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DIGITAL ANALYSIS OF ACOUSTIC DATA FROM HERRING SCHOOLS

by

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1. INTRODUCTION

Previous analysis of acoustic data collected during surveys of cod in the southern Gulf of St. Lawrence indicated that, depending on the area and time of day, much of the acoustic data collected was from fish that were in schools so that a 20 log R time-varied gain would be appropriate (Shotton and Dowd, 1976). In this analysis the objective was to determine if echoes from fish that were resolved individually by the system, i.e. a 40 log R gain situation, contributed a significant amount of the acoustic intensity received by the system during an acoustic survey of a herring stock.

The digital methods of analysis have been developed to enable post-cruise analysis of acoustic data that contains returns both from single fish and fish schools. This should enable fish that can be separated in range or schooling fish with detectable differences in the acoustic signature of their schools to be assessed simultaneously when they occur in the same area. These methods should satisfy at least some of the requirements noted by Coombs (1977) and considered desirable by Cushing (1978). An additional benefit is that successive echoes from individual fish can be identified thus enabling better estimates of their target strength.

2. THE COMPUTERIZED ECHO COUNTING SYSTEM

The computerized echo counting system (Dowd, 1975) was designed to achieve two objectives. Firstly, in acting as a fish counter it gives real time estimates of fish density for four size intervals and two depth ranges over periods that can be varied from 10 s to 10 min. Secondly, it acts as a data logging system by buffering to magnetic tape the sea floor echo return time for each pulse and the time for fish echo returns together with their 12-bit analogue-digital (A/D) amplitude values. In addition, the time the bottom echo exceeds a specified threshold value is recorded. This last feature helps in rejecting sea floor echoes taken as fish echos when bottom echo rise-time is slow.

In count mode the system operates with a 50 kHz, a 400 μs pulse, and a 600 μs sample rate on any return echo. Software and additional hardware patterned on the integrator developed by Dr. J. Ehrenberg of the Applied Physics Laboratory in Seattle is also part of the system. In integrator mode a 100 μs sample rate is used, but the raw data output to magnetic tape consists of the integrated values for 30 consecutive depth ranges of a minimum thickness of 1 m. Hence, although it is intrinsically finer in detail with a 7.5 cm sample rate, this information is not accessible for subsequent analysis.

It became apparent from earlier cruises that there were several difficulties in real-time estimation of fish numbers. Firstly, beam angle was entered as a constant and, for stocks of different target strength, this parameter would in fact be a dynamic variable. Secondly, the underlying assumption of a homogeneous Poisson process to describe the distribution of fish did not hold. Bias in density counts was particularly sensitive to multiple counts due to overlapping of the insonified volumes, and would cause bias in the unadjusted target strength distributions of the insonified fish. Another source of bias both in numbers and measurement of intensity was the occurrence of groups of echos whose geometry indicated that they constituted a fish school rather than an individual fish. Hence it appeared that both 40 log R and 20 log R situations were intermixed and were inseparable during real time analysis.

3. DIGITAL ANALYSIS AND DATA STRUCTURE

To enable digital analysis of the echo record several computer programs were written to sequentially process the data. Although some of these programs could be combined, they have been kept separate to facilitate analysis. Because of the amounts of data that are collected for analysis (a 10-day cruise collected 260,000 echos, with 7 words of information per echo) program failures have occurred due to time limits, or data format errors. A step by step program development, although more costly due to the large amounts of data input/output time required, has been more effective in minimizing the amount of reprocessing necessary due to program failure.

The first step in the digital analysis is the extraction of the raw data buffers from the magnetic tape and the conversion of the data from the 16-bit binary word (2 frames on the 9-track magnetic tape) structure of the Honeywell 316 computer to the word size of the shore-based computer. For this analysis a CDC 6400 (60-bit word) system has been used.

The raw data structure (shown in Table 1) consists of 16-bit octal words. The first word is a data buffer count; here data buffer 150 (Octal 2226) is shown. The first bit of the second word (100105) indicates that the buffer contents are in binary format as opposed to ASCII format, which is used for system messages, real-time density estimates, or operator-entered transect information. The number "105" indicates that the buffer contains "raw data". The number of words in the buffer is signified by word 3. Words 4, 5, and 6 contain the time from one year to one-twentieth of a second that the buffer began to fill. This enables echos to be fixed in space by reference to the cruise logs.

Following the six header words are the data. Each interrupt is stored as a time after transmit and a 12-bit analogue-digital value. The first pair shown here, at time 3, is caused by back reverberation of the transmit pulse. Data for an apparent fish echo in the fourth pulse is underlined.

When a bottom threshold is reached the first bit in the time word is turned on. The bottom echo is then sampled every 600 μs to verify that it is above threshold. From the number of such samples, a decision algorithm can be established to identify bottom samples that would otherwise be considered as fish.

From the raw data, the echo data together with the buffer number, the sea depth, and the pulse number are extracted (Table 2). The echo data are then grouped so that echos from successive pulses, and with the same time range within the limits of the echo sample frequency (600 μs or 45 cm), are together. Each such group is given a unique number. Based on the transducer beam angle, the sounder pulse rate, the ship's speed, the depth of the target, and the number of consecutive pulses for which the target returns echos, a decision is made whether the group constitutes a single fish, a fish school, or an intermediate situation. For individual fish,

$$\text{Number of successive pulses with echoes} < 1 + \frac{2\,h\,\tan\theta}{S} \qquad (1)$$

where h = mean echo depth

θ = estimated half beam angle

S = distance travelled between pulses.

For fish schools,

Number of successive pulses for which echoes are returned

$$> 1 + \frac{4\ h\ \tan\theta}{2} \quad (2)$$

There is the potential for improving the algorithm by estimating the effective beam angle, θ, from an examination of the amplitude values from the group. Echos from single targets are written to a 'singles' file, echo data from schools are written to a 'multiples' file (Tables 3 and 4), and echo sequences that fall between these two groups are written to an 'intermediates' file.

After this the single fish data can be analyzed as desired. Range gates can be used in the analysis to exclude echo groups from above a demersal trawl headline or groups outside the expected depth of operation of a midwater trawl if comparisons of the acoustic system and catch results are required.

A program has been written that analyzes each pattern type separately. Decisions as to whether a pattern consists of two or more fish can be made at this stage, and as a direct count of fishes insonified (Table 5). With estimates of target strength from the data the correct sampling volume can be determined, and hence the total numbers estimated.

Similarly, echo data for each school traversed can be examined separately (Table 6). By examining the amplitude values through schools, we can examine the decay of amplitude due to absorption or scattering. Various methods for estimating abundance of schooling fish from this data should be possible.

4. HERRING DATA RESULTS

4.1 Introduction

These data were collected during daylight hours from herring in the Bay of Fundy, between Nova Scotia and New Brunswick. Data are presented for three transects run in the same area. The system was operated in count mode with a pulse rate of 96 min^{-1}, a towing speed of 6 knots, and a 50 kHz pulse of length 400 μs. Receiver sensitivity was -81 dB. The beam factor, $\int_0^\Omega b(\theta)d\theta$, for the 12.5 inch diameter transducer was estimated as -44.2 dB.

Table 7 shows the relative frequency of echos from school and single fish situations for three transects. Using the criteria of equations 1 and 2 to separate groups of echos from single (40 log R TUG situation) fish, then 24.8%, 45.7%, and 39.9% of the echos for the three respective transects could be attributed to such single groups, for an overall mean of 41.4%. Schools are determined to be shallow if:

$$\frac{2\ h\ \tan\theta}{J} < 1$$

where h = school depth

θ = beam angle

$$J = \int_0^{\pi/2} \frac{2\ S\ \sin\theta\ d\theta}{\pi}$$

where S = distance travelled between pulses.

Intermediate schools are those for which

$$2 > \frac{2\ h\ \tan\theta}{J} > 1$$

and deep schools those for which

$$\frac{2\ h\ \tan\theta}{J} > 2$$

This information is used to adjust the intensity values of the initial and final pulses, which would not be expected to fully cover a school. In this way negative bias in the estimates of the mean intensity values is reduced.

Table 7

Echo Data for Transects

Transect	1	2	3
Length (minutes)	35.8	27.3	42.0
Number of interrupts (standardized to 42 min)	3982	7528	15638
% from single groups	24.8	45.7	39.9
% from schools	69.2	40.0	49.8
% from intermediate situations	6.0	14.3	10.3
Number of schools	151	163	237
% shallow	7.8	35.8	13.9
% intermediate depth	23.3	11.3	29.1
% deep	69.0	52.8	57.0

4.2 Relative Intensity

A mean intensity of echos for the three categories (single and intermediate groups and schools) is given in Table 8.

Table 8

Intensity Values for Transects (W m^{-2}) 10^{-6}

Transect	1	2	3
singles	1.80	1.31	0.82
intermediates	6.03	3.61	2.87
schools	4.47	5.21	4.68

Apart from the intensity values for the intermediate category in transect 1, the trends in values are as would be expected, but preliminary calculations indicate that the differences are not as large as should be expected.

4.3 School Data

Typical output for the analysis of schools in a sum is shown in Table 6, and the data for the three transects is listed in Table 9.

Table 9

School Data

Transect	1	2	3
Length (m)	13.2	13.4	16.0
Thickness (m)	1.9	2.1	1.9
School depth (m)	28.7	28.6	31.1
Volume scattering coefficient (dB)			
Surface	-123.7	-122.1	-124.7
Total	-122.4	-120.9	-123.8

No further analysis has been completed at this time. Two estimates of the volume scattering coefficient were made. The 'surface' value was taken from the first echo interrupt for each pulse insonifying the school. The 'total' value used all values obtained from the school. It had been thought that subsequent samples from the same pulse would decrease in amplitude due to absorption and scattering within the school. However amplitude generally increases for the second and third interrupts, i.e. over at least the first 1200 μs or 90 cm. Some of this increase can be attributed to a larger amount of the pulse volume insonifying the school, but consideration of the directivity pattern of the beam and sample rate indicates that some of the increase in amplitude may also be due to reverberation within the school.

5. COMMENT

In performing an acoustic survey of fish such as herring during daylight hours, it has been assumed that biases due to inappropriate TVG of echoes from single fish would not be appreciable. Given that equations 1 and 2 are an effective method for distinguishing the echoes of single fish from those of schools, then a large portion of the received intensity will be processed with the inappropriate gain compensations for spreading losses. Such bias could be minimized by post-cruise analysis and correction.

LITERATURE CITED

Coombs, R.F. 1977. Digital system for recording fish echoes. *N.Z. J. Mar. Freshw. Res. 11* (3): 479-488.

Cushing, D.H. 1978. The present state of acoustic survey. *J. Cons., Cons. Int. Explor. Mer 38* (1): 28-32.

Dowd, R.G. 1975. A computerized echo-counting system for demersal fishes. Bedford Institute of Oceanography, 196 pp.

Shotton, R., and R.G. Dowd. 1976. Preliminary analysis of single and multiple echoes obtained from an acoustic survey of a cod population. ICES CM 1976/B:31, Gear and Behavior Committee, 12 pp.

TABLE I

RAW DATA

BUFFER NUMBER — INDICATES BINARY DATA — RAW DATA CODE — No. OF WORDS IN BUFFER — DATE & TIME CODE — TIME — A/D LEVEL

000226	100105	000502	035116	004427	011417	000003	006744	000011
004712	000741	006751	100742	006753	100747	006742	1st TRANSMIT	
100763	006756	100771	005165	101000	005132	101007		
002052	101025	001044	101034	001315	101043	004277	101052	004416
101061	002502	101070	001276	000003	006737	000737	005767	100742
006745	100746	006747	100754	006751	2nd TRANSMIT		100770	006761
100776	001315	101004	002107	101012			001551	101026
003065	101034	002756	101042	002615	101050	001332	101056	000675
000003	006737	000011	004711	000737	004072	100744	006744	100747
006752	3rd TRANSMIT		100763	006755	100771	006761	100777	006245
101005			003645	101021	000705	101027	001277	101035
000577	101043	003376	101051	003004	101057	001676	101065	000761
000003	006746	000011	004722	000733	000357	000742	006747	100743
006717	100751	006745	100757	006752	100765	006757	100773	006722
101001	006756	101007	004735	101015	002770	101023	001556	101031
001166	101037	001643	101045	001425	101053	001331	101061	000437
000003	006737	000740	004777	100743	006745	100750	006744	100757
006751	100766	006755	100775	006761	101004	FISH ECHO		003373
101022	002606	101031	001326	101040	001707			101056
001464	101065	001542	101074	001332	000003	006735	000501	000411
000510	000322	100743	006741	100745	006755	100753	006742	100761
006753	FISH ECHO		100775	006172	101003	004161	101011	002411
101017			001337	101033	001245	101041	002712	101047
001505	101055	001531	101063	000615	000003	006741	000011	004706
000255	000426	000475	002237	000504	004113	000513	003465	000522
002645	000531	002445	000540	000535	000553	001744	000562	000655
000574	000416	100751	006742	100753	006755	100762	006742	100770
006752	100776	006757	101004	005555	101012	005112	101020	003356
101026	002035	101034	001457	101042	001415	101050	002705	101056
001412	101064	002406	101072	001235	000003	006736	000011	004705
000467	001035	000477	1st BOTTOM INTERUPT			000513	005531	000521
006742	000527	004677				003245	000551	002755
000557	001277	000565	002505	100741	006741	100742	006755	100750
006742	100756	006752	100764	006757	100772	005012	101000	003035
101006	0025[illegible]2	101014	002052	101022	001327	101030	002417	101036
003275	101044	002132	101052	00117[illegible]	101060	001535		

TABLE 2
FISH ECHO DATA

BUFFER NUMBER	ECHO TIME	SEAFLOOR TIME	A/D VALUE	PULSE NUMBER	No. OF BOTTOM INTERUPTS
000226	0741	0742	06751	973	14
000226	0737	0742	05767	974	14
000226	0737	0744	04072	975	15
000226	0733	0743	00357	976	14
000226	0742	0743	06747	976	14
000226	0740	0743	04777	977	14
000226	0501	0743	00411	978	15
000226	0510	0743	00322	978	15
000226	0255	0751	00426	979	15
000226	0475	0751	02237	979	15
000226	0504	0751	04113	979	15
000226	0513	0751	03465	979	15
000226	0522	0751	02645	979	15
000226	0531	0751	02445	979	15
000226	0540	0751	00535	979	15
000226	0553	0751	01744	979	15
000226	0562	0751	00655	979	15
000226	0574	0751	00416	979	15
000226	0467	0741	01035	980	15
000226	0477	0741	03777	980	15
000226	0505	0741	05607	980	15
000226	0513	0741	05531	980	15
000226	0521	0741	06742	980	15
000226	0527	0741	04677	980	15
000226	0535	0741	02722	980	15
000226	0543	0741	03245	980	15
000226	0551	0741	02755	980	15
000226	0557	0741	01277	980	15
000226	0565	0741	02505	980	15
000227	0457	0757	00352	981	14
000227	0471	0757	01657	981	14
000227	0500	0757	02777	981	14
000227	0507	0757	06717	981	14

TABLE 3

ECHO DATA FOR SINGLE FISH

BUFFER NUMBER	ECHO TIME	SEAFLOOR TIME	A/D VALUE	PULSE NUMBER	GROUP NUMBER	PATTERN CODE
150	475	483	239	976	90037	10000
150	328	483	210	978	90039	10000
150	321	483	265	978	90038	10000
150	352	489	349	979	90046	10000
150	173	489	278	979	90040	10000
150	380	489	270	979	90049	10000
150	370	489	429	979	90048	10000
151	383	495	854	981	90054	10000
151	376	495	791	981	90053	10000
151	390	495	581	981	90055	10000
151	303	495	234	981	90051	20001
151	301	483	557	982	90051	20001
153	470	476	1962	1003	90059	10000
154	328	474	297	1012	90063	10000
154	321	474	602	1012	90062	10000
154	308	474	350	1012	90061	20002
154	314	474	227	1012	90061	20002
154	292	474	774	1012	90060	10000
154	353	479	218	1013	90071	10000
154	295	479	509	1013	90064	10000
154	311	479	717	1013	90066	10000
155	360	473	315	1016	90073	10000
155	356	479	502	1017	90078	10000
155	349	479	789	1017	90077	10000
155	363	479	281	1017	90079	10000
155	359	475	364	1018	90081	10000
156	385	481	293	1021	90087	10000
156	378	481	265	1021	90086	10000
156	396	480	351	1022	90090	10000
156	389	480	464	1022	90089	10000
156	308	481	1929	1021	90082	20006
156	310	480	1018	1022	90082	20006
156	382	480	387	1022	90088	20005

TABLE 4

ECHO FROM SCHOOLS

BUFFER NUMBER	ECHO TIME	SEAFLOOR TIME	A/D VALUE	PULSE NUMBER	GROUP NUMBER
150	317	489	1183	979	90050
150	324	489	2123	979	90050
150	331	489	1845	979	90050
150	338	489	1445	979	90050
150	345	489	1317	979	90050
150	363	489	996	979	90050
150	311	481	541	980	90050
150	319	481	2047	980	90050
150	325	481	2951	980	90050
150	331	481	2905	980	90050
150	337	481	3554	980	90050
150	343	481	2495	980	90050
150	349	481	1490	980	90050
150	355	481	1701	980	90050
150	361	481	1517	980	90050
150	367	481	703	980	90050
150	373	481	1349	980	90050
151	313	495	943	981	90050
151	320	495	1535	981	90050
151	327	495	3535	981	90050
151	334	495	3554	981	90050
151	341	495	3562	981	90050
151	348	495	3562	981	90050
151	355	495	3562	981	90050
151	362	495	2505	981	90050
151	369	495	1498	981	90050
151	315	483	1375	982	90050
151	321	483	1477	982	90050
151	327	483	3553	982	90050
151	333	483	3562	982	90050
151	339	483	3562	982	90050
151	345	483	3565	982	90050
151	351	483	2509	982	90050
151	357	483	3014	982	90050

END OF FILE
??

TABLE 5. SINGLE ECHO DATA RESULTS

40 LOG R TVG ASSUMMED FOR THIS RUN
SYSTEM OVERALL GAIN OF ¯52 DB ASSUMMED
INPUT NAME OF INPUT FILE....→
SSU1

***** START OF A NEW RUN *****

PATTERN TYPE IS 10000

```
A
```

MEAN BOTTOM DEPTH	SEA DEPTH	TARGET STRENGTH	DISTANCE OFF BOTTOM	NO. OF GROUPS	°/° ABOVE HEADLINE
23.65	31.91	¯52.81	8.26	546	70.88

MEANS AND STANDARD DEVIATIONS FOR INDIVIDUAL ECHOES

A
¯52.8
7.3

PATTERN TYPE IS 20001

```
-B
--
A-
```

MEAN BOTTOM DEPTH	SEA DEPTH	TARGET STRENGTH	DISTANCE OFF BOTTOM	NO. OF GROUPS	°/° ABOVE HEADLINE
26.59	32.77	¯50.86	6.18	23	69.57

MEANS AND STANDARD DEVIATIONS FOR INDIVIDUAL ECHOES

A	B
¯51.1	¯50.7
8.7	8.4

/

TABLE 5. (Cont.)

PATTERN TYPE IS 20002

```
A
-
-
-
-
-
B
```

MEAN BOTTOM DEPTH	SEA DEPTH	TARGET STRENGTH	DISTANCE OFF BOTTOM	NO. OF GROUPS	°/° ABOVE HEADLINE
25.61	30.82	¯52.58	5.20	17	76.47

MEANS AND STANDARD DEVIATIONS FOR INDIVIDUAL ECHOES

A	B
¯52.0	¯53.2
5.4	5.1

PATTERN TYPE IS 20003

```
-B
A-
```

MEAN BOTTOM DEPTH	SEA DEPTH	TARGET STRENGTH	DISTANCE OFF BOTTOM	NO. OF GROUPS	°/° ABOVE HEADLINE
28.78	31.82	¯49.81	3.04	23	43.48

MEANS AND STANDARD DEVIATIONS FOR INDIVIDUAL ECHOES

A	B
¯50.3	¯49.3
8.1	7.8

TABLE 6. FISH SCHOOL DATA

```
⎕LOAD 'MULTAN2'
MULTAN2 78/09/11 11:38:03

DRIVER
INPUT NAME OF INPUT FILE....→
SMU2
  THIS PROGRAM ASSUMES:
                          (1) A SHIPS SPEED OF 6 KNOTS
                          (2) BEAM ANGLE OF 6 °
                          (3)TVG OF 40 LOG R USED
                          (4) PULSE LENGTH OF .4MSEC
                          (5) TRANSDUCER DEPTH OF 4M
  DATA NOT ADJUSTED FOR EXPECTED CHORD LENGTH
 DATA ADJUSTED FOR 40 LOG R IN FN ADDLINE

INPUT NAME OF OUTPUT FILE...→
RMU2
```

MEAN VALUES

SIZE	LENGTH	HEIGHT	SEA DEPTH	SCHOOL DEPTH	DIST OFF BOTTOM	VOLUME SCATTERING COEFF SURFACE	TOTAL
18.46	13.14	2.06	58.42	28.60	29.81	¯122.06	¯120.87

THE NUMBER OF SCHOOLS ANALIZED= 106
NUMBER OF SCHOOLS IN SHALLOW SITUATIONS = 38
NUMBER OF SCHOOLS IN INTERMEDIATE SITUATIONS = 12
NUMBER OF SCHOOLS IN DEEP SITUATIONS = 56

THE FOLLOWING IS THE DATA FOR THE LARGEST SCHOOLS ENCOUNTERED

GROUP NUMBER	SIZE	LENGTH	HEIGHT	SEA DEPTH	SCHOOL DEPTH	DIST OFF BOTTOM	VOLUME SCATTERING CO SURFACE	TOTAL
91216	84.00	21.88	8.32	53.39	45.01	8.38	¯129.87	¯123.34
91417	53.00	20.17	6.60	50.22	46.34	3.87	¯133.19	¯130.29
91608	73.00	26.52	6.97	50.67	38.02	12.65	¯129.03	¯122.90
91498	54.00	29.54	3.97	50.37	44.60	5.77	¯134.04	¯129.88
91389	91.00	35.76	5.69	50.69	47.26	3.43	¯128.82	¯124.65
91500	48.00	19.31	3.67	50.39	29.39	20.99	¯127.20	¯120.56
91344	228.00	50.09	13.80	51.36	40.47	10.89	¯130.19	¯124.14
91578	162.00	27.44	11.40	50.82	43.60	7.22	¯128.46	¯122.79
91745	70.00	22.26	6.90	51.25	35.59	15.65	¯131.05	¯123.41
91543	63.00	20.39	7.57	50.58	35.94	14.63	¯124.57	¯121.86