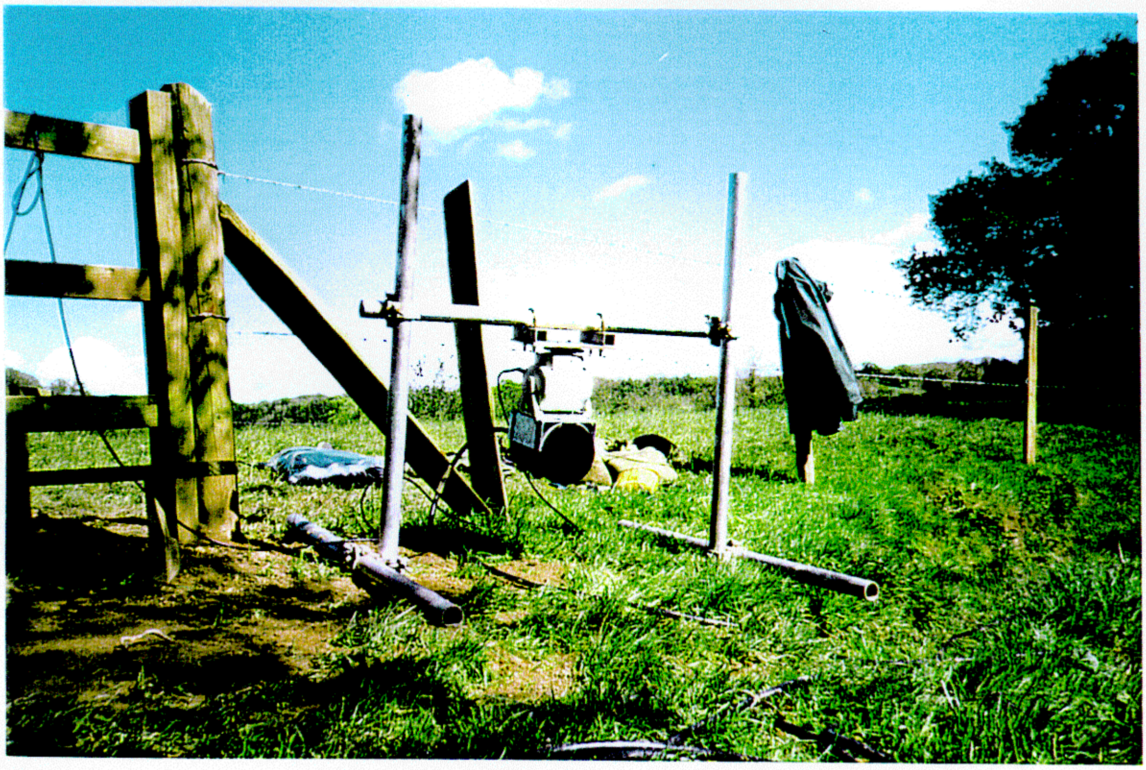


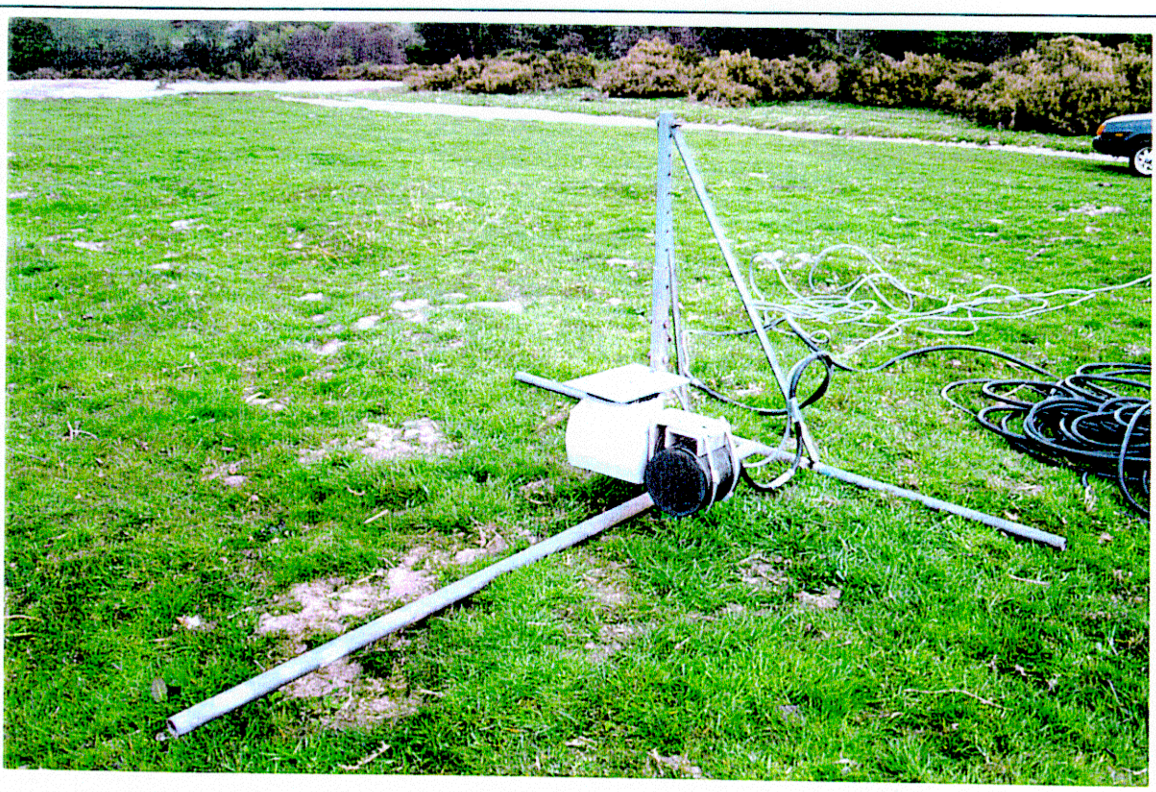
Figure 3.3 Diagram of the "slide and trolley" mount designed for the Wye.

The transducer is attached to a trolley that can be winched down a slide. In this picture, two transducer/rotator pairs are mounted on the trolley.

The trolley is locked into position at the bottom of the slide.
Figure 3.4: Photographs of the Wye mount.



A temporary transducer mount used on the Wye.



The transducer mount designed for the River Spey.

Figure 3.5: Photographs of two types of temporary transducer mount.

4.0 Counter Operation

The acoustic counter under assessment on the River Wye was an HTI model 243 split beam system with FM Slide capabilities. As with any acoustic system, this comprises transducer and processor components centred around an echosounder. It is the echosounder that controls the transmission, reception and amplification of signals and the precise timing of functions. A personal computer (PC), networked to the echosounder, analyses, displays and outputs the data. The HTI system can be seen in Figure 4.1.

Figure 4.1. HTI echosounder, echo processor and peripheral equipment deployed on site.

This section describes the structure and operation of the commercially available HTI system.

4.1 Digital Echo Sounder

The HTI Model 243 split-beam system is a scientific echosounder designed for fisheries and other biological research. The echosounder generates an electronic pulse which is transmitted into the water as high frequency sound by a transducer. Before sending the next pulse, the transducer receives any returning echoes from objects in the water. Received echoes are converted back into electrical signals by the transducer and sent to the echosounder where they are digitised. A real time display of detected echoes is produced by the echo processor and a summary of target strength, range and depth of each echo is given. This information for each echo is stored within a raw data file on the PC.

The automatic tracking facility of the echo processor assimilates echoes together that come from a likely single fish target. The decision parameters used to filter echoes and associated fish targets are user changeable. The collection of echoes is stored as a single fish track event in two separate data files.

The various components of the split-beam system are outlined in Figure 4.2.

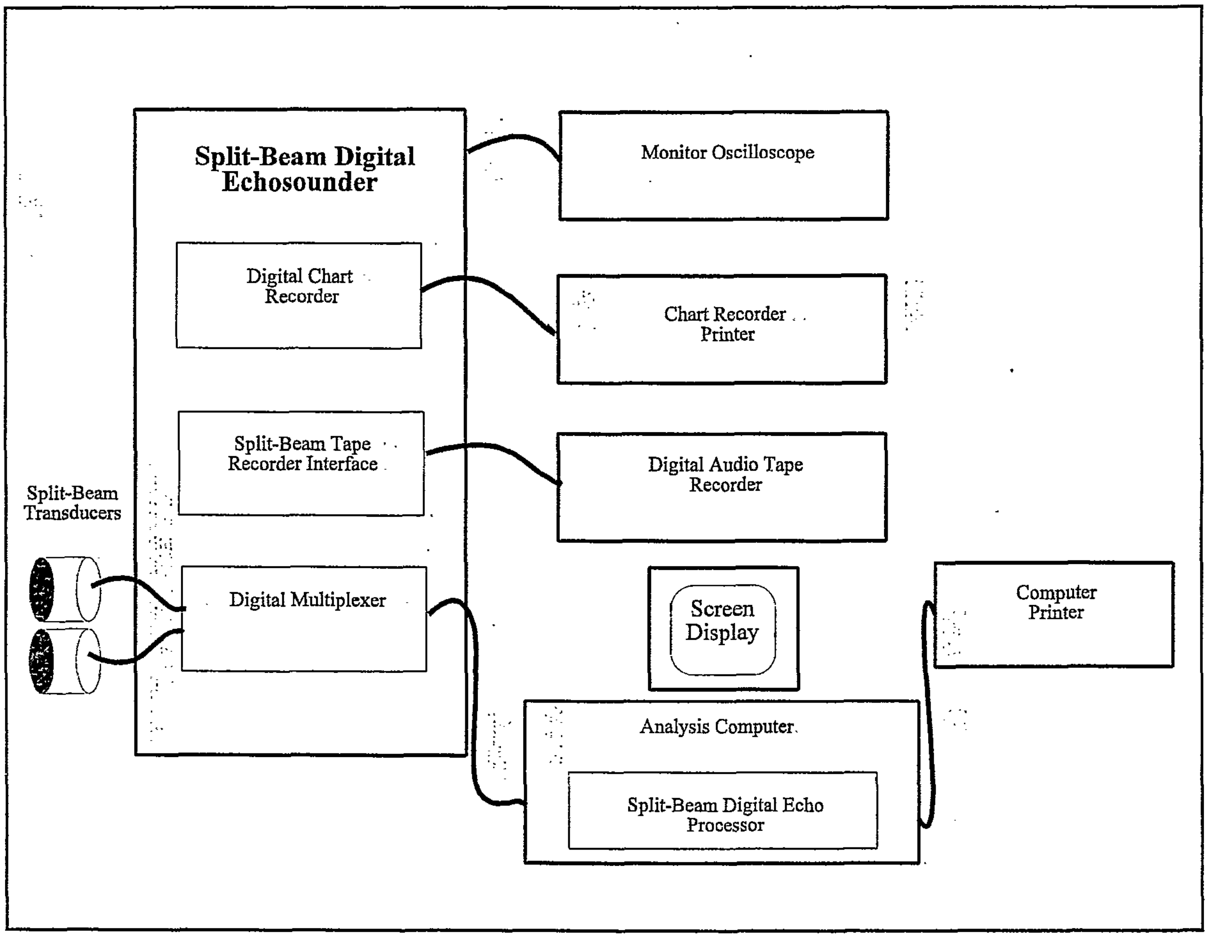


Figure 4.2 Diagram of the Model 243 Split Beam system used on the Wye

A multiplexer capable of switching between two transducers is incorporated into the sounder. Transducers can be sampled either randomly or sequentially. It also has interfaces for a paper chart recorder and digital tape output.

The technical specifications of the 243 echosounder used on the Wye are shown in Appendix 1.

The properties of the signal transmitted by the sounder can be altered via an interface with the echo processor.

4.2 Digital Echo Processor

The Digital Echo Processor (DEP) is a desk top computer with specialised hardware and associated software installed to process the signals received from the echosounder. The echosounder and echo processor are networked together and all parameters for both signal generation and processing criteria are changed through this network interface.

A minimum specification for an echo processor can be found in Appendix 1.

The echo processor assesses whether an echo meets the selection criteria for it to be stored. This is based on many parameters such as pulse width; signal strength and range from the transducer.

During automatic tracking a software program called Tracker discriminates and filters out echoes from single fish targets in real time. Data for each individual echo of the fish "track" is stored. The criteria the program uses for this can vary between sites. Fish tracking is controlled by up to nine user changeable parameters. An example of these parameters and typical values used on the Wye are shown in Appendix 2.

The echo processor stores all data in up to four different files with the file name ***.raw**, ***.ech**, ***.fsh** and ***.sum**. The prefix * is a number made up of the Julian date and time at which the file was created. All output files are written in ASCII format and can be easily edited or exported into spreadsheet packages.

The ***.raw** files contain information on every echo detected by the echosounder. It therefore contains data on all untracked echoes and echoes from tracked objects. These files can become very large under certain conditions. On the River Wye during high flow conditions, up to 10MB of data per hour can be stored in these files so sufficient memory must be present on the Processor's hard drive.

The ***.raw** file contains data under the following headings:

1. Ping Number
2. Distance to target in metres
3. Amplitude of target echo in volts

4. Pulse width at 1/2, 1/4 and 1/8 amplitude points (in digital samples)
5. Echo angle off-axis in the horizontal plane
6. Echo angle off-axis in the vertical plane
7. Transducer port number.

Files with the ***.ech** extension are similar in format to the ***.raw** files but only contain data from those echoes that make up a tracked fish. All other echoes are excluded. The raw echoes that comprise each track in the ***.ech** file are still duplicated in the ***.raw** file.

The ***.ech** file contains data under the following headings:

1. Tracked fish number
2. Ping number
3. Metres left or right of acoustic axis
4. Metres above or below acoustic axis
5. Range of echoes in metres
6. Pulse width at 1/2, 1/4 and 1/8 amplitude points (in digital samples)
7. Amplitude of echo (sum channel in volts)
8. Overall beam pattern factor
9. Average target strength

The ***.fsh** files are a summary of all the data collected for each tracked fish target. A line of data describes each fish track and contains the following information:

1. Tracked fish number
2. Start ping number
3. End ping number
4. Number of accepted echoes
5. First **x** coordinate (metres from acoustic axis)
6. First **y** coordinate (metres from acoustic axis)
7. First **z** coordinate (metres from transducer face)
8. Distance travelled in **x** plane (metres)
9. Distance travelled in **y** plane (metres)
10. Distance travelled in **z** plane (metres)
11. Average swimming speed (average of each ping to ping speed measurement)
12. Mean target strength of all tracked echoes
13. Transducer port number

A simple Cartesian **x**, **y**, **z**, coordinate system is used for target positioning. The **x** direction is the upstream/downstream direction, where positive numbers are to the right and negative ones to the left. Surface to bottom numbers are given by the **y** coordinate, where positive numbers are toward the surface and negative numbers toward the bottom. The **z** direction is the target's range from the transducer, where the transducer face is at range 0.

The ***.sum*** files summarise the tracked fish data for either every hour or every 24 hours. They contain information on the following:

1. Transducer port number
2. Start time of summary
3. End time of summary
4. Total sample time
5. Number of echoes
6. Number of tracked fish
7. Weighted fish passage (e.g. entrainment)
8. Estimated fish passage
9. Cumulative fish passage
10. Mean target strength
11. Mean fish velocity

4.3 Transducers and Cables

The transducers used on the River Wye were HTI Model 540 elliptical transducers, with a beam width of 2.8° high by 10° wide. An elliptical beam pattern allows greater coverage near "boundaries" such as the river bed or water surface and has a rapid increase in its ability to detect echoes from the edges to the centre, compared to circular transducers.

The transducer cables supplied with the system contained twisted shield pairs for the transmitter and pre-amplified transducer signals. Additional conductors supply power and control signals to the transducer. The cable jackets are made from highly resilient, extruded polyurethane. At Redbrook these cables are run through underground cable ducting along the bankside. This ducting provides extra protection for the cables. Three standard 82 metre transducer cable lengths required to reach from the echosounder in the gauging station, to the transducer in the river.

4.4 Peripherals

Digital Audio Tape Recorder

A DAT recorder is used to digitally record raw data in real time. This is a permanent record of echosounder signals and enables the data to be subjected to a variety of analysis techniques at a later date. This is useful in comparing the effect different parameter settings in the sounder have on the overall performance of the system.

Monitor Oscilloscope

An oscilloscope gives a visual representation of the amplitude of signals received by the echosounder. It is a useful diagnostic tool and helps to aim transducers near acoustic boundaries. It is particularly useful when carrying out standard target tests and calculating background noise levels.

Chart Recorder

A continuous feed chart recorder is used to display echoes on paper printouts known as echograms. Echograms provide a permanent graphical record of fish targets and are useful in aiming transducers near boundaries such as the surface or river bed.

An example of an echogram output is shown in Figure 4.3. It is in plan view, with the transducer on the left transmitting 20 pings per second. Each dot represents an echo detected by the transducer. This example covers a time period of about 2 minutes.

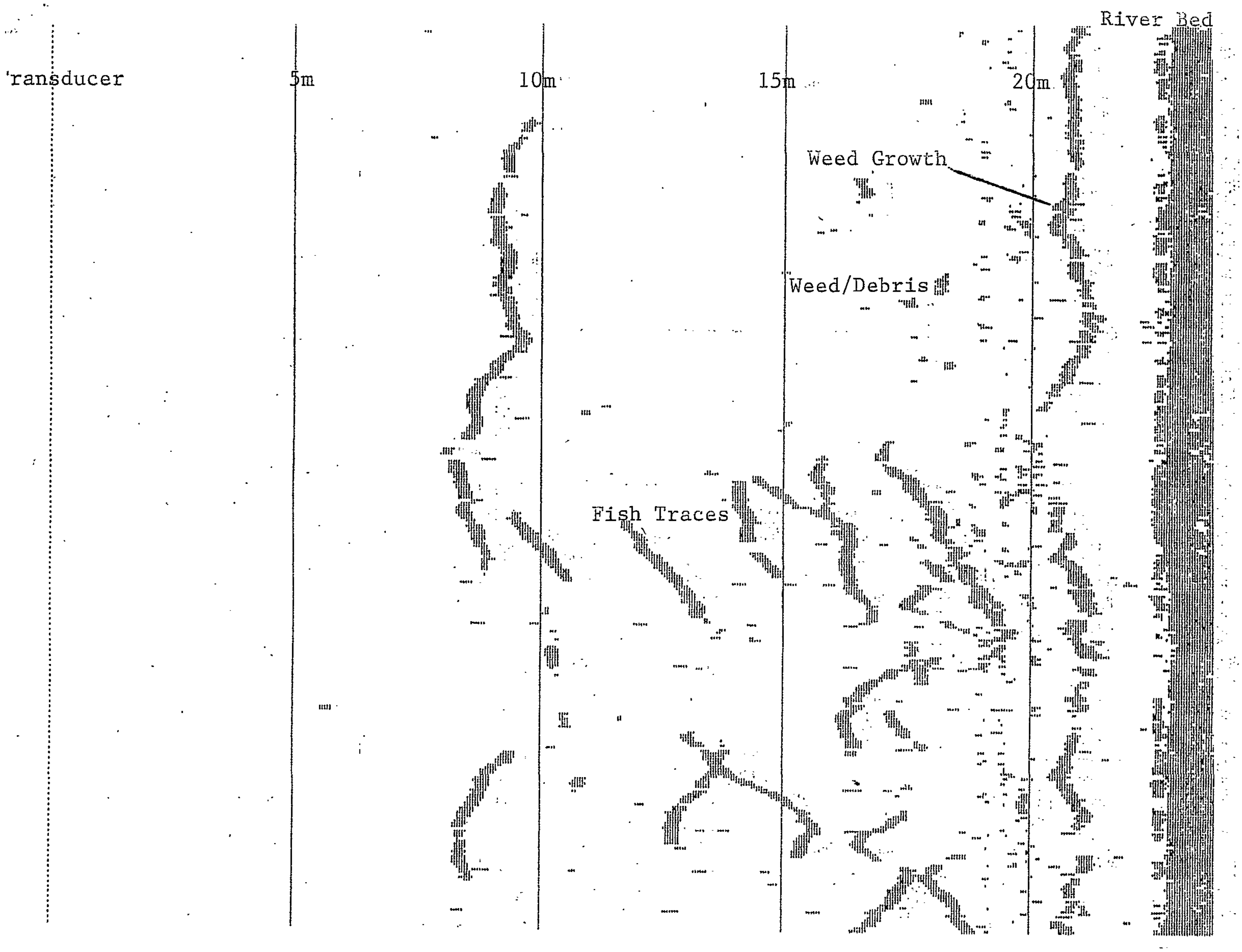


Figure 4.3. An echogram recorded during a period of heavy fish passage at Redbrook.

Pan and Tilt Rotators

The transducers used at the Wye site were mounted on pan and tilt rotators. A rotator permits accurate, precise aiming of the transducer. It also allows repeatability of position. Rotators are essential for fixed station riverine deployment.

A number of companies produce rotators suitable for underwater use. Initially, Videmech 600 series units were used. These were superseded by the much lighter and smaller 555P unit.

4.5 Post Processing Software

Part of the remit of the Wye project was to assess the efficiency of the automatic fish tracking facility of the HTI system. This assessment was largely carried out using manual post processing software (called Trakman) developed by HTI that allows all the echoes within a fish track to be examined and a three dimensional assessment of their validity to take place.

This software proved essential for enumerating fish on the Wye. The automatic tracking facility encountered numerous problems and the Trakman software (applied after data collection) was relied upon when manually verifying the presence of fish in the acoustic beam. These problems are described in Section 5.0.

4.6 Calibration

All HTI echosounders and transducers are calibrated in a laboratory by the manufacturers before supply. Overall system characteristics can vary slightly in the field and this was monitored closely on the Wye by an examination of the data on a daily basis and at least a monthly in-situ calibration with a standard target. Daily examination of target strengths would reveal any changes in trends. Large changes could indicate a problem with the system and standard target calibrations were carried out whenever this occurred.

Calibration was performed using a precisely machined tungsten carbide sphere of a known and constant target strength (-38.5 dB). The target is held in a fine nylon mesh bag and suspended in the hydroacoustic beam. An extendable, carbon fibre fishing pole is used to suspend the sphere at a range of approximately 4 metres from the transducer, until enough echo returns have been obtained for analysis (usually not less then 500). Using an adaptation of this technique it is possible to accurately map the area of water covered by the beam.

The system manufacturers, HTI, recommend the echosounder be returned on an annual basis for laboratory calibration.

5.0 Progress Against Specific Objectives

This section describes the progress made against each objective as set out in the original project plan described in Section 1.0.

5.1 Deployment Procedures

Objective:
To install a hydroacoustic counter, and to develop the deployment techniques to ensure that optimum target counting in the expected range of river flows is achieved. This will include the development of mounting and deployment equipment, examination of the aspect of the transducers in the river, and the development of control procedures for the equipment.

Following initial trials, a transducer mount was designed to remain permanently in place on the Wye for the remaining two years of the project. It consisted of a slide of 14 metres dug into the river bank with a flat platform on the river bed. The transducer and rotator unit were fixed to a trolley that could be winched down the slide and securely fixed to the underwater platform at the bottom. The transducer and rotator are located on the downstream side of the trolley and so are afforded a degree of protection from any water borne debris. Exceptionally high flows (over 340 cubic metres per second) did not cause any physical damage to the transducer or cables.

The mount is shown in Figure 3.4, Section 3.

The transducer mount was fully operational from March 1995 and the equipment was deployed for a week each in April and May. These two weeks were mainly used for equipment familiarisation and training purposes. Deployment commenced in earnest at the end of May.

The dry summer forced the removal of the transducer in late June. The flow had reached a level (10 cubic metres per second) below which it was not possible to fit the beam into the water column without increasing the interference from the water surface.

The equipment was redeployed towards the end of September and remained in river until 15th December.

During this period a second transducer was deployed directly opposite the left bank structure to investigate fish passage on the right hand bank. This second transducer was mounted on an aluminium frame. No rotator was used and the transducer was strapped directly to a cross piece. The beam was aimed towards the centre of the river, overlapping the first by 2 metres.

The system was slow multiplexed, sampling alternating between the right and left bank transducers every 10 minutes. During this time the only upstream fish movements occurred in the 2 metre overlap zone.

Data collected in 1995 relied upon manipulation of the automatically tracked targets within a spreadsheet package to discard non-fish. The specific objectives for 1995 concentrated on other areas and the resources were not available for thorough verification by Trakman.

A summary of 1995 deployment is shown below.

Left Bank Deployment		**Right Bank Deployment**	
Month	Dates	Month	Dates
April	18-21,30 (5 days)	October	18-31 (14 days)
May	1-4,29-30(6 days)	November	1-14 (14 days)
June	1-20(20 days)		
September	27-30(4 days)		
October	continual		
November	continual		
December	1-15 (15 days)		
TOTAL	111 Days	**TOTAL**	28 days

Figure 5.1 shows the daily mean flows throughout 1995 and 1996. This shows that the summer flows in 1995 regularly dropped below 10 cubic metres per second, whereas those in 1996 did not. Removal of the transducer in the summer of 1996 was not necessary although the system was turned off for 8 weeks during a period of extended low flows and minimal fish passage.

In 1996 the counter was deployed on 25th January until 29th July and from the 23rd September until early December. Data collection was continuous and verified throughout the September to December deployment. Figure 5.2 shows the verified count for this period.

The verified autumn run in 1996 occurred within a period of little more than one month from data collection. Technical problems meant that for four days data was not collected. It is possible that many fish may have passed undetected during this time as high numbers of salmon were counted on the days either side of this breakdown. This illustrates the importance of reliability for any fish counting method.

5.11 Deployment Problems

Problems with the collection of data were largely the result of operator error. This occurred less frequently with experience but provided many frustrating diagnostic sessions. The Wye system was upgraded in 1996 giving it a completely new front end operator interface. A few minor bugs in the new software caused some problems. These have been corrected by the manufacturers in later versions of the software.

An erratic power supply caused the system to crash, on numerous occasions. This was alleviated by the installation of a unit to maintain a constant power supply.

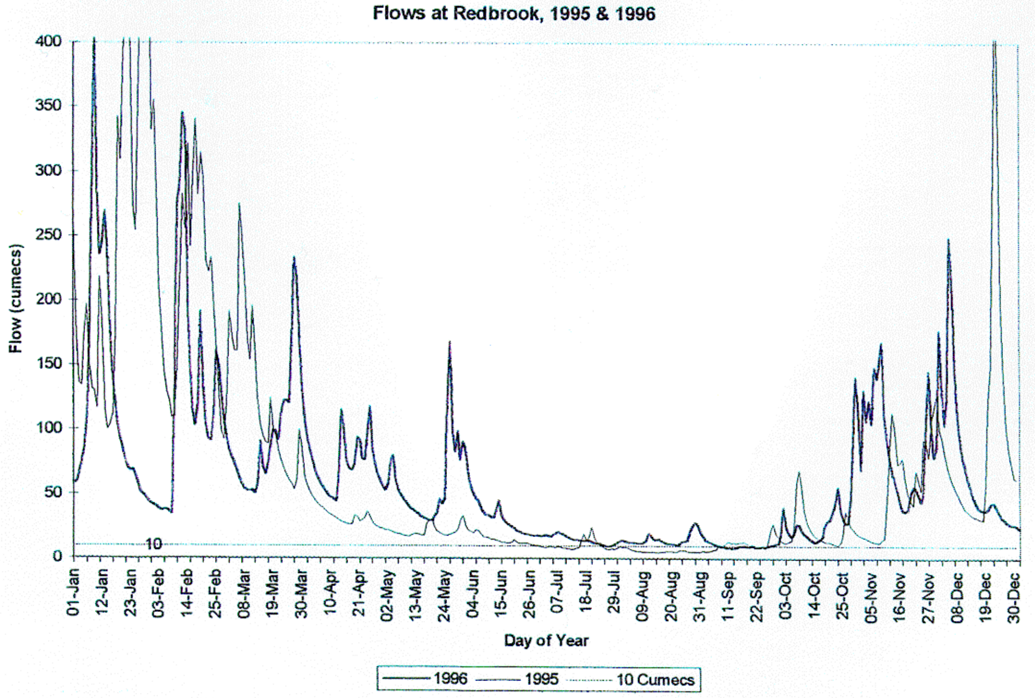


Figure 5.1: Daily mean flows throughout 1995 and 1996 (cubic metres per second).

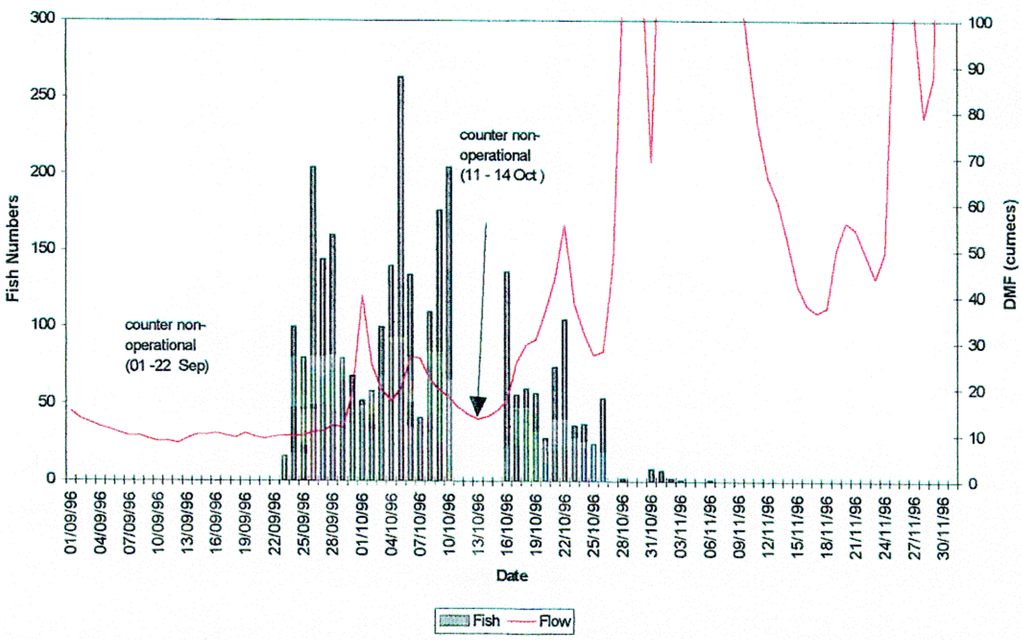


Figure 5.2: Verified acoustic fish count and daily mean flow for Autumn 1996.

The transducers appeared surprisingly robust to physical damage, with one surviving a hit by the propeller of an outboard motor with no loss of performance. However, a second transducer failed completely with no obvious cause. This was replaced by the manufacturer.

Problems were also experienced with water ingress into the rotator units.

5.2 Equipment Calibration

All Echo Sounders and transducers are laboratory calibrated by the manufacturers prior to supply. Overall system characteristics can vary slightly in the field and this was monitored closely on the Wye by monthly in-situ calibrations with a standard target.

Calibration also provides a simple diagnostic check on the system. On the River Wye this has led to the identification of operator errors in the Echo Sounder parameter settings.

The variation in target strength between consecutive echoes from a standard target is shown in Figure 5.3 and a frequency distribution in Figure 5.4. This variation, though considerable, compares favourably to that observed in other applications (Johnston and Ransom,1994, Johnston et al, 1993, Bob Laughton, pers. com.).

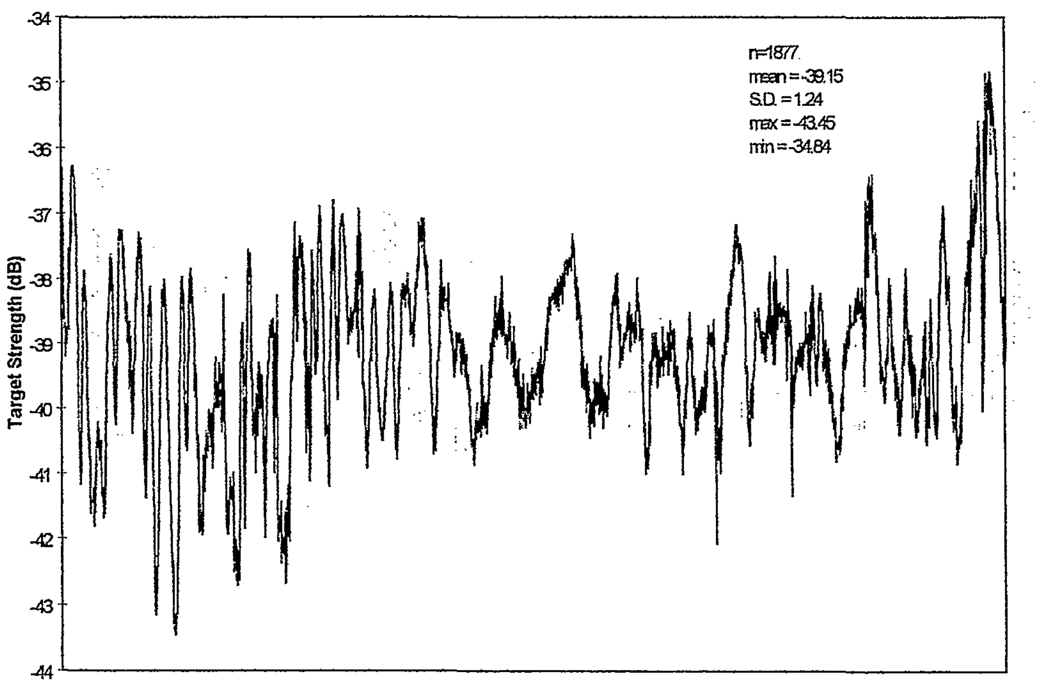


Figure 5.3: Ping to ping target strength variation during a standard target test.

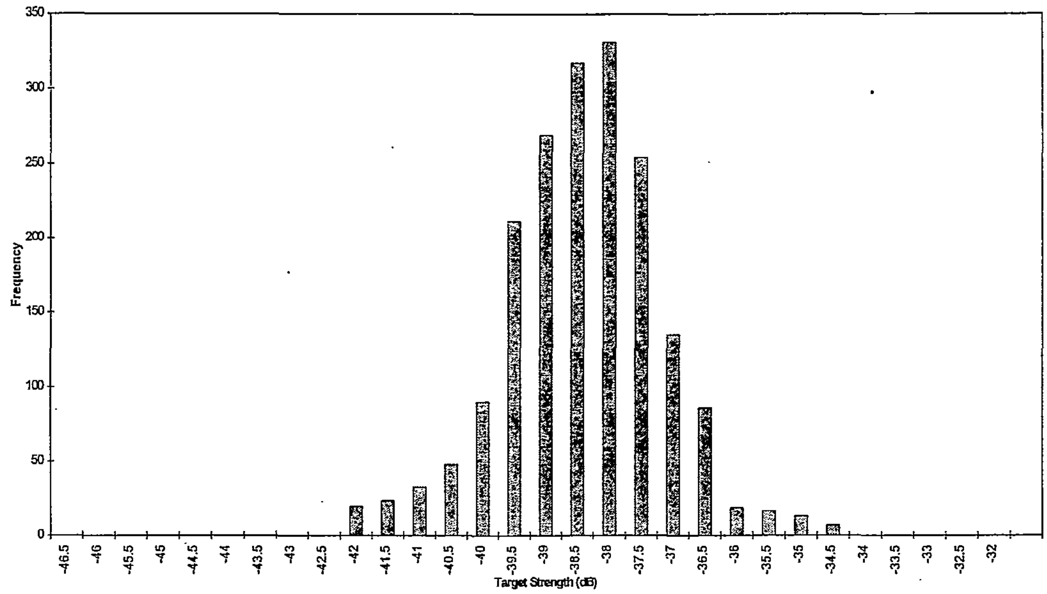


Figure 5.4: Frequency distribution of the same target test.

5.3 Establish Operating Procedures

5.31 Automatic Fish Counting

A significant part of the 1995 deployment concerned the attempt to optimise fish tracking parameters so that the system could automatically provide real-time information on fish passage. Data was collected across a range of environmental conditions and the parameters varied to assess all combinations. In addition, numerous filters and macros were applied to the automatically tracked fish within a spreadsheet package.

By the commencement of the second year it was realised that obtaining accurate fish counts is currently not possible by automatic tracking alone and that every fish event should be verified by the Trakman post-processing software.

The automatic tracking software always caused an over count of fish targets. There were two major factors contributing to this.

Firstly, the system was unable to discriminate downstream moving weed and debris from fish. Initially this was thought to effect downstream counts only. However, the random way in which echoes were received from downstream drifting objects, periodically caused the tracking program to assimilate stray echoes together. In this way, the final echoes of a track could be further upstream than the first echo and give the appearance of net upstream movement.

Figure 5.5 illustrates this effect. This 'Trakman' screen shows the position of each raw echo in three dimensions. Highlighted echoes are displayed against range from the transducer (the right hand axis). The inserted box shows the X-Y plot of the highlighted echoes. The blue square indicates the first ping of the track and the yellow square indicates the last and the river flow is from right to left. Selected echoes are plotted moving in a progressively downstream direction. However, the last two pings in this track have been selected upstream of the very first echo (the blue square) giving the appearance of net upstream movement.

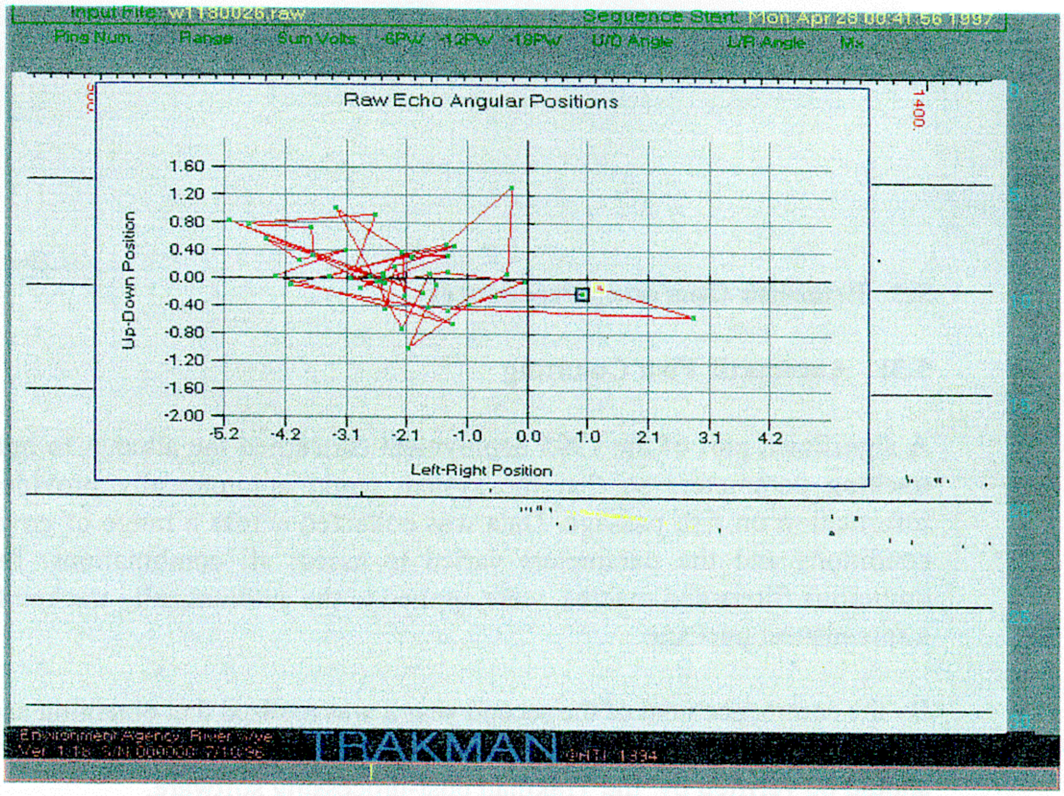


Figure 5.5: Downstream moving target with 2 stray final echoes causing the appearance of net upstream movement.

The second factor was that fish tracks would frequently break down and a new track would commence of the same fish in the beam. Although it was possible to reduce the occurrence of this by changing parameter settings, this tended to compromise other aspects of the tracking program and cause more spurious target counts. The effect of both these factors resulted in an over counting of real fish numbers.

Figure 5.6 shows a single fish broken into two or more targets. Again this is a Trakman screen and shows an X-Y plot of a single target moving in a constant direction through the bottom the beam. The highlighted trace also appears as a single target but the presence of small gaps between consequent echoes results in the automated tracking software separating the track into several targets.

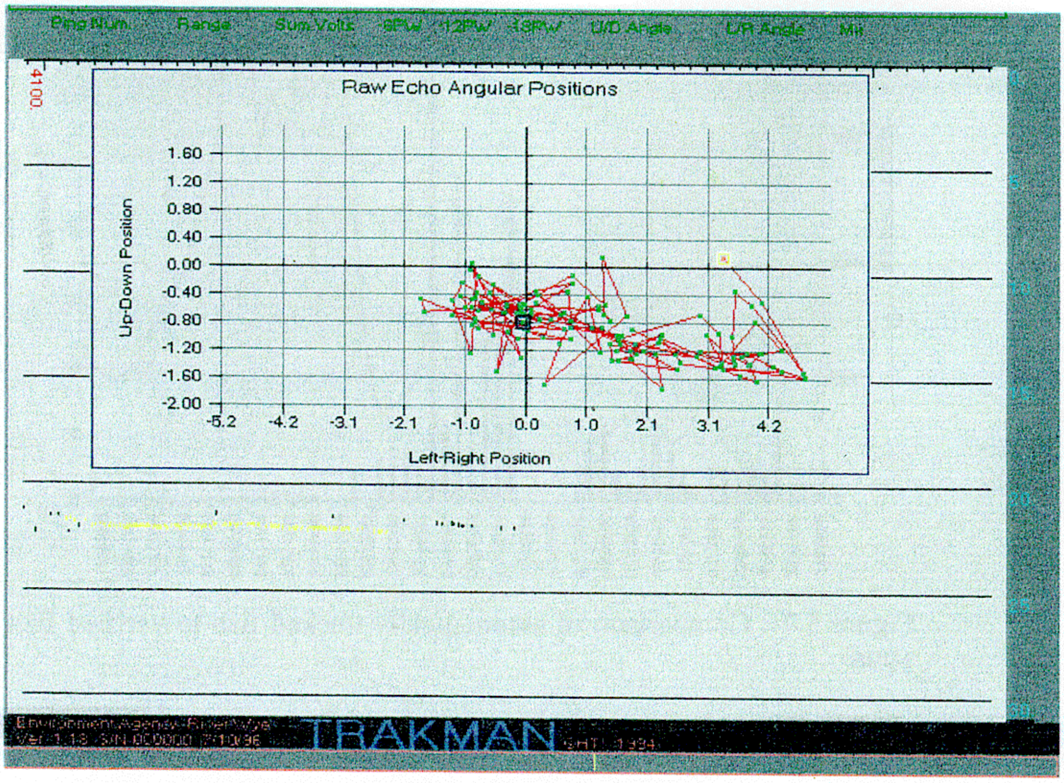


Figure 5.6: Example of a single fish trace that was broken up into several fish by the automated tracking software.

During 1996, all the raw data were processed through Trakman. The output from this was taken as the verified fish count. Figure 5.7 compares the automatically tracked fish to Trakman verified fish for the same period. This shows the consistently higher counts recorded by the automated tracking software compared with verified counts.

During October the difference is exaggerated when the river level rises over a period of eight days. Both counts drop away at the end of October as the river goes into flood.

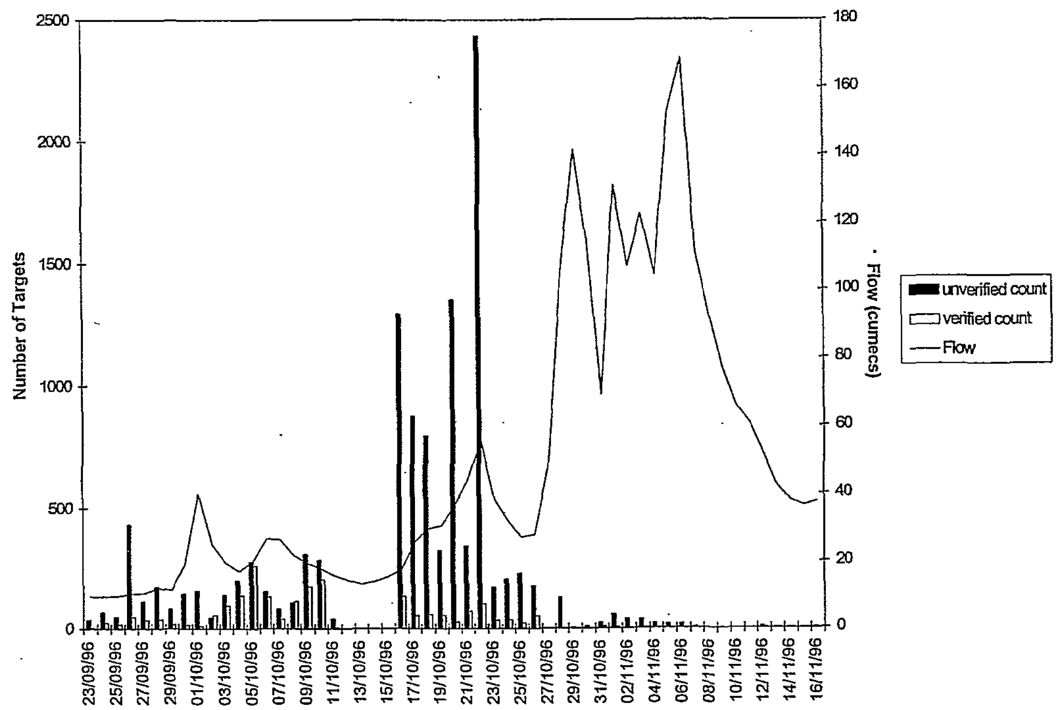


Figure 5.7: Comparison of automatically tracked fish to verified fish for autumn 1996

The relationship between automated counts and verified "trakman" counts is complex. The over counting is due to weed, debris and leaf material. The extent to which these are carried downstream is not just a function of river flow. The time of year, air and water temperature, the elapsed time since the last spate and any anthropogenic impact all contribute. For example, a rapid rise in water levels in May could precipitate considerably less water borne material than a similar rise in October. But, two similar spates in October may have different impacts as the first spate would have picked up debris from the backside and washed it down stream.

All the major riverine projects using acoustics in this application post-process the data in this way to achieve a verified count. Only the Fraser river in British

Columbia, Canada, uses automated tracking numbers due to the necessity for real-time data. However, most of the data is subjected to post-processing techniques for verification.

Although automated counting is flawed on the Wye, rarely will it undercount fish. If a fish is in the beam and the returning echoes break the preset threshold then it will be detected by the echo sounder. This is utilised in post processing as Trakman is only used to examine those targets identified as moving upstream. The automatic counting facility is therefore an integral component of the operating procedures.

The necessity for processing data after collection has some major resource implications. For example, high flows in October 1996 meant both high debris load and fish passage. There were several 24 hour periods that took eight hours to process. This effectively means that for at least a month, the "Trakmaning" of data is a full time task.

Video images (see Section 5.62) allowed the positive identification of weed as it passed through the beam. Figure 5.8 shows the "Trakman" X-Y plot of a downstream moving piece of weed identified from video. This weed was tracked by the automated tracking software giving a trace 41 pings long.

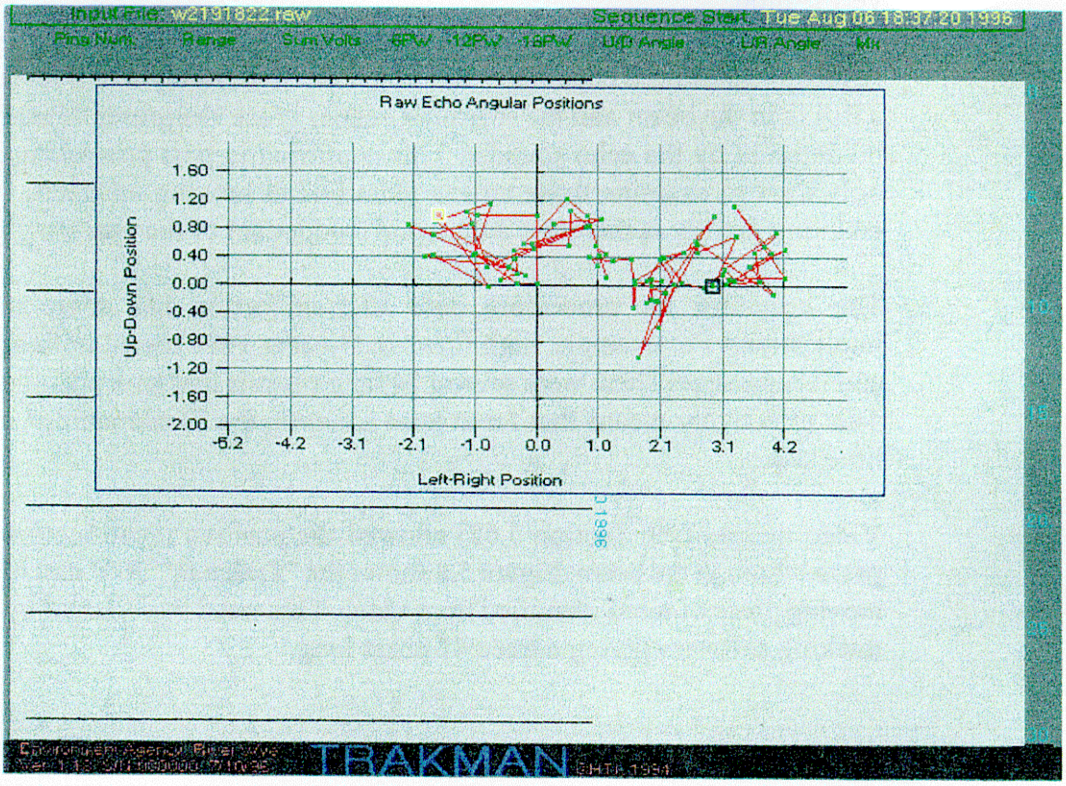


Figure 5.8: TRAKMAN screen showing an X -Y plot of downstream moving weed that has been tracked by the automated tracking software.

5.4 Feasibility of Monitoring Smolts

The inability of the system to reliably differentiate between downstream moving debris and fish meant that attempts to monitor smolts in this environment were unsuccessful. It was also found that aiming the acoustic beam along the water surface where smolts tend to migrate was considerably more difficult than along the river bed. There are a greater number of drifting objects near the surface. Changes in water height and the effects of snow, hail, rain and even wind can be detected acoustically when a transducer is aimed near the surface. This not only makes interpretation difficult, but can mask true fish movements.

There are circumstances where smolts are enumerated successfully. In North

America, acoustic techniques are highly successful at counting the number of smolts migrating around hydropower dams. The system used on the Wye is capable of detecting fish of a similar length to smolts. In an environment with less debris and a consistent boundary along which to aim a transducer, smolts detection would be possible in a UK river. However, based on the Wye experiences, using current technology it is highly unlikely that a quantitative assessment of a smolt run would be possible where migration takes place across the width of the river near the water surface.

5.5 Feasibility of Monitoring Shad

Twaite shad (*Alosa fallax*) migrate and spawn in the Wye in large numbers. The rarer Allis shad (*Alosa alosa*) is also seen regularly in the Wye. Internationally, both are threatened species and listed as such in conservation legislation.

The twaite shad migration usually begins in May and lasts about four weeks. It was expected that during this period they would be detected by the acoustic counter and offer the opportunity for enumeration.

Twaite shad displayed distinct and unequivocal avoidance behaviour to the acoustic beam. Large shoals of shad were observed below the counter site during operation. These shoals would disperse and migrate past the transducer within seconds of disabling the acoustic beam. This was recorded on video cassette from both an underwater camera array and a conventional video camera.

It has been previously reported that some clupeid species were sensitive to sound frequencies up to 140kHz. Denning and Ross (1992) studied reactions of the alewife, *(Alosa psueudoharengus)*, to sound at 125 KHz and observed strong avoidance behaviour. Nestler et al (1992) found that frequencies of 140 KHz partially repelled blue back herring, *(Alosa aestivalis)*.

A trial with a 420kHz dual beam system on the River Wye did not affect shad and they passed the counting area undisturbed. This system was capable of resolving individual fish within the shoal as separate targets. A 420 kHz split-beam system should therefore be able to detect and enumerate shad as they migrate upstream.

On the River Wye, to avoid the counter becoming a barrier to shad migration, the operating software was altered so that the acoustic beam would shut down for 15 minutes every hour to allow shad passage. The salmon counts for the full hour were extrapolated accordingly.

5.6 Validate and verify data

Objective

To validate the data produced by the equipment at the range of flows used by the fish for migration. This will include the use of existing methods, and development of new ones for the interpretation of acoustic data and fish behaviour. Validation procedures will also include the use of acoustic and radio telemetric techniques (a Regional radio-tracking programme is to commence on the Wye in 1994/5), perhaps including high-resolution tracking of tagged salmon approaching and traversing the ensonified area, and the use of this data to confirm acoustic data.

Validation of fish counter efficiency is an essential part of the commissioning period for any fish counter.

The validation of the acoustic counter can be split into verification and pure validation. Verification involves the application of specialist software that enables the progress of a target through the beam to be viewed in three dimensions. It is relatively simple for a person to recognise the distinctive pattern typical of a fish passage. Pure validation refers to positive confirmation by observation of targets as they pass through the beam.

5.61 Verification of counter data

American operators have developed and relied on post-processing software to verify fish counts rather than validate them. Software developed by HTI (such as Fishproc, Trakman and Pinglook) allow individual echoes and whole fish tracks to be viewed in three dimensions. An operator can verify tracked targets as fish by examining the three dimensional properties. For example, a target moving upstream with little variation in vertical height between successive echoes is regarded, with a high degree of certainty, as a fish. Trakman was used exclusively on the Wye to verify all upstream targets identified by the automated tracking process.

Milling Fish

Examination of data collected in the summer months revealed that some remained in the beam for considerable amounts of time. They also passed through the beam in both directions. With the low flows and increasing river temperatures it was considered that high counts of 40 to 50 per day could be caused by a small number of fish that take up residence and mill around the site.

The overriding factor in causing this type of fish behaviour appeared to be river flow. Low flow velocities presumably promote such behaviour in fish which expend little energy milling in the area. With an extra year of data collection it is anticipated that it will be possible to determine the flow thresholds below which fish begin to mill and cease active migration. In 1996, data collection was suspended on 29th July due to the presence of milling fish when the flow level was 10 cubic metres per second. Collection recommenced on 23rd September following a prolonged rise in flow.

Verified Data

The data collected and verified for the autumn run in 1996 was analysed and presented to show various aspects of fish behaviour as they passed the site. This in itself acted as a form of verification as it enabled comparison with the expected pattern of migration (based on knowledge of fish behaviour, radio tracking and experience from other rivers).

The horizontal and vertical positions of upstream moving fish are shown in Figures 5.9 and 5.10 respectively. There is a peak in fish movement 12.5 metres from the transducer which declines gradually out towards the maximum range covered by the beam (22.5m). There is little movement within 10 metres of the transducer.

Figure 5.11 shows the vertical position of fish under low flow conditions and the majority of fish targets are moving close to and below the central axis of the acoustic beam, in the lower region of the water column. By comparison, Figure 5.12 shows fish moving under elevated flows. These targets are closer to the vertical centre of the beam.

The diel distribution of fish targets is shown in Figure 5.13 and demonstrates two active periods of fish movement; dawn and dusk. The highest fish passage occurs between 7pm and midnight, followed by a steady decline in fish numbers until 7am. Few fish are seen to move between the hours of 8am and 5pm.

The swimming speeds for fish targets as they pass through the beam are shown in Figure 5.14. Swimming speeds were calculated by dividing the distance the fish travelled in the beam by the time difference between first and last detection. The majority of fish are moving at ground swimming speeds of 0.05 - 0.25 m / sec. This corresponds closely with a study on acoustically tagged salmon in the River Wye, where ground speeds of 0.007 - 0.214 m / sec were noted (Gough, Gee & Harris, 1982). Other studies on Atlantic salmon have also noted ground speeds of 0.046 - 0.139 m / sec (Hayes,1953; Stasko,1975). Higher rates of progress, most likely involving periods of burst swimming, have been recorded by Webb (1989) on the River Tay.

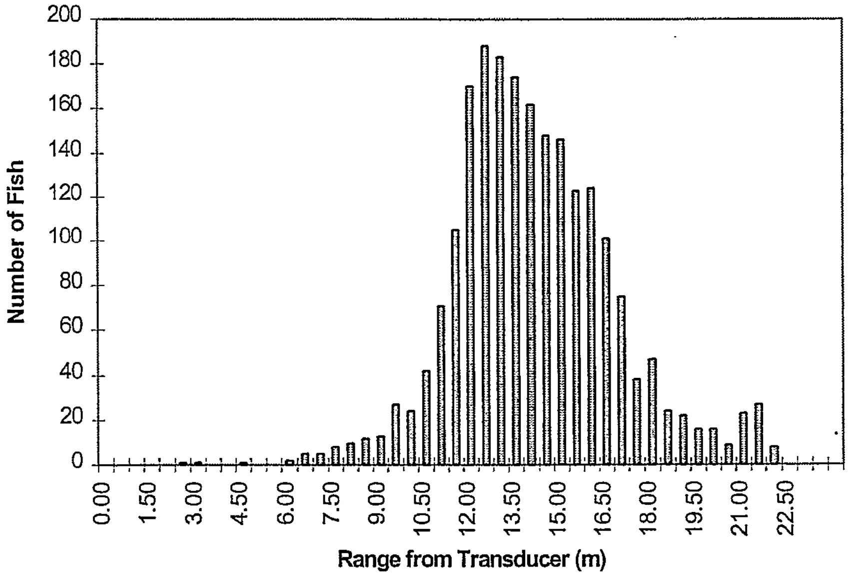


Figure 5.9: Horizontal position of verified upstream moving fish - Autumn 1996.

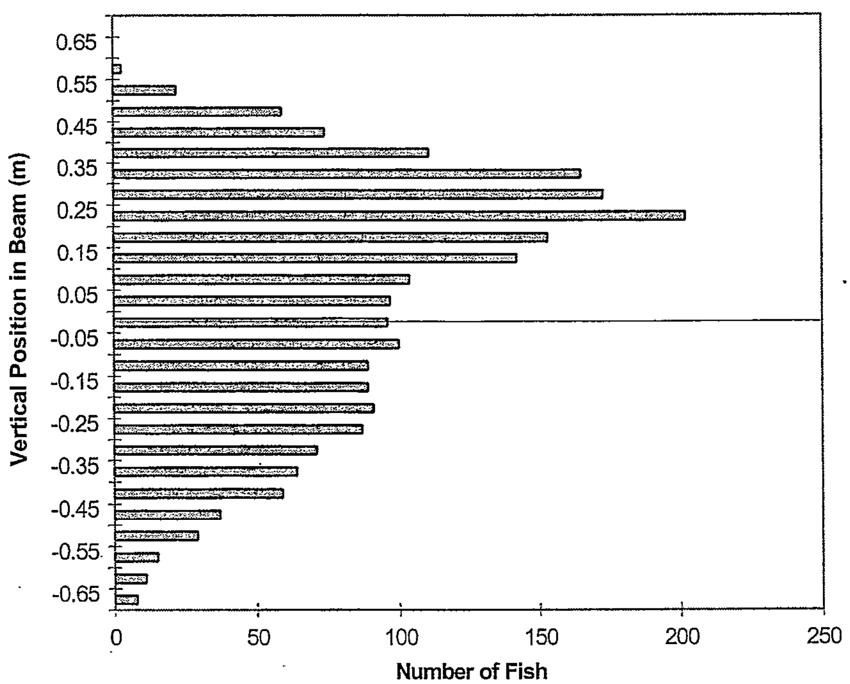


Figure 5.10: Vertical position of verified upstream moving fish - Autumn 1996.

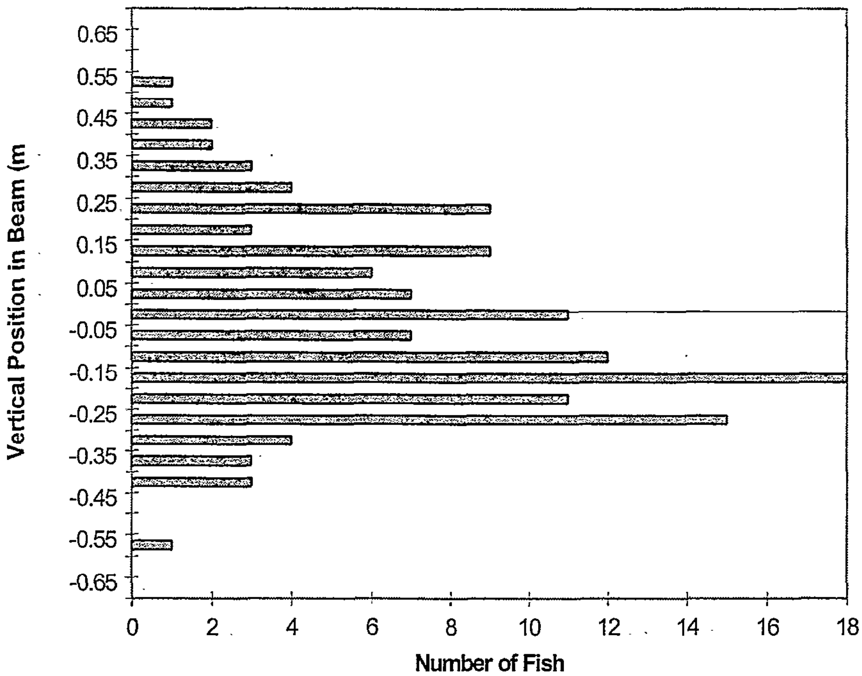


Figure 5.11: Vertical position of upstream moving fish under conditions of low flow - data taken from 24/09/96 to 27/09/96 (ave flow = 10.22cumecs).

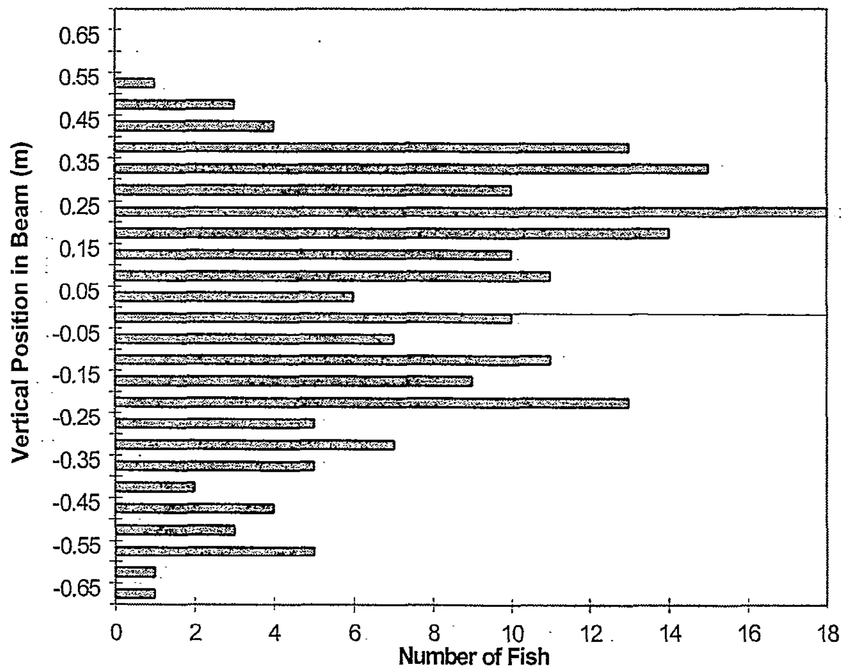


Figure 5.12: Vertical position of upstream moving fish under conditions of elevated flow - data taken from 30/09/96 to 03/10/96 (ave flow = 26.145cumecs).

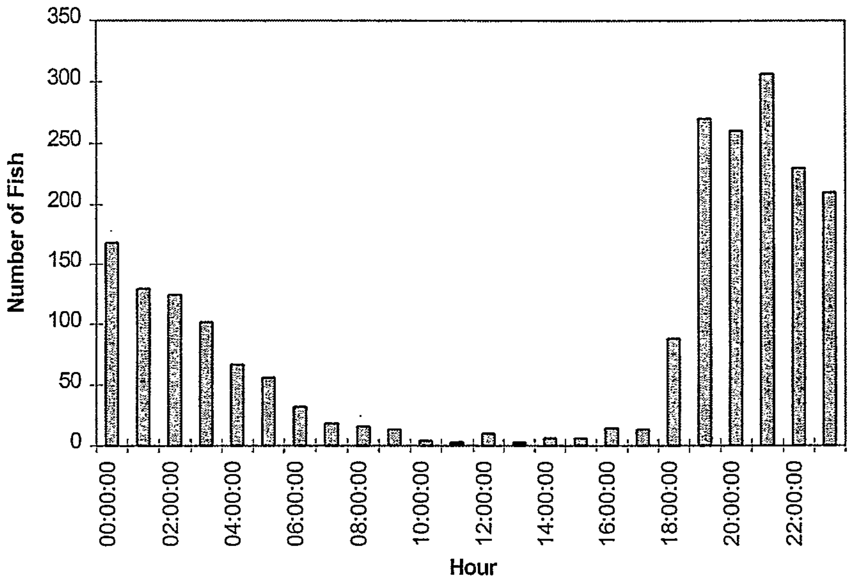


Figure 5.13: Diel distribution of fish targets - Autumn 1996.

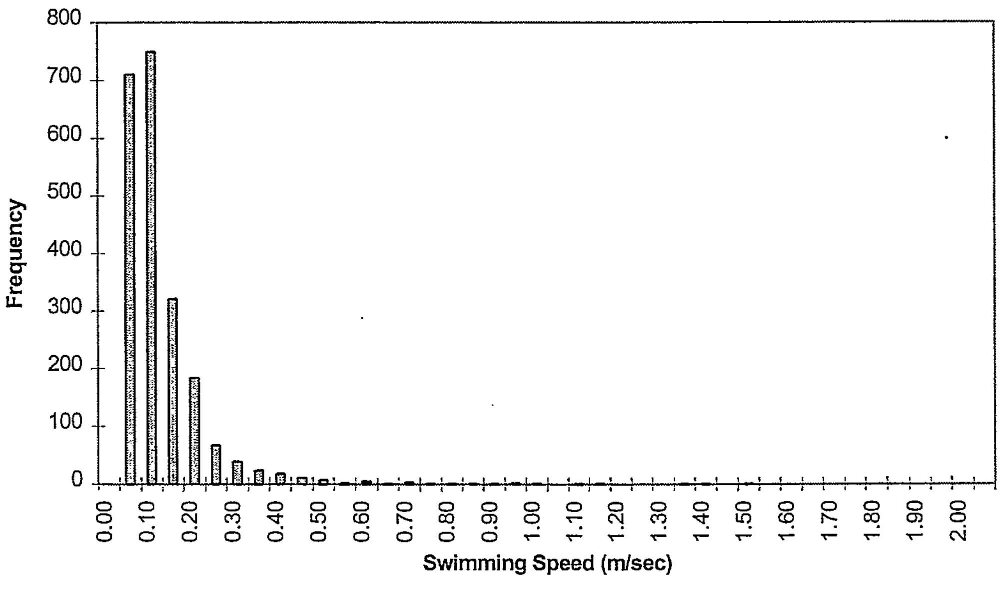


Figure 5.14: Ground swimming speed of verified fish targets - Autumn 1996.

Figure 5.15 shows the number of echoes (pings) per fish plotted against arrival time in hours. A higher number of echoes is an indication that the fish took longer to traverse the beam. Figure 5.15 shows that higher numbers of pings per fish occur more frequently between the hours of 5pm and 4am, corresponding to the peak times for fish movement. During the daylight hours (i.e. between 5am and 5pm) less than 10 fish gained more than 100 pings each.

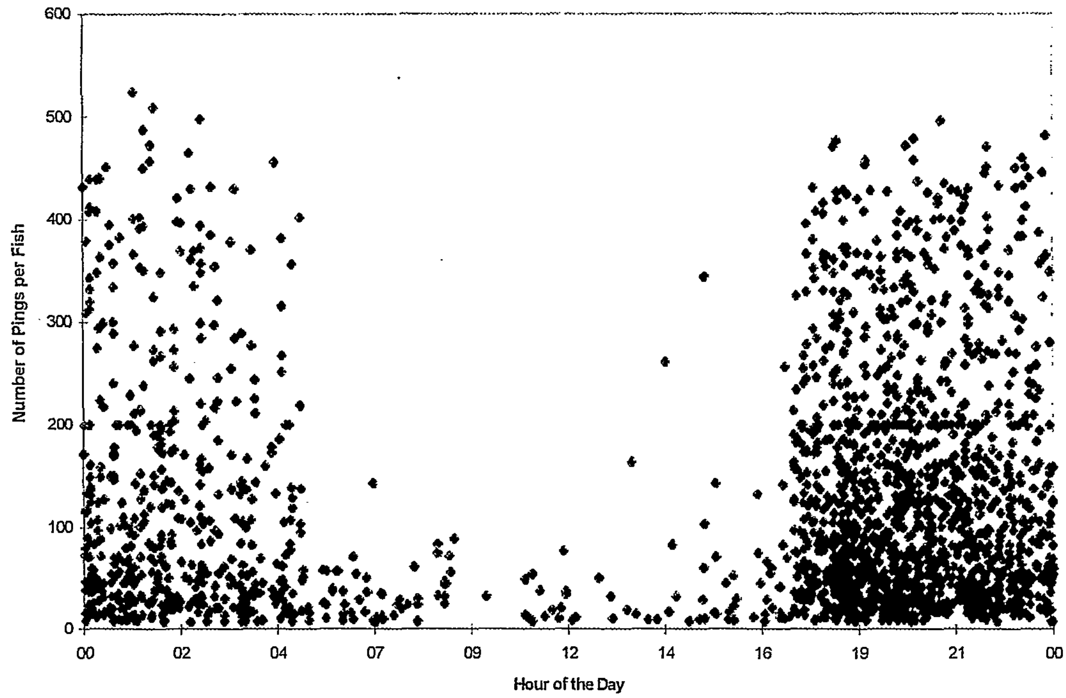


Figure 5.15: Number of pings per fish against arrival time - Autumn 1996.

Rod Catch

The acoustic counter on the Wye is situated approximately half way along the stretch of river for which Heritage Investments own the fishing rights. This fishery has accurate records of rod catches dating from the 1986 fishing season. Recorded details include date and place of capture, bait used (e.g. fly or worm), weight of fish and presence or absence of sea lice. No measure of fishing effort is noted.

Fish catches for the 1996 season were obtained from the Wyesham Fishery records. This was compared to counts of upstream running salmon obtained from the acoustic counter and is shown in Figure 5.16.

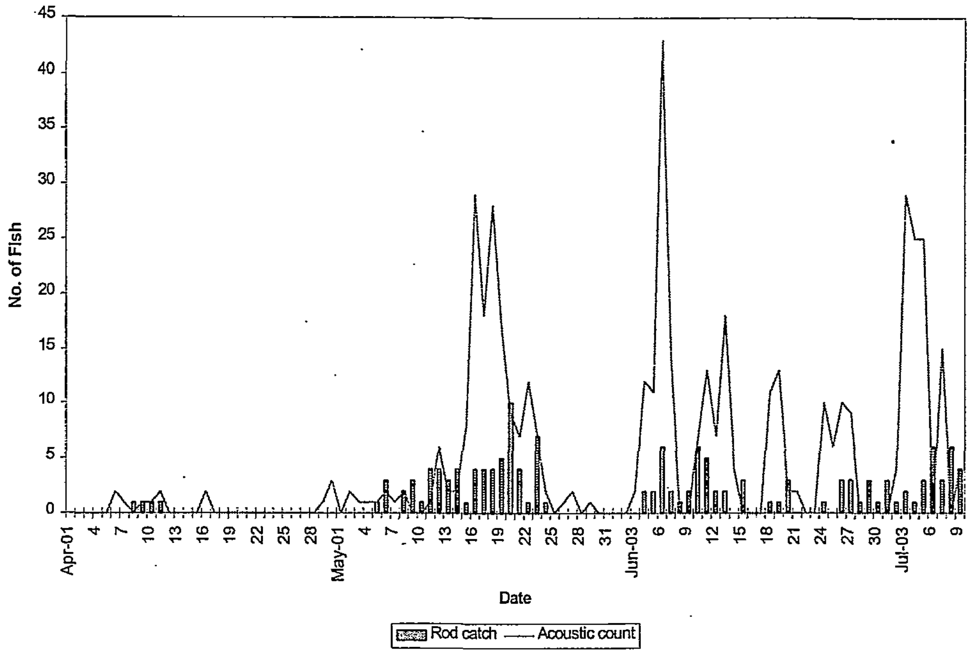


Figure 5.16: Wyesham Fishery catch data against acoustic count for 1996 (Jul-09).

The rod catches show peaks of high acoustic count appear to precede increased fish catches.

Fundamental differences exist between these two techniques which create difficulties when comparing results directly. The acoustic counter operates with a constant sampling effort but the number of rods fished per day (i.e. the fishing effort) varied according to fishing conditions. For example, high flows at the end of May were unfishable for anglers and the highest acoustic salmon counts occurred during the dawn and dusk periods when fishing effort was zero.

Peaks of high acoustic counts appear to precede increased fish catches. This suggests that the two techniques do show similarities in recording changes in fish population abundance. However, the extent of validation that this observation provides is limited.

Radio Tracking

During 1995 and 1996 an Agency radio tracking program was carried out on the River Wye to assess the survival to spawning of early season salmon after being caught and released by the rod fishery. A total of 26 fish were tagged in 1995 and 12 in 1996. All bar five were tagged at Lower Lydbrook, several kilometres above the site of the acoustic counter. Logistically it was not possible to tag any of these fish below the Redbrook site.

Some data on the movement of 14 tagged fish is available and, together with data from other studies, may provide information on upper and lower flow thresholds for salmon migration.

5.62 Validation

Full validation of any fish counter compares counter produced data to an independent and unequivocal representation of counted targets. This effectively means video or photography. Validation may simply involve measuring the efficiency of the counter at detecting target species or could mean assessing the counters ability to size fish. On the River Wye, a trial study that attempted both was carried out.

Resistivity counters have used a combination of video and still cameras to record images of fish as they pass over a weir in water depths that were typically about 0.5 metres. For acoustic counters this is an entirely different proposition as the water depths can be in excess of 3 metres. The logistical and technological difficulty in obtaining video images from fish passing through an acoustic beam was the main reason why no such validation of an acoustic counter had been attempted up until 1994. The current study is the first known attempt to do this.

In the summer of 1996, an underwater camera array was positioned beneath the acoustic beam with the cameras on the river bed looking up at the surface. Using the contrast against the water surface of an object passing through the camera view it was possible to identify fish and discriminate species, even in low light conditions.

By examining the recorded video images an assessment of the proportion of fish passing the site detected by the counter (counter efficiency) could be made for the area covered by the camera array. The relative abundance of non-target coarse fish species could also be determined, and whether these non-target species were detected by the acoustic counter.

Images of a single target from two or more cameras could also be used to estimate the size of fish targets using a stereo photogrammetry technique, this figure subsequently being compared to acoustic size.

The deployment of equipment in 1996 was therefore intended as a trial to see if it was possible to:

1) Assess proportion of target species evading detection
2) Assess relative abundance and acoustic detectability of non-target species
3) Assess the potential for the stereo photogrammetry technique to size fish.
4) Examine fish behaviour.

It was not an objective to assess the automatic fish tracking software but a comparison of performance was possible.

Videoing equipment

The videoing equipment comprised of a set of four underwater video cameras (3.6mm lens), attached to an H-shaped metal construction and spaced at intervals of 20 cm. Four diving weights were attached to the corners to supply additional stabilization and weighting. The camera array is shown in Figure 5.17.

The remaining video equipment consisted of a camera control box, 9-channel multiplexer, VHS video recorder and monitor screen. The video equipment, powered by a generator, was set up in the back of an estate vehicle for filming.

Camera deployment

In order to determine the best position (i.e. where salmon passage was greatest) to deploy the set of cameras, previous data was analysed. Target position within the acoustic beam was plotted to show vertical position of targets and target range distribution plotted to show horizontal position from transducer. To determine the most productive time for videoing, an arrival time frequency distribution was plotted. From this, the bulk of targets were seen to be in the lower half of the beam and passing through the central, deeper region of the river. Peak travelling times occurred in the early hours of the morning and late in the evening. The cameras were therefore positioned towards the middle of the river channel (15m) and video sessions took place between 5pm and 10pm.

Deployment of the cameras consisted of positioning a transect, with marked 1m intervals, across the river along the path of the beam. The camera array was then lowered from a boat at the desired range (Figure 5.18).

The array was positioned perpendicular to the flow so that the maximum range across the river could be filmed.

Video analysis

All 4 camera views were viewed simultaneously and events identified. The time of fish events seen on the video was noted and compared to the same time in Trakman to see if the videoed fish had been acoustically detected.

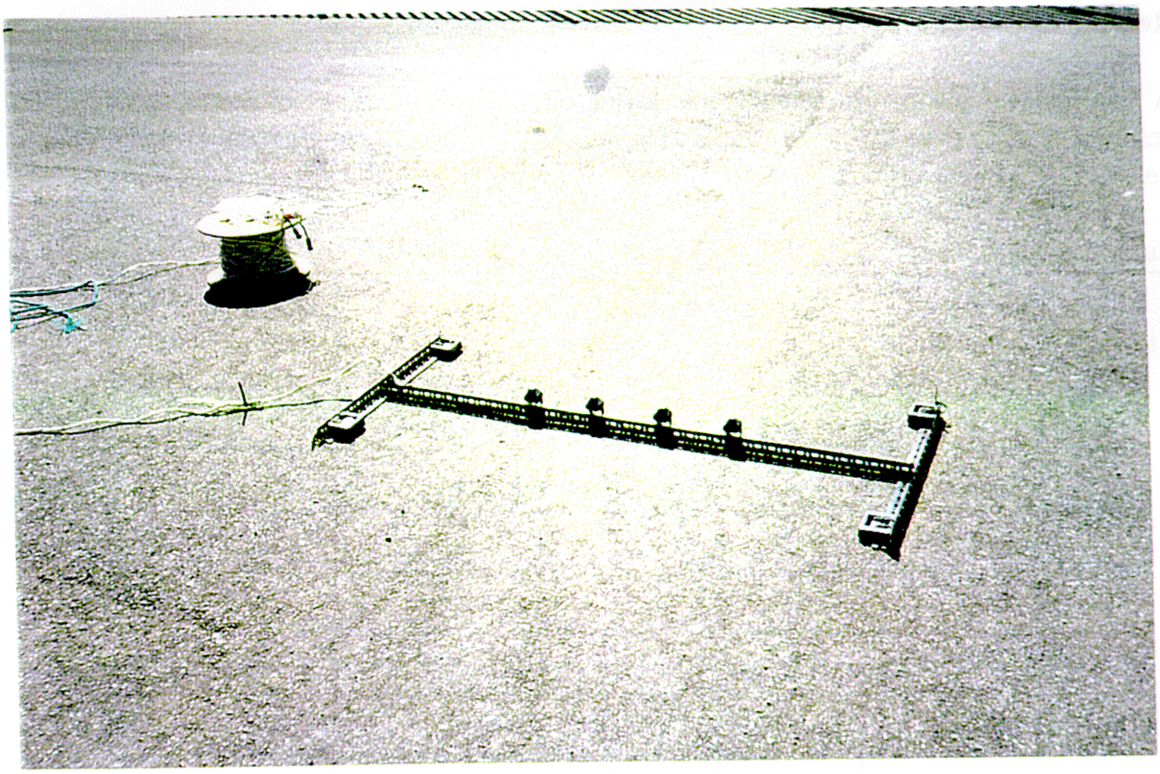


Figure 5.17: Four cameras mounted ready for deployment.

Figure 5.18: Deployment of the camera array on the Wye.

Results

A total of 10 videoing sessions were carried out on various dates over the summer. These sessions lasted between 2 and 4 hours. The results of each session are summarised in the table below.

Summary table of summer video session results.

Video session	Date	No.of salmon filmed	No.of filmed salmon tracked	No. of non-target* species filmed	No.of filmed non-target* species tracked
1	02/07/96	4	2	1	0
2	03/07/96	9	0	7	0
3	04/07/96	4	1	5	2
4	10/07/96	5	5	7	0
5	16/07/96	3	1	5	0
6	30/07/96**	0	0	2	2
7	31/07/96	0	0	6	2
8	01/08/96	6	6	19	2
9	06/08/96	3	1	8	1
10	07/08/96	2	2	14	1

(* Includes unidentifiable species seen only partially in video frames)
(** On this date, the threshold value was increased from 450mV to 750mV and the ping rate increased from 10 pings/sec to 20 pings/sec)

Two additional videoing sessions were carried out during the autumn salmon run on 9th and 10th September. Due to the shortened day length, videoing commenced at the earlier hour of 3.30pm. Fish activity, as recorded by the acoustic counter, was seen to increase after approximately 6.30pm. This correlates with the period when light intensity decreased to a level that prevented useful filming. Hence no fish were seen on either video from these two dates.

Overall, 50% of the clearly identifiable filmed salmon were acoustically tracked. The video frames of the "acoustically missed" salmon enabled parameter adjustments to be calculated. Following these adjustments, the percentage of filmed salmon that were acoustically tracked rose to 80%.

No identifiable non-target species were acoustically tracked. Ten acoustic tracks correlated with partial video shots of fish. These could not be unequivocally identified as being salmon and so were classified as non-target species.

5.7 Acoustic Size of Target Species

Target strength measurements of all verified fish targets were analysed and are presented in Figure 5.20. The graph shows a normal distribution of target strengths ranging from -30 dB to -15 dB. The mode is -23.5 dB. No bimodal distribution was observed between grilse and multi sea winter fish.

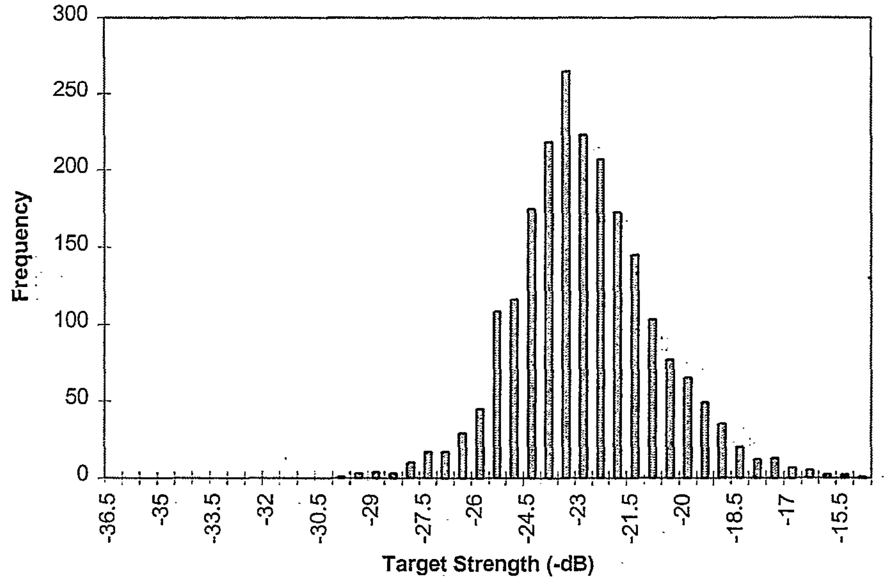


Figure 5.20: Acoustic size of verified fish targets on the River Wye - Autumn 1996.

Many authors have detailed work on the relationship between acoustic target strength, body size and body aspect (Love, 1969, 1977; Foote, 1986, 1987; MacLennan and Simmonds, 1992, Duncan and Kubecka, 1993). All of this work demonstrates the large change in target strength with fish orientation to the beam.

None of the above work has been carried out on Atlantic salmon or sea trout. Burwin and Fleishman, (1997 in press) have reported a difference in target strength of two species of Pacific salmon. Sockeye (Oncorhynchus nerka) and chinook (Oncorhynchus tshawytcho) salmon of the same length produced a difference in target strength of 2dB. This demonstrates that target strengths can differ between salmon species and therefore may differ between salmon and sea trout, adding to the complexity of interpretation of target strength data in a mixed stock river.

The requirement for a target strength relationship was recognised early in the project. Duncan and Kubecka, (1993) carried out a study of coarse fish target strengths for the NRA and detailed a rig in which anaesthetised fish were secured in a carousel and their target strength measured as they were rotated in respect to the acoustic beam. The logistics of applying this to free swimming, unanaesthetised salmon led to its use being rejected.

Target strength measurements in riverine situations assume that fish orientation in the beam is consistent. Transducers are frequently deployed perpendicular to the line along which it is assumed fish migrate to ensonify fish targets in side aspect. This assumption has the potential for a source of error when examining target strengths of individual fish.

An additional consideration when comparing target strengths is the minimum threshold for receiving echoes. A low threshold will mean more echoes of a low target strength can be received. This will lower the mean target strength of that event and give a lower number than if the same fish was detected at a higher threshold setting.

The lack of target strength information on free swimming Atlantic salmon of a known size was considered an impediment to interpreting the data gathered by the counter on the Wye. In an attempt to aid interpretation of target strength data, a project was initiated to gather information on free swimming Atlantic salmon. This trialed two different methods of collecting such information; tethered fish and stereo photogrammetry.

5.71 Ensonification of Tethered Fish

The counter was temporarily deployed on the River Taff in Cardiff, above a fish trap operated by the Agency.

Live fish were taken from the trap and placed in a trough of water containing anaesthetic. Once the fish had experienced equilibrium loss, a short length of nylon stocking was inserted into its mouth and out through the operculum. This was knotted to form a loop through which a length of twine was attached.

The fish was then returned to the river and taken to a point about 10 metres in front of the transducer where it was held until recovered from the anaesthetic. This operation took no longer than five minutes and every care was taken to minimise unnecessary stress.

Once recovered from the anaesthetic the fish was released into the beam and held on the tether by a person standing approximately 3 metres upstream. The fish was allowed to swim freely in the beam while the sounder was enabled. An operator could study the real time data produced by the acoustic system and instruct the fish wrangler of its location in the beam, which could be adjusted by pulling on or slackening the tether. Data was recorded from each fish for a period of at least five minutes (potentially 6000 pings). If any of the fish showed signs of undue stress while tethered they were immediately released.

A total of eight fish were used over two trials; three in the first and five in the second. Raw data from each of the trials was examined and any extraneous echoes, or groups of echoes when the target was not clearly discernible, were rejected.

In the first trial, all data was processed. For the second trial, an underwater video camera array was deployed to observe fish behaviour. Occasions when the fish were seen to present good side aspect to the transducer were processed only.

System calibrations with a standard target were carried out before and after each trial.

Results

Results were obtained from six of the eight fish. One other fish exhibited exceptionally unnatural movement as a reaction to the tethering and was immediately removed from the experiment whilst the other was held in the beam for too short a time to allow satisfactory size estimates to be made. The results are shown below.

Acoustic Sizes of Tethered Salmon and Sea-Trout.

Species	Sea trout	Salmon	Salmon	Salmon	Sea trout	Salmon
Length (mm)	600	740	590	780	600	610
Mean TS	-31.33	-30.13	-31.59	-29.36	-32.95	-31.87
ST. Dev.	3.52	3.79	3.10	5.48	3.78	6.10
Max.	-17.71	-18.27	-20.06	-20.02	-21.08	-17.99
Min.	-37.71	-36.6	-37.33	-45.46	-39.18	-40.06
n.	554	612	841	24	156	118

From the very small sample, no difference between the target strengths of salmon and sea trout could be discerned. The differences in target strengths between different size salmon do not seem to be great although the relationship between fish length and target strength does show a consistent significant trend. Target strength increases with increasing fish length (r2 = 0.7892). This relationship is shown in Figure 5.21.

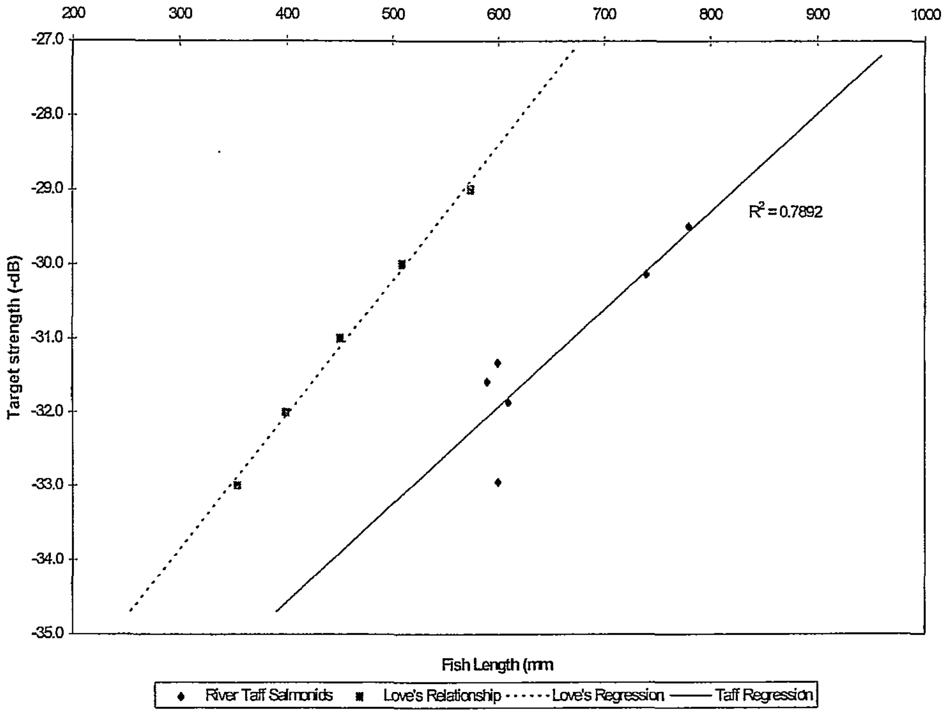


Figure 5.21: Target Strength Length Relationship Taff Salmonids vs. Love's Relationship

Discussion

This preliminary investigation with a small data set indicates that the target strengths recorded from tethered fish are smaller than the mean target strengths recorded at any time at Redbrook. If it is assumed that rod caught fish from the Wye at Redbrook are representative of those recorded on the counter then the average sized fish at Redbrook (740 mm) has a target strength of approximately -24dB (Figure 5.20). A salmon of 740mm in the acoustic trial was found to have a target strength of -31.3dB. This is a large difference even accepting possible errors in the estimation of target strengths from Redbrook.

There are various possible explanations to the discrepancy between the target strengths. Examinations of fish tracks show that the movement of tethered fish is far more erratic than naturally free swimming fish. The positional variation of a tethered fish is far greater than a wild fish and it is therefore likely to present a smaller acoustic target.

It is also possible that the use of anaesthetic increases and prolongs the erratic movement of the fish. The fish were released in the beam when it appeared that they had recovered from the effects of the anaesthetic. If recovery was not complete then the ability of the fish to maintain equilibrium would be greatly reduced and swimming movements would be erratic. The anaesthetic itself may also have a physiological effect on the swim bladder of the fish (Duncan and Kubecka, 1993) , any change of which would greatly affect the overall target strength of individual fish. It may be possible to rectify this by either increasing the recovery time of the fish before each trial or by dispensing with the anaesthetic.

Conclusions

The trial demonstrated that it was logistically possible to ensonify tethered fish and indicated that target strength is positively related to fish size. With the small sample trialed, acoustic sizes appeared considerably smaller than sizes gathered under natural conditions.

Increasing the length of future trials would allow greater amounts of data to be gathered. The amount of data obtained should be gathered on a ping basis, rather than a time basis. This would allow statistical comparisons to be made between the trials.

Attempts to accurately monitor the movement of the tethered fish were confounded by the narrow field of view of the four video cameras used. For large periods of time the fish were not in the field of view and so their behaviour could not be monitored. Increasing the field of view of the camera array would permit closer monitoring of the behaviour of tethered fish.

If possible the fish should be positioned at a greater range in the beam. At 10 metres the beam width is 1.75 metres by 0.5 metres. Increasing the range will increase the amount of data collected for each fish.

5.72 Stereo Photogrammetry

The video array deployed on the Wye to validate fish counts has been described in Section 5.62. The images from two or more of these cameras could theoretically be used to size objects from the screen (Fewings, pers. comm.). This process is similar to stereophotography techniques reported by a number of authors (Klimley and Brown, 1983; Van Long and Aoyama, 1985; Boisclair, 1992).

Requirements for sizing calculations include that the image must be captured on two screens simultaneously. This allows coordinates from the same point on the fish on both screens to be noted. These can then be used to calculate the range of the fish from the camera face as long as the field of view is known. The cameras' field of view was measured and is shown in Figure 5.22. In order to obtain simultaneous pictures of fish, the gap between each camera had to be by 20cm. This resulted in adjacent fields of view crossing at approximately 23cm above the camera face.

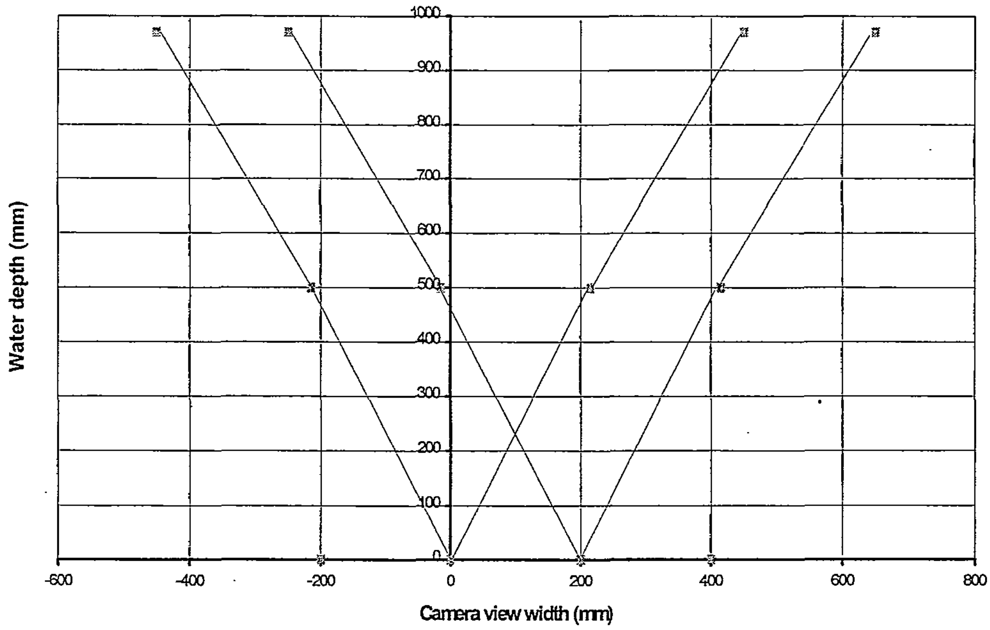


Figure 5.22: Video camera field of view.

Once a range has been established, from a point on the fish in two cameras, the length can be calculated using an image from just one screen. Due to the large size of many River Wye migrating salmon and their river bottom orientation, many fish had only part of their length on screen at any one time. In these cases the length from snout to pectoral fin was calculated. It was assumed that a relationship existed between this length and total body length for salmon and, in order to establish this, measurements from salmon caught in a fish trap on the R. Dee (N. Wales) were recorded. The resultant relationships, obtained using measurements from over 100 salmon, were as follows;

1. Snout to pectoral fin root: **$y = 4.046x + 165.26$**
2. Snout to pectoral fin tip: **$y = 2.8045x + 93.005$**

The method for calculating fish length from video images is shown in Appendix 3.

Results

Fish that appeared simultaneously in two cameras from the summer video validation work were sized using this technique. These included 6 salmon (4 of which had been acoustically tracked), 1 sea trout, 1 chub and 1 shad. The total lengths of the non-salmon species could be calculated directly whereas the salmon total lengths had to be estimated using the conversion equations as described earlier.

Table 1. Non-salmon fish sizes (mm)

Species	Total length (estimate i)	Total length (estimate ii)
Sea trout	323	342
Chub	624	_
Shad	310	_

Table 2. Salmon sizes (mm)

Salmon no.	1	2	3	4	5	6
Snout-pect tip	218	379	244	_	_	179
Conversion to total length	704	1156	777	_	_	595
Snout-pect root	_	234	_	233	75	_
Conversion to total length	_	1112	_	1108	468	_

Salmonids were also filmed during the target strength experiments on the River Taff at Blackweir. As the real lengths of these fish were known, this sample group can be used to validate the stereo technique. Four salmon and one sea trout (fish no.4) were sized. Due to the fact that these fish could not be viewed in their entirety on screen the snout-pectoral fin conversion equations were used. Figure 5.23 shows the calculated lengths with 95% confidence levels against real lengths.

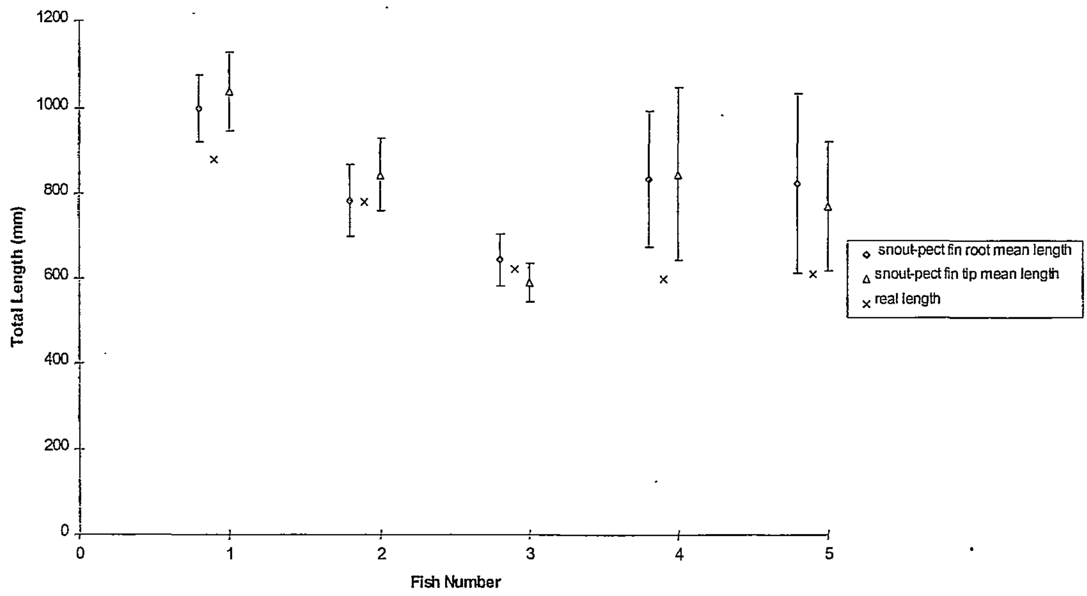


Figure 5.23: Calculated Lengths with 95% CL against real fish lengths.

It is recognised that a method is needed to measure the accuracy of this sizing technique.

Klimey and Brown (1983), who utilized stereophotography to size free swimming sharks, used a staff scaled with black and white bands. Stereophotographs were taken of this staff at three different ranges in a swimming pool, and repeated measurements were made of a section of the staff. This data was then corroborated with length determinations taken from streamer tags of a known length. These streamer tags (dart tags) were speared into the sharks' dorsal fin resulting in the vinyl tubing trailing back parallel to the torso of the swimming shark, and thereby acting as a scale. This study also noted that a flexible ruler was needed to measure the 'sinusoidal' configuration of the fish during swimming if total length was measured in a single screen. Alternatively, measurements of an inflexible body part such as pectoral fin length could be used to avoid this problem. This correlates with the use of snout to pectoral fin measurements used on the Wye. It was also noted that image lengths should be between 25 and 100% of the frame width in order to obtain acceptable length dimensions for stereophotographic analysis. Obtaining image lengths of this size was not a problem on the Wye due to the large size of the salmon and their closeness of movement to the cameras.

Long, Aoyoma and Inagaki (1985) also carried out experiments to measure the accuracy of using stereophotography as a sizing technique. Synchronised photographs, from two parallel cameras, were taken of a television test pattern plate. Numerous measurements were made and lengths calculated. Correction rates were then calculated. This study also noted that human errors were unavoidable and vary at each measurement. A later study by Long and Aoyamo (1985) utilized the above technique and associated correction factors on free swimming fish. It was noted that the accuracy of the calculation of the spatial position of a fish may fall off in relation to the increase in distance from the camera. This is due to a decrease in object parallax on the stereo films plus errors in image reading. Sufficient contrast was an essential factor needed to read images accurately. This depended on the clarity of the water and the camouflage and shading of the fish. Due to the ventral view of fish, from the cameras on the Wye, camouflage and shading do not present a relevant problem. The clarity of water on the Wye does have a substantial effect on image reading and, during periods of high colouration, can completely prevent useful videoing.

Long and Aoyamo (1985) concluded that by use of a combination system of the stereo camera system and an echosounder, it is expected that an accurate estimation of *in situ* acoustic target strength of fish will be possible.

5.8 Investigate the Presence of Non-target Species

Acoustic systems cannot discriminate between species of fish. They merely offer information relating to the presence and size of the fish. Therefore, in choosing any acoustic site it is important to avoid areas where non-target species of a similar acoustic size might be detected. For example, a resident population of large chub or individual brown trout or a pike could lead to large errors in over counting. It is important to note that little adequate information exists on the target strength of free swimming non-salmonids ensonified at a frequency of 200 kHz.

Pre-site selection information on the presence of non-target species at Redbrook was largely based on anecdotal evidence from ghillies and coarse fisherman. Both sources suggested that the area surrounding the counter supports a limited coarse fish population with few, if any, large fish.

It was an important objective of the project to investigate this assumption.

A combination of fyke netting, video images and the catch from coarse fish anglers was used to assess the abundance of non-target species in the area sampled by the acoustic counter.

Fyke Nets

Fyke netting surveys were carried out in September and December, when conditions allowed. Ten nets, in five arrays, were set in the vicinity of the acoustic transducer. In September a line of six nets was set, parallel with the river flow, in mid channel. Four other nets, two downstream of the fishing croy and two downstream of the transducer, were set perpendicular to the river flow on opposite sides of the channel. All nets were fitted with otter guards.

These nets were set in the late afternoon and checked the following morning. Fish were placed in a large water filled bucket for processing on the river bank. For eels, numbers and size range were noted, individual fish were not measured. In other species fork lengths were taken.

In December four nets were set in the vicinity of the counter. One large net was set immediately downstream of the counter, perpendicular to the flow. This net was larger than those previously employed and extended two-thirds of the river width. Additional nets were set on the opposite bank to the counter; immediately opposite and 20m upstream and downstream of the counter. No otter guards were fitted to the nets to avoid any size bias and the nets were therefore kept under continual surveillance. These nets were set in the early morning and checked towards dusk.

Results of Fyke Netting Survey*

SPECIES	NUMBER	SIZE	NETTING DATE
Eel	42	350-650mm	19-20/9
Gudgeon	1	135mm	19-20/9
Roach	1	120mm	19-20/9
Flounder	2	95, 140mm	19-20/9

*no fish were caught during the December netting.

Video Capture

As a part of the validation of the acoustic counter an array of video cameras was periodically deployed on the river bed during the summer. As well as recording salmon as they passed through the beam, other fish species were also identified.

A total of 74 fish that were not salmon were recorded on video over 10 deployments in July and August. Results of the video analysis are shown below.

Species Composition of Non-Target Species Detected by Video

SPECIES	NUMBER
Eel	2
Shad	6
Minnow	2
Chub	6
Roach	17
Dace	1
Trout	1
Indeterminate	39

These fish appeared to be small (under 200mm) and the largest 3 non target species were sized using stereo-video photogrammetry. The lengths of these fish are given below:

Trout: 342mm
Chub: 624mm
Shad: 310mm

None of the coarse fish recorded on video were detected by the acoustic counter.

Anglers Catches

The River Wye between Redbrook and Monmouth supports a winter coarse fishery, which operates during the salmon close season. Catch data from a match held on December 8th were supplied by the secretary of Caerphilly and District Anglers. The top weight was a 6lb bag of chub.

Chub were the only species recorded in the catch data. Nevertheless they are not caught in large numbers, especially in the vicinity of the acoustic counter. This would suggest that they will interfere little with the acoustic counts.

Eels are behaviourally and anatomically unlikely to interfere with salmon counts. They are heavily bottom orientated and even with the transducer aimed close to the river bed would mainly pass below the beam. Neither of the eels seen on the video recordings were tracked by the counter, which would appear to support this observation. It is also possible that, given their shape and relatively small swim bladders, eels are acoustically invisible at the thresholds used for this study.

The vast majority of the fish recorded on video are small cyprinids, primarily roach. These small fish are unlikely to break the detectable threshold set in the data collection software. A lesser number of chub were recorded, one such individual being of a physical size comparable to that of a salmon. This fish was not tracked since it was moving above the acoustic beam in the middle of the channel. This fish was recorded during a period of low flows and elevated river temperatures in which very little salmon migration was detected.

6.0 Conclusions

Overall Conclusion

The hydroacoustic system has unequivocally demonstrated the following.

If a fish of a size large enough to be detected above background noise levels and pre-set thresholds passes through the acoustic beam, it will be detected over a range of environmental conditions. Atlantic salmon have been found to present an acoustic target sufficiently large enough to be detected from background noise levels typical of sites on many, if not all, UK rivers.

The post-processing data analysis package available for the acoustic system was capable of discerning individual upstream movements of fish and enumerating their passage accordingly. It is possible to obtain the signal strength and three-dimensional positions of every returning echo. Aspects of fish passage such as range, depth in the water column and ground swimming speed can therefore be ascertained. The mean acoustic size of each fish, as measured by the system, is also obtained.

This technique therefore represents a potentially powerful management tool for quantifying salmonid migration in a riverine environment and assessing factors which may influence it.

Like the alternative methods of salmonid enumeration, the successful application of this tool is dependant on aspects of site selection, riverine characteristics and fish behaviour. In addition, the ability to assess what proportion of the fish run is passing through the ensonified area of the water column over a range of flows is required.

Based on the findings of this report, the commissioning period for an acoustic counter intended for permanent deployment would, in some cases, be at least two years. This period could be extended if the high degree of technical expertise and experience needed to manage an acoustic system was not available. In some cases where conditions and resources are favourable, commissioning might be achieved in one year, although this would be less likely to have covered the expected range of environmental conditions.

The selection of a site suitable for the implementation of hydroacoustics is of paramount importance. There will be river systems where a suitable site does not exist naturally.

There are several difficult areas that require further investigation and research.

The automatic "real time" fish tracking and counting facility of the system cannot currently be relied upon to obtain robust data on fish passage. Multiple counting of single targets and spurious counts from downstream drifting weed causes the tracking software to over count. This means that every upstream target has to be verified manually after data collection. This has a resource implication for year round production of counts.

It was not possible to accurately filter out the fish from the downstream moving targets, due to the large amount of drifting debris. No downstream fish counts were attempted on the Wye. Although this problem is exaggerated by the high macrophyte growth within the Wye catchment, studies on the River Spey demonstrate similar problems, where the downstream count is biased to an unknown extent by drifting debris (Bob Laughton, pers. com.).

The high debris load caused other problems. Following a period of low flow, particularly in the summer, the first flood washes an enormous amount of vegetation and debris downstream. Therefore during the initial few hours of a rise in water levels, the river is thick with this drifting debris, effectively masking any true fish movements at this time. However, it is considered unlikely that fish will be migrating under these conditions.

Specific Conclusions

Equipment

Although it was never an objective of the R&D project to compare different systems and manufacturers, it is appropriate to comment on the type of system bought for the study.

The decision to base the equipment trial on a split-beam acoustic system was unquestionably the right one. The specific problems encountered on the River Wye, particularly with the amount of downstream drifting macrophytes, were resolved by using information only available from a split-beam system. Split-beam is the latest technological development in fisheries acoustics. All the developments in scientific echo sounders over the last three years have been carried out on split-beam systems.

The split-beam system manufactured by Hydroacoustic Technology Incorporated (HTI) is designed specifically to monitor salmonids in a fixed location application. More important, the support software available for processing data has been under constant development for years and continues to evolve to suit the needs of their clients. Consequently, the hardware and software package available with the HTI system is still considered a few years more advanced than its rivals. In addition, HTI is the only major manufacturer to be able to offer the services of an experienced consultancy team.

Operating procedures

The necessity to verify all upstream targets after data collection had a considerable resource implication. It is difficult to see how the automated tracking process can be improved to count slow moving fish as a single target without compromising other aspects. However, these fish can be identified from a spreadsheet. It should be possible to design a macro that would identify and delete duplicate counts based on temporal and spatial proximity.

The counting of downstream drifting debris as upstream moving targets remains the biggest problem for automated tracking on the Wye. It is possible for the human eye to identify genuine fish from debris based on pattern recognition features. It is more difficult for a processor to do this. Fitting a line through the pings in a fish track and removing outliers may be possible in real time allowing a more realistic apportionment of direction. This would improve the automatic fish counting ability of the Wye system. Changes to the existing tracking program can only be made by the manufacturers.

Recommendation: There are several areas that can be looked at to improve the automatic tracking facilities. The acoustic system has been developed for the rivers and salmon species of North America. The problems experienced with downstream drifting weed, milling fish and an almost year round migration window appear to be UK specific. It may be possible to identify weed by its acoustic properties and filter it out of the data gathering process. This is very much in the manufacturers interest. UK users have an opportunity to collect relevant data to develop a UK specific system. The formation of a national group to focus and influence development will be integral to this process.

Validation

Validation proved difficult but possible over the relatively low river flows trialed. The rather basic and inexpensive video equipment deployed obtained a measure of counting efficiency of 80%. This is based on data from a small section of the river width but demonstrates the potential of the technique. It would be possible to use this technique to devise a detailed validation programme over a much more extensive range of flows. The difficulty in obtaining visual images in poor visibility is acknowledged.

Recommendation: The performance of acoustic counters needs to be assessed over a range of flow conditions. The use of video technology represents the most ideal method but deployment of equipment at resistivity counter sites of known efficiency may prove a more practical answer. Due to the importance of validation and the relative cost of such an exercise it is recommended that the Agency collaborate with interested partners to develop procedures. Such a programme would undertake full evaluation and experimentation of the application and validation of hydroacoustic technology as a method for enumerating migratory adult salmonids in UK rivers. Collaboration would share cost, experience and equipment, enabling much more to be accomplished than by any individual partner.

The application of video cameras on the river bottom for recording silhouettes of fish in contrast against the sky has not been carried out before to validate acoustic counters. Performance should be assessed on a range of river types and flow conditions. Alternative deployments and methodologies for validation should also be explored. It is therefore recommended that this be carried out possibly in collaboration with the other two acoustic counter sites in the UK, on the River Tavy and the River Spey.

The outputs of such a collaborative project would ensure that the Environment Agency and its partners will develop and uptake an important and cost-effective new management tool for the reliable enumeration of salmon and sea trout escapement in rivers. This would significantly enhance fisheries management capabilities, including provision of a mechanism for data collection to supplement the setting of spawning targets, and improve fisheries and river management.

Acoustic Size of Target Species

Work carried out examining the relationship between target strength and fish length using tethered fish was inconclusive. The results showed inconsistency when compared to free swimming fish. The sizing of fish by stereo photogrammetry produced some encouraging results although much more work on the technique will be required.

Due to the large variation in target strength measurements, it is difficult to see how target strength could be used to differentiate species or year classes. Where the length distribution shows strong bi-modality, with a clear fall in frequency between modes, the means of which differ by a factor greater than two, it may be possible. This assumes that the target strengths of salmon and sea trout are the same for a given fish size. Considering the differences found between chinook and sockeye salmon of the same size (Fleishman, pers. com.) this is not a safe assumption.

Recommendation: The issue of relating target strength to fish size needs to be addressed for free swimming fish. This should initially start with a desk study of the information currently available and an investigation of methods for obtaining a target strength to size relationship. Sizing from video images and the deployment of acoustic systems immediately above resistivity counters with a sizing capability may have potential.

Early results from tethered fish trials suggest that this may not be a suitable method. However, due to the relative ease of gathering data on tethered fish, this method should be explored further to attempt to simulate free swimming conditions for fish.

Smolt Monitoring

Monitoring smolts in an open water, riverine situation where the fish are predominantly near the water surface is not a possibility on the River Wye with the current generation of acoustic counters. Problems with surface interference, downstream drifting debris and small target sizes are exacerbated when trying to monitor smolts. On other river systems there may be some applications where smolt enumeration is possible, such as through sluice gates and turbine intakes at dams and barrages.

Recommendation: To observe developments in technology with regard to smolt monitoring and report through a national group.

Shad Monitoring.

Shad avoided an acoustic beam transmitted at a frequency of 200 kHz. During the annual shad migration, the equipment (which uses an operating frequency of 200 kHz) was turned off for a significant period to allow the fish to pass unhindered. Trials of a different system transmitting at a frequency of 420 kHz showed that fish swam through the beam undisturbed. This trial on the Wye demonstrated that it is possible to detect and enumerate the passage of shad.

A system configured and aimed to monitor salmon may not be capable of simultaneously monitoring shad. The two species may migrate in different areas of the water column. A counter deployed to monitor both species would either multiplex two transducers or automatically re-aim a single transducer for a set time each hour. A different set of parameters may also be required for each species.

Recommendation: English Nature and The Countryside Council for Wales (CCW) have been given a new remit under the EU Habitats and Species Directive with regard to monitoring shad. This is further required under the species Biodiversity Action Plan for shad. Discussions should therefore commence on the joint development of systems for the monitoring of shad. This is relevant for the River Wye, and also for the River Towy in West Wales that has a significant run of shad and is due to have an acoustic monitoring programme initiated in 1998.

Presence of non-target species

The fyke netting, video and fishing match results suggest a relative absence of fish species above 40 cm in the area of the counter. A contributory factor in locating the equipment on this site was the perceived absence of non-target species.

Recommendation: The presence of non-target species should be monitored on an annual basis if the counter site is to be operated as a permanent site. A regular programme of fyke netting and monitoring of angling matches should be maintained.

Promotion.

There is much more information that can be obtained from an acoustic system than simply the number of fish migrating past. Behavioural data on swimming speed, depth and range of travel and information on run timing can also be gleamed. A system may provide information on the upper and lower flow thresholds for migration on some rivers. There maybe many other practical applications for this technology in the UK besides the general management need to accurately enumerate the annual run of fish.

Recommendation: The capabilities and potential of acoustic systems should be widely promoted. This can be done via a national group.

Suitability of the chosen Wye site for acoustic monitoring

The Wye site is not an ideal site for the monitoring of salmon migration. The depth profile has two undulations where fish could pass undetected. It is too close to the large pool behind the fishing croy. On certain flows, fish hold in this pool and almost certainly move a short distance up and down river while "holding". Under these circumstances there is a possibility that the same fish may be counted more than once.

The extent to which fish migrate on the opposite bank during elevated flows is also unknown. Although no upstream moving fish have been detected in this area, it was not routinely sampled by the acoustic system.

These issues have actually contributed positively to the objectives of the project, allowing a full appraisal of acoustic counter performance in a challenging environment. While issues such as these can be considered benefits for assessment purposes, they represent potential problems for routine counter operation and need to be addressed.

Recommendation

A validation programme should provide information on the proportion of salmon that pass unsampled by the acoustic beam. Any "gaps" in the river bed could be artificially filled with sandbags by a diving team. It may also be possible to identify flow thresholds where active migration ceases and milling behaviour increases. Sampling could be avoided at these times.

The resources required to operate the Wye counter as a routine monitoring site would be 1 FTE with a budget for consumable items. This assumes that all the hardware and analysis software remains available to the Wye project.

Future Acoustic Sites

During the three years of the project, a substantial amount of experience and expertise in the application of acoustic counters for monitoring salmonids has been acquired, probably more than any team outside of North America. To take full advantage of this, the team should be utilised to advise on the deployment and commissioning of potential acoustic sites on other salmonid rivers, particularly within Wales. Despite the outstanding issues that need to be addressed, with an experienced and adequately resourced team the technique has been shown to produce operational data on fish passage at a difficult site like the River Wye at Redbrook. The same team and resources applied to other sites could produce improved results.

7.0 References

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Appendix 1.

Technical Specifications of the Model 243 Digital Echo Sounder

Size:	282mm wide x 522 high x 500 long, with handle
Weight:	28kg
Mains Voltage:	220 VAC, 50-60 Hz
Operating Temperature:	0-50 C
Power Consumption:	100 watts
Frequency:	200 kHz standard (38 kHz, 60 kHz, 120 kHz, 420 kHz and 1 mHz optional)
Transmit Power:	250 watts standard for 60-200 kHz
Dynamic Range:	Overall dynamic range is 140dB
Transmitter:	40 dB volts range, continuously variable
Pulse Length:	0.1 msec to 10 msec, continuously variable
Bandwidth:	0.1 kHz increments, tied to pulse width
Receiver Gain:	40 dBvolts range, continuously variable
TVG Functions:	Simultaneous 20 and 40 log(R) + 2αr TVG start to nearest 0.1 m The minimum TVG start is 1.0 m
Receiver Blanking:	Start and stop range to 1.0 m
Undetected Output:	12 kHz, for each formed beam
Detected Output:	10 volts peak
System Synchronisation:	Internal or external trigger
Ping Rate:	0.1-40.0 pings/sec
Phase calculation:	Quadrature demodulation
Angular Resolution:	+/- <0.1 (6 beam width, 200 kHz)
Tape Recording:	Optional with Split-Beam Data Tape Interface and Digital Audio Tape (DAT) recorder. Directly records the digitized split-beam data, permitting complete reconstruction of the raw data output.
Calibrator:	Local receiver calibration check using internal calibration source. Pulse and CW calibration functions provided in step settings.
Positioning:	Optional GPS or Loran positioning available, with position data recorded to DAT with acoustic data.

Minimum specification for an Echo Processor:

CPU:	IBM compatible Pc, 486 x DX4 100 MHz, with Windows 95 and maths coprocessor
RAM:	16 MB
Hard Drive:	420 MB hard drive (1 GB recommended)
Ports:	1 parallel and 2 serial ports
Network:	Ethernet Adapter (10base2) suitable for LANTASTIC network software (Ver 6.0)

Appendix 2.

Parameters used by the automatic tracking facility of the acoustic system.

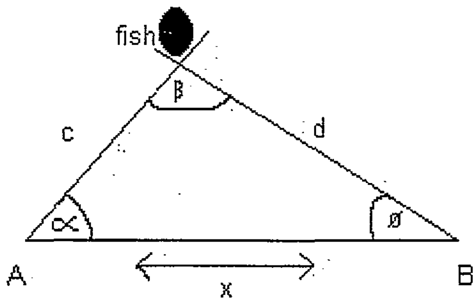
DEP Tracker Parameters

Parameter Number	Typical Values	Wye Values	Comments
105	3-10	8-15	**Maximum ping gap**, or maximum amount of time to allow between echoes from one fish, expressed in pings.
106	3-10	8-10	**Minimum numbers of pings per fish**, or minimum number of pings which user will accept as making up a fish (not necessarily consecutive). Dependant on ping rate, beam width and fish velocity.
234	4.0	5-10	**Maximum expected fish velocity** - usually set higher than the actual velocity the fish are expected to swim to account for uncertainty in angle measurements.
240	1.0	0.1-0.3	**Window expansion exponent** - used when 2D tracking only, to allow for expanding a 2D tracking window at a greater rate with each successive missed echo; helpful for very erratic fish swimming behaviour.
241	0.35	0.35	**Maximum change in range in m/ping** - Used in 2D tracking to set the size of the tracking window in the range dimension.
260	0.0	0-0.25	**Minimum absolute distance fish must travel in the x direction in m** - useful for removing targets which do not move in the x dimension, like rocks. Highly variable angle measurements limit this parameters usefulness.
261	0.0	0.0	**Minimum absolute distance fish must travel in the y direction in m** - useful for removing targets which do not move in the y dimension, like rocks. Highly variable angle measurements limit this parameters usefulness.
262	0.0	0.0	**Minimum absolute distance fish must travel in the z direction in m** - useful for removing targets which do not move in the z dimension, like rocks.

Appendix 3

Calculation of fish length by stereo photogrametric method

In the following arrangement, A and B represent the two adjacent cameras and x represents the known distance between them (200mm here). The target range (i.e. fish range) is estimated using a trigonometric rearrangement of the sine rule.



This rule takes the form:-

$x / \sin\beta = c / \sin\theta = d / \sin\alpha$

This can then be rearranged to provide c and d:-

$c = x \sin\theta / \sin\beta$
$d = x \sin\alpha / \sin\beta$

where $\beta = 180 - (\alpha + \beta)$

The angle of resolution of each camera can be calculated in degrees per pixel from the measured field of view at a known depth and the measured number of pixels across the screen for that camera view. Knowing the length c, the width (in pixels) of an object from point A, the angle of resolution of camera A and assuming that the measured object is approximately perpendicular to the axis of the camera, an estimate of the real width of the object can be made using Pythagoras' theorem. Similarly, an estimate can be made from the view of B giving two range estimates and therefore two scale factors for view (Fewings, pers comm).

Calculation Steps

1. Distance between two cameras (mm) = x
2. Field of view of camera (degrees) = 52.65
3. Offset from plane = 90 - (field of view of camera / 2)
4. Lefthand edge of camera 1 view (x coordinate) = LH C1
5. Righthand edge of camera 1 view (x coordinate) = RH C1
6. Lefthand edge of camera 2 view (x coordinate) = LH C2
7. Righthand edge of camera 2 view (x coordinate) = RH C2

Appendix 3 Cont.

8. Image width from camera 1 = RH C1 - LH C1
9. Image width from camera 2 = RH C2 - LH C2
10. Angle of resolution C1 (/100) = (field of view of camera / image width C1)/100
11. Angle of resolution C2 (/100) = (field of view of camera / image width C2)/100

Ranging :
12. Ranging point on fish from C1 (x coordinate)
13. Ranging point on fish from C2 (x coordinate)
14. Alpha = (((RH C1 - ranging point from C1) *100)* angle of resolution C1(/100))
+ offset from plane
15. Theta = (((ranging point from C2 - LH C2)*100)* angle of resolution C2(/100)
+ offset from plane
16. Pi / 180 = PI() / 180
17. Sin theta = sin (theta* Pi/180)
18. Sin alpha = sin (alpha* Pi/180)
19. Range from C1(mm) = dist between cameras/ sin(Pi/180*(180- (alpha+theta)))
* sin theta
20. Range from C2(mm) = (range from C1 / sin theta) * sin alpha

Sizing :
21. X start coordinate
22. X end coordinate
23. Y start coordinate
24. Y end coordinate
25. X length of fish = x end coordinate - x start coordinate
26. Y length of fish = y end coordinate - y start coordinate
27. Angular length of fish = SQRT {(x length of fish)^2 + (y length of fish)^2}
28. Calculated fish angle = angular length of fish * angle of resolution C1 * 100
29. Real length of fish (mm) = range from C1 * tan (calculated fish angle * Pi/180)