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ACOUSTIC/MIDWATER TRAWL SURVEY OF GULF OF ALASKA

by

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Director

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INTRODUCTION

Information on the biomass and biological condition of both pelagic and demersal fish stocks in the Gulf of Alaska is needed as a basis for rational management under the requirements of the Fishery Conservation and Management Act of 1976 (P. L. 94-265). Provisional management plans for the fishery resources of this area depend heavily on fisheries data from foreign fleets. Information is incomplete or seriously deficient in many areas including fishing effort, age and size data, and species breakdown. While improvements are being made, factors such as fishing effort are virtually impossible to fully quantify. Further, it is widely recognized that existing theories and models for fishery resources management based on analysis of commercial catch data suffer from fundamental inadequacies which severely limit their usefulness.

In contrast, research vessel surveys can provide an independent and, at least theoretically, less biased means of assessing fish stocks, since sampling can be standardized. In recognition of these advantages, the National Marine Fisheries Service (NMFS) Northwest and Alaska Fisheries Center (NWAFC) conducted a research vessel survey of groundfish resources of the Gulf of Alaska (Dixon Entrance to Kodiak Island) during July-November 1978. The work was undertaken as part of a multi-year survey of rockfish and other groundfish of the northeast Pacific which began in 1977. In 1977, an intensive bottom trawl and acoustic/midwater trawl survey, which targeted on rockfish and Pacific hake, was conducted along the California-Washington coast.

The principal target species of the 1978 survey were Pacific ocean perch, other rockfishes, and walleye pollock. The survey included bottom trawl sampling from Dixon Entrance to Kodiak Island by two chartered trawlers and the NOAA R/V MILLER FREEMAN. Because, as was true for the 1977 survey, the target "groundfish" in the Gulf of Alaska are actually semi-pelagic, a complementary hydroacoustic/midwater trawl survey to obtain direct information on the size of the off-bottom component of these species was also conducted. Although biomass estimates of semi-pelagic groundfishes are frequently derived from bottom trawl surveys, such estimates are usually extremely conservative because net efficiencies are less than 100%, especially if a significant fraction of the stock is in midwater, thus unavailable to the trawl.

The hydroacoustic/midwater trawl survey was conducted by the MILLER FREEMAN prior to the time it began bottom trawl sampling. Limitations on vessel time prevented coverage of the entire Dixon Entrance to Kodiak Island area. Consequently, the survey was focused on the areas off Southeast Alaska and Kodiak Island where it was considered most important to obtain information on Pacific ocean perch and walleye pollock. In addition, because of a 13-day delay due to mechanical problems on the MILLER FREEMAN, the planned coverage of the two areas, particularly that off Southeast Alaska, was appreciably reduced. Since the NWAFC acoustic equipment and personnel were largely committed to other tasks, the primary responsibility for providing acoustic equipment, for the acoustic data collection and analysis, and for integration with the NMFS-directed midwater trawl sampling was contracted to the Fisheries Research Institute. This report documents the results of the survey.

MATERIALS AND METHODS

Schedule and Location

After field tests in Puget Sound and the Strait of Juan de Fuca, the MILLER FREEMAN departed Seattle on August 21, 1978. Nineteen transects and four midwater trawl hauls were conducted off southeastern Alaska from August 25 to 30 (Fig. 1). Because of a failure with the main echosounder on August 29, the data from the last three transects were limited to echograms from the ship´s Elac echosounder. This first leg of the cruise terminated in Sitka, Alaska on August 31.

The second leg of the cruise extended from September 8-20, off Kodiak Island. Twenty transects and six midwater trawl hauls were completed (Fig. 2). Weather conditions prevented survey operations during 3 days of Leg II.

The acoustic transects and trawl sampling were conducted during daylight hours. Independent oceanographic research was done during night and while in transit between Sitka and Kodiak.

Acoustic Equipment

The acoustic equipment consisted of an echosounder, transducer, towing system, and data-processing system (Fig. 3). The echosounder was a 38 kHz Simrad scientific sounder (EK 38). The transducer produced an 11° full beam angle at -3 dB (Fig. 4). The source level was 121 dB//1 μbar at 1 m and the receiving sensitivity of the transducer was -73.7 dB//1 volt per μbar. System gain was monitored at regular intervals by means of a calibration oscillator whose input was -59.7 dBVrms. Various pulse lengths were used, but was usually 1 msec.

Portability was the key consideration in the choice of the towing system. A telescoping, hand-operated towing arm that had been developed for research off Peru under the CUEA program (NSF-IDOE) was used from the MILLER FREEMAN (Fig. 3a). The towing arm was designed for use with an Endecon 2-ft V-fin towed vehicle. Modifications were required since the 38 kHz transducer was too large for the instrument cavity of the 2-ft V-fin (Fig. 3b). An inconsistent bottom echo observed during initial operations was eventually found to be the result of instability of the towed vehicle. Two additional modi-

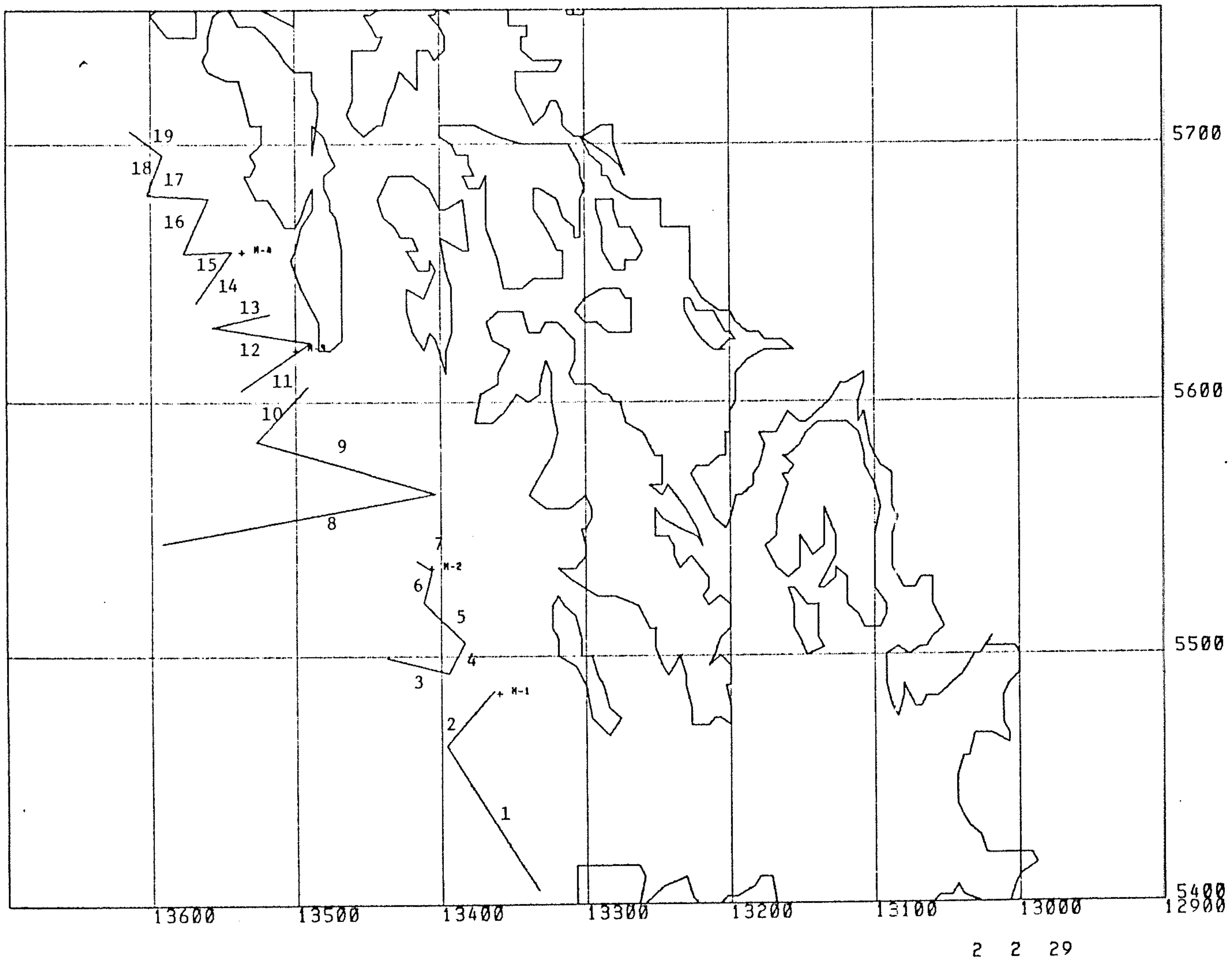


Fig. 1. Locations of transects and trawl hauls off southeastern Alaska during Leg I of MILLER FREEMAN cruise 78-3 (+ designates haul location).

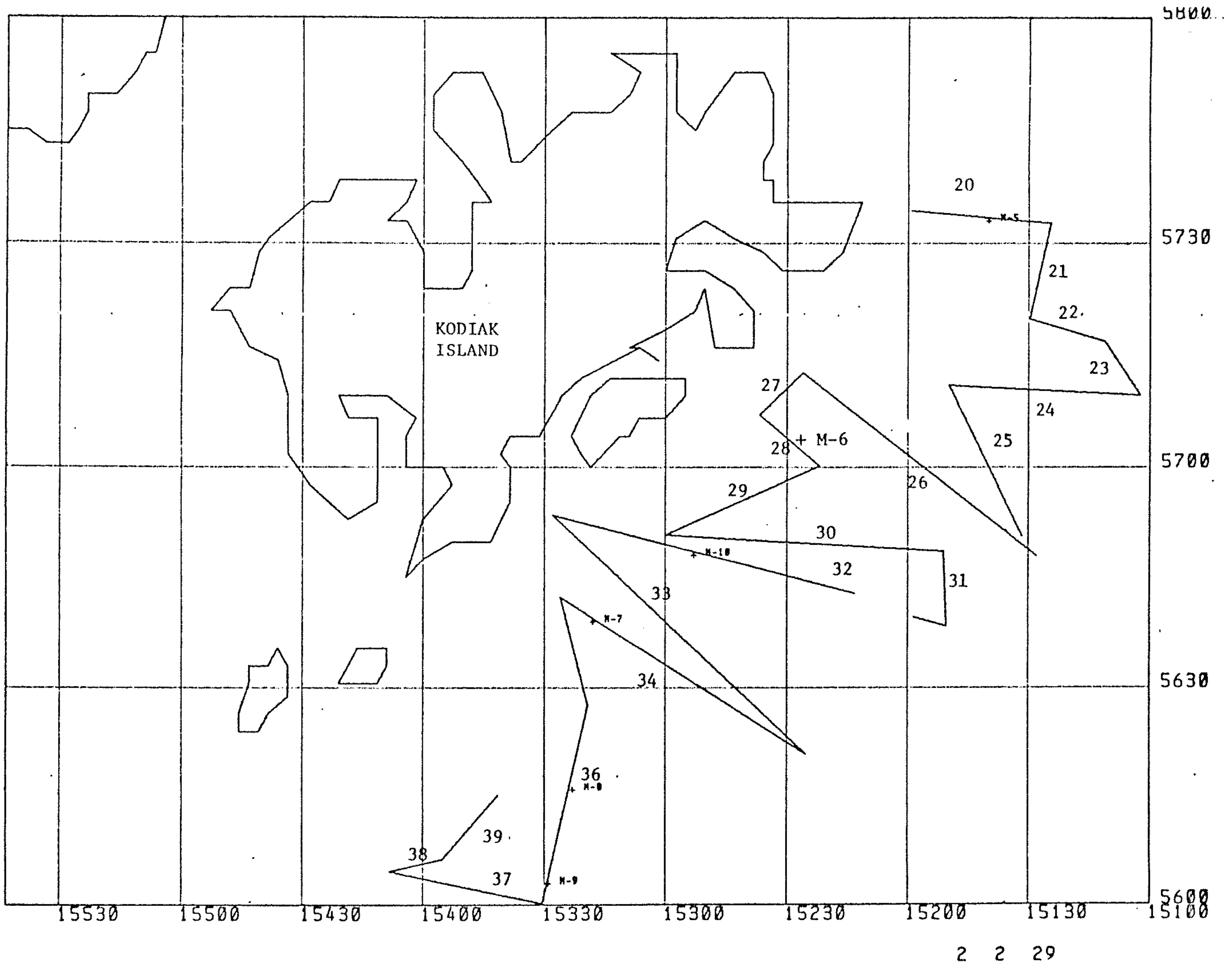


Fig. 2-a. Locations of transects and trawl hauls off Kodiak Island during Leg II of MILLER FREEMAN cruise 78-3 (+ designates haul location).

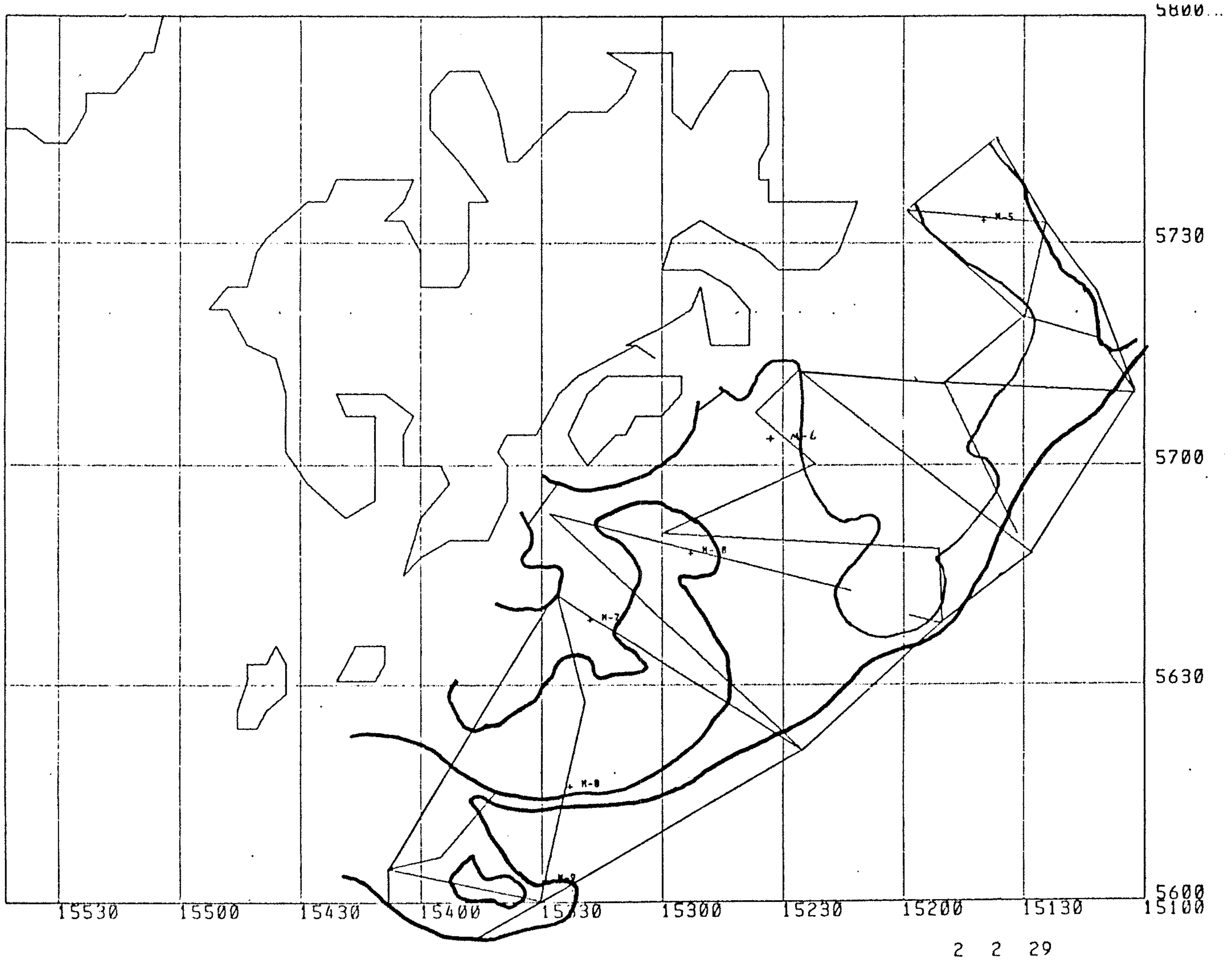


Fig. 2-b. Location of transects and trawl hauls off Kodiak Island in relation to assumed total survey area and 50 and 100 fathom contours.

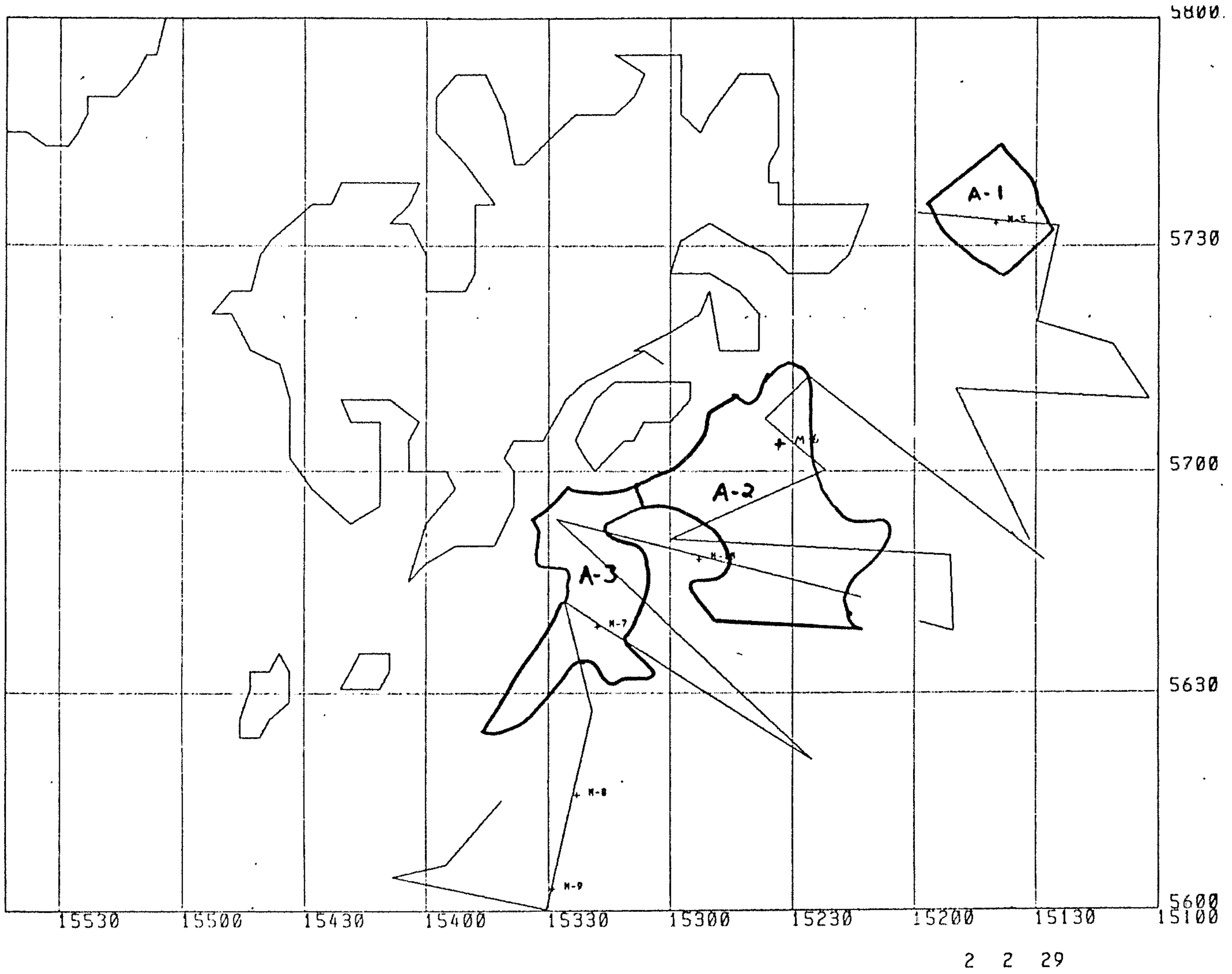
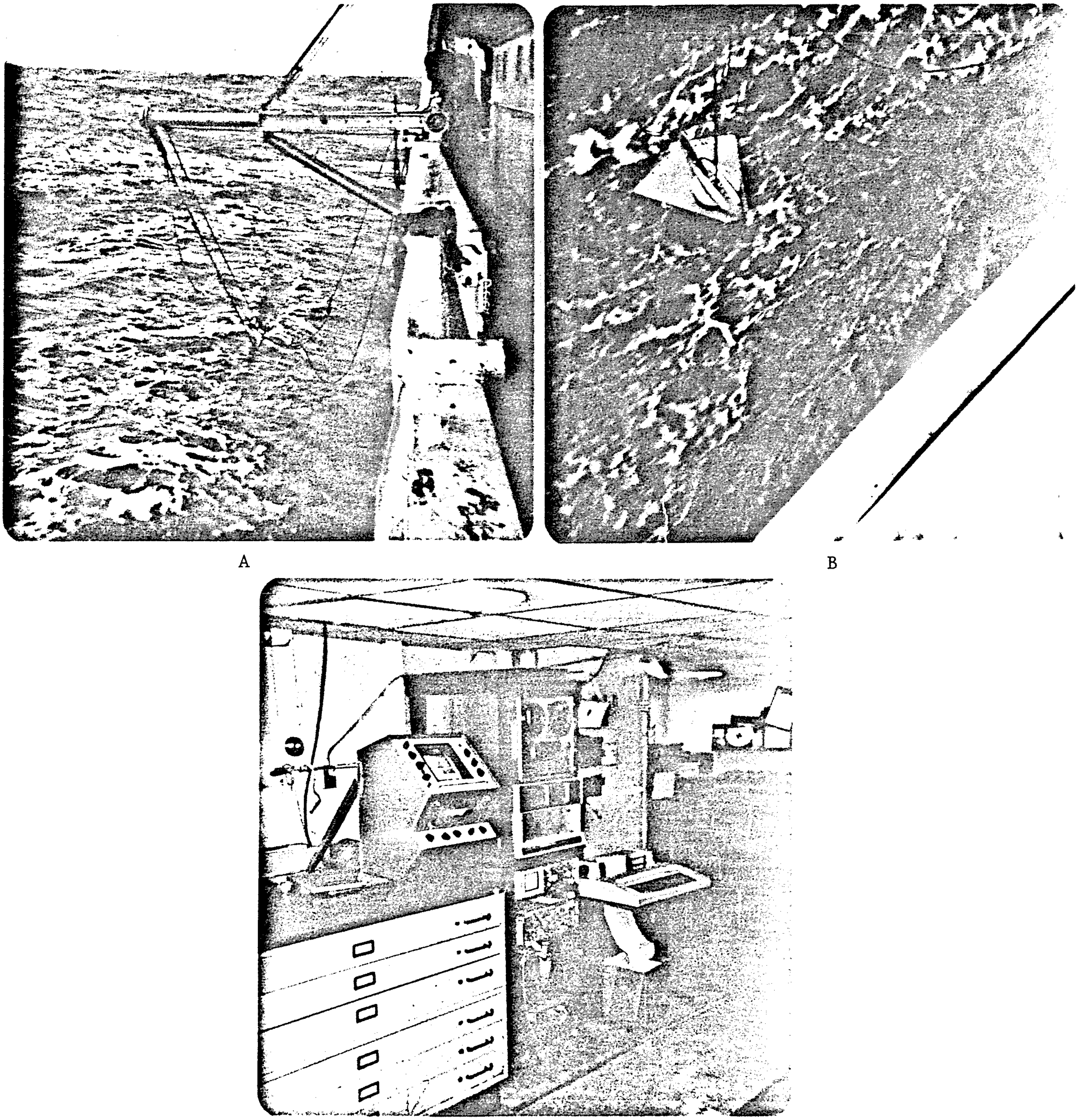


Fig. 2-c. Location of transects and trawl hauls off Kodiak Island showing relation to areas of pollock concentration.



A

B

C

Fig. 3. Pictures of acoustic equipment used for survey including (a) towing system, (b) towed vehicle and (c) echosounder and data processing system.

APL/UW FORM NO. 565 (Rev. 4-75)

XMTG XDCR UUJI4
RECEIVER E41
FREQUENCY 38.0 kh
DATE 12-17-75 OP.

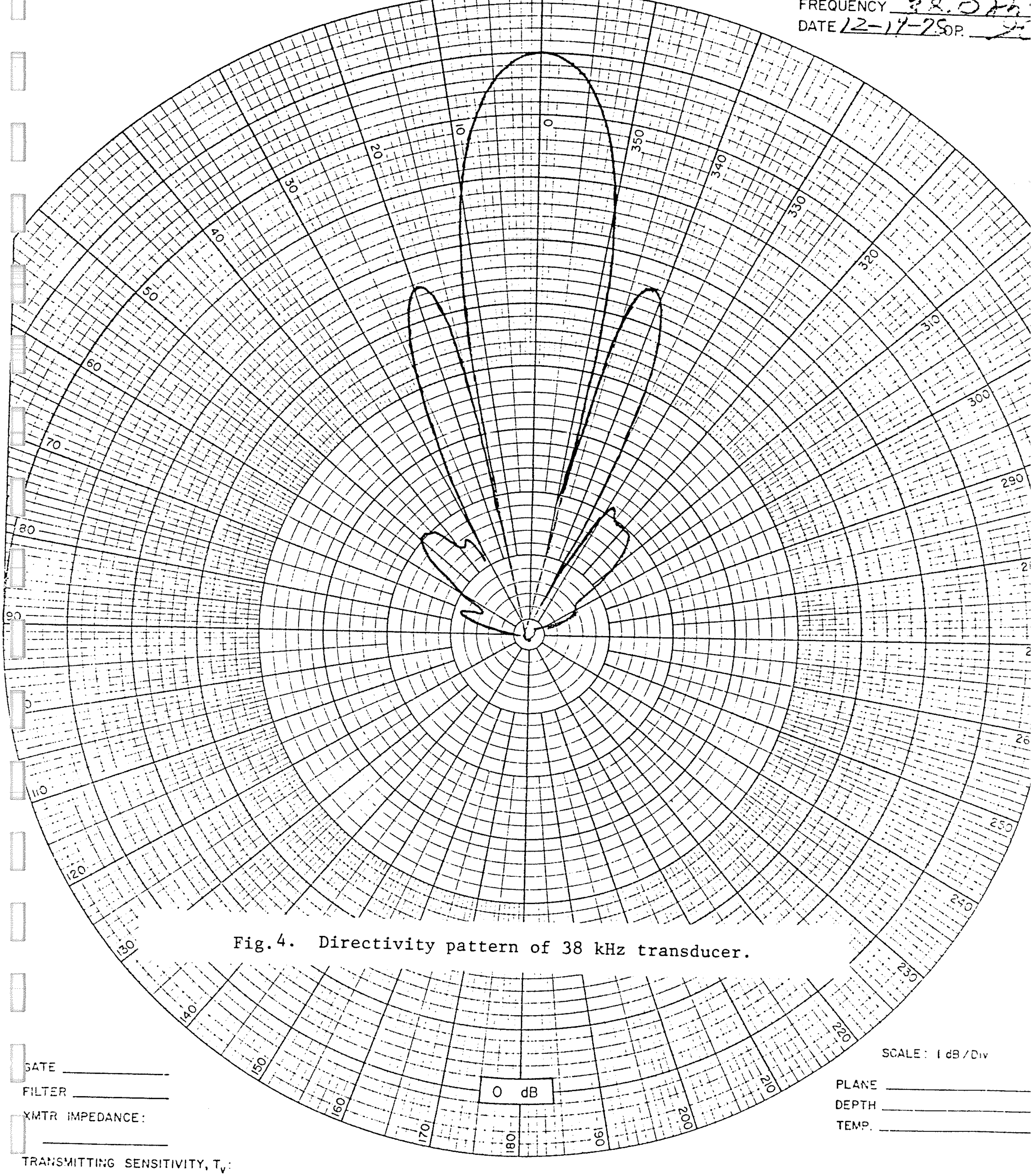


Fig. 4. Directivity pattern of 38 kHz transducer.

SCALE: 1 dB/Div

GATE

FILTER

XMTR IMPEDANCE:

PLANE

DEPTH

TEMP.

TRANSMITTING SENSITIVITY, T_v:

P ______ $-G$ 25.0 $-S_s$ -206.3 $+R$ 15.6 $-V$ 24.2 = 172.7 dBμPa/V, 1

TRANSMITTING POWER RESPONSE, T_w:

T_v ______ $-\Omega$ ______ $+Z$ ______ = ______ dBμPa/Watt, 1

FFICIENCY: T_w ______ $-D$ ______ -170.6 ______ dB= ______

fications were made on August 28 to correct the instability: (1) addition of shock cords to damp out accelerations due to roll and pitch of the vessel, and (2) adjustment of the vertical stabilizer of the V-fin. Towing speed during transects was typically 7-8 knots. The upper limit was set by greater instability at higher speeds and by concern for loss or damage to the system from surface debris or kelp.

The data processor was an Ecosonics Digital Echo Integrator System, which includes a special purpose analog to digital input system, a Digital Equipment Corporation PDP 11/10 general purpose computer, and a digital cassette drive. Input and output was accomplished by means of a Decwriter provided by NWAFC. The analog to digital input system consists of: (1) a calibrated input amplifier, (2) analog to digital converter, (3) digital squaring circuitry, and (4) transmit and bottom pulse circuitry for automatic bottom tracking. The data processing system acts as a 50 channel digital echo integrator and is intermediate in capability to the systems described in Thorne (1973, 1977).

Data Analysis Procedures

Echosounding was conducted continuously along transects. The data processor was set to measure echo voltages from 20 to 500 m, typically in 25 m intervals over the range of primary interest. Density estimates were averaged over 10 min durations. Typical input and output of the processor are shown in Figs. 5 and 6. The relative densities were converted to absolute values from post-cruise calibration and assuming an acoustic target strength of -35 dB/kg. All calculations were based on the system gain as measured with the calibration oscillator at 150 msec (112.5 m). Deviations of the echosounder′s time-varied-gain from ideal were about ± 1 dB over the depth range of significant fish densities (80-175 m) when referenced to this depth (Fig. 7). The result of these deviations was to slightly underestimate fish densities at depths less than 112 m and to slightly overestimate at greater depths. However, the effect on the biomass estimates per unit surface area is insignificant.

The total biomass of fish was determined by extrapolating the estimates of fish biomass per unit area over the approximate surface area represented by the various outputs. The survey results of Leg II were divided into four areas: Three different areas in which pollock were believed to be the predominant species, and which were bordered by 50 and 100 fathom contours, and a fourth area comprising the remainder (Fig. 2b, c). The data from Leg I were simply extrapolated over the entire area of the survey, giving equal weight to all outputs.

```
.R INT78
CASSETTE OUTPUT FILENAMD (UP TO 6 CHARACTERS, NO EXTENSION) = MFSA03

1?


COMMENT ?
AUG 27 78 0540  MILLER FREEMAN 78 - 3


1.  NUMBER OF PINGS ?
 :  240


2.  NORMALIZING CONSTANT ?
 :  1.


3.  THRESHOLD VOLTAGE ?
 :  0


4.  LIST DEPTHS

D  :  20

D  :  60

D  :  100

D  :  125

D  :  150

D  :  175

D  :  200

D  :  225

D  :  250

D  :  275

D  :  300

D  :  325

D  :  350

D  :  375

D  :  400

D  :  500

D  :  -1


5.  BOTTOM TRACKING BUFFER ?
 :  18


6.  CURRENT BOTTOM DEPTH ?
 :  700
```

Fig. 5. Example of input format for data processing system.

```
 1
   7
P =    480
 20.0  -    40.0          0.978E-05        1.000

 40.0  -    60.0          0.268E-06        1.000

 60.0  -    80.0          0.916E-05        1.000

 80.0  -   100.0          0.656E-04        1.000

100.0  -   125.0          0.986E-01        1.000

125.0  -   150.0          0.119D 01        0.991

150.0  -   175.0          0.123D 01        0.367

175.0  -   200.0             0.000
```

Fig. 6. Example of data processing system output from 480 soundings (10 min.) showing sampled depth intervals, relative density estimates and sampled proportions of depth intervals.

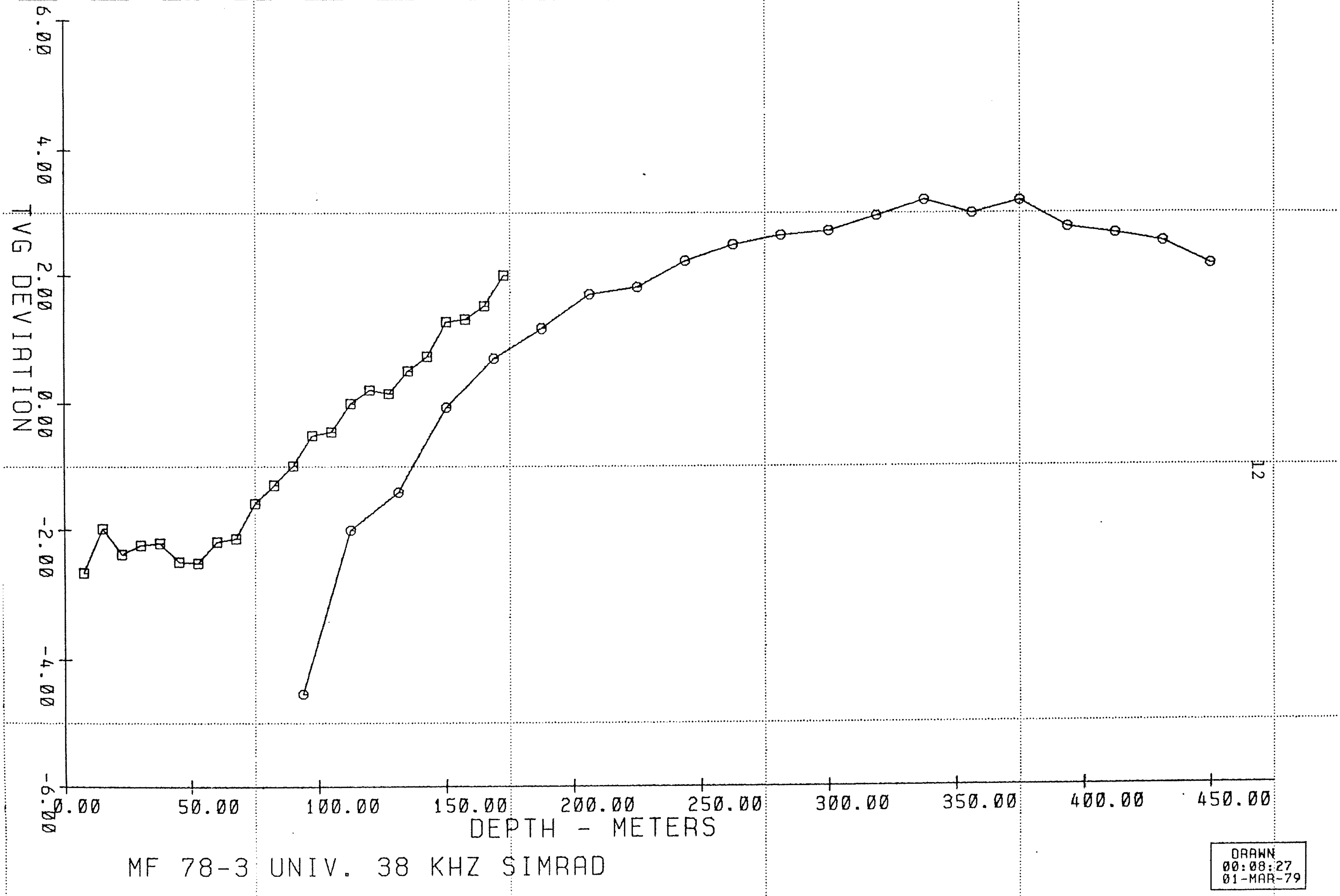


Fig. 7. Deviations of TVG from theoretical ideal as measured with high and low input signals.

Trawling Procedures

Concentrations of fish were sampled for species composition and biological data with a Herman Engel midwater trawl. Tows varied in duration from 30 to 90 min. Catches were weighed and counted by species and subsampled for other biological measurements. Acoustic measurements were usually made concurrent with trawl hauls, although the towed vehicle was not very stable at the trawling speed.

RESULTS

Results of Midwater Trawl Sampling

Catch data and corresponding acoustic measurements of density for the 10 trawl hauls are given in Table 1. The largest catch was 25,400 lb of pollock on haul 6. During this haul the average density from the acoustic measurements was 43 g/m^3 in the 90-105 m interval, including a peak observation of 244 g/m^3 in the 95-100 m interval over a 6-min period. The second highest catch, also primarily pollock, was 3,364 lb (haul 3). The acoustic observation of fish density during this haul was only 1 g/m^3, but it was definitely biased downward by the instability of the towed vehicle during the tow.

Results of Acoustic Survey

The locations and estimated densities of fish and other backscattering organisms are given in Table 2. Representative echograms from these observations are shown in Figs. 8 through 21. There were 637 estimates of biomass per unit surface area, 255 during Leg I and 382 during Leg II. Densities greater than 0.5 g/m^2 were calculated on 204 of the observations (32%) assuming -35 dB/kg target strength. The 204 observations include 66 from diffuse scattering layers in which fish were probably a minor component (Table 3).

The distribution of density observations is definitely non-normal. Four observations were over 0.8 kg/m^2, including one over 3 kg/m^2 with an average volumetric density of 88 g/m^3 over a 36-m layer. The average of the 138 observations from fish concentrations is 110 g/m^2, and the standard deviation is 315 g/m^2. The unweighted average densities of fish from all observations, assuming values of zero for the non-fish scattering layers, are 6.9 g/m^2 (24 $mt/(n.mi)^2$ from Leg I 37 g/m^2 (125 $mt/(n.mi)^2$), from Leg II and 25 g/m^2 (84 $mt/(n.mi)^2$) for the entire cruise.

The area defined by the end-points of the transects during Leg I is approximately 4,000 $n.mi^2$. An estimate of 90,000 mt is obtained by extrapolation of the estimated mean fish density over this area. No further analysis or breakdown was made on the data from Leg I for the following reasons: (1) the biomass is a small proportion of the total

Table 1. Summary of catches and acoustic measurements of density during midwater trawls on R/V MILLER FREEMAN cruise 78-3.

Tow #	Date	Set time (hr)	Gear depth (m)	Duration (min)	Typical densities from acoustic data	Catch		Comments
						Species	wt(lb)	
1	8/25	21	106	40	0.1 g/m^3	juvenile pollock	39	vertical migration during tow
2	8/26	18	110	90	body unstable - no acoustic measurement	juvenile pollock prowfish jellyfish	1.5 3.0 200	took 3 hours to set
3	8/28	09	145	36	measured 1.0 g/m^3 body unstable	pollock pop squid	3357 5 2	wide layer
4	8/29	09	82	60	0.1 g/m^3 in 60-100 m but body unstable	herring jellyfish	3 40	near bottom layer
5	9/8	20	110	30	no measurement	juvenile pollock other fish jellyfish	5.5 3.3 ~300	tow at dusk
6	9/10	18	100	70	43 g/m^3 90-105 m 2.8 g/m^3 105-120 m peak = 244 g/m^3 95-100, 288 pings	pollock jellyfish	25400 27	schools at top of layer
7	9/17	09	105	40	1.3 g/m^3 105-110 m 1.5 g/m^3 110-115 m 2.9 g/m^3 115-120 m 1.0 g/m^3 120-125 m	pollock chinook salmon other fish jellyfish	310 14 1 194	
8	9/18	18	55	60	no measurement	sockeye salmon other fish jellyfish	6 9 300	shallow layer
9	9/19	09	250	30	1.0 g/m^3 250-300 m very uniform	fish jellyfish	10 300	deep scattering layer
10	9/20	14	45	30	0.2 g/m^3 40-50 m 0.5 g/m^3 50-55 m	fish jellyfish	4 500	shallow scattering layer

Table 2. Densities and depths of significant biological backscattering encountered during MILLER FREEMAN cruise 78-3.

Date	Transect	Time	File - output	Depth Interval (m)	Density g/m^3	Density g/m^2	Bottom Depth (m)	Remarks
8/25	1	1200	Test-8	20-100	8.0	442	70	first output of cruise, schools on bottom, species unknown
			11	150-175	15.8	39.6	130-155	schools above bottom, could be pollock
			12	150-175	5.1	116	180-230	
				175-200	9.5	134	"	
				200-225	5.1	26.4	"	output total = 277 g/m^2
			13-21 (ave.)	275-325	1.3	66.2	300-350	deep scattering layer
		1540	29	175-200	0.8	10.5	190	large schools to bottom
			31	150-200	0.1	5.3	200	
			32	200-225	0.3	4.6	220	low level, near bottom scatter
			34	200-225	0.1	4.0	240	
			35	200-225	0.4	11.9	235	
			36	200-225	0.1	2.0	230	
			41	175-200	0.1	3.5	205	
		1748	42	175-200	0.1	3.2	205	end transect, 35 outputs
	2		44	175-200	0.1	2.7	205	start of transect
			45	175-200	0.5	11.2	205	
			46	175-200	0.2	4.6	200	
			47	175-200	0.1	2.7	200	
			48	175-200	0.2	3.3	200	
			55	80-125	0.8	22.4	115	juvenile pollock? small schools above bottom (same area as tow 1) (see figure 8)
		2010	57	-	-	-	-	end transect, 14 outputs
8/26	3	0620	MFGA02-8	-	-	-	-	start transect
		0800	13	150-175	2.2	22.4	165	low level, near bottom scatter
			14	125-150	6.1	21.9	160	
			15	125-150	1.7	4.8	155	
		0900	21	-	-	-	-	end transect, 14 outputs
	4	0900	22	-	-	-	-	start transect
			26	100-125	0.2	2.1	115	scattering layer
			27	100-125	0.3	1.7	110	
			28	100-125	0.1	0.7	110	
			29	100-125	0.2	0.7	105	end transect, 8 outputs

Table 2. Densities and depths of significant biological backscattering encountered during MILLER FREEMAN cruise 78-3 - continued.

Date	Transect	Time	File - output	Depth Interval (m)	Density g/m^3	Density g/m^2	Bottom Depth (m)	Remarks
8/26	5	1015	30	-	-	-	-	start transect
			38	150-175	0.1	2.7	165	scattering layer
			40	-	-	-	-	end transect, 11 outputs
	6	1210	41	150-200	6.2	18.5	183	school on bottom
			47	-	-	-	-	end transect, 7 outputs
	7		48	-		-	-	start transect
			49	100-125	0.2	0.7	110	corresponds to tow 2, schools in scattering layer (see figure 9)
		1342	50	60-125	0.1	4.1	115	
			51	-	-	-	-	end transect, 4 outputs
8/27	8	0613	MFGA03-9	-	-	-	-	starts transect
		0640	11	60-100	0.2	8.9	260	midwater scattering layer
			12	40-100	0.2	14.1	260	
			36	-	-	-	-	end transect, 28 outputs
	9	1045	37	-	-	-	-	start transect
		1400	51	125-150	0.1	2.2	165	diffuse scattering layer
			52	125-175	0.1	5.2		
			53	100-150	0.1	5.9		
				150-175	0.1	9.7		output total = 15.6 g/m^2
			54	100-150	0.3	10.4	170	
				150-175	0.6	11.1		output total = 21.5 g/m^2
			55	100-175	0.2	13.3		
			56	100-175	0.3	18.5		
			57	100-150	0.1	4.4		
			58	60-150	0.1	12.6		
			59	100-150	0.3	14.1		
			MFGA04-11	-	-	-		end transect, .34 outputs
	10		12-26	-				no fish during transect, 15 outputs
	11	0620	MFGA05-7	-	-	-		start transect
			17	100-175	0.3	5.6	170	pollock (corresponds to tow 3)
		0820	18	100-150	0.6	22.3		(see figure 10)
		1218	30	60-175	0.4	104	160	
			31	60-125	0.9	65.7	130	
			34	60-100	4.9	193	140	(see figure 10)
			35	60-100	0.6	34.1		
				100-125	3.3	89.6		output total = 124 g/m^2
								end transect, 18 outputs

Table 2. Densities and depths of significant biological backscattering encountered during MILLER FREEMAN cruise 78-3 - continued.

Date	Transect	Time	File - output	Depth Interval (m)	Density g/m^3	Density g/m^2	Bottom Depth (m)	Remarks
8/27	12	1305	36	60-100	0.4	17.3		
				100-125	5.4	134		output total = 151 g/m^2
			37	100-125	0.4	10.6		
			38	100-150	0.6	14.5		
			39	100-125	0.3	9.5		
			41	60-100	1.3	31.2		
				100-125	8.3	195		output total = 226 g/m^2
			43	125-175	0.1	2.5	160	
			44	125-175	0.1	3.8		
			48	-	-	-	-	end transect, 13 outputs
	13		49-71	-	-	-		no fish on transect, 22 outputs
8/29	14	0647	MFG806-7	150-325	0.1	7.8	325	unknown species, scattering layer herring? corresponds to tow 4
			10	60-125	0.1	1.5	170	
			11	60-125	0.1	1.5	160	
			14	100-125	0.1	0.9	115	
			16	80-125	0.1	0.9		
			17	60-100	0.1	3.4	105	(see figure 11)
			18	60-100	0.4	8.3	90	
			19	60-100	0.1	1.0	85	
			20	-	-	-	-	end transect, 14 outputs
	15		21	-	-	-	-	start transect
		1236	27	80-125	0.2	3.9	110	
			28	80-125	0.3	4.7	120	
			29	100-150	0.1	1.4	135	
			30	100-150	0.1	1.5	135	
			31	100-125	0.1	0.6	150	
			33	150-200	0.1	1.0	190	pollock?
			34	150-225	0.1	1.3	210	
			35	150-200	0.1	2.3	230	
				200-225	0.2	3.6		output total = 5.3 g/m^2 end transect, 15 outputs
	16		36	175-200	0.1	1.0	230	
				200-225	0.1	2.4		output total = 3.3 g/m^2
			38	-	-	-	-	end transect, 3 outputs end computer analysis, leg 1
9/8	20	1745	MFGA07-4	-	-	-	-	start leg 2
		1805	6	100-125	0.1	0.9	100-130	pollock, layer near bottom
				125-150	13.8	4.1		output total = 5.0 g/m^2
			7	125-150	10.7	67.5	140	
			8	60-100	1.1	44.6		
				100-125	0.6	13.9		
				125-150	1.9	19.9		output total = 78.2 g/m^2

Table 2. Densities and depths of significant biological backscattering encountered during MILLER FREEMAN cruise 78-3 - continued.

Date	Transect	Time	File - output	Depth Interval (m)	Density g/m^3	Density g/m^2	Bottom Depth (m)	Remarks
9/8			9	60-100	0.4	15.5		
				100-125	0.7	17.9		
				125-150	3.5	42.8		output total = 76.4
			10	60-100	1.6	64.4		
				100-125	1.0	23.1		
				125-150	16.0	105.4		output total = 192 g/m^2
			11	60-100	4.9	197	130	(see figure 12)
				100-125	9.6	218		output total = 426 g/m^2
				125-150	6.1	10.3		halt transect, 8 outputs
9/9	20	0648	MFGA08-3	60-125	0.6	19.1	110	continue transect
			5	60-100	0.3	7.5	80	still layer near bottom, probably
			6	60-100	0.4	12.1		pollock
			7	60-100	0.4	6.5	70	
			9	-	-	-	-	end transect, 7 outputs, total = 15 outputs
	21	0820	MFGA09-1	60-80	0.2	1.3	110	shallow layer, unknown composition
			2	40-60	0.2	4.2		
				60-80	0.7	14.1		midwater schools, total 18.2 g/m^2
			3	40-150	0.1	16.9	135	midwater schools above near bottom
			4	40-150	0.1	26.3	140	layer
			5	125-150	0.6	9.3	145	
			6	60-125	0.7	43.5	140	
			7	100-125	0.1	2.5	120	
		1002	10	-	-	-	-	end transect, 10 outputs
	22		11	-	-	-	-	start transect
		1022	14	80-100	3.3	43.5	110	(see figure 13)
				100-125	2.0	41.5		output total = 85.2 g/m^2
		1122	19	-	-	-	-	end transect, 9 outputs
	23	1122	20	-	-	-	-	start transect
		1222	25	125-200	2.0	41.5	200	concentration at shelf break
			26	150-350	1.4	231	350	scattering layer (similar to figure 21)
			27	250-375	0.7	105	375	end transect, 8 outputs
	24	1250	28	250-375	0.7	100	400	
			29	150-300	1.4	143	300	
			30	125-150	13.6	192	110-180	concentration at shelf break
			33	40-100	2.0	33	100	(see figure 14) computer tracked over part of school
			35	125-150	0.3	1.6	130	
			51	-	-	-	-	end transect, 24 outputs

Table 2. Densities and depths of significant biological backscattering encountered during MILLER FREEMAN cruise 78-3 - continued.

Date	Transect	Time	File - output	Depth Interval (m)	Density		Bottom Depth (m)	Remarks
					g/m^3	g/m^2		
9/19	25		52	-	-	-	-	start transect
		1840	64	100-125	0.1	1.3	120	school on bottom
			67	300-325	0.1	0.4	225-300	scattering layer
			68	275-350	0.1	8.8	350	
			69	300-350	0.1	5.8	400	end transect, 18 outputs
9/10	26	0605	3	100-200	1.0	49.1	500	scattering layer
				275-350	0.1	9.2		output total = 58.3 g/m^2
			4	125-350	1.1	89.6		
			5	200-350	0.1	4.4		
			7	275-500	0.1	38.9	324-500	(see figure 15)
			9	150-200	0.3	4.5	170	concentration at shelf break
		1325	35	40-60	5.7	23.0	50	schools near bottom
			36	40-60	1.1	3.1	60	
		1405	40	-	-	-	-	end transect, 38 outputs
	27		41	-	-	-	-	start transect
		1425	42	60-100	2.0	41.6	100	probably pollock (see figure 16
			43	80-100	2.7	18.9	100	
			44	60-100	0.7	7.7	90	
			45	40-80	1.1	6.1	80	
			46	60-100	4.4	94.6	100	end transect, 6 outputs
	28	1510	47	60-125	1.4	32.2	105	
			48	60-125	2.3	48.4	115	
			49	80-125	0.9	13.5	120	
			50	80-150	11.2	276	135	pollock (see figure 17)
			51	80-125	4.8	199	140	
			52	100-125	20.6	94.0	140	halt transect, 6 outputs
9/11	28	0600	MFGA11- 3	60-150	3.3	192	135	continue transect
			4	80-150	2.8	145		
			5	60-125	1.1	45.7	130	
			6	80-125	1.4	16.0	115	
			8	-	-	-	-	end transect, 6 outputs, total = 12 outputs
	29	0700	9	-	-	-	-	start transect
		0730	11	100-125	11.9	176	120	
			12	80-125	32.8	830	125	(see figure 18)
			13	100-125	1.3	31.0	130	
			14	100-150	8.5	168	145	
			15	100-150	9.8	222	155	
			16	100-150	5.2	109	145	
			17	100-150	2.0	60.3	140	
			18	100-150	1.3	31.0	135	
			19	100-125	0.9	14.4	120	
		0920	23	-	-	-	-	end transect, 15 outputs

Table 2. Densities and depths of significant biological backscattering encountered during MILLER FREEMAN cruise 78-3 - continued.

Date	Transect	Time	File - output	Depth Interval (m)	Density g/m3	Density g/m2	Bottom Depth (m)	Remarks
9/11	30		24	20-80	1.6	21.1	75	layer near bottom, unknown composition
		1122	34	125-150	1.8	22.6	145	small schools above bottom, probably pollock
			35	100-150	2.6	114	155	
			36	125-150	1.3	26.6	150	(see figure 18)
			37	125-150	1.7	22.7	145	
			38	100-150	0.8	3.8	135	
		1520	58	-	-	-	-	end transect, 35 outputs
	31		59-69	-	no significant concentrations			11 outputs
9/13	32	0606	MFGA12-3	-	-	-	-	start transect
		0645	6	80-150	85.6	859	135	(see figure 19)
			7	100-175	87.8	3178	165	probably pollock, highest density observed
			8	125-175	58.6	1596		
		0732	MFGA13-1	100-150	10.2	165	145	
			2	125-150	5.9	51.2	140	
		0817	6	20-60	5.9	187	55	shallow layer to bottom, unknown composition
			7	20-60	11.4	288	50	
			8	20-60	6.6	178		
			9	20-60	4.2	106		
			10	20-60	3.6	123		
			11	20-60	5.9	139		
			12	20-40	7.8	146	45	
			13	20-40	8.7	110		
			14	20-40	0.8	19.8		
			15	20-40	0.3	10.0		
			16	20-40	0.6	123		
		1053	22	100-175	2.9	121	160	probably pollock, layer near bottom
			23	100-150	3.7	105	150	
			24	125-150	0.1	1.3	140	
			25	100-150	1.4	14.5	135	
		1143	27	-	-	-	-	end transect, 33 outputs
	33	1522	28	-	-	-	-	start transect
		1551	31	100-125	3.7	13.6	120	
			32	100-150	5.6	126	145	
			33	125-150	3.6	68.1		
			34	100-150	3.5	98.4		
			35	100-150	1.6	46.4	155	
			36	100-150	9.0	232		
			37	100-150	14.7	267	145	
		1701	38	100-150	1.4	68.1	140	
		1831	48	-	-	-	-	halt transect, 21 outputs

Table 2. Densities and depths of significant biological backscattering encountered during MILLER FREEMAN cruise 78-3 - continued.

Date	Transect	Time	File output	Depth Interval (m)	Density		Bottom Depth (m)	Remarks
					g/m^3	g/m^2		
9/16	33	1050	MFGA15-3	80-100	0.1	1.6	110	scattering layer, continue
			4	80-100	0.1	2.7	100	transect after break for weather
			5	20-100	0.3	12.7	80	midwater schools, unknown composition
			6	60-80	0.3	1.0	70	
			24	250-325	0.2	9.4	315	deep scattering layer
			25	100-275	0.5	46.4	280	concentration at shelf break
		1451	26	-	-	-	-	end transect, 24 outputs, total = 45 outputs
	34	1500	MFGA16-1	-	-	-	-	start transect
			2	150-300	4.9	94.6	285	(see figure 20)
			3	225-325	0.4	14.8	315	scattering layer
			4	250-350	0.3	18.7	340	
			5	275-350	0.1	8.8	350	
			6	200-275	0.3	7.5	300	
		1900	24	20-40	0.1	3.3	65	near surface layer, unknown composition
			25	20-40	0.1	3.0	75	
			27	100-150	1.1	139	135	similar to tow 7, halt transect, 27 outputs
9/17	34	0631	MFGA17-3	-	-	-	-	continue transect
			4	100-125	0.4	3.3	130	
			7	100-125	0.4	8.8		
			8	100-125	0.3	5.4	120	break for tow 7
			MFGA18-7	-	-	-	-	end 34, 7 outputs 34 outputs total
9/18	35	1145	MFGA19-3	-	-	-	-	start transect
		1255	9	100-125	0.1	1.9	125	scattered small schools in diffuser layer
		1415	17	-	-	-	-	end transect
	36	1415	18	-	-	-	-	start transect
		1554	27	40-60	0.3	1.6	50	corresponds to tow 8 - near bottom layer
			28	40-60	0.6	6.2	60	
			29	40-80	0.4	9.0	70	
			30	40-60	0.1	2.5		
			31	-	-	-	-	halt transect, 14 outputs

Table 2. Densities and depths of significant biological backscattering encountered during MILLER FREEMAN cruise 78-3 - continued.

Date	Transect	Time	File output	Depth Interval (m)	Density g/m^3	Density g/m^2	Bottom Depth (m)	Remarks
9/19	36	0647	MFGA20-3	-	-	-	-	continue transect
		0720	7	200-350	0.5	39.0	355	deep scattering layer
			8	200-350	0.6	65.6		
			9	200-350	1.1	105		
			10	225-350	2.1	185		
			11	225-300	1.0	62.4	300	
			12	200-275	0.8	29.6	275	break for tow 9
	36	1115	MFGA21-1	225-275	0.8	22.3	280	
		1156	4	-	-	-	-	end transect, 14 outputs
	37	1156	5	-	-	-	-	start transect
			15	40-60	0.6	1.5	65	unknown composition, school on bottom
			16	40-60	0.3	3.3		
			20	60-125	0.3	79	115	
			28	-	-	-	-	end transect, 24 outputs
	38		29-37	-	-	-	-	no sign 9 outputs
	39	1720	38	-	-	-	-	start transect
			39	125-200	5.9	309	205	thick scattering layer
			40	150-225	8.3	141	215	
			41	150-225	0.8	38.6		
			42	60-200	2.3	145	200	
			43	100-175	1.2	26.9	170	
		1850	45	-	-	-	-	end transect, 8 outputs end series after tow 10

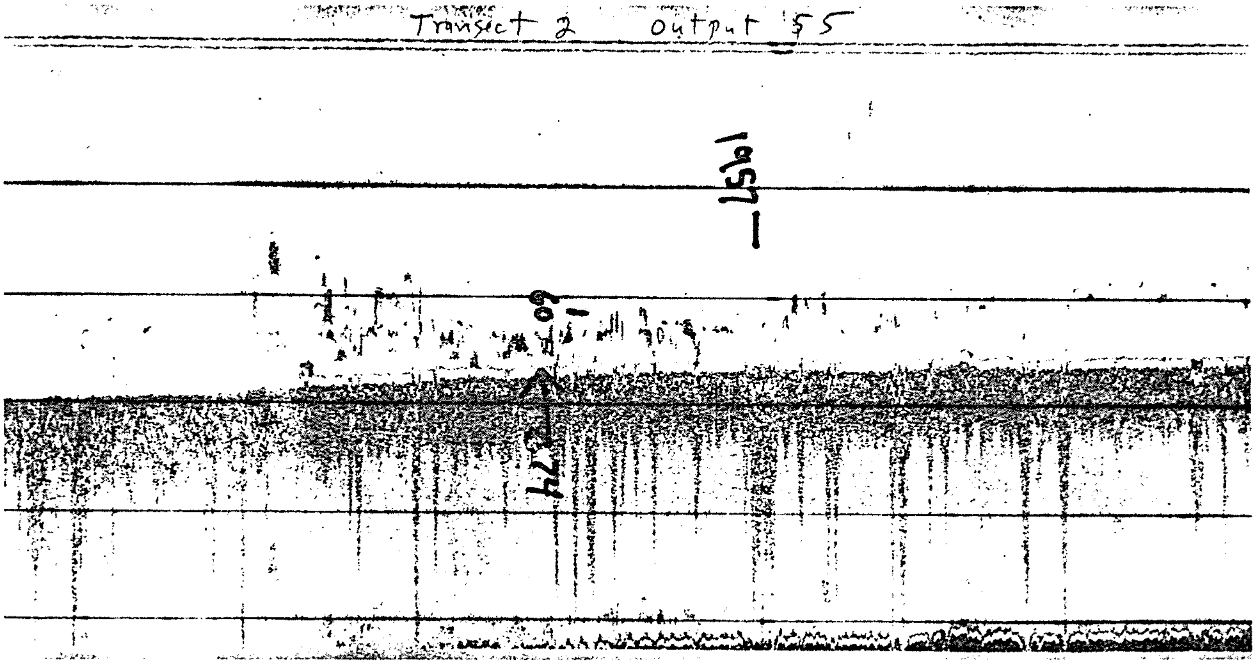


Fig. 8. Echogram corresponding to output 55 of file TEST, transect 2, and showing echoes from small schools of juvenile pollock just above bottom.

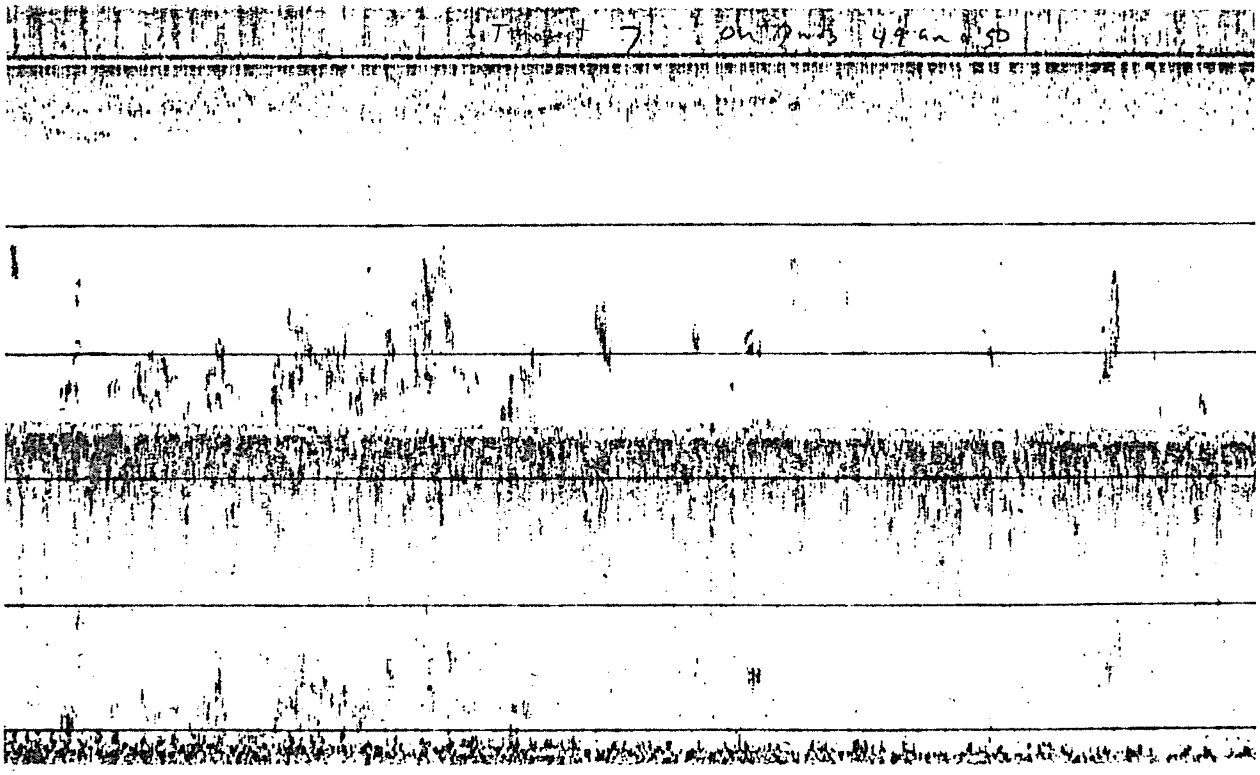


Fig. 9. Echogram corresponding to outputs 49 and 50 of file MFGA02, transect 7, and showing echoes from schools of juvenile pollock and prowfish in a layer of jellyfish.

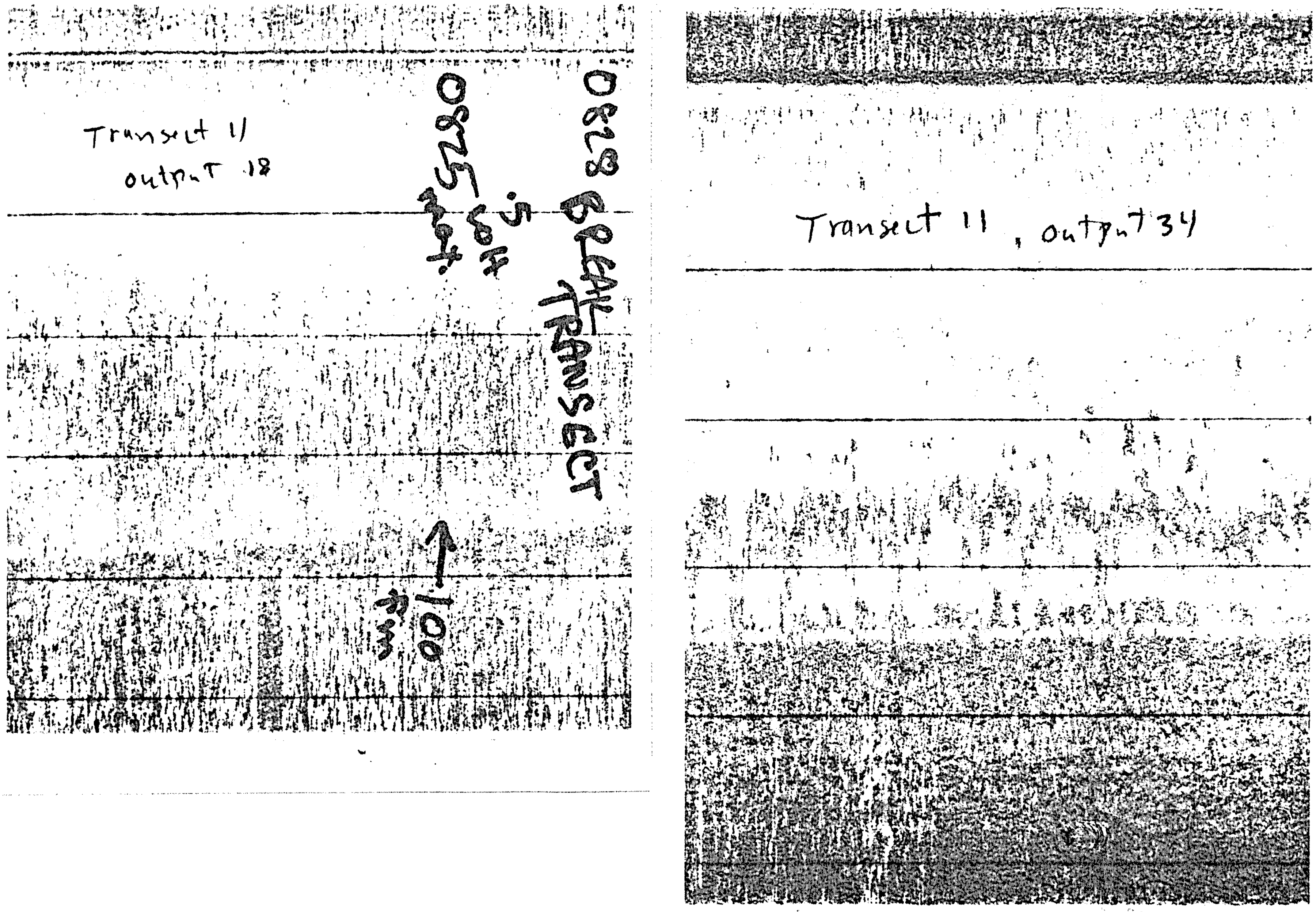


Fig. 10. Echogram corresponding to outputs 18 and 34 of file MFGA05 transect 11, and showing echoes from adult pollock.

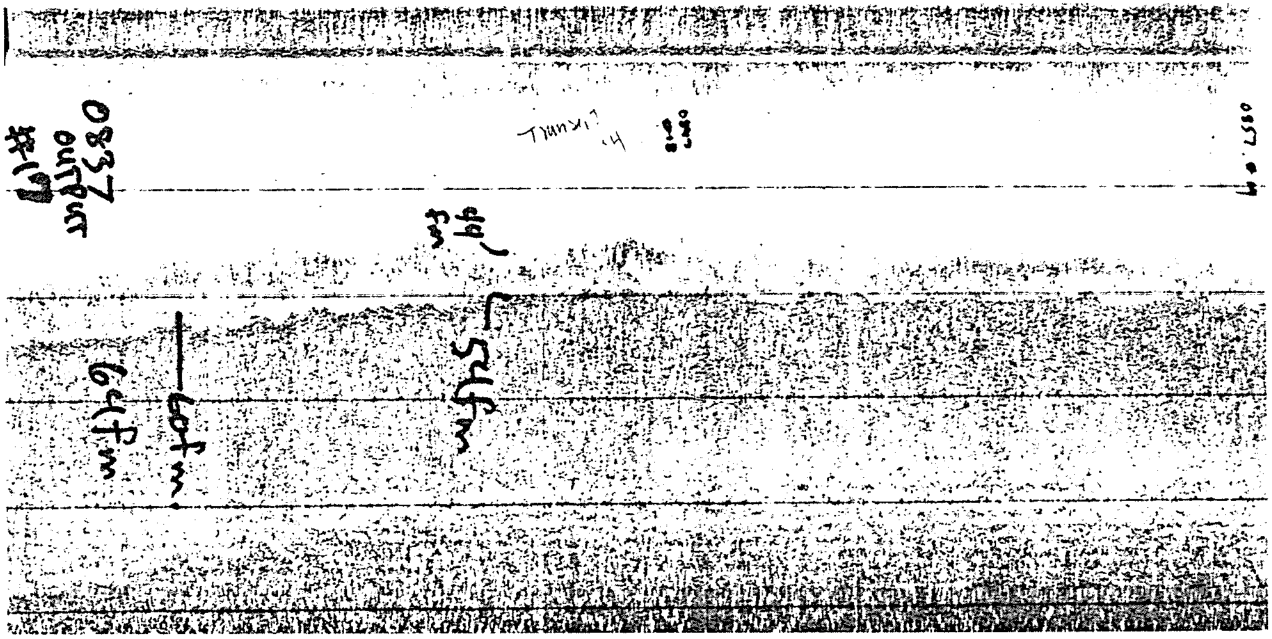


Fig. 11. Echogram corresponding to outputs 17 and 18 of file MFGA06, transect 14, and showing layer of herring near bottom.

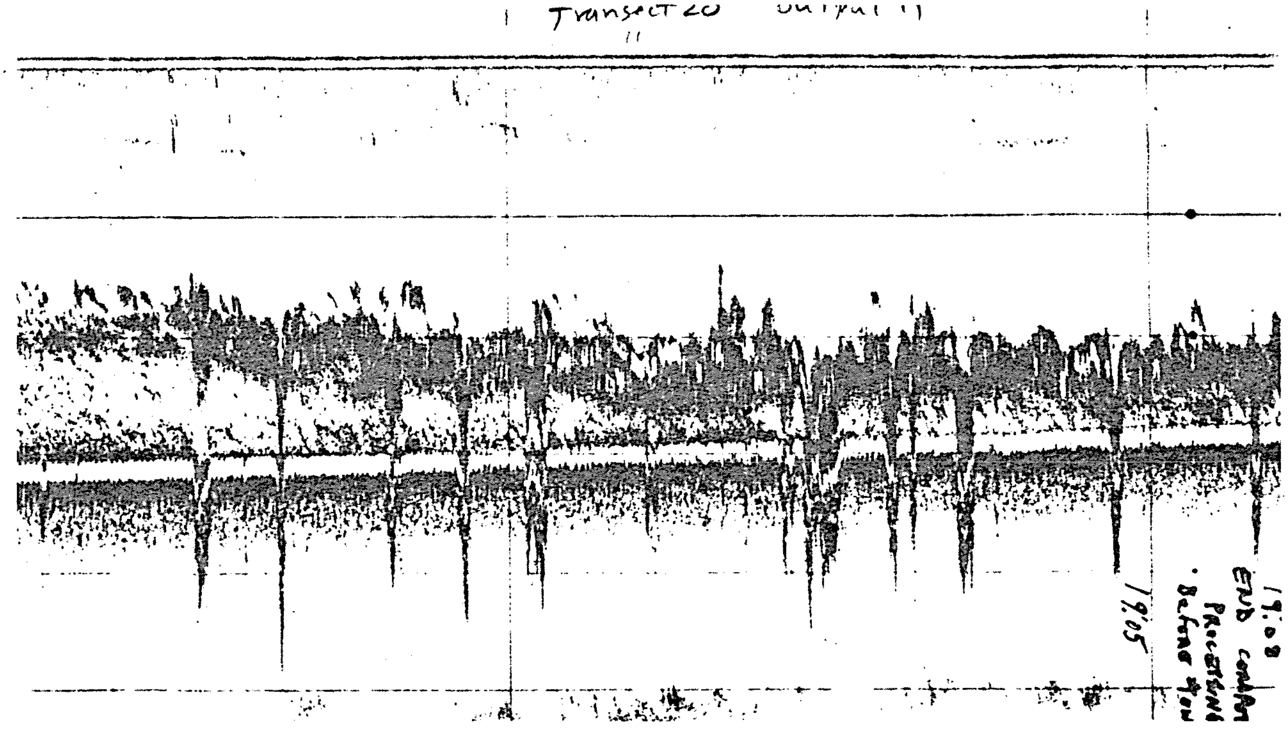


Fig. 12. Echogram corresponding to output 11 of file MFGA07, transect 20, and showing concentrations of pollock above bottom.

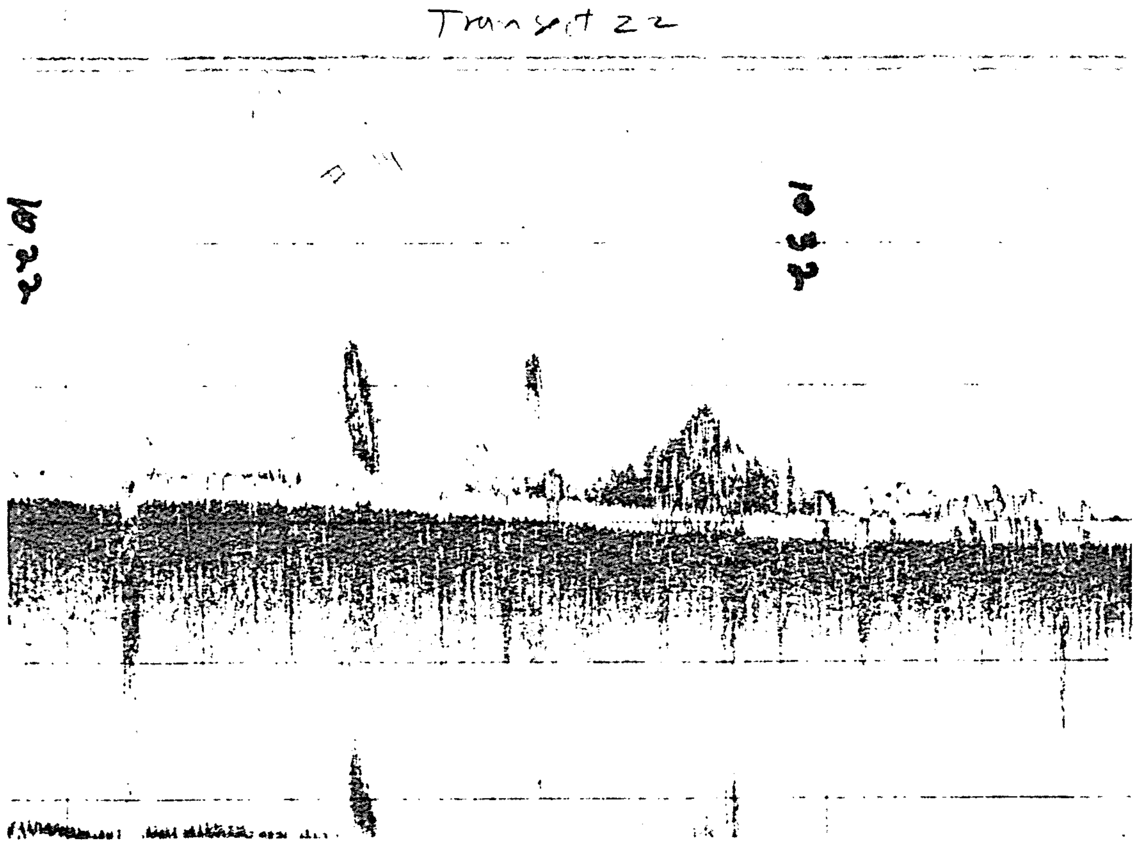


Fig. 13. Echogram corresponding to output 14 of file MFGA09, transect 22, and showing unidentified fish concentrations.

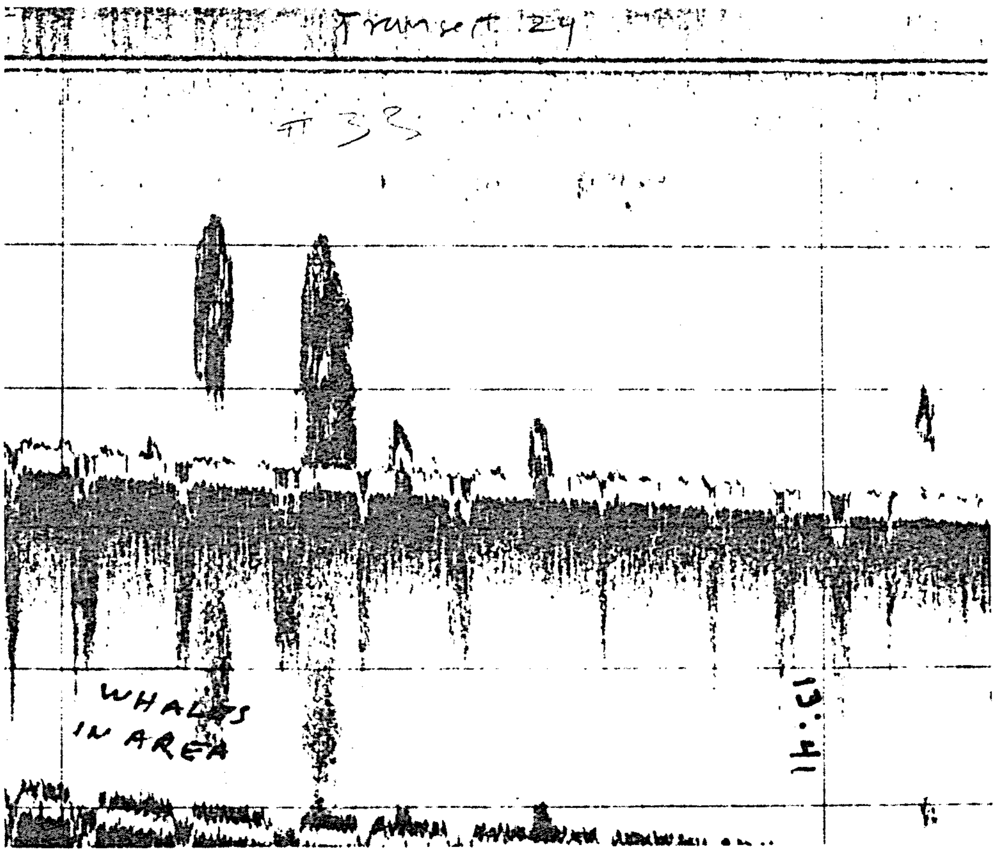


Fig. 14. Echogram corresponding to output 33 of file MFGA09, transect 24, and showing unidentified schools of fish.

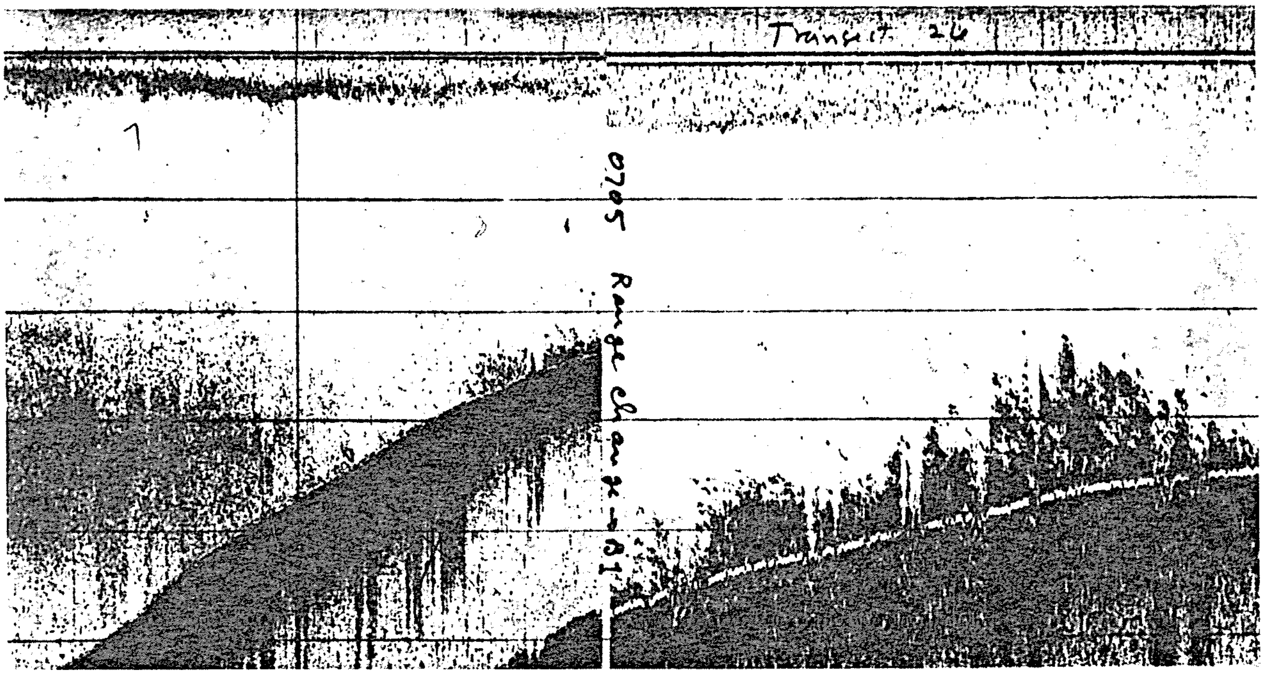


Fig. 15. Echogram corresponding to outputs 7, 8, and 9 of file MFGA10, transect 26, and showing nonfish scattering layer above continental slope and unidentified fish concentration near bottom at shelf break.

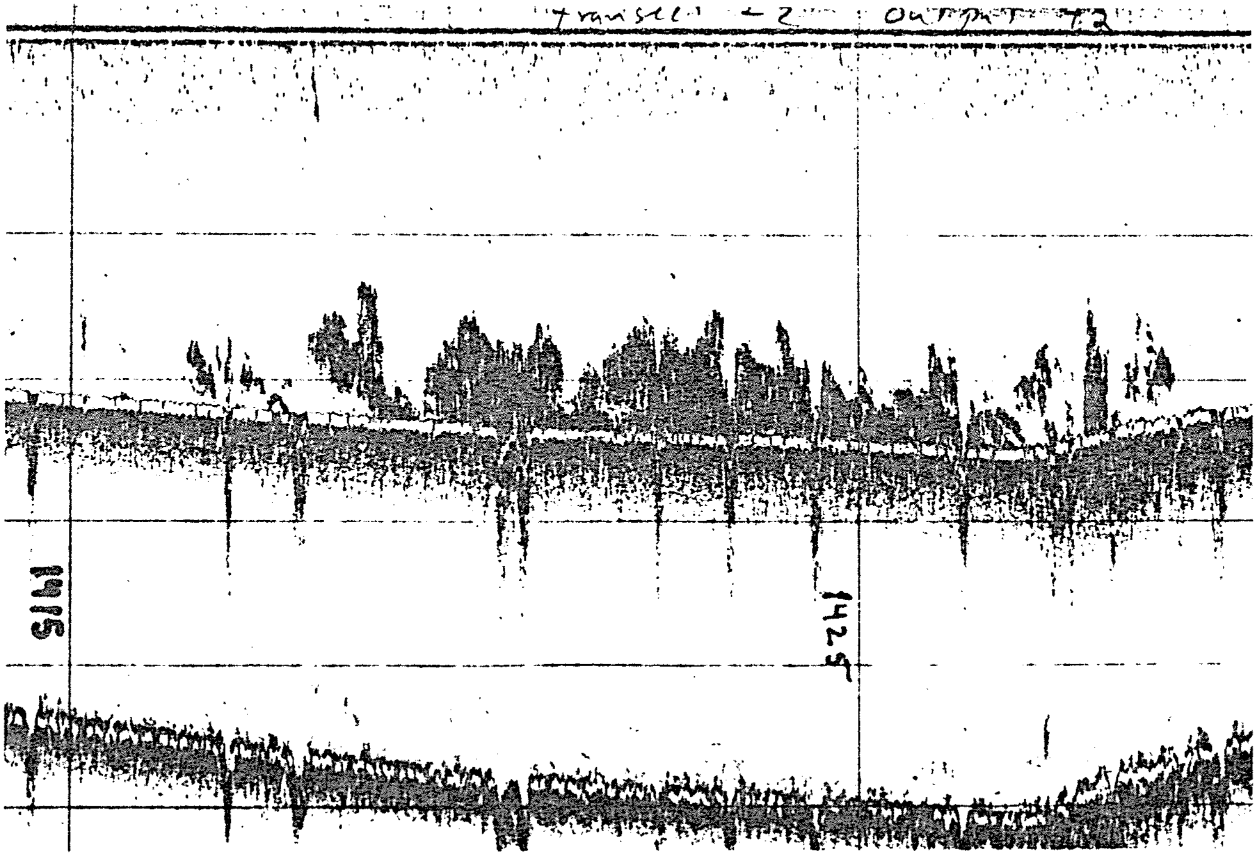


Fig. 16. Echogram corresponding to output 42 of file MFGA10, transect 27, and showing near bottom concentration of fish, probably adult pollock.

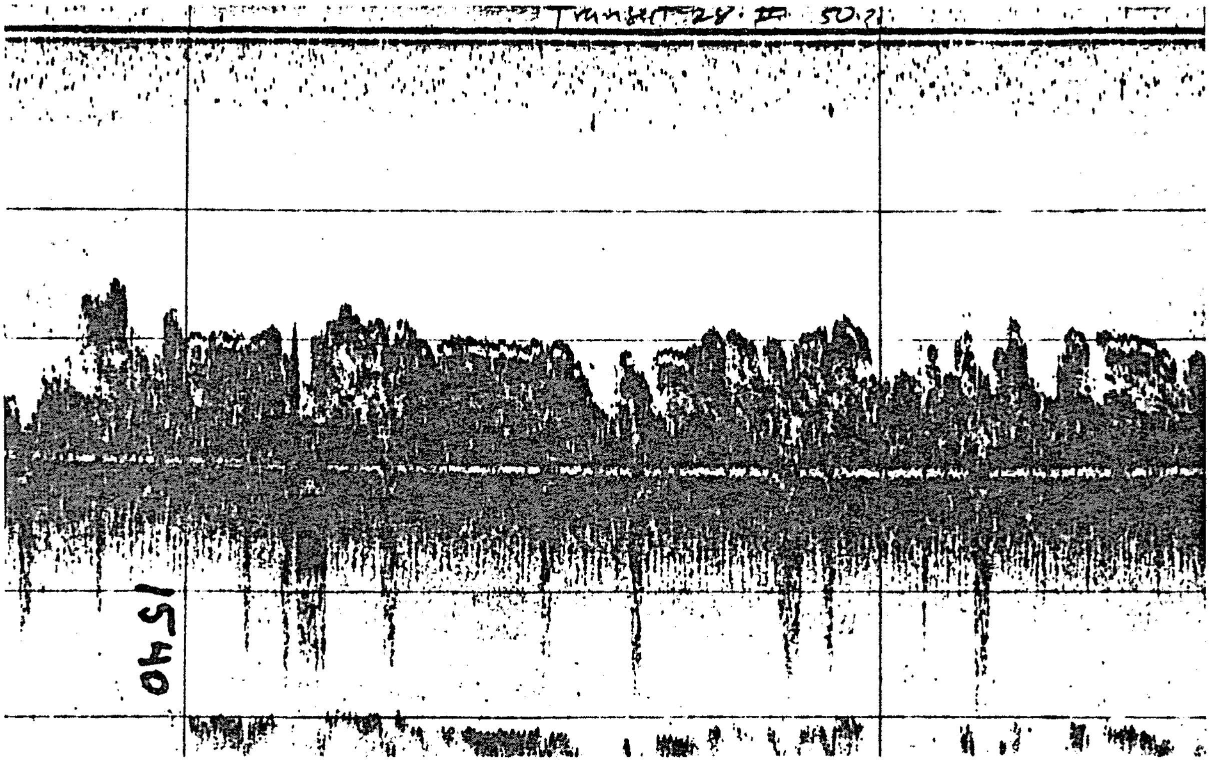


Fig. 17. Echogram corresponding to output 50 of file MFGA10, transect 28, and showing off-bottom concentrations of adult pollock.

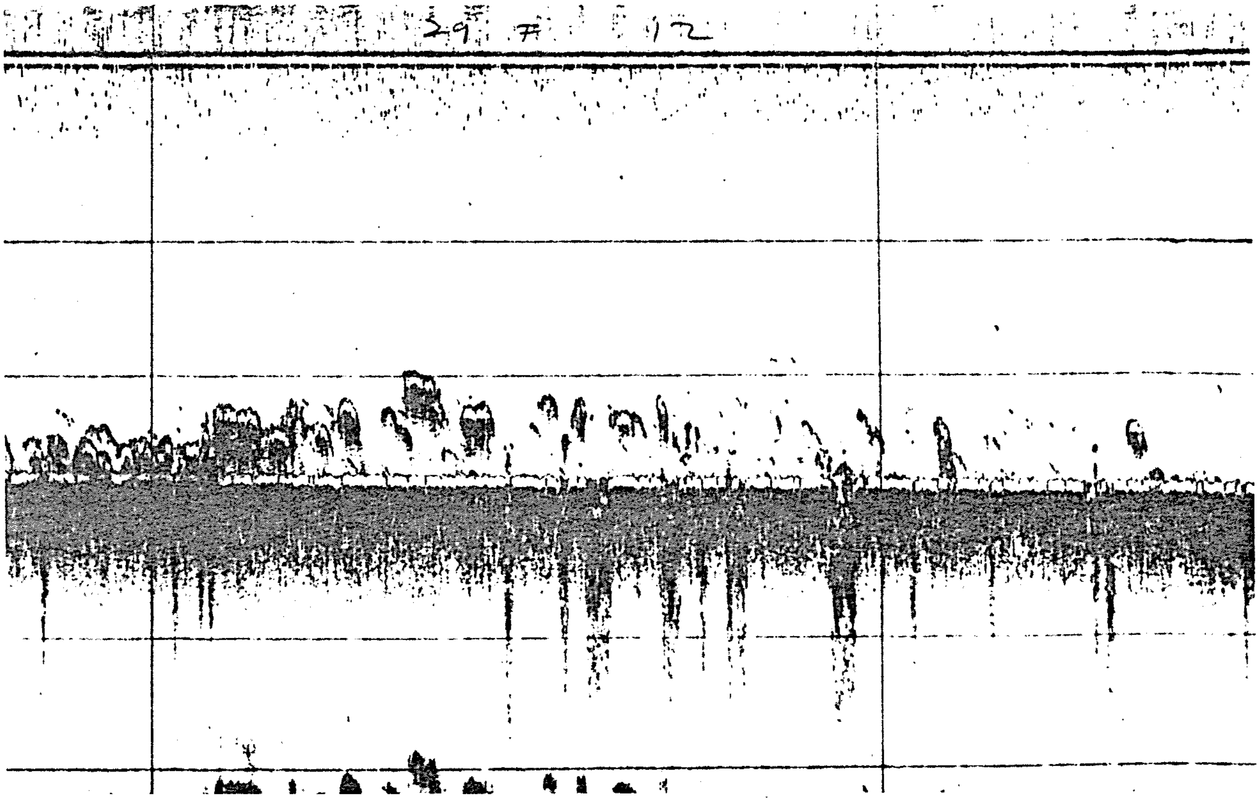


Fig. 18. Echogram corresponding to output 12 of file MFGA11, transect 29, and showing high density schools of fish, probably pollock, just above bottom.

Tran 30

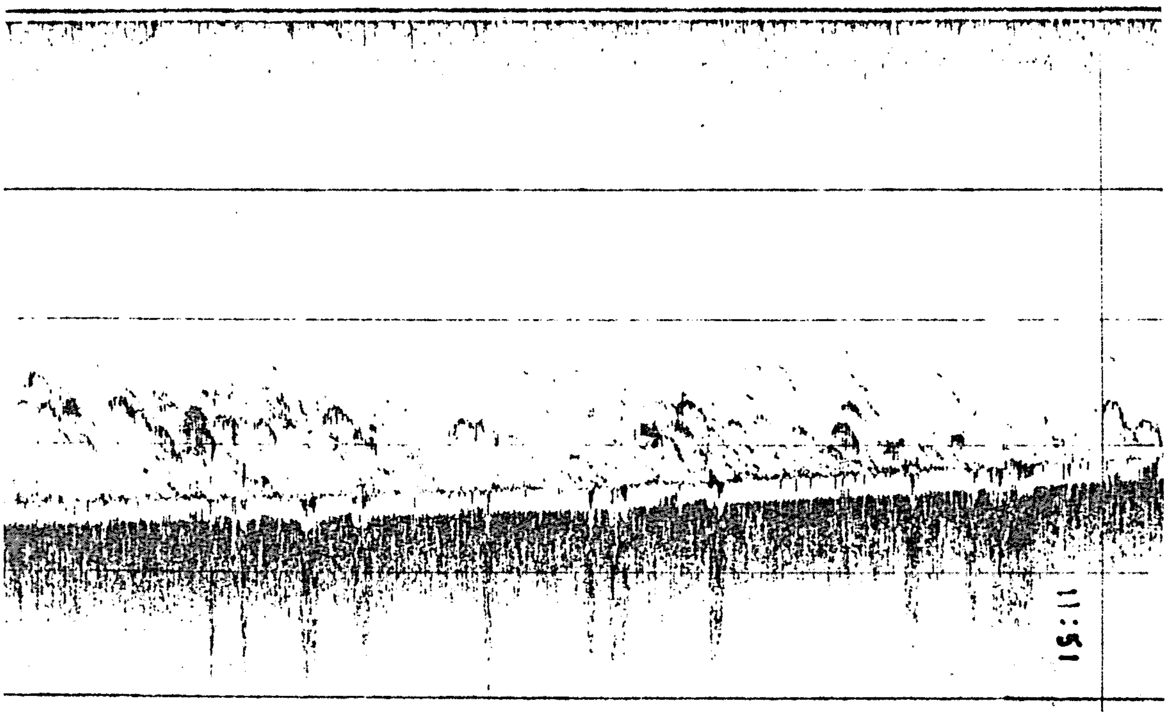


Fig. 19. Echogram corresponding to outputs 36 and 37 of file MFGA11, transect 30, and showing small off-bottom schools of fish, probably pollock.

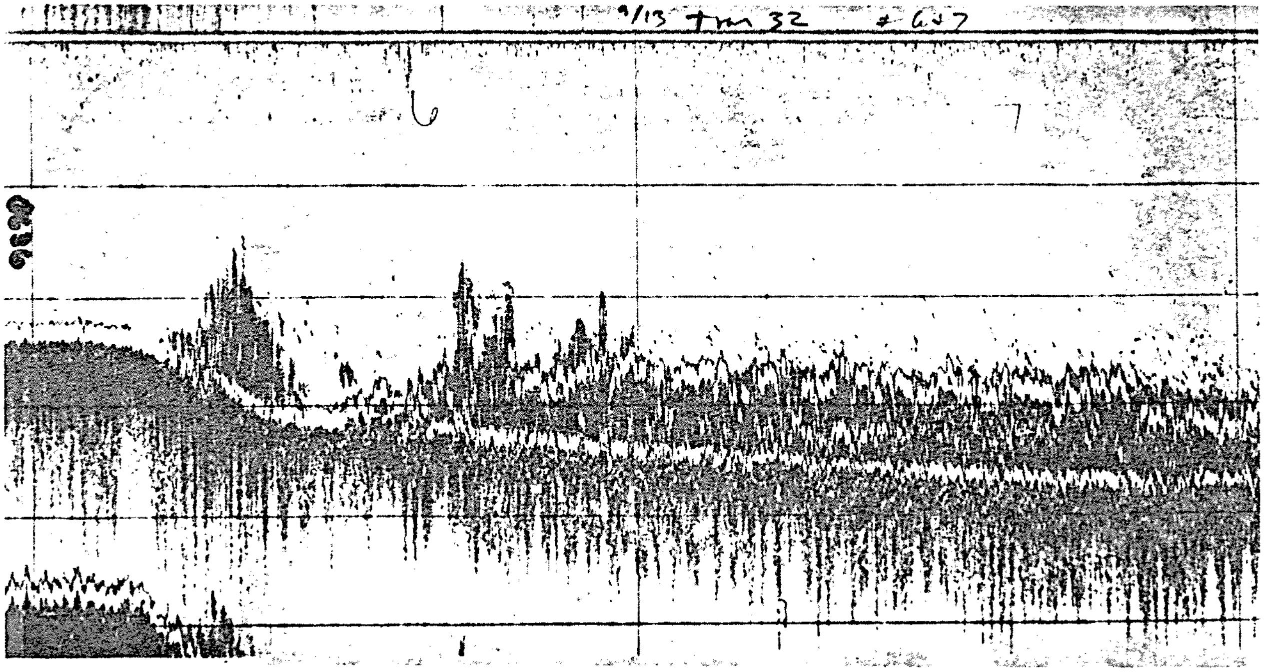


Fig. 20. Echogram corresponding to outputs 6 and 7 of file MFGA12, transect 32, and showing high densities of fish near bottom, probably mostly pollock.

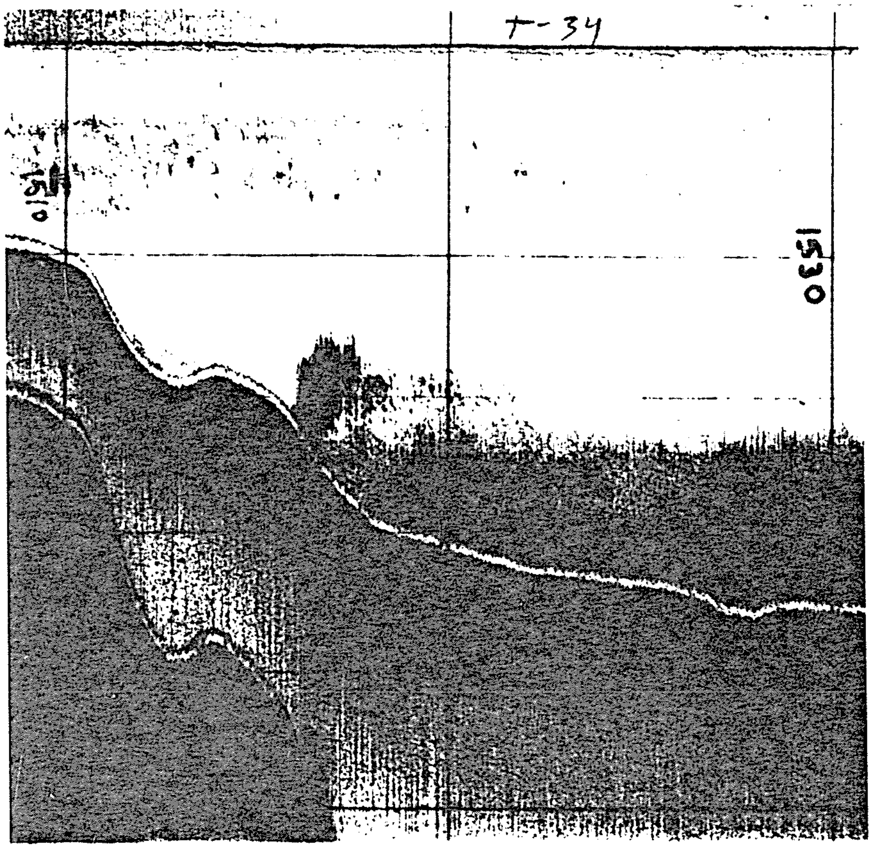


Fig. 21. Echogram corresponding to outputs 2 and 3 of file MFGA16, transect 34, and showing concentration of fish just above bottom of continental slope and offshore deep scattering layer.

Table 3. Number of density measurements from various categories of backscattering organisms along various transects.

Transect	Total	Insignificant backscatter	Non-fish scatter	Unidentified fish	Identified fish	Species
1	35	15	15	5	0	
2	14	8	5	0	1	Juvenile pollock (tow 1)
3	14	11	3	0	0	
4	8	4	4	0	0	
5	11	10	1	0	0	
6	7	6	0	1	0	
7	4	2	0	0	2	Juvenile pollock (tow 2)
8	28	26	2	0	0	
9	34	25	9	0	0	
10	15	15	0	0	0	
11	18	12	0	0	6	Pollock (tow 3)
12	13	6	0	0	7	" "
13	22	22	0	0	0	
14	14	6	1	0	7	Herring (tow 4)
15	15	7	0	0	8	Herring & pollock
16	3	2	0	0	1	Pollock
Leg 1 Subtotal	255	177	40	6	32	
20	15	5	0	0	10	Pollock
21	10	3	1	6	0	
22	9	8	0	1	0	
23	8	5	2	1	0	
24	24	19	2	3	0	
25	18	14	3	1	0	
26	38	31	4	3	0	
27	6	1	0	0	5	Pollock
28	12	2	0	0	10	"
29	15	6	0	0	9	"
30	35	29	0	1	5	
31	11	11	0	0	0	
32	33	14	0	11	8	"
33	45	31	3	3	8	"
34	34	23	4	3	4	Mostly pollock (tow 7)
35	14	13	0	1	0	
36	14	4	6	0	4	
37	24	21	0	3	0	
38	9	9	0	0	0	
39	8	3	0	5	0	
Leg 2 Subtotal	382	256	26	37	63	
Grand total	637	433	66	43	95	

observed during the entire cruise, (2) the species composition is uncertain because of the limited trawl data, (3) a substantial proportion of the observations were on immature fish or non-target species, (4) the acoustic data are questionable because of the unstable towed vehicle, and (5) the open-ended survey area limited the usefulness of the results. These aspects are discussed in the next section of the report.

As described previously and illustrated in Fig. 2, the results of Leg II were divided into four areas. Adult pollock concentrations were observed only in areas bounded by 50 and 100 fathom contours. The first area is defined by these contours and the end-points of transect 20. (Midwater trawl haul No. 5 was taken in this area.) The second consists of the area in this depth range represented by transects 27-31 and part of 32. (Trawl haul No. 6 was made here.) The third consists of the area in this depth range represented by part of transect 32 and transects 33 and 34. (Trawl haul No. 7 was made in this area.) The last consists of the remainder of the area represented by the survey, including areas of 50-100 fathom depths which did not contain significant pollock concentrations.

The surface areas are 125, 560, 380, and 3,300 $n.mi^2$ for areas 1-4, respectively. Similarly, estimated mean densities are 64 g/m^2 (219 $mt/(n.mi)^2$), 178 g/m^2 (610 $mt/(n.mi)^2$), 27 g/m^2 (93 $mt/(n.mi)^2$), and 11 g/m^2(38 $mt/(n.mi)^2$), and biomasses 44, 303, 38, and 126 thousand mt. The total estimated biomass from areas 1-3 which consisted predominantly of pollock, is 335,000 mt. The total estimated fish biomass from Leg II is 510,000 mt.

DISCUSSION

Comparison With Other Estimates

The only comparable survey of the Gulf of Alaska was conducted by the Polish research vessel PROFESOR SIEDLECKI during July and August, 1977. However, the hydroacoustic methods which were employed by the Polish scientists differed considerably in that the acoustic data was converted to biomass estimates on the basis of bottom trawl catches, rather than using target strength information (Thorne and Carlson 1977). Also, the PROFESOR SIEDLECKI cruise was longer in duration (30 days versus 18) and covered the entire continental shelf and slope of the Gulf of Alaska (30,800 $n.mi^2$ compared with 8,400 for MILLER FREEMAN cruise 78-3). The survey by the PROFESOR SIEDLECKI was similarly divided into two areas, in this case by 144° W longitude.

The density estimates were 23.9 $mt/(n.mi)^2$ for the southeastern area and 86.4 $mt/(n.mi)^2$ for the northwestern area, compared with 24 and 116 for the MILLER FREEMAN cruise. The total biomass of fish for the entire Gulf of Alaska was estimated as 1.8 million mt from the

PROFESOR SIEDLECKI cruise, compared to 0.60 million mt for the MILLER FREEMAN cruise.

The predominant species from both surveys was pollock. The exploitable biomass of this species in the Gulf of Alaska has been estimated at 1.1-2.1 million mt from demersal surveys (Alton 1976).

Sources of Uncertainty

The results are affected by four primary sources of uncertainty. These are: (1) the target strength assumption, (2) equipment performance, (3) species composition including non-fish scattering layers, and (4) statistical.

A target strength value of -35 dB/kg was considered the best estimate given the species composition and available data on fish target strengths. However, there are considerable differences between absolute values of target strength obtained by different workers, ranging from -30 to -40 dB/kg (Anon. 1978). The measurements of Nakken and Olsen (1977) are considered among the best. They report 34.5 dB/kg for a 50 cm cod, which is most similar to the pollock in the Gulf of Alaska. Traynor reported -38 dB/kg for 40 to 60 cm fish including Pacific hake, pollock and yellowtail rockfish. However, more recent measurements indicate a value of -35 dB/kg (Traynor, personal communication). Target strengths of smaller fish, 10-30 cm are probably in the range of -33 to -34 dB/kg. The selection of -35 dB/kg for the density estimates in this report assumes that the revised values of Traynor are the most appropriate for the adult pollock, which was by far the most abundant. An assumption of -37 dB/kg would have increased the density values by 58%, whereas an assumption of -33 dB/kg would have reduced them by 37%. The author considers -33 to -37 dB/gk to be the maximum extent of the uncertainty from this source.

The electronic aspects of the system appeared to be stable. Maximum drift was ± 0.5 dB (11-12%). The TVG was inaccurate at shallow and deep ranges, but was within ± 1 dB (21-26%) over the range of primary interest. The major problem with the hydroacoustic data was the instability of the towed body, particularly during the first 4 days. This instability tended to reduce the strength of the fish echoes. As a result, the density values from transects 1 to 13 are underestimated relative to the other transects.

Species indentification cannot be made from the acoustic data alone, but depends on the trawl sampling operations. However, several characteristics of the echoes can give clues to species identity, thus minimizing the required trawl sampling effort. These clues include amplitude distribution and vertical and horizontal location and extent.

Pollock was by far the predominant species, comprising 99.8% by weight of the total trawl catch for the survey. Its distribution was characterized by a dense layer or many small dense schools within 50 m of the bottom over bottom depths of 100 to 200 m (see Figs. 10, 12, and 16-20). This predominance of pollock and its apparently well-defined distributional characteristics would appear to greatly diminish the uncertainty associated with this error component. Although nearly one-third of the observations from fish were considered unidentified (Table 3; Figs. 13-15, and 21), the contribution to the total biomass from these observations was small. Unfortunately, the conclusion that pollock was predominant is based on very few hauls. Only haul 3 during Leg I and haul 6 during Leg II had large catches. Haul 7 had a moderately large catch (95% pollock) and may be typical of area 3. Haul 5 was taken in area 1 on an echo sign similar to the adult pollock in other areas, but caught mostly juvenile pollock. However, the result is questionable since the haul was made at dusk. The strongest evidences for the predominance of pollock are the consistent, well-defined distributional characteristics and the lack of catches of other species. Future trawl sampling on similar echo sign in these areas may reduce the present uncertainty from this source.

Sixty-six density observations were from scattering layers which probably consisted primarily of non-fish. Tow 9 is a typical example of the catch and acoustic measurements from a deep scattering layer (Table 2). In general, scattering layers did not complicate interpretation of the measurements. Measurements of equivalent fish densities over 50 g/m^2 were obtained in some cases because of the consistency and large vertical extent of these layers, but they were readily identified by the low and very uniform amplitude. In most cases, separation could be readily made from the echograms (Figs. 15 and 21). The potential difficulty with the scattering layers is masking of fish concentrations within the layers. Undoubtedly some masking occurred. However, the error is small since masking is limited to low fish densities.

The highly contagious distribution of fish is reflected in the large standard deviation of the fish density. The uncertainty added by this source can also be seen by the fact that removal of the 4 highest of the 637 observations would reduce the mean density by 41%, or in other words, 0.6% of the observations produce 41% of the estimated biomass. Despite this large variability of the individual observations, the sample size is large (138 observations of fish plus 499 observations treated as effectively zero fish density), and, according to the Central Limit Theorem, estimates of the mean density will be normally distributed even though the individual observations are lognormally distributed (Saville 1977). The 95% confidence intervals around the estimated mean fish density from the 138 observations is ± 50%.

One way to reduce the error caused by patchiness is through the transect design. Usually, this means allocation of effort in proportion to expected abundance. Often such allocation can be made on the basis of bathymetry. During Leg II effort was concentrated on the depth range from 50-100 fathoms. This design was successful in that most of the fish were observed within this range. However, a comparison of the biomass estimates derived by the division into four areas with that obtained by unweighted extrapolation indicates that further improvements could be made. An estimate of 545,000 mt is obtained by simple extrapolation of the unweighted mean density over the survey area, compared to 510,000 mt by the method used in this report. Thus allocation of effort within the survey area resulted in an estimate of total biomass which differed by only 7% from the estimate which would be obtained by assuming a simple random sampling design. The allocation of the trawl hauls was poor, with only 50% of the trawl hauls during Leg II made in the areas which contained 75% of the total biomass, including virtually all of the biomass of target species.

CONCLUSIONS AND RECOMMENDATIONS

The major limitations of the 1978 survey of the Gulf of Alaska were the area coverage (less than one-third of the 1977 PROFESOR SIEDLECKI cruise) and the net sampling (10 midwater trawl hauls versus 71 midwater and bottom trawl hauls for the PROFESOR SIEDLECKI). While the density estimates are affected by uncertainties from the target strength and equipment performance, these are overshadowed by the uncertainties from species and unsampled areas. The effect of the instability of the towed body during the first few days was small since few fish were encountered during the first 10 transects. Unlike the acoustic methodology employed by the Polish scientists, the uncertainty from the target strength assumption can be reduced by future research and provides a repeatable relative index of abundance. However, the results have only limited value as an estimate of the fish stocks in the Gulf of Alaska with 70% of the continental shelf and slope area unsampled.

Despite these limitations, the cruise demonstrates the potential value of acoustic assessment surveys and contributes to the development of optimal procedures, both in proving the suitability of some techniques and in defining the limitations and needs for further effort or research in others.

In general, the equipment performance was satisfactory, especially after adjustments in the towing system in the middle of Leg I. The failure of the echosounder near the end of Leg I was the result of operator error. The towed system was still operable in weather that was untrawlable. Strands of kelp occasionally caused problems, but the loss of time to remove kelp from the towed vehicle was minor. Only post-cruise calibration of the acoustic system was accomplished because of scheduling problems. Pre-cruise calibration should have been done and would have provided a better basis for trawl sampling decisions.

Although the PDP 11/10 computer system lacks the versatility of the PDP 11/45 systems (Thorne 1977), it met the basic data analysis requirements and has the further advantage of portability and simplicity. The capability of the larger computer to automatically correct for deviations from ideal of the echosounder TVG would have been desirable, but was not critical for the depth distribution encountered during this cruise. Correction factors from Fig. 7 could be applied to the data in Table 2. However, density measurements outside the range of primary interest (the pollock concentrations) have little meaning since, in most cases, data on species, size, and target strength are not available for these targets.

More precise information is needed on the target strengths of various species, but this need is widely recognized and the subject of considerable research around the world. In the meantime, the limits of uncertainty are reasonably well defined, and the results provide a repeatable index of abundance.

Determination of species composition with the midwater trawl was a major weakness in the survey. The number of trawls was very small, and the trawling procedure was too time-consuming because of the inexperience of the crew and officers and the slow retrieval time of the main trawl winches. The time from detection of a fishable concentration to trawl equilibrium was typically 2 hr. In some cases, fish concentrations moved or altered appreciably in this interim. Total time consumed for an individual trawl haul was usually over 3 hr.

Serious consideration should be given to using separate vessels for the acoustic and trawling operations. The acoustic operations do not require anywhere near as large a vessel or crew. Considering the fact that 78% of the observations during MILLER FREEMAN cruise 78-3 were essentially zero fish density, the inclusion of net-sampling capability and man-power is obviously inefficient. The best survey procedure for large area surveys such as the Gulf of Alaska would be a smaller acoustic vessel running widely-spaced transects and an acoustic-trawling vessel running closely-spaced transects and trawling in areas of high fish abundance. This procedure would be a more efficient use of vessels and manpower, and the stratified sampling design would minimize the variance of the acoustic estimate (Thorne, Reeves, and Millikan 1971). Two vessel operations are now used routinely during most acoustic surveys conducted by the author and have been adopted by the Washington Department of Fisheries for herring surveys. The particular approach varies according to the degree of patchiness and stability of fish concentrations. Operations in Lake Washington, Gulf of Georgia, and Southern California illustrate the range. Juvenile sockeye salmon in Lake Washington exhibit low patchiness and high stability. Systematic trawl stations in various areas and depths are made independent of the acoustic sampling except for input on general allocation of effort over the various areas. Herring in the Gulf of Georgia are intermediate in patchiness and stability. In this case, the trawl sampling vessel follows and is directed by the acoustic survey vessel to sample in various depths and areas where fish are concentrated. The fish concentrations observed during impact studies of power plant intakes off Southern California are transitory and extremely contagious. For this situation the net sampling vessel follows immediately behind the acoustic vessel. When a fish concentration is detected by the acoustic survey vessel, it is marked by a surface buoy and immediately set upon by the trailing vessel. A similar procedure might be necessary to sample concentrations like those illustrated in Figs. 13 and 14.

A two-vessel operation was attempted by NWAFC in 1976 without much success. Such operations require good communication, experience, and a well-conceived operational design. A single previous failure by NWAFC is not indicative of the merit of this approach given its theoretical advantages and the successful applications of others.

A major result of MILLER FREEMAN cruise 78-3 is the documentation of the semi-pelagic nature of substantial fish biomass in the Gulf of Alaska. The off-bottom distribution of pollock was especially evident. The results from haul 6 are a good example of this distribution. Peak fish densities were 20 m above the bottom. The inadequacy of bottom trawl surveys alone is apparent from these results. The distribution of fish in relation to the bottom obviously varies among species and may vary seasonally. Close coordination between bottom trawling and acoustic-midwater trawling operations is essential in order to adequately sample the fish resources of the Gulf of Alaska.

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