Variability in Mobile Acoustic Fish Community Assessment

R&D Technical Report W2-063/TR/2

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This technical report comprises a critical examination of variability in mobile acoustic fish community assessment. The information is for use by EA staff and others involved in development of acoustic surveying methodology.

Key Words
Hydroacoustics, stock assessment, variability, freshwater fishes, rivers

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EXECUTIVE SUMMARY

Hydroacoustics is a cost-effective tool for surveying fish communities in large lowland rivers and lakes and will be a key element in providing temporal and spatial data for the national fisheries monitoring programme and the Water Framework Directive. However, deployment of sonar in horizontal mobile surveys is still in the developmental stage, and successive surveys on the same fish populations can produce very variable results. In addition, three types of echosounder are currently in use within the Environment Agency and comparisons between results obtained from different systems are difficult to conduct. In order to improve robustness of information obtained from horizontal hydroacoustic fisheries surveys, this project was commissioned to account for the observed sampling variability. Two potential sources of variability were examined:
1) Differences between echosounders in operation.
2) Variability due to key abiotic factors affecting fish behaviour.

One dual-beam (BioSonics model 102) and two split-beam (HTI model 241, Simrad EY500) echosounders were tested for variability in reported target strength (TS) and fish density. The objectives of these comparisons were:
- A recommended standard echosounder system for Environment Agency mobile horizontal surveys.
- To validate cross-calibration of echosounder outputs, enabling comparisons between rivers surveyed using different gears.

The impact of key abiotic factors on fish behaviour was examined through a comprehensive literature review and an examination of existing acoustic data. Fish density results from long-term studies of the Rivers Thames, Trent and Ouse were examined in relation to three environmental factors; water temperature, river discharge and moon phase. These two studies had the following objectives:
- An assessment of the role of different fish behaviours in influencing the vulnerability of fish to acoustic detection.
- An indication of environmental sources of variability in acoustic data.

All studies were also expected to contribute recommendations to the design of a future programme to establish the influence of key abiotic factors on acoustic assessments of fish communities.

Echosounder configurations were individually standardised for echo-counting. The non-uniform operation and echo-selection criteria of the echosounders generally restricted analyses to relative comparisons of density and TS, rather than absolute values. In tank tests, reported TS varied by range from the transducers and between replicate samples of standard targets. Higher levels of variability were noted for the dual-beam BioSonics. For comparisons of density outputs, two types of data were collected and compared;

1) by passing a known number of targets through the echosounder beams and calculating volume density for a fixed time-window;
2) by collecting fish abundance data by mobile horizontal survey of six reaches of the River Thames and one reach of the Manchester Ship Canal.

In all studies, paired density estimates were significantly correlated, however HTI densities were often an order of magnitude higher than equivalent BioSonics or Simrad estimates. No

evidence was found for reporting of 'false' targets, therefore the differences were attributed to the HTI having superior single-target reporting performance over the ranges analysed.

The literature review was conducted by Dr Martyn Lucas of Durham University, the output of which is a complementary report, "*A Review of Fish Behaviours Likely to Influence Acoustic Fish Stock Assessment in Shallow Temperate Rivers and Lakes*" (Lucas *et al.* 2001). The review of acoustic datasets failed to identify significant sources of variability in acoustic assessments. However, the short duration of the studies, 'snapshot' measurements of environmental factors and difficulties accounting for the interactive effects of key factors restricted the analyses.

This study concluded that the variability in reported TS is of little significance in the context of mobile horizontal surveys. The HTI would be recommended as the standard Agency system for such surveys primarily based on single target reporting and user-definable ping-rates, however other systems must be gradually phased out with substantial (but undefined) overlap periods to enable cross-calibration of acoustic outputs. Finally, recommendations were made for the design of a future programme to determine the influences of abiotic factors on acoustic estimates. These included; use of a single echosounder system, studies on a number of sites and rivers with differing properties, multiple measurements of environmental parameters and combined mobile / fixed location studies.

CONTENTS

1. INTRODUCTION

Horizontal mobile hydroacoustic fisheries surveys of rivers have been applied in Europe for over ten years (Lucas *et al.* 1998; Kubecka *et al.* 2000). The technique has shown promise as a cost-effective tool for surveying the distribution, abundance and, to an extent, the size-structure of fish communities in large lowland rivers that are difficult to investigate using conventional methods. Application of these techniques is currently undergoing a transition, increasingly moving from the experimental stage under a small group of experts (e.g. Nan Duncan, Jan Kubecka) to routine use by appropriately trained fisheries scientists (Lyons, 1998; Hughes, 1998). This is certainly the position within the UK, where > 140 survey sites within the Environment Agency's core fisheries monitoring programme now require hydroacoustic methods as part of their integrated fish stock assessment.

One factor that probably inhibits a greater rate of acceptance and understanding of mobile horizontal hydroacoustic surveys by fisheries managers is temporal variability in reported results. For example, successive surveys on the same fish populations can produce highly variable density estimates (Lucas *et al.* 1998; Duncan and Kubecka, 1996). In order to improve robustness of information obtained from horizontal mobile surveys, this R&D was commissioned to account for sampling variability from two potential sources:

- Variability due to different echosounder systems being deployed.
- Temporal variability due to the effects of key environmental factors on coarse fish behaviour.

To manage these investigations, the R&D was divided into four Phases with the following objectives:

- Phase 1: Compare three echosounder systems for variability in reported Target Strength (TS) and reported fish densities.
- Phase 2: Review and collate existing Environment Agency (Agency) acoustic data and identify sources of variability due to selected abiotic environmental factors.
- Phase 3: Review existing literature on factors influencing coarse fish behaviour and assess how such behaviour will influence susceptibility to acoustic detection.
- Phase 4: Design and implement a programme to assess the influence of abiotic factors on temporal variability in acoustic estimates of fish communities at a variety of sites.

Only Phases 1 – 3 are described in this report. Phase 4 is dependant to a large extent on the output of the first three Phases and is scheduled for implementation at a later date.

The contents of this report assumes a good understanding of the physics of underwater acoustics as well as the operation of split and dual beam echosounders. MacLennan and Simmonds (1992) provides a modern review of fisheries acoustics and a useful summary is presented in Duncan and Kubecka (1993).

1.1 Variability Due To Different Echosounder Systems (Phase 1)

Three types of scientific echosounder are currently in routine operation by the Agency for mobile horizontal surveys of rivers; dual beam BioSonics Model 102 (420 kHz), split beam HTI Model 241 (200 kHz) and split beam Simrad EY500 (120 kHz). The BioSonics is only in regular use within Thames Region, the HTI is operated in Thames and South West

Regions, whereas the Simrad is principally deployed in North East and Midlands Regions, and to a lesser extent on North West, Anglian, Southern and EA Wales rivers.

Although the hardware varies, there has been some standardisation of acoustic outputs within the Agency. Echo-integration (EI) was considered less robust than echo-counting (EC) in environments with a low signal to noise ratio (SNR), such as horizontal surveys of rivers (Kubecka *et al.* 1992). EC results presented as volume densities (fish $1000m^{-3}$) were therefore chosen as the standard Agency output, providing minimum estimates of the acoustically detectable fish community for selected reaches. Following practical experience and manufacturers' advice, standardised settings for echo-counting were individually developed for each echosounder system (e.g. Simrad operation described in Hillary *et al.* 1999).

No detailed studies have been performed comparing TS and volume density outputs of the three systems, indeed few inter-gear comparisons of any description have been published. Dual beam and split beam echosounders have been compared for variability around TS measurements and fish detection performance (Traynor and Ehrenberg, 1990; Burwen *et al.* 1995). There have recently been some multi-gear, mobile surveys of lakes comparing density and TS distribution estimates (Rudstam *et al.* 1999; Mehner *et al.* in press). However, this study may be the first investigation in the context of mobile horizontal surveys of rivers.

Due to differences in hardware (e.g. working frequency) and non-uniform operational settings, comparisons of absolute densities would be difficult and in general, analyses would have to be restricted to comparisons of relative density outputs. Nevertheless, inter-gear comparisons are desirable, as they would contribute significantly to the following objectives:

- A recommended echosounder system for mobile horizontal surveys.
- Cross-calibration of historic acoustic data collected by different echosounders, to facilitate comparisons between river systems and permit a standardised acoustic output for the fisheries monitoring programme.
- Provide recommendations for the experimental design of a study assessing the influence of abiotic factors on temporal variability in acoustic estimates of fish communities (Phase 4).

The three echosounder systems were therefore compared for variability in TS measurements in tank tests and variability in volume density estimates in field studies on the River Thames.

1.2 Variability Due To Fish Behaviour – Data Review (Phase 2)

Fish in lowland rivers exhibit a variety of behaviours likely to have significant impacts on acoustic assessments, for example movements between feeding, resting and spawning habitats, exploratory migrations and refuge seeking behaviour (Lucas *et al.* 2001). There are also a large number of abiotic factors that will contribute to acoustic variability, mediated through changes in fish behaviour. These factors include temperature (Lucas *et al.* 2001), hydrology (e.g. river discharge. Lucas *et al.* 1998), light intensity / moon phase (Kubecka and Duncan, 1998; Gaudreau and Boisclair 2000) and water quality parameters (e.g. dissolved oxygen. Hendry *et al.* 1994).

Acoustic surveys of rivers are particularly vulnerable to such sources of variability as shallow water habitats (<5 m deep) are more poorly buffered against environmental change than, for example, deep lakes. To minimise the impact of environmental variability and to optimise conditions for echo-counting, the Agency routinely conducts hydroacoustic surveys during the summer months, at night, near base flow conditions when fish are generally well dispersed throughout the water column (Butterworth *et al*, 1993). Despite attempting to standardise survey conditions, temporal variability in acoustic results is evident. For example, replicate runs during one night along a Thames reach identified a patchy distribution of fish with densities that gradually increased with time (Duncan and Kubecka, 1996).

The role of key environmental factors in acoustic variability therefore needs to be identified. One approach is to review historic acoustic data, aiming to correlate trends in acoustic results with environmental variability. This requires access to long-term datasets conducted on the same reaches of rivers, at similar times of year using unchanged equipment and operational settings. In addition, associated environmental data must be readily available. Extracting the main source of variability from such reviews can prove difficult, as many factors are inter-related (e.g. rainfall increases river discharge and turbidity but decreases water temperature) and there is also a need to consider interactive or synergistic effects of abiotic factors on fish behaviour (Lucas *et al.* 2001).

Although difficult, resolving environmental sources of variability in acoustic results is valuable as it would increase the robustness of information based on acoustic surveys and would contribute towards the following project objective:

- Provide recommendations for the experimental design of a study further assessing the influence of abiotic factors on temporal variability in acoustic estimates of fish communities (Phase 4).

Three Agency studies appeared to meet the necessary criteria; the Rivers Thames, Yorkshire Ouse and Trent. Acoustic estimates from these investigations were therefore compared with three key environmental parameters; water temperature, moon phase, river discharge.

1.3 Variability Due To Fish Behaviour – Literature Review (Phase 3)

A second approach to help account for variability in acoustic outputs is a comprehensive literature review of all factors that may modify fish behaviour in shallow waters. This Phase of the project was contracted to Dr Martyn Lucas and associates at Durham University. Their final report, "*A Review of Fish Behaviours Likely to Influence Acoustic Fish Stock Assessment in Shallow Temperate Rivers and Lakes*" (Lucas *et al.* 2001) was published separately, but is intended to complement this report and it is strongly recommended neither report should be read in isolation of the other.

2. METHODS

2.1 Inter-Gear Variability

2.1.1 Systems and data processing

Hardware

The performances of three scientific echosounders currently in use by the Environment Agency were compared with respect to TS measurements and volume density estimates in horizontal orientation. The sounders examined were HTI Model 241 (200 kHz) and Simrad EY500 (120 kHz) split beam devices and the BioSonics Model 102 (420 kHz) dual beam device. The hardware associated with each echosounder is summarised in Table 2.1. For brevity, the echosounders and their associated post-processing software packages are subsequently referred to in this report as 'the HTI, Simrad and BioSonics'.

Table 2.1. Hardware used during project

Sounder	HTI Model 241	BioSonics Model 102	Simrad EY500
Source	EA Thames Region	EA Thames Region	EA NW Region
Type	Split-beam	Dual-beam	Split-beam
Operating Frequency	200 kHz	420 kHz	120 kHz
Transducer	6° circular	6° / 15° circular	7° circular
Near Field Distance	0.8 m	0.41 m	0.85 m
Processor	Dell Latitude LM	Toshiba T6600C	Toshiba T1950CT
Tape recorder	Panasonic SV3700 DAT	Panasonic SV3700 DAT	
Tape recorder interface		BioSonics Model 171	
Oscilloscope	Philips PM97 Scopemeter	Fluke 97 Scopemeter	

Circular transducers were used in conjunction with the echosounders. In the UK, elliptical transducers are preferred for horizontal applications in shallow waters as they are manufactured with small side-lobes, however broadly similar elliptical beam angles were not available for all three echosounders within the Agency inventory. Nominal beam angles for the circular transducers were 6° narrow beam / 15° wide beam (BioSonics), 6° (HTI) and 7° (Simrad). All data collection occurred at ranges at least double the respective near field distances of these transducers (Table 2.1). Sounder configurations were individually standardised for echo-counting (Table 2.2) based on earlier studies and manufacturer's recommendations (Simrad – Hillary *et al.* 1999; BioSonics – Duncan and Kubecka, 1993; HTI – Gregory *et al.* 2001; Butterworth, personal communication).

Calibration

All echosounders were calibrated in the field using manufacturers' recommended target spheres immediately prior to a trial. To facilitate positioning of standard targets on the acoustic axis, the three transducers were mounted on a common bracket attached to a Videmech 610 rotator (except Hydraulics Research in February, see Section 2.3.2).

- HTI

The calibration procedure is summarised in the HTI Operator's Manual (HTI, 1997) with modifications in Gregory *et al* (2001). The HTI was calibrated with a 36.0 mm tungsten carbide sphere suspended >5m from the transducer by monofilament line and fine mesh netting. Data from >1000 pings were stored to DAT and subsequently replayed through the digital echo processor with 40LogR TVG to obtain a mean voltage for the standard target.

Table 2.2. Echosounder settings used during project

Sounder	HTI Model 241	BioSonics Model 102	Simrad EY500
Operational Settings			
Pulse Length	0.2 ms	0.4 ms	0.3 ms
Ping Rate	10 pings.s^{-1}	10 pings.s^{-1}	Set at maximum but variable ~3.3 - 5 pings.s^{-1}
TVG	40LogR	40LogR	20LogR
Transmit Power	+20 dBW	-3 dB	
Receiver Gain	-12 dB	-12 dB	
Through System Gain	From calibration	From calibration	Sv/TS Transducer Gain: From calibration
Bandwidth	Auto	5kHz	12kHz
Echo selection criteria			
Minimum TS	-50 dB	-50 dB	-50 dB
Minimum Echo Length (at ½ amplitude)	0.15 ms	0.4 ms (narrow beam)	0.24 ms
Maximum Echo Length (at ½ amplitude)	0.25 ms	0.64 ms (narrow beam)	0.42 ms
Maximum Angle Off-axis	± 3°	± 3°	Max. Gain Compensation: 3.0 dB
Other Criteria			Max. Phase deviation: 4.0

The through system gain (40LogR Go) was calculated from the following equation and inserted in the calibration file:

TS = -SL – Go – RG + Vo

Where; TS = Target Strength of standard target.
SL = Source Level
Go = Through System Gain (40 Log)
RG = Receiver Gain
Vo = 20 * Log (mean voltage amplitude)

- BioSonics

Calibration of the BioSonics has been comprehensively described in a previous study (Duncan and Kubecka, 1994). Calibration was conducted with a 36.0 mm or 17.0 mm tungsten carbide sphere suspended >5m from the transducer by monofilament line and fine mesh netting.

- Simrad

The Simrad was calibrated using the LOBE programme as described in the Simrad EY500 Instruction Manual (Simrad, 1996) and Simrad field guide (Hillary *et al.* 1999). A 23 mm copper sphere was suspended by monofilament line >5m from the transducer and moved throughout the acoustic beam by fine adjustment of the rotator.

Data collection and post-processing

- HTI

The digital output from the HTI was stored to DAT during the survey. The tapes were post-processed in real time for noise-handling (establishing TS thresholds for each run based on a signal to noise ratio, SNR, of 3:1) and manual bottom tracking. Bottom (.BOT) and tracked echo (.ECH) files were exported to Excel spreadsheets to calculate the total volume sampled, TS measurements and the number of accepted single targets.

Single target volume density (fish $1000m^{-3}$) for targets >-50 dB was calculated from the volume of a cone with the maximum accepted off-axis angle (±3°):

$$= \frac{\Sigma^{i}_{1} n_i}{\Sigma^{i}_{1}\left((TAN(3\pi/180)D_i)^2 \pi D_i/3 - (TAN(3\pi/180)d_i)^2 \pi d_i/3\right)_i} .1000$$

where; n_i = number of accepted targets for ping i
D_i = maximum range sampled for ping i
d_i = minimum range sampled for ping i

- BioSonics

Data collection and processing is described in Duncan and Kubecka (1993) and Hughes *et al.* (1995). 40LogR TVG was applied to the narrow and wide beam signals and stored to DAT during the survey via a model 171 tape recorder interface. These tapes were played back through the interface and post-processed using a model 281 echo signal processor (ESP) for noise-handling and bottom tracking. Single target volume density estimates for targets >-50dB were calculated using BioSonics ESP Target Strength (ESP_TS) post-processing software.

On-axis TS measurements were obtained from files extracted from the .dat files using BioSonics ESP Output File Viewer (ESP_VIEW) software.

- Simrad

20LogR data were logged to the fixed disc with automatic bottom tracking on. Noise thresholds were not calculated as a default minimum TS detection value of –50 dB was used for all Simrad data (Hillary *et al.* 1999). Files were post-processed using Simrad's EP500 v5.4 software (Simrad, 1996). The bottom was manually redefined where required and volume density for single targets (fish $1000m^{-3}$) calculated:

$$= \frac{sa(tr)}{sa} . \text{Volume Density}$$

where; sa(tr) = area back-scattering coefficient for accepted single targets (from echo-counting).
Sa = total area back-scattering coefficient (from echo-integration).
Volume Density = Total volume density of fish (from echo-integration).

A second method for estimating single target volume densities using Simrad data was calculated by applying the process used for the HTI. The volume sampled was calculated using a cone with a nominal 3.5° half-beam angle. Such analyses were conducted on mobile Thames data (Section 2.1.2).

On-axis TS measurements were obtained directly from the raw data files (.dg files) using Simrad's SHOW programme, which translates binary telegrams into ASCII telegrams. The resulting ASCII files were exported to Excel spreadsheets and the telegrams sorted using the macro Simrad QED.XLS. This also enabled individual pings with their associated time-based identifiers to be extracted for the drifting study (see section 2.1.2).

2.1.2 Field experiments

TS measurements of on-axis targets were conducted at Hydraulics Research Offshore Tank Facility at Wallingford on 1-2 March and 23-24 May 2001. Mobile surveys were conducted on the River Thames between Benson Lock, Wallingford and Iffley Lock, Oxford from 27 June - 5 July 2001, and the Manchester Ship Canal (Latchford to Irlam Lock) on November 7th 2001. Cross-talk experiments (tests for interference between echosounders) were run on the River Mersey at Warrington on 18 June 2001, Davenham Fisheries Depot on 26th October, and the Manchester Ship Canal on 7th November.

Tank Trials at Hydraulics Research

The freshwater tank used for the TS variability study at Hydraulics Research was square, with vertical sides and approximate dimensions 25 x 25 x 2 m deep. The beams were orientated to avoid structures within the tank, including metal poles and a square pit, resulting in >12 m of unobstructed water being available. A mobile gantry spanned the tank, which was useful for the positioning of targets at different ranges from the transducers (Figures 2.1 and 2.2).

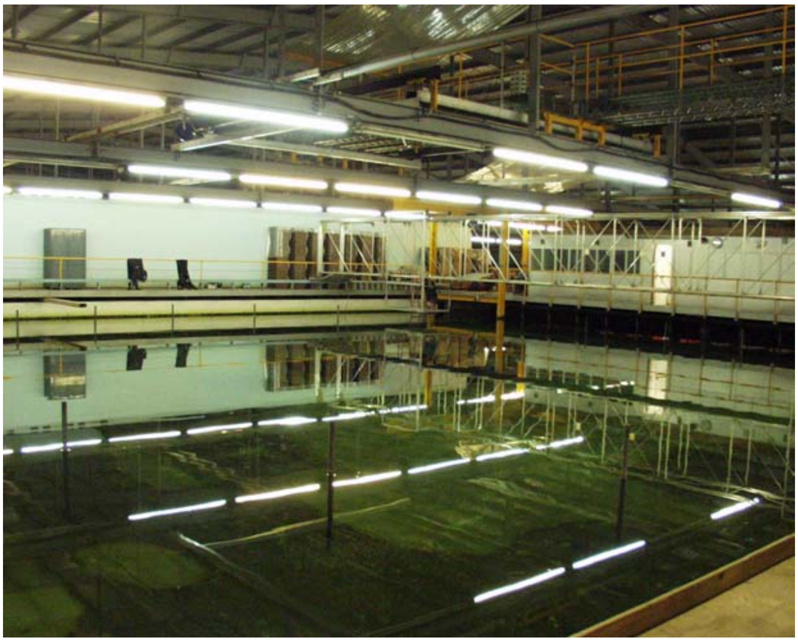


Figure 2.1. Hydraulics Research Tank Facility

Figure 2.2. Gantry over tank used for suspending targets

In March, the HTI and BioSonics transducers were mounted on a common bracket attached to a Videmech 610 rotator, whilst the Simrad was mounted separately on a Videmech 556 rotator (Figure 2.3). Difficulties were encountered positioning targets in the centre of the Simrad beam and a common bracket for all three transducers was used in conjunction with the Videmech 610 rotator in May. The rotators were mounted on a steel H-frame so that the transducers were exactly mid-water (1 m depth).

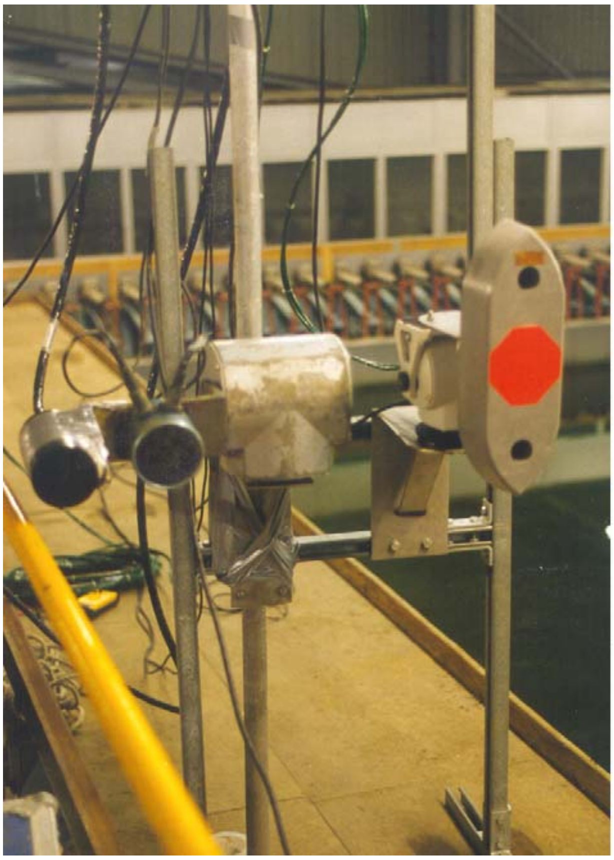


Figure 2.3. Transducer mountings, Hydraulics Research, March

Following calibration, spherical targets of various sizes and materials were dipped in a weak detergent solution and presented to the echosounders at different ranges (Table 2.3). Targets were positioned on the acoustic axis of each echosounder in turn and 3 minutes of data captured to DAT or fixed disc. For replicates, the targets were removed from the water and repositioned on the acoustic axis.

Table 2.3. Targets presented to echosounders, Hydraulics Research tank trials

Diameter	**Shape**	**Materials**
36 mm	Spherical	Tungsten carbide
20 mm	Spherical	Tungsten carbide
17 mm	Spherical	Tungsten carbide
23 mm	Spherical	Copper
40 mm	Spherical	Ping pong ball
73 mm	Spherical	Plastic
114 mm	Mostly spherical, flanged surface	Plastic, flanged surface*
114 mm	Mostly spherical, ribbed surface	Plastic, ribbed surface*

The TS data were sorted by range in Excel and any echoes not relating to the standard target were deleted. Mean TS, mean cross-sectional area (σ), and coefficient of variation of σ (as %) were calculated for each run on a target.

River Thames Trials

Mobile surveys were conducted on board Thames Region sonar boat *Pingu* (Figure 2.4). The three transducers were mounted in horizontal orientation on a common bracket attached to a Videmech 610 rotator and submerged 1 m below the surface, approximately 1 m in front of the hull on a scaffolding pole (Figure 2.5). All echosounders ran off 240 V supplied by a diesel generator. Two types of survey were conducted; a drifting target study designed to mimic a mobile survey, and a mobile survey of the Thames between Benson and Iffley Locks.

Figure 2.4. Thames Region sonar boat *Pingu*

Figure 2.5. Transducer mounting on *Pingu*. The transducers and rotator were submerged once alignment had been checked

- Drifting Target Study

This trial was designed to imitate a mobile survey, by moving a known number of shifting aspect targets past stationary transducers.

The boat was securely moored to the river bank in the sluiceway at Day's Lock and the transducers tilted to cover the maximal usable range (Duncan and Kubecka, 1994). 6 x 18 mm hexagonal nuts were suspended from a 6 m fibreglass pole at ~0.8 m intervals by 2.0 m lengths of monofilament. This length of line ensured a number of the targets remained within the beams as they drifted past and the spacing interval allowed each echosounder to resolve adjacent nuts as targets. The pole was secured on top of a small, flat-bottomed dinghy with the nuts submerged. Computer times and data logging were synchronised and the dinghy was drifted past the transducers with the pole approximately in line with the beams (Figure 2.6). Once the targets were well clear of the acoustic beams, logging was stopped simultaneously. 10 runs with targets were conducted and one run with no targets (control).

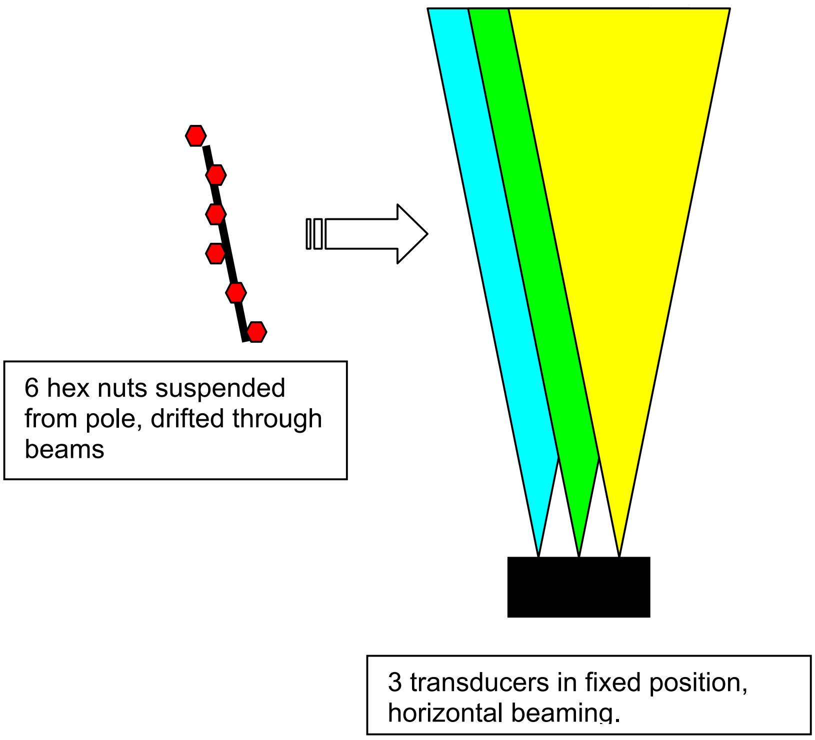


Figure 2.6. Diagram summarising drifting target study

A 30 second time window was analysed for each run. The window was based on the Simrad echogram and included buffer periods at both ends when no targets were recorded in the beam. The start and finish pings of the window were extracted from the raw data files giving their individual time-identifiers, and these times enabled the equivalent HTI and BioSonics windows to be selected. The respective tapes were replayed through oscilloscopes to ensure these windows also contained the targets with target-free 'buffer' periods at the beginning and end.

Simrad and HTI single target volume densities were calculated between 2 – 10 m range for each 30 second window as described in Section 2.1.1. The second method for calculating density by the Simrad was also employed ('Simrad 2'). In ESP_TS, the total number of pings in the density formula is determined by subtracting the ping number of the first target in the file. If there are no targets detected for significant periods at the beginning or end of a data collection period, then the density estimate for the whole run may be overestimated (BioSonics, 1991). Therefore, to calculate the volume sampled by the BioSonics, the ESP_TS volume results for each run were plotted against the number of pings between the first and last targets and a regression performed (Figure 2.7). Volume sampled between 2 – 10 m in a 30 second window (300 pings) was estimated to be 641 m^3.

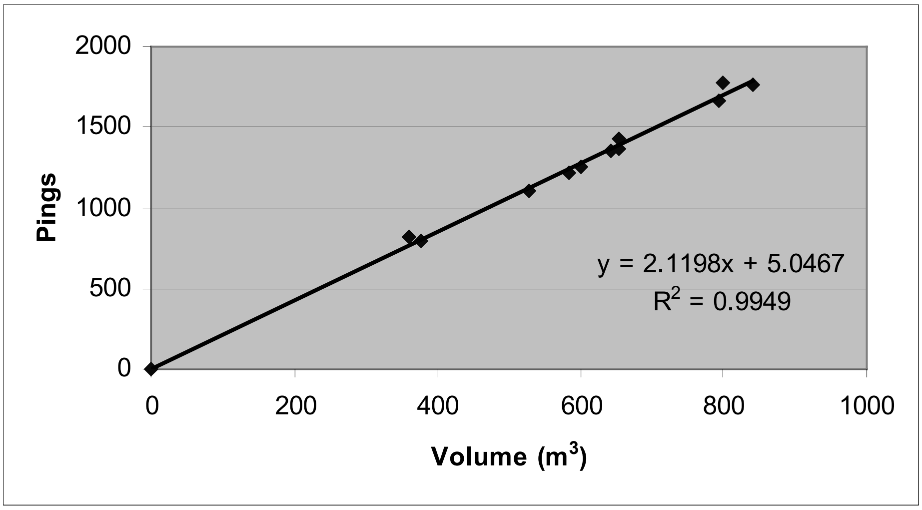


Figure 2.7. Estimate of water sampled in drifting target study by BioSonics using ESP_TS output

The ability of each echosounder to report targets was estimated from the ratio of 'hits' and 'misses' on the nuts. For each run, accepted single targets were plotted by distance from the transducer against relative ping number (to compensate for the slower Simrad ping-rate). Nuts that were 'hit' more than once by an echosounder (i.e. produced accepted echoes) were selected and the number of pings between the first and last 'hits' totalled. Subtracting the number of 'hits' from this total gave the number of pings that 'missed' that nut (i.e. did not produce an accepted echo). 'Hits' and 'misses' were totalled for every selected nut, the proportion of 'hits' calculated (termed the detection probability) and echosounders compared by one-way ANOVA with Tukey's multiple comparison test.

- River Thames Mobile Survey

The six study reaches on the River Thames are illustrated in Figures 2.8 – 2.11 and survey details are summarised in Table 2.4. A reach is defined as a stretch of river between navigation weirs.

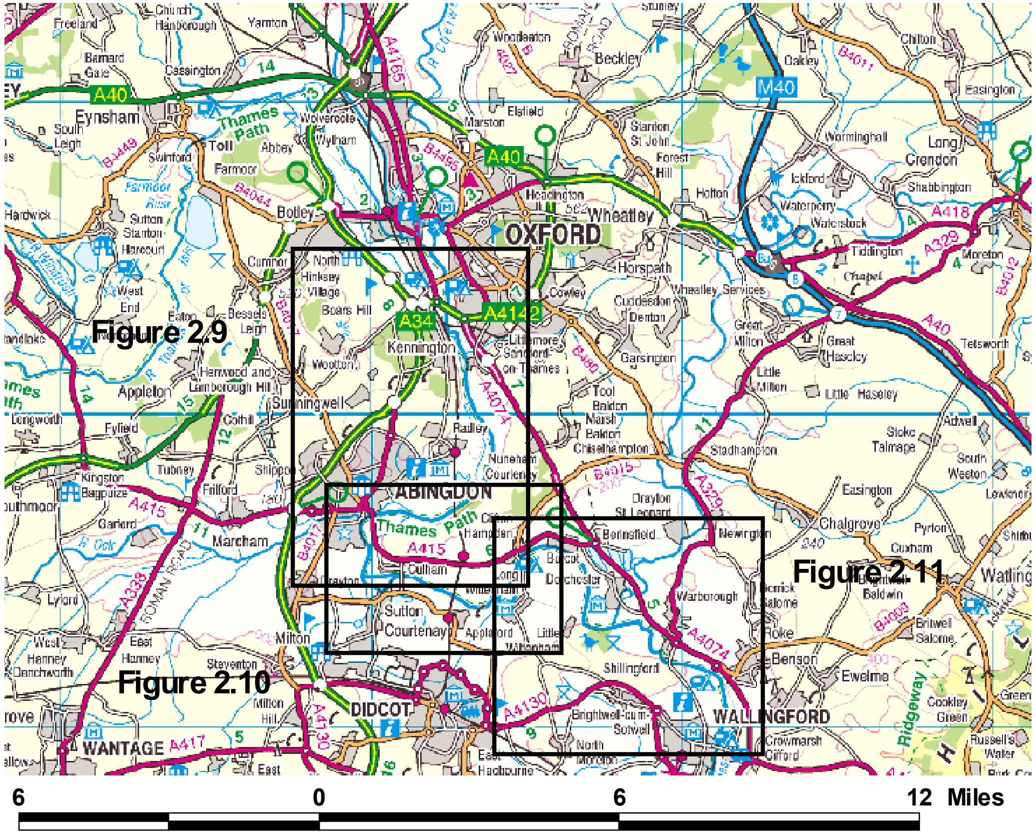


Figure 2.8. The River Thames at Oxford

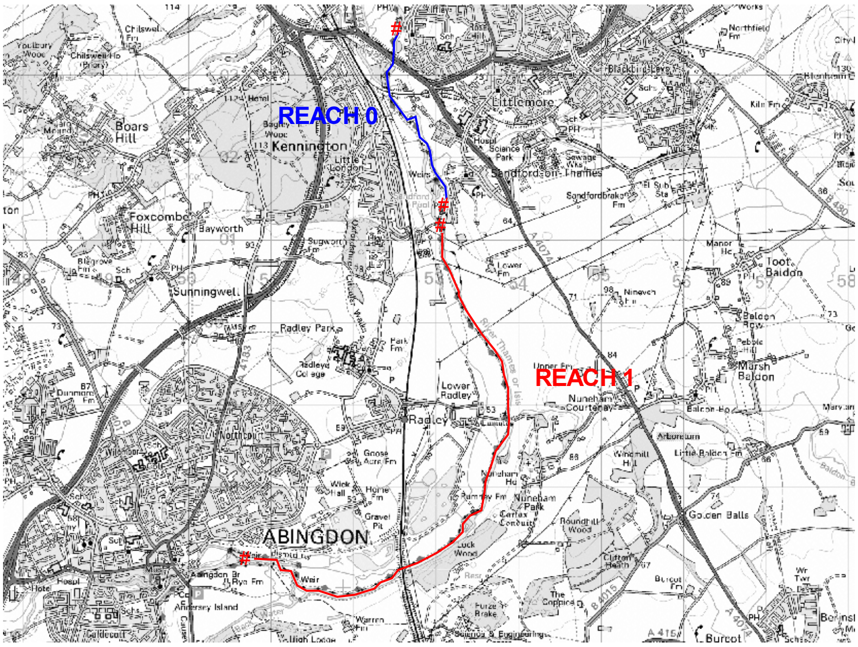


Figure 2.9. Reach 0 and 1, River Thames

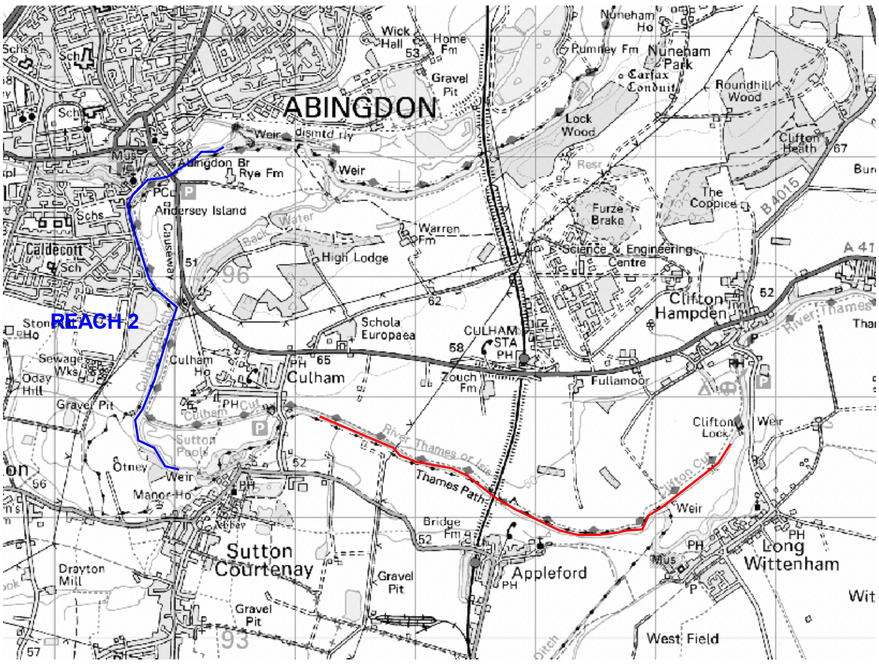


Figure 2.10. Reach 2 and 3, River Thames

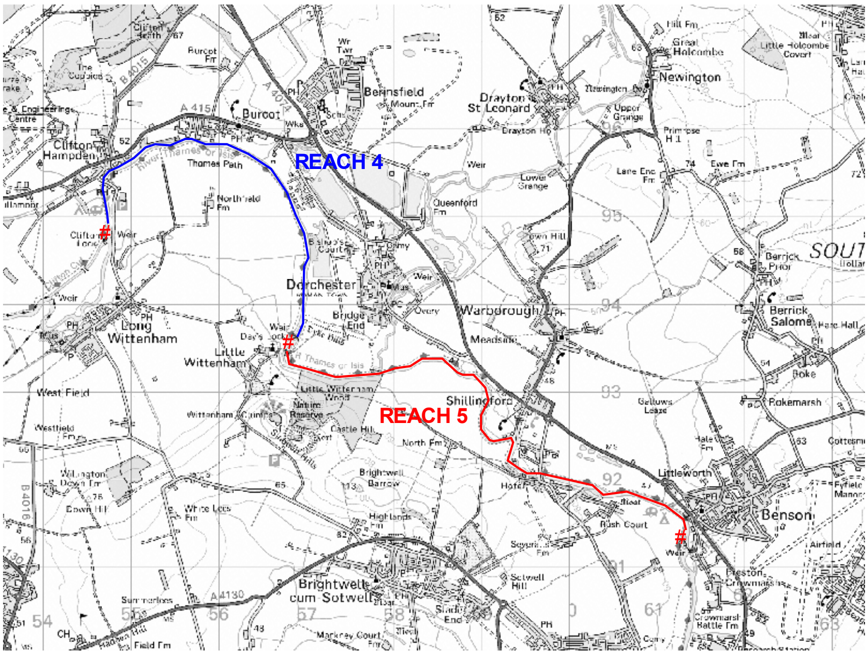


Figure 2.11. Reach 4 and 5, River Thames

Table 2.4. River Thames and Manchester Ship Canal reach and survey details. A reach is defined as a stretch of river between navigation locks / weirs

Reach	Length (m)	Date Surveyed	Time Surveyed
Thames 0	2 300	July 4th / 5th	22:21 – 02:00
Thames 1	7 000		
Thames 2	3 600	July 3rd / 4th	23:25 – 02:40
Thames 3	4 000		
Thames 4	4 700	July 2nd / 3rd	22:35 – 03:00
Thames 5	6 100		
MSC 1	12 000	November 7th	18:33 – 22:54

On all three nights the sky was clear and calm. At dusk on July 2nd water temperature was 19.6°C and air temperature 23.5°C. Moon phase was approaching full and there was abundant insect activity above the river, with mayflies (Order Ephemeroptera) particularly prevalent.

Once all gear and personnel were on board, the transducers were tilted to cover the maximal usable range. The boat was driven downstream along the right bank and upstream along the left bank at a constant 1400 rpm, resulting in approximate survey speeds of 7 and 6 $km.h^{-1}$ respectively. Data were generally stored in 10 minute-long files, however files were occasionally shortened or extended depending on in-river structures, obstructions, macrophytes on the transducers etc. Data were collected between 4 and 12 m, as previous surveys of the River Thames using the BioSonics indicated this stratum was the most representative based on the probability of recording targets of different sizes (Hughes, 1993). Within this study range, two voltage thresholds (4 – 8 m and 8 – 12 m) were set for the BioSonics and HTI, based on a 3:1 SNR.

Single target (>-50 dB) volume densities were calculated for each 10-minute data-set. Paired comparisons of echosounders were conducted in two ways:

1) by pairing density estimates and conducting Pearson (product moment) correlation coefficient analyses; and
2) by ranking each data-set and conducting Spearman correlation coefficient analyses on the paired values.

For comparisons of TS distributions, accepted single targets were partitioned into 3 dB size-classes between –17 and –50 dB. All runs from reach 5 were pooled and the frequency and relative frequency of each size-class plotted for the three echosounders.

Manchester Ship Canal mobile trials

Mobile surveys were conducted on board North West Region sonar boat *Nab 17*. The Simrad and HTI transducers were mounted in horizontal orientation on a common bracket attached to a vertical scaffolding pole and submerged 1 m below the surface, approximately 1 m in front of the hull. Beam orientation was adjusted by shifting equipment and personnel within the boat to achieve maximal usable range. All echosounders ran off 12V DC supplies from car batteries and invertors were required for the HTI PC and DAT deck.

The study reach on the Manchester Ship Canal (MSC) is illustrated in Figure 2.12 and survey details are summarised in Table 2.4. At dusk on November 7th water temperature was 10.1°C and air temperature 11°C. Moon phase was full moon – 6, however cloud cover was complete and heavy rain and a strong westerly wind persisted throughout the survey.

Data were generally collected as for the mobile Thames survey, however greater mean channel width, deeper water and lower background noise levels permitted a greater range for analyses (4 – 25 m). Data were collected between 4 and 25 m range and within this study range five voltage thresholds (4 – 8 m, 8 – 12 m, 12 – 16 m, 16 – 20 m and 20 – 25 m) were set for the HTI, based on a 3:1 SNR. Single target (>-50 dB) volume densities outputs and TS distributions were compared as described for the Thames survey (without Spearman rank correlation analyses).

Tank trials at Davenham depot
To examine the effect of different operational and echo-selection settings on volume-density estimates, fixed location trials were conducted in tanks at the EA Davenham Fisheries depot for the HTI and Simrad echosounders.

The transducers were deployed on an H-frame at mid-water in two 12 x 4 x 1–1.5 m settlement tanks. The echosounders were calibrated in a tank containing no fish and the Simrad ping-rate estimated from the TS histograms update rate in the TS Detection menu (Hillary *et al.* 1999). The HTI was calibrated for two set-ups:

1) the normal mobile configuration (Table 2.2); and
2) the nearest possible configuration to the Simrad's (ping-rate = 3.3 pings s^{-1}, pulse length = 0.3 ms and echo-selection criteria as for Table 2.2).

One 5 minute file (~1000 pings) was logged simultaneously by the echosounders using the Simrad configuration in the tank without fish. The rig was then moved into an identical tank containing >2000 roach (*Rutilus rutilus*), rudd (*Scardinius erythrophthalmus)* and crucian carp (*Carassius carassius)* and four files logged by the echosounders simultaneously. The HTI was subsequently reconfigured to the normal mobile settings and a further four files logged. Notes on fish behaviour were taken during the course of these trials.

Single target volume densities (>-50 dB) were calculated for each file between 2 and 7 m range.

Cross-talk trials
Some cross-talk between the three echosounders was noted in the Hydraulics Research study. In order to test whether this interference was a result of the acoustically reflective tank environment and any potential impact on density estimates, the echosounders were deployed at three fixed location sites.

- River Mersey

The River Mersey at Westy (NGR SJ629883) is the site of an Agency hydrometric gauging station. The site was chosen as it has 240 V mains supply and offers a relatively target-free environment. The three transducers were mounted on a common bracket and H-frame (as described in Section 2.3.2) and submerged on the left bank. The echosounders were set-up with standard mobile configurations (Table 2.2) and 1½ minute files logged in the sequence shown below:

File	Echosounders Enabled
1	Simrad
2	HTI
3	BioSonics
4	Simrad + HTI
5	Simrad + BioSonics
6	HTI + BioSonics
7	Simrad + HTI + BioSonics

Echograms (Simrad) and oscilloscope displays of returning signals (HTI and BioSonics) were examined for transmitter pulse interference. Files were post-processed and analysed for single target volume densities.

- Davenham Depot

HTI / Simrad cross-talk was examined in tank studies at Davenham Fisheries Depot. Details of the Davenham set-up are given above. Simrad files were logged with the HTI transmitter enabled and disabled and the resultant raw data files sent to Simrad for interpretation and comment.

- Manchester Ship Canal

Further HTI / Simrad cross-talk trials were conducted on the Manchester Ship Canal at Irlam Lock (NGR SJ727938). The two transducers were mounted 1 m below the surface on an A-frame 1 m in front of the hull of the NW Region sonar boat *NAB 17*. The Simrad transceiver was set in passive mode, the background noise level monitored (TEST menu) and files logged with the HTI transmitter enabled and disabled. Echograms were examined for transmitter pulse interference and analysed for single target volume densities.

2.2 Review of Data.

To investigate the impact of abiotic factors on variability in acoustic data, Agency datasets were examined for inclusion in a review of historic data. Suitable studies needed to be long-term replicate surveys of reaches at a similar time of year under unchanged survey protocols and acoustic practitioners. Abiotic data matching each acoustic survey must also be readily available. Three investigations were considered suitable for a preliminary assessment of water temperature, river discharge and moon phase on sources of variability in density estimates; River Thames, River Trent and River Ouse.

2.2.1 River Thames, 1994 – 1998

The River Thames between Sandford and Benson Locks has been surveyed with hydroacoustics on an annual basis since 1993 as part of the Thames Water Abingdon Reservoir Proposal Study (TWARP. Originally called 'South West Oxfordshire Reservoir Proposal' or SWORP). Surveys were conducted in the first two weeks of July using the same equipment (BioSonics 102), experimental design (Hughes, 1993; Hughes, 1995) and with few changes in personnel. Single target volume density data for 5 reaches (Reaches 1 – 5, section 2.1.2) were available from 1994 to 1998 (Table 2.5). Mean daily flow (m^3 s^{-1}) and temperature data were respectively measured at Days weir gauging station (top of reach 5) and at Cleeve, located downstream of the survey reaches.

2.2.2 River Trent, 1994 – 1998

The River Trent has been monitored by hydroacoustics since 1994. Surveys were conducted in July and August using a Simrad EY500 system with standardised settings, and the data processed with EP500 software to generate single target volume densities (Lyons, 1998). Data from four reaches; Stoke Bardolph – Gunthorpe, Thrumpton – Beeston, Colwick – Clifton and Cromwell – Nether Lock were available for 1994 – 1998 (Table 2.5). 1995 data were combined upstream and downstream runs and as the 1997 data could not be readily partitioned by individual reaches, only Stoke Bardolph – Gunthorpe was used for that year. Hydrological information was provided by field measurements of water temperature prior to the survey and mean daily flow rates (m^3 s^{-1}) were obtained from Agency gauging stations at Shardlow (for Thrumpton), Colwick (for Colwick and Stoke Bardolph) and North Muskham (for Cromwell).

2.2.3 River Ouse, 1996 – 2000

The Yorkshire Ouse has been acoustically monitored under an unchanged format since 1996 (summarised in Lucas *et al.* 1998). Annual surveys of three reaches (Milby – Linton, Linton

Table 2.5. Historic datasets used in data review.

River	Year	Survey Period	No. Reaches Surveyed
Thames	1994	11 – 14th July	5
Thames	1995	10 – 13th July	5
Thames	1996	12 – 14th July	5
Thames	1997	7 – 11th July	5
Thames	1998	1 – 2nd July	5
Trent	1994	4 – 10th August 30th August	2 1
Trent	1995	12 – 17th July	4
Trent	1996	10 – 23rd July	4
Trent	1997	30th July	1
Trent	1998	1st July 23rd July – 3rd August 25th August	1 4 1
Ouse	1996	9 – 11th July 29 – 31st July 27 – 29th August	2 3 3
Ouse	1997	18 – 20th July 27 – 29th August 27 – 29th October	3 3 3
Ouse	1998	18 – 20th August	3
Ouse	1999	16 – 18th August 9 – 11th November	3 3
Ouse	2000	7 – 9th August	3

– Clifton and Clifton – Naburn) were conducted each August using a Simrad EY500 sonar, with subsequent EP500 post-processing for single target volume densities. Additional surveys of these reaches were conducted at various times of the year in 1996, 1997 and 1999 (Table 2.5). Field measurements of water temperature and mean daily flow (m^3 s^{-1}) data from Kilgram (River Ure) and Skelton (River Ouse) gauging stations were used for hydrological information.

3. RESULTS AND OBSERVATIONS

3.1 Inter-Gear Variability

3.1.1 Target Strength (TS) variability

Tank trials at hydraulics research
The primary aims of the tank trials were, for each echosounder, to investigate variability in:

- Reported TS of replicate samples of standard targets.
- Reported TS of standard targets by distance from the transducer.
- Individual TS measurements of standard targets.

The trial was not intended to compare the echosounder's measurements of TS for individual targets, as this is dependant on such factors as frequency of operation, material properties and size (Maclennan and Simmonds, 1992).

In addition to the TS variability study, the two periods spent at Hydraulics Research were invaluable for system familiarisation and debugging prior to the mobile survey of the River Thames. In March, the trials demonstrated that mounting transducers on the Videmech 556 was inappropriate for TS measurements, as the movements of this rotator were too coarse for target alignment. The Simrad recorded few measurements of standard targets and a common bracket was fabricated for all 3 transducers by the second trial in May. Cross-talk between the HTI and BioSonics was noted in both trials as a periodic ripple on both oscilloscope traces, appearing to move away from the transducer with a gradually increasing amplitude. Trials to quantify the impact on single target volume density estimates were subsequently planned.

The results of the TS variability study are presented in Table 3.1 and summarised in Figure 3.1 (a – h).

Replicate samples measured by both the HTI and Simrad could generate marked differences in mean TS values. For example, a 2.4 dB difference beween ping-pong ball samples measured by the Simrad and a 4.7 dB difference measured by the HTI for the 20 mm tungsten-carbide sphere. All three echosounders also produced highly variable TS measurements of targets at different distances from the transducer (e.g. Figure 3.1 b).

Duncan and Kubecka (1993) described variability in on-axis calibrations as coefficients of variation (COV) of voltages and squared voltages. As voltages are not output from the Simrad, COV of cross-sectional area (σ) were used to describe variability in TS measurements on a common linear scale. The variation for spherical targets ranged from 1.25 – 14.21% (Simrad), 2.08 – 24.91% (HTI) and 1.89 – 41.07% (BioSonics). BioSonics estimates appeared to be the most variable (Table 3.1) and often exceeded recommended levels of variability during calibration (COV in V^2 = ±7%; Duncan and Kubecka, 1993. In this study COV in V^2 ranged from 1.26 – 36.1%). To test for differences in mean σ COV, the values were logged to approximate normality and compared by one-way ANOVA. Mean σ COV was found to be significantly different ($F = 6.37$, 2 d.f., $P < 0.005$) with the BioSonics having a higher mean than the Simrad (Tukey's Paired comparisons). However, the number of samples was small and difficulties aligning targets on the acoustic axes (particularly using the Videmech 556 rotator which affected the Simrad) may have resulted in the more variable measurements being rejected. Also, some standard targets could not be easily resolved as targets, for example the 114mm plastic ball with the ribbed surface caused problems for the BioSonics.

Table 3.1. TS variability, Hydraulics Research Trials

Standard Target	**Echosounder**	**Range (m)**	**No. Single Targets**	**Mean TS**	**Mean σ (m^2)**	**σCOV (%)**
36 mm tungsten carbide	Simrad	4.44	531	-41.77	6.66E-05	3.89
36 mm tungsten carbide	Simrad	6.81	819	-40.59	8.83E-05	14.21
36 mm tungsten carbide	HTI	4.27	1775	-40.19	9.57E-05	2.89
36 mm tungsten carbide	HTI	8.51	1745	-40.12	9.95E-05	21.23
36 mm tungsten carbide	HTI	11.39	1323	-38.99	1.26E-04	5.08
36 mm tungsten carbide	BioSonics	4.4	1799	-41.86	6.95E-05	41.07
36 mm tungsten carbide	BioSonics	6.8	2045	-39.79	1.06E-04	14.39
36 mm tungsten carbide	BioSonics	11.6	1001	-43.33	4.65E-05	1.89
20 mm tungsten carbide	Simrad	4.38	539	-45.43	2.86E-05	1.72
20 mm tungsten carbide	Simrad	4.38	675	-45.73	2.68E-05	1.25
20 mm tungsten carbide	Simrad	6.81	1537	-43.94	4.07E-05	12.36
20 mm tungsten carbide	HTI	4.27	702	-50.21	9.57E-06	9.09
20 mm tungsten carbide	HTI	4.27	1801	-45.47	2.84E-05	2.08
20 mm tungsten carbide	HTI	6.73	1540	-45.09	3.20E-05	24.91
20 mm tungsten carbide	BioSonics	4.4	2201	-43.69	4.28E-05	5.14
20 mm tungsten carbide	BioSonics	11.5	1193	-47.06	1.97E-05	7.01
17mm tungsten carbide	Simrad	4.38	1146	-45.73	2.70E-05	12.45
17mm tungsten carbide	Simrad	4.38	1071	-47.46	1.80E-05	1.83
17mm tungsten carbide	HTI	4.35	976	-51.60	6.95E-06	10.30
17mm tungsten carbide	HTI	11.45	1816	-48.53	1.40E-05	4.21
17mm tungsten carbide	BioSonics	4.4	1816	-51.40	7.65E-06	32.33
23mm Copper	Simrad	4.41	643	-40.54	8.84E-05	4.17
23mm Copper	Simrad	4.41	148	-40.47	8.98E-05	4.04
23mm Copper	HTI	4.27	250	-51.51	7.15E-06	14.63
23mm Copper	BioSonics	4.4	1808	-41.05	8.03E-05	20.23

Table 3.1. TS variability, Hydraulics Research Trials (continued)

Standard Target	Echosounder	Range (m)	No. Single Targets	Mean TS	Mean σ (m^2)	σCOV (%)
40mm ping-pong	Simrad	4.53	1019	-42.22	6.00E-05	5.36
40mm ping-pong	Simrad	4.35	648	-39.76	1.06E-04	5.33
40mm ping-pong	HTI	4.45	1755	-41.71	6.75E-05	3.16
40mm ping-pong	HTI	4.26	1599	-41.50	7.08E-05	4.19
40mm ping-pong	BioSonics	4.4	1743	-41.35	7.52E-05	23.03
73mm plastic	Simrad	4.53	1303	-34.97	3.18E-04	2.17
73mm plastic	Simrad	4.38	964	-34.34	3.68E-04	1.76
73mm plastic	Simrad	6.78	1187	-34.45	3.59E-04	1.81
73mm plastic	HTI	4.44	1240	-34.94	3.24E-04	14.23
73mm plastic	HTI	4.3	1253	-33.78	4.19E-04	5.65
73mm plastic	HTI	6.7	1323	-34.77	3.34E-04	6.67
73mm plastic	BioSonics	4.4	1886	-35.21	3.10E-04	23.25
73mm plastic	BioSonics	6.8	2097	-34.22	3.80E-04	8.51
114mm Plastic Flanged	Simrad	4.32	827	-36.38	2.45E-04	32.96
114mm Plastic Flanged	Simrad	4.41	1041	-35.60	2.82E-04	20.38
114mm Plastic Flanged	Simrad	7.05	863	-34.47	3.59E-04	8.01
114mm Plastic Flanged	HTI	4.21	1041	-36.91	2.06E-04	16.28
114mm Plastic Flanged	HTI	4.3	1618	-41.59	7.07E-05	19.98
114mm Plastic Flanged	BioSonics	4.4	949	-40.09	9.93E-05	17.42
114mm Plastic Ribbed	Simrad	4.47	907	-30.80	8.33E-04	6.53
114mm Plastic Ribbed	Simrad	4.44	688	-30.26	9.41E-04	3.69
114mm Plastic Ribbed	HTI	4.38	2194	-29.97	1.01E-03	2.35
114mm Plastic Ribbed	HTI	4.36	2001	-32.05	6.24E-04	3.04

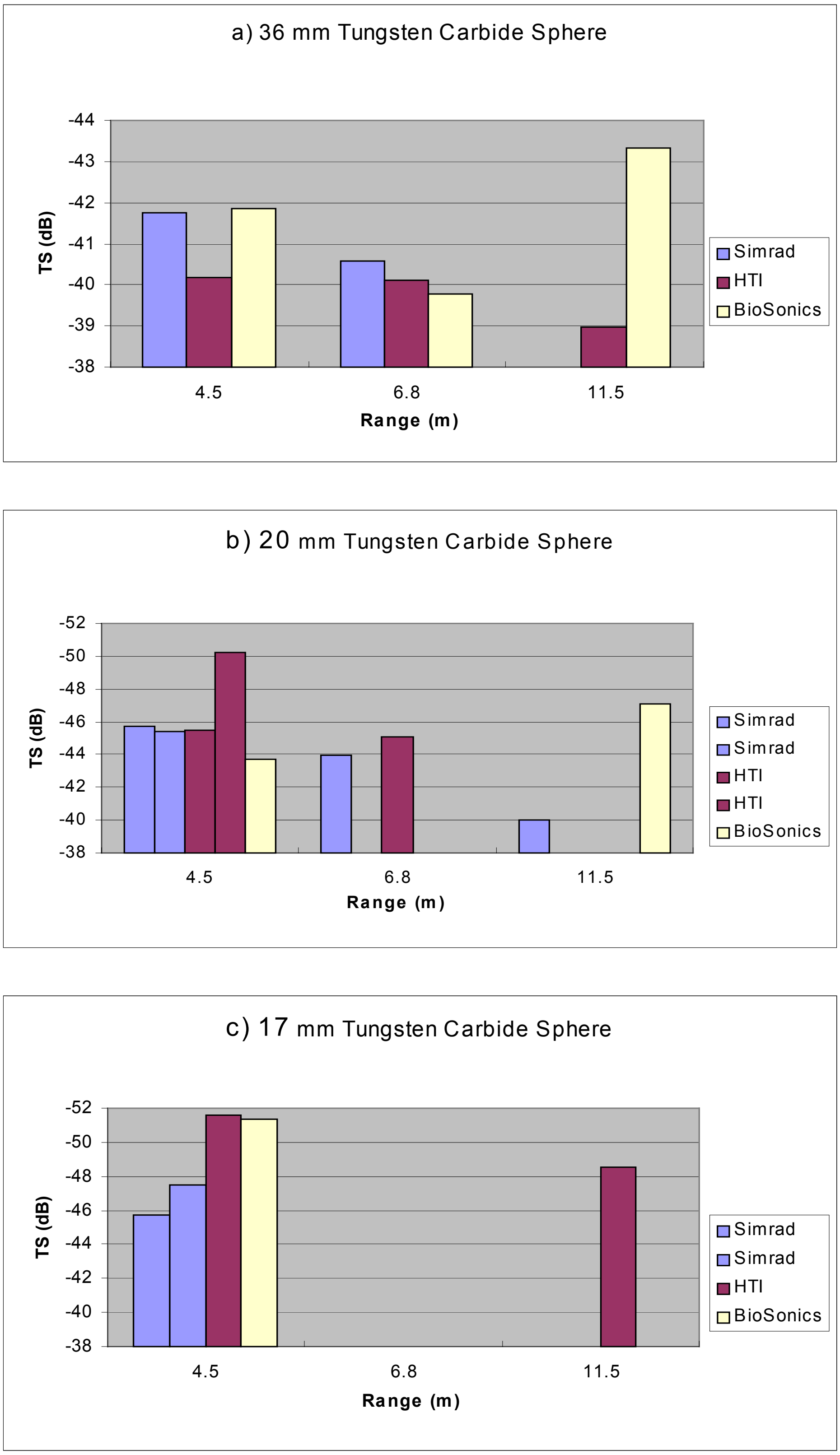


Figure 3.1 (a – c). Variation in target strength (TS) with range as detected by 3 echosounders for 3 targets. Replicate samples appear as two bars at the same range. Ranges without bars indicate tests were not conducted

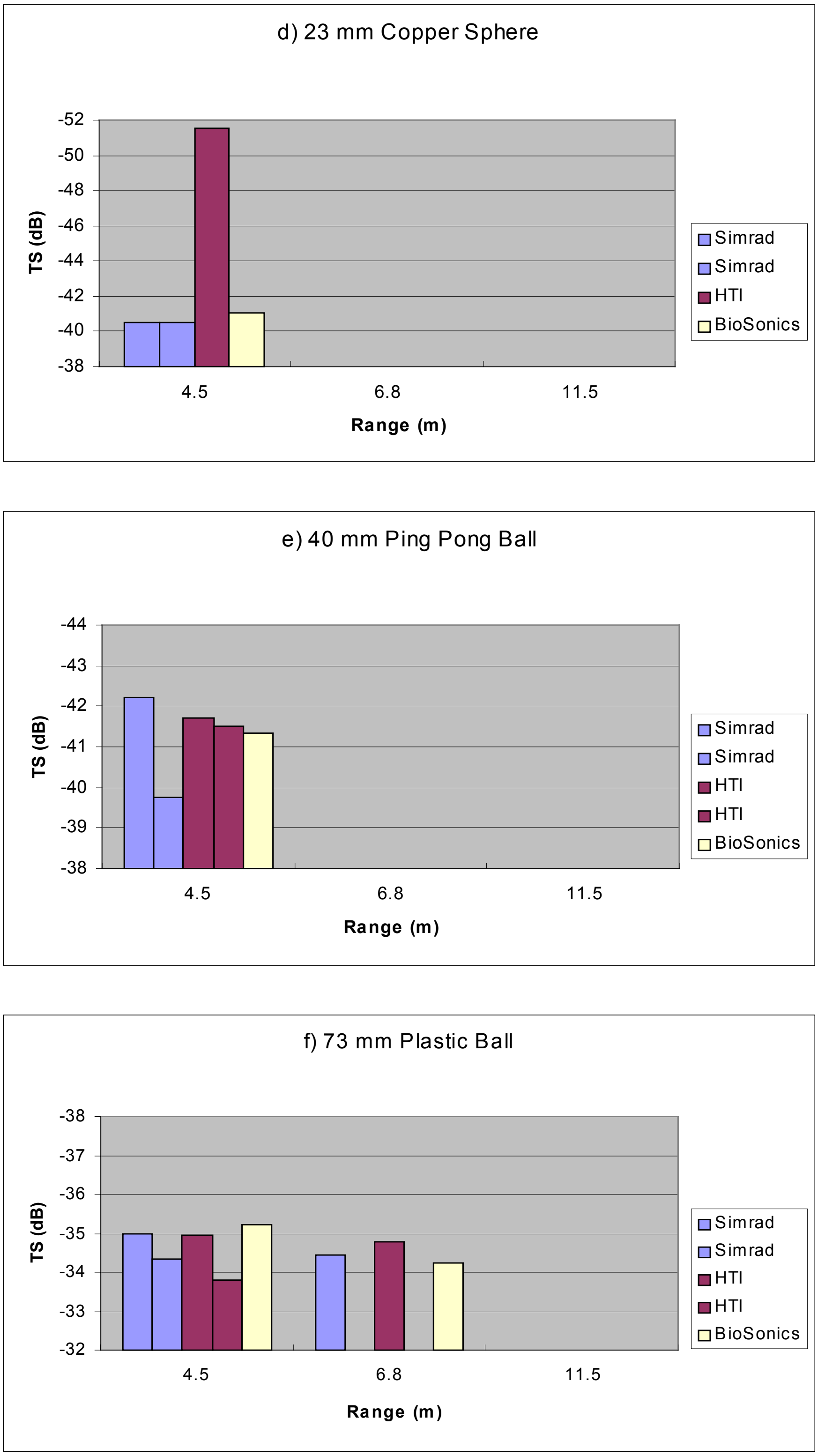
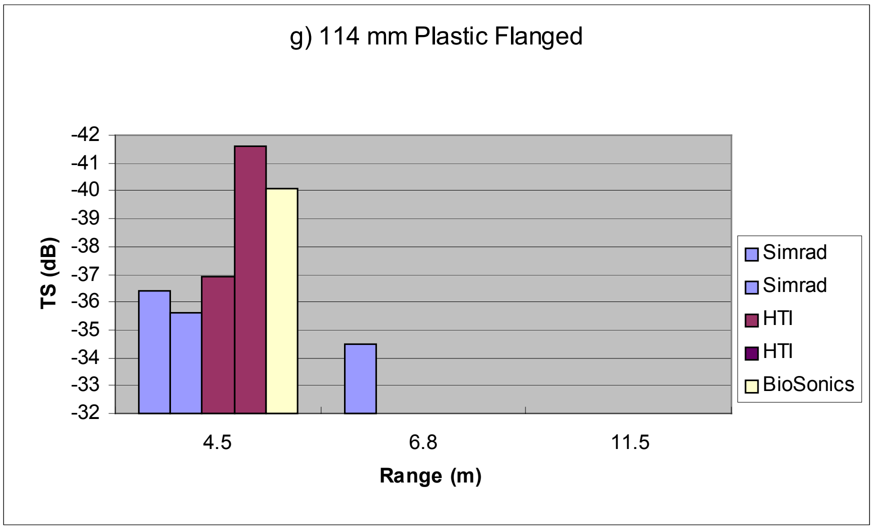


Figure 3.1 (d – f). Variation in target strength (TS) with range as detected by 3 echosounders for 3 targets. Replicate samples appear as two bars at the same range. Ranges without bars indicate tests were not conducted



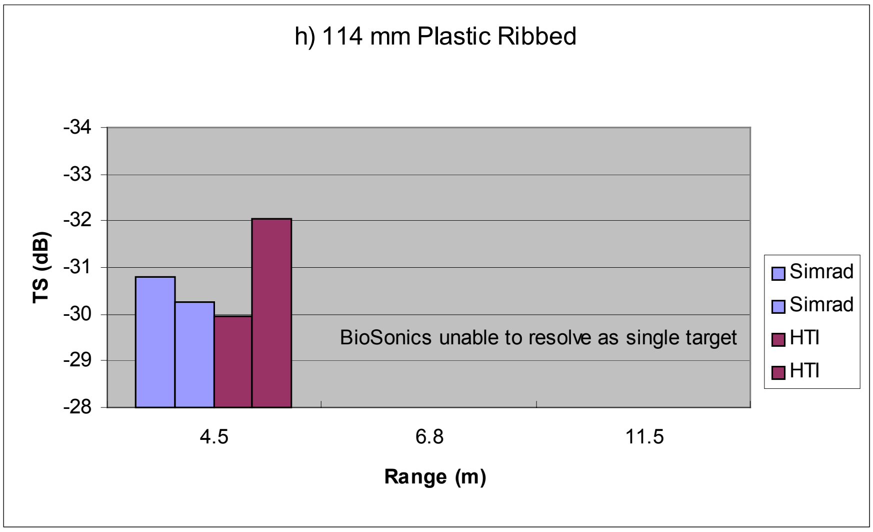


Figure 3.1 (g – h). Variation in target strength (TS) with range as detected by 3 echosounders for 2 targets. Replicate samples appear as two bars at the same range. Ranges without bars indicate tests were not conducted

3.1.2 Volume density variability

River Thames Trials

- Drifting target study

The drifting target trials had 3 functions:

1) to compare echosounders by volume density outputs;
2) to compare echosounders by target acquisition and reporting capability; and
3) to ensure the 3 acoustic beams were sampling approximately the same body of water prior to the Thames mobile survey.

1) Volume density comparisons

Single target volume density estimates for the 11 runs (Section 2.1.2) are summarised in Figure 3.2. Run 8 was the control sample with no targets presented to the echosounders. Recorded densities (fish 1000m^{-3}) for all other runs ranged from 8.5 – 104.3 (Simrad 1), 7.6 – 63.1 (Simrad 2), 4.7 – 125.0 (HTI) and 4.7 – 20.3 (BioSonics). The large range in densities recorded by an individual echosounder was a result of a number of factors, including the numbers of targets within the beam, the time targets spent within the beam and their aspect to the transducer.

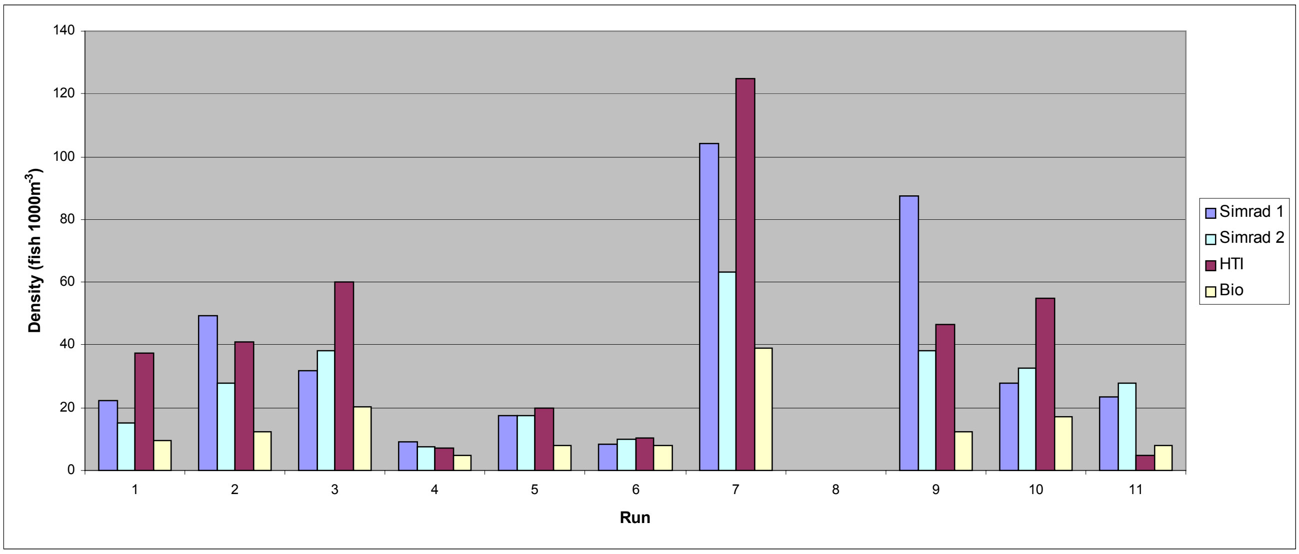


Figure 3.2. River Thames drifting targets study. Volume densities by run and echosounder

Paired density estimates were significantly correlated for all combinations of echosounder / calculation method (Figures 3.3 – 3.8 and Table 3.2), indicating good agreement on what constituted high and low density runs in relative terms. In absolute terms, the two split-beam echosounders almost invariably produced higher density estimates than the BioSonics and typically by a factor of 3 – 4.

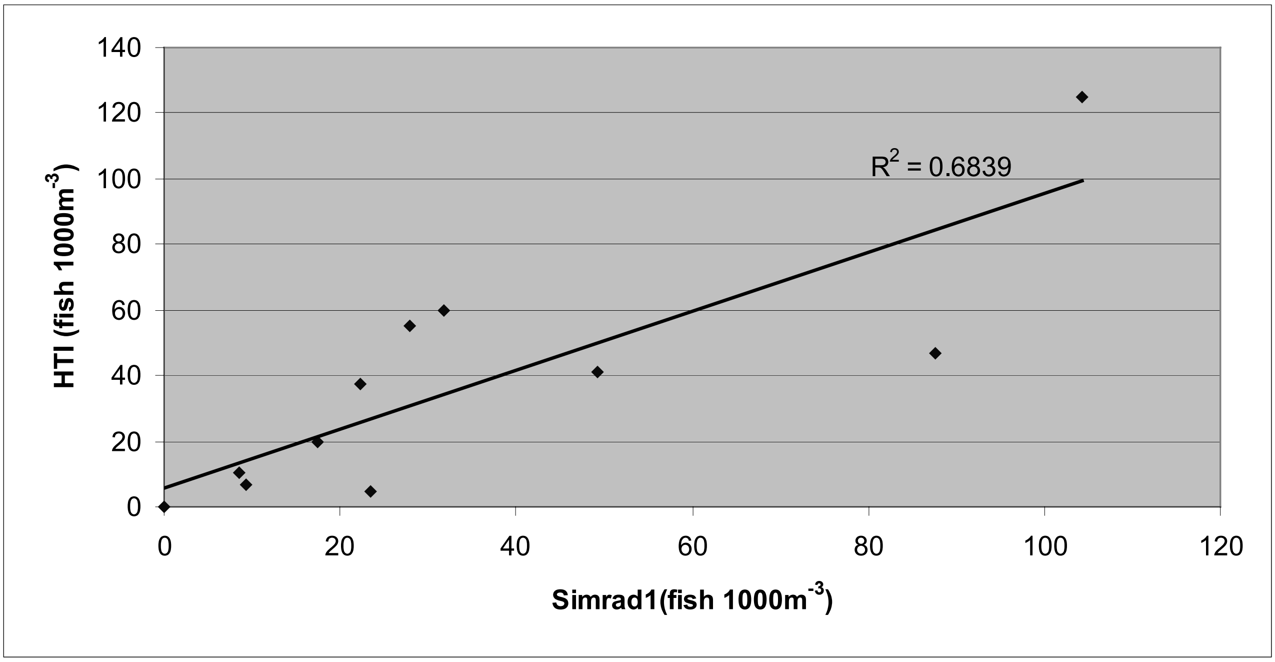


Figure 3.3. Pairwise comparisons of volume density estimates from drifting target study; Simrad1 vs HTI

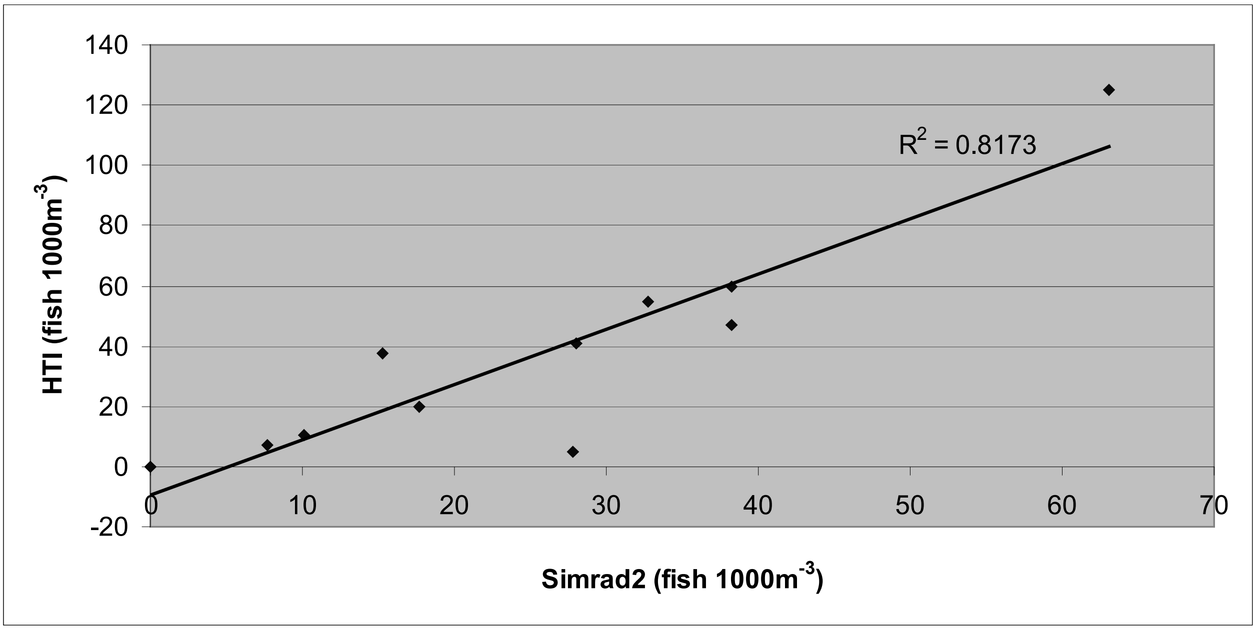


Figure 3.4. Pairwise comparisons of volume density estimates from drifting target study; Simrad2 vs HTI

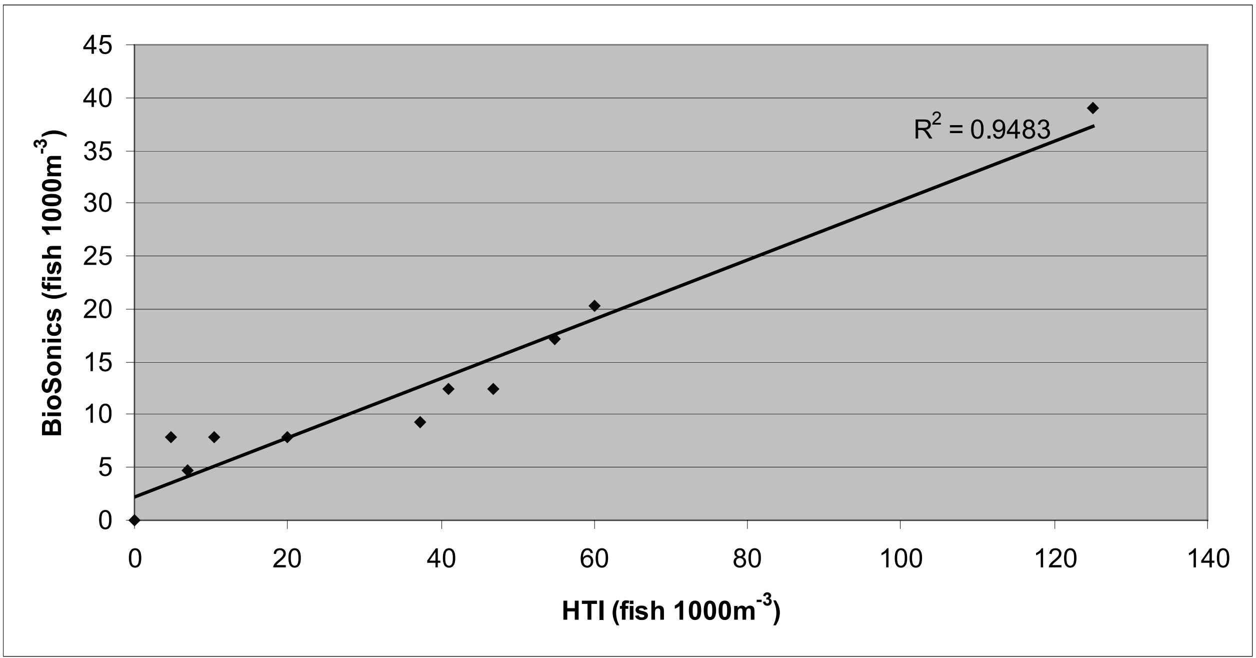


Figure 3.5. Pairwise comparisons of volume density estimates from drifting target study; HTI vs BioSonics

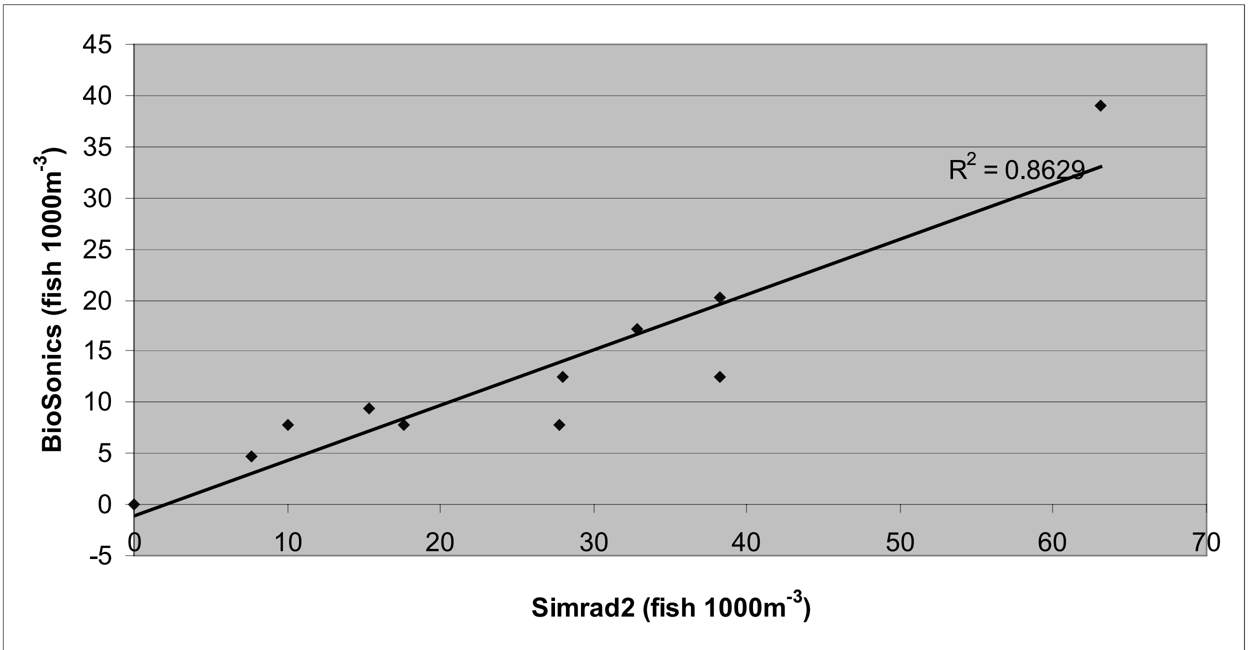


Figure 3.6. Pairwise comparisons of volume density estimates from drifting target study; Simrad2 vs BioSonics

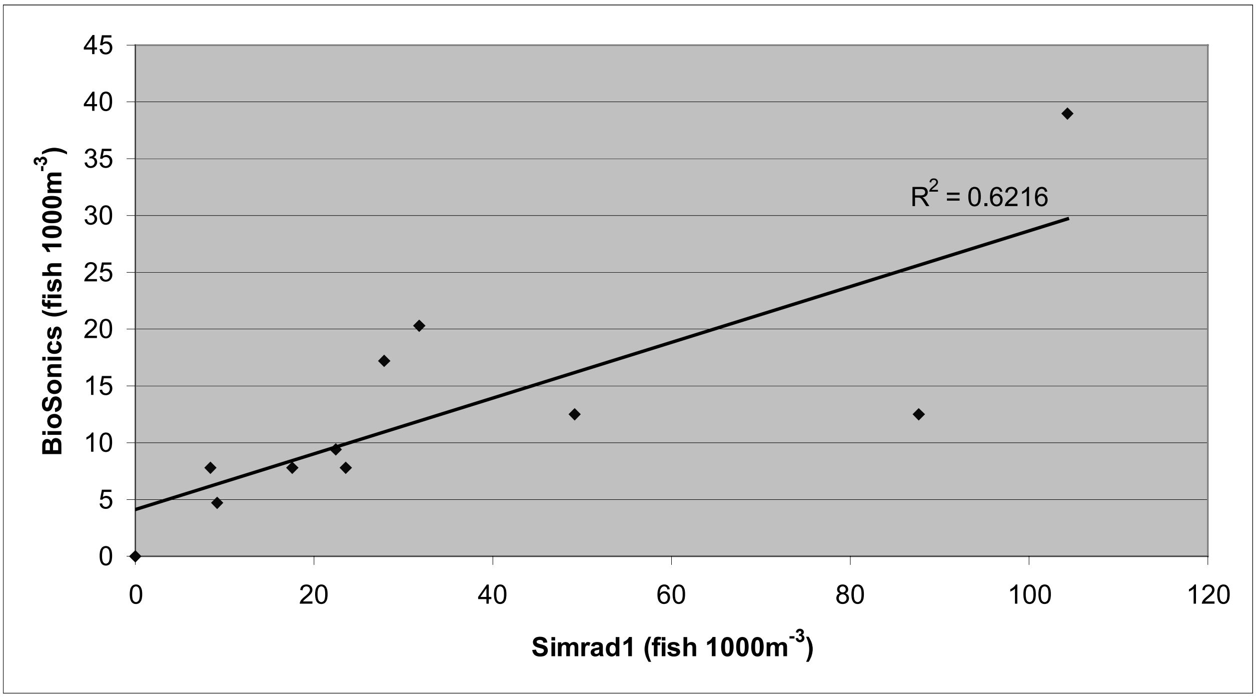


Figure 3.7. Pairwise comparisons of volume density estimates from drifting target study; Simrad1 vs BioSonics

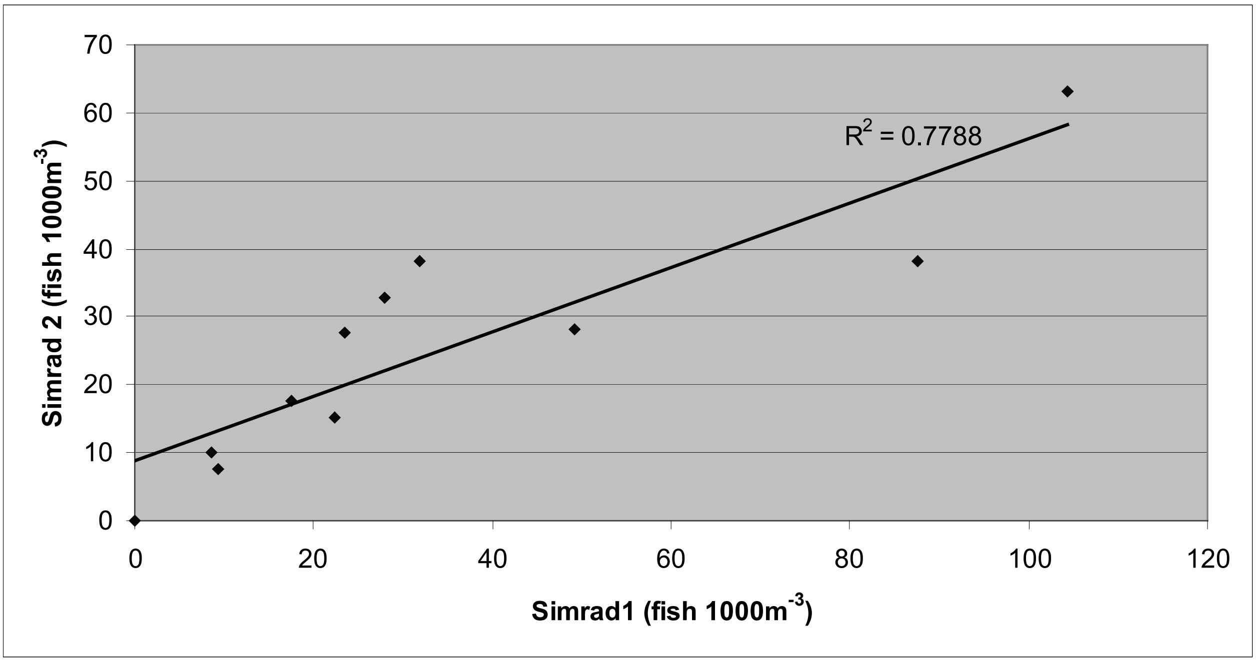


Figure 3.8. Pairwise comparisons of volume density estimates from drifting target study; Simrad1 vs Simrad2

Table 3.2. Correlation coefficients for Paired volume density estimates from drifting target study. Critical value $r_{0.05,\,2,\,9} = 0.602$

Paired echosounders	Correlation coefficient (r)	Probability
Simrad 1 vs HTI	0.827	P < 0.002
Simrad 2 vs HTI	0.904	P < 0.001
Simrad 1 vs BioSonics	0.788	P < 0.005
Simrad 2 vs BioSonics	0.929	P < 0.001
HTI vs BioSonics	0.974	P < 0.001
Simrad 1 vs Simrad 2	0.882	P < 0.001

2) Target acquisition and reporting comparisons

Plots of accepted single targets by echosounder for each run are shown in Figures 3.9 (i – j). The movement of targets through the beams can be clearly seen in a number of the plots, e.g. run 7 where the HTI reported all six nuts and run 2 where the Simrad and HTI reported four. Other plots are less clear with more scattered target distributions (e.g. run 10), possibly due to targets being near the edge of beams or the acquisition of riverine targets.

Table 3.3 shows the number of targets reported, the number reported with multiple 'hits', and the probability of detecting an echo from a passing target for each echosounder over all runs. Although the total number of targets reported was similar, the BioSonics and Simrad had a much higher proportion of single 'hit' targets that could not be included in the subsequent analysis. In the case of the Simrad, the lower ping-rate probably contributed significantly to this count. The detection probability by echosounder was found to be significantly different by one-way ANOVA ($F = 13.49$, 2 d.f., $P < 0.001$) with the BioSonics having a lower mean than both the HTI and Simrad (Tukey's Paired comparisons).

Table 3.3. Target acquisition and reporting results

Echosounder	Number of targets hit	Number of targets with multiple 'hits'	Detection Probability	Standard Deviation
HTI	37	33	0.678	0.267
BioSonics	42	22	0.369	0.226
Simrad	40	25	0.699	0.231

3) Volume of water sampled

The close correlation of volume density estimates and the juxtaposition of reported targets indicated a very similar body of water was being insonified by the three beams when mounted on the common bracket. A number of plots in Figure 3.9 suggested the Simrad acquired targets slightly before the other echosounders. This is probably due in part to the slightly wider beam width of the Simrad transducer, but also a fractionally offset transducer in the horizontal plane (a greater degree of panning was needed to acquire the standard target on-axis for the Simrad in the tank studies when moving from the HTI and BioSonics positions).

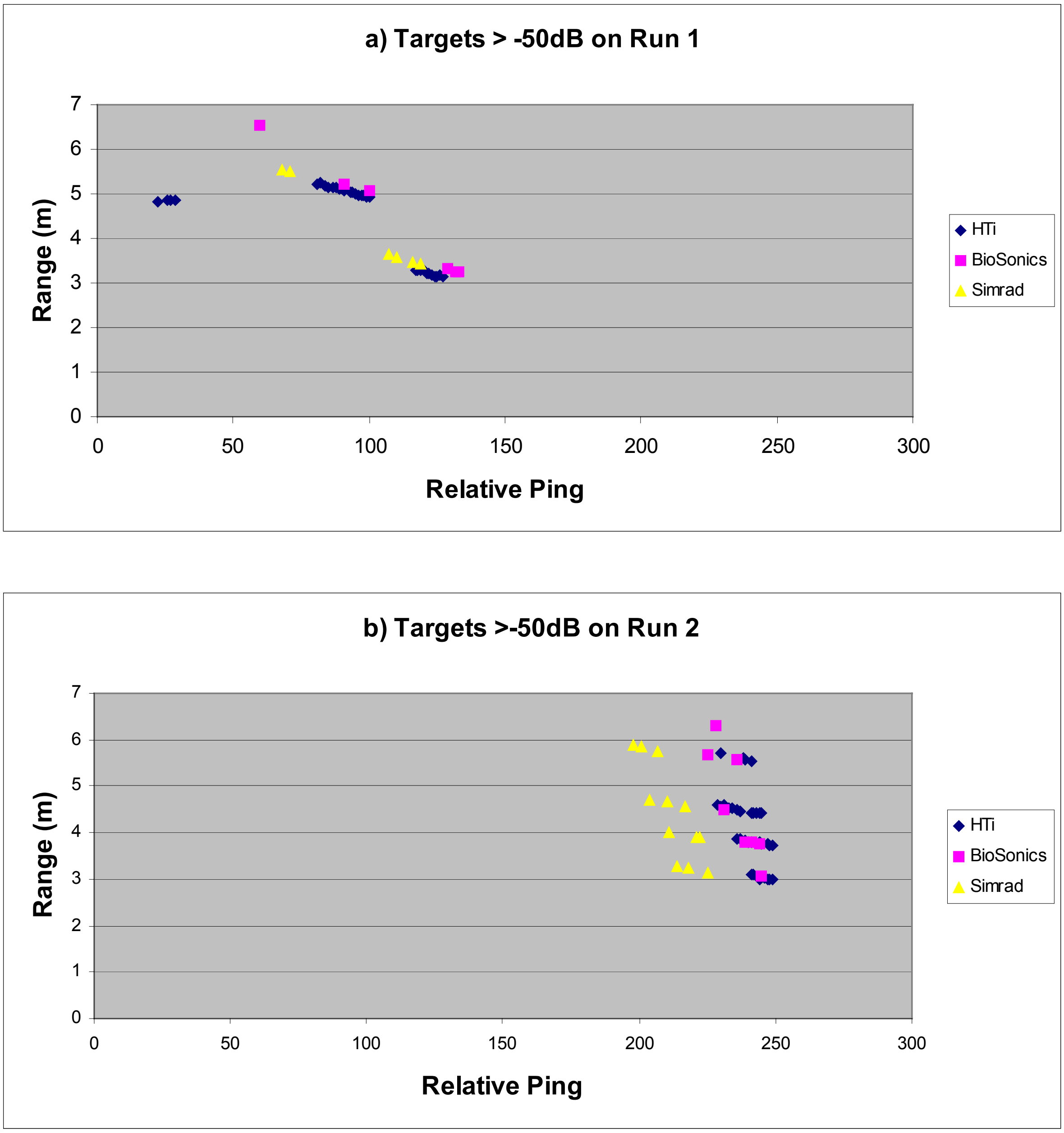
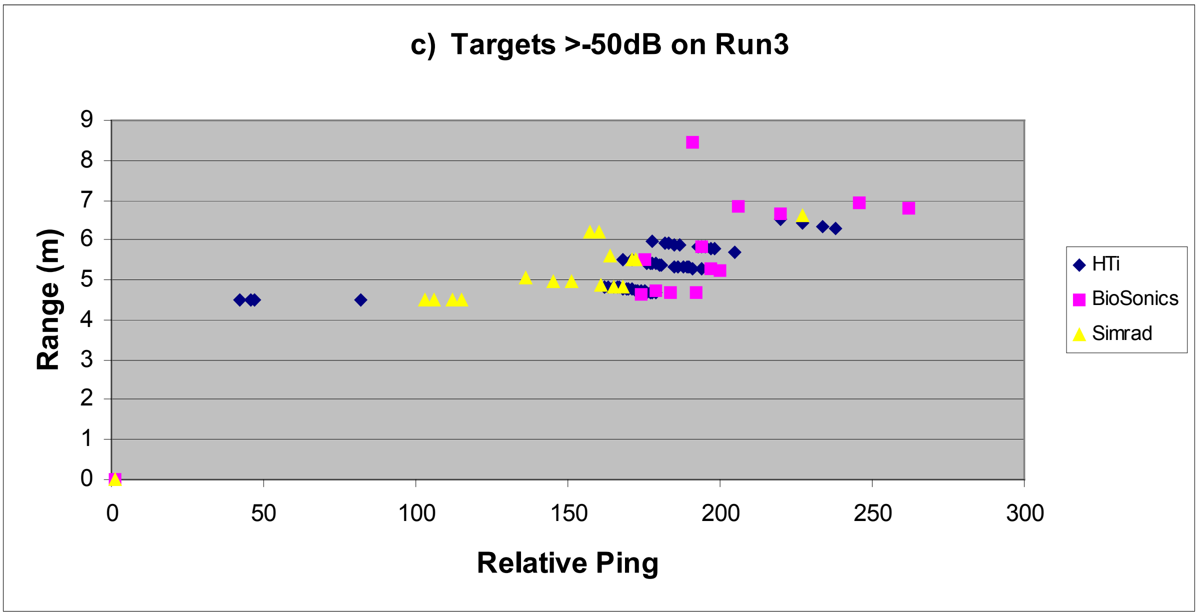


Figure 3.9 (a – b). River Thames drifting target trials. Single targets (>-50dB) acquired by echosounders within a 30 second window



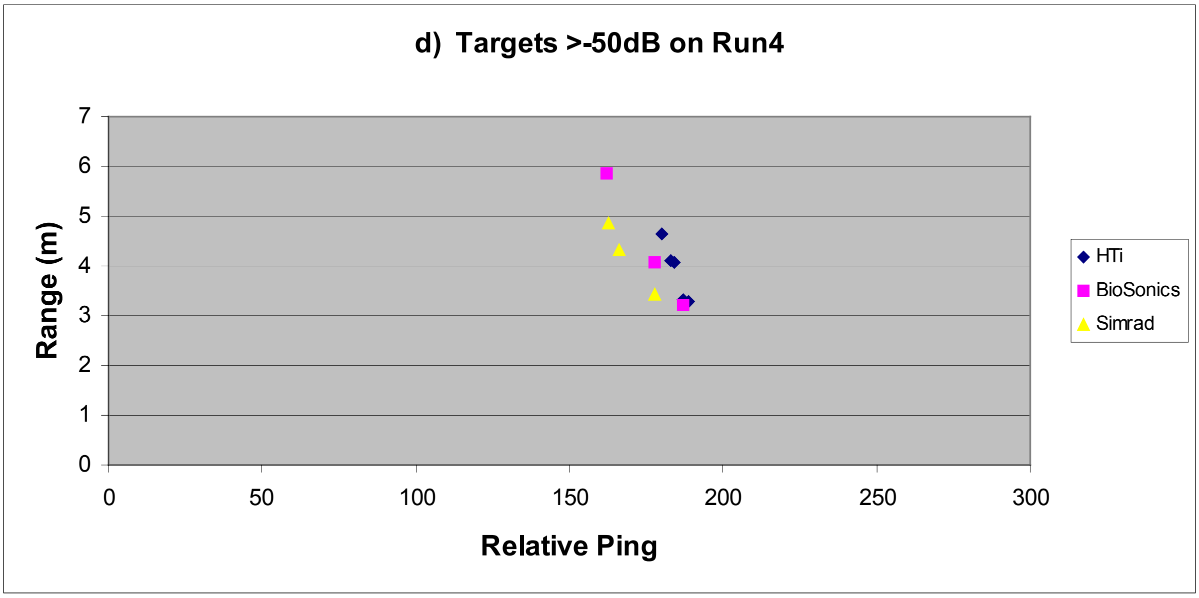
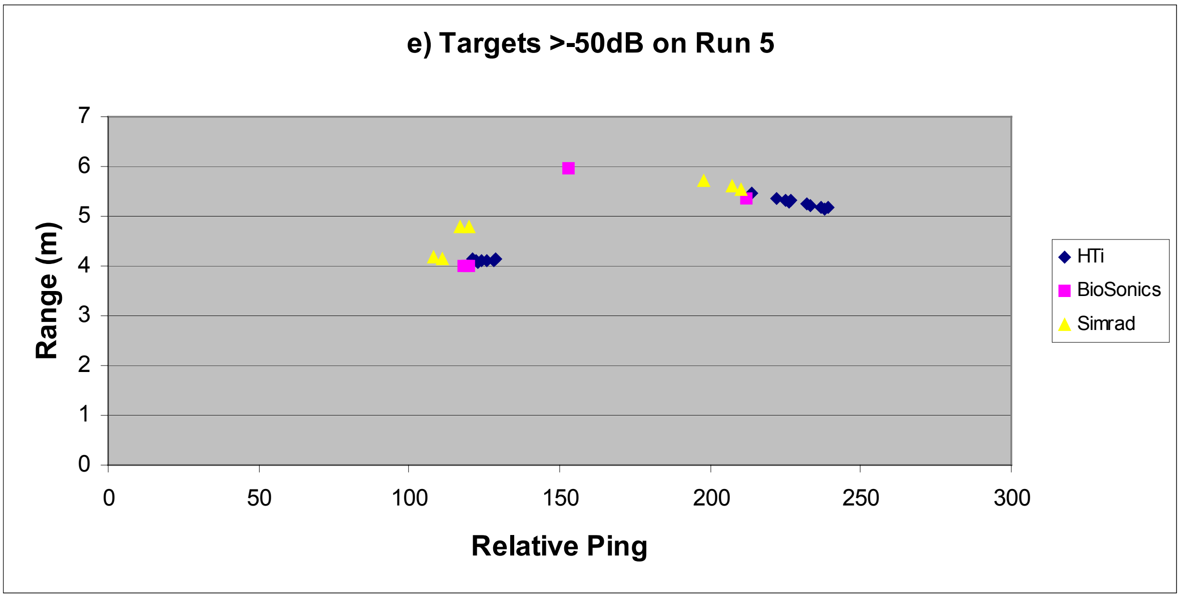


Figure 3.9 (c - d). River Thames drifting target trials. Single targets (>-50dB) acquired by echosounders within a 30 second window.



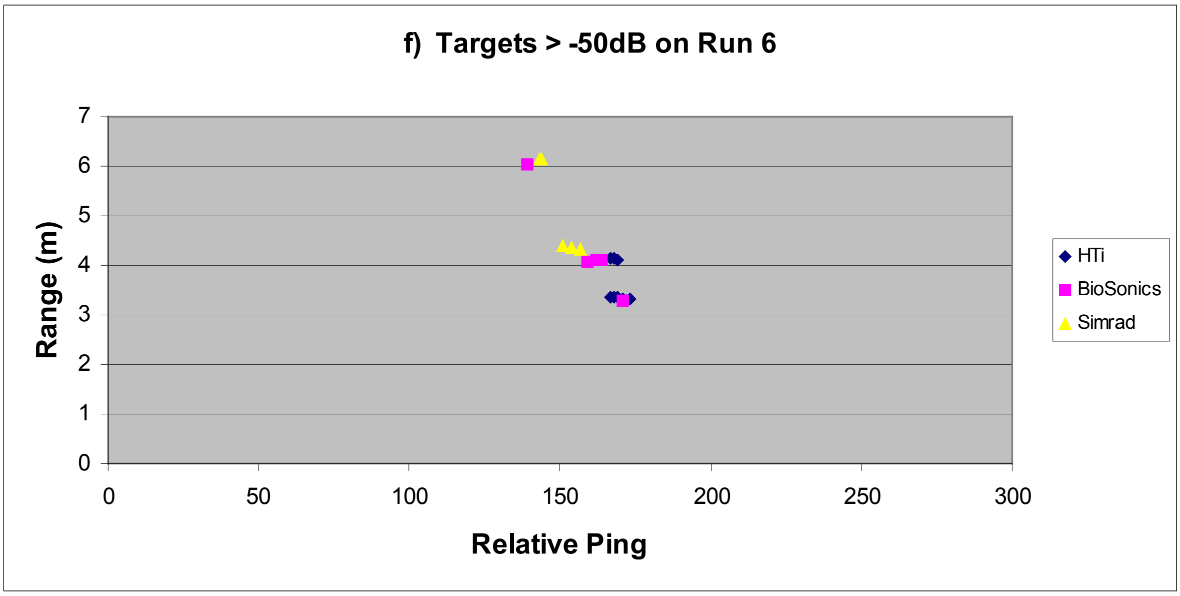
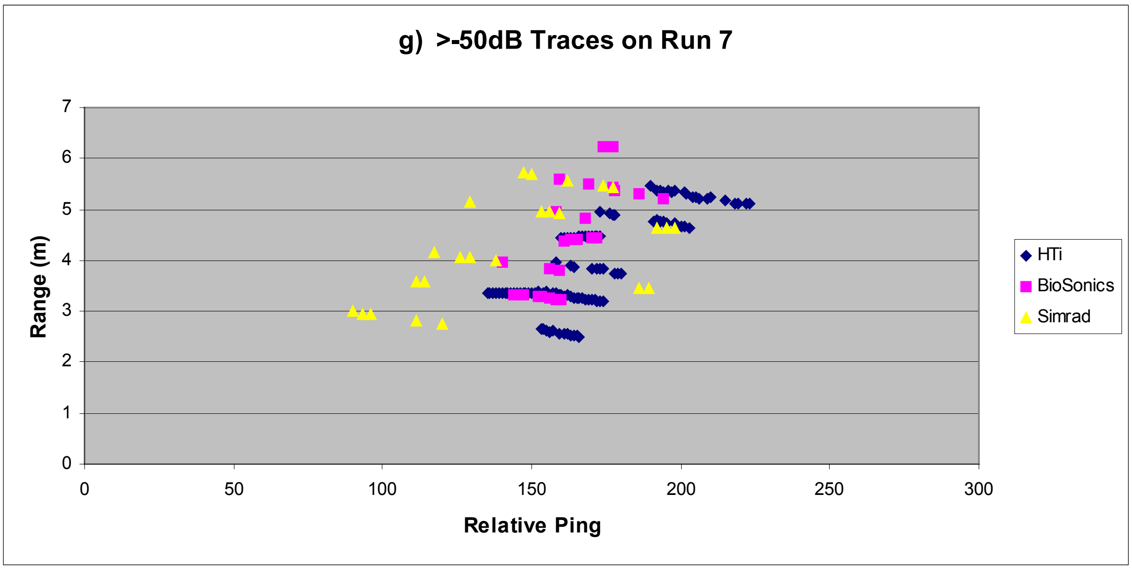


Figure 3.9 (e - f). River Thames drifting target trials. Single targets (>-50dB) acquired by echosounders within a 30 second window.



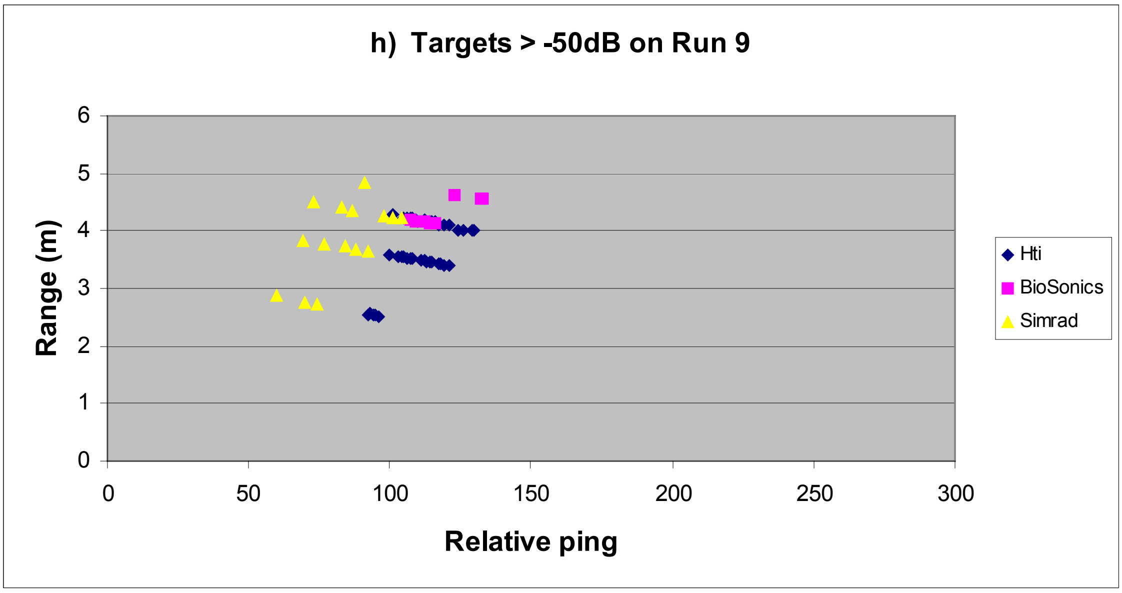
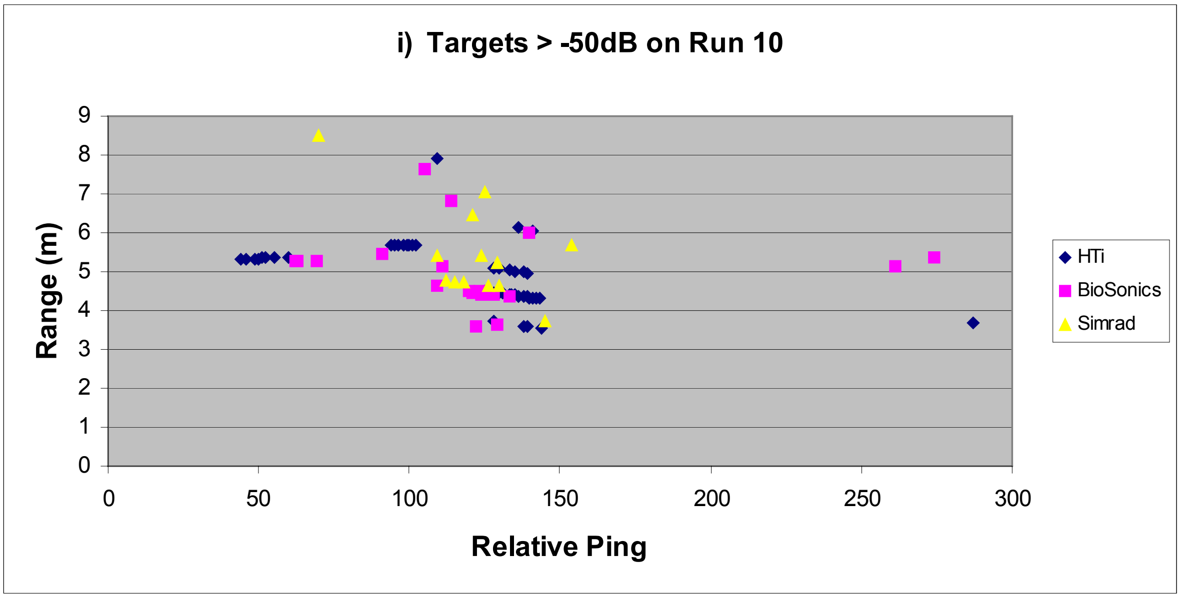


Figure 3.9 (g - h). River Thames drifting target trials. Single targets (>-50dB) acquired by echosounders within a 30 second window



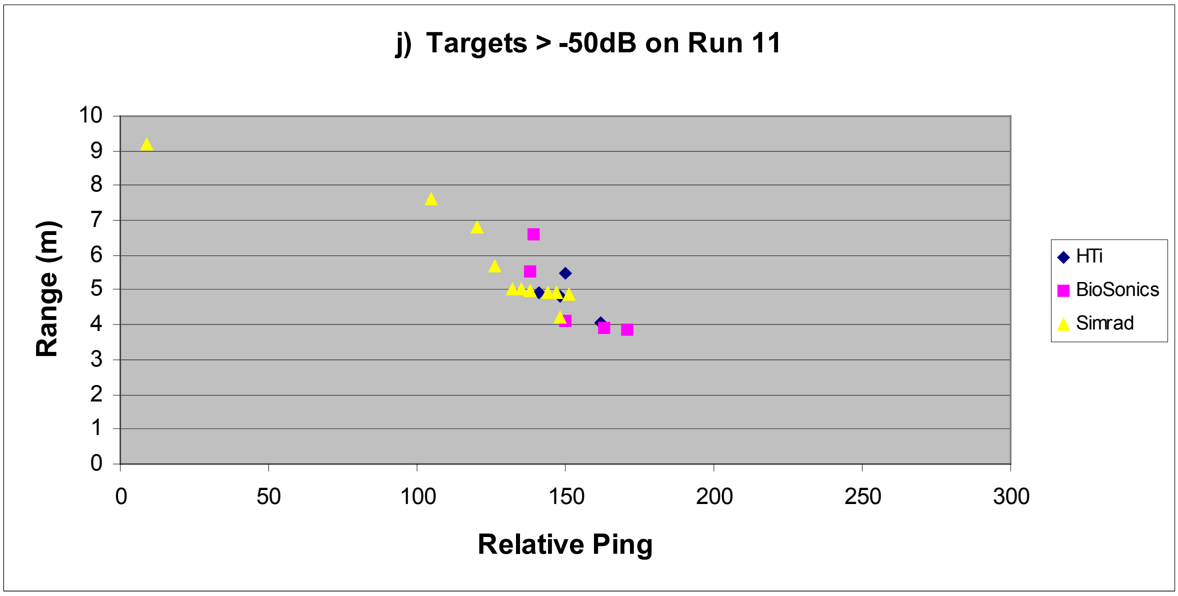


Figure 3.9 (i - j). River Thames drifting target trials. Single targets (>-50dB) acquired by echosounders within a 30 second window.

- River Thames Mobile Survey

The primary purpose of the mobile survey on the River Thames was to compare the performances of the three echosounders by volume density estimates in a horizontal survey of a typical large river.

Sample echograms from one reach of this survey are presented in Figure 3.10 with their associated single target counts and volume density estimates. In general, echograms appeared clear of noise in the 4 - 12 m sample range, however macrophytes were occasionally a problem on reaches 0 and 5, and shallows on reach 4 reduced the available range or caused the boat to ground.

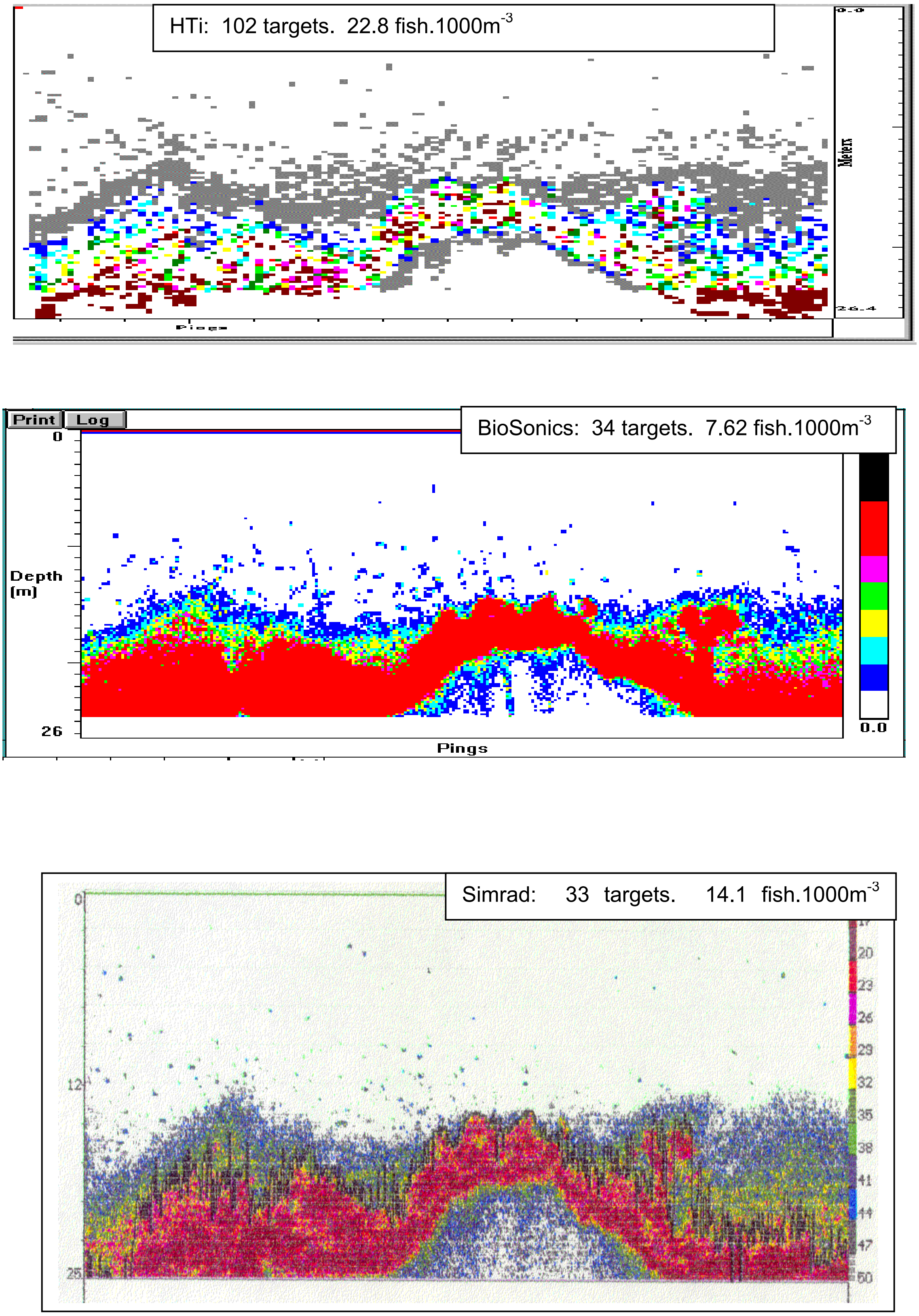


Figure 3.10. Sample echograms extracted from a section of reach 5, River Thames mobile survey. Each echogram represents approximately the same 2 minute portion of data. The number of accepted single targets and volume density estimates obtained from these portions are shown

Single target volume densities were plotted by site moving down the Thames from reach 0 to reach 5 (Figure 3.11). Considerable inter-gear variability was observed. The HTI invariably produced the highest fish densities, ranging from 15 – 261.6 fish 1000m^{-3}, which were typically an order of magnitude higher than the BioSonics (3.3 – 33 fish 1000m^{-3}) and Simrad (1.1 – 25.7 fish 1000m^{-3}). Correlation analyses were conducted to ensure these differences were not a result of different sampling volumes being analysed. This may occur if either transducer became misaligned during the survey, different bottom-tracking procedures were adopted during post-processing or variable file lengths were collected. HTI and BioSonics sampling volumes and file lengths were significantly correlated (Figures 3.12 and 3.13, Table 3.4) indicating the density differences were due to variable numbers of single targets being accepted by the systems. Similar volume comparisons with the Simrad could not be made as volume sampled was not output by the EP500 software, however the number of pings collected per file by the Simrad was also significantly correlated with the other echosounders (Figure 3.14, Table 3.4).

The effect of sampling frequency was tested by artificially reducing the HTI ping rate to approximate the Simrad rate. Five randomly selected files were reanalysed for even-numbered pings only, thereby providing density estimates at 5 pings s^{-1}. When the two ping-rates (5 and 10 pings s^{-1}) were compared by one-way ANOVA, no significant difference was found in density estimates ($F = 0$, 1 d.f., $P < 0.001$). The Simrad ping rate was observed to vary slightly during the survey, for example total number of pings per 10 minute file ranged from 2723 – 3429 (Figure 3.14) and ping rate was negatively correlated to river width (Figure 3.15. Critical value $r_{0.05,\,2,\,10} = 0.576$, $r = 0.857$, $P < 0.001$).

Relative performances were compared in two ways:

1) Pearson (product moment) correlation analyses of paired density estimates; and
2) ranking sites by density for each echosounder and subsequent Spearman rank correlation analyses.

Paired density estimates were significantly correlated for all combinations of echosounder (Figures 3.16 – 3.18 and Table 3.5) as were Spearman rank correlation coefficients (Figure 3.19, Table 3.5). The relationships appeared weaker for the ranked data, particularly between the Simrad and HTI. This is not surprising as these echosounders gave very variable densities and because the high densities coincided, they resulted in high Pearson coefficients. The Spearman coefficient is based on rank and so the influence of high densities was less, resulting in lower coefficients.

TS data were collected from reach 5 and analysed in four strata; 4 – 6 m, 6 – 8 m, 8 – 10 m and 10 – 12 m. TS frequency distributions for each echosounder are presented in Figure 3.20. With the exception of the 4 – 6 m strata, the HTI reported substantially more targets than the other echosounders over all ranges and size-classes. The Simrad performed equally well for the nearest strata allowing for the slower ping rate (~5 pings.s^{-1}, half the HTI and BioSonics ping rate). However, in comparison to the others, the number of targets reported by the Simrad dropped significantly with increasing range. The BioSonics appeared to report slightly more targets in the two furthest strata.

The same data were plotted as percentage frequency distributions (Figure 3.21). The HTI TS distribution appeared broadly similar over the four strata, however the BioSonics and Simrad clearly exhibited a loss of the smaller targets (e.g. –50 to -44 dB) with increasing range and

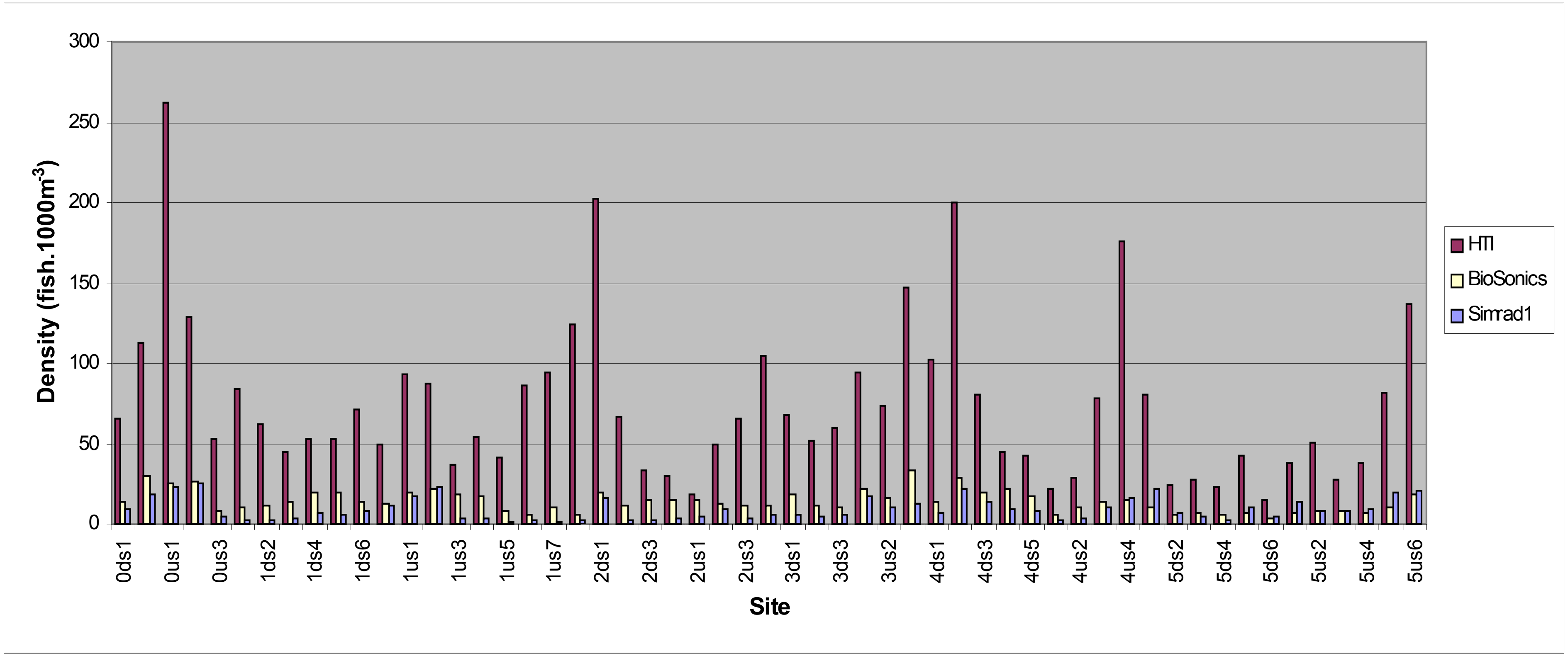


Figure 3.11. Volume densities by site and echosounder for Thames mobile survey. The 10 minute datasets were renamed sites and labelled according to reach, direction of travel and order of collection (e.g. the 4th file collected on the downstream run of reach 1 = 1DS4)

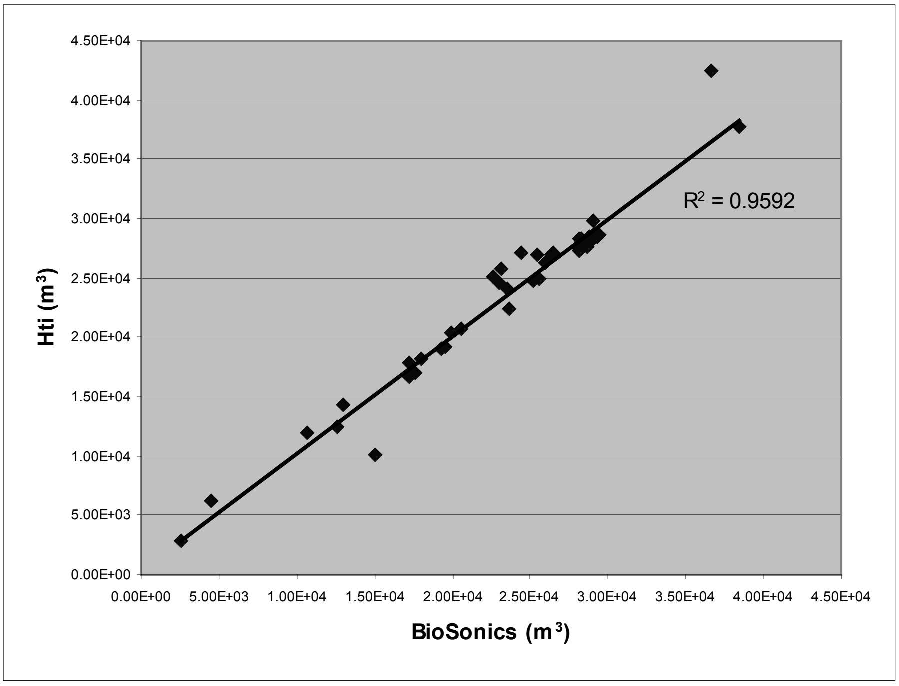


Figure 3.12. Volumes sampled per file during the mobile Thames survey; HTI vs BioSonics

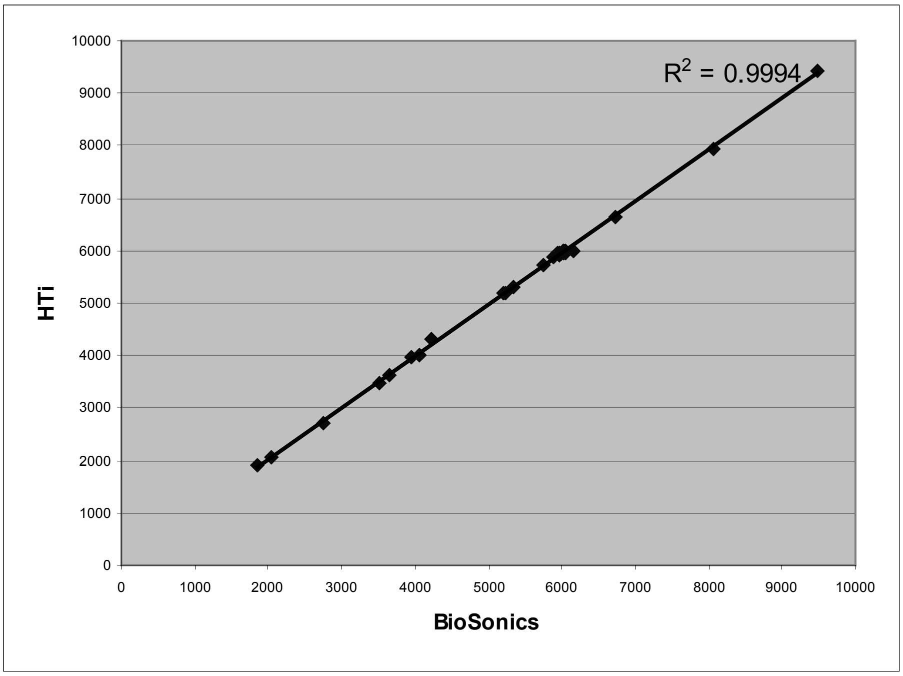


Figure 3.13. Number of pings collected per file during the mobile Thames survey; HTI vs BioSonics

Table 3.4. Correlation coefficients for volumes sampled and number of pings collected by file from mobile Thames study. Critical value $r_{0.05, 2, 53} = 0.265$

Paired echosounders	Correlation coefficient (r)	Probability
	Volumes Sampled	
BioSonics vs HTI	0.979	P < 0.001
	Pings Sampled	
BioSonics vs HTI	1.000	P < 0.001
Simrad vs HTI	0.969	P < 0.001
Simrad vs BioSonics	0.969	P < 0.001

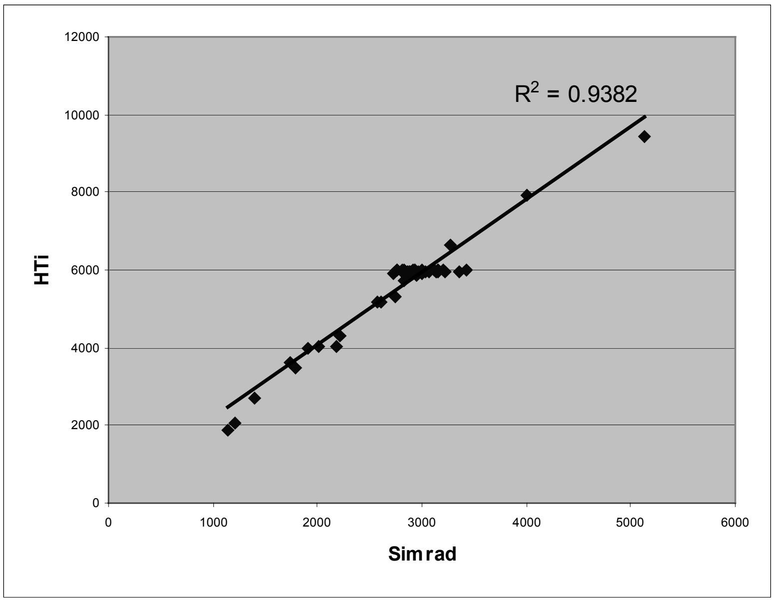


Figure 3.14. Number of pings collected per file during the mobile Thames survey; Simrad vs HTI

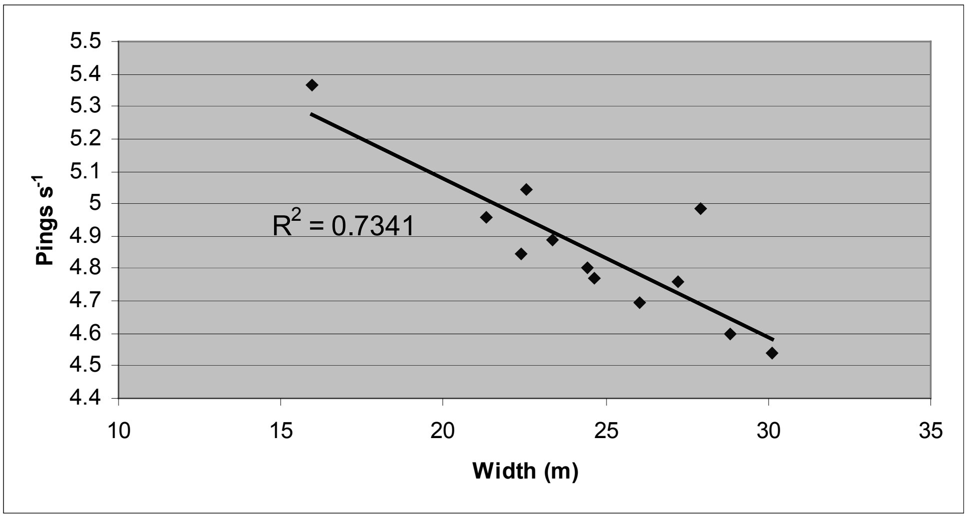


Figure 3.15. Simrad ping rate by mean river-width for files collected on reach 5, River Thames

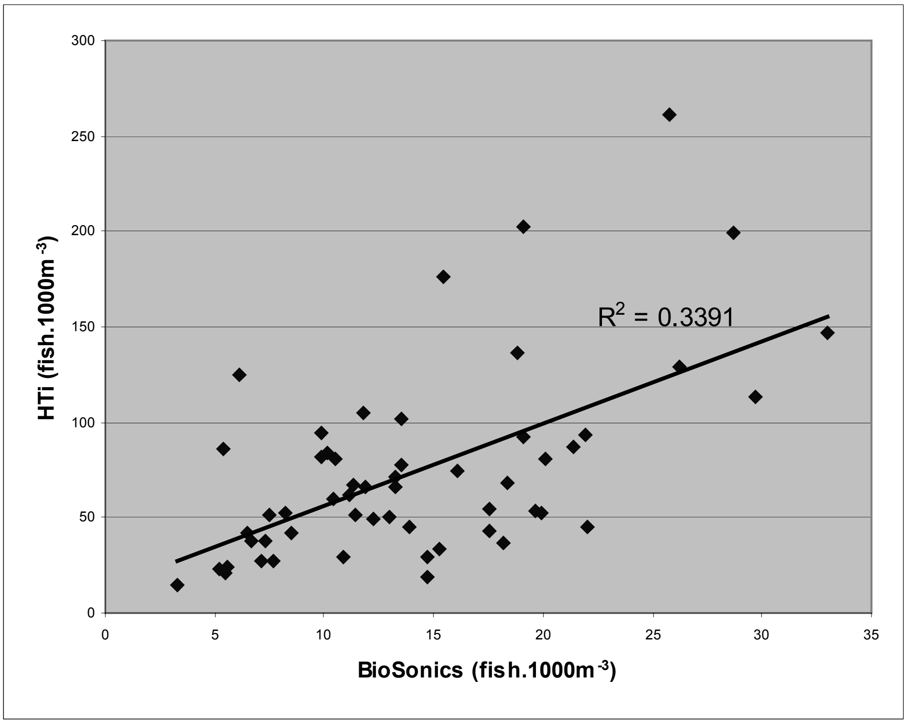


Figure 3.16. Paired volume density estimates from mobile Thames survey; BioSonics vs HTI

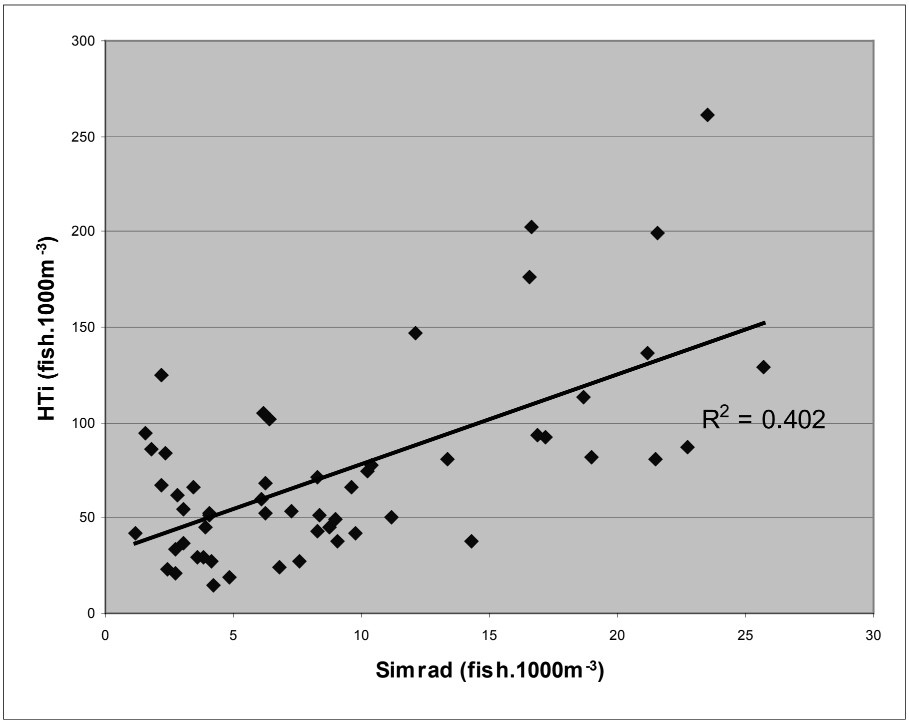


Figure 3.17. Paired volume density estimates from mobile Thames survey; Simrad vs HTI

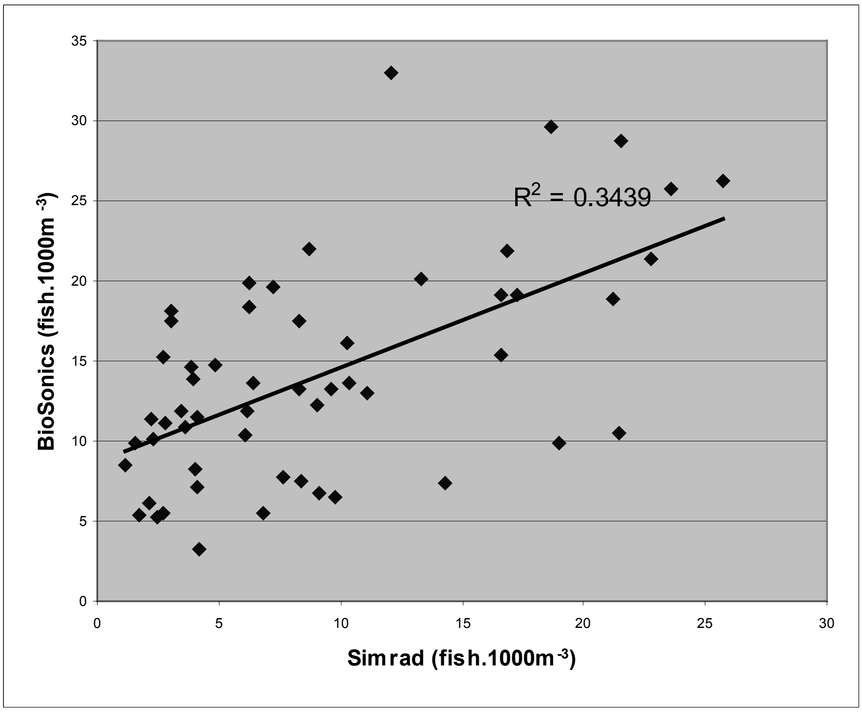


Figure 3.18. Paired volume density estimates from mobile Thames survey; Simrad vs BioSonics

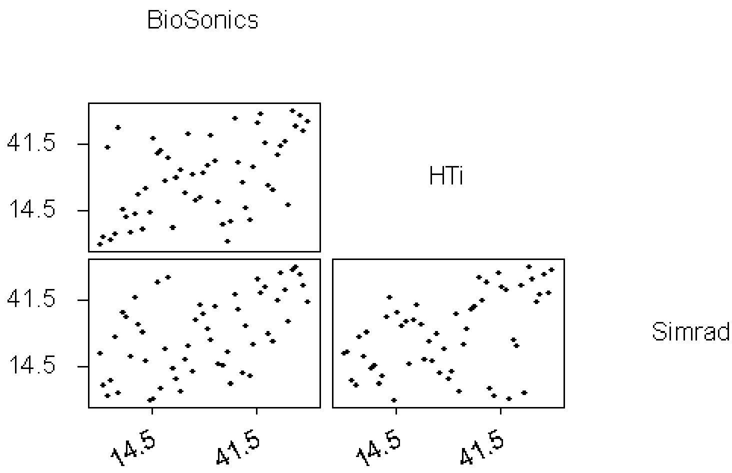


Figure 3.19. Matrix plot of paired ranked volume density estimates from Thames mobile study

Table 3.5. Correlation coefficients for paired volume density estimates and ranked volume density estimates from mobile Thames study. Critical value $r_{0.05, 2, 53} = 0.265$, $r_{s\ 0.05, 2, 53} = 0.271$

Paired echosounders	**Correlation coefficients (r and r_s)**	**Probability**
	Product moment (r)	
BioSonics vs HTI	0.582	P < 0.001
Simrad vs HTI	0.634	P < 0.001
Simrad vs BioSonics	0.586	P < 0.001
	Spearman rank (r_s)	
BioSonics vs HTI	0.511	P < 0.001
Simrad vs HTI	0.464	P < 0.001
Simrad vs BioSonics	0.536	P < 0.001

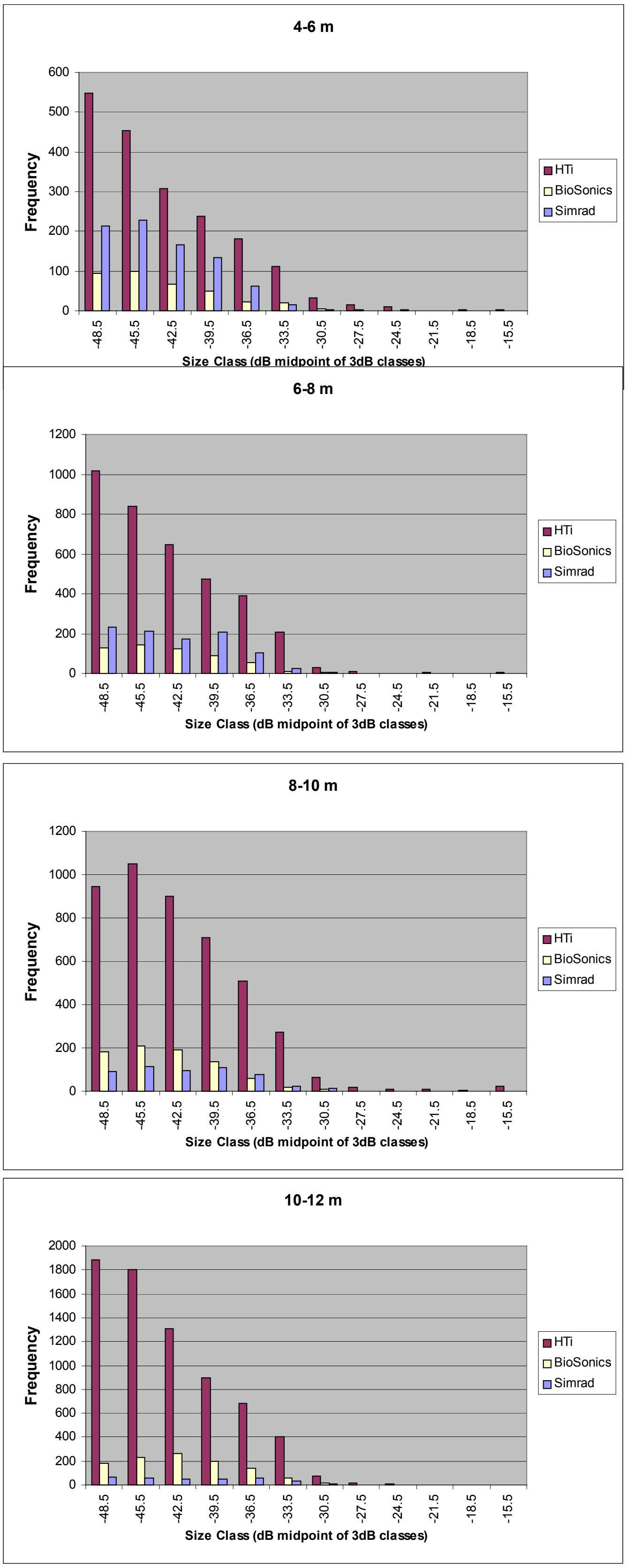


Figure 3.20. TS frequency distributions for reach 5, River Thames, by strata and echosounder

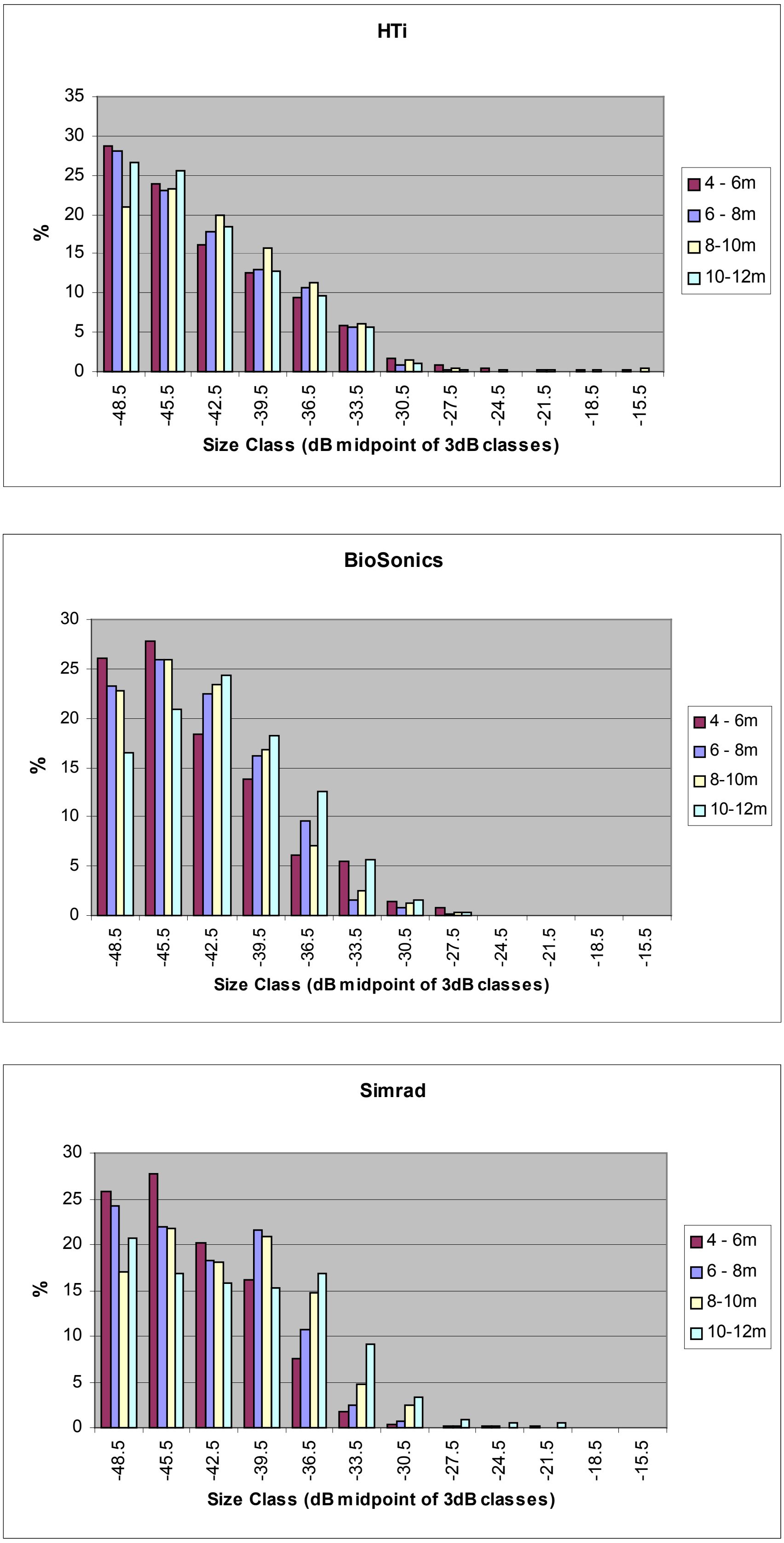


Figure 3.21. TS percentage frequency distributions for reach 5, River Thames, by strata and echosounder

an associated increase in the proportion of larger targets. These results demonstrate considerable differences in the ability of the echosounders to report single targets, particularly smaller targets at greater ranges, in horizontal mode under their respective configurations.

Manchester Ship Canal mobile Survey

The purpose of the mobile survey on the MSC was to compare the performances of the two split beam echosounders in a river system with lower background noise levels and fish densities

The HTI again reported consistently higher volume density estimates, ranging from 1.2 – 18.4 fish 1000^{-3} compared to 0.2 – 4.0 fish 1000^{-3} for the Simrad. Paired density estimates were also significantly correlated (Figure 3.22. Critical value $r_{0.05, 2, 17}$= 0.456, r = 0.918, P < 0.001). TS data were analysed in four strata; 4 – 10 m, 10 - 15 m, 15 - 20 m and 20 - 25 m, and percentage frequency distributions by echosounder are presented in Figure 3.23. On this occasion, the Simrad did not appear to have difficulty reporting small targets with increasing range, as both the Simrad and HTI TS distributions appeared broadly similar over the four strata.

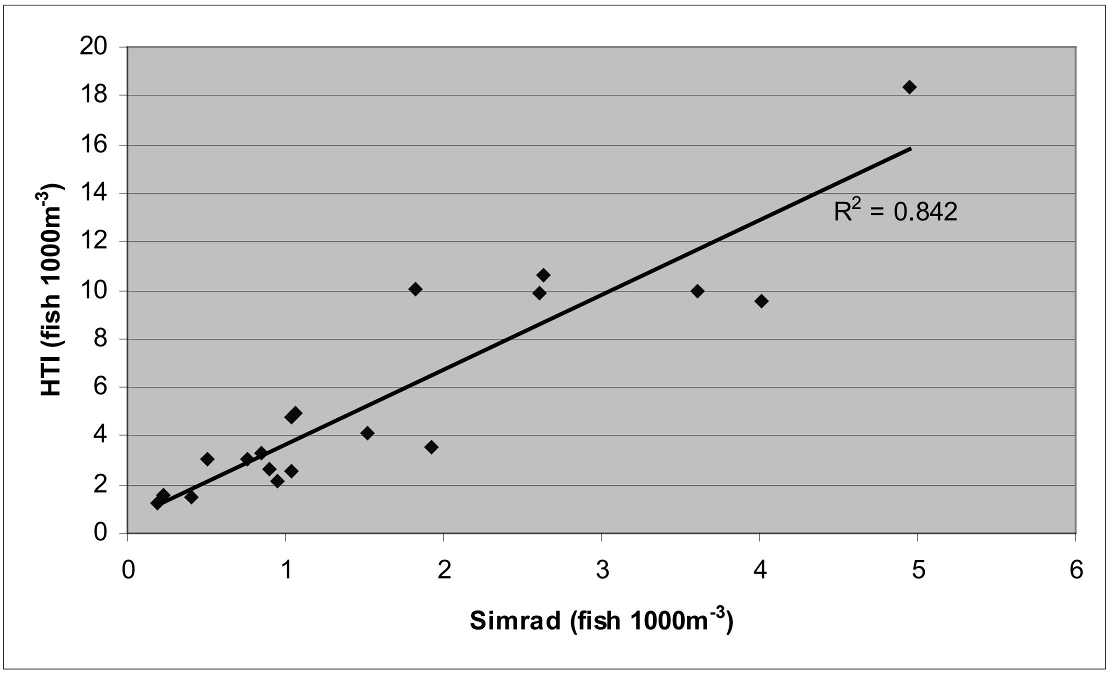
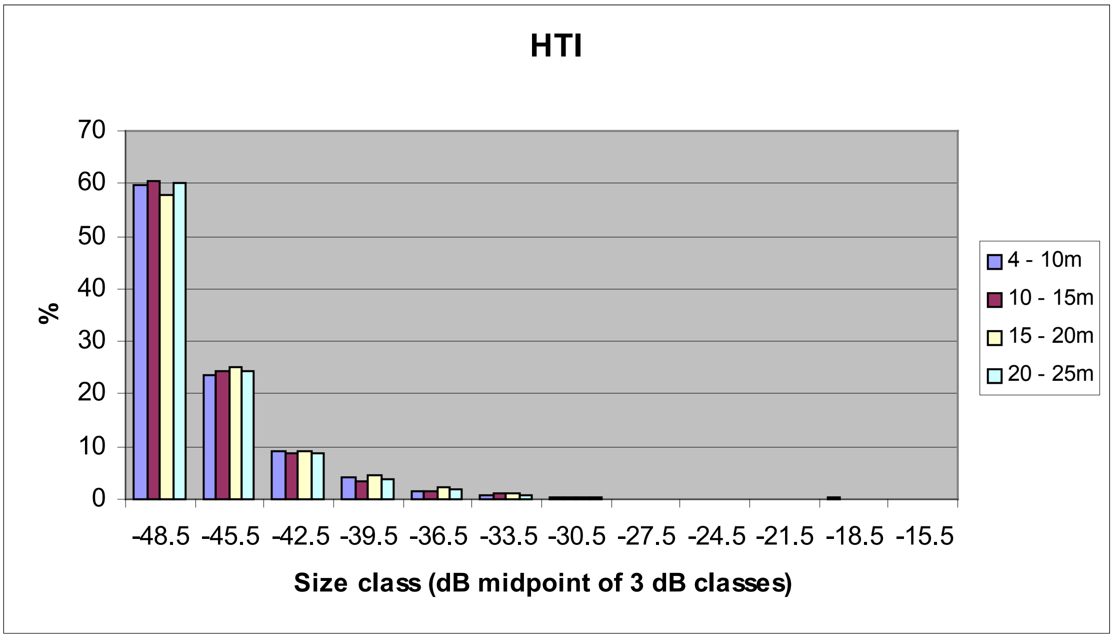


Figure 3.22. Paired volume density estimates from Manchester Ship Canal survey; Simrad vs HTI



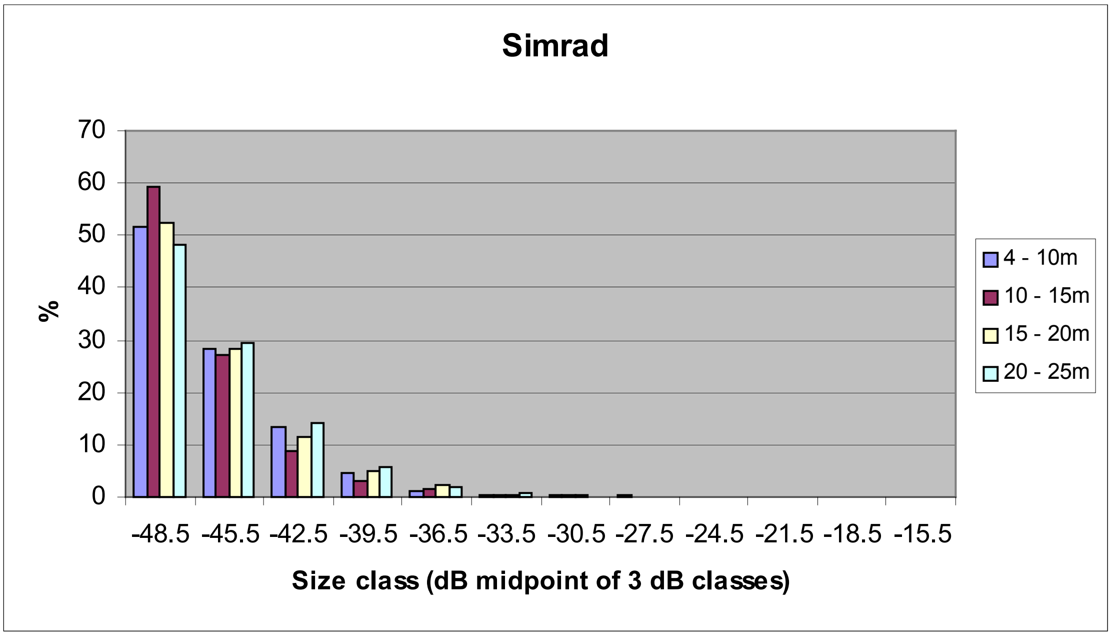


Figure 3.23. TS percentage frequency distributions for Manchester Ship Canal reach, by strata and echosounder

Tank trials at Davenham depot

The large differences in absolute density outputs from the Thames mobile survey by the two split beam echosounders was further investigated in tank studies. Attempts were made to standardise configurations and echo-selection criteria by running the HTI alongside the Simrad in two set-ups; 'normal' HTI and as close as possible to the 'Simrad' configuration. Density outputs are presented in Figure 3.24 with a summary of fish behaviour inferred from echograms and field observations.

The first five samples were taken with the HTI operating under the 'Simrad' configuration. Sample 1 was from a tank containing no fish, and a few scattered targets resulted in low densities of 4.2 (HTI) and 3.7 fish $1000m^{-3}$ (Simrad). Samples 2 – 5 were taken with fish present and resulted in the HTI recording higher single target volume densities than the

Simrad by factors of 1.4 – 6.2. Samples 6 – 9 were taken with the HTI operating under the 'normal' configuration and here HTI volume density estimates were greater than Simrad densities by factors of 6.6 – 14.6.

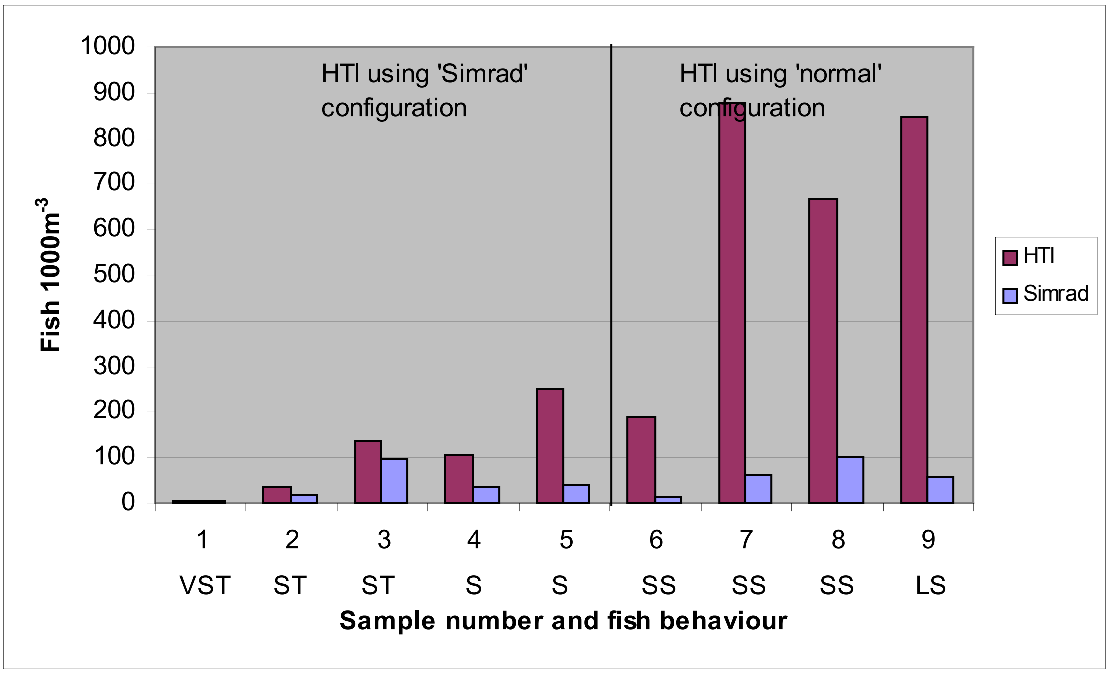


Figure 3.24. Volume density estimates obtained from fixed location tank studies at Davenham depot. Two configurations were employed by the HTI; 'normal' HTI and 'Simrad'. Fish behaviour summarised using the following key: VST = very scattered targets (no fish), ST = scattered targets, S = one small shoal, SS = small shoals, LS = large shoal

The HTI therefore appeared able to report more single targets than the Simrad regardless of the configuration in use. The 'normal' HTI set-up generally produced the highest densities, however the influence of fish behaviour needs to be taken into consideration. The early trials were conducted when it was raining and few fish were visible on the echograms or near the water surface. The rain had eased off by the later trials, fish were visibly higher in the tank and appearing as a number of small shoals or a single large shoal on the echograms.

Echosounder density estimates were not compared with the true fish density as the tank was not drained down until many weeks after the trials. During this time fish may have been removed by mortality or predation by birds. In addition, as a large proportion of the fish were aggregated during the trials and could not be resolved as single targets, the echosounders would have significantly underestimated the true density.

3.1.3 Cross-talk trials

Cross-talk may affect volume density estimates in two ways; the generation of false targets potentially increasing the density, or interference masking true targets thereby decreasing the density. Once cross-talk was identified at Hydraulics Research, a number of trials were conducted in order to:

- determine whether cross-talk occurs in the riverine environment and between which echosounders; and
- quantify the effect on volume density estimates.

River Mersey

The presence of cross-talk between echosounders is summarised in Table 3.6. Problems with the rotator power-supply resulted in the transducers being tilted too far down, restricting the detection of interference to a range of ~6 m. Examination of oscilloscope traces and echograms only identified cross-talk between the HTI and BioSonics. The HTI transmitter pulse appeared on the BioSonics narrow and wide beam signals as a periodic and irregular ripple rapidly moving away from the transducer with increasing amplitude. At 5 m range the peak amplitude of the ripple on the narrow beam signal was ~80 mV, compared to noise levels of 16 – 20 mV. As the threshold voltage for a –50 dB target was predicted to be ~ 900 mV (from BIOCALIB.XLS; Duncan and Kubecka, 1994), no false targets would be expected over this short range and the half-amplitude echo length of real targets should not be affected. However, the increasing amplitude of the interference with time suggests false targets or masking of targets would be possible at greater ranges.

Table 3.6. Summary of River Mersey cross-talk trials

File	Echosounders Enabled	Echosounder exhibiting cross-talk
1	Simrad	None
2	HTI	None
3	BioSonics	None
4	Simrad + HTI	None
5	Simrad + BioSonics	None
6	HTI + BioSonics	BioSonics
7	Simrad + HTI + BioSonics	BioSonics

As the cross-talk could not be replicated during the Thames drifting target trial, it was decided to proceed with the mobile survey without further investigation. Very occasionally, the cross-talk occurred during this study, but the peak voltages were again below the threshold for a –50 dB target. As masking can not be ruled out, the overall effect of the HTI on BioSonics interference was probably a very small underestimation of volume density on a small number of runs.

Davenham Depot

Simrad data collected during the Davenham depot trials exhibited interference from the HTI as high-energy echoes scattered around the echogram (Figure 3.25). These spikes were very short (< 0.2ms) and were generally excluded as single targets by the echo-selection criteria (minimum echo length = 0.24 ms). However, an exceptionally high trace sa from a single ping in sample 9 resulted in a sample volume density of 618 fish $1000m^{-3}$, compared with 58 fish $1000m^{-3}$ with the ping excluded. The file was sent to Simrad for interpretation and they concluded that part of a transmitter pulse from the HTI had become integrated with an accepted single target, without changing the reported TS (-41.2 dB).

No such interference was noted on either of the Thames trials. If it had occurred, this type of noise would have caused the Simrad to over-estimate single target volume densities (although the considerably larger volumes sampled on the mobile survey would have diluted the effect).

Manchester Ship Canal

The potential impact of the HTI / Simrad cross-talk on the mobile surveys was further investigated on the Manchester Ship Canal. With the Simrad in passive mode, the background noise levels measured were -141.0 dB with the HTI disabled and –132.2 dB with

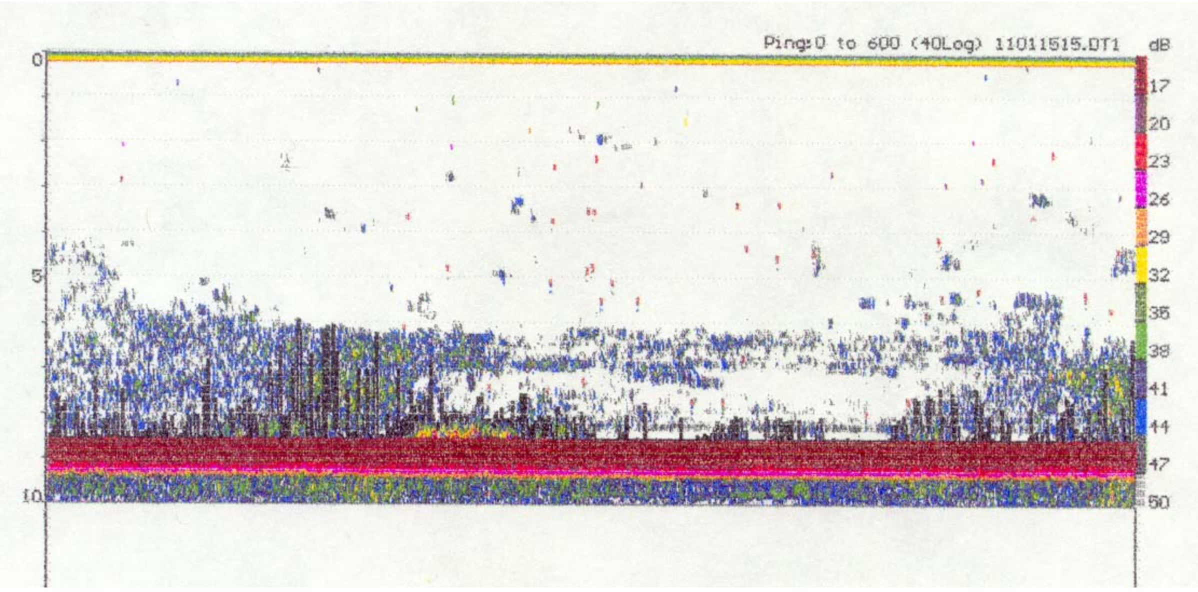


Figure 3.25. Simrad echogram extracted from sample 9, Davenham tank trials. High energy spikes from the HTI transmitter pulse appear as scattered red echoes

the HTI enabled. Both values are within the recommended levels of system noise for operation in horizontal mode (Hillary *et al.* 1999). A Simrad file logged when the HTI was disabled did not display any noise, however interference was detected when the HTI was enabled (Figure 3.26). None of these transmitter pulses were accepted as single targets. Simrad echograms collected when both echosounders were transmitting did not display the cross-talk identified at Davenham. This type of interference may therefore be confined to that tank trial.

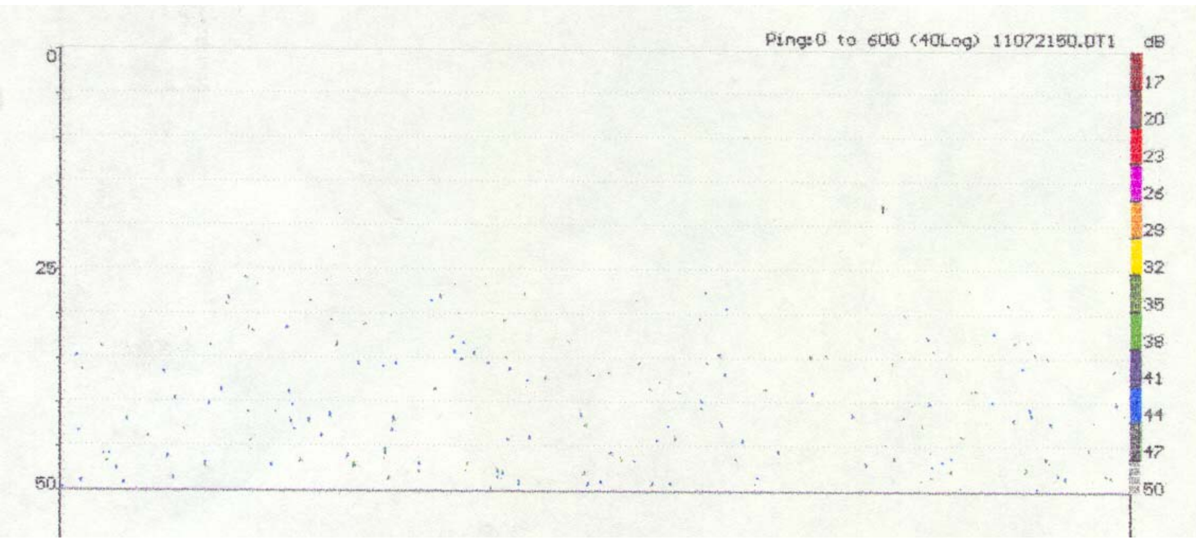


Figure 3.26. Simrad echogram extracted from Manchester Ship Canal Trial. The Simrad transceiver was in passive mode with the HTI transducer enabled. Interference appeared as scattered echoes at > 25 m range

3.2 Review of Data

All upstream and downstream runs were combined to give annual mean densities for each river. These were plotted against mean river discharge, temperature and moon phase during the course of the surveys to examine variability in acoustic density estimates by year.

3.2.1 River Thames, 1994 – 1998

A weak but non-significant correlation (critical value $r_{0.05, 2, 3} = 0.878$, $r = 0.837$, $P > 0.05$) between log annual mean density and mean discharge was identified on the Thames (Figure 3.27a). The remaining scatter plots showed no obvious relationship between acoustic density estimates and temperature or moon phase (Figure 3.27 b-c).

3.2.2 River Trent, 1994 – 1998

No obvious relationships between acoustic density and abiotic factors were apparent from the plots (Figure 3.28), however discharge and water temperature data were not available for 1997.

3.2.3 River Ouse, 1996 – 2000

Considering August surveys alone, there were no obvious correlations between fish density and the abiotic factors examined (Figure 3.29). Inclusion of surveys conducted at other times of year may indicate slightly higher acoustic densities being associated with lower mean flows (Figure 3.29a), however no tested trendline was significant.

The larger number of samples available from the Ouse permitted a crude test for the interactive effects of the three environmental factors on density estimates. Nine surveys were ranked by each factor, with a high ranking (low number) given to those conditions which best suit horizontal acoustic surveys (i.e. low flow, high temperature and new moon. Lucas *et al*., 2001). The rank values were then summed to give a cumulative ranking based on all factors, against which ranked density was plotted (Figure 3.30). As expected, the graph shows higher density estimates generally being associated with combined environmental conditions that are believed to favour acoustic surveying, although the correlation was not significant (Spearman rank correlation coefficient critical value $r_{0.05, 2, 7} = 0.786$, $r = 0.494$, $P > 0.5$).

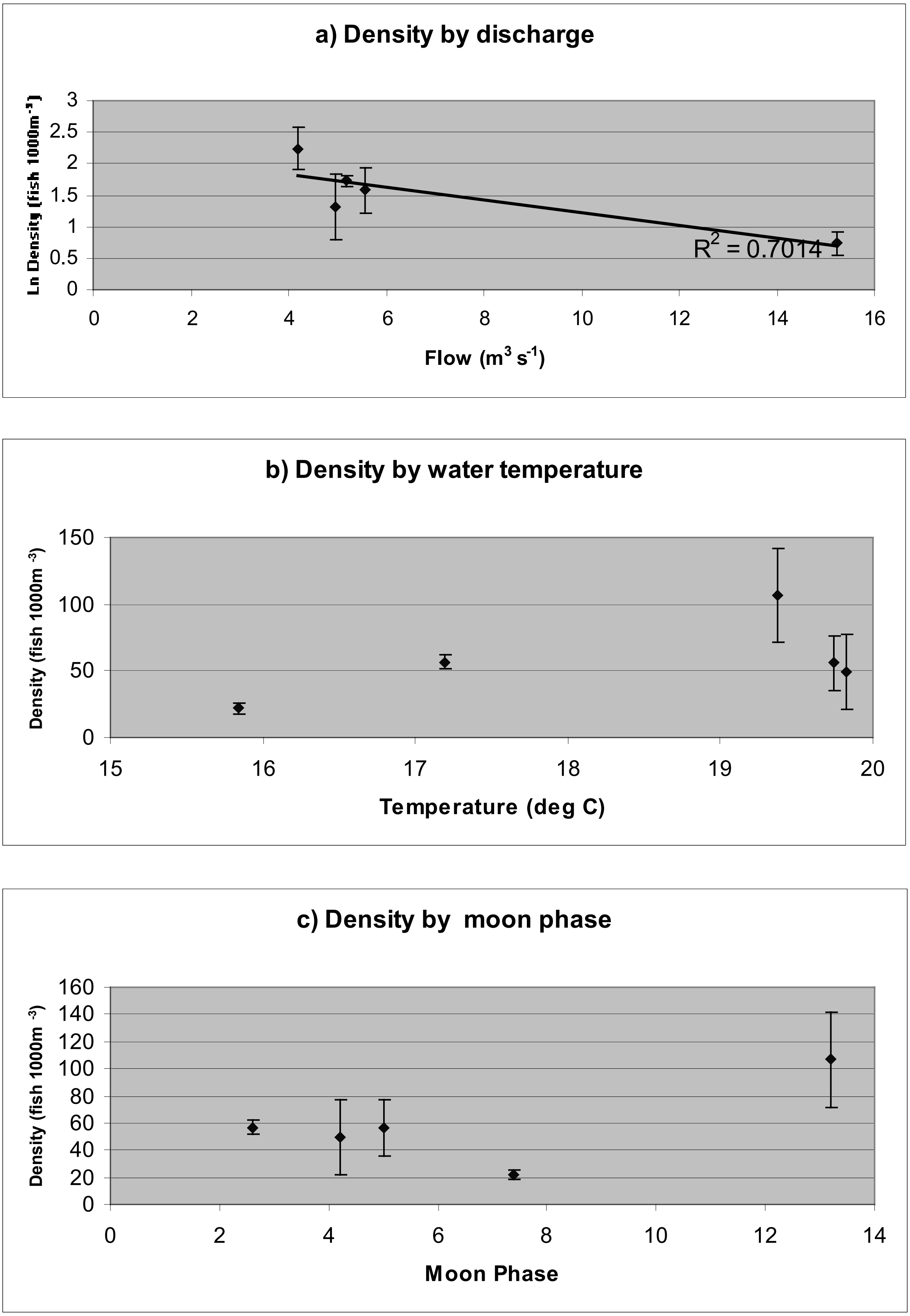


Figure 3.27. River Thames 1994 – 1998. Annual mean acoustic densities by a) mean discharge, b) mean water temperature, and c) mean moon phase (0 = new moon, 14 = full moon). Error bars are 95% confidence limits. Note log vertical axis in (a)

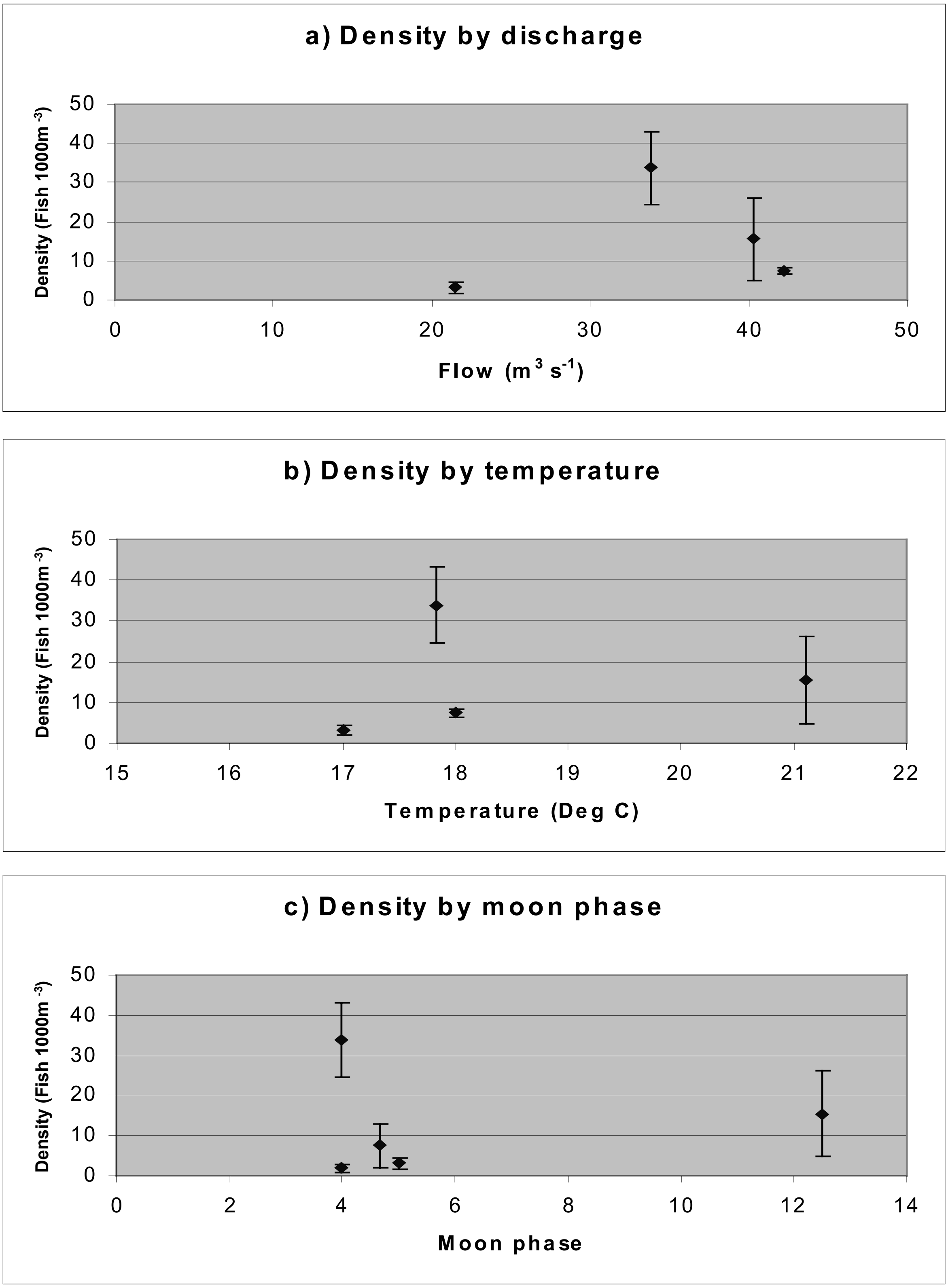


Figure 3.28. River Trent 1994 – 1998. Annual mean acoustic densities by a) mean discharge, b) mean water temperature, and c) mean moon phase (0 = new moon, 14 = full moon). Error bars are 95% confidence limits

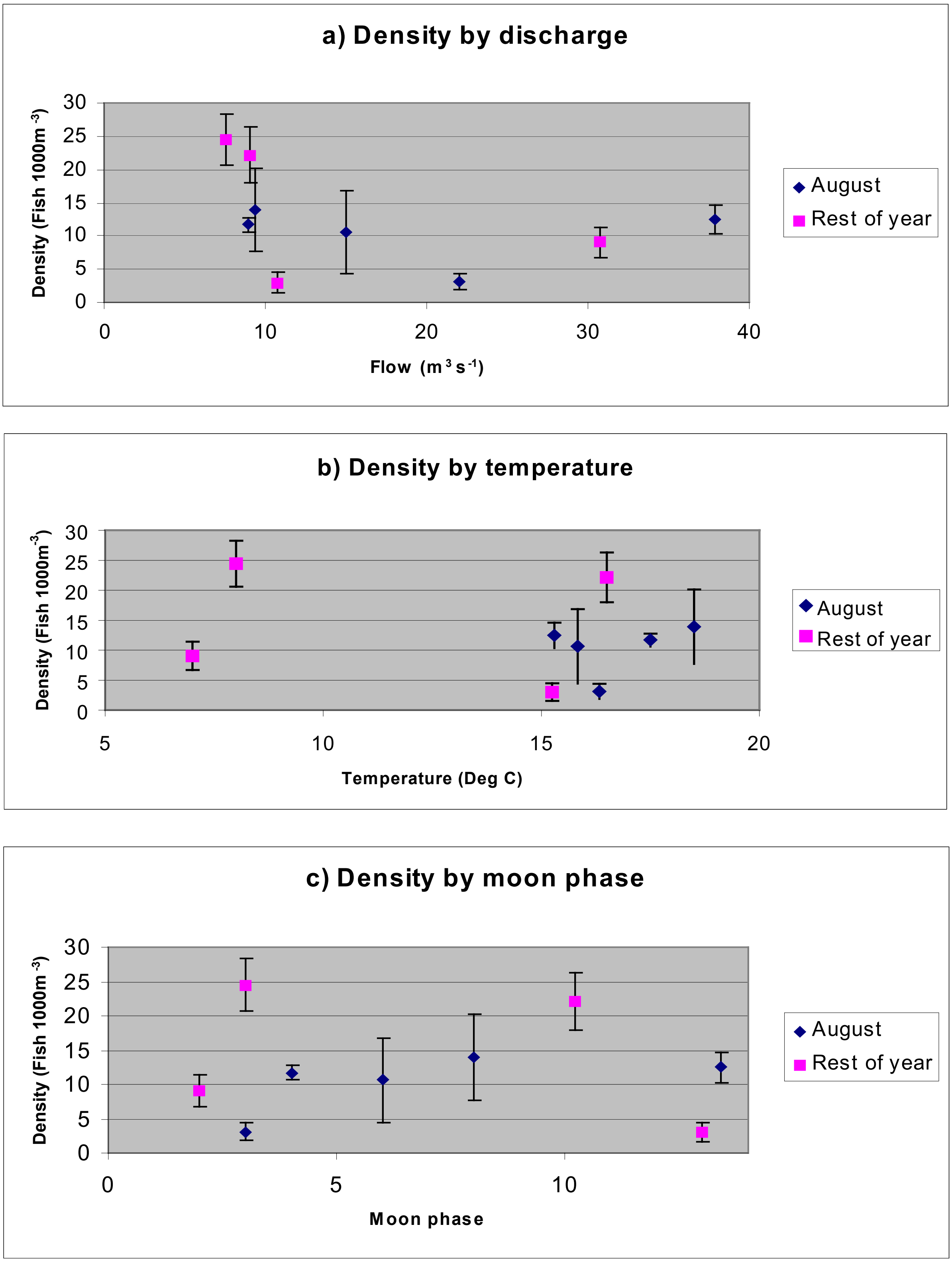


Figure 3.29. River Ouse 1996 – 2000. Annual mean acoustic densities by a) mean discharge, b) mean water temperature, and c) mean moon phase (0 = new moon, 14 = full moon). Error bars are 95% confidence limits. August surveys and surveys conducted at other times of the year are shown separately

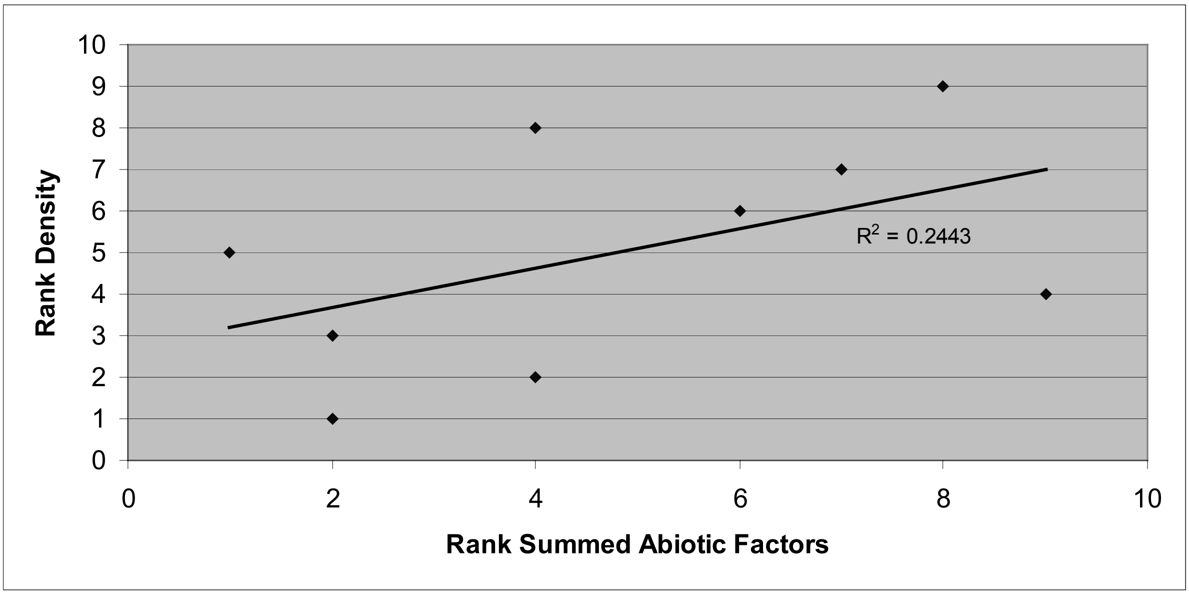


Figure 3.30. River Ouse 1996 – 2000. Nine surveys were ranked by density and plotted against ranked cumulative abiotic factors (see text). Figure shows a general, but non-significant, trend of higher densities (low rank number) being associated with combined conditions considered best for acoustic surveying

4. DISCUSSION

4.1 Inter-Gear Variability

The Environment Agency routinely operates three makes and models of echosounder for horizontal mobile surveys of large, lowland rivers. The purpose of this study was to investigate inter-gear variability and ensure each system is describing the environment in the same way, in terms of density and TS outputs. Satisfying this requirement would significantly contribute to the following project goals:

- A recommended echosounder system for mobile horizontal surveys.
- Cross-calibration of historic acoustic data collected by different echosounders, to facilitate comparisons between river systems and permit a standardised acoustic output for the National Monitoring Programme.
- Provide recommendations for the experimental design of a study assessing the influence of abiotic factors on temporal variability in acoustic estimates of fish communities.

Different operational frequencies, sounder types (split beam, dual beam) and transducer beam widths would not permit identical configurations for each sounder and valid comparisons of absolute values. Instead, sounders were individually configured for echo-counting and analyses were generally restricted to relative comparisons of density and TS.

Very few studies have been published comparing the performance of scientific echosounders and these have generally been restricted to mobile vertical surveys of lakes (Rudstam *et al.* 1999) and fixed location horizontal surveys of rivers (Burwen *et al.* 1995). Mehner *et al*. (in press) did compare two identically configured Simrad EY500 systems deployed in horizontal and vertical modes on boats, however the present study may be the first investigation in the context of mobile horizontal surveys of rivers.

4.1.1 TS variability

Although a large and relatively deep (2 m) freshwater tank may seem an ideal environment for horizontal TS measurements, there are a number of potential sources of error:

- The vertical sides and fixed structures will reflect echoes around the tank and further unwanted reflections may occur off the bottom and smooth water surfaces (Kubecka, 1996). Recording of multipath echoes was avoided by careful orientation of the acoustic beams and checking the tilt potentiometer setting on the rotator control box to ensure they were parallel to the bottom.
- The circular transducers tested are designed for vertical beaming in a free field and identification of targets may have been a problem at greater ranges. For example, the side-lobes are relatively large compared with elliptical transducers and strong echoes in these side-lobes may appear as targets in the main beam.
- Cross-talk between the echosounders was most evident in enclosed tank environments such as those at Davenham and Hydraulics Research, and such interference could modify the signal from standard targets. The problem of interference adversely affecting the study was avoided by restricting transmitter activity to one echosounder at a time.

The few trials conducted at Hydraulics Research demonstrated considerable variation in TS estimates between replicates and by distance from the transducer. Some of the variability may be due to slightly non-homogeneous spheres (MacLennan and Simmonds, 1992). For example, poor manufacture of plastic targets like ping-pong balls, or excessive mesh netting around metal targets will result in different scattering properties as the target rotates. Inappropriate time-varied gains normally used in echosounders may also be responsible for TS variability with range, as standard formulae for sound dispersion and energy loss compensation may not apply in shallow waters (Balk, 2001; Knudsen and Saegrov, 2001).

The higher levels of variability about TS estimates measured by the BioSonics is expected, as dual beam measurements of TS are more variable than those derived using the split-beam technique (Traynor and Ehrenberg, 1990). The Simrad generated the lowest coefficients of variation in cross-sectional area but the sample size was small (14), no targets at ranges > 8 m were included and levels of variability were not significantly different from the HTI.

There appear to be two schools of thought regarding the importance of TS variability in the context of horizontal mobile surveys. Duncan and Kubecka (1993) attached considerable importance to it, as the level of variability in on-axis TS measurements determines the quality of calibration and the precision of the target strengths subsequently determined by dual beam or split beam processing. They therefore produced guidelines for an acceptable level of variation in horizontal calibrations of the BioSonics (coefficient of variation in voltage^2 ± 7%). HTI and Simrad operators within the Agency considered prescriptive levels of acceptable variability as unnecessary, in view of the large number of factors which can affect target strength measurements in the field (e.g. size / shape of the swimbladder, fish physiology, fish orientation to the beam, swimming speed). Partly on manufacturers' advice, < 1 dB changes in mean TS (HTI) or < 1 dB changes in TS Transducer Gain (Simrad) between calibrations were considered acceptable levels of TS variability (J. Lyons, J. Gregory, Personal communication).

4.1.2 Variability in volume density estimates

The combined River Thames and MSC mobile studies demonstrated the three echosounders were orientated in the same direction, sampled similar volumes of water, and their respective volume density estimates were significantly correlated. However, the HTI produced considerably higher absolute density values, averaging > 8 times higher than the Simrad and > 5 times the BioSonics' outputs. Despite non-uniform operation of the sounders limiting such comparisons of absolute values, these differences cannot be ignored. The possibilities of conservative target reporting configurations within the Simrad and BioSonics and high 'false' target reporting by the HTI (e.g. from reverberation) were therefore examined.

The drifting target trials indicated that over short ranges the HTI was not reporting false targets, as there was good agreement between all echosounders on the range and movement of accepted targets relative to the transducers. In addition, the absolute density estimates generated by the Simrad and HTI were reasonably close. The BioSonics had a significantly lower proportion of pings hitting the nuts suggesting a poorer ability to recognise and report targets in low SNR conditions. This effect was also recorded by Burwen *et al* (1995), although to a lesser extent. Dual beam echosounders may be more vulnerable to noise interference as increases in both wide and narrow beam voltages will tend to increase the off-axis distance, and 'real' targets may be displaced beyond the imposed threshold beam pattern factor (BPF) of -3 dB (Kubecka *et al.* 1992).

Range-dependant differences in target reporting by the two split-beam systems were evident in the Thames mobile study. The HTI reported similar TS distributions regardless of range from the transducer, whereas the Simrad reported proportionately fewer small targets with increasing range. The total number of targets reported by the Simrad (and the number of smaller targets in particular) dropped dramatically with range despite the increased sampling volume (Figure 3.21). This resulted in skewed TS distributions and depressed overall densities, for example, densities from the 4 – 6 m stratum were typically an order of magnitude higher than estimates from the 10 – 12 m stratum on reach 5.

There are a number of possible reasons why the Simrad was comparatively poor at reporting targets over ranges routinely analysed in horizontal mobile surveys:

- The HTI operated with the shortest pulse length (0.2 ms) and would therefore be expected to be able to resolve targets positioned closer together (~15 cm vs. ~23 cm).
- Single echo detection in commercially available sonar were optimised for accuracy in TS estimates rather than detection probability (Balk, 2001), and the Simrad's operational settings / echo-selection criteria may have been more conservative than those used for the HTI. For example, Simrad echo detection includes an additional discriminatory criterion, maximum phase deviation, which has been found to have the highest rejection rate of echoes as targets (Balk, 2001). Attempts to harmonise the two system's settings at Davenham suggested the HTI continued to produce higher densities, however not all target detection options could be matched (e.g. electrical phase jitter inside an echo pulse).
- The Simrad may have been more susceptible to noise resulting in the loss of targets, particularly those near the threshold TS and at greater ranges. This is supported by its improved performance in the MSC, in terms of target reporting at greater ranges, as background noise levels in this environment were considerably lower than in the Thames. Bottom or surface reverberation caused by side lobes can form an important source of interference in turbid lowland rivers (Kubecka *et al.* 1992). In addition to having a slightly wider beam width (7°), the Simrad transducer also had wider first side lobes than the HTI (12° vs 10°; both ~18 dB below the maximum response), increasing the chance of boundary interference.

Combined fixed-location acoustic, netting and electrofishing surveys were conducted on the Rivers Thames and Wey to validate density estimates from BioSonics dual beam echosounders operating under identical system settings to the present study (Duncan and Kubecka, 1993; Kubecka *et al.* 1992). A significant correlation between log echo-counted densities and log catch was found which was very close to a 1:1 relationship. This strong correlation, however, does not mean the HTI has been significantly over-estimating fish densities on the Thames, as virtually all the trials were conducted in daylight. In the one night survey conducted, netted fish density was greater than the acoustic estimate by a factor of 25 (Duncan and Kubecka, 1993).

4.1.3 Recommended echosounder system for mobile horizontal surveys

Any recommendation for a single echosounder system would be primarily based on one mobile survey without validation against known fish densities and sizes. It would also be based on the assumption the Agency will continue to use echo-counting techniques rather than echo-integration, as it is believed to be more robust where marginal acoustic conditions are prevalent (Kubecka *et al.*, 1992). Finally, resource implications such as cost and technical support are not considered.

The following basic specifications are highly desirable in an echocounter employed in mobile horizontal surveys:

- Split beam.
- High system stability.
- Good target reporting in low SNR environments.
- Robust and portable.
- Manual control of operational settings.
- Flexible noise-handling facilities.
- Data playback.
- Rapid and flexible post-processing.

The BioSonics 105 is a relatively old, analogue dual beam system that is due for replacement. Both of the split beam echo-counting systems tested in this study appear suitable for mobile horizontal surveys and are highly adaptable. A small number of practical problems or disadvantages unique to each system were identified (Table 4.1). Under the study test conditions, the HTI did, however, appear to have two advantages over the Simrad:

1) Greater single target detection with increasing range from the transducer. If this was primarily a boundary interference problem, the performance of the Simrad may be significantly improved by using one of the elliptical transducers routinely in use within the Agency for mobile horizontal surveys (e.g. 4° x 10° or 2° x 10°). The HTI may be similarly improved as a broad range of elliptical transducers are also available (e.g. 2.8° x 10° and 4° x 10°). If noise was masking small targets, SNR can be improved by increasing the pulse duration and decreasing the bandwidth. However, this would be achieved at the cost of a larger sampling volume and reduced target resolution (MacLennan and Simmons, 1992). Problems with shadowing and range definition have also been noted (Hillary *et al.* 1999). Finally, relaxing the relatively conservative Maximum Phase Deviation criteria (e.g. from 4 to 10 phase steps) would result in the acceptance of weak echoes in noisy conditions (Knudsen, personal communication).
2) Constant pulse rate. The Simrad pulse rate and hence sample rate is dependant on the activities of the CPU. Running the Simrad with a printer significantly lowers the ping rate (Hillary *et al.* 1999) and the rate can change during a survey depending on the range surveyed (Figure 3.15; P. Frear, Personal communication). This introduces the possibility of biased sampling. For example, if narrow sections of the channel are associated with higher fish densities then these densities will be sampled at a faster rate.

Table 4.1. Practical problems / disadvantages encountered with Simrad and HTI systems under test conditions

Simrad	**HTI**
Replacement PCs hard to obtain and configure for operation with EY500	Limited post-processing software for volume density estimates and lengthy post-processing
Ping rate can vary during survey	Vulnerable connection between digital echosounder and LAN card in PC
Poor reporting of small targets at range in low SNR environments	Bulky DAT deck for taped data storage

Reservations regarding the relatively convoluted calculation of single target volume density by the Simrad appear unfounded. Within EP500, the area back-scattering coefficient for single targets is summed to give the trace sa value. Trace sa is then partitioned by the normalised distribution of the various size groups identified by the sounder to give density (Bodholt, 1990). Significant correlations were found between this 'EP' method (Simrad 1) and density calculations based simply on the number of targets identified and known sample volume (Simrad 2; Section 2.1.1. Figures 4.1 and 4.2). The drifting target correlation appeared to deviate from a 1:1 relationship, with the 'EP' method generally reporting higher densities than the 'non-EP' method. However, these density estimates were based on few accepted targets in small sample volumes. The two methods generated very similar paired density estimates when applied to the mobile Thames data, possibly due to increased volumes sampled and number of targets identified. In conclusion, this study identified no reason to reject the standard method used by the Agency, particularly as use of EP500 outputs is considerably faster than working with the raw data files.

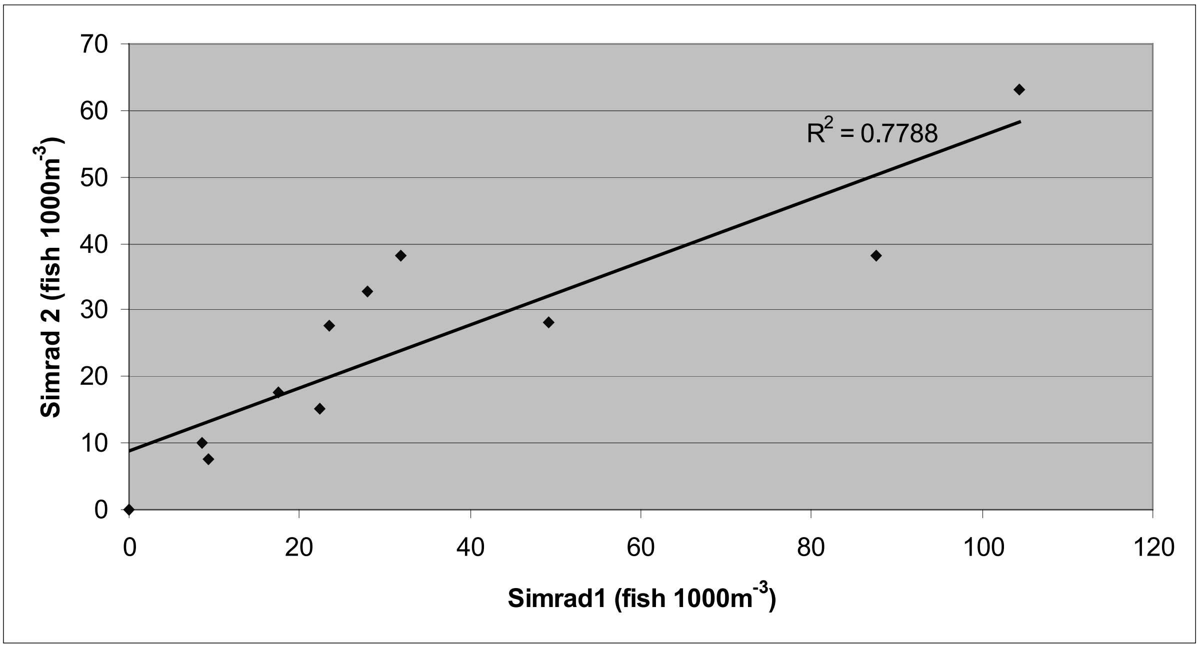


Figure 4.1. Paired volume density estimates from drifting target study showing significant correlation between Simrad 1 ('EP' method) vs Simrad 2 ('non-EP' method). Critical value $r_{0.05, 2, 9} = 0.602$, $r = 0.882$, $P < 0.001$

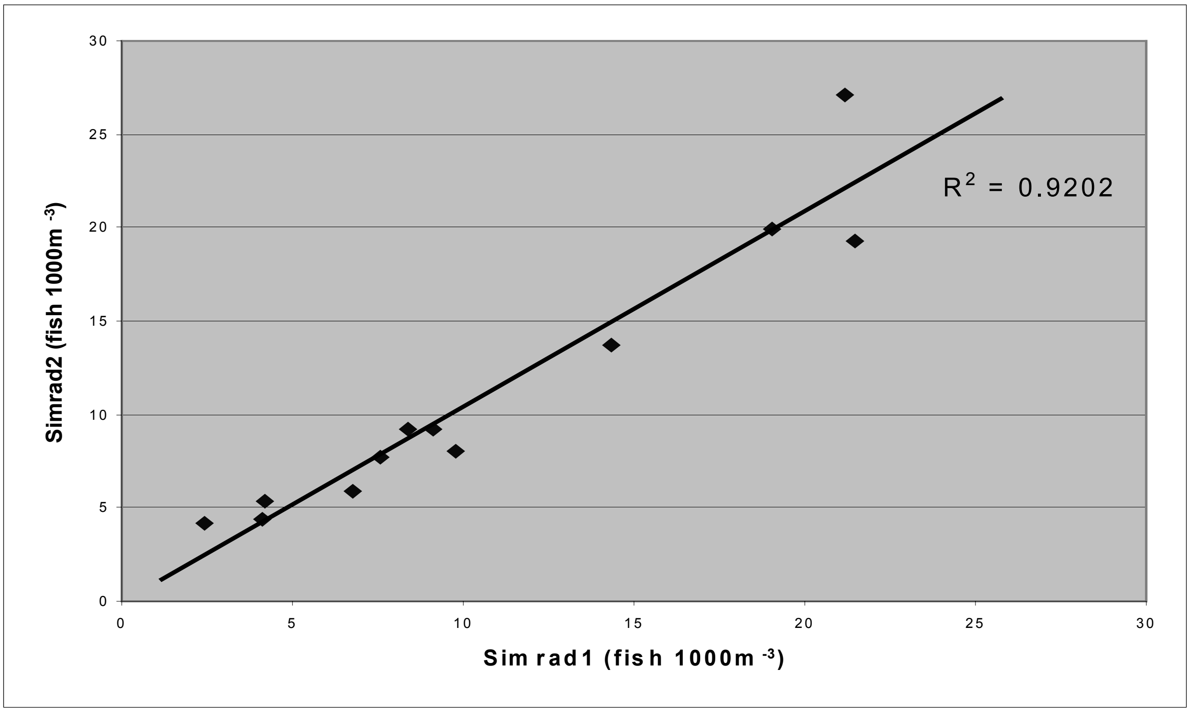


Figure 4.2. Paired volume density estimates from reach 5 of the mobile Thames study showing significant correlation between Simrad 1 (‘EP’ method) vs Simrad 2 (‘non-EP’ method). Critical value $r_{0.05, 2, 10} = 0.576$, $r = 0.959$, $P < 0.001$

4.1.4 Cross-calibration of historic acoustic data collected by different echosounders

Prior to and within the NRA, development of hydroacoustics in fisheries monitoring was not centralised and resulted in different systems being routinely used on different rivers (e.g. BioSonics on the Thames, Simrad on the Trent and Ouse). This has limited spatial and temporal comparisons to studies within a river, or possibly between rivers when identical operational and post-processing settings have been used. A single sonar system with standard core configuration settings is preferable, as this would produce a nationally consistent output and enable comparisons to be made between river systems. Ideally, large historic acoustic datasets such as the Trent, Ouse and Thames would also be included if these data could be cross-calibrated against the standard system.

The correspondence in density estimates supports the possibility of acoustic data collected by different echosounders being cross-calibrated. For example, correlation equations from paired density comparisons may be used to scale BioSonics densities to Simrad or HTI ‘equivalents’. This can only hold true if the relationships are very stable. However, there is evidence for considerable temporal variability in density correlations, as HTI and BioSonics density data collected simultaneously in 1998 had a very different relationship from those collected in 2001 (Figure 4.3). It should be noted these data were based on all targets accepted using 3:1 SNR thresholds rather than a nominal –50 dB threshold, post-processing was conducted by different people and only a selection of files were taken from reaches 1,2,3 and 5 in 1998. Nevertheless, this exercise provides little confidence in a single cross-calibration and demonstrates the need for a large overlap of sonar systems before phasing in a replacement echosounder. In view of the unique physical and biological characteristics of individual rivers, cross-calibrations must occur on every river surveyed by the redundant system.

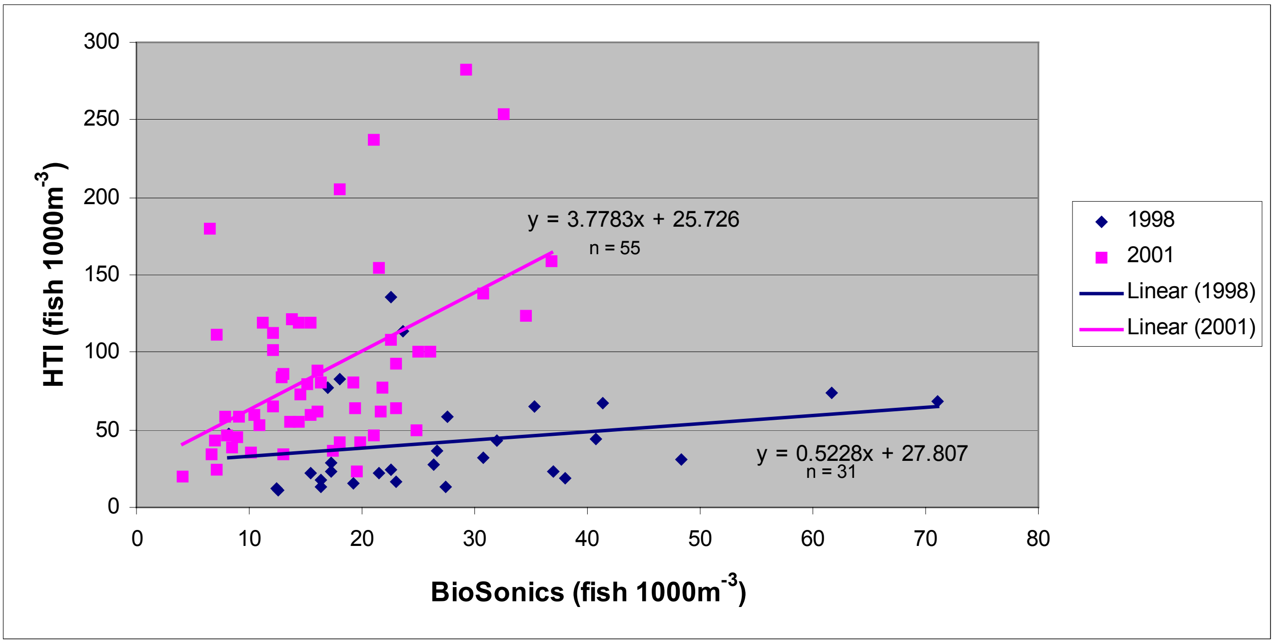


Figure 4.3. Paired volume density estimates and associated correlation equations from mobile Thames surveys conducted in 1998 and 2001; HTi vs BioSonics. Densities are calculated from all accepted targets using 3:1 SNR

In contrast to this investigation, other cross-calibration studies have demonstrated good correspondence in absolute density and TS estimates from single investigations. Comparisons between various split beam and single beam systems on lakes and the Baltic Sea found good correspondence in absolute density estimates and TS distributions (Rudstam *et al.* 1999; Winfield, unpublished). However, these were vertical surveys when acoustic conditions would be expected to be far less marginal than rivers (e.g. higher SNR). Mehner *et al* (in press) did compare echosounders in mobile horizontal mode and found good agreement in EI-derived density and TS outputs, but they were identically configured Simrad EY500 systems. Burwen *et al* (1995) ran dual and split-beam systems concurrently during a fixed location river survey and found the number of targets detected was almost identical. Poor temporal stability of density correlations may therefore just be a feature of surveys conducted in very noisy environments such as mobile surveys of lowland rivers.

4.1.5 Recommendations for the experimental design of a study assessing the influence of abiotic factors on temporal variability in acoustic estimates of fish communities (Phase 4)

The primary recommendation for Phase 4 (Section 1) from the inter-gear variability study would be restricting analyses of acoustic variability to a single echosounder system. When operated as an echocounter, this system would be best able to resolve variability in fish density in response to changing abiotic factors. Phase 4 would probably be a new and independent trial rather than a development of an existing survey (Section 5). In which case, either of the split-beam systems could be used although the HTI (used in conjunction with an elliptical beam transducer) would be preferred primarily based on single target reporting and user-definable ping-rates.

4.2 Review of Data

This study was a preliminary assessment of the effect of three environmental factors on acoustic density estimates, with two expected outputs:

- Identifying sources of variability in acoustic datasets due to river discharge, water temperature and moon phase.
- Providing recommendations for the experimental design of a study further assessing the influence of abiotic factors on temporal variability in acoustic estimates of fish communities.

4.2.1 Sources of variability in acoustic data

Identifying sources of variability in acoustic data due to environmental factors was restricted to long-term datasets. Only three Agency studies satisfied this criterion and in these, sampling occurred at approximately the same time in summer in order to maximise echo-counts and to limit the impact of seasonal changes in fish behaviour (Lucas *et al.*, 2001). This resulted in a number of deficiencies in the data and reduced the probability of identifying sources of acoustic variability for the following reasons:

- The available data only covered a short period of time (maximum 5 years).
- Measurements of temperature and discharge were restricted to 'snapshots' of environmental conditions at the time of sampling, whereas the rate of change of these factors prior to the survey may have been of significance (e.g. Rakowitz and Zweimuller, 2000).
- Moon phase was considered in isolation. If light intensity is the critical factor in modifying fish behaviour, the effects of cloud-cover and water turbidity also need to be considered.
- The opportunistic nature of the data review presented difficulties in investigating the interactive effects of environmental factors on acoustic data.

Several hydroacoustic surveys in rivers have demonstrated the potential impact of high river flow events on recorded fish densities in the river (e.g. Lucas *et al*. 1998a). Moon phase strongly influences diel migratory behaviour of fish in some lakes (Luecke and Wurtsbaugh 1993, Gaudreau and Boisclair 2000), although there is little firm evidence that light intensity associated with moon phase has a marked effect on observed target density within river systems (Lucas *et al*., 2001). Similarly, the effects of minor and short-term temperature fluctuations on target density typically occurring during the acoustic survey period are unclear and have not been quantified (Lucas *et al*., 2001). As the data review failed to identify relationships between these environmental factors and acoustic variability, a dedicated rather than opportunistic investigation is required.

4.2.2 Recommendations for the experimental design of a study assessing the influence of abiotic factors on temporal variability in acoustic estimates of fish communities (Phase 4)

The aim of Phase 4 is to assess the influence of the following key parameters on acoustic assessments of fish communities; water and air temperature, discharge, light intensity, precipitation, barometric pressure and diurnally fluctuating water quality parameters (DO, ammonia and pH). Many of these factors are highly inter-related, for example rainfall induces changes in water flow, light transmissivity, oxygen content and temperature, making it extremely difficult to determine which of these factors is prevalent in shaping migration patterns and therefore variability in acoustic estimates. The primary sources of variability are likely to differ between river systems (because of differences in fish community and habitat structure), though some may be identified by statistical methods (Lucas *et al.*, 2001).

The output from Phase 4, therefore, should not be the establishment of standard conditions under which acoustic surveys are carried out, since this is unlikely to be possible. However, the work may be more valuable in terms of increasing our understanding of the factors responsible for acoustic variability (Lucas *et al.*, 2001). In view of this and experiences from the data review process, the following recommendations are made for Phase 4:

- A number of rivers with different biological and physical characteristics need to be examined.
- Much of the environmental information used in the data review originated from single measurements or daily means from distant sites. Micro-geographic and temporal variability may be of more significance in determining fish behaviour and therefore more supporting field measurements are required during the course of individual acoustic surveys. Regular or continuous DO, pH, transmissivity and flow readings can be easily obtained from portable instruments.
- Survey reaches, equipment, operational settings and data processing procedures must remain unaltered during the course of the study.
- Intensive replicate acoustic sampling over a small number of survey seasons may provide sufficient data for correlation analyses, otherwise long-term studies will probably be required. In both cases, the fish communities within the survey reaches must remain stable in terms of density and size-distribution.

5. CONCLUSION

Although the tank studies demonstrated variability in reported TS of standard targets, it would be negligible in comparison to the variability in field measurements of TS. Target strengths of fish in rivers will vary substantially due their size, orientation relative to the beam, size and shape of the swim bladder, fish physiology and possibly swimming speed (Maclennan and Simmonds, 1992; Bodholt, 1990). A small amount of variability around TS measurements is therefore unlikely to have any impact on overall density estimates unless the sampled population consists of very few fish, all of which are sized close to the threshold TS.

The echosounders did agree on the spatio-temporal distribution of fish or artificial targets, however under their respective configurations there was poor agreement on the absolute densities recorded. This is not a significant problem when the systems are being operated as echo-counters, as they are being used to provide an index of fish abundance rather than quantifying the total number of fish present. However, for an echosounder to be sensitive to changes in fish densities, it should be capable of reliably reporting a good range of densities sampled from a body of water at some distance from the transducer. The HTI clearly had the edge over the other systems in this respect, although the performance of the Simrad could probably be improved by modifying some single target acquisition parameters.

Cross-calibration of echosounder outputs would enable comparisons to be made between rivers surveyed by different equipment, permit a single results format for the fisheries monitoring programme and facilitate continuity of data when echosounders are replaced. Other workers have found a good correspondence in absolute acoustic densities reported by different echosounders (Burwen *et al.*, 1995; Winfield, unpublished), however this study indicates cross-calibration should not be attempted from a single survey and a significant overlap period when both systems are operated simultaneously is probably necessary. Due to the different biological and physical characteristics of rivers, cross-calibration will also be required on each river surveyed by the redundant device. Considerable care must be taken to avoid cross-talk being incorporated into the subsequent comparisons and the number of cross-calibration runs required needs to be determined in a future project.

The close inter-relatedness of environmental factors and the interactions between them make it difficult to extract those variables that are primarily responsible for influencing acoustic estimates. The effect of small changes in some factors, for example temperature or light intensity, on fish behaviour is unknown (Lucas *et al.*, 2001). As such changes may occur during the course of a night's survey, the likelihood of identifying such sources of variability opportunistically from a data review containing point or averaged environmental measurements is very much reduced. A dedicated investigation is therefore required based on a number of rivers, replicate samples and using a single echosounder system. This should combine horizontal mobile surveys with fixed location studies to determine the impact of diel vertical movements of fish and their use of littoral areas on acoustic estimates (Lucas *et al.*, 2001). In both cases, supporting environmental data need to be continuously logged (e.g. temperature, DO, pH, transmissivity) or sampled regularly (e.g. light intensity, rainfall).

6. RECOMMENDATIONS

- The Agency should standardise on one echosounder system for a single survey output format and to permit comparisons between rivers. Based on the experimental configurations tested in this project, the HTI is recommended for mobile horizontal surveys of rivers.
- In view of the widespread use of the Simrad throughout the regions and the expense of new systems, gradual replacement by the HTI must be accompanied by a significant overlap period to facilitate cross-calibration of results. Similarly, the BioSonics must not be immediately withdrawn from service (e.g. from TWARP survey) but needs to be run alongside the HTI for an extended period.
- Cross-calibration studies will be required on all rivers previously surveyed by other echosounders to permit continuity of data. A new project should be initiated to determine the number of cross-calibration runs that are needed to statistically validate comparisons.
- The following recommendations are made for the design of a programme to assess the influence of abiotic factors on temporal variability in acoustic estimates of fish communities (Phase 4).
    - Studies should be conducted on a number of sites and rivers with different biological, physical and chemical characteristics.
    - Replicate surveys are required.
    - One echosounder system should be employed for these studies.
    - Multiple or continuous sampling of environmental factors must accompany the acoustic surveys.
    - The studies should include mobile and fixed location components to better investigate the impact on acoustic estimates of diel vertical movements and diel patterns of use of littoral zones by fish.

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Figure 3.18. Paired volume density estimates from mobile Thames survey; Simrad vs BioSonics.

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Figure 3.20. TS frequency distributions for reach 5, River Thames, by strata and echosounder.

Figure 3.21. TS percentage frequency distributions for reach 5, River Thames, by strata and echosounder.

Figure 3.22. Paired volume density estimates from Manchester Ship Canal survey; Simrad vs HTI.

Figure 3.23. TS percentage frequency distributions for Manchester Ship Canal reach, by strata and echosounder.

Figure 3.24. Volume density estimates obtained from fixed location tank studies at Davenham depot. Two configurations were employed by the HTI; 'normal' HTI and 'Simrad'. Fish behaviour summarised using the following key: VST = very scattered targets (no fish), ST = scattered targets, S = one small shoal, SS = small shoals, LS = large shoal.

Figure 3.25. Simrad echogram extracted from sample 9, Davenham tank trials. High energy spikes from the HTI transmitter pulse appear as scattered red echoes.

Figure 3.26. Simrad echogram extracted from Manchester Ship Canal Trial. The Simrad transceiver was in passive mode with the HTI transducer enabled. Interference appeared as scattered echoes at > 25 m range.

Figure 3.27. River Thames 1994 – 1998. Annual mean acoustic densities by a) mean discharge, b) mean water temperature, and c) mean moon phase (0 = new moon, 14 = full moon). Error bars are 95% confidence limits. Note log vertical axis in (a).

Figure 3.28. River Trent 1994 – 1998. Annual mean acoustic densities by a) mean discharge, b) mean water temperature, and c) mean moon phase (0 = new moon, 14 = full moon). Error bars are 95% confidence limits.

Figure 3.29. River Ouse 1996 – 2000. Annual mean acoustic densities by a) mean discharge, b) mean water temperature, and c) mean moon phase (0 = new moon, 14 = full moon). Error bars are 95% confidence limits. August surveys and surveys conducted at other times of the year are shown separately.

Figure 3.30. River Ouse 1996 – 2000. Nine surveys were ranked by density and plotted against ranked cumulative abiotic factors (see text). Figure shows a general, but non-significant, trend of higher densities (low rank number) being associated with combined conditions considered best for acoustic surveying.

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GLOSSARY

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

Agency: Environment Agency.

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

ANOVA: Analysis of variance.

COV: Coefficient of variation.

Cross-calibration: Correlating the density outputs of different echosounders.

Cross-sectional area (σ): A measure of the reflectivity of a target. Target strength (TS) is equal to $10 \text{ Log}_{10} \sigma$.

Bandwidth: The receiver filters the transducer signal, rejecting components of the signal at frequencies outside the pass-band of the amplifier. The filtering is described by the bandwidth, which normally means that signals at frequencies ± half the sonar frequency are attenuated by 3dB relative to the response at the sonar frequency.

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, this is the ratio of the received signal intensities from the narrow and wide beams. Assuming 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 angle in dgress describing the full angular width of the acoustic sound cone.

.BOT: HTI bottom tracking file.

Bottom tracking: A circuit or algorithm that predicts the location of the bottom based on previous bottom detection. Bottom tracking is used to terminate processing of the acoustic return just prior to the bottom pulse. The bottom can also be tracked manually by the operator during post-processing using the scope display (HTI and BioSonics).

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

Calibration: Method of defining and setting characteristics of the electronic / mechanical equipment which allows repeatability of results. Field calibration is carried out by locating a standard target of known acoustic size in the acoustic beam and measuring the amplitudes of the echoes received.

Cross-talk: Interference caused by the acoustic pulse from one transducer being received by another.

.dat: BioSonics raw data file.

DAT: Digital audio tape.

.dg: Simrad raw data file.

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

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

.ECH: HTI file containing information on individual tracked fish.

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

Echo-counting (EC): Fish abundance estimation method applicable to dispersed populations of fish. Volume / area density estimates are generated from counts of single accepted targets.

Echogram: A display of a time series of received echo pulses.

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

Echo-length: The length or duration in time of the received acoustic pulse, usually expressed in msec.

EP500: Simrad post-processing software.

ESP: BioSonics echo-signal processing software.

ESP_TS: BioSonics echo-counting post-processing software.

ESP_VIEW: BioSonics output file viewer enabling binary data files to be examined.

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, Hz). Hydroacoustic systems usually have frequencies in the range 20-500 kHz.

Gain: Amplification applied by hardware or software to increase signal levels or compensate for some systematic signal loss.

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.

LOBE: Simrad field calibration software.

Maximal usable range: The distance from the transducer where the acoustic beam fills all the water column between the surface and bottom.

Mobile survey: A hydroacoustic survey conducted from a mobile boat.

MSC: Manchester Ship Canal.

Multipath: Sound waves scattering off other objects or boundaries, such as the surface, before returning as echoes to the transducer. The time-lag between the returning echoes from the fish and reflected echoes produce a trace beyond the real target.

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

MUR: See Maximal Usable Range.

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.

Noise: Unwanted signals that interfere with the signals to be quantified. Sources include 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 etc.).

Ping: Informal name for the transmission of a single pulse of known frequency and duration generated by the echosounder.

Ping rate: The pulse repetition rate. The rate of repetitive acoustic pulses emitted by the transducer (usually in pings per second).

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

Range: Distance from the transducer face to the target.

Range resolution: Minimum distance between targets, which can be discriminated on the same bearing. Mainly dependant on pulse duration.

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

Rotator: Continuous or stepping electronic motors used to rotate the orientation of objects such as transducers.

sa: Simrad term; the total area back-scattering coefficient.

sa (tr): Simrad term; the area back-scattering coefficient for accepted single targets.

SHOW: Simrad output file viewer enabling binary data files to be examined.

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

Signal to noise ratio: Signal to noise ratio. Ratio of signal strength to backgound noise level.

SNR: See signal to noise ratio.

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 different elements in the transducer.

Standard target: A target of known acoustic size. Standard targets are designed to be omni-directional and have stable reflective properties with depth and temperature.

SWORP: South West Oxfordshire Reservoir Proposal.

Target Strength: Acoustic size of target in dB.

Threshold: An amplitude value (in dB or mV) below which all echoes are rejected. A threshold is set to reject noise and signals from very small targets which are not of interest.

Time-varied gain: 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.

TS: See Target Strength.

TWARP: Thames Water Abingdon Reservoir Proposal.

TVG: See time-varied gain.

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