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CALIFORNIA CURRENT ECOSYSTEM SURVEY 2006 ACOUSTIC CRUISE REPORTS FOR NOAA FSV *OSCAR DYSON* AND NOAA FRV *DAVID STARR JORDAN*

Edited by

G. R. Cutter, Jr.
and
David A. Demer

NOAA-TM-NMFS-SWFSC-415

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

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TABLE OF CONTENTS

BACKGROUND 3

OBJECTIVES 3

SUMMARY OF RESULTS 4

DESCRIPTION OF OPERATIONS 4

SCIENTIFIC PERSONNEL 6

CRUISE REPORTS 7

I. California Current Ecosystem Survey 2006 (OD0406) Acoustics Cruise Report for NOAA FSV *Oscar Dyson*, by D. A. Demer, G. R. Cutter Jr., D. Needham, and R. P. Hewitt 7

I.1 Objectives 8
I.2 Accomplishments 8
I.3 Methods and Results 10
I.4 Tentative Conclusions 48
I.5 Problems and Suggestions 50
I.6 Disposition of Data 51
I.7 Acknowledgements 51
I.8 References 52
Appendix I.1. Computers in the Acoustics Laboratory aboard FSV *Oscar Dyson* 53
Appendix I.2. ADCP Log 54
Appendix I.3. ADCP setup file 56

II. California Current Ecosystem Survey 2006 (DSJ0406) Acoustics Cruise Report for NOAA FRV *David Starr Jordan*, by G. R. Cutter Jr., S. Sessions, H. Smit, D. Krause, and D. Demer 59

II.1 Objectives 60
II.2 Accomplishments 60
II.3 Methods and Results 62
II.4 Tentative Conclusions 95
II.5 Problems and Suggestions 96
II.6 Disposition of Data 98
II.7 Acknowledgements 98
II.8 References 98

BACKGROUND

The California Current Ecosystem Survey 2006 was conducted to assess the spatial distribution of pelagic fish, ichthyoplankton and fish eggs, principally the Pacific sardine (*Sardinops sagax*), from offshore of the northern tip of Vancouver Island, B.C., Canada to San Diego, California using acoustical and direct-capture methods. The survey results include descriptions of the pelagic habitat.

Sardines are important commercially and ecologically. Sardines supported a major fishery on west coast of the United States of America from the early 1900s, until the stocks declined beginning in the 1940s and reached a minimum in the 1970s (Hill et al., 2006). Sardines are key members of the pelagic ecosystem as consumers of phytoplankton, copepods and euphausiids, for example, and as high energy prey for other fish (Emmett et al., 2005), sea birds, and marine mammals.

Routine scientific monitoring of sardine populations and ecology has been a major focus of the California Cooperative Fisheries Investigations (CalCOFI) program since 1949. The surveys described by this report followed sampling lines developed for the CalCOFI program and provide a continuation of long-term time-series data for understanding and managing sardines and their environment.

OBJECTIVES

The overall objectives of the California Current Ecosystem Survey 2006 were to describe the spatial distribution of eggs, larvae, and adults of *S. sagax* along the entire U.S. West Coast; to gather data for estimating spawning biomass; to collect acoustic data from scientific echosounders, in order to characterize the water-column environment, and record current profiles; and to collect observations of marine mammals and sea birds.

The objectives of the acoustics portion of the survey were: to acoustically map the distributions and estimate the abundances and biomass of coastal pelagic fish; to characterize their biotic and abiotic environment; to investigate ecological linkages, and gather information about fish schooling behavior, diel vertical migration, and avoidance reactions to the survey vessel.

SUMMARY OF RESULTS

The fish species caught in highest abundance by trawls during the survey were the northern anchovy (*Engraulis mordax*), Pacific sardine (*Sardinops sagax*) and Pacific mackerel (*Scomber japonicus*). Some 39 species of fish and invertebrates were caught by the 40 surface trawls on the *Oscar Dyson*. Acoustic scattering from fish alone was identified using a method involving frequency-differencing, which allowed fish biomass density to be estimated from the 38 kHz echosounder data. The mean biomass density estimated from the EK60 acoustic data collected on the *Oscar Dyson* was 0.0027 kg/m^2 (C.V. = 0.79). The product of the biomass density and estimated size of the entire West Coast acoustic survey area (751,567 km^2) results in the preliminary total biomass estimate for pelagic fish from acoustic data of 2.00 Mt (million metric tons).

For approximately the same area, the total spawning biomass of *S. sagax* estimated from the daily egg production method (DEPM) was 1.3 Mt (C.V. = 0.47) within a 885,523 km^2 spawning area (Hill et al., 2006).

This document contains the cruise reports for the acoustic surveys conducted on the NOAA FSV *Oscar Dyson* and the NOAA FRV *David Starr Jordan* that describe in detail the acoustic devices, calibrations, operational protocols, analyses, and results.

DESCRIPTION OF OPERATIONS

The 2006 California Current Ecosystem Survey used two vessels: the NOAA FSV *Oscar Dyson* and the NOAA FRV *David Starr Jordan*. The plan was for the FSV *Oscar Dyson* was to survey the northern part and the FRV *David Starr Jordan* to survey the southern part using identical methods. However, equipment failures prevented trawling operations on the FRV *David Starr Jordan*, and trawling was only conducted from the FSV *Oscar Dyson* and the survey plan of the FSV *Oscar Dyson* was extended to cover the entire West Coast down to San Diego, California.

Both vessels collected water samples from a CTD-rosette, ichthyoplankton samples from plankton nets and meteorological data from weather station sensors at prescribed and *ad-hoc* stations. At some of these and other locations, surface trawls were collected during night from the FSV *Oscar Dyson*. Underway operations on each ship included operating a continuous underway fish egg sampler (CUFES), an acoustic Doppler current profiler (ADCP), multiple-frequency split-beam echosounders and a multi-beam echosounder. Daytime underway operations included bird and mammal observations.

The acoustic surveys were accomplished using Simrad EK60 split-beam echosounders. Four echosounders were operated on the *David Starr Jordan* at 38, 70, 120 and 200 kHz, and five were operated on the *Oscar Dyson* at 18, 38, 70, 120 and 200 kHz. Each echosounder was calibrated prior to the survey using the standard sphere method. Echosounders were operated continuously during the survey transits and stations.

References

Emmett, R. L., Brodeur, R. D., Miller, T. W., Pool, S. S., Krutzikowsky, G. K., Bentley, P. J., and McCrae, J. 2005. Pacific sardine (*Sardinops sagax*) abundance, distribution, and ecological relationships in the Pacific northwest. Coop. Oceanic Fish. Invest., 46:122-143.

Hill, K. T., Lo, N. C. H., Macewicz, B. J. and Felix-Uraga, R. 2006. Assessment of the Pacific sardine (*Sardinops sagax caerulea*) population for U.S. management in 2007. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SWFSC-396, 105 p.

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CRUISE REPORTS

I. California Current Ecosystem Survey 2006 (OD0406) Acoustics Cruise Report for NOAA FSV *Oscar Dyson*, by D. A. Demer, G. R. Cutter Jr., D. Needham, and R. P. Hewitt

Report of the data collection, preliminary analyses and tentative conclusions for the multi-frequency echosounder, multi-beam sonar, and ADCP surveys from NOAA FSV *Oscar Dyson* off the west coast of the U.S.A., 12 April to 8 May 2006

by
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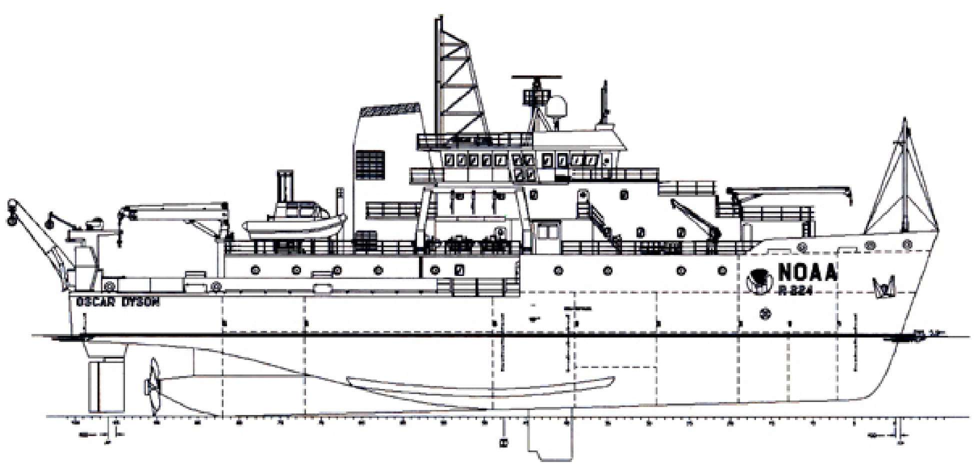


I.1 Objectives

Objectives of the California Current Ecosystem Survey 2006 were to acoustically map the distributions and estimate the abundances of coastal pelagic fish, including Pacific sardine (*Sardinops sagax*), northern anchovy (*Engraulis mordax*), Pacific mackerel (*Scomber japonicus*) and jack mackerel (*Trachurus symmetricus*), off the west coast of the United States of America; to characterize the biotic and abiotic environments of these coastal pelagic species (CPS) and investigate linkages; and to gather information about fish schooling behavior, diel vertical migration, and avoidance reactions to the survey vessel.

I.2 Accomplishments

Five frequency split-beam (18, 38, 70, 120, and 200 kHz), single frequency multi-beam (90 kHz), and single-frequency ADCP (75 kHz) data were collected from NOAA FSV *Oscar Dyson* throughout the April/May 2006 California Current Ecosystem Survey. The survey transects totaled approximately 4700 n.mi. including 18 west-east and 18 north-south transects spanning an area from the northern tip of Vancouver Island, B.C., Canada (51° N), to San Diego, California (31°N), and from approximately 5 to 200 n.mi offshore (Fig. I.1). The transects were approximately 100-200 n.mi. long and were typically 40-80 n.mi. apart.

Mechanical problems with the winches of NOAA FRV *David Starr Jordan* prevented completion of planned trawling operations in the southern survey area; however, the acoustic, egg pump, oceanographic and ichthyoplankton sampling plan was maintained. Consequently, the survey plan for FSV *Oscar Dyson* was modified after completing Transect 4 (Fig. I.1) to cover the entire West Coast survey area. To accommodate this additional coverage, the distances between transects were increased and the number of stations were reduced. Acoustic (multi-frequency echosounder, multi-beam sonar, and ADCP), egg pump, thermosalinograph, and meteorological data were collected continuously while the ship was underway, and pairovet, trawl, and CTD data were collected at prescribed and ad-hoc stations. The following itinerary was followed by the *Oscar Dyson*:

1930 06 April	Depart Seattle
2300 08 April	Arrive Ketchikan
1500 09 April	Depart Ketchikan for noise range trials
1830 10 April	Exchange personnel at noise range, depart for Leg 1-survey area
2200 11 April	Embark two Canadian scientists at Port Hardy, BC
0149 12 April	Arrive at first station
2030 16 April	Disembark Canadians at Ucluelet, BC; Embark two videographers
0800 21 April	Arrive Coos Bay; disembark two videographers and one scientist; embark six scientists
1330 23 April	Depart Coos Bay for Leg 2-survey area
0800 08 May	Arrive San Francisco, CA; all scientists disembark.

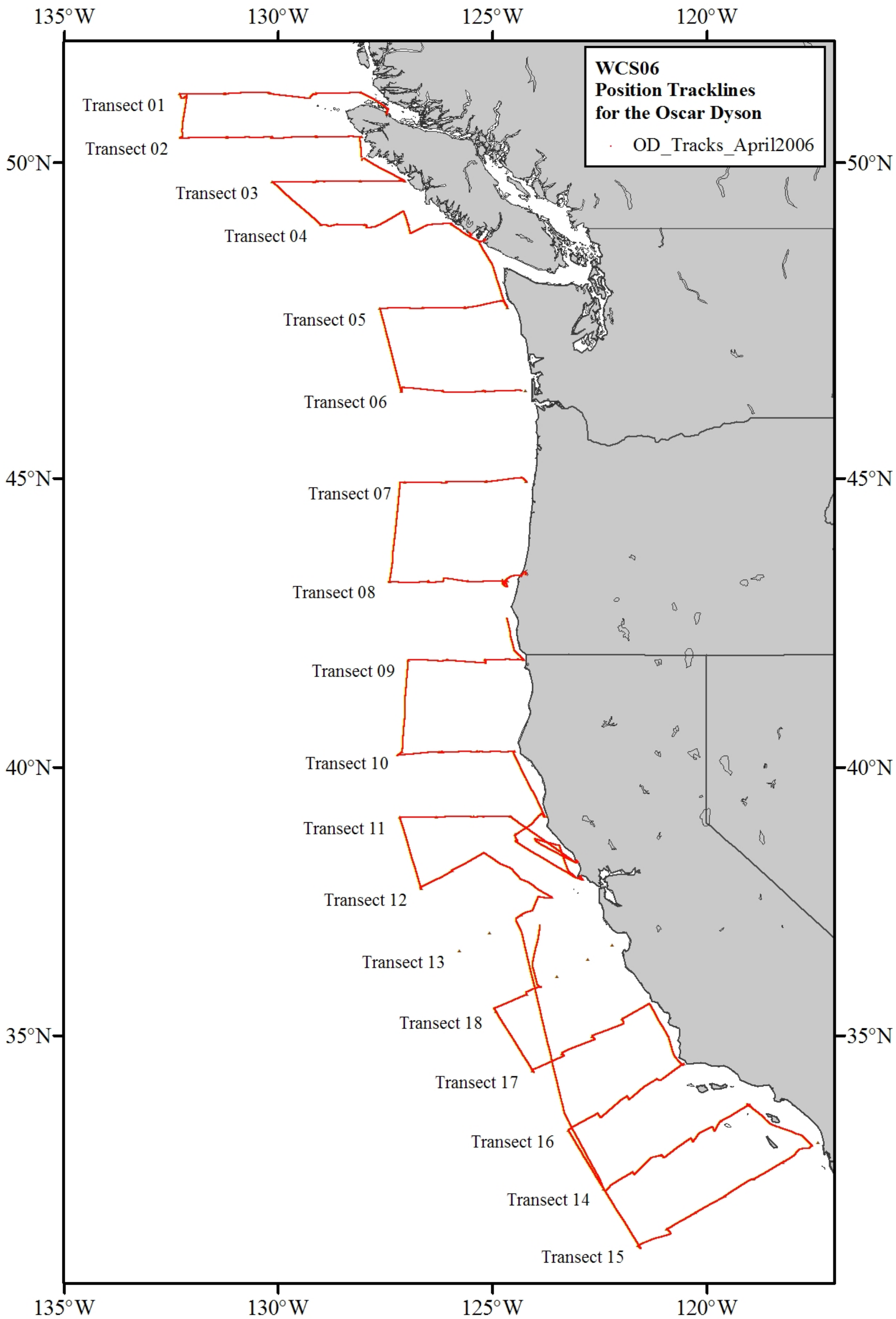


Figure. I.1. Transect line and sample station plan for the 2006 California Current Ecosystem Survey cruise aboard the NOAA FSV *Oscar Dyson*.

I.3 Methods and Results

Throughout the April/May 2006 California Current Ecosystem Survey, split-beam echosounder, multi-beam sonar, and ADCP data were collected and processed aboard NOAA FSV *Oscar Dyson*. The primary instrumentation included a Simrad EK60 multi-frequency echosounder (see section I.3.1), a Kongsberg-Mesotech SM2000 90 kHz multi-beam sonar (see section I.3.2), and an RDI 75 kHz Ocean Surveyor ADCP (see section X.3.3).

I.3.1 EK60 multi-frequency echosounders

Volume backscattering data (S_v; dB re 1 m) and target strength measurements (TS; dB 1 m^2) were collected using five calibrated Simrad EK60 transceivers, split-beam transducers, and Simrad ER60 and SonarData Echolog software, at frequencies of 18 kHz, 38 kHz, 70 kHz, 120 kHz and 200 kHz (Table I.1). A Leica MX 420 GPS was used to provide navigational data input to the ER60 and Echolog software. The ER60 output the 18 kHz bottom sounding to the Scientific Computing System (SCS) and Globe navigational software.

Table I.1. EK60 operational calibration settings on the *Oscar Dyson*.

Frequency (kHz):	18	38	70	120	200
Transducer Model No.	ES18	ES38-B	ES70-7C	ES120-7C	ES200-7C
Transducer Serial No.	2042	30473	122	306	274
Transmit Power (W)	2000	2000	750	500	100
Pulse Duration (µs)	1024	1024	1024	1024	1024
Pulse Repetition (s)*	2	2	2	2	2
TS Gain (dB)**	22.83/23.00	22.78/22.86	26.50	26.66	25.79
Sa Correction (dB)**	-0.50/-0.59	-0.64/-0.68	-0.31	-0.32	-0.20
EBA (dB)	-17.4	-20.8	-21.0	-20.3	-20.7
Angle Sensitivity Along	13.9	21.9	23.0	23.0	23.0
Angle Sensitivity Athwart	13.9	21.9	23.0	23.0	23.0
3 dB Beam width Along	10.50	6.80	6.80	7.30	6.90
3 dB Beam width Athwart	10.10	7.00	6.80	7.40	7.10
Offset Along	0.12	-0.05	0.01	0.00	-0.11
Offset Athwart	0.10	-0.06	-0.03	0.00	0.02

* During the early part of the cruise, the pulse interval ranged from of 2 to 8 seconds because the maximum echosounder range was extended to measure depth for some CTD casts; it was not always reset to 500m.
** Parameters were initially set on 11 April, then adjusted on 14 April.

I.3.1.1 EK60 System calibration

Alaska Fisheries Science Center (AFSC) personnel calibrated the acoustic system in May, June, July and August 2005, January 2006, and 4 April 2006. At the beginning of the survey, average TS gain and Sa correction figures (Table I.1) were entered into the ER60 software:

- 18 and 38kHz: Average from calibration in May, June, July and August 2005, and January 2006.
- 70 and 200kHz: Average from calibrations in January and April 2006.
- 120kHz: Average from calibration in April 2006.

Values from the transducer specification sheets were used for the 3 dB beamwidth, and alongship and athwartship angle settings. ER60 default values were used for the angle sensitivity (along and athwartship) and beam offset (along and athwartship) settings.

On 14 April 2006, Neal Williamson (AFSC) emailed updated figures for the 18 and 38kHz calibrations. These new TS gain and Sa correction figures were entered into the ER60 software before the start of Transect 3 and used thereafter. All of the calibration parameters used during the survey are summarized in Table I.1.

I.3.1.2 EK60 Transducer mounting

The split-beam and ADCP transducers were mounted on a retractable centerboard keel. The keel could be used in retracted, intermediate, or extended positions, placing the transducer faces at 0m, 2m or 3.75m below the ship's hull, respectively (5.4m, 7.4m or 9.15m below the sea surface; Figs. I.2-I.4 and Table I.2). The survey was generally conducted with the keel lowered to the intermediate position, such that the transducers were 7.4 m below the mean water surface. During a few episodes of bad weather or shallow water, the keel was fully extended or retracted, as initiated by the bridge officer, respectively. These changes were entered in the ER60 software's "Transducer Depths" setup menu and noted in the OD0406 acoustics logbook.

I.3.1.3 EK60 Triggering

The EK60 trigger pulse was used to synchronize the transmissions of the five echosounders as well as the Konsberg-Mesotech SM20/SM2000 multi-beam sonar, and the RDI 75kHz Ocean Surveyor ADCP. Except for these acoustic systems, all other echo sounders, speed logs and sonars operating at or near the survey frequencies were secured during survey operations. Exceptions were made during stations, when the watch officer sometimes activated the Doppler speed log and bridge echosounder(s).

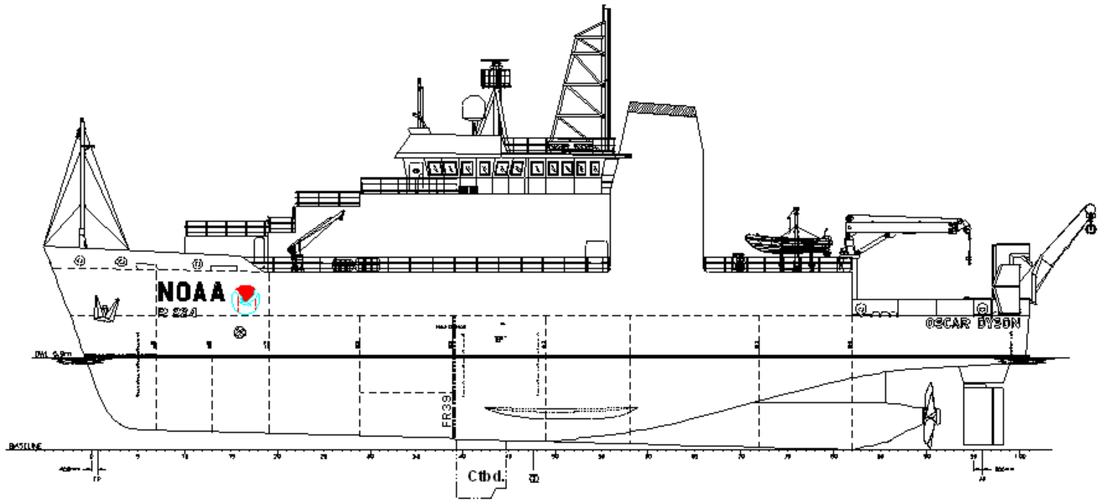


Figure I.2. Location of the centerboard (labeled "Ctbd") and frame 39 ("FR39") on FSV *Oscar Dyson*. Port-side outboard profile view is shown.

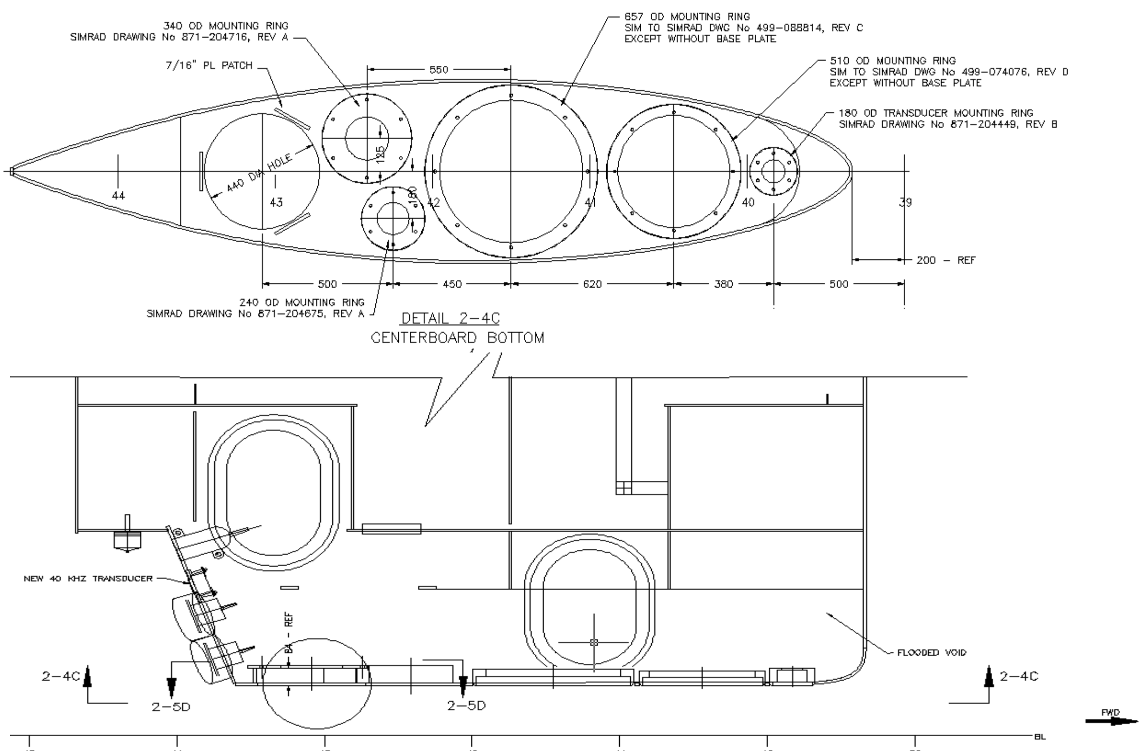


Figure I.3. Locations of the EK60 and ADCP transducers on the centerboard of FSV *Oscar Dyson*. (Bottom view looking up, shown from right to left, fore to aft, are the 200, 38, 18, 120, 70 kHz ES60s, and the ADCP transducer). Frames 39 – 44 (upper) and 39 – 45 (lower) are shown.

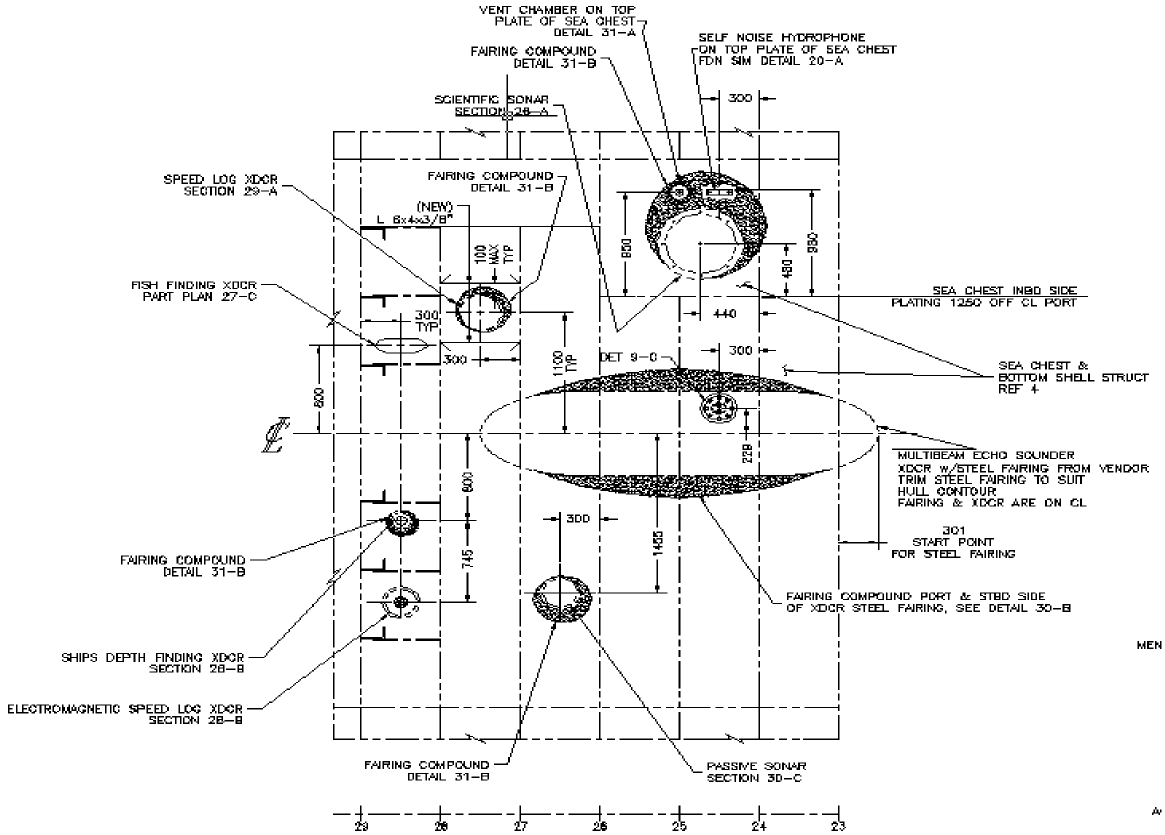


Figure I.4. Location of the hull-mounted SM2000 transducers on FSV *Oscar Dyson*.

Table I.2. Locations of the survey transducers on the hull of FSV *Oscar Dyson*.

Distance (mm) from centers of transducers

kHz	**Alongship Aft of frame 39 (mm)**	**Alongship Forward of DWL center** [1]	**Alongship Forward of MP** [2] **(Fig. I.2)**	Athwartship	
200	500	6138	4707	0	
38	880	5758	4327	0	
18	1500	5138	3707	0	
120	1950	4688	3257	180	port
70	2050	4588	3157	125	starboard
ADCP	2450	4188	2757	0	

Distance from center of 38 kHz split-beam transducer (ES38-B)

kHz	**Alongship**	**Athwartship**
200	380 fwd	
18	620 aft	
120	1070 aft	180 port
70	1170 aft	125 starboard
ADCP	1570 aft	
SM20	9271 fwd (8391mm to frame 39)	

Distance to other points of reference seen in Fig. I.2.

DWL center to frame 39 [1]	6638
MP (; Fig. I.2) to frame 39 [2]	5207

[1] "DWL center" indicates the point that bisects the designed waterline (DWL) as projected on the port side outboard profile view of the ship in Fig. I.2. Frame 39 is located 23.40 m from the bow at waterline, and DWL center is 30.04 m from the bow at the waterline.

[2] The symbol shown in Fig. I.2, indicates the midships perpendicular (MP), half the horizontal distance between the forward and aft perpendiculars. This perpendicular is estimated to be 28.62 m from the bow at waterline.

I.3.1.4 EK60 Data Collection and Archive

EK60 data was collected to 500 m depths by transmitting the five frequencies simultaneously in 1024 µs duration pulses every 2 seconds. The echoes were received with bandwidths of 1.574, 2.425, 2.859, 3.026, and 3.088 kHz, respectively, and digitized in quadrature every 256 µs (ER60; .raw data format). These data were also averaged every 1 m in range from 0 to 500 m and stored in BI500 (.ek) and EK500 (.dg) data formats. Simrad ER60 (Version 2.1.2) software was used to log the .raw and .dg files. Sonardata Echolog software (Version 3.50.0) was used to log .ek5 files to a networked file server. Data backups were made at regular intervals to DVD+R media, a USB V2.0 external hard disk, and an internal hard disk on a networked computer.

I.3.1.5 EK60 Data Processing

Post-processing was accomplished on a third networked computer using SonarData Echoview software (V3.50.54.3818). First, the ER60 software was used to generate a single .dg file for each transect (equals .raw data averaged over 1 m depth bins). Each .dg file was loaded into an Echoview fileset and an .ev file was created using a custom data processing template. Echograms of the volume backscattering strength data (S_v; m^2/m^3) at each of the five frequencies were displayed. An integration start line was created at a fixed depth of 12 m (apx. 4.6 m below the transducers). An integration stop line was created 2 m above the 38 kHz sounder detected bottom. The S_v echograms were filtered of on-station time periods using a slow (i.e. <8 knots) ship speed as a proxy. The difference between S_v at 200 kHz and S_v at 38 kHz (S_{v200}-S_{v38}) was then used to filter the S_v data at all frequencies for fish with swimbladders (-30 dB< S_{v200}- S_{v38}<5 dB). The resulting masked S_v data were thresholded at –60 dB, integrated over 5 m depth and 1 n.mi. cells, from 12 to 500 m, and output to .csv files for each transect and frequency.

A Matlab script was used to read the .csv files, integrate the volume backscattering coefficients from 12 to 70 m, and convert the resulting area backscattering strengths (m^2/m^2) to fish biomass density (kg/m^2) and biomass. The conversions factors were combined target strength-to-length and length-to-biomass relationships developed by Barange and Hampton (1997). The relationships for anchovy (*E. capensis*) and sardine (*S. sagax*) are based on *in-situ* target strength (TS) measurements (Barange et al., 1996):

$$TS\ (dB/kg) = -12.1*\log L_t-21.1 \quad \text{for anchovy; and} \quad (Eq.\ 1)$$
$$TS\ (dB/kg) = -14.9*\log L_t-13.2 \quad \text{for sardine,} \quad (Eq.\ 2)$$

where L_t (cm) is total fish length determined from the trawls. Calculations were performed using distributions of fish length estimated from the trawl catches. Note that Eq.s (1) and (2) predict ~5dB difference in TS/kg, for anchovy and sardine of the same length.

The survey was conducted along regularly-spaced parallel transects (Fig. I.1). Each east-west transect was considered a sampling unit. The method of Jolly and Hampton (1990) was used to estimate biomass density and sampling variance from the transect data, assuming that the fish were randomly distributed throughout the survey area. The coefficient of variation was calculated as the ratio of the standard deviation to the mean of the mean density for each of the transects.

Distributions of epipelagic swimbladdered fish (e.g. anchovy and sardine) were mapped in relation to sea surface temperature (SST) and the coastline using ESRI ArcGIS/ArcMap 9.1. The daily SST from the GOES 10-12 satellite were downloaded from http://poet.jpl.nasa.gov/ and averaged over two two-week periods using a Matlab script. Estimated fish distributions from the acoustic data collected aboard FSV *Oscar Dyson* were overlaid on the daily SST averaged from 20 April to 4 May 2006.

I.3.1.6 EK60 Results

The multi-frequency acoustic data indicated that epipelagic fish were very patchily distributed throughout the survey area (Fig. I.5). Highest fish densities were located in the southern portion and in areas with SST ranging from 11-16 °C. A strong positive relationship was observed between the largest densities fish and the number of anchovy and sardine eggs collected by CUFES. In most areas where high densities of CPS were mapped, either sardine or anchovy eggs were collected by the CUFES system.

Following the procedures of Jolly and Hampton (1990), the mean biomass density for the west-east transects 1-18 was 0.0027 kg/m^2 with a C.V. of 79.2%. Assuming all of the 38 kHz backscattering filtered for epipelagic fish with swimbladders was from sardine, the preliminary biomass estimate is 2.00 Mt (million metric tons). Additional analyses will be done to apportion this total biomass to sardine, anchovy, and Pacific and jack mackerel.

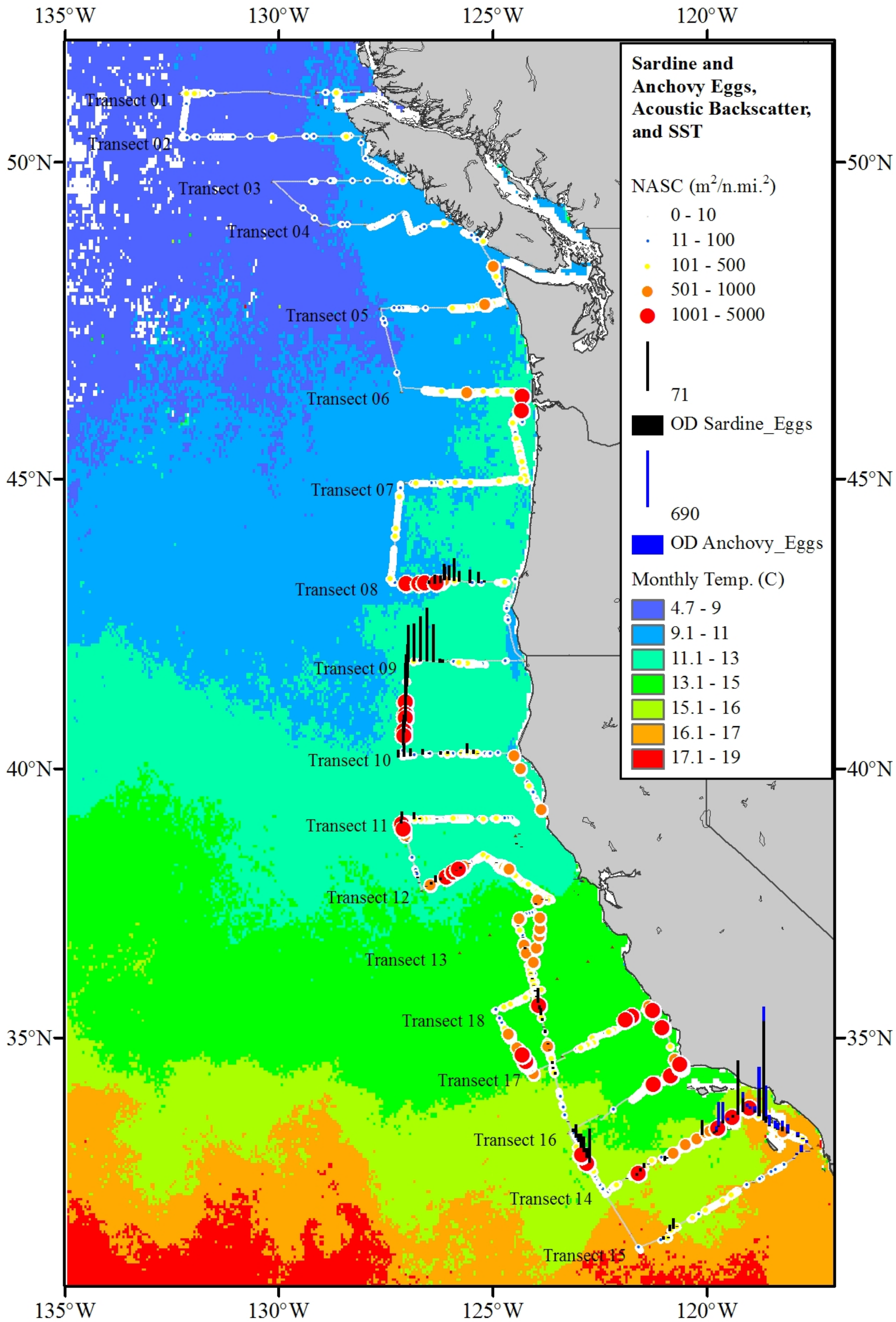


Figure I.5. Integrated volume backscattering coefficients (NASC at 38 kHz; $m^2/n.mi.^2$) attributed to epipelagic (12-70 m) fish with swimbladders (colored dots), overlaid on sea-surface temperatures (GOES 10-12 satellite) averaged from 20 April to 4 May and egg-pump counts (from FSV *Oscar Dyson* only) for anchovy (blue bars) and sardine (black bars).

Table I.3. Preliminary estimates of biomass density and biomass for all epipelagic fish with swimbladders (12-70 m depth). The conversion from integrated volume backscattering coefficients to biomass density assumed all targets were sardine and the target strength-to-mass relationship (dB/kg) reported by Barange and Hampton (1997) is accurate. From the west-east transects, numbers 1-18: mean biomass density = 0.0027 kg/m^2; C.V. = 79.2%; biomass = 2.00 Mt (million metric tons).

Transect	Segment	Length (n.mi.)	Biomass Density (kg/m^2)	Standard Deviation
1	1	181	0.0003	0.0013
	2	44	0.0010	0.0010
2	3	189	0.0003	0.0009
	4	68	0.0003	0.0003
3	5	145	0.0003	0.0014
	6	63	0.0001	0.0001
4	7	155	0.0005	0.0007
	8	111	0.0009	0.0028
5	9	123	0.0036	0.0061
	10	83	0.0001	0.0001
6	11	128	0.0048	0.0052
	12	107	0.0043	0.0124
7	13	128	0.0021	0.0025
	14	105	0.0016	0.0019
8	15	138	0.0046	0.0193
	16	105	0.0001	0.0002
9	17	124	0.0009	0.0020
	18	100	0.0048	0.0193
10	19	138	0.0007	0.0020
	20	78	0.0017	0.0058
11	21	136	0.0024	0.0034
	22	82	0.0030	0.0148
12	23	88	0.0053	0.0132
	24	90	0.0083	0.0080
13	25	68	0.0026	0.0053
	26	346	0.0021	0.0052
14	27	224	0.0072	0.0270
	28	95	0.0054	0.0214
15	29	253	0.0009	0.0020
	30	167	0.0023	0.0166
16	31	171	0.0051	0.0189
	32	85	0.0219	0.1183
17	33	175	0.0033	0.0153
	34	91	0.0091	0.0242
18	35	66	0.0030	0.0029
	36	116	0.0024	0.0067

From the west-east transects, numbers 1-18: mean biomass density = 0.0027 kg/m^2; C.V. = 79.2%; biomass = 2.00 Mt.

There is likely a negative bias in these data due to diel vertical migration. That is, the fish may move from depths of 15-70 m during the day to 0-15 m at night, where they are ineffectively sampled by the down-looking echosounders and sonar. Some evidence that this is the case is found in the trawl data; the surface trawls only caught fish at night. Additionally, averaging the acoustically estimated epipelagic fish densities over depth and hour of the day, a reasonably clear pattern of this effect emerges (Fig. I.6). Nearly all of the acoustical detections of fish occurred in daylight hours between 0500 and 2000 PST. Therefore, the nighttime data is negatively biased, if useable for CPS.

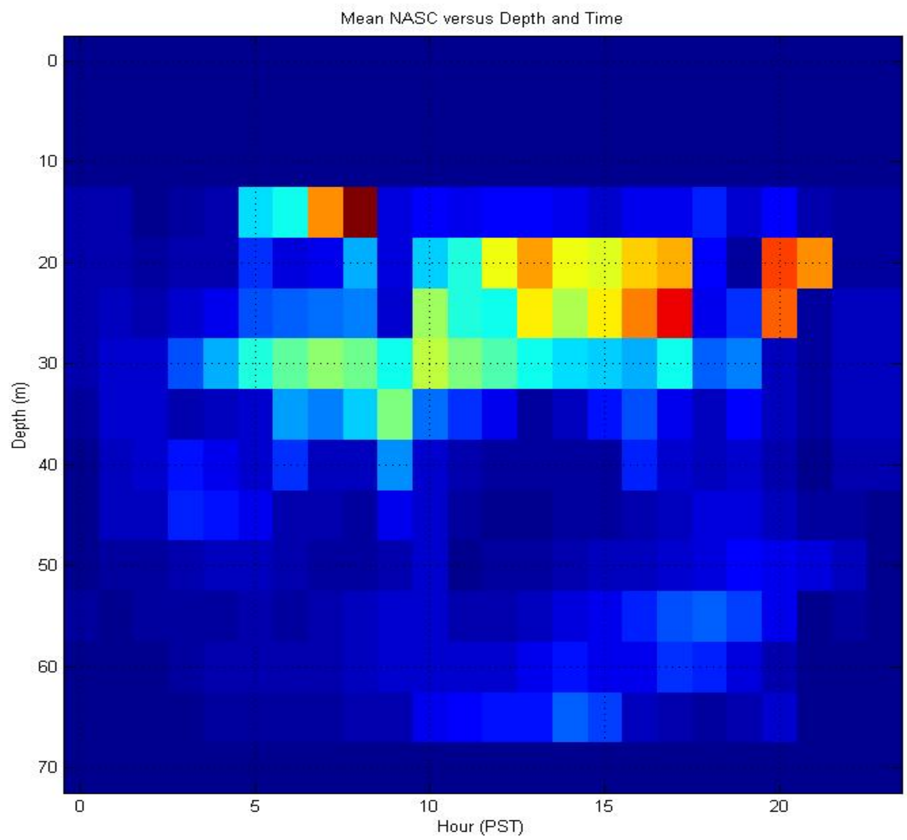


Figure I.6. Average NASC ($m^2/n.mi.^2$) attributed to epipelagic fish schools on west-east transects versus depth (5 m bins) and time of day (PST; 1 hour bins). Diel vertical migration is apparent; most fish detections were during daylight hours.

In addition to the fish scatter from epipelagic fish, other large fish schools and aggregations of zooplankton were observed at greater depths. All sound 38 kHz sound scatterers observed were described in (Table I.4), and imaged for each transect (Figs. I.7-I.42). In shallow water, aggregations of demersal fish are commonly seen in the echograms. Large zooplankton aggregations are evident at almost every crossing of the continental shelf break. Offshore, many large fish schools were mapped at depths from 70 to 300 m.

Table I.4. Transect Summaries (Dates and times in GMT).

Transect Name	Start Latitude	Start Longitude	Start Time	Start Date	End Latitude	End Longitude	End Time	End Date	Comments
Transect 1	51° 03.26' N	128° 05.57' W	0342	12-Apr-06	51° 01.82' N	132° 17.09'W	0304	13-Apr-06	Onshore – offshore. 4 segments between 5 stations. 1st segment < 150 m water depth, several schools of fish near bottom in latter part of segment. 2nd segment: fish aggregation associated with shelf break at mile 64. 3rd segment: light scattering layer, strongest at higher frequencies, descending from 150 m to 350 m. 4th segment: light scattering layer, strongest at higher frequencies ascending from 300 m to 200 m. Moderate scattering layer on all frequencies in upper 50 m.
Transect 1 to 2	51° 00.35' N	132° 07.92' W	0732	13-Apr-06	50° 22.84' N	132° 13.88' W	1045	13-Apr-06	
Transect 2	50° 22.64' N	132° 17.07' W	1554	13-Apr-06	50° 23.93' N	128° 03.41' W	1325	14-Apr-06	Offshore – onshore. 4 segments between 5 stations. 1st segment: moderate scattering layer 250 – 300 m strongest at low frequencies, sparse scattering layer 25 – 50 m strongest at high frequencies, 4 s ping interval. 2nd segment: sparse to moderate scattering layer 250 – 350 m strongest at low frequencies, moderate scattering layer 25 – 50 m strongest at high frequencies, 4 s ping interval. 3rd segment: sparse scattering 250 m rising to 100 – 150 m strongest at low frequencies, 4 s ping interval. 4th segment: bottom ghost on 18 and 38 kHz, sparse scattering layer 150 m strongest at low frequencies, sparse scattering layer 0 – 100 m strongest at high frequencies, shelf break at mile 194, thin dense layers strongest at low frequencies, 2 s ping interval.
Transect 2 to 3	50° 23.97' N	128° 05.19' W	1511	14-Apr-06	49° 43.69' N	127° 02.49' W	2015	14-Apr-06	
Transect 3	49° 43.84' N	127° 03.36' W	2058	14-Apr-06	49' 43.02' N	130° 07.98' W	1325	15-Apr-06	Onshore – offshore. 3 segments between 4 stations. 1st segment: weak scattering layer in upper 50m along the shelf, strongest in higher frequencies. Strong targets at 200 to 250m, strongest at low frequencies and sparse scattering layer at 350m off the shelf break. Bottom ghost on 18 and 38 kHz. 2nd segment: sparse to moderate scattering layer 250 – 350 m strongest at low frequencies, with defined patches at higher frequencies. Weak scattering layer 25 – 50 m strongest at high frequencies. Bottom ghost on 18 and 38 kHz. 3rd segment: sparse scattering layers at 50 –100m and 250–350m at lower frequencies and 25-50m at high frequencies. Bottom ghost on 18 and 38 kHz.
Transect 3 to 4	49° 42.31' N	130° 06.65' W	1409	15-Apr-06	49° 03.66' N	129° 00.14' W	1850	15-Apr-06	
Transect 4	49° 03.65' N	128° 58.22' W	2035	15-Apr-06	49° 04.37' N	125° 56.56' W	1636	16-Apr-06	Offshore – onshore. 2 segments between 3 stations. 1st segment: weak scattering layer 150- 300in, strongest at low frequencies. Stronger scattering layer around 50m at all

									frequencies. 2nd segment: jogging transect, skipped station. Moderate scattering layer around 50m, intensifying and spreading to 100m on the shelf, with targets on the shelf break, strongest at low frequencies. Bottom ghost on 18 and 38 kHz.
Transect 4 to 5	48° 52.77'N	125° 31.70' W	1930	16-Apr-06	47° 46.46' N	124° 39.06' W	0820	17-Apr-06	
Transect 5	47° 52.37' N	124° 48.04' W	1127	17-Apr-06	47° 45.40'N	127° 36.89' W	2343	17-Apr-06	Onshore – offshore. 3 segments between 4 stations. 1st segment: dense scattering layer 9 - 100m across the shelf, strongest at low frequencies. Dense to moderate scattering layer in upper 50m off the shelf with stronger targets patches in the high frequencies. Moderate scattering layer 150 –300m, strongest at low frequencies. Bottom ghost on 18 and 38 kHz. 2nd segment: Moderate to dense scattering layer in upper 50m, strongest at low frequencies. Weak scattering layer 200 – 300m, strongest at low frequencies. Bottom ghost on 18 and 38 kHz. 3rd segment: Weak to moderate scattering layer in upper 50m, strongest at low frequencies. Weak scattering layer 200 – 300m, strongest at low frequencies.
Transect 5 to 6	47° 44.60' N	127° 36.70' W	0115	18-Apr-06	46° 26.09' N	127° 07.63' W	0707	18-Apr-06	
Transect 6	46° 29.57' N	127° 04.42' W	1044	18-Apr-06	46° 26.42' N	124° 13.46' W	0000	19-Apr-06	Offshore – onshore. 3 segments between 4 stations. 1st segment: moderate to dense layer 0 – 75 m strongest at lower frequencies, bifurcating at mile 24 into two layers one in upper 50 m, the other descending to 200 m and then disappearing just before station. Another layer beginning at mile 36 and extending into station 100 – 150 m strongest at higher frequencies. 2nd segment: sparse layer 150 m strongest at low frequencies, very sparse layer 200 – 250 m strongest at 38 kHz, bottom ghost on 18 and 38 kHz at mile 60, sparse to moderate layer 175 – 275 m starting at mile 77 strongest at higher frequencies. 3rd segment: ghost bottom on 18 and 38 kHz mile 88 – 99, sparse layer 200 – 300 m strongest at 18 kHz, sparse layer 300 – 400 m strongest at 38 kHz, both rising and merging at shelf break mile 112 strongest at higher frequencies, extremely dense fish schools near bottom at mile 125.3 and 125.5 excluded as bottom.
Transect 6 to 7	46° 25.60' N	124° 14.11' W	0048	19-Apr-06	44° 56.98' N	124° 12.57' W	1012	19-Apr-06	
Transect 7	45° 00.62' N	124° 17.41' W	1347	19-Apr-06	44° 56.22' N	127° 00.93' W	0240	20-Apr-06	Onshore – offshore. 3 segments between 4 stations. 1st segment: moderate to dense layer 0 – 75 m strongest at lower frequencies. Very dense layer at low frequencies at mile 11.5, approximately 70m thick, following the shelf contour, then forming a weak layer around 250m. 2nd segment: Moderate to very dense layers between 12 and 100m, strongest on lower frequencies. Sparse layer between 200 and 350m. Ghost bottoms on 18 and 38 kHz. 3rd segment: Very dense to moderate layer between 12 and 100m,

									strongest at lower frequencies. Sparse layer 200 – 400 m, strongest on higher frequencies.
Transect 7 to 8	44° 56.01’ N	127° 08.97’ W	0603	20-Apr-06	43° 15.63’ N	127° 23.85’ W	1315	20-Apr-06	
Transect 8	43° 15.32’ N	127° 25.35’ W	1455	20-Apr-06	43° 16.32’ N	124° 39.62’ W	0525	21-Apr-06	
Transect 8 to 9	43° 21.69’ N	124° 21.75’ W	1626	23-Apr-06	41° 54.65’ N	124° 16.44’ W	2316	23-Apr-06	
Transect 9	41° 54.14’ N	124° 27.51’ W	0106	24-Apr-06	41° 54.11’ N	126° 57.17’ W	1555	24-Apr-06	
Transect 9 to 10	41° 53.24’ N	126° 57.89’ W	1737	24-Apr-06	40° 16.51’ N	127° 06.12’ W	0408	25-Apr-06	
Transect 10	40° 12.86’ N	127° 12.81’ W	0730	25-Apr-06	40° 17.16’ N	124° 29.39’ W	2202	25-Apr-06	
Transect 10 to 11	40° 14.80’ N	124° 29.65’ W	2355	25-Apr-06	39° 08.71’ N	123° 47.62’ W	0508	26-Apr-06	
Transect 11	39° 06.28’ N	124° 34.63’ W	0215	29-Apr-06	39 05.79’ N	127 09.41’ W	1313	29-Apr-06	This transect was added on 28 April by the lab. Former Transect 11 was renamed 12 and all subsequent transects follow in sequence.
Transect 11 to 12	39° 04.50’ N	127° 09.38° W	1316	29-Apr-06	37° 46.56’ N	126° 39.42’ W	1910	29-Apr-06	
Transect 12	37° 48.01’ N	126° 40.37’ W	2056	29-Apr-06	38° 26.47’ N	125° 11.62’	0548	30-Apr-06	
Transect 12 to 13	38° 25.31’ N	125° 09.41’ W	0558	30-Apr-06	37° 36.75’ N	123° 36.25’ W	1247	30-Apr-06	
Transect 13	37° 36.67’ N	123° 36.29’ W	1252	30-Apr-06	37° 12.94’ N	124° 26.86’ W	1734	30-Apr-06	Begin at inshore CalCOFI Station 60.0/60.0, surveyed to station 60.0/70.0, then broke line to head south for better conditions. Headed to CalCOFI Line 80.0.
Transect 13 to 14	37° 12.84’ N	124° 26.88’ W	1735	30-Apr-06	31° 56.11’ N	122° 21.65’ W	1941	1-May-06	
Transect 14	31° 57.01’ N	122° 20.47’ W	1948	1-May-06	33° 39.46’ N	118° 58.59’ W	1714	2-May-06	CalCOFI Line 80.0.
Transect 14 to 15	33° 39.55’ N	119° 02.34’ W	1843	2-May-06	32° 50.98’ N	117° 31.74’ W	0214	3-May-06	
Transect 15	32° 47.69’ N	117° 36.53’ W	0349	3-May-06	30° 50.81’ N	121° 35.36’ W	0756	4-May-06	
Transect 15 to 16	30° 47.65’ N	121° 31.87’ W	0927	4-May-06	33° 09.01’ N	123° 13.26’ W	0001	5-May-06	
Transect 16	33° 09.36’ N	123° 12.87’ W	0004	5-May-06	34° 26.44’ N	120° 31.97’ W	1720	5-May-06	
Transect 16 to 17	34° 24.99’ N	120° 32.62’ W	1842	5-May-06	35° 36.55’ N	121° 19.61	0101	6-May-06	
Transect 17	35° 36.51’ N	121° 20.15’ W	0104	6-May-06	34° 20.02’ N	124° 04.07’ W	1813	6-May-06	
Transect 17 to 18	34° 16.73’ N	124 01.33’ W	1937	6-May-06	35° 30.73’ N	124° 56.89’ W	0502	7-May-06	
Transect 18	35° 31.01’ N	124 57.74’ W	0524	7-May-06	35° 55.47’ N	123° 52.83’ W	1121	7-May-06	Transect ended prematurely to head north for trawling.
Transect 18-19	35° 20.20’ N	123 56.00’ W	1003	7-May-06	37° 23.10’ N	123° 56.00’ W	0114	8-May-06	Trawling not possible due to 30+ kt winds.

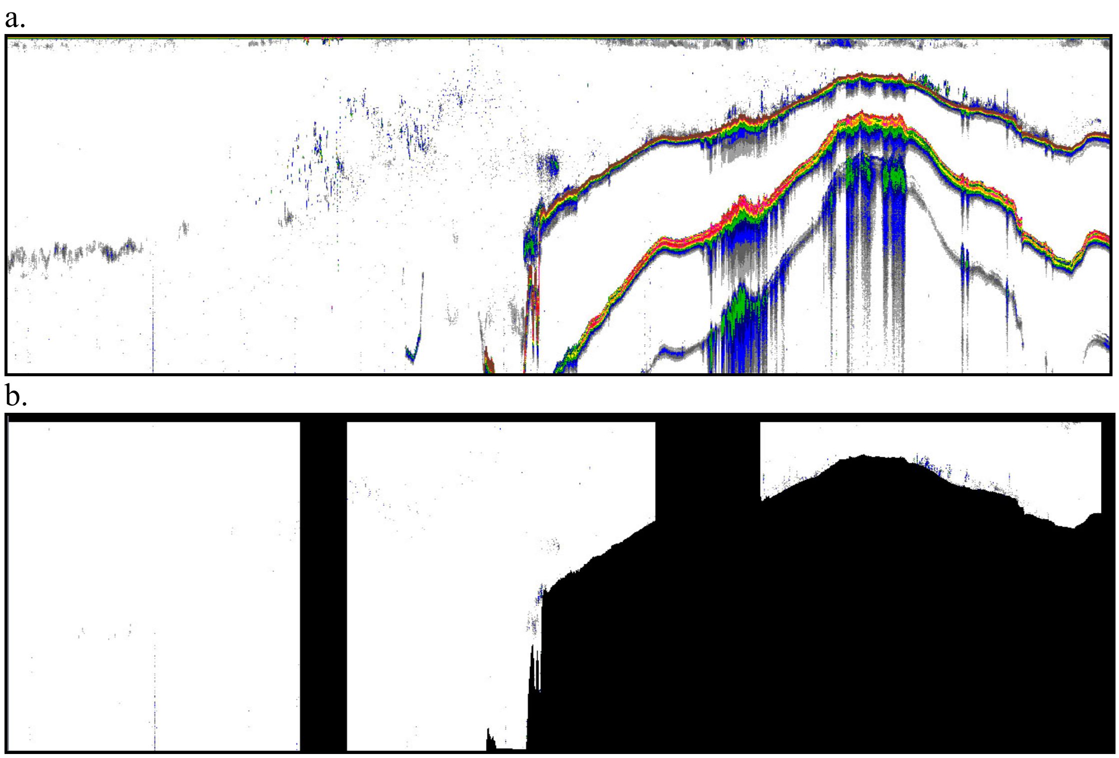


Figure I.7. Transect 1: original (a) and filtered (b) echograms (depth: 0-500m; distance: 181 n.mi.; not to scale). The filtering process is described in section I.3.1.5.

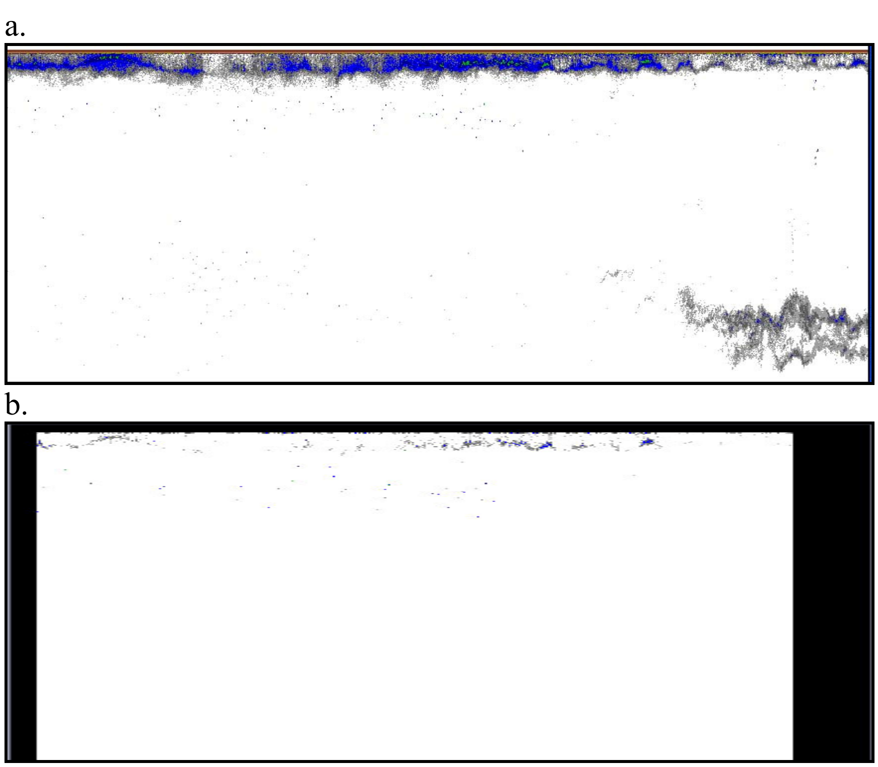
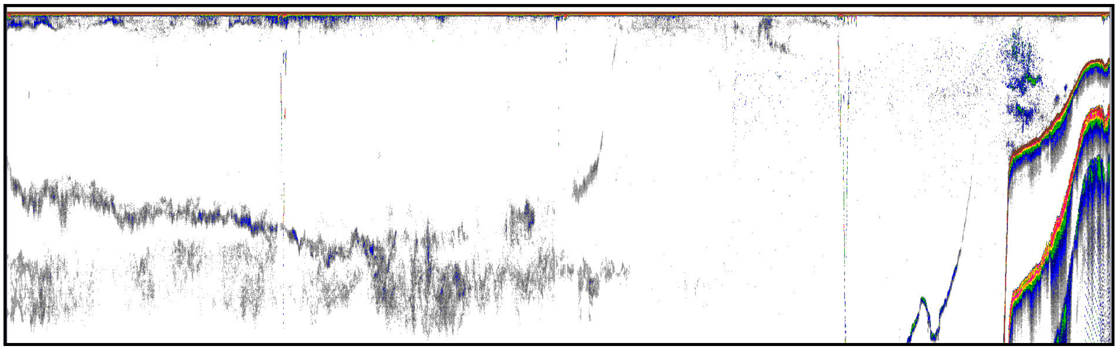


Figure I.8. Segment 1 to 2: original (a) and filtered (b) echograms (depth: 0-500m; distance: 44 n.mi.; not to scale).

a.



b.

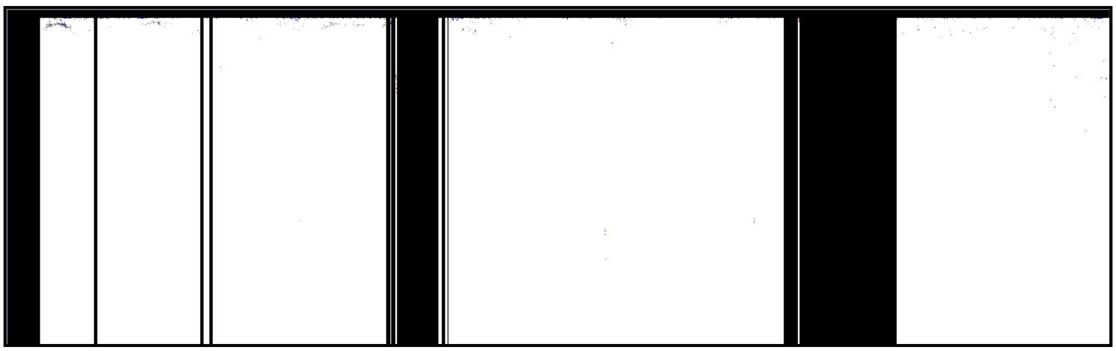
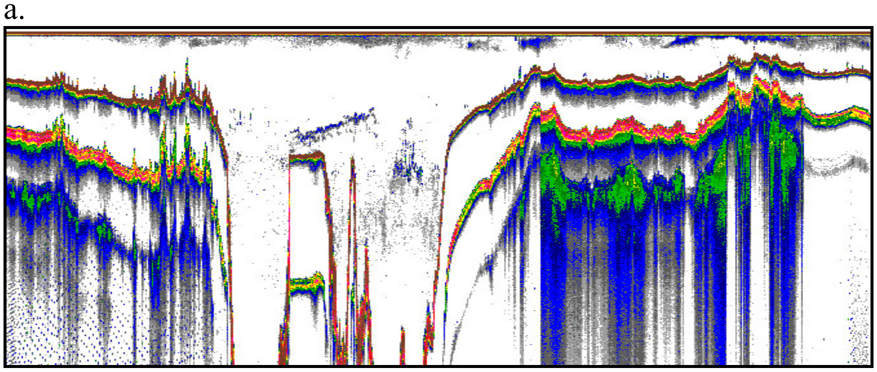


Figure I.9. Transect 2: original (a) and filtered (b) echograms (depth: 0-500m; distance: 189 n.mi.; not to scale).

a.



b.

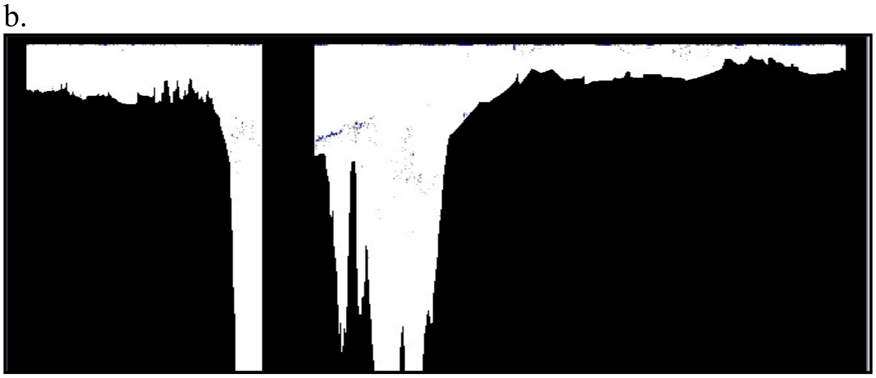


Figure I.10. Segment 2 to 3: original (a) and filtered (b) echograms (depth: 0-500m; distance: 68 n.mi.; not to scale).

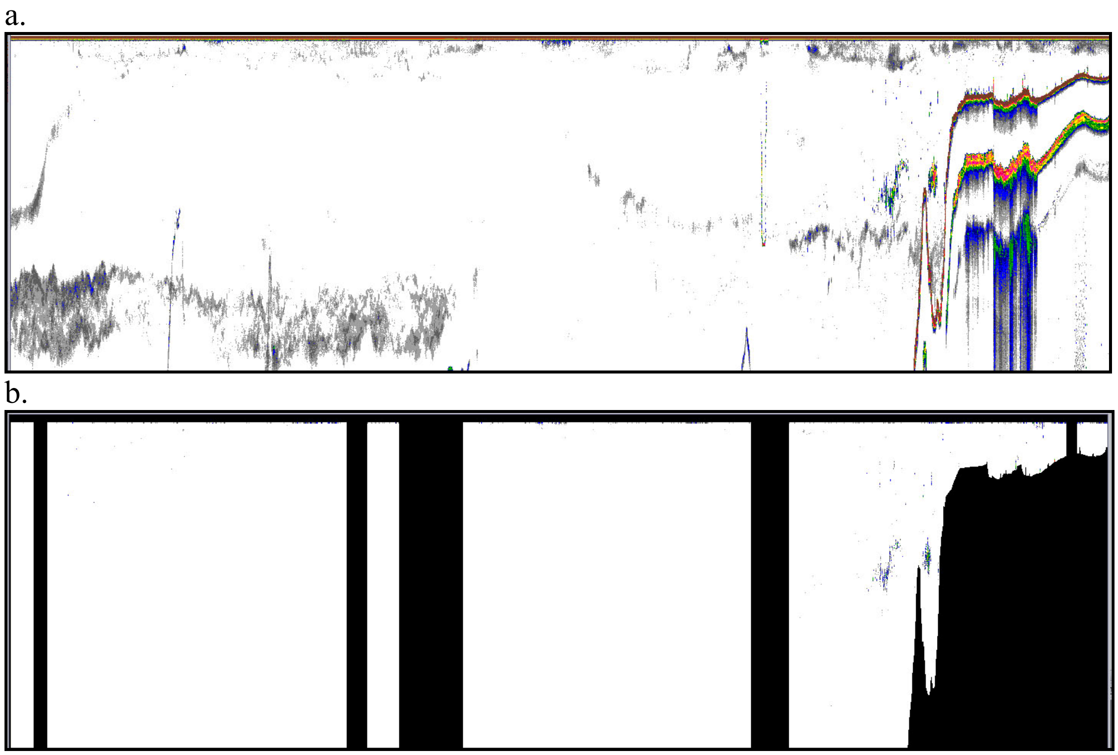


Figure I.11. Transect 3: original (a) and filtered (b) echograms (depth: 0-500m; distance: 145 n.mi.; not to scale).

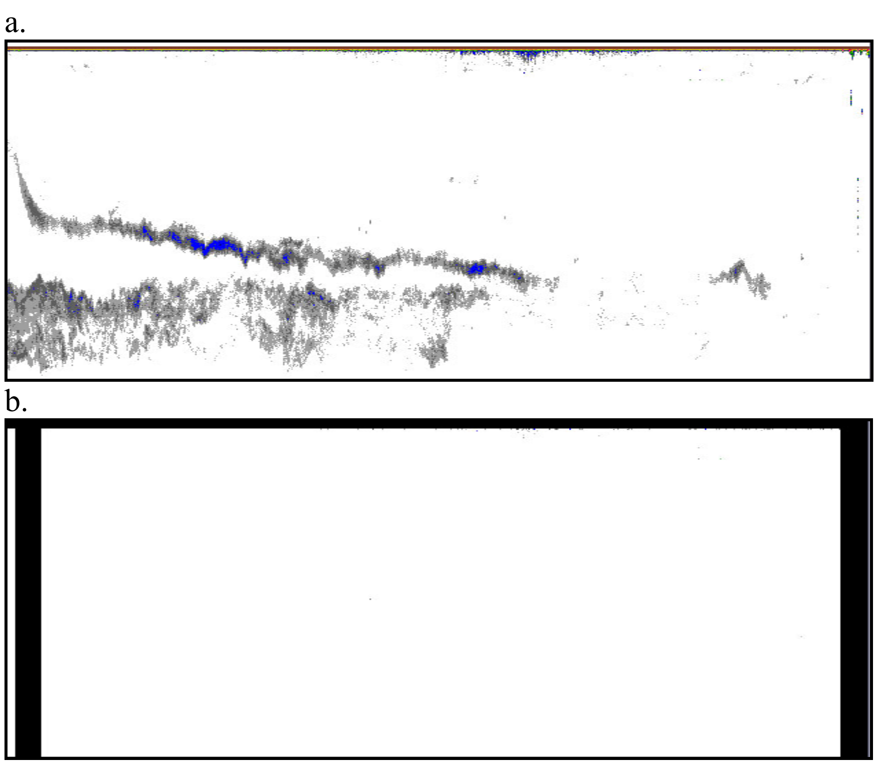
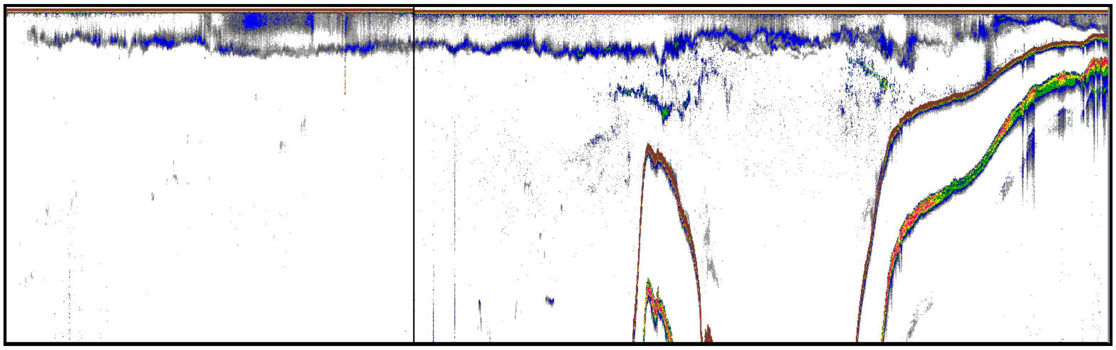


Figure I.12. Segment 3 to 4: original (a) and filtered (b) echograms (depth: 0-500m; distance: 63 n.mi.; not to scale).

a.



b.

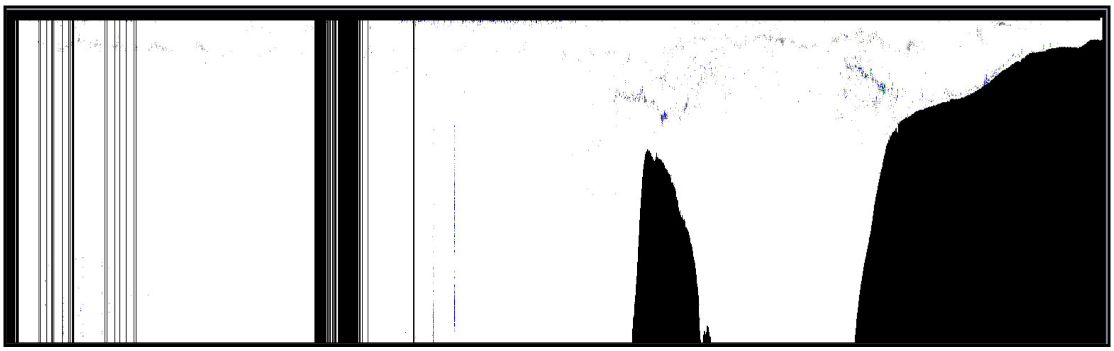
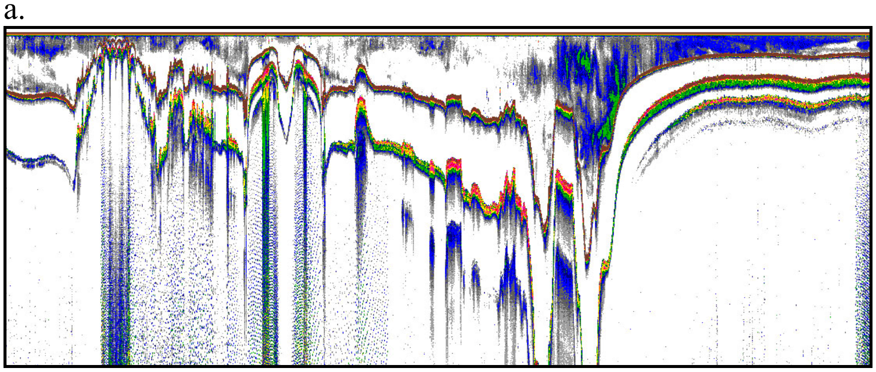


Figure I.13. Transect 4: original (a) and filtered (b) echograms (depth: 0-500m; distance: 155 n.mi.; not to scale).

a.



b.

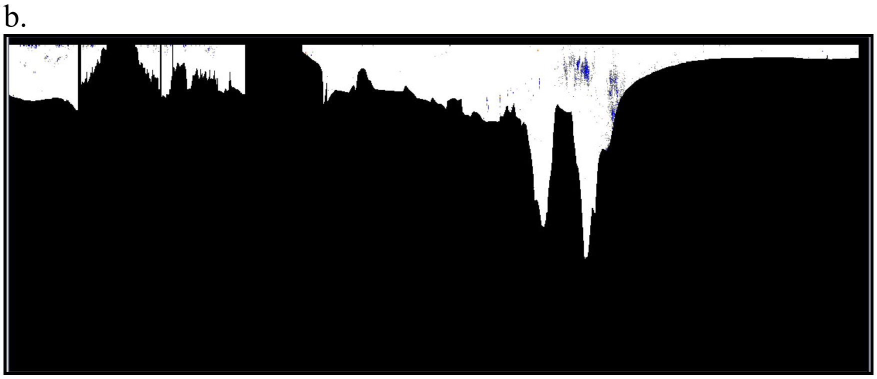
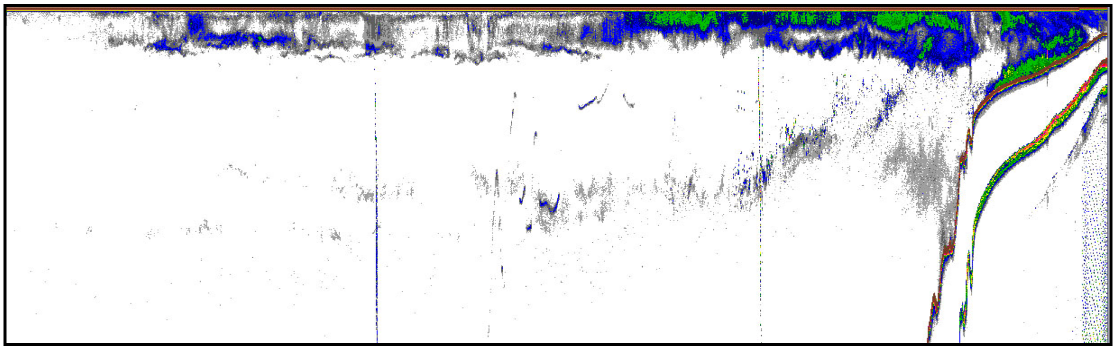


Figure I.14. Segment 4 to 5: original (a) and filtered (b) echograms (depth: 0-500m; distance: 111 n.mi.; not to scale).

a.



b.

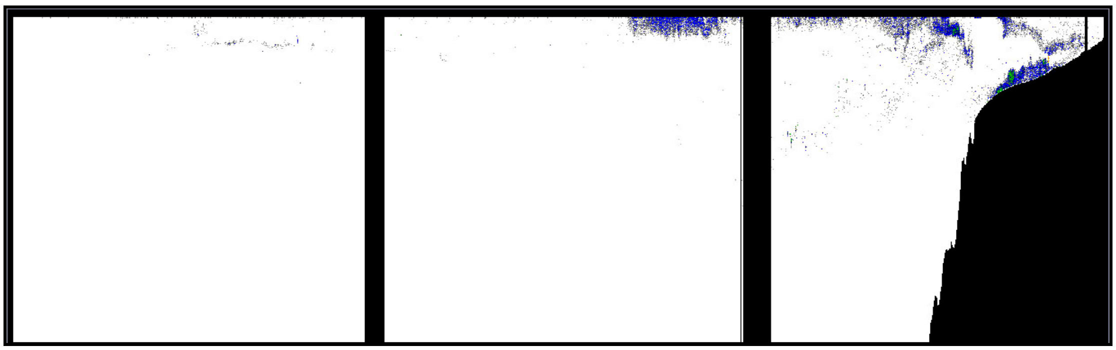
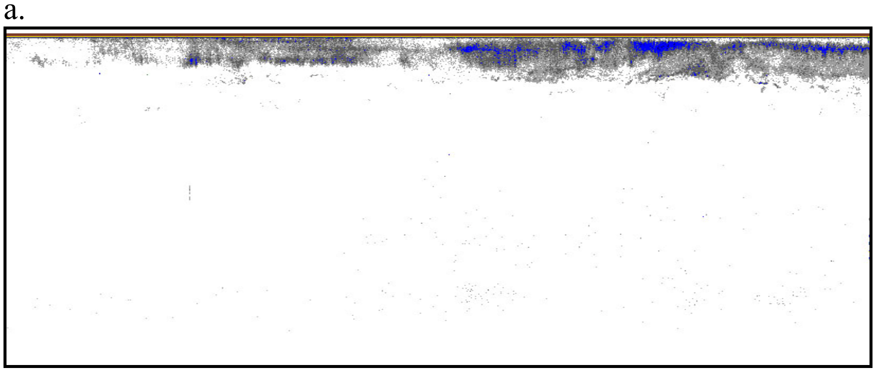


Figure I.15. Transect 5: original (a) and filtered (b) echograms (depth: 0-500m; distance: 123 n.mi.; not to scale).

a.



b.

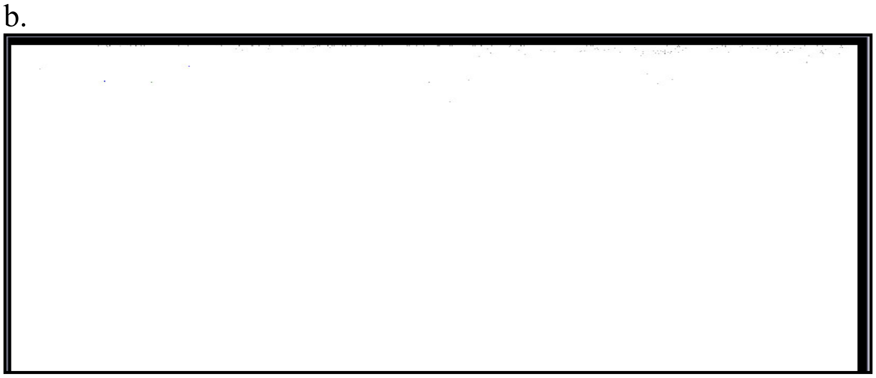
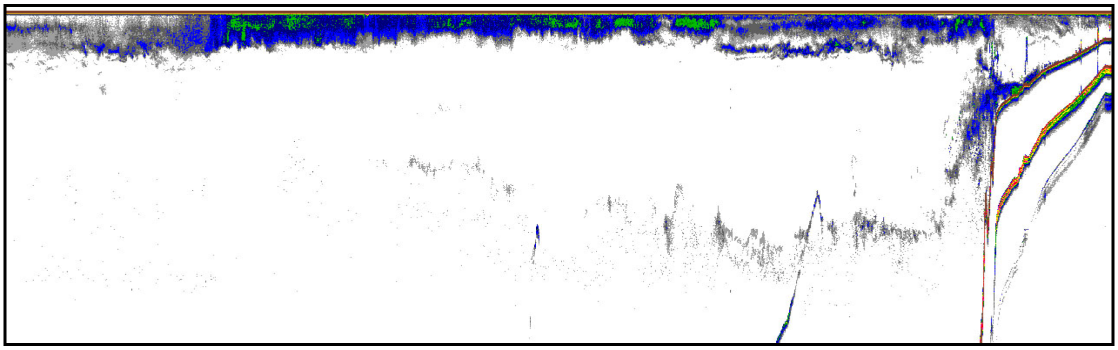


Figure I.16. Segment 5 to 6: original (a) and filtered (b) echograms (depth: 0-500m; distance: 44 n.mi.; not to scale).

a.



b.

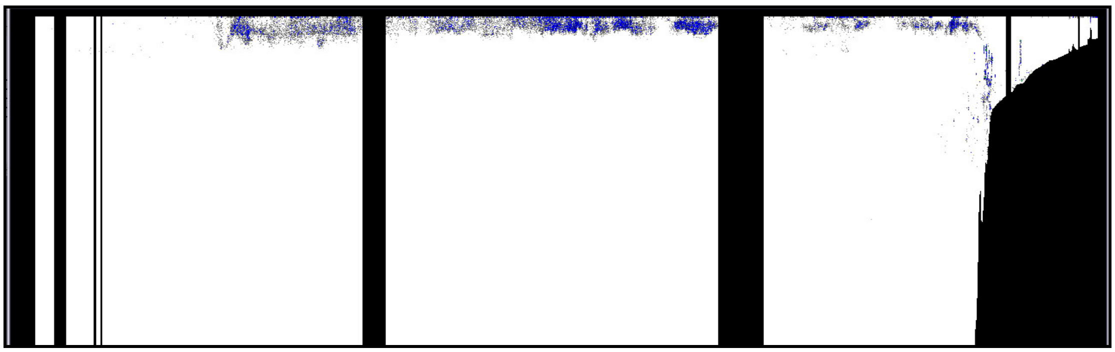
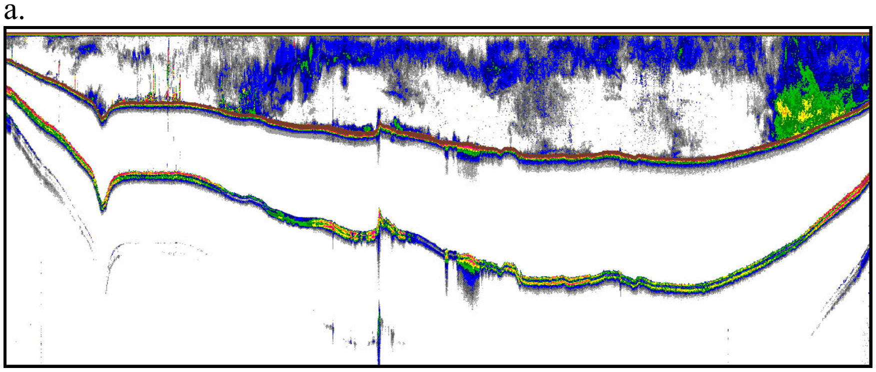


Figure I.17. Transect 6: original (a) and filtered (b) echograms (depth: 0-500m; distance: 128 n.mi.; not to scale). Note demersal fish, zooplankton on break, and false bottom.

a.



b.

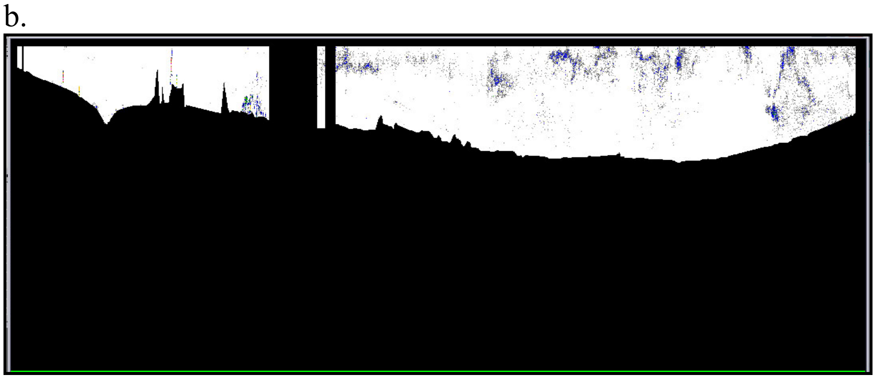


Figure I.18. Segment 6 to 7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 107 n.mi.; not to scale).

a.
b.

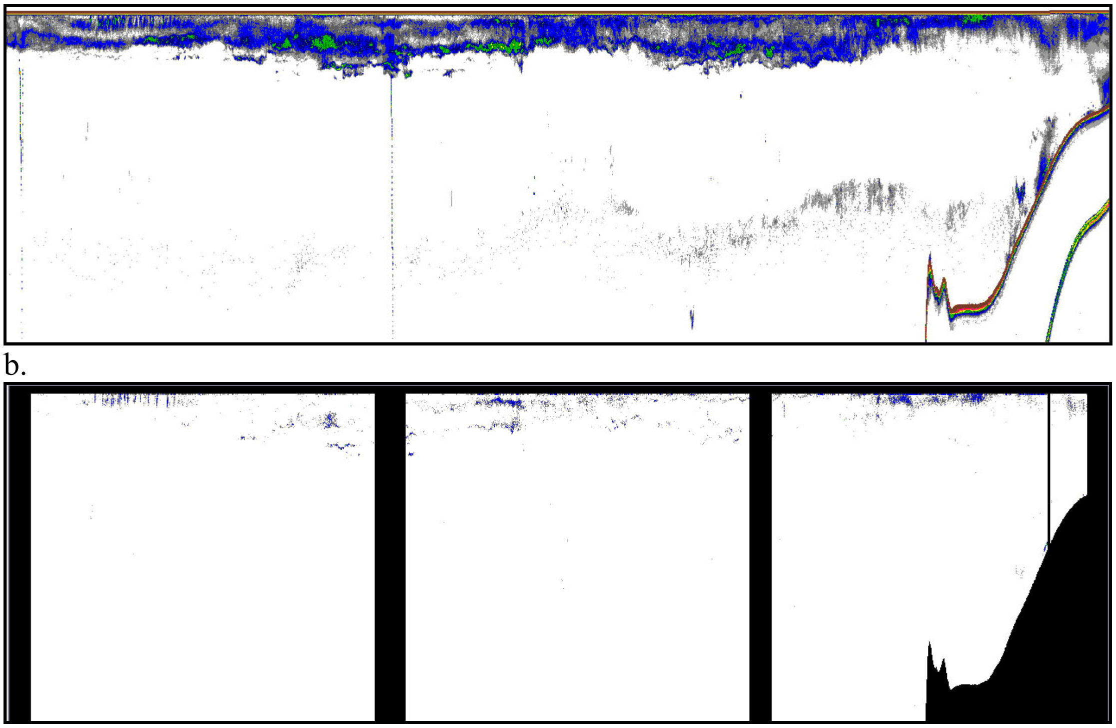


Figure I.19. Transect 7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 128 n.mi.; not to scale).

a.
b.

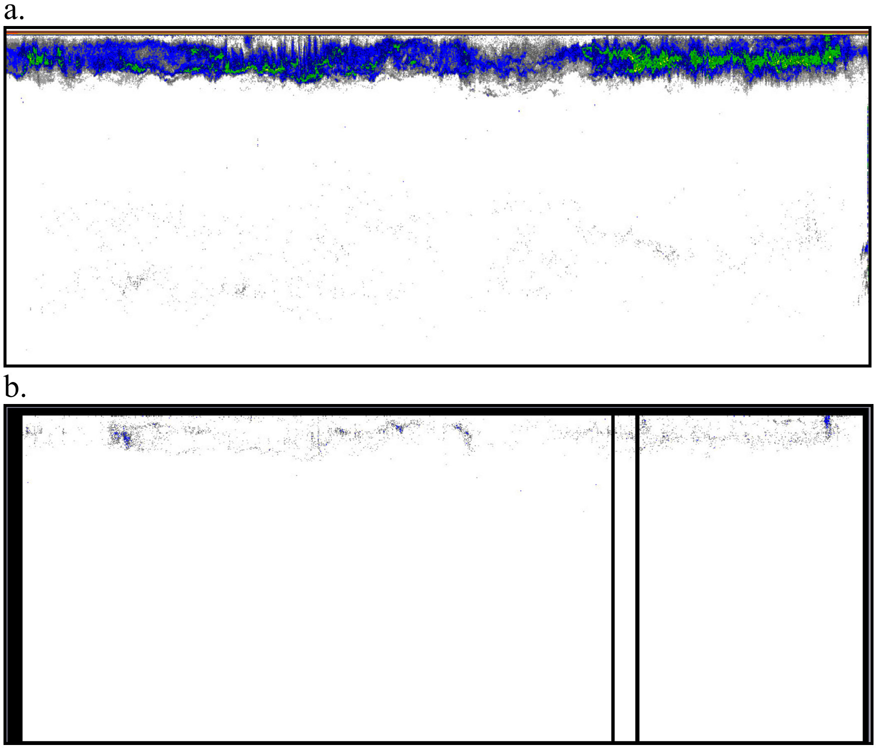
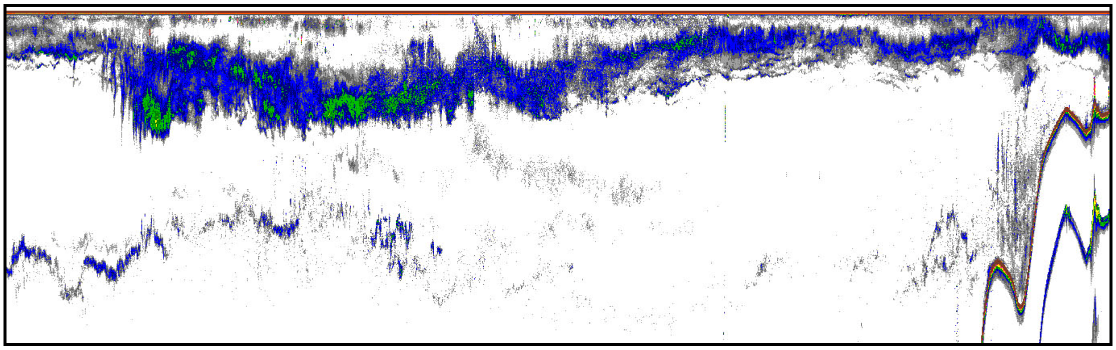


Figure I.20. Segment 7 to 8: original (a) and filtered (b) echograms (depth: 0-500m; distance: 105 n.mi.; not to scale).

a.



b.

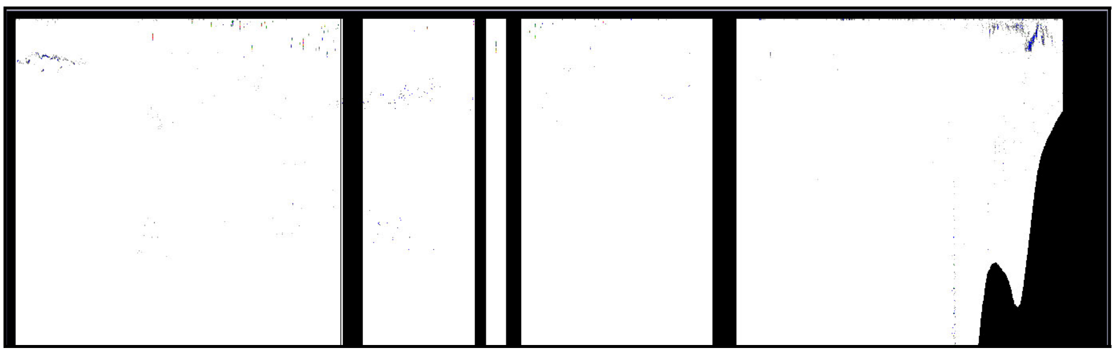
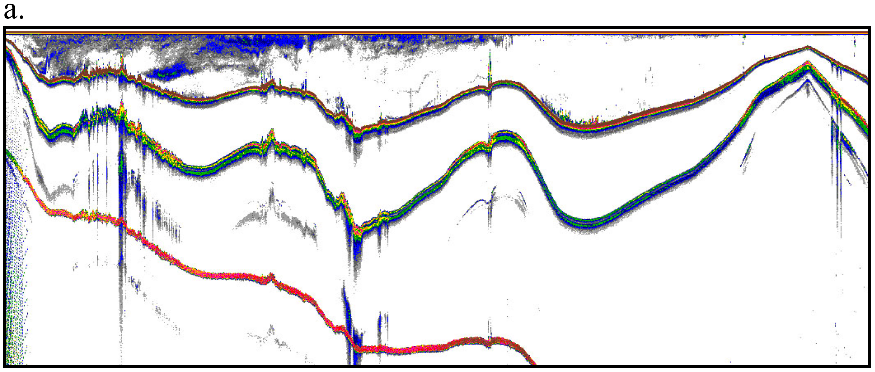


Figure I.21. Transect 8: original (a) and filtered (b) echograms (depth: 0-500m; distance: 138 n.mi.; not to scale).

a.



b.

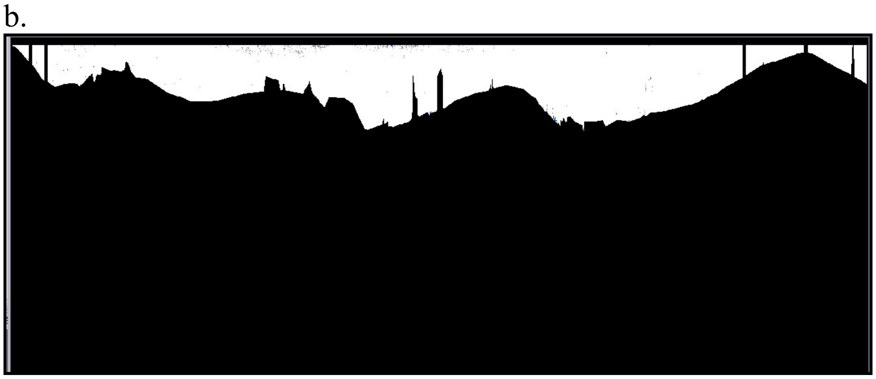


Figure I.22. Segment 8 to 9: original (a) and filtered (b) echograms (depth: 0-500m; distance: 105 n.mi.; not to scale).

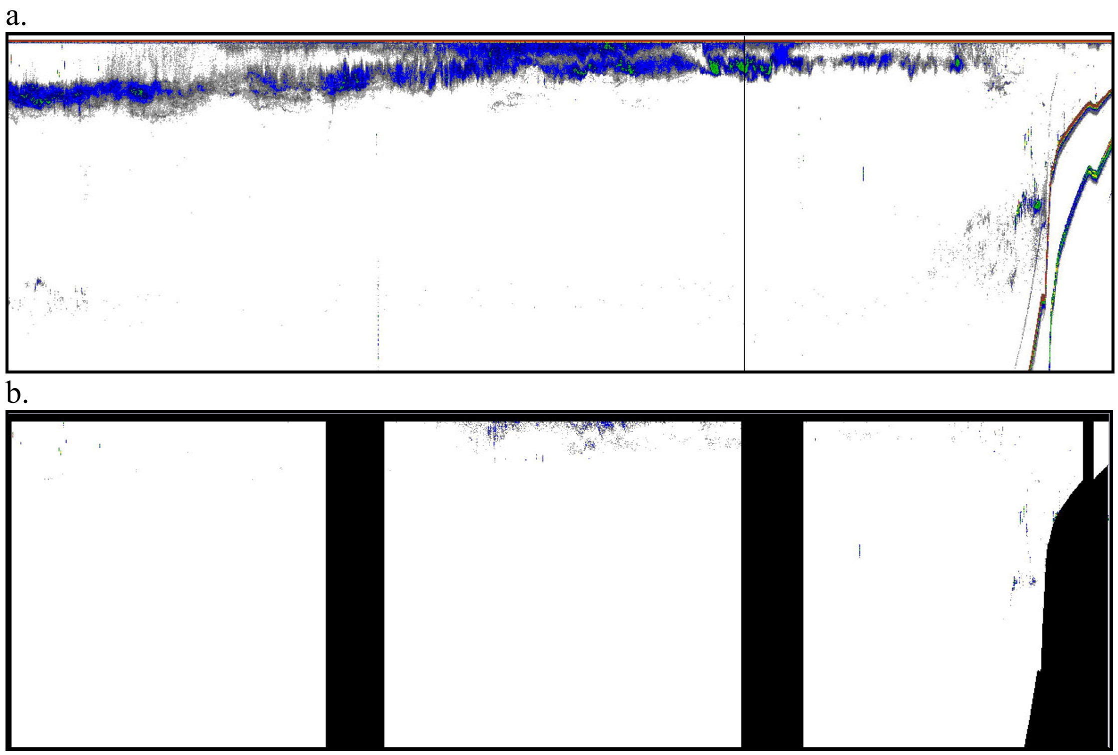


Figure I.23. Transect 9: original (a) and filtered (b) echograms (depth: 0-500m; distance: 124 n.mi.; not to scale).

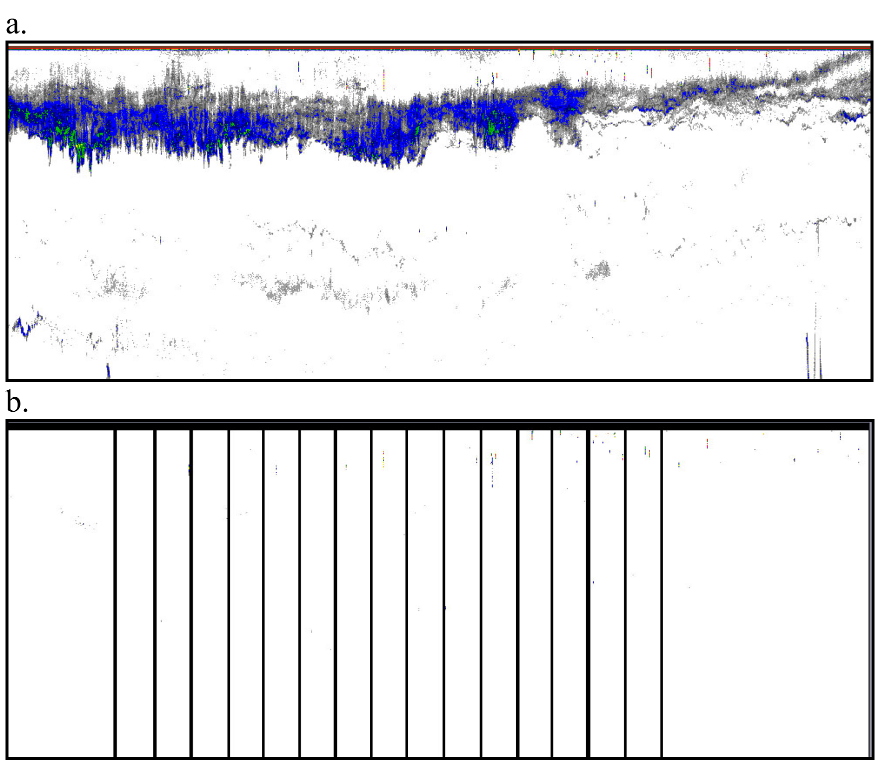


Figure I.24. Segment 9 to 10: original (a) and filtered (b) echograms (depth: 0-500m; distance: 124 n.mi.; not to scale).

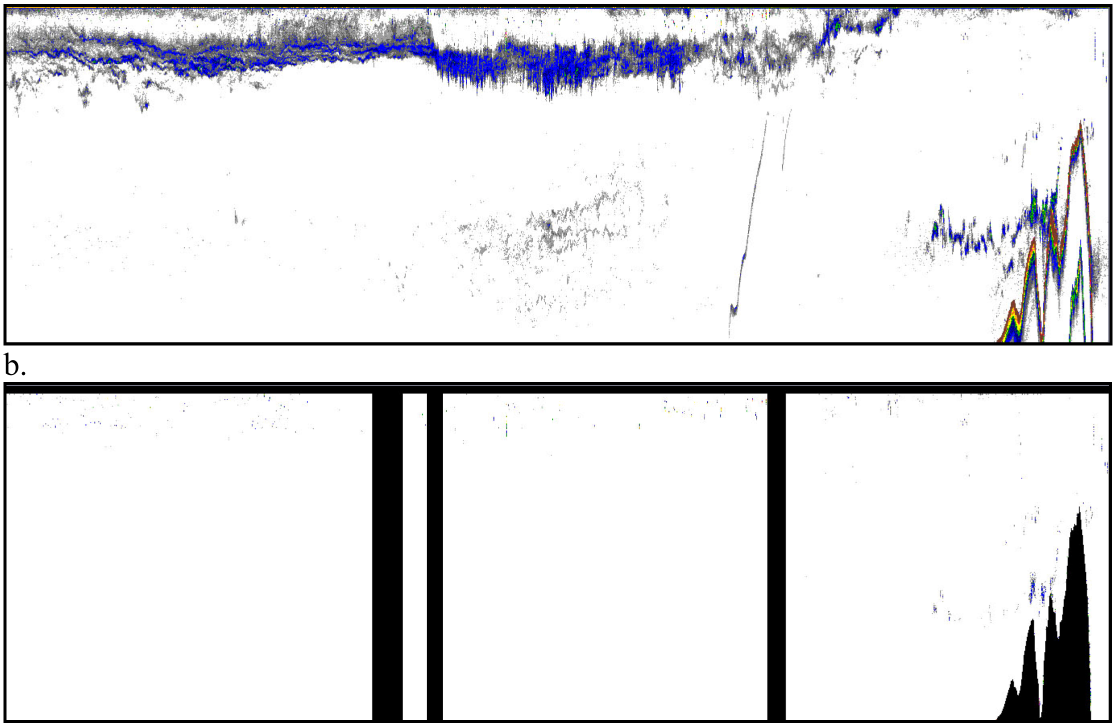
a.
b.


Figure I.25. Transect 10: original (a) and filtered (b) echograms (depth: 0-500m; distance: 138 n.mi.; not to scale).

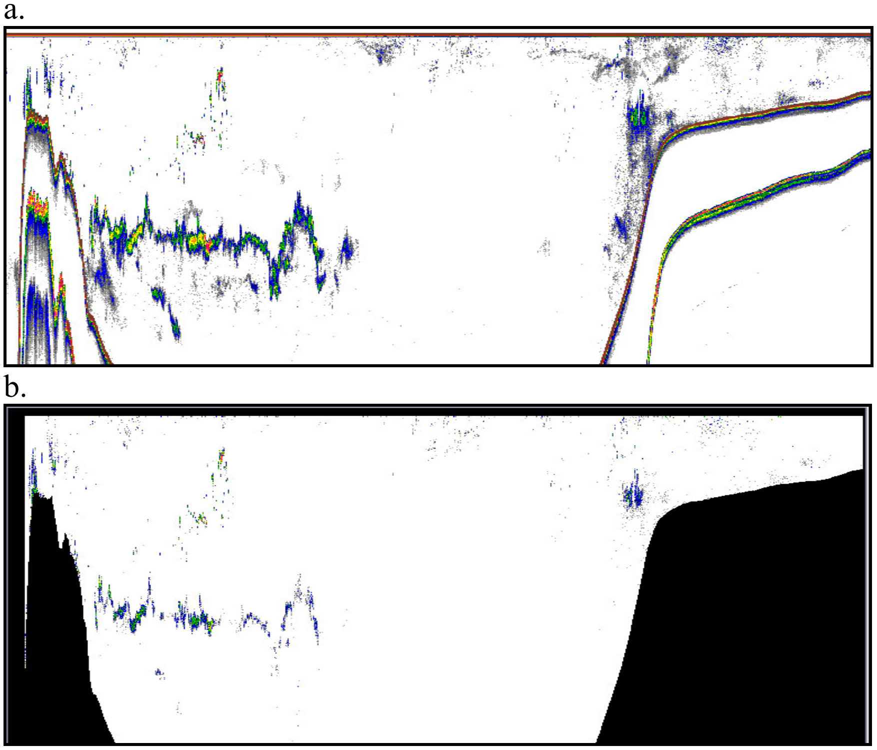
a.
b.


Figure I.26. Segment 10 to 11: original (a) and filtered (b) echograms (depth: 0-500m; distance: 78 n.mi.; not to scale).

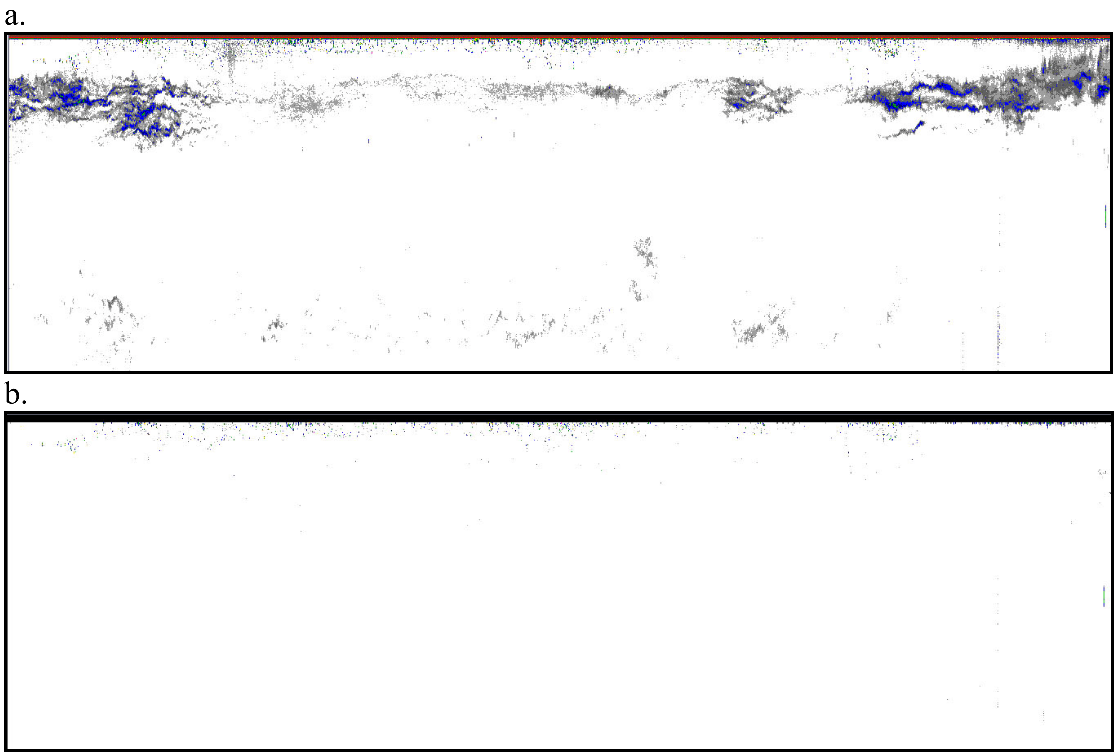


Figure I.27. Transect 11: original (a) and filtered (b) echograms (depth: 0-500m; distance: 136 n.mi.; not to scale).

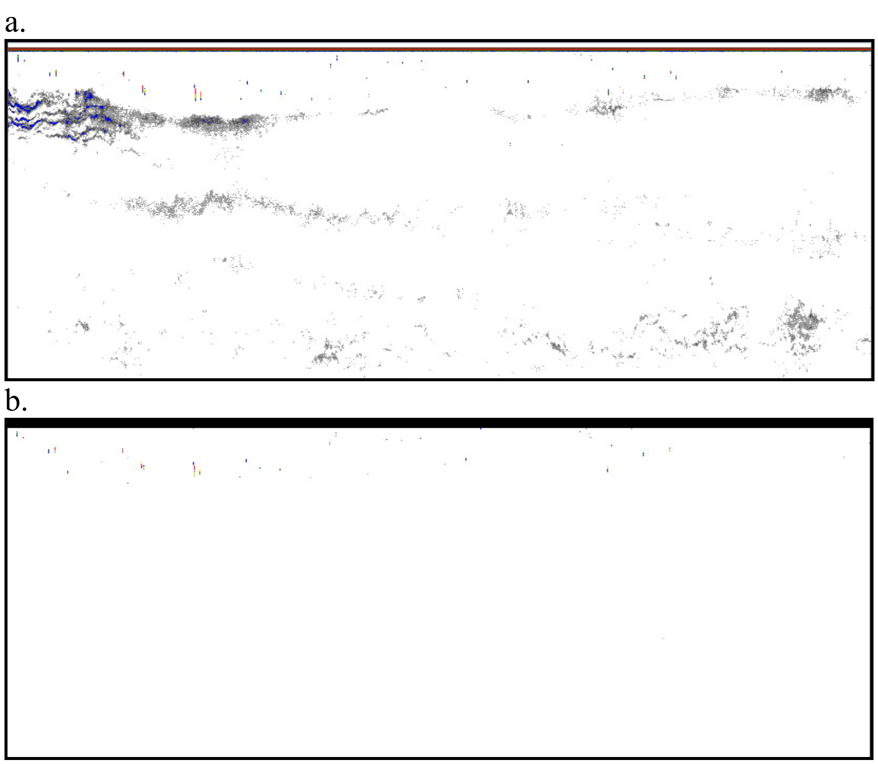


Figure I.28. Segment 11 to 12: original (a) and filtered (b) echograms (depth: 0-500m; distance: 82 n.mi.; not to scale).

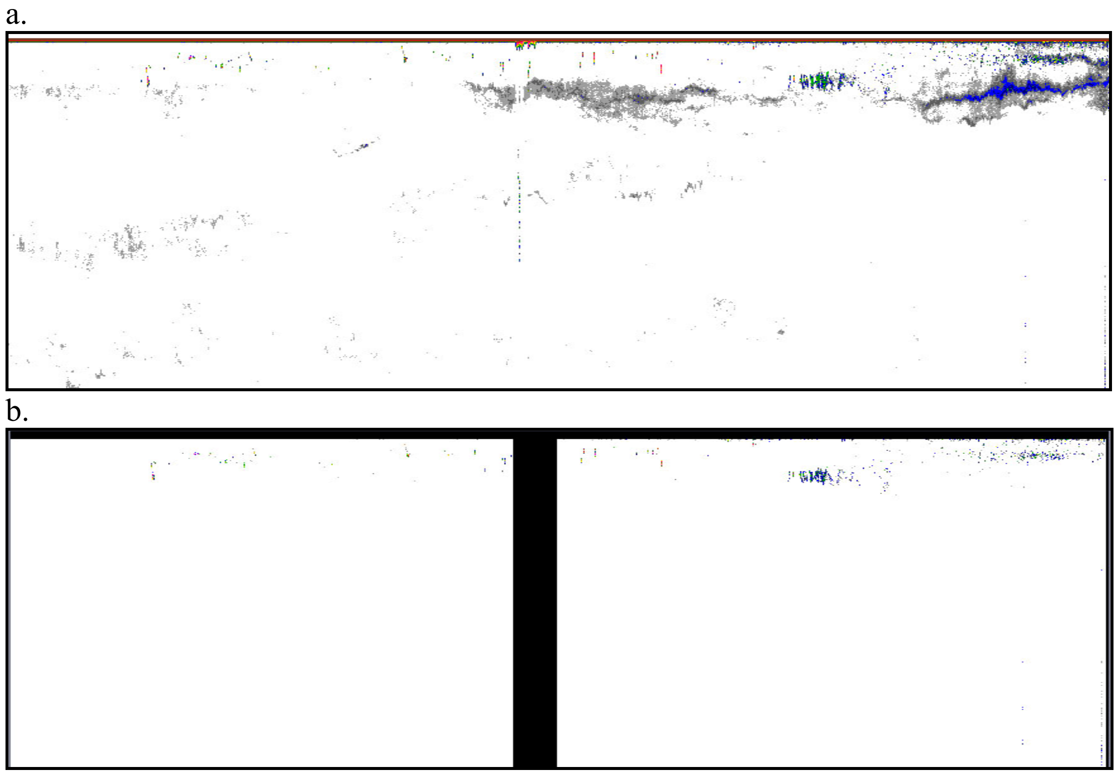


Figure I.29. Transect 12: original (a) and filtered (b) echograms (depth: 0-500m; distance: 88 n.mi.; not to scale).

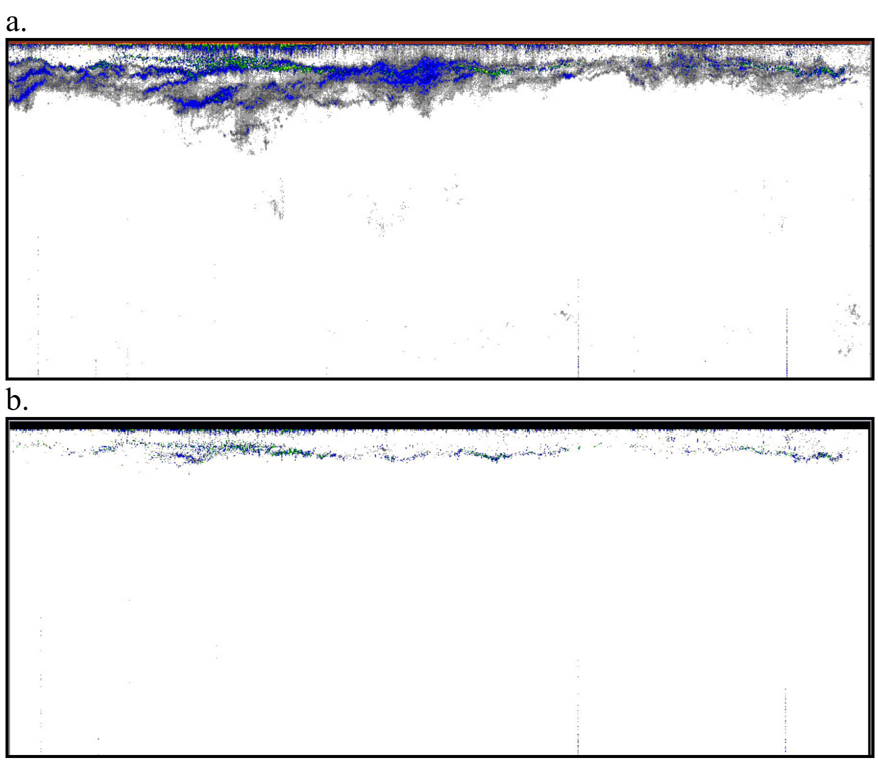
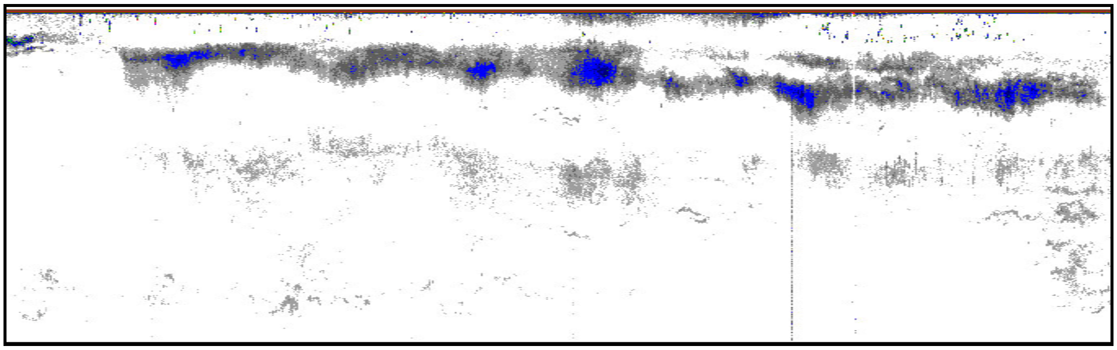


Figure I.30. Segment 12 to 13: original (a) and filtered (b) echograms (depth: 0-500m; distance: 90 n.mi.; not to scale).

a.



b.

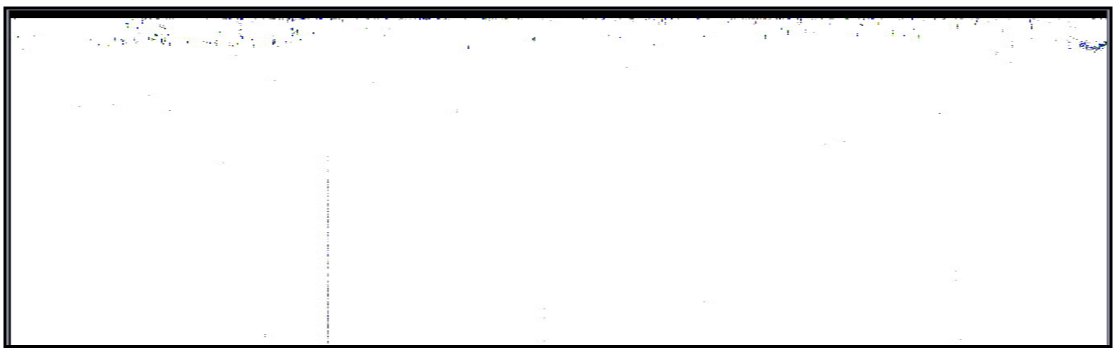
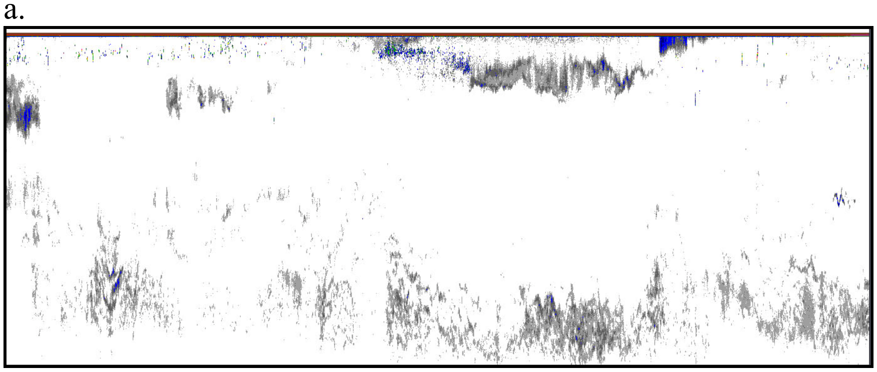


Figure I.31. Transect 13: original (a) and filtered (b) echograms (depth: 0-500m; distance: 68 n.mi.; not to scale).

a.



b.

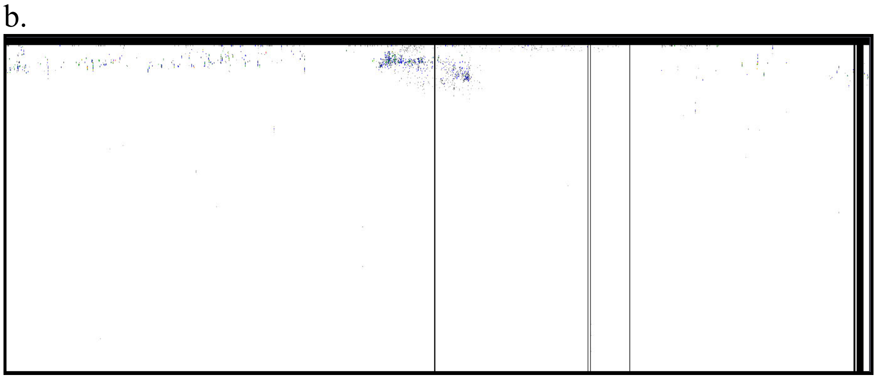
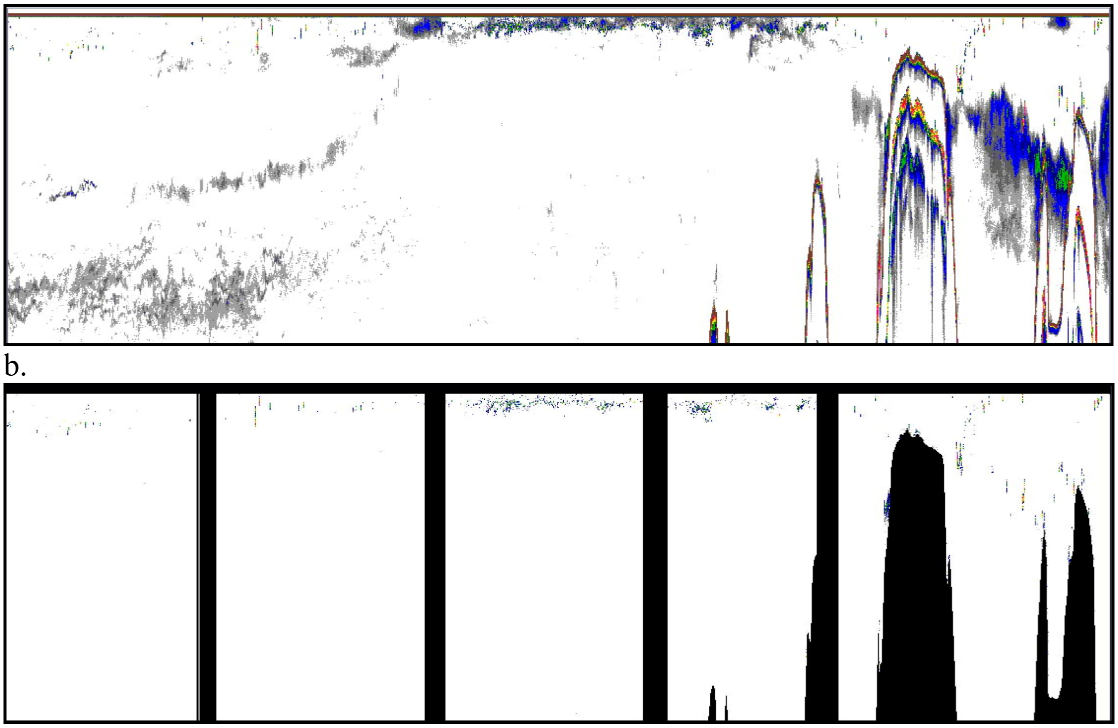


Figure I.32. Segment 13 to 14: original (a) and filtered (b) echograms (depth: 0-500m; distance: 346 n.mi.; not to scale).

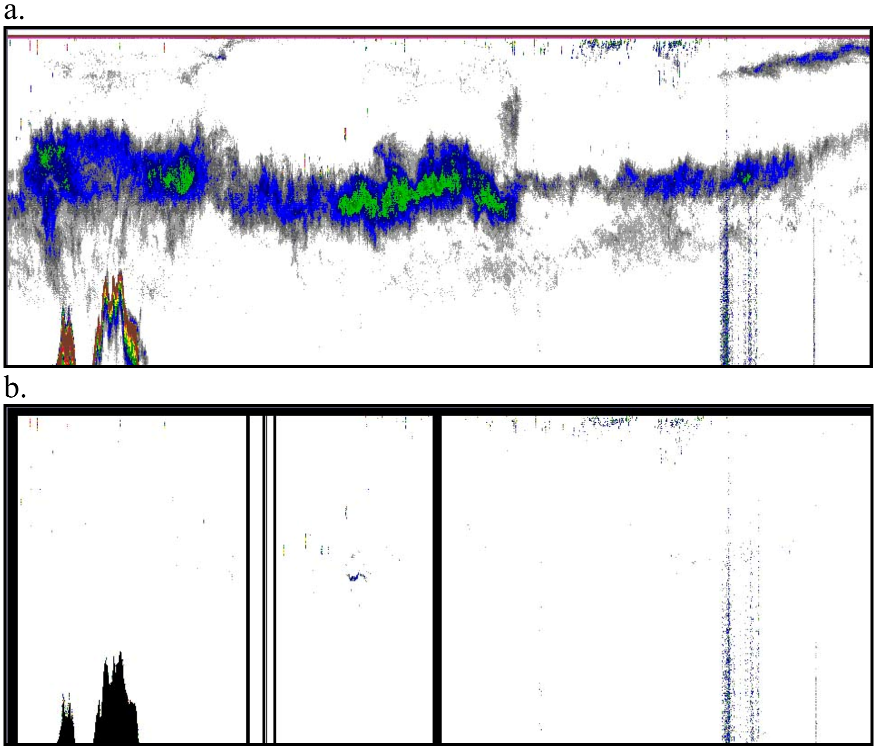
a.



b.

Figure I.33. Transect 14: original (a) and filtered (b) echograms (depth: 0-500m; distance: 224 n.mi.; not to scale).

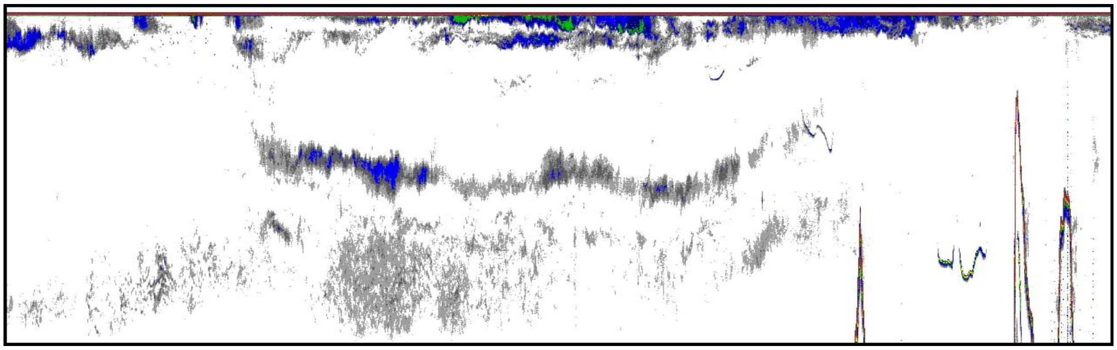
a.



b.

Figure I.34. Segment 14 to 15: original (a) and filtered (b) echograms (depth: 0-500m; distance: 95 n.mi.; not to scale).

a.



b.

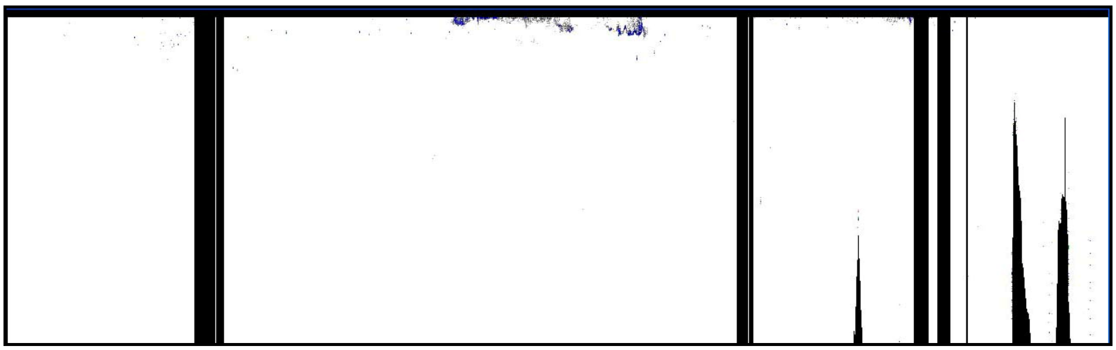
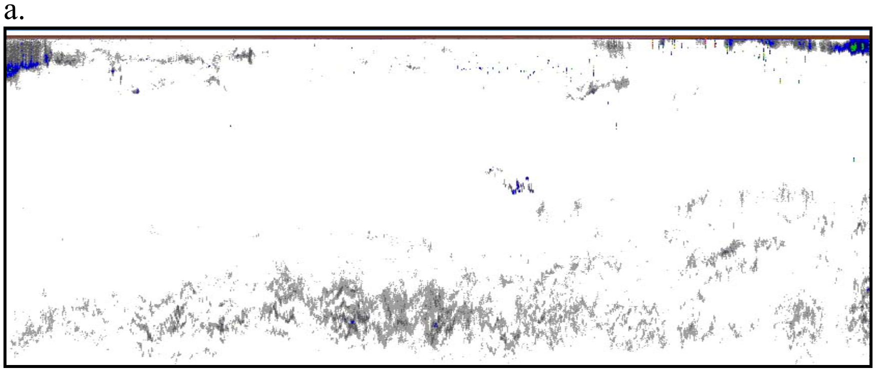


Figure I.35. Transect 15: original (a) and filtered (b) echograms (depth: 0-500m; distance: 253 n.mi.; not to scale).

a.



b.

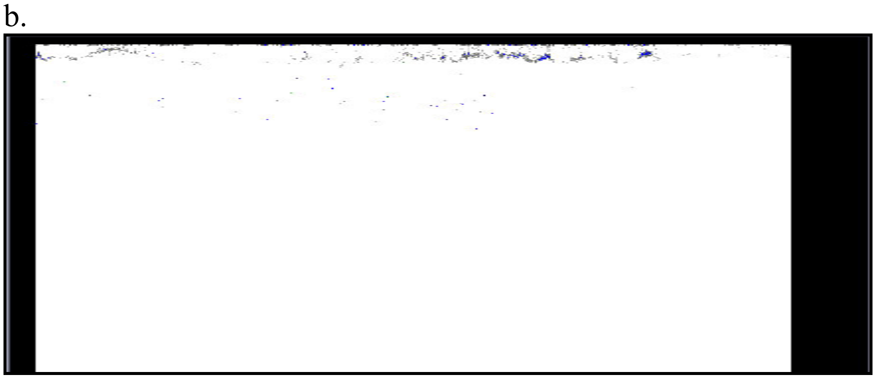


Figure I.36. Segment 15 to 16: original (a) and filtered (b) echograms (depth: 0-500m; distance: 167 n.mi.; not to scale).

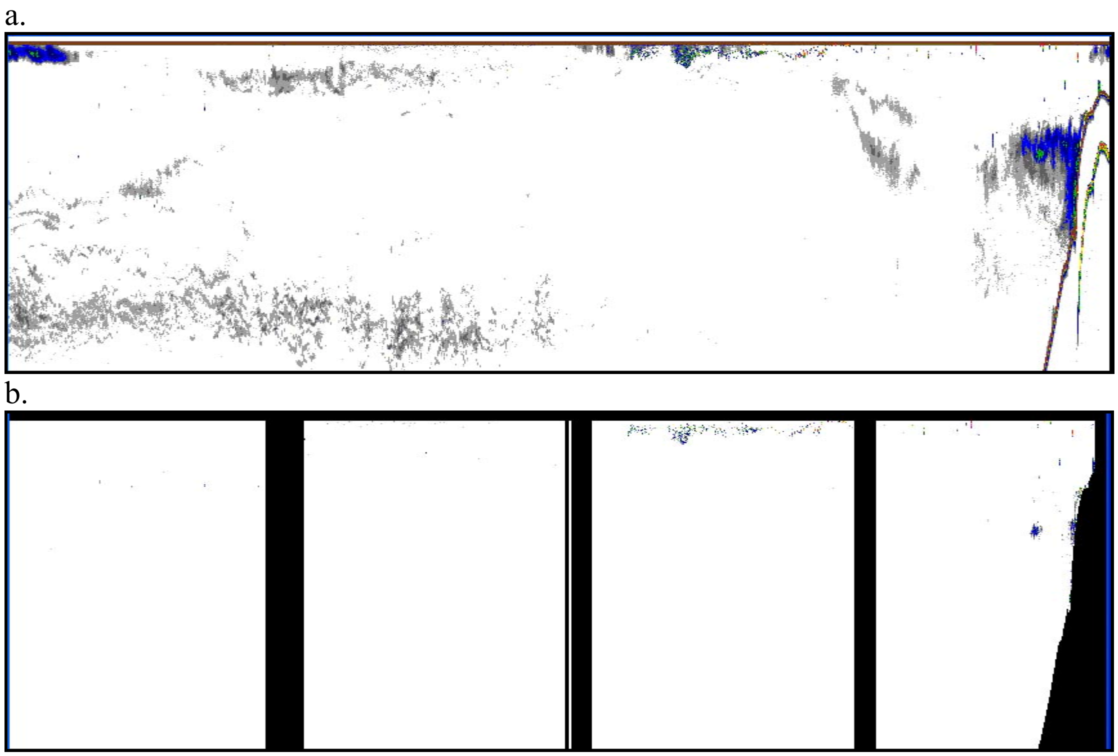


Figure I.37. Transect 16: original (a) and filtered (b) echograms (depth: 0-500m; distance: 171 n.mi.; not to scale).

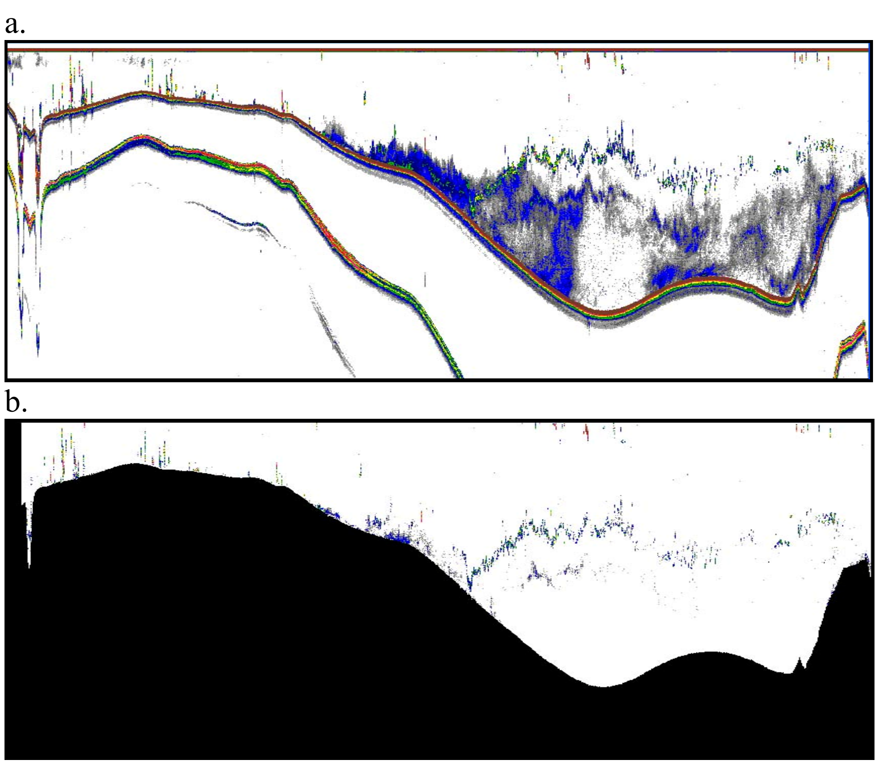
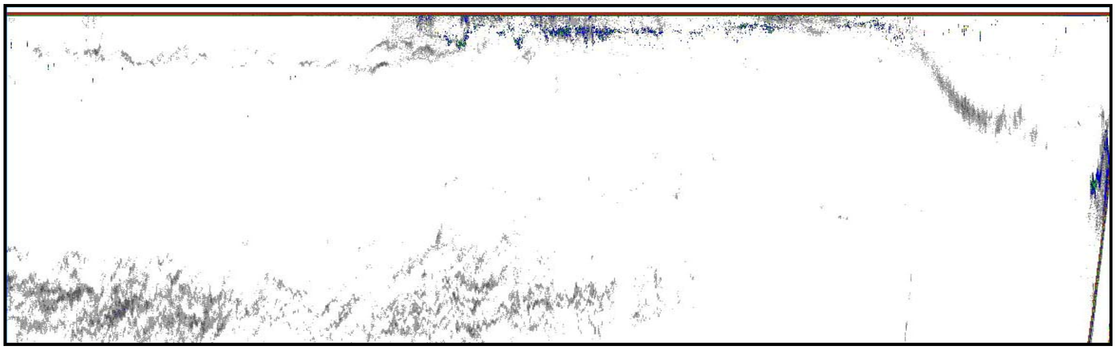


Figure I.38. Segment 16 to 17: original (a) and filtered (b) echograms (depth: 0-500m; distance: 85 n.mi.; not to scale).

a.



b.

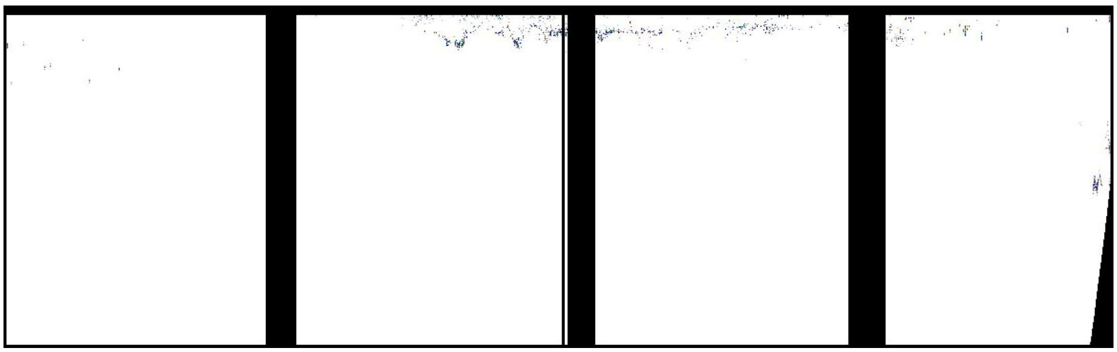
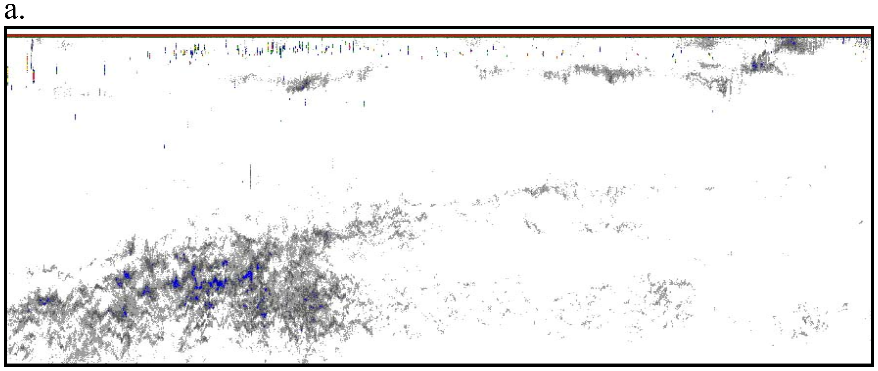


Figure I.39. Transect 17: original (a) and filtered (b) echograms (depth: 0-500m; distance: 175 n.mi.; not to scale).

a.



b.

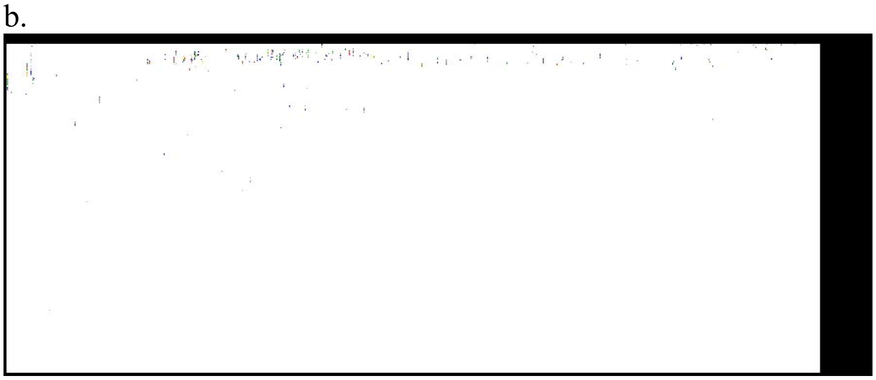


Figure I.40. Segment 17 to 18: original (a) and filtered (b) echograms (depth: 0-500m; distance: 91 n.mi.; not to scale).

a.

b.

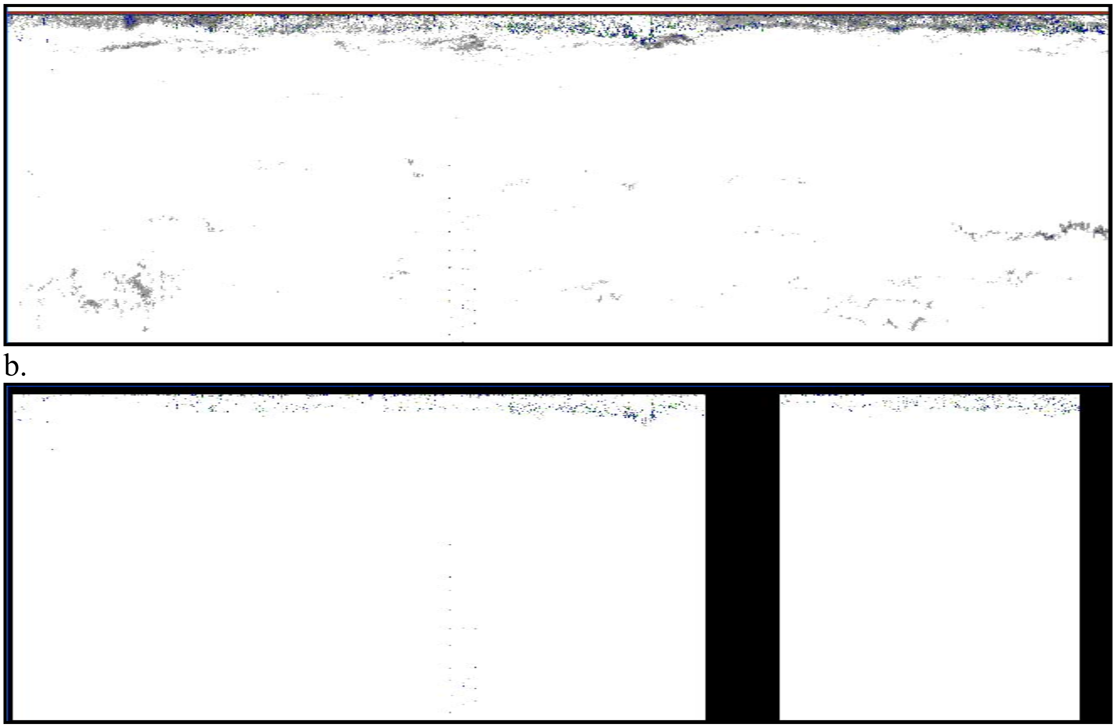


Figure I.41. Transect 18: original (a) and filtered (b) echograms (depth: 0-500m; distance: 66 n.mi.; not to scale).

a.

b.

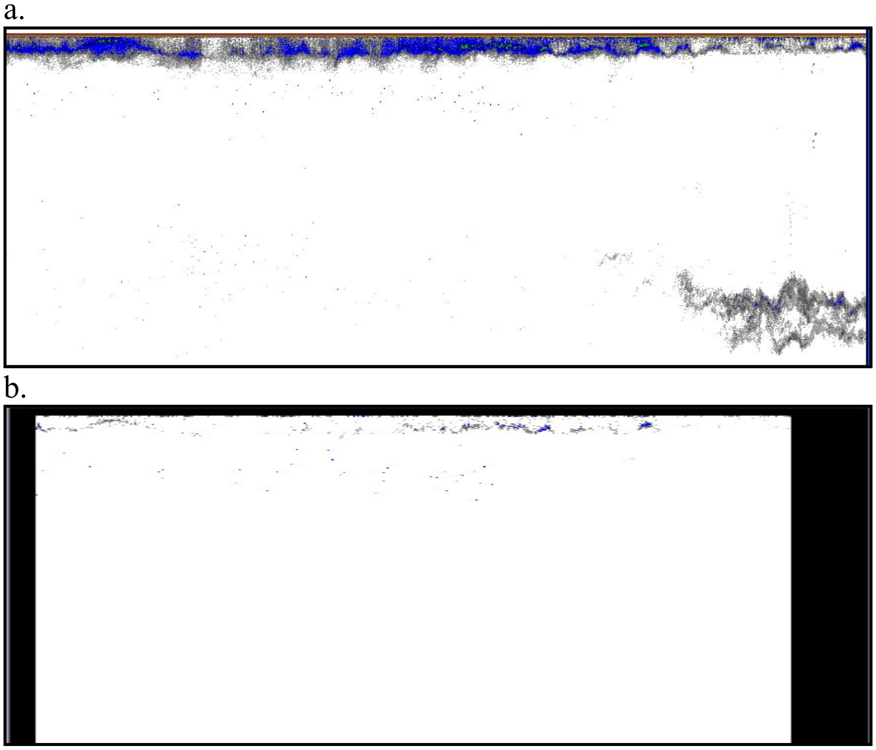


Figure I.42. Segment 18 to 19: original (a) and filtered (b) echograms (depth: 0-500m; distance: 44 n.mi.; not to scale).

I.3.2 SM20 Multi-beam sonar

A Kongsberg-Mesotech SM2000 90 kHz multi-beam sonar (90° model) and a SM20 processor were used on FSV *Oscar Dyson*. The SM2000/SM20 system images a 90° swath with 128 acoustic beams, fanning 45° to port and starboard. The system has two transducers: a semi-circular array that can be used to both transmit and receive when operating in imaging mode; and a long stave that can be substituted for the transmitter, receiving on the semi-circular array, when operated in echosounding mode. This survey was conducted in echosounding mode only.

I.3.2.1 SM20 System calibration

The SM2000/SM20 system was not calibrated for this survey. Comparisons between the volume backscattering recorded by the multi-frequency echosounder and multi-beam sonar may be instructive for semi-quantitative interpretation of the volume scattering data.

I.3.2.2 SM20 Tranducer mounting

The SM2000 is hull-mounted, protruding, and located forward of the centerboard and aft of the bow thruster at approximately 5.7 m below the water surface. The distances from the center of the SM2000 head to frame 39 of the vessel and to the center of ES38 transducer is 8391 mm and 9271 mm, respectively (Table I.2).

I.3.2.3 SM20 Triggering

To minimize interference with the split-beam echosounders, the 90-kHz SM20 was triggered and fired synchronously with the EK60s. To do this, the surface telemetry board (STB) of the SM20 processor received the trigger out pulse from the EK60.

I.3.2.4 SM20 Data Collection and Archive

The SM2000 was controlled and data were logged using a Kongsberg-Mesotech SM20 processor unit. A range of 200 m was chosen and used except during a few trawls when the range was set to 100 m for increased resolution. The pulse duration was 385 μs at 200 m range and was 220 μs at 100 m range. High power level was used for the SM20. System gain was set to 75%. Display gain was set to 300%.

The SM20 was used in echosounder mode (transmission via the external transmit transducer). Echosounder mode produces much narrower along-ship beamwidths (approximately 1.3°) than imaging mode (20°). In both modes, across-ship beamwidth is approximately 1.5°. Raw data from the SM20 were stored to Kongsberg-Mesotech format (.SMB) files.

I.3.2.5 SM20 Data processing

The purpose of analyses of the SM20 multi-beam echosounder data during the survey was to: (1) document schools and other biological aggregations imaged by the SM20 multi-beam echosounder; and (2) compare the biological aggregations imaged and detected in the EK60 echograms with those detected in the SM20 data by documenting presence and absence of schools in the SM20 and EK60, and by documenting on- and off-vessel-axis encounters.

On-board analyses of data from the Kongsberg-Mesotech SM20 multi-beam echosounder (90° head, 90-kHz model) on the *Oscar Dyson* were done using data from Transect 14 (Fig. I.43).

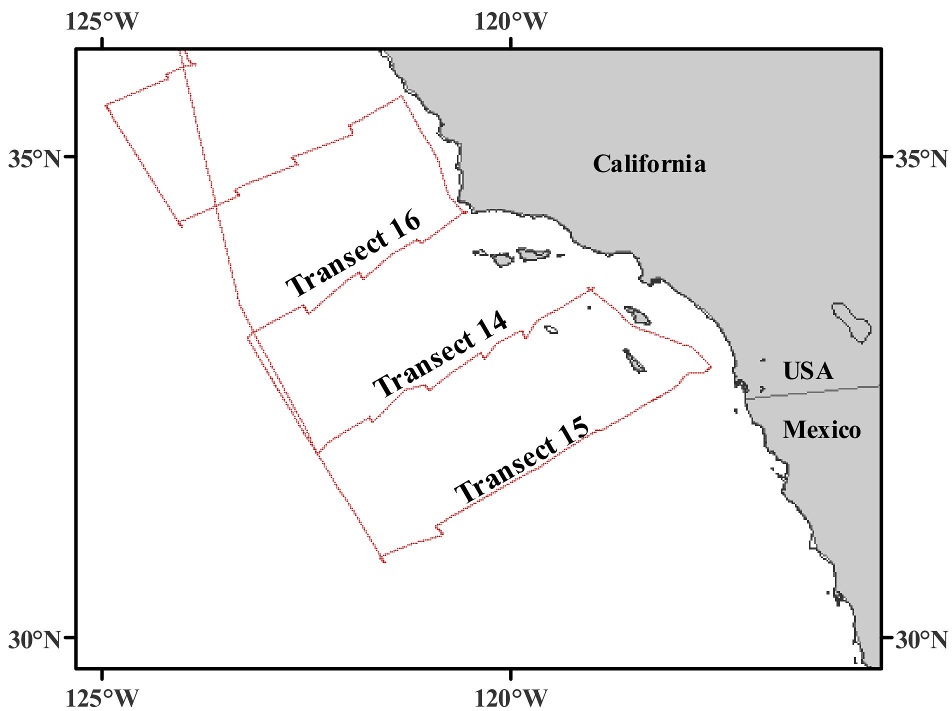


Figure I.43. School detections were done on SM20 data from Transect 14 from the West Coast Survey aboard the *Oscar Dyson*.

To determine that targets imaged by the SM20 were likely to be fish, and to document correspondences between schools imaged by the SM20 and EK60s, it was first necessary to detect schools in the EK60 data. School detection was done using Echoview 3.50.

<u>*I.3.2.5.1 SM20 School detections in processed 38 kHz echograms*</u>

Schools were detected in the processed 38 kHz echograms from the EK60, henceforth referred to as fish echograms, using Echoview 3.50 with parameter values determined from examination of the raw data (parameter values are set in EV file Props: Schools). The parameter values controlling school size threshold that were used to detect the single beam schools are presented in Table I.5.

Table I.5. Echoview school detection parameters.

Parameter	Length (m)
Minimum Total School Length (m)	4.0
Minimum Total School Height (m)	4.0
Minimum candidate length (m)	3.0
Minimum candidate height (m)	3.0
Maximum vertical linking distance (m)	5.0
Maximum horizontal linking distance (m)	25.0

A S_v minimum threshold of -60 dB was used for school detections, and upper and lower boundaries were 12 and 70 m depth, respectively. Data from Transect 14 were processed as a case study where fish schools were known to be abundant from the EK60 data.

I.3.2.5.2 Ranges to acoustic targets in SM20 echograms

The offset from the water surface to the SM2000 head was not entered into the SM20 setup parameters for acquisition. Therefore, SM20 range measurements indicate range from the sonar head, not the water surface. The EK60 range data indicate distance from the water surface. The EK60s were located on the centerboard that was lowered to 7.4 m during the survey. The SM2000 head was hull mounted at approximately 5.7 m below the water surface. To find corresponding target depths in SM20, 5.7 m was subtract from the EK60 target depths.

I.3.2.6 SM20 Results

I.3.2.6.1 SM20 School detections

48 schools were detected from the 38 kHz EK60 fish echograms. These detections were exported from Echoview into an ASCII text file (Tr14 ES38 schools from Proc Data T2.csv) using Analysis By Regions, then converted to a spreadsheet file (.xls). Metrics of these schools detected are presented in Tables I.6 and I.7. The mean depth of the centroids of the 48 schools was 36.5 m. The minimum mean-depth was 17.0 m, and the maximum mean-depth was 68.0 m. The average of the mean S_v values was -46.7 dB (±5.8 dB).

Table I.6. Descriptive statistics for attributes of schools detected in the 38 kHz EK60 fish echograms.

	Mean S_v (dB)	Mean Height (m)	Mean depth (m)	Corrected length (m)	Corrected thickness (m)	Corrected area (m^2)	3D school volume (m^3)
Min.	-55.8	1.6	17.0	4.2	3.3	13.6	46.9
Max.	-32.4	8.8	68.0	78.1	29.3	621.8	702.3
Mean	-46.7	3.7	36.5	32.0	5.5	105.1	120.9
SD	5.8	2.0	13.1	18.6	4.5	117.7	117.6

Table I.7. Metrics of 48 schools detected from the 38 kHz EK60 fish echogram, Transect 14.

Region ID	Date	Time (GMT)	Time (PST)	Latitude	Longitude	Sv mean (dB)	Corrected length	Corrected thickness	3D school area	3D school volume	Range mean	Ping Start	Ping End
1	20060501	19:51:42.37	11:51 AM	31.96255	-122.32748	-52.8	50.1	4.3	851.9	113.7	59.0	81	84
2	20060501	19:54:02.37	11:54 AM	31.96900	-122.32074	-49.2	36.2	4.3	614.6	158.4	60.7	151	153
3	20060501	19:56:38.37	11:56 AM	31.97627	-122.31320	-53.1	11.6	3.3	151.0	96.3	38.0	230	230
4	20060501	20:17:52.37	12:17 PM	32.03543	-122.25174	-45.1					68.0	867	867
5	20060501	20:46:28.35	12:46 PM	32.10120	-122.15177	-40.6	16.7	3.3	217.1	34.6	64.0	1725	1726
6	20060501	21:01:06.36	1:01 PM	32.13116	-122.09663	-45.1	78.1	8.3	2577.1	431.8	58.0	2162	2167
7	20060501	21:07:44.35	1:07 PM	32.14471	-122.07134	-51.8	24.6	4.3	418.8	175.0	56.6	2363	2364
8	20060501	22:32:44.32	2:32 PM	32.31002	-121.74121	-41.4	4.2	3.3	54.4	34.7	51.0	4912	4912
9	20060502	00:46:02.25	4:46 PM	32.35426	-121.58357	-39.3	72.3	29.3	8460.0	3435.8	44.6	8905	8910
10	20060502	00:49:58.25	4:49 PM	32.36410	-121.57202	-32.4	61.2	9.3	2263.7	2298.3	23.9	9023	9027
11	20060502	01:00:16.26	5:00 PM	32.38966	-121.54103	-47.8	63.7	12.3	3120.1	1239.6	31.0	9332	9336
12	20060502	01:26:46.24	5:26 PM	32.45765	-121.46221	-53.9	38.6	4.3	655.5	81.6	30.6	10127	10129
13	20060502	01:31:42.23	5:31 PM	32.47030	-121.44784	-37.8	35.9	5.3	754.6	191.9	26.9	10275	10277
14	20060502	02:16:54.22	6:16 PM	32.58682	-121.30915	-50.7	24.9	8.3	821.3	451.6	35.0	11632	11633
15	20060502	02:23:52.22	6:23 PM	32.60516	-121.28743	-44.2	9.3	7.3	270.4	384.9	33.0	11841	11841
16	20060502	05:17:24.14	9:17 PM	32.69208	-120.85311	-53.2	12.6	3.3	163.2	104.1	29.0	17045	17045
17	20060502	05:23:10.14	9:23 PM	32.70637	-120.83116	-53.3	42.4	3.3	551.2	101.9	42.2	17217	17219
18	20060502	05:32:40.13	9:32 PM	32.72957	-120.79578	-43.9	25.3	4.3	430.6	121.8	26.9	17502	17503
19	20060502	05:34:38.13	9:34 PM	32.73439	-120.78847	-53.6	27.5	4.3	468.0	108.2	34.8	17561	17562
20	20060502	05:35:26.13	9:35 PM	32.73640	-120.78546	-48.2	41.6	3.3	540.2	64.5	27.1	17584	17586
21	20060502	05:40:24.13	9:40 PM	32.74897	-120.76697	-47.8	71.6	3.3	931.1	104.1	29.3	17732	17736
22	20060502	05:58:40.13	9:58 PM	32.79468	-120.69809	-47.9	28.7	3.3	373.0	59.5	24.0	18282	18283
23	20060502	06:06:30.13	10:06 PM	32.81332	-120.66792	-54.6	28.3	3.3	367.6	70.8	28.0	18517	18518
24	20060502	06:39:02.10	10:39 PM	32.88817	-120.54001	-54.5	14.0	4.3	237.8	198.4	25.5	19492	19492
25	20060502	09:40:38.03	1:40 AM	32.98870	-120.25221	-49.8	24.6	3.3	320.0	51.0	36.0	24937	24938
26	20060502	09:45:08.02	1:45 AM	33.00248	-120.24053	-48.1	37.9	3.3	492.9	78.6	32.0	25071	25073
27	20060502	10:44:46.00	2:44 AM	33.14500	-120.03708	-52.8	41.7	3.3	542.4	123.7	30.6	26860	26862
28	20060502	10:50:23.99	2:50 AM	33.15504	-120.01465	-48.6	39.5	5.3	829.9	113.3	32.0	27029	27031
29	20060502	10:56:51.99	2:56 AM	33.16651	-119.98854	-35.2	19.8	3.3	256.9	93.4	44.2	27224	27225
30	20060502	11:12:52.00	3:12 AM	33.19488	-119.92374	-46.6	24.4	3.3	317.4	126.2	34.3	27703	27704
31	20060502	11:13:18.00	3:13 AM	33.19565	-119.92205	-48.6	36.1	3.3	469.8	57.0	35.9	27715	27717
32	20060502	11:13:30.00	3:13 AM	33.19597	-119.92124	-48.4	64.0	5.3	1343.2	259.8	36.3	27720	27724
33	20060502	11:13:58.00	3:13 AM	33.19676	-119.91940	-47.1	50.0	3.3	650.5	86.1	32.8	27735	27738
34	20060502	11:15:16.00	3:15 AM	33.19889	-119.91422	-47.2	38.7	3.3	503.4	76.3	31.1	27774	27776
35	20060502	11:16:21.99	3:16 AM	33.20076	-119.90984	-47.5	24.3	3.3	315.8	50.4	33.0	27808	27809
36	20060502	13:23:19.94	5:23 AM	33.15834	-119.78666	-43.7	20.3	8.3	669.9	530.1	35.6	31613	31614
37	20060502	13:43:11.92	5:43 AM	33.21922	-119.74850	-43.1	10.2	4.3	173.9	145.2	20.5	32209	32209
38	20060502	14:15:05.92	6:15 AM	33.31483	-119.67359	-47.2	19.5	6.3	488.3	311.9	60.2	33166	33167
39	20060502	15:08:51.90	7:08 AM	33.41630	-119.46544	-41.3	19.7	3.3	256.0	30.8	53.0	34779	34780
40	20060502	15:14:25.89	7:14 AM	33.42343	-119.44855	-55.8	8.5	3.3	110.5	70.5	58.0	34946	34946
41	20060502	15:21:51.89	7:21 AM	33.43653	-119.41942	-50.7	11.5	4.3	195.0	162.7	23.5	35169	35169
42	20060502	15:23:23.89	7:23 AM	33.43941	-119.41331	-35.1	23.1	3.3	300.0	59.0	31.0	35215	35216
43	20060502	15:27:45.88	7:27 AM	33.44824	-119.39609	-47.3	12.1	3.3	157.4	100.4	17.0	35346	35346
44	20060502	17:01:09.86	9:01 AM	33.63358	-119.02821	-37.5	54.2	17.3	3742.2	1421.6	28.5	38147	38150
45	20060502	17:03:01.86	9:03 AM	33.63725	-119.02061	-53.0	12.4	4.3	211.3	176.3	31.5	38204	38204
46	20060502	17:03:23.86	9:03 AM	33.63796	-119.01912	-37.8	40.1	7.3	1164.2	1001.1	22.7	38214	38216
47	20060502	17:04:33.86	9:04 AM	33.64019	-119.01435	-42.3	25.7	9.3	950.3	878.6	24.0	38250	38251
48	20060502	17:07:07.85	9:07 AM	33.64506	-119.00397	-43.6	26.1	5.3	547.8	110.8	19.0	38327	38328

Echograms of Transect 14 from the EK60 and SM20 show simultaneously detected fish schools (Fig. I.44). The EK60 echograms provide an along-ship vertical profile through the water-column, and the SM20 provides an athwart-ship slice of the same school. Both the EK60 beam and the nadir beam of the SM20 point vertically downward from the centerline of the ship. Therefore, the vertical profile data of the EK60 echograms corresponds to a vertical 7° cone extending from the apex of the triangular, 90° swath of the SM20. Throughout the survey, schools were consistently imaged simultaneously in several EK60 frequencies and the SM20.

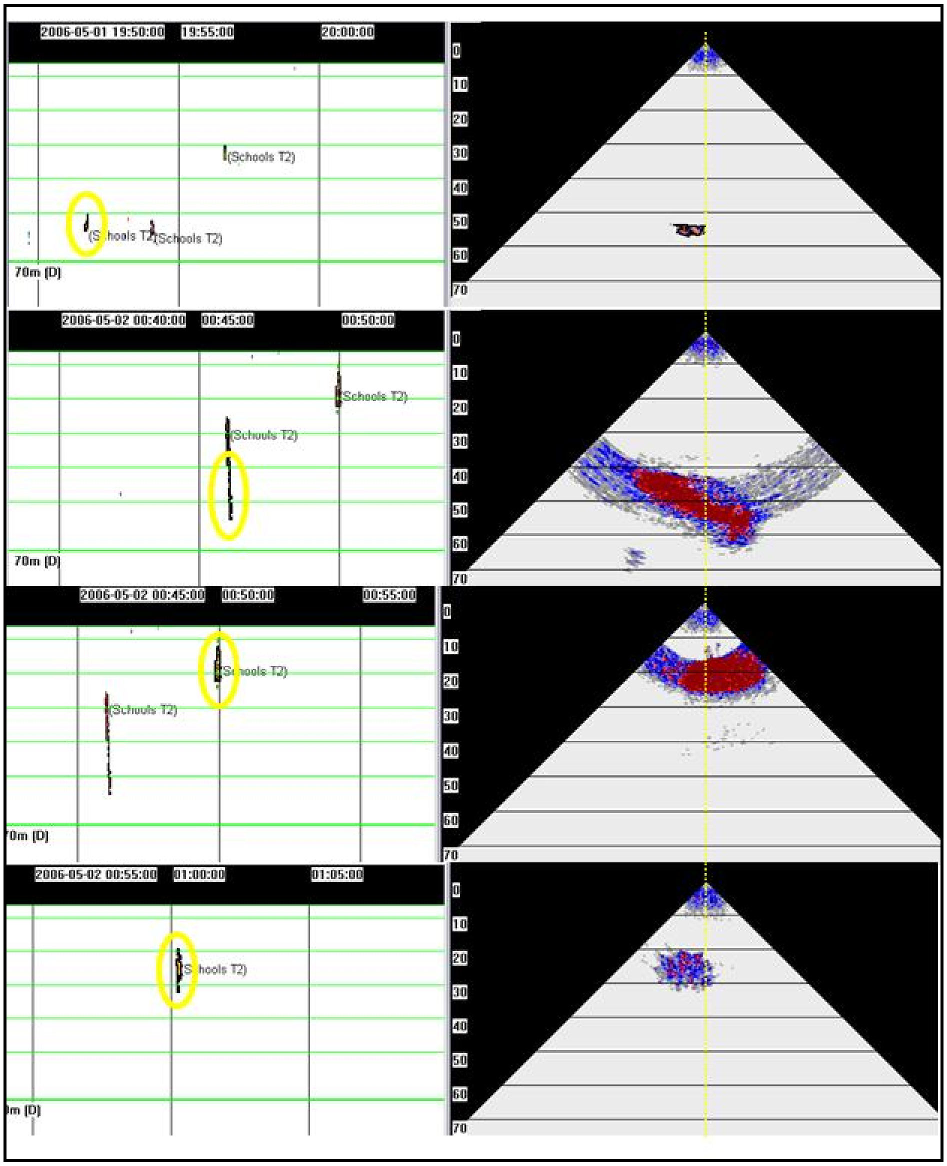


Figure I.44. Echograms of four fish schools (see Table 7; numbers 1, 9, 10, and 11, top-to bottom, respectively) imaged with the 38 kHz EK60 (left), and the SM20 (right). The pale green lines indicate 10 m depth increments below the SM2000 face, and the bold green line indicates 70 m below the sea-surface.

Some schools were imaged by the SM20, but not by the EK60, because they were not directly beneath the vessel (eg. Fig. I.45).

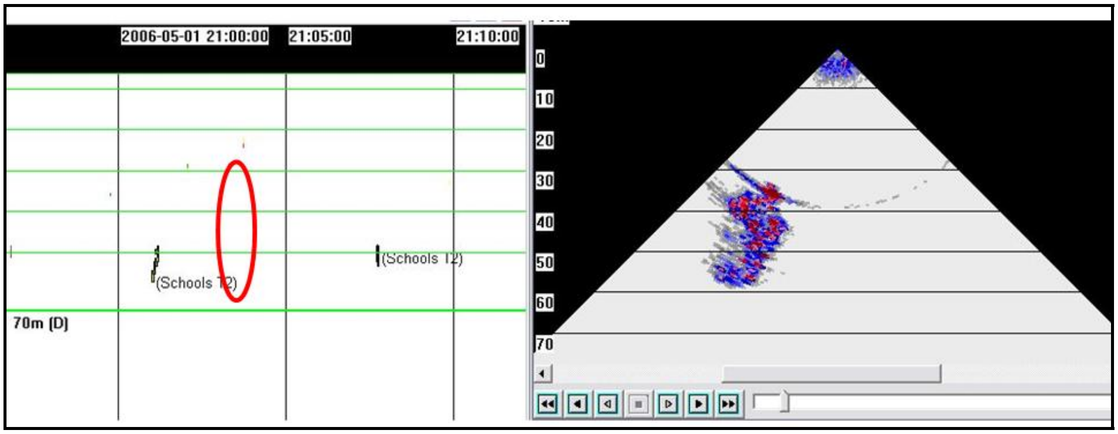


Figure. I.45. A school imaged by the SM20 (right) is absent from the EK60 echogram (left) because it was located approximately 15 m to port from the vessel centerline. The school was observed by the SM20 at the time indicated (red oval) in the EK60 echogram.

Sequences of echograms from the SM20 multi-beam echosounder provided details about shapes of schools (Fig. I.46). Examination of patterns evident from sequences of multi-beam echograms can help determine if fish are exhibiting vessel-avoidance behavior.

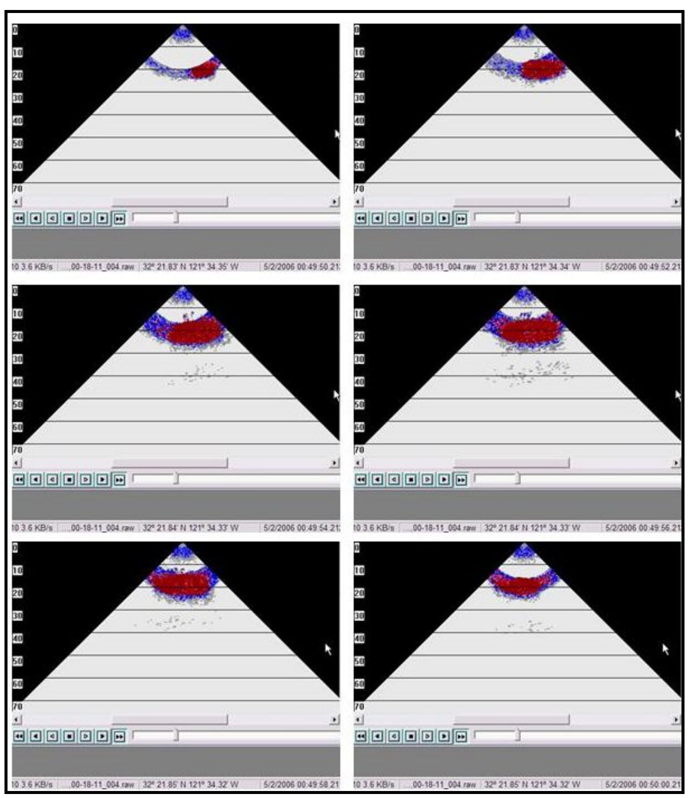


Figure I.46. SM20 echograms from six pings imaging a single school from Transect 14. The school was first encountered to the starboard side and then directly beneath the ship during this 12-s interval (a distance of approximately 90 m along-track).

A three-dimensional rendition of schools imaged by split- and multi-beam echosounders demonstrates the enhanced perspective provided by the simultaneous deployment of these echosounders (Fig. I.47).

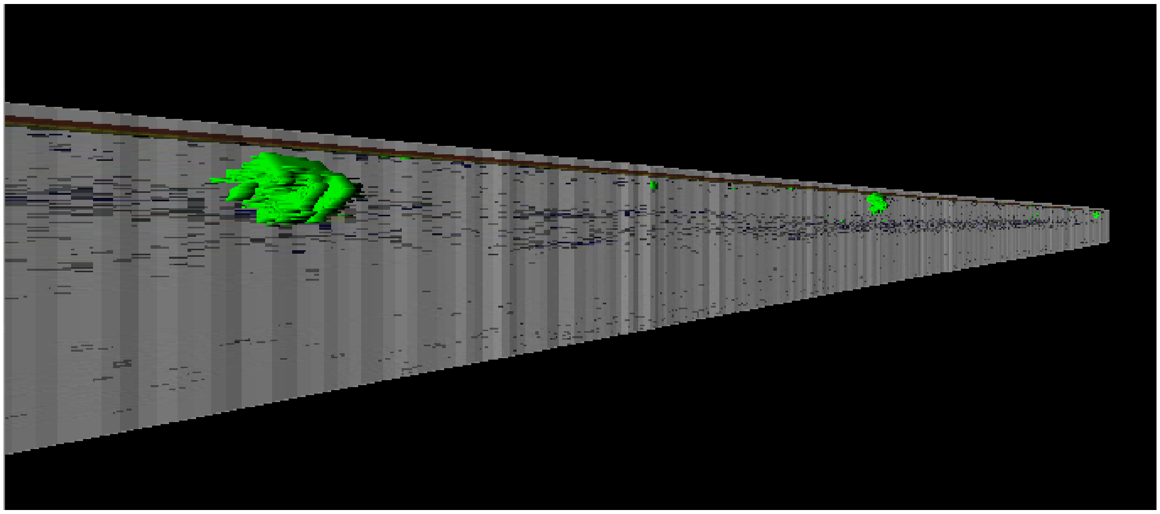


Figure I.47. 3-D rendition of four schools imaged by the SM20 on Transect 14 superposed on a curtain-image representing a vertical profile provided by the 38-kHz EK60.

I.3.3 Ocean Surveyor ADCP

The RD Instruments Ocean Surveyor 75kHz ADCP system, permanently installed aboard the FSV *Oscar Dyson,* was used to collect data throughout the survey (see Appendix 2; ADCP Log). The deck unit and dedicated computer were installed in an equipment rack located in the Acoustics Laboratory aboard the *Oscar Dyson*. Data from the Leica 470 GPS (ship's position and speed), and Applanix POS MV 320 (heading, pitch, roll, and heave) were input in RS-232 format.

I.3.2.1 ADCP System calibration

The ADCP system was not calibrated for absolute backscatter intensity or water velocities.

I.3.2.2 ADCP Transducer mounting

The ADCP transducer array was located on the aft end of the centerboard, on the bottom, 1570 mm (center to center) aft of the Simrad 38kHz transducer. The centerboard could be set to depths of 5.4m, 7.4m or 9.15m below the sea surface (0m, 2m or 3.75m below the ship's hull), depending on weather conditions and sea states. Generally, the transducer was positioned 7.4 m below the sea-surface.

I.3.2.3 ADCP Triggering

To minimize interference with the five split-beam EK60s and the multi-beam SM20 echosounder systems, the 75 kHz ADCP was triggered and fired synchronously using the trigger pulse generated by the EK60 system every two seconds. No interference from the ADCP was detected on the EK60 or SM20 systems.

I.3.2.4 ADCP Data Collection and Archive

The ADCP was controlled by RDI's VMDAS version 1.42 software using a setup file supplied by Ms. Teri Chereskin (teri@coast.ucsd.edu), to modify the original settings.txt file of the system. The following setup changes were made (see Appendix 3):

broadband to narrowband mode
removed the original WV390 (390cm/s ambiguity velocity) command
set the transducer misalignment in the settings file from EA00000 to EA04500 and set the transducer misalignment in VMDAS to 0°
added an external trigger command CX1,0
pitch and roll set to 0° in the VMDAS Tilt Source menu

Raw data were stored in .ENR, .ENX, .N1R, .NMS, .LTA and STA format files. Data, log and settings files were periodically backed up to a USB drive.

I.3.2.5 ADCP Data processing

The ADCP data were archived but not processed.

I.4 Tentative Conclusions

I.4.1 EK60 multi-frequency echosounders

The multi-frequency acoustic data indicated that epipelagic fish were very patchily distributed throughout the survey area (Fig. I.5). Highest fish densities were located in the southern portion and in areas with SST ranging from 11-16 °C. A loose positive relationship was observed between the largest densities fish and the number of anchovy and sardine eggs collected by CUFES.

The distributions of epipelagic fish off the west coast of the United States are highly skewed (i.e. most of the biomass is concentrated in a small number of schools). This patchiness is generally characteristic of coastal pelagic species. Barange and Hampton (1997) noted that sardines are more patchily distributed than anchovies, and that fewer than 20% of the data points contributed over 90% of the biomass. This survey suggested similar results.

Multiple coastal pelagic species with swimbladders (i.e. anchovy, sardine, and Pacific and jack mackerel) can be the source of 38 kHz acoustic backscatter in the depth range from 12 to 70 m. Consequently, the trawl, egg pump, and SST information were used to better apportion the integrated acoustic backscattering coefficients (NASC; $m^2/n.mi.^2$) to these candidate species.

For the area where eggs were found, the ratio of the anchovy spawning biomass to the sardine spawning biomass R can be estimated as:

$$R = \left[\frac{\sum e_{anchovy}}{\sum e_{sardine}}\right] \times \left[\frac{e_{sardine}}{w_{sardine}} \Big/ \frac{e_{anchovy}}{w_{anchovy}}\right] = \frac{300\,(e_{sardine}/g)}{500\,(e_{anchovy}/g)} = \left[\frac{\sum e_{anchovy}}{\sum e_{sardine}}\right] \times 0.6 \qquad \text{(Eq. 3)}$$

where *e* represents the number of eggs, *w* represents average weight of the fish, and *g* represents fish mass in grams. Assuming the ratio of immature fish of anchovy and sardine is the same as for mature fish, the same ratio can be applied. This, coupled with consideration of the trawl catches, should be used to apportion the total epipelagic fish biomass to the four candidate species.

Even so, biomass estimates of epipelagic fish surveyed with a down-looking echosounder are susceptible to large biases due to diel vertical migratory and schooling behavior. Barange and Hampton (1997) reported that anchovy near South Africa form high-density schools during the day, and break into larger low-density aggregations at night. In contrast, sardine in the same region remain in relatively high-density schools throughout the day. All CPS species in this area appear to reside deeper in the water column during the daytime and shallower at night, as none of the daytime trawls caught CPS. Moreover, the ship speed (typically 12-14 kts) and the ping interval (2 s) were too large to accurately survey highly patchy fish schools. Also, especially for shallow depths, the echosounder pings do not overlap, leading to a negative bias. That is, multiple meters between pings are not insonified with a 7° beam width transducer, and transiting at speeds of 6-7 m/s.

Another potentially large source of error is target strength (TS; dB re 1 m^2). TS depends on several aspects, such as the physiological state of the fish (stage of sexual maturity and fat content), its behavior and the time of day (Ona, 1999). In this study, measurements were made at all times of day, but only during spring. Thus, diel variations are likely, but variations due to seasonal factors should have been minimal. During the day, sardines gather in schools and descend, even close to the bottom in shallow water areas. Consequently, their swim bladders may have a smaller volume and lower TS at day versus night. These changes can lead to both systematic and random errors in the estimated biomasses of each CPS.

I.4.2 SM20 multi-beam sonar

The SM20 multi-beam echograms aid interpretation of the EK60 echograms by providing perspective from an additional spatial dimension. For instance, the multi-beam echogram can be used to determine which part of a school was imaged by the split-beam echosounders, whether the central portion or the edge of a school, or whether the vertical split-beam echosounder did not sense a school located to either side of the vessel. Such information will allow assessment and compensation for sampling bias.

Many of the aggregations evident in the multi-beam echosounder data might represent organisms other than fish. The SM20 multi-beam operates at a 90 kHz. Some invertebrates such as krill and squid and non-gas-bearing small fish can cause significant backscattering at that frequency, or higher frequencies. However, spatial patterns in the multi-beam volume scattering data might provide metrics to distinguish fish schools from aggregations of other organisms.

I.4.3 Ocean Surveyor ADCP

The ADCP functioned well, collecting data for the duration of the cruise. It showed no signs of crosstalk interference between the split-beam and multi-beam echosounder systems.

I.5 Problems and Suggestions

I.5.1 EK60 multi-frequency echosounder

Acoustic crosstalk was appreciable between the bridge's acoustic instrumentation (i.e. Doppler speed log, and Furuno and Simrad navigation echosounders), and the EK60 multi-frequency echosounders. This interference was generally worst at 70 kHz, but was significant at all frequencies.

The bow thruster produces electrical noise on the EK60 70kHz, even in standby mode. The bow thruster was therefore secured during survey transects.

The survey speed (typically 12-14 knots) and the ping interval (2 s) were too fast to effectively survey coastal pelagic species. When traveling at 14 knots (7 m/s), the ship passes over a 25 m wide fish school in 3.5 s. Pinging every two seconds, the school may be detected with only one or two pings. Schools smaller than 14 m across may be missed entirely. Therefore, either the ship speed or the ping interval, or both, must be reduced. To maintain a high survey speed, the range of acoustic observations must be reduced from 500 m to say 250 m (ping interval = 1 s), or 100 m (ping interval = 0.4 s). However, anchovy and mackerel are known to reside deeper than 100 m, to depths of 300 m. Therefore, unless the survey is focused on sardine, the ship speed must be reduced substantially, say to 9 knots (4.5 m/s).

I.5.2 SM20 multi-beam sonar

The 90 kHz SM20 has constant electrical interference from an unknown source. This noise is evident in the echogram as variably bright concentric rings evident at all ranges, but weak at close ranges, and strong beyond about 80 m. Additionally, a rainbow of color (high noise levels in all beams) is constant in the first 12 meters of the echogram. The noise is not affected by ship speed or by changing the range settings on the echosounder, and was present when all other acoustic devices were turned off.

I.5.3 Ocean Surveyor ADCP

No obvious problems were encountered with the ADCP system. However, a gyro synchro or stepper input should be hardwired into the ADCP deck unit, as the present serial string heading input is slower than a direct connection.

I.5.3 General Suggestions

Strong extractor fans cause low pressures in the Acoustics Laboratory. Whenever a hatch is opened around the ship, the rapid change in ambient pressure causes significant discomfort to those working in the room. A continually compensating supply of filtered air would eliminate the pressure differentials.

A porthole would improve the acoustic operator's ability to note weather, sea state, surface fish, seabird and mammal activity; and quality of living.

I.6 Disposition of Data

Archived on DVDs and computer hard disk are approximately 250 GB of raw and processed data from the EK60 and SM2000. Contact: David Demer (address: Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037, U.S.A.; phone: 858-546-5603; email: david.demer@noaa.gov) or Randy Cutter (address: Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037, U.S.A.; phone: 858-546-5691; email: george.cutter@noaa.gov).

I.7 Acknowledgements

We are greatly appreciative of Chris Wilson, Alex De Robertis, Rick Towler, and Scott Furnish of the MACE Division of AFSC who calibrated the echosounders prior to our arrival, welcomed us into their new acoustics laboratory aboard *Oscar Dyson*, and provided us with outstanding equipment orientation and support. Also, we appreciate very much the efforts of CO John Herring and crew of *Oscar Dyson*.

I.8 References

Barange, M., and Hampton, I. 1997. Spatial structure of co-occurring anchovy and sardine populations from acoustic data: implications for survey design, *Fish. Oceanogr.*, 6(2): 94-108.

Barange. M., Hampton, I., and Soule, M.A. 1996. Empirical determination of the in situ target strengths of three loosely aggregated pelagic fish species. *ICES J. Mar. Sci.,* 53

Jolly, G.M., and Hampton, I. 1990. A stratified random transect design for acoustic surveys of fish stocks. *Can. J. Fish. Aquat. Sci*., 470: 1282-1291.

Ona, E. 1999. Methodology for target strength measurements. ICES *Coop. Res. Rep.*, 235: 59 pp.

Appendix I.1. Computers in the Acoustics Laboratory aboard FSV *Oscar Dyson*.

SWITCH ID	APPLICATION DATA PATH	PC NAME	PC PURPOSE
1. Workstation 1		MACE03	General Purpose
2. EK60	ER60 Master running	MACE08	Primary Logger
2. EK60	ER60 writing .raw & .dg MACE08 E:\Raw Data\OD April 2006	MACE08	Primary Logger
3. Globe	Globe running & writing	MACE06	Globe on Display 4 (Analog)
4. Logger	ECHOLOG running	MACE10	Backup Logger
4. Logger	ECHOLOG writing .ek5 files MACE10 E:\Backup Logger\OD April 2006 EK5 Files	MACE10	Backup Logger
5. SCS	SCS Remote Display	MACE07	SCS Remote Display on Display 3 (Analog)
6. Display PC	ER60 Remote Display running	MACE13	Digital input Disp1,2 & 3
7. ME70			
8. SM20	SM20 running	MACE09	SM20 Control & Log
8. SM20	SM20 writing	MACE09	SM20 Control & Log
Workstation 2	ECHOVIEW running:	MACE04	Workstation 2
Workstation 2	ECHOVIEW writing liveviewing .ev files	MACE08	Primary Logger
Workstation 2	Backup .raw & .dg files	MACE04	Workstation 2
Workstation 2	Backup .raw & .dg files to USB HDD	MACE04	Workstation 2 USB HDD

Appendix I.2. ADCP Log

Monday 10th April 2006
Problem with heading, pitch and roll not getting to VMDAS was found to be that these settings were turned off in the VMDAS setup menu.

1330 GMT Made new ADCP setup file: Teri_NB_WBT_WXT.txt and edited this to match the emailed .txt file from Teri Chereskin.

Changed the .ini settings to match setup manual from Teri and saved as: Teri_NB_WBT_WXT.ini

Started pinging with ADCP slaved to the Simrad EK60 echosounder trigger (every 2 seconds).

Tuesday 11th April 2006
Logging.

Wednesday 12th April 2006
0825 GMT Changed transducer depth from 9.2m to 5.4m (ED00054) in .txt file as the transducer centerboard is being run in the "Retracted" position.

Thursday 13th April 2006
0752 GMT Changed transducer depth from 5.4m to 7.4m (ED00074) in .txt file as the transducer centerboard was lowered to 7.4m ("Intermediate" position) due to bad weather.

Sunday 16th April 2006
1750 GMT Changed transducer depth from 7.4m to 5.4m (ED00054) in .txt file as the transducer centerboard was raised to the "Retracted" position due to ship heading for port. Restarted VMDAS.

Monday 17th April 2006
1127 GMT Changed transducer depth from 5.4m to 7.4m (ED00074) in .txt file as the transducer centerboard was lowered to the "Intermediate" position due to ship heading for port. Restarted VMDAS.

Wednesday 19th April 2006
0738 GMT Changed transducer depth from 7.4m to 5.4m (ED00054) in .txt file as the transducer centerboard was raised to the "Retracted" position due to ship heading inshore.

1447 GMT Changed transducer depth from 5.4m to 7.4m (ED00074) in .txt file as the transducer centerboard was lowered to 7.4m ("Intermediate" position) due to heading offshore.

Friday 21st April 2006
1400 GMT Stopped VMDAS on entering Coos Bay.

Sunday 23rd April 2006
1630 GMT Running ADCP with centerboard at 7.4m after leaving Coos Bay.

Tuesday 25th April 2006
0707 GMT Powered off and rebooted ADCP and VMDAS system to check if it was the source of noise on the SM20 sonar system.

Wednesday 26th April 2006
2138 GMT Sheltering from weather in Drake's Bay. Centerboard in Retracted (5.4m) position. Transducer offset left at 7.4m.

Thursday 27th April 2006

1315 GMT changed transducer offset to 5.4m.
2048 GMT. Stopped pinging ADCP, EK60s, and SM20, because the centerboard was to be raised to maintenance position.
2107 GMT. Started ADCP. Centerboard in retracted position (5.4 m).

Friday 28th April 2006
1858 GMT Started pinging, centerboard and VMDAS transducer depth set to 7.4m.

Monday 1st May 2006
1415 GMT Backed up data and settings files to Mace04 (Workstation 2).

Saturday 6th May 2006
1829 GMT Stopped VMDAS to backup data and settings files to Mace04 (Workstation 2).

1900 GMT Started pinging.

Monday 8th May 2006
1034 GMT Stopped pinging and shutdown VMDAS. Backed up files and shut down system outside San Francisco.

Appendix I.3. ADCP setup file

(Changes from original RDI OS75 noted in **bold** text)

; Filename: Teri_NB_WBT_WXT.txt
; Narrow Band, With Bottom Track, With External Trigger
;
; Setup by Derek Needham for FSV Oscar Dyson from files sent by Teri Chereskin
; 10 April 2006
;
; Created from original file used on FSV Oscar Dyson   OS75BBDEF
; Last modified 27 Jan 2006
;
;---\
; ADCP Command File for use with VmDas software.
;
; ADCP type: 75 Khz Ocean Surveyor
; Setup name: default
; Setup type: Low resolution, long range profile (narrowband)
;
; NOTE: Any line beginning with a semicolon in the first
;   column is treated as a comment and is ignored by
;   the VmDas software.
;
; NOTE: This file is best viewed with a fixed-point font (e.g. courier).
;---/

; Restore factory default settings in the ADCP
cr1 **(same)**

; set the data collection baud rate to 38400 bps,
; no parity, one stop bit, 8 data bits
; NOTE: VmDas sends baud rate change command after all other commands in
; this file, so that it is not made permanent by a CK command.
cb611 **(same)**

; Set for narrowband single-ping profile mode (NP), 50 (NN) 16 meter bins (NS),
; 8 meter blanking distance (NF), 390 cm/s ambiguity vel (WV)

WP0 **(was NP0)**
NP00001 **(was WP00001)**
NN050 **(was WN060)**
NS1600 **(was WS800)**
NF0800 **(was WF0800)**
;WV390 **(was active, but commented out –confirmed with Teri)**

; Disable single-ping bottom track (BP),
; Set maximum bottom search depth to 1200 meters (BX)
BP000 **(same)**
BX12000 **(same)**

; output velocity, correlation, echo intensity, percent good
ND111100000 **(was WD111100000)**

; One and a half seconds between bottom and water pings
TP000150 **(was TP000000)**

; Three seconds between ensembles
; Since VmDas uses manual pinging, TE is ignored by the ADCP.
; You must set the time between ensemble in the VmDas Communication options
TE00000150 **(was TE00000300)**

; Set to calculate speed-of-sound, no depth sensor, external synchro heading
; sensor, no pitch or roll being used, no salinity sensor, use internal transducer
; temperature sensor
EZ1020001 **(same)**

; Output beam data (rotations are done in software)
EX00000 **(same)**

; Set transducer misalignment (hundredths of degrees)
EA04500 **(was EA00000 and 45° entered in VMDAS, now 0° in VMDAS)**

; Set transducer depth (decimeters)
ED00074 **(was ED00092 for fully deployed centerboard)**

; Set Salinity (ppt)
ES35 **(same)**

; External trigger
CX1,0 **(added as Oscar Dyson's ADCP synched with EK60 sounders)**

; save this setup to non-volatile memory in the ADCP
CK **(same)**

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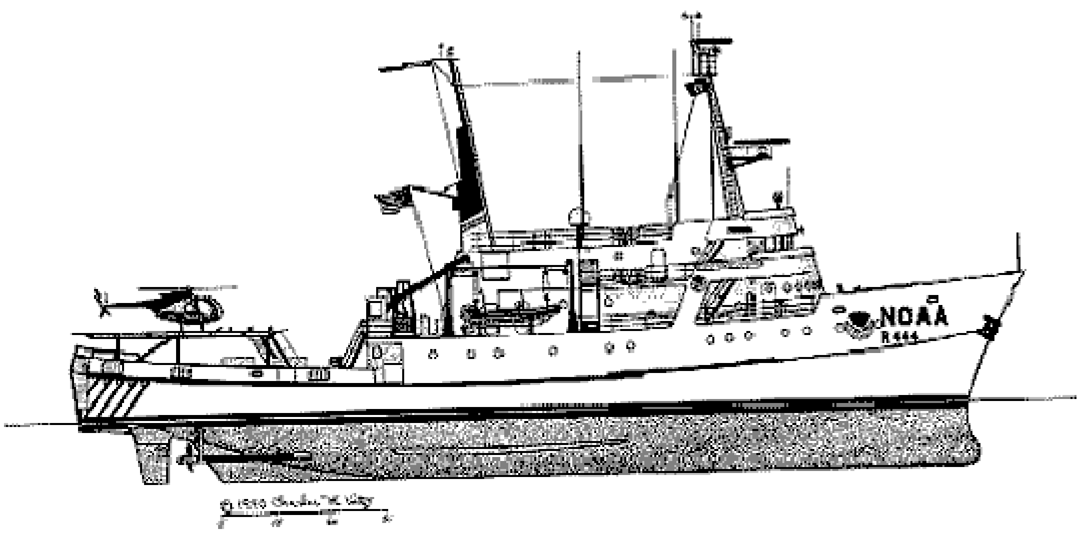
II. California Current Ecosystem Survey 2006 (DSJ0406) Acoustics Cruise Report for NOAA FRV *David Starr Jordan*, by G. R. Cutter Jr., S. Sessions, H. Smit, D. Krause, and D. Demer

Report of the data collection, preliminary analyses and tentative conclusions for the multi-frequency echosounder, multi-beam sonar, and ADCP surveys from NOAA FRV *David Starr Jordan* off the west coast of the U.S.A., southern area (CalCOFI Lines 51.7 through Line 95), 5 to 28 April 2006

G. R. Cutter Jr. (1), S. Sessions (1), H. Smit (2), D. Krause (1), and D. Demer (1)

(1) - NOAA Southwest Fisheries Science Center, Fisheries Research Division, Advanced Survey Technologies Group
(2) – Sea Technologies Services, Cape Town, South Africa



NOAA FRV *David Starr Jordan*

II.1 Objectives

The purpose of this survey was to acoustically map the distributions and estimate the abundances of coastal pelagic fish, including sardine, anchovy, and Pacific and jack mackerel, off the west coast of the United States of America; to characterize the biotic and abiotic environment of these coastal pelagic species (CPS) and investigate linkages; and to gather information about fish schooling behavior, diel vertical migration, and avoidance reactions to the survey vessel.

II.2 Accomplishments

Four frequency split-beam echosounder (38, 70, 120, and 200 kHz), single frequency multi-beam sonar (200 kHz), and single-frequency, 150 kHz, Acoustic Doppler Current Profiler (ADCP) data were collected from NOAA FRV *David Starr Jordan* throughout the April/May 2006 California Current Ecosystem Survey. The survey transects totaled approximately 3004 n.mi. including 10 east-west and 9 north-south transects spanning an area from San Diego, California to just north of Point Arena, California, ranging from approximately 31° to 39° north latitude (Fig. II.1). The transects were approximately 100-300 n.mi. long and were typically 60 n.mi. apart. Leg 1 occurred 5 to 17 April, 2006, and leg 2 occurred 18 to 28 April, 2006. Ship problems caused returns to port or nearshore and interrupted the survey on several occasions.

Mechanical problems with the winches of NOAA FRV *David Starr Jordan,* prevented completion of planned trawling operations in the southern survey area; however, the *David Starr Jordan* was able to accomplish acoustic, CUFES egg pump and ichthyoplankton sampling. Acoustic (multi-frequency echosounder, multi-beam sonar), egg pump, thermosalinograph, and meteorological data were collected continuously while the ship was underway, and pairovet, bongo-net and CTD data were collected at prescribed and ad-hoc stations. The ship's ADCP was operated, but failed to record data.

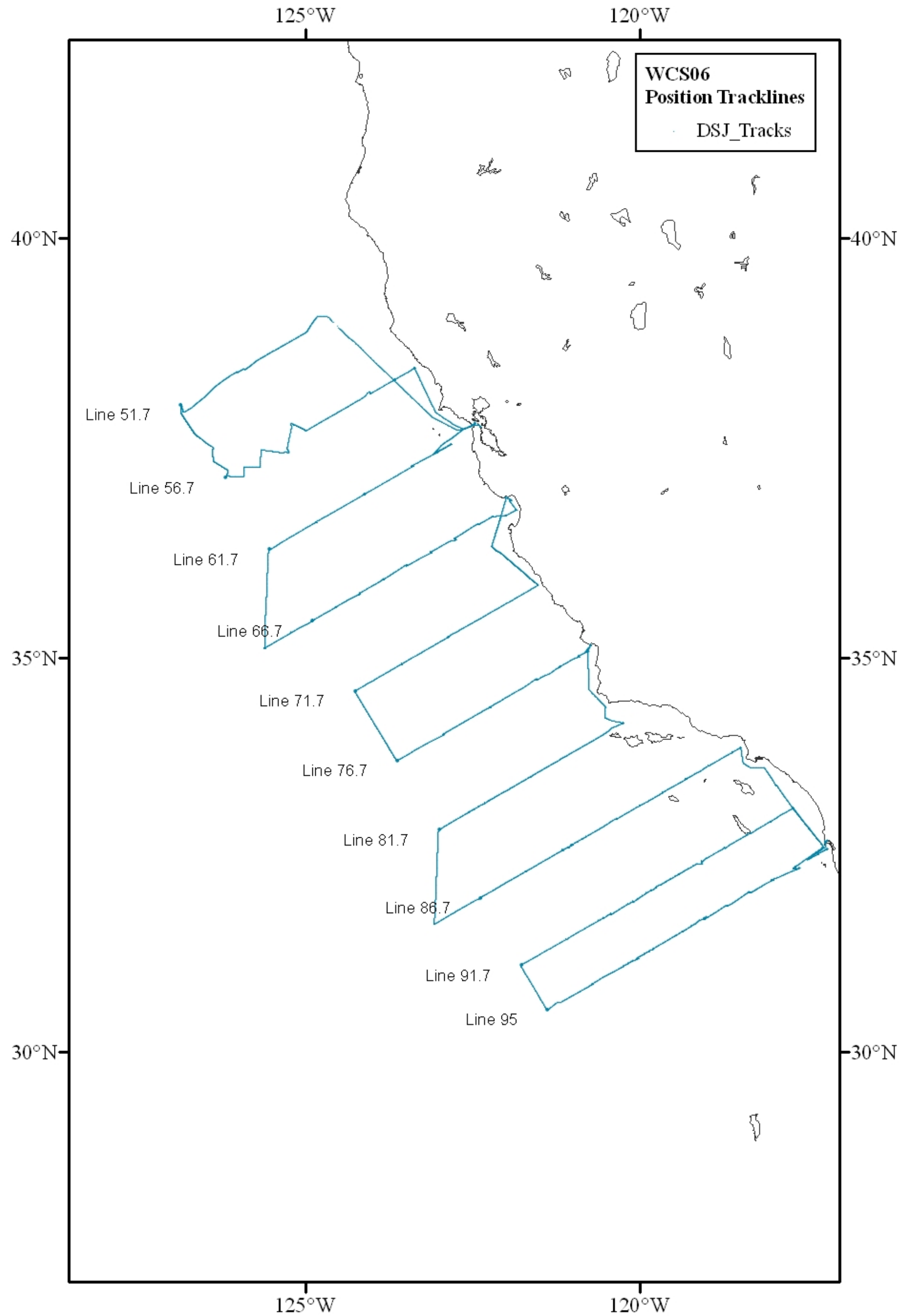


Figure. II.1. Transect line and sample station plan for the 2006 California Current Ecosystem Survey cruise aboard the NOAA FRV *David Starr Jordan*.

II.3 Methods and Results

Throughout the April 2006 California Current Ecosystem Survey aboard NOAA FRV *David Starr Jordan*, split-beam echosounder, multi-beam sonar, and ADCP data were collected and processed. The primary instrumentation included a Simrad EK60 multi-frequency echosounder (see section II.3.1), a Kongsberg-Mesotech SM2000 200 kHz, 180° multi-beam sonar (see section II.3.2), and an RDI 150 kHz ADCP (see section II.3.3).

II.3.1 EK60 multi-frequency echosounder

Throughout the survey, acoustical volume backscattering strengths (S_v; dB re 1 m) and *in-situ* target strengths (TS; dB 1 m^2) were measured continuously by four Simrad split-beam transducers with operating frequencies 38, 70, 120, and 200 kHz. The models (and serial numbers) were: ES38-B (27281), ES70-7C (108), ES120-7 (27612), ES200-7C (238). The four split-beam transducers on *David Starr Jordan* were all mounted on a steel blister on the hull, located approximately 1 m to the port side of the keel and one-third the ship's length from the bow. The transducers were thus positioned approximately 3.75 m from the sea-surface. Synchronized pulses of 1024 μs were transmitted downward every 2 seconds, received with bandwidths of 0.8745, 1.6375, 2.3435, 2.7785, and 2.986 kHz, respectively, and digitized in quadrature every 64 μs ("raw" data format). In addition to being stored in raw data format, these data were averaged every 1-m interval in range and stored in the "EK500" data format. Except for the EK60 sounders being used for these surveys and the 150 kHz broad bandwidth ADCP, all other echo sounders and sonars operating at or near the survey frequencies were secured during all survey operations. On *David Starr Jordan*, this included the ship's, 200 kHz Doppler speed log, Wesmar 160 kHz sonar, and 200 kHz Skipper echo sounder. The 50 kHz ES60 navigation sounder was synchronized with the EK60s to reduce interference with the survey measurements. The ADCP was triggered by the EK60s. Despite these measures, appreciable noise degraded the echograms at all four frequencies when surveying in inclement weather and swell. Data corresponding to ranges of 500m beneath the transducers were recorded in both formats on computer hard disk and backed-up to external USB V2.0 hard disk and DVD+R media. Data were processed with Echoview V3.50.54.3818, and distribution maps were created with ArcGIS/Map 9.0.

Volume backscattering data (S_v; dB re 1 m) and target strength measurements (TS; dB 1 m^2) were collected using four calibrated Simrad EK60 transceivers, split-beam transducers, and Simrad ER60 and SonarData Echolog software, at frequencies of 38 kHz, 70 kHz, 120 kHz and 200 kHz (Table II.1). A POS-MV V4 Wavemaster GPS was used to provide navigational data input to the ER60 and Echolog software, and GPS data were also logged separately from the ship's Northstar 952X GPS.

Table II.1. EK60 operational settings for the *David Starr Jordan*.

Frequency (kHz)	38	70	120	200
Transducer Model No.	ES38-B	ES70-7C	ES120-7	ES200-7C
Transducer Serial No.	27281	108	27612	238
Transmit Power (W)	1000	1000	500	300
Pulse Duration (μs)	1024	1024	1024	1024
Pulse Repetition (s) *	2	2	2	2
TS Gain (dB)	26.50	27.00	25.70	27.00
Sa Correction (dB)	0.00	0.00	0.00	0.00
EBA (dB)	-20.6	-21.0	-20.8	-20.7
Angle Sensitivity Along	21.9	23.0	21.0	23.0
Angle Sensitivity Athwart	21.9	23.0	21.0	23.0
3 dB Beamwidth Along	7.10	7.00	7.10	7.00
3 dB Beamwidth Athwart	7.10	7.00	7.10	7.00
Offset Along	0.00	0.00	0.00	0.00
Offset Athwart	0.00	0.00	0.00	0.00

* The intended pulse repetition interval was two seconds. That pulse interval was not always achieved. During the early part of the cruise, pulse interval ranged from of 3 to 6 s; on and after 14 April the interval was 2 s.

II.3.1.1 EK60 System calibration

On 05 April, 2006, echosounder calibrations were conducted in San Diego Bay, aboard the NOAA FRV *David Starr Jordan*. Personnel participating in the calibrations were G. Cutter, H. Smit, S. Sessions, and D. Krause. Calibrations were performed using a 38.1 mm diameter tungsten-carbide sphere with properties reported by Foote (1990) for all frequencies. The echosounders were calibrated for the pulse duration and power levels to be used for the survey (Table II.1). The SM20 was not operated during calibration.

The *David Starr Jordan* anchored at 18:00 GMT (10:00 PST) for calibration on a site just off Harbor Island in San Diego Harbor, within charted special anchorage number 215, at approximate position: 32 43.25 N, 117 11.91 W. The charted water depth was 14 m. Calibrations were expected to be difficult because of vessel motion due to wind and tide. The wind caused the *David Starr Jordan* to swing on anchor, and because of a bathymetric slope and tide, caused the depth below transducers to range from as shallow as 6.5 m to as deep as 12.5 m. The calibration sphere was lowered below the vessel by three lines, each remotely controlled with a motorized downrigger (Fig. II.2).

Figure. II.2. The calibration sphere and lead weight (left) suspended 2 m apart on monofilament line, and (right) one of the three remote-control downriggers used to position the target sphere.

The downriggers were labeled A, B, and C. A was attached to the 02 deck rail forward on the port side, B was attached to the 02 rail amidships on the starboard side, and C was attached to the 02 rail aft on the port side, making a triangular suspension for the sphere

(Fig.2; and Table II.2). A 1 kg lead weight was suspended by monofilament 2 meters below the calibration sphere. The three lines to the sphere were joined by three metal clips 2 m above the sphere.

At 11:29 PST (19:29 GMT) raw data recording was initiated with the ER60 software and was recorded for the duration of the calibration effort. In the ER60 software, a layer was created to bound the depth range just above and below the target return in the echogram that was determined to be the sphere. The range used was 4.5 to 6 m. Target data collection occurred within the calibration subprogram of the ER60, accessed via the single target detection dialogue of the ER60 software.

The 38 kHz echosounder was calibrated first, yielding the following beam model parameter values: Transducer gain = 25.46, SaCorrection = -0.62 dB, Athwartship Beam Angle = 7.07°, Alongship Beam Angle = 7.19°. Attempts were made to calibrate the 200 kHz echosounder, but the return strength of target sphere was not in an allowable range, and calibration could not be completed. Raw data were saved in case that calibration could be accomplished later with these data. Calibration of the 120 kHz echosounder yielded the following beam model parameter values: Transducer gain = 22.42, SaCorrection = -0.53 dB. Despite several efforts by the entire group over a period of two hours, the sphere could not be located in the beam of the ES70-7C. The unsuccessful calibrations were the result of incorrect transducer wiring (i.e. the 70 and 200 kHz echosounders were wired to the 200 and 70 kHz transducers, respectively). The wiring was corrected on 07 April, 2006.

On 10 April, 2006, during an unscheduled port-call for ship repairs, additional calibrations of the 70 and 200 kHz echosounders were successfully conducted in San Diego Harbor by G. Cutter and H. Smit. At 20:19 GMT (12:19 PST), the surface water temperature was 15.24 C, salinity was 33.43 ppt, and the sound speed was calculated to be 1509.5 m/s. Downriggers were attached as on 05 April, with A forward to port, B midship to starboard, and C aft to port.

Table II.2. Downrigger line lengths (feet) when the sphere was observed in the beams during calibration of the EK60s on the David Starr Jordan, April, 2006.

	Line	ES38-B	ES70-7C	ES120-7	ES200-7C
5 April, 2006	A	41	-	41	39
	B	44	-	44	43
	C	50	-	50	51
10 April, 2006	A	41	45*	41	44*
	B	44	48*	44	49*
	C	50	52*	50	53*

- sphere could not be located
* sphere in center of acoustic beam

Because of the difficulties experienced in conducting the calibrations and the uncertainties about the initial results, default calibration parameters (Table II.1) were used during the survey. Data were adjusted for the correct calibration parameters (Table II.3) when post-processing using SonarData Echoview.

Table II.3. Summary of beam model results from calibrations for ES38-B, ES70-7C, ES120-7, ES200-7C on the *David Starr Jordan* during April 2006.

	ES38-B	ES70-7C	ES120-7	ES200-7C
Transducer Gain	25.46 dB	26.11 dB	22.42 dB	25.60 dB
Athw. Beam Angle	7.07°	6.26°	8.01°	6.26°
Athw. Offset Angle	-0.01°	-0.05°	-0.17°	0.07°
SaCorrection	-0.62 dB	-0.34 dB	-0.53 dB	-0.29 dB
Along. Beam Angle	7.19°	6.22°	7.17°	6.37°
Along. Offset Angle	0.15°	0.04°	0.09°	-0.09°

II.3.1.2 EK60 Transducer mounting

The echosounder transducers on *David Starr Jordan* are mounted ~2.75 m below the mean water surface in a blister pod located on the port side of the ship, toward the bow, nearly directly beneath the wheelhouse along the forward axis (Fig. II.3).

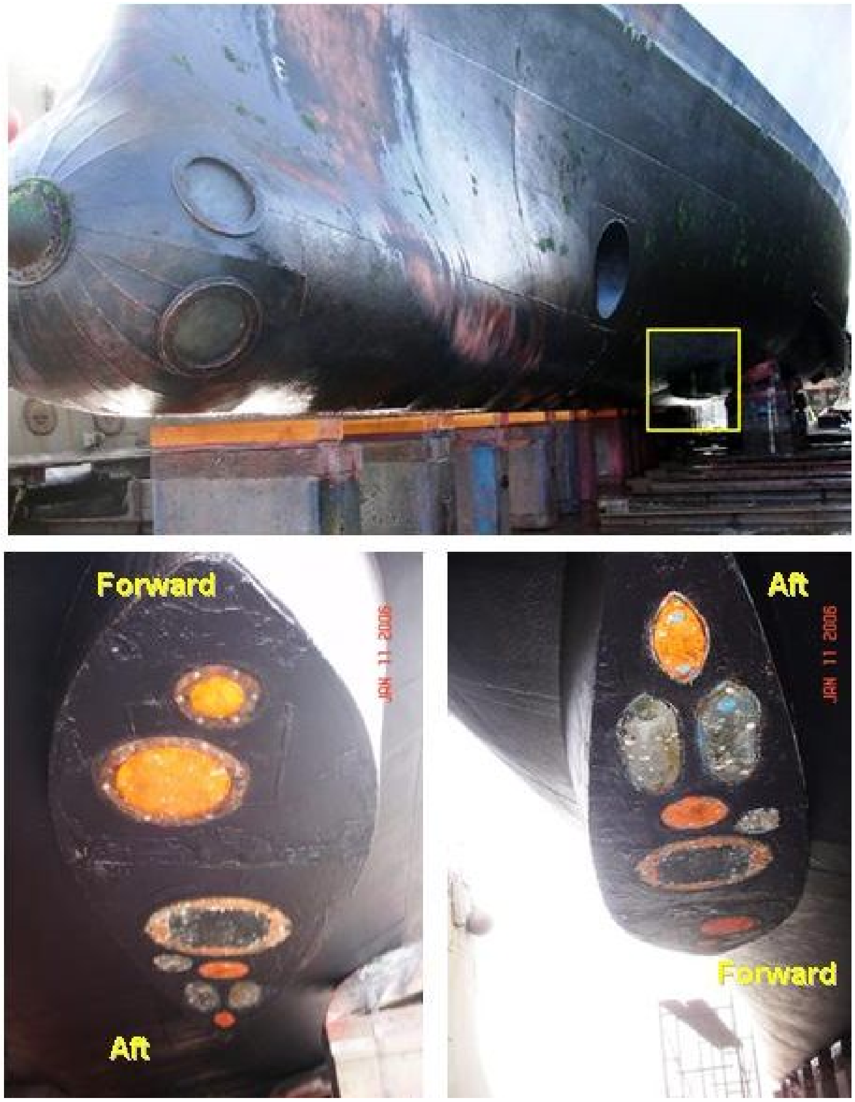


Figure II.3. Locations of the Simrad split-beam echosounder transducers on FRV *David Starr Jordan*.

II.3.1.3 EK60 Triggering

The EK60 General Purpose Transceivers (GPTs) were each supplied with a trigger signal from a basic multiplexer unit (Sea Technologies Services) and the *Basic mux* software application (Fig. II.4). Triggering was synchronous for all EK60s. A trigger pulse was sent to the EK60s every two seconds.

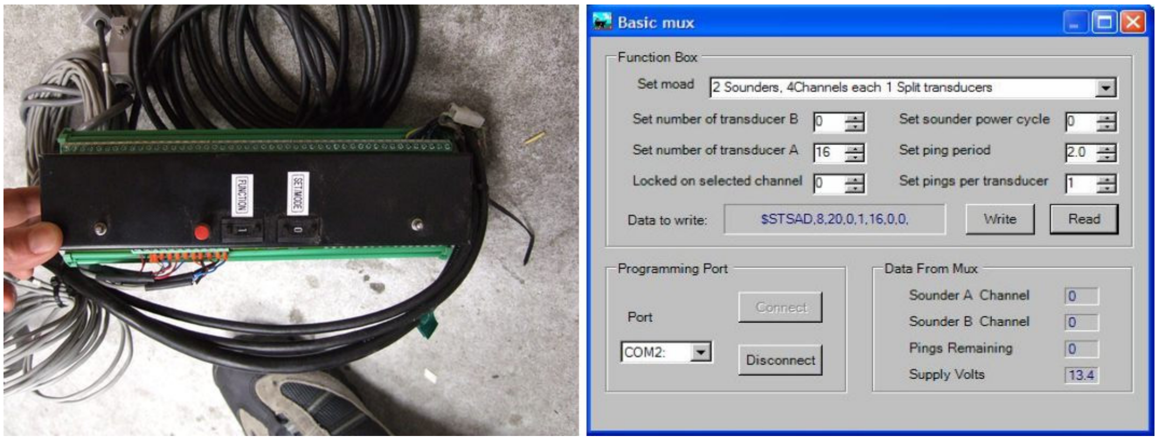


Figure II.4. The basic multiplexer unit (left) and the software application interface (right) for controlling the multiplexer and triggering the echosounders..

II.3.1.4 EK60 Data Collection and Archive

EK60 data were collected to 500 m depths by transmitting the four frequencies simultaneously in 1024 μs duration pulses every two seconds. The echoes were received with bandwidths of 2.425, 2.859, 3.026, and 3.088 kHz, respectively, and digitized in quadrature every 256 μs (ER60; .raw data format). These data were also averaged every 1 m in range from 0 to 500 m and stored in BI500 (.ek) and EK500 (.dg) data formats. Simrad ER60 (Version 2.1.1) software was used to log the .raw and .dg files. SonarData Echolog software (Version 3.50.0) was used to log .ek5 files to a networked file server. Data backups were made at regular intervals to DVD+R media, a USB V2.0 external hard disk, and an internal hard disk on a networked computer.

II.3.1.5 EK60 Data Processing

Post-processing was accomplished using SonarData Echoview software (V3.50.65.4670). First, the ER60 software was used to generate a single .dg file for each transect (equals .raw data averaged over 1 m depth bins). Each .dg file was loaded into an Echoview fileset and an .ev file was created using a custom data processing template. Echograms of the volume backscattering strength data (S_v; m^2/m^3) at each of the five frequencies were displayed. An integration start line was created at a fixed depth of 12 m (apx. 9.25 m below the transducers). An integration stop line was created 2 m above the 38 kHz sounder detected bottom. The S_v echograms were filtered of on-station time periods using a slow (i.e. <6 knots) ship speed as a proxy. The difference between S_v at 200 kHz and S_v at 38 kHz (S_{v200}-S_{v38}) was used to filter the S_v data at all frequencies for fish with swimbladders (-30 dB< S_{v200}-S_{v38}<5 dB). The resulting masked S_v data were thresholded at –60 dB, integrated over 5 m depth and 1 n.mi. cells, from 12 to 500 m, and output to .csv files for each transect and frequency.

A Matlab script was used to read the .csv files, integrate the volume backscattering coefficients from 12 to 70 m, and convert the resulting area backscattering strengths (m^2/m^2) to fish biomass density (kg/m^2) and biomass. The conversions factors were combined target strength-to-length and length-to-biomass relationships developed by Barange and Hampton (1997). The relationships for anchovy (*E. capensis*) and sardine (*S. sagax*) are based on *in-situ* target strength (TS) measurements (Barange et al., 1996):

$$TS\ (dB/kg) = -12.1*\log L_t - 21.1 \quad \text{for anchovy; and} \quad \text{(Eq. II.1)}$$
$$TS\ (dB/kg) = -14.9*\log L_t - 13.2 \quad \text{for sardine,} \quad \text{(Eq. II.2)}$$

where L_t (cm) is total fish length determined from the trawls. Calculations were performed using distributions of fish length estimated from the trawl catches. Note that Eq.s (1) and (2) predict ~5dB difference in TS/kg, for anchovy and sardine of the same length.

The survey was conducted along regularly-spaced parallel transects (Fig. II.1). Each east-west transect was considered a sampling unit, and the coefficient of variation was calculated as the ratio of the standard deviation to the mean of the mean density for each of the transects. The method of Jolly and Hampton (1990) was used to estimate biomass density for the transects, assuming that the fish were randomly distributed throughout the survey area, rather than utilizing stratified and randomly spaced transects.

Distributions of epipelagic swimbladdered fish (e.g. anchovy and sardine) were mapped in relation to sea surface temperature (SST) and the coastline using ESRI ArcGIS/ArcMap 9.1. The daily SST from the GOES 10-12 satellite were downloaded from http://poet.jpl.nasa.gov/ and averaged over two two-week periods using a Matlab script. Estimated fish distributions from the acoustic data collected aboard FRV *David Starr Jordan* were overlaid on the daily SST averaged from 5 to 19 April 2006.

II.3.1.6 EK60 Results

The multi-frequency acoustic data indicated that epipelagic fish were very patchily distributed throughout the survey area (Fig. II.5). Highest fish densities were located in the southern portion and in areas with SST ranging from 11-16 °C. A strong positive relationship was observed between the largest densities fish and the number of anchovy and sardine eggs collected by CUFES. In most areas where high densities of CPS were mapped, either sardine or anchovy eggs were pumped.

Following the procedures of Jolly and Hampton (1990), the mean biomass density for the west-east transects 1-10 was 0.0028 kg/m^2 with a C.V. of 62.17 %. Assuming all of the 38 kHz backscattering filtered for epipelagic fish with swimbladders was from sardine, the preliminary biomass estimate is 2.10 Mt. Additional analyses will be done at a later date to apportion this total biomass to sardine, anchovy, and Pacific and jack mackerel.

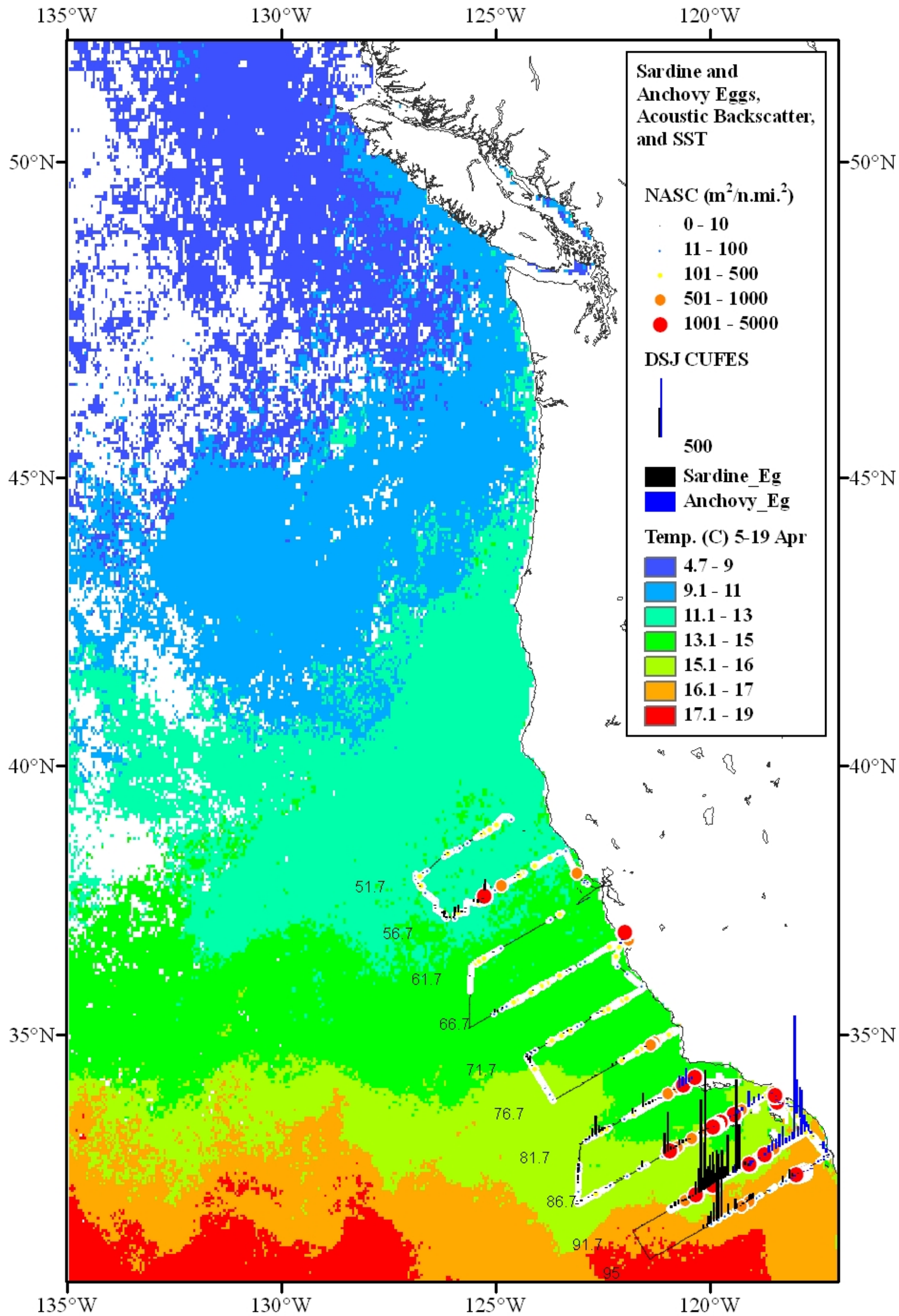


Figure II.5. Integrated volume backscattering coefficients (NASC at 38 kHz; $m^2/n.mi.^2$) from the FRV *David Starr Jordan* attributed to epipelagic (12-70 m) fish with swimbladders (colored dots), overlaid on sea-surface temperatures (GOES 10-12 satellite) averaged from 5 to 19 April and egg-pump counts (from FRV *David Starr Jordan* only) for anchovy (blue bars) and sardine (black bars).

There is likely a negative bias in the echo-integration data due to diel vertical migration. That is, the fish may move from depths of 15-70 m during the day to 0-15 m at night, were they are ineffectively sampled by the down-looking echosounders and sonar. Some evidence for this diel migration was documented from the EK60 data from the FSV *Oscar Dyson* survey.

A summary of all survey transects is provided in Table II.4, Raw 38 kHz echograms and 38 kHz echograms processed using the algorithm for fish detection for all survey transects are presented in Figs. II.6-II.24. These echograms have been resampled spatially, along-track, for each to fit on a single page.

Table II.4. Transect Summaries for the FRV *David Starr Jordan* (Dates and times in GMT).

Transect Name	Start Latitude	Start Longitude	Start Time (GMT)	Start Date	End Latitude	End Longitude	End Time (GMT)	End Date	Comments
Line 95	32° 37.62' N	117° 16.41' W	1650	06-Apr-06	30° 34.05 N	121° 23.99 W	2004	08-Apr-06	Onshore – offshore transect.
Segment 95 to 91.7	30° 34.07 N	121° 24.00 W	2004	08-Apr-06	31° 07.21 N	121° 46.84 W	2359	08-Apr-06	Segment connecting offshore endpoints of Lines 95 and 91.7.
Line 91.7	31° 07.37 N	121° 46.94 W	0001	08-Apr-06	33° 05.90 N	117° 40.83 W	14:31	10-Apr-06	Offshore – onshore transect. After Line 91.7, the vessel returned to San Diego Bay for repairs.
Segment 91.7 to 86.7	32° 41.60 N	117° 13.92 W	0229	15-Apr-06	33° 49.36 N	118° 37.67 W	1659	15-Apr-06	Segment extending from San Diego Bay to Line 86.7 and connecting nearshore endpoints of Lines 91.7 and 86.7.
Line 86.7	33° 47.77 N	118° 28.52 W	1442	15-Apr-06	31° 39.89 N	123° 04.45 W	0822	17-Apr-06	Onshore – offshore transect.
Segment 86.7 to 81.7	31° 41.81 N	123° 04.32 W	0836	17-Apr-06	32 49.18 N	123 0.69 W	1630	17-Apr-06	Segment connecting offshore endpoints of Lines 86.7 and 81.7.
Line 81.7	32° 50.180 N	123° 00.660 W	1645	17-Apr-06	34° 11.13 N	120° 15.63 W	1400	18-Apr-06	Offshore – onshore transect.
Segment 81.7 to 76.7	34° 10.42 N	120° 17.707 W	1349	18-Apr-06	35° 04.899 N	120° 46.646 W	2300	18-Apr-06	Segment connecting nearshore endpoints of Lines 81.7 and 76.7.
Line 76.7	35° 05.17 N	120° 46.58 W	0350	19-Apr-06	33° 43.13 N	123° 37.60 W	0414	20-Apr-06	Onshore – offshore transect.
Segment 76.7 to 71.7	33° 43.13 N	123° 37.60 W	0415	20-Apr-06	34° 34.92 N	124° 15.58 W	1142	20-Apr-06	Segment connecting offshore endpoints of Lines 76.7 and 71.7.
Line 71.7	34° 35.09 N	124° 15.70 W	1146	20-Apr-06	35° 53.76 N	121° 31.75 W	0747	21-Apr-06	Offshore – onshore transect.
Segment 71.7 to 66.7	35° 53.95 N	121° 31.99 W	0751	21-Apr-06	36° 47.79 N	121° 50.66 W	0405	22-Apr-06	Segment connecting nearshore endpoints of Lines 71.7 and 66.7. Also, part covers meandering around Monterey Bay.
Line 66.7	36° 47.80 N	121° 50.65 W	0407	22-Apr-06	35° 26.42 N	124° 55.01 W	1646	23-Apr-06	Onshore – offshore transect.
Segment 66.7 to 61.7	35° 26.12 N	124° 55.45 W	1651	23-Apr-06	36° 19.11	125° 32.83	0707	24-Apr-06	Segment connecting offshore endpoints of Lines 66.7 and 61.7.

Line 61.7	36° 19.08 N	125° 32.65 W	0719	24-Apr-06	37° 19.33 N	123° 24.81 W	0248	25-Apr-06	Offshore – onshore transect.
Segment 61.7 to 56.7	37° 47.04 N	122° 41.28 W	1828	25-Apr-06	38° 28.85 N	123° 22.86 W	0125	26-Apr-06	Segment connecting nearshore endpoints of Lines 61.7 and 56.7.
Line 56.7	38° 28.85 N	123° 22.84 W	0125	26-Apr-06	37 18.01 N	126 12.47 W	0433	27-Apr-06	Onshore – offshore transect.
Segment 56.7 to 51.7	37° 18.04 N	126° 12.51 W	0433	27-Apr-06	38° 00.49 N	126° 43.04 W	1805	27-Apr-06	Segment connecting offshore endpoints of Lines 56.7 and 51.7.
Line 51.7	38° 00.56 N	126° 42.89 W	1806	27-Apr-06	39° 02.10 N	124° 35.87 W	1023	28-Apr-06	Offshore – onshore transect.

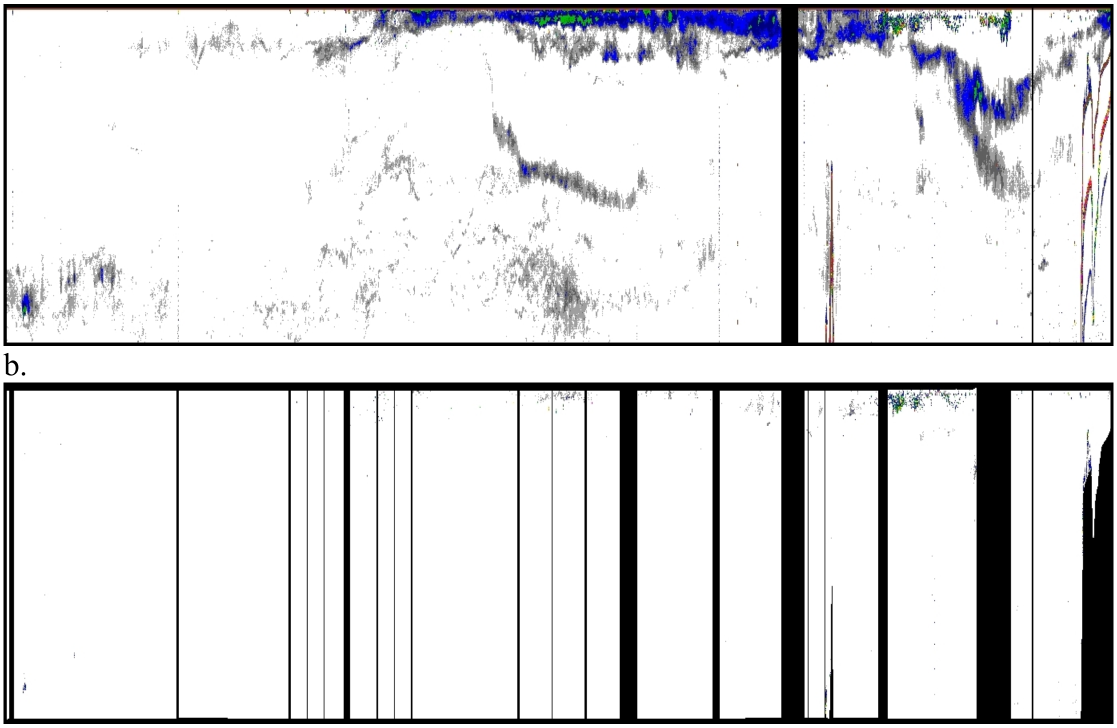
a.
b.


Figure II.6. Line 95: original (a) and filtered (b) echograms (depth: 0-500m; distance: 274 n.mi.; not to scale). The filtering process is described in section II.3.2.5.

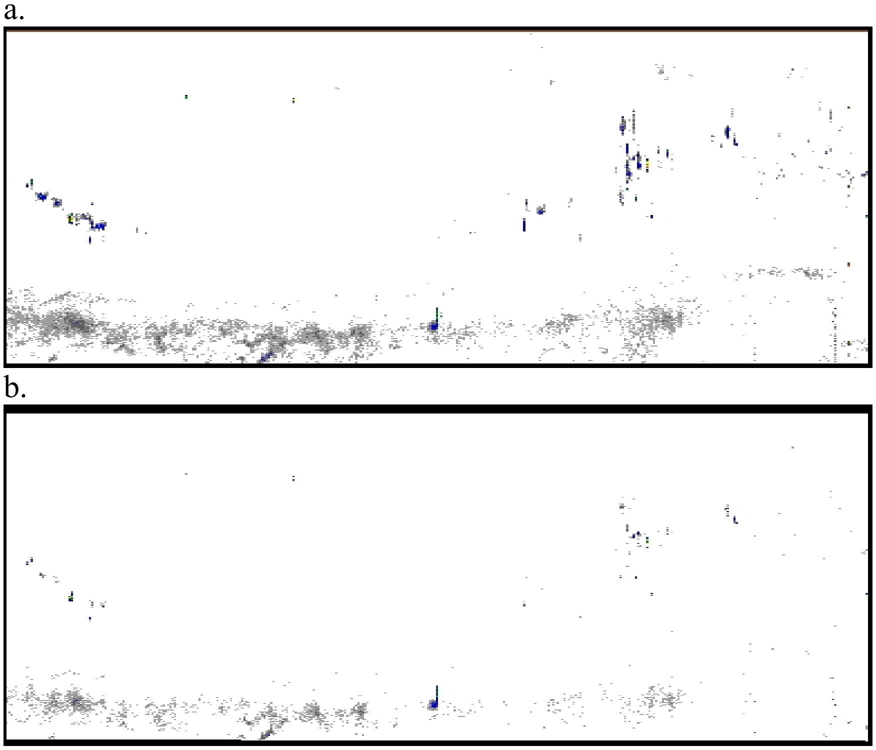
a.
b.


Figure II.7. Segment 95 to 91.7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 47 n.mi.; not to scale).

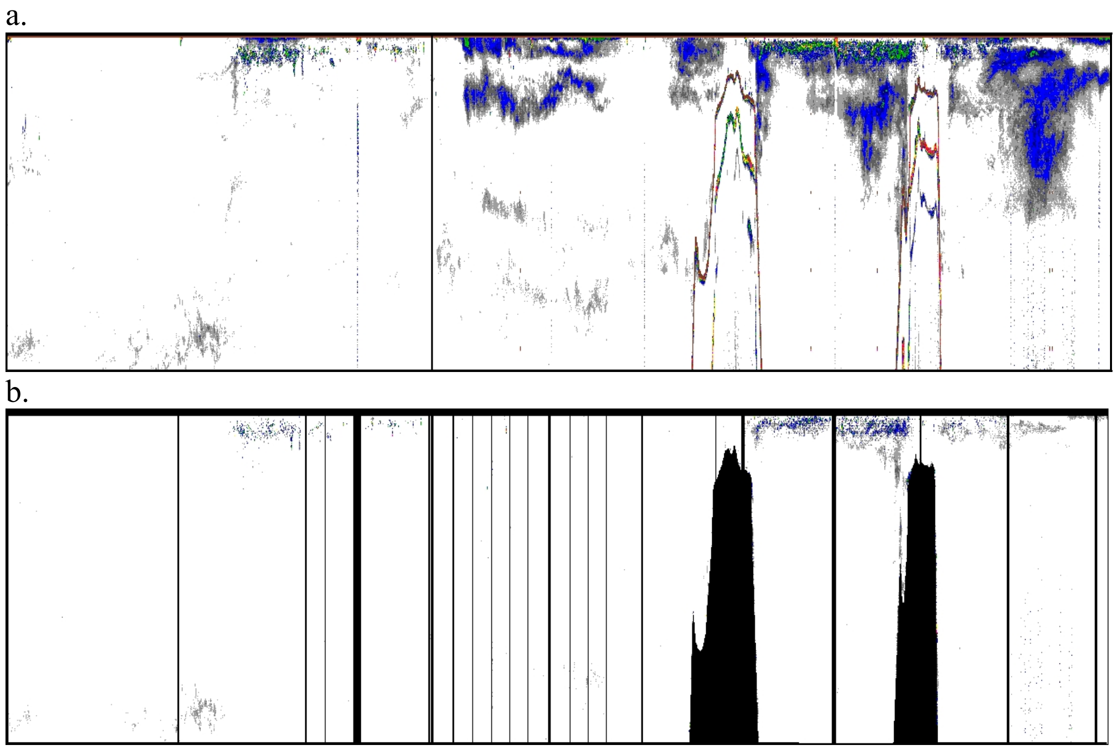


Figure II.8. Line 91.7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 283 n.mi.; not to scale).

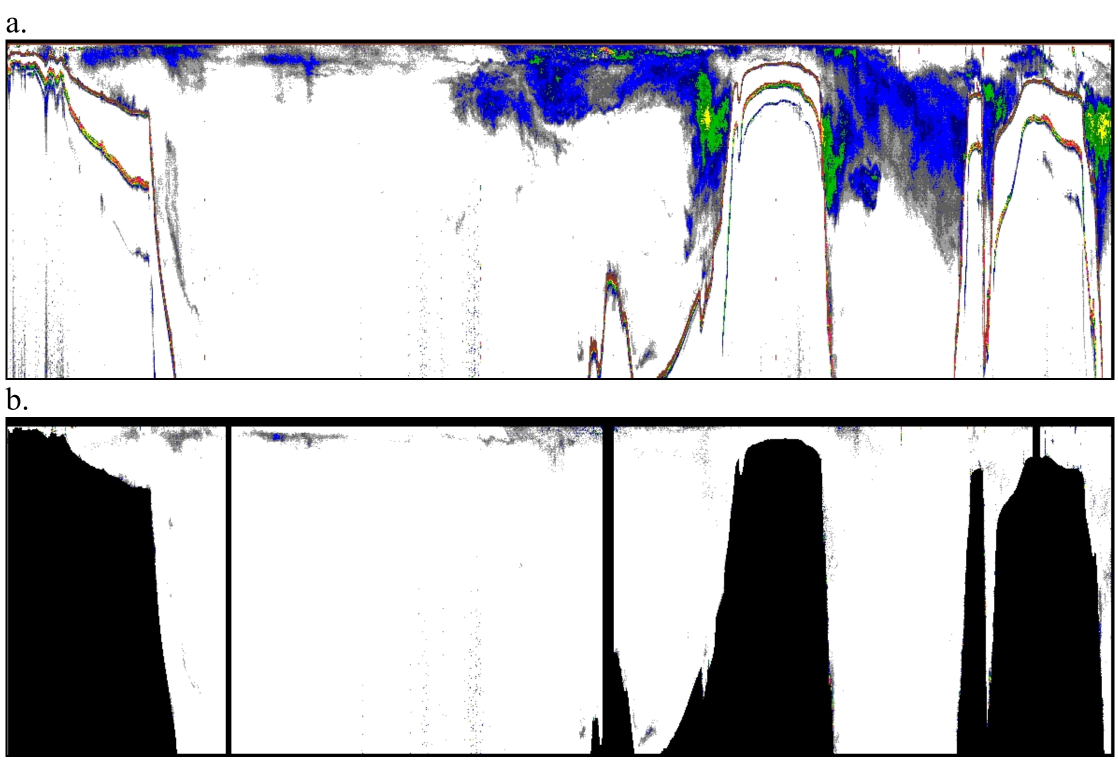
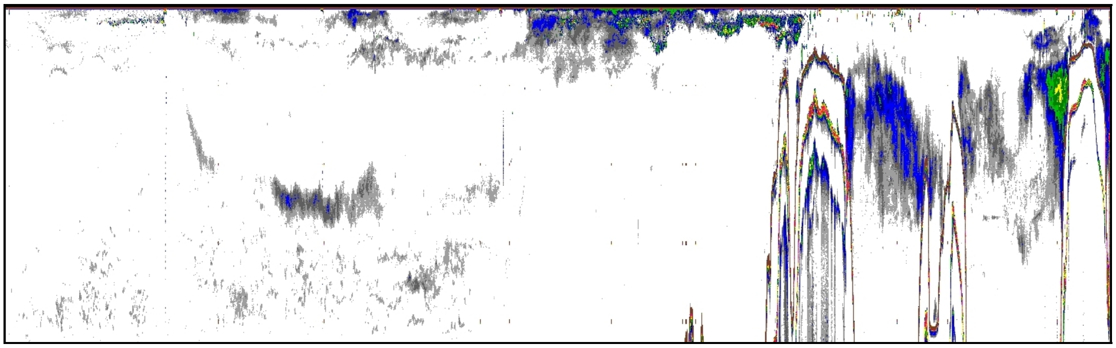


Figure II.9. Segment 91.7 to 86.7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 119 n.mi.; not to scale).

a.



b.

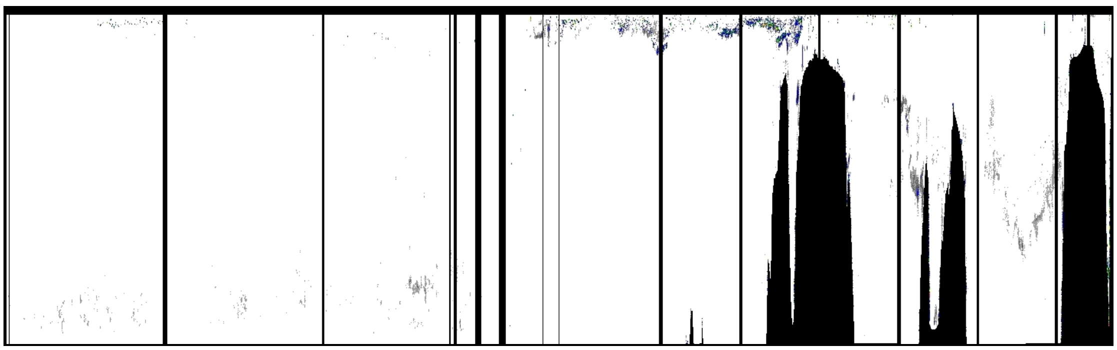
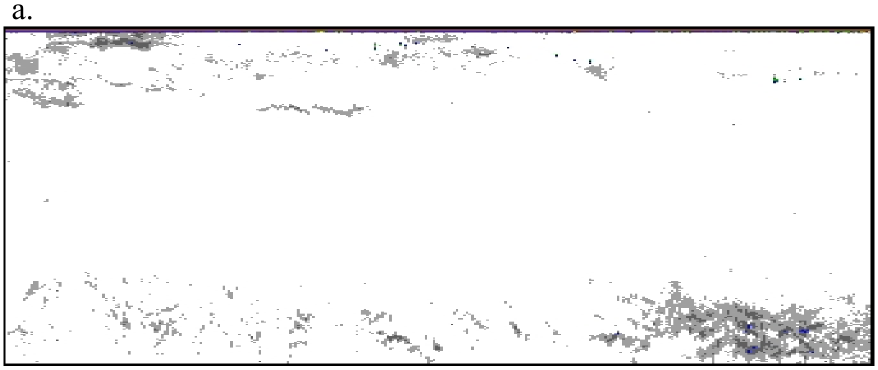


Figure II.10. Line 86.7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 318 n.mi.; not to scale).

a.



b.

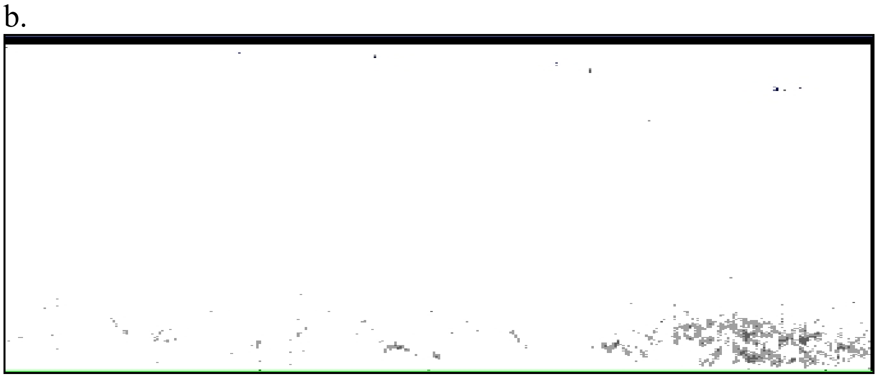


Figure II.11. Segment 86.7 to 81.7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 84 n.mi.; not to scale).

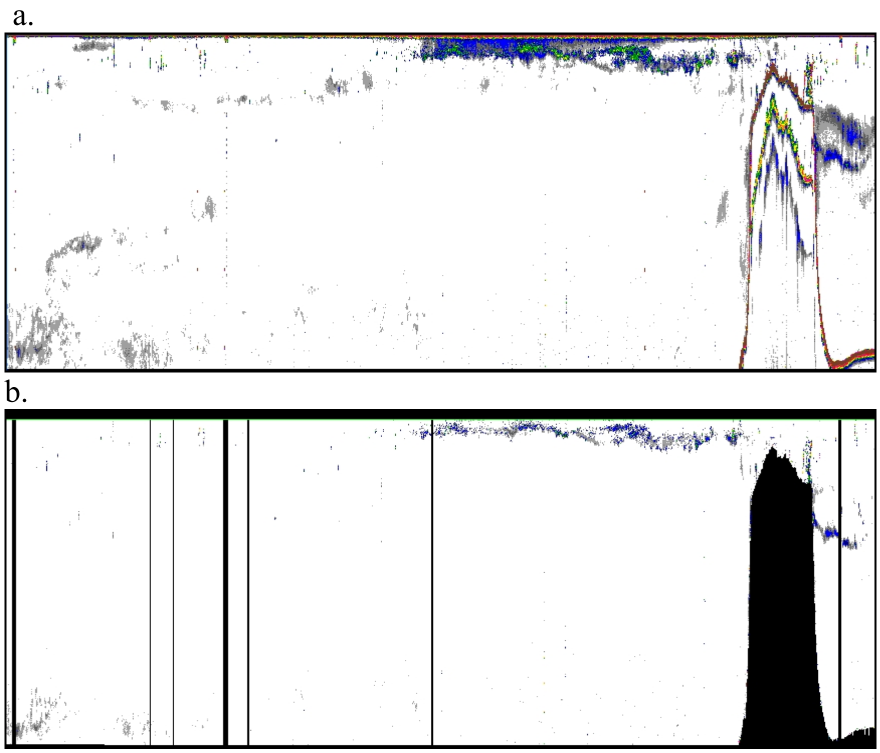


Figure II.12. Line 81.7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 191 n.mi.; not to scale).

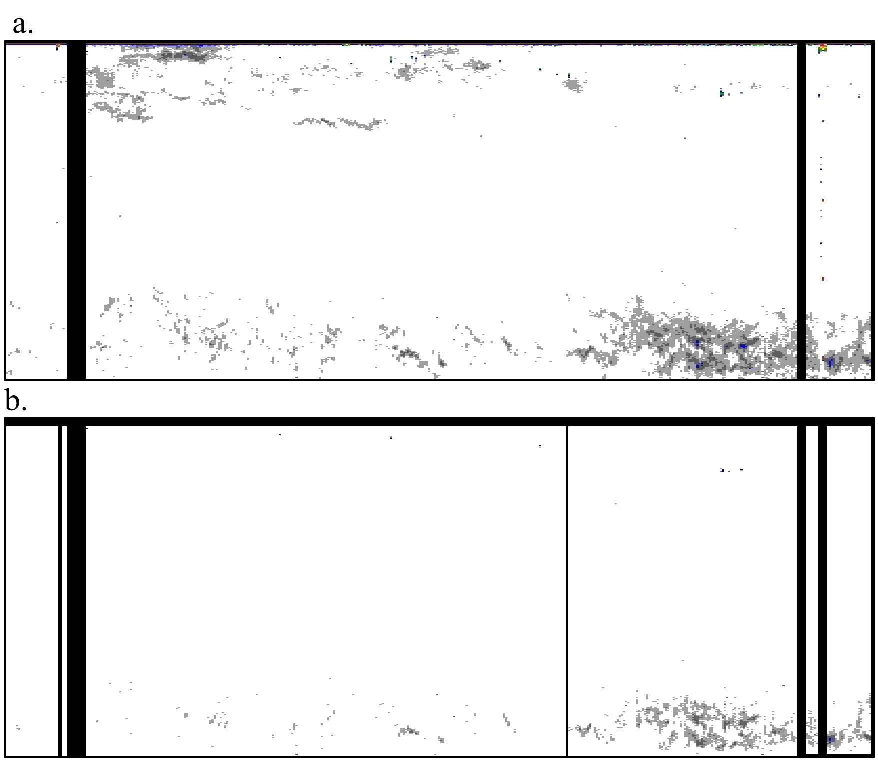
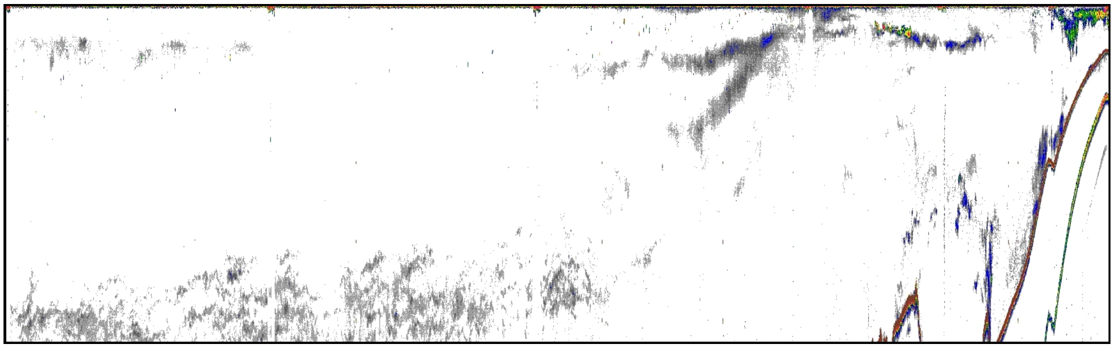


Figure II.13. Segment 81.7 to 76.7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 71 n.mi.; not to scale).

a.



b.

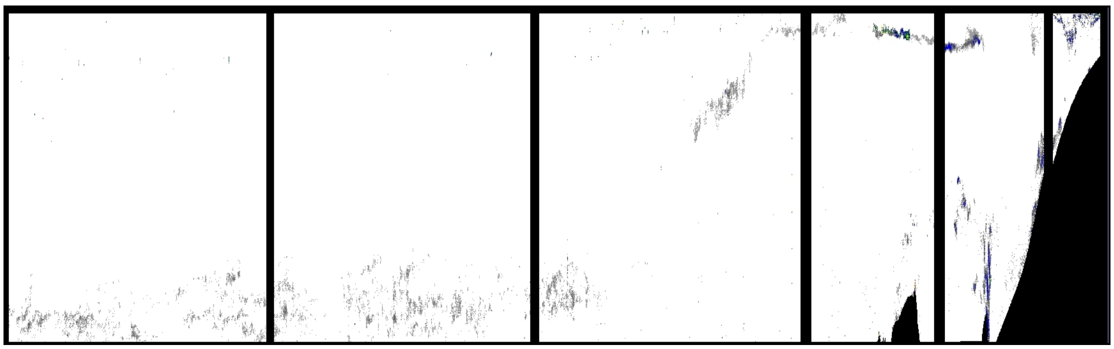
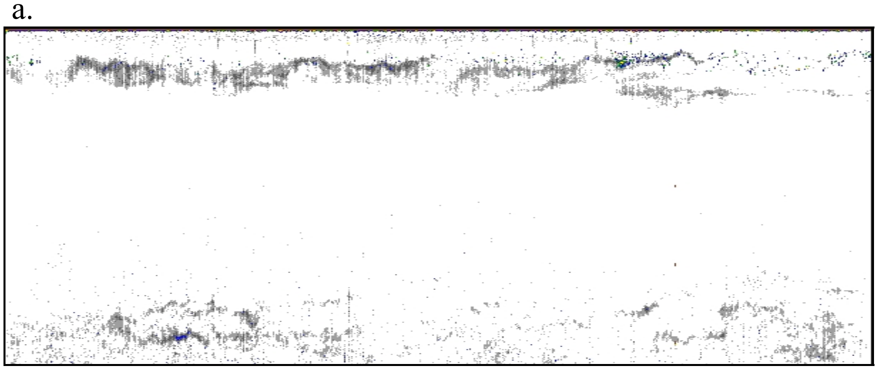


Figure II.14. Line 76.7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 194 n.mi.; not to scale).

a.



b.

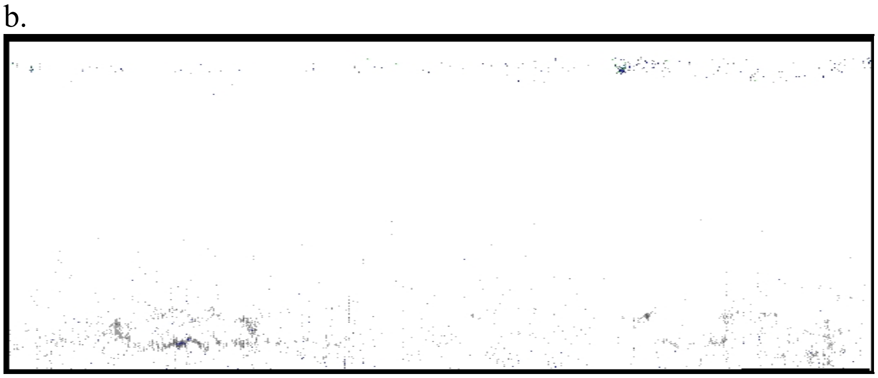
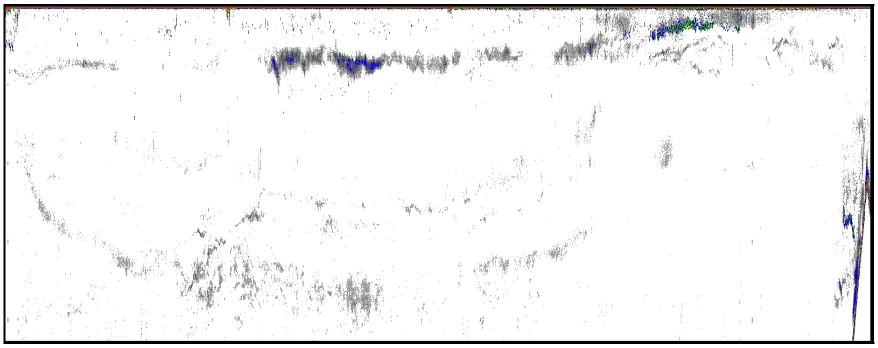


Figure II.15. Segment 76.7 to 71.7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 72 n.mi.; not to scale).

a.



b.

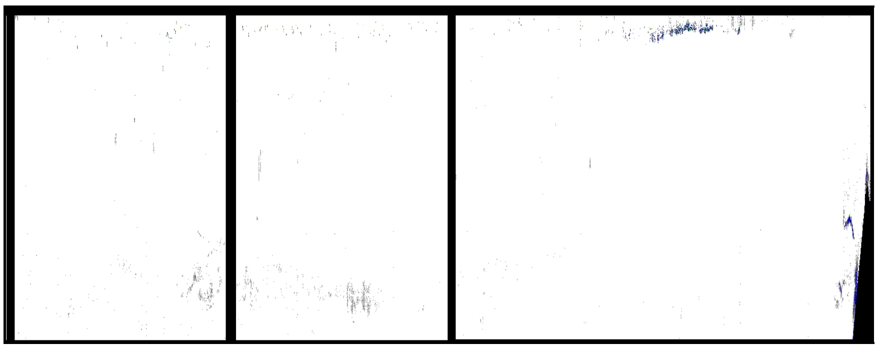
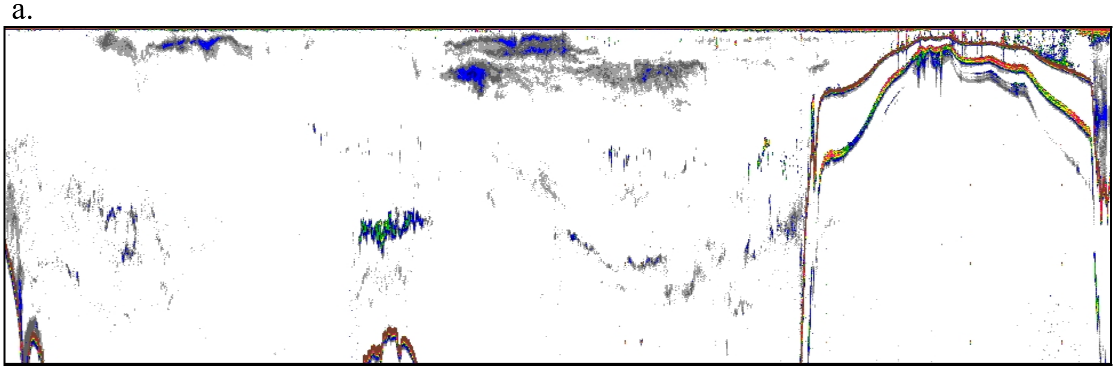


Figure II.16. Line 71.7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 190 n.mi.; not to scale).

a.



b.

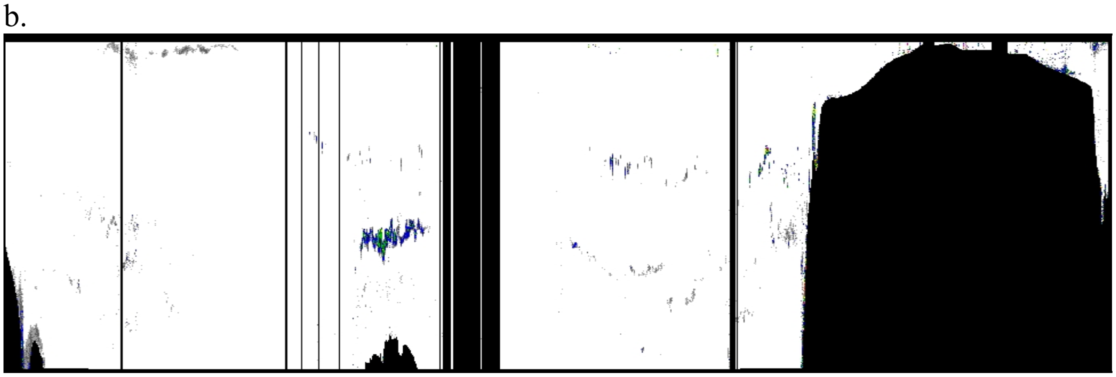
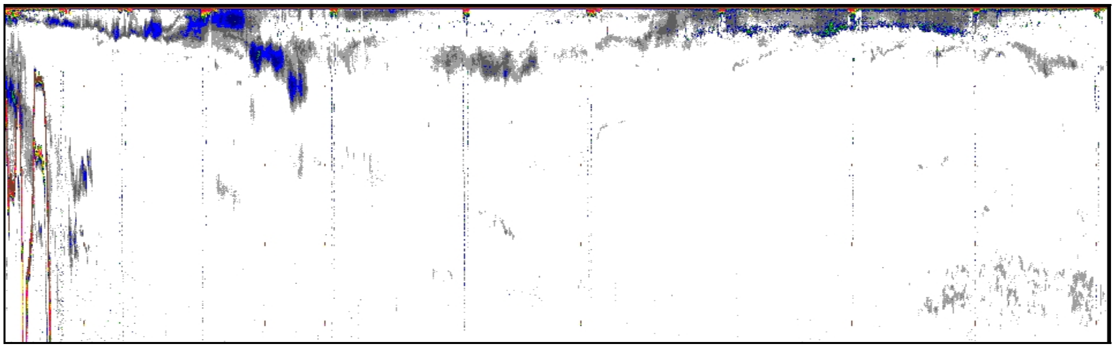


Figure II.17. Segment 71.7 to 66.7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 115 n.mi.; not to scale).

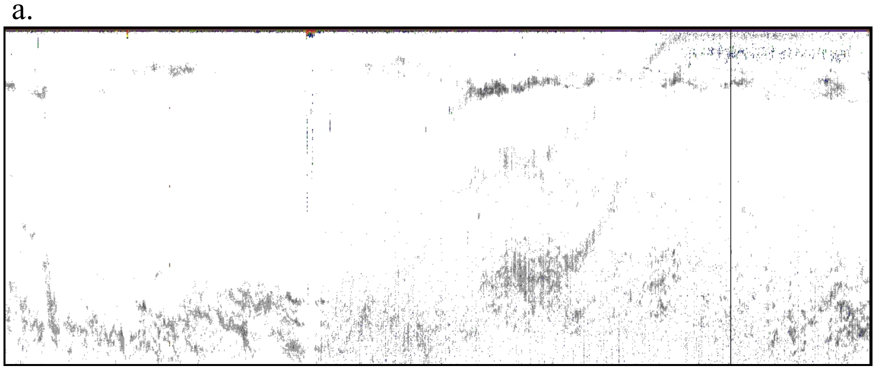
a.



b.

Figure II.18. Line 66.7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 257 n.mi.; not to scale).

a.



b.

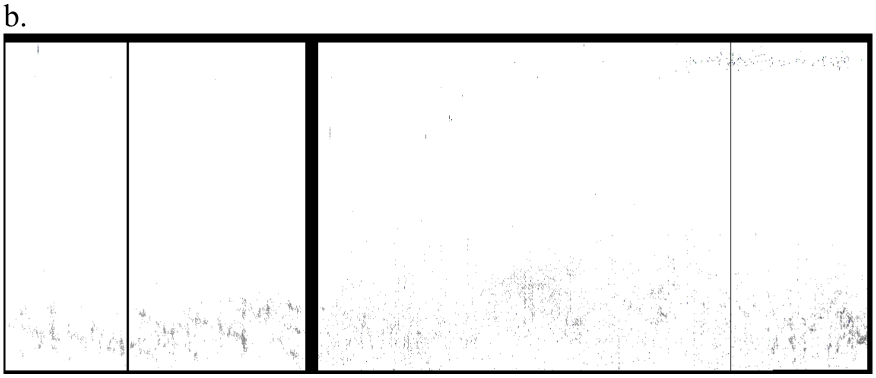
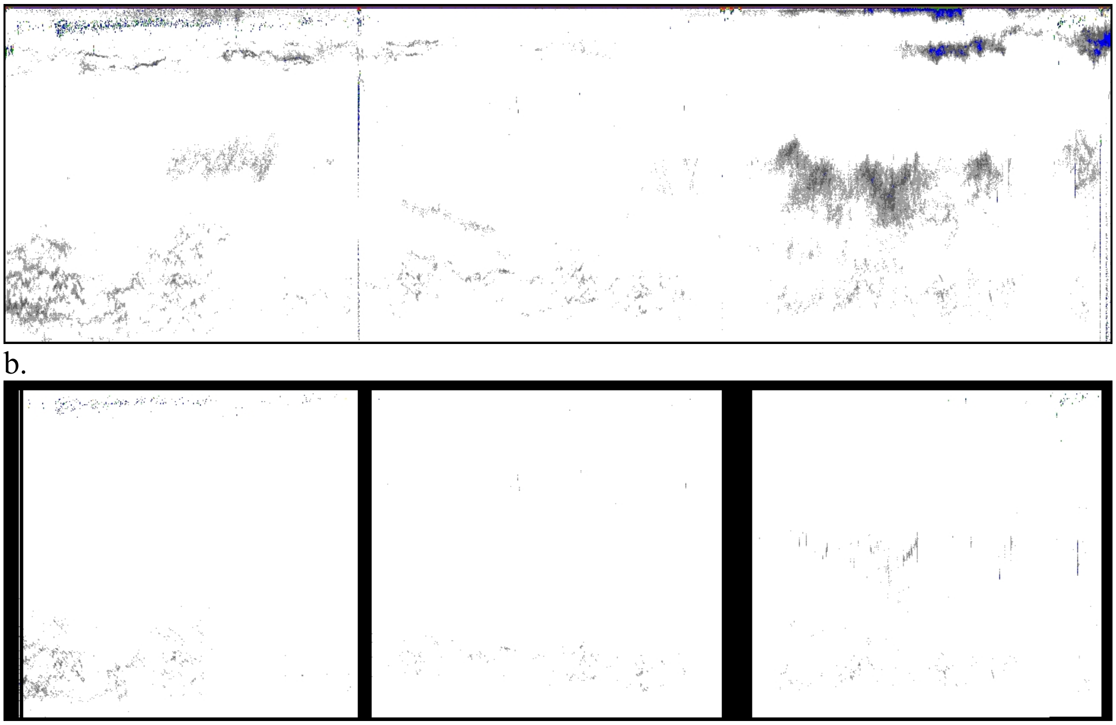


Figure II.19. Segment 66.7 to 61.7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 89 n.mi.; not to scale).

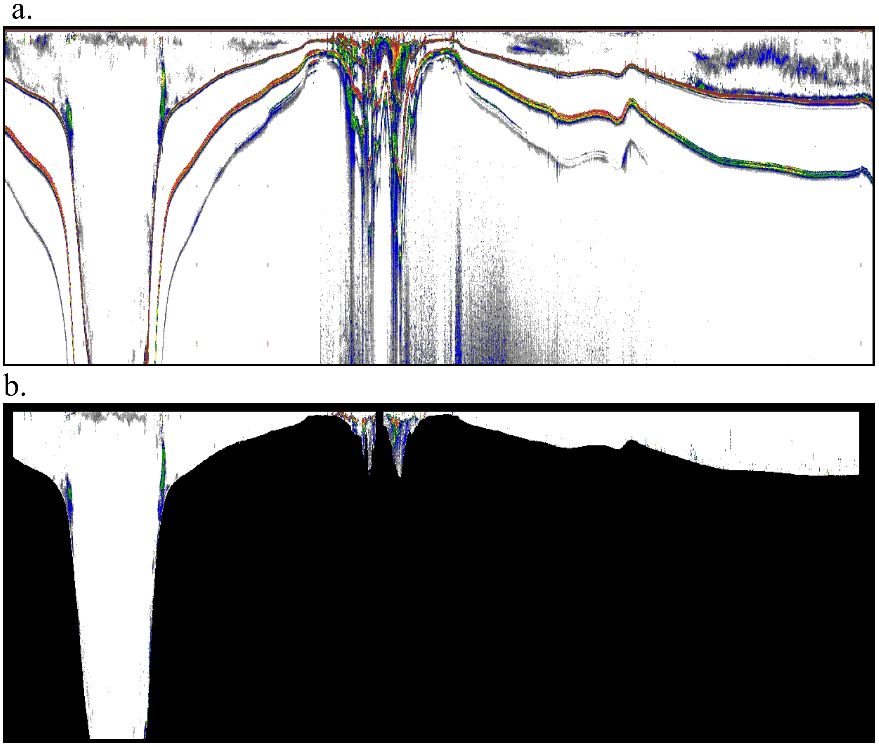
a.



b.

Figure II.20. Line 61.7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 186 n.mi.; not to scale).

a.



b.

Figure II.21. Segment 61.7 to 56.7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 83 n.mi.; not to scale).

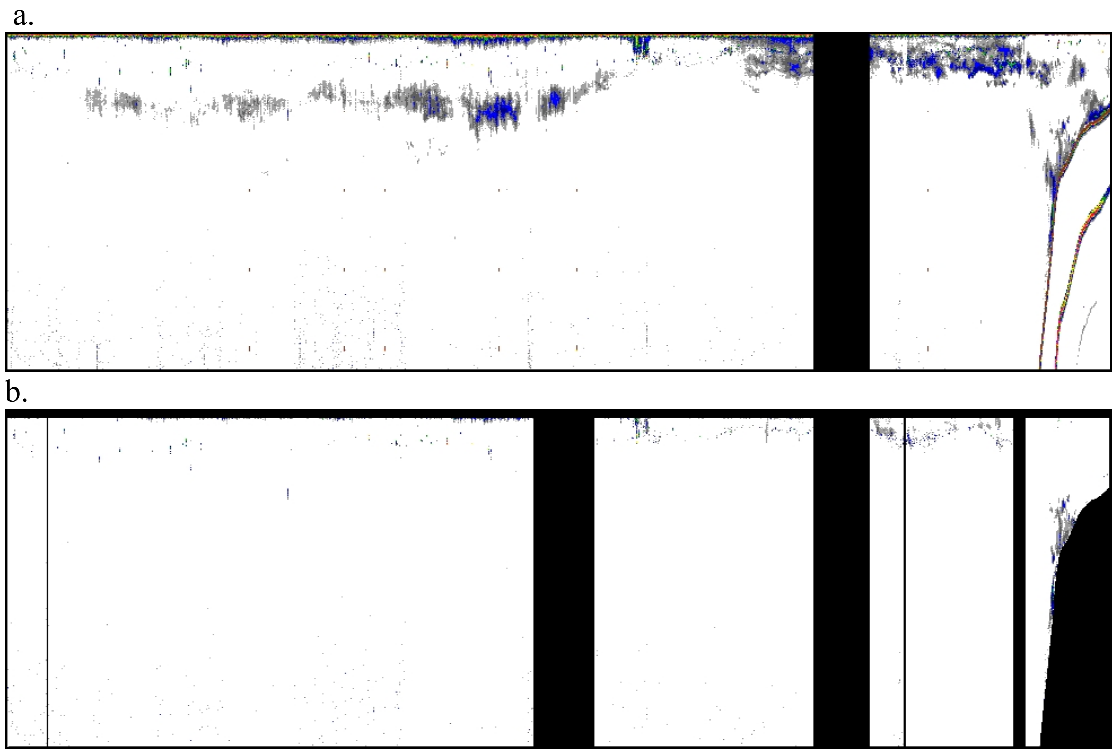


Figure II.22. Line 56.7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 191 n.mi.; not to scale).

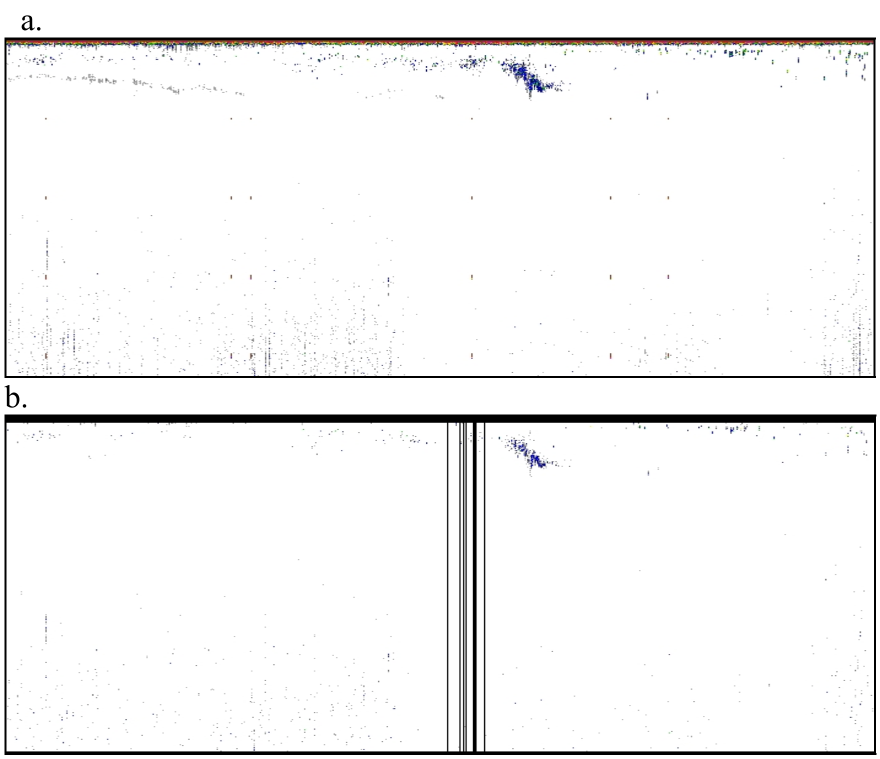
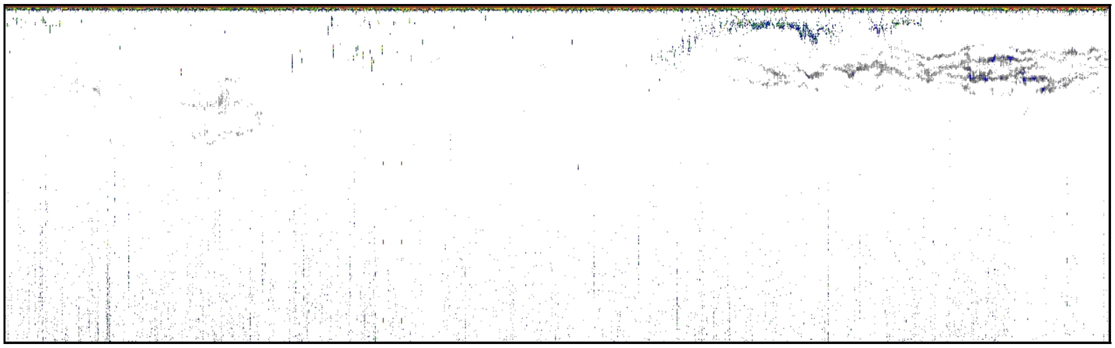


Figure II.23. Segment 56.7 to 51.7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 73 n.mi.; not to scale).

a.



b.

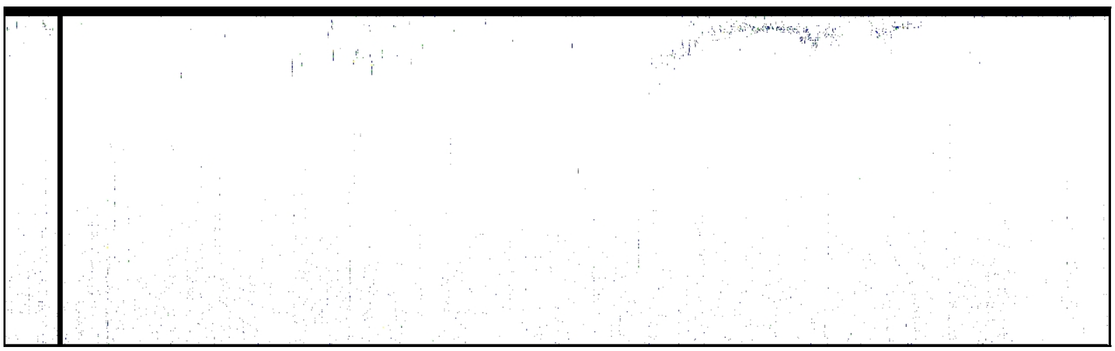


Figure II.24. Line 51.7: original (a) and filtered (b) echograms (depth: 0-500m; distance: 154 n.mi.; not to scale).

II.3.2 SM20 Multi-beam sonar

A Kongsberg-Mesotech SM2000 200 kHz multi-beam sonar, 180° model (with nominal 150° and 155° transmit beam patterns in imaging and echosounding transmission modes, capable of forming an image over a 180° swath) and a SM20 processor were used on FRV *David Starr Jordan*. The SM2000/SM20 system forms 128 beams that cover up to a 180° swath. The SM2000 system has two transducers: a cylindrical array that can be used to both transmit and receive when operating in imaging mode; and a long stave that can be used as the transmitter, when operated in echosounding mode, with receiving on the cylindrical array. This survey was conducted in echosounding mode only.

II.3.2.1 SM20 System calibration

The SM2000/SM20 system was not calibrated for this survey. Comparisons between the volume backscattering recorded by the multi-frequency echosounder and multi-beam sonar may be instructive for semi-quantitative interpretation of the volume scattering data.

II.3.2.2 SM2000 Tranducer mounting

The SM2000 sonar head was mounted on a pole attached to the port side of the *David Starr Jordan*. The SM2000 head was attached at an angle of 30° off nadir to port using a custom-manufactured adapter bracket (Figs. II.25 and II.26). The SM2000 head was located at a depth of 3.1 m below the mean water surface.

Figure II.25. Angled bracket for mounting the SM2000 head at 30° off-nadir to port on the bottom of the steel pole.

Figure II.26. SM2000 sonar head mounted on the pole.

The SM2000 pole was lifted using the ship's crane and installed on the port side just aft of midships. In deployed mode, the pole rested against and pole-receptacle bracket welded to the port-side hull (Fig. II**.**27). Initially, the pole was stabilized using rope lines and a come-along. Later, on 06 April 2006, the rope lines were replaced with steel cables.

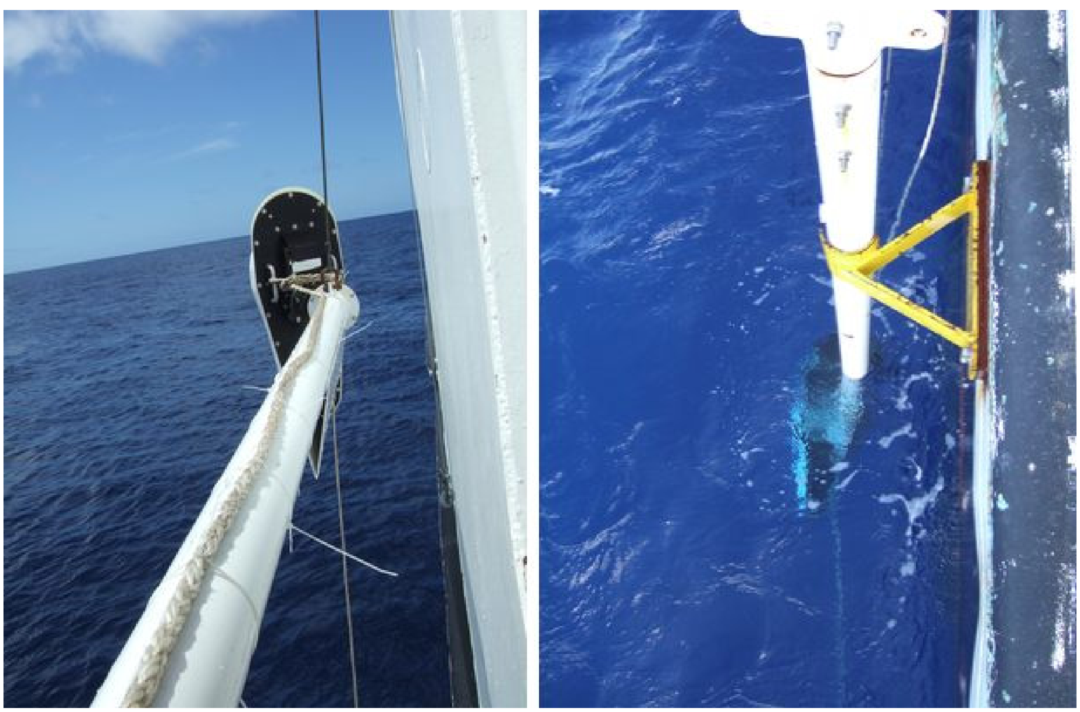


Figure II.27. SM2000 sonar head and pole in raised position (left, looking forward) held by the crane and a pivot arm in a pivot socket on the rail, and in deployed position (right) with the pole resting against and pole-receptacle bracket welded to the port-side hull. Notice the tilt off to the port side.

II.3.2.3 SM20 Triggering

The EK60s and the SM20 processor surface telemetry board (STB) were both triggered using a basic multiplexer unit (Fig. 4). Triggering was synchronous for all EK60s, and asynchronous between the EK60s and the SM20 in order to prevent interference. One of the EK60s and the SM2000 both operated at frequencies of 200 kHz. A trigger pulse was sent to the EK60s every two seconds. One second after the pulse was sent to the EK60s, a pulse was sent to the SM20.

II.3.2.4 SM20 Data Collection and Archive

The SM2000 was controlled and data were logged using a Kongsberg-Mesotech SM20 processor unit. A range of 200 m was chosen and used except during a few instances when the range was set to 100 m for increased resolution. The pulse duration was 385 μs at 200 m range and was 220 μs at 100 m range. High power level was used for the SM20. System gain was set to 67.5%, and on occasion to 75%. Display gain was set to 300%.

For the first three days of surveying, covering Lines 95, 95 to 91.7, and 91.7, the SM20 was operated in imaging mode (internal transmit transducer). In imaging mode uses the same cylindrical transducer for transmission and reception. On, and after, 10 April 2006 the SM20 was used in echosounder mode (external transmit transducer). Echosounder mode produces much narrower along-ship beamwidths (1.5 to 2.0°) than imaging mode (20°). In both modes, across-ship beamwidth is approximately 2.0°. Raw data from the SM20 were stored to Kongsberg-Mesotech format (.SMB) files.

The SM2000 imaged a swath extending from the sea surface on the port side to 60° to starboard (128 beams were formed over a 180° swath; Fig. II.28). In practice, useful data is obtained from a swath of only 150 to 155°, limiting the observational swath between the sea surface to port and approximately 45° off nadir to starboard (Fig. II.28).

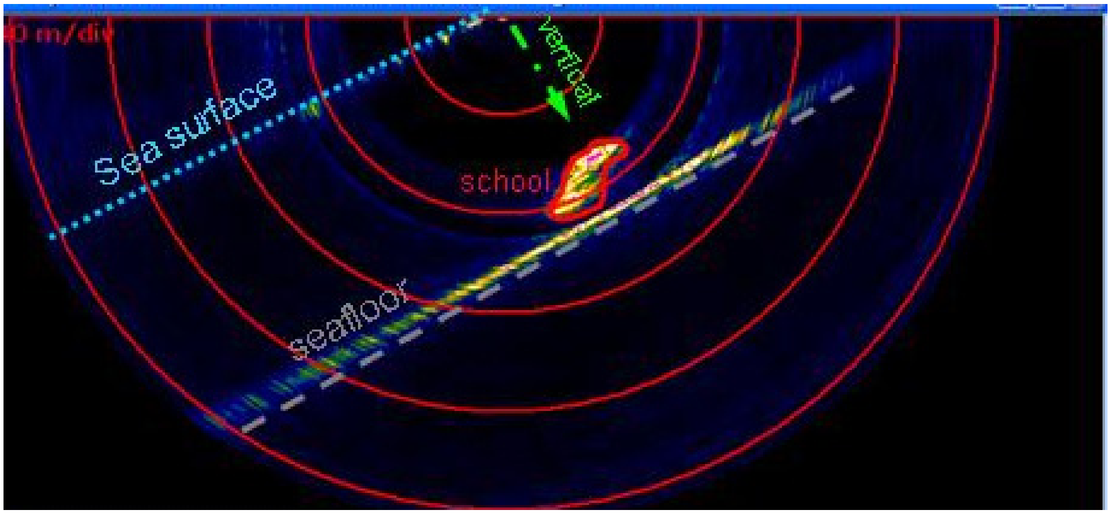


Figure II.28. An example of the image produced by the SM2000/SM20 when mounted at a 30° angle to port on the FRV *David Starr Jordan*. The nearly straight feature with high return values (yellows and reds) between the second and third range lines, is the seafloor (followed by the gray dashed line). The sea surface includes the medium-valued returns radiating toward the top of the image in the upper-left underlined by the blue dashed line; when conditions were rough the surface appears as a broad angular sector with high return values. The green dashed arrow points approximately to nadir below the ship.

The SM2000 observations encompassed those of the split-beam echosounders. The EK60 beams were aligned with the green arrow in Fig. II.28, but offset approximately 2 m to starboard.

II.3.2.5 SM20 Data processing

The objectives of the multi-beam sonar observations were to: (1) map and characterize aggregations of biological sound scatterers; and (2) compare features of the aggregations to the observations (e.g. presence and absence, on- and off-vessel-axis encounters, sizes and depths) made by the split-beam echosounders Images from both the SM20 (real-time and replayed) were compared to those from the EK60.

II.3.2.5.2 Ranges to acoustic targets in SM20 echograms

The offset from the water surface to the SM2000 head was not entered into the SM20 setup parameters for acquisition. Therefore, SM20 range measurements indicate range from the sonar head, not from the water surface. The EK60 transducers were hull-mounted at an estimated depth of 2.75 m below the water surface, but that draft was accounted for in post-processing, and therefore the EK60 range data indicate distance from the water surface. Because the SM2000 head was pole-mounted at 3.1 m below the water surface, to find corresponding target depths in SM20 echograms, 3.1 m was subtracted from the target depths measured from EK60 echograms.

II.3.2.6 SM20 Results

II.3.2.6.1 SM20 target features: aggregations of biological sound scatterers

On 9 April 2006 (20060409) at 08:22 GMT (00:22 PST) an aggregation of acoustic targets resembling a fish school (maybe sardines) was imaged simultaneously in both the 200 kHz echosounder and the SM20 (Fig. II.29).

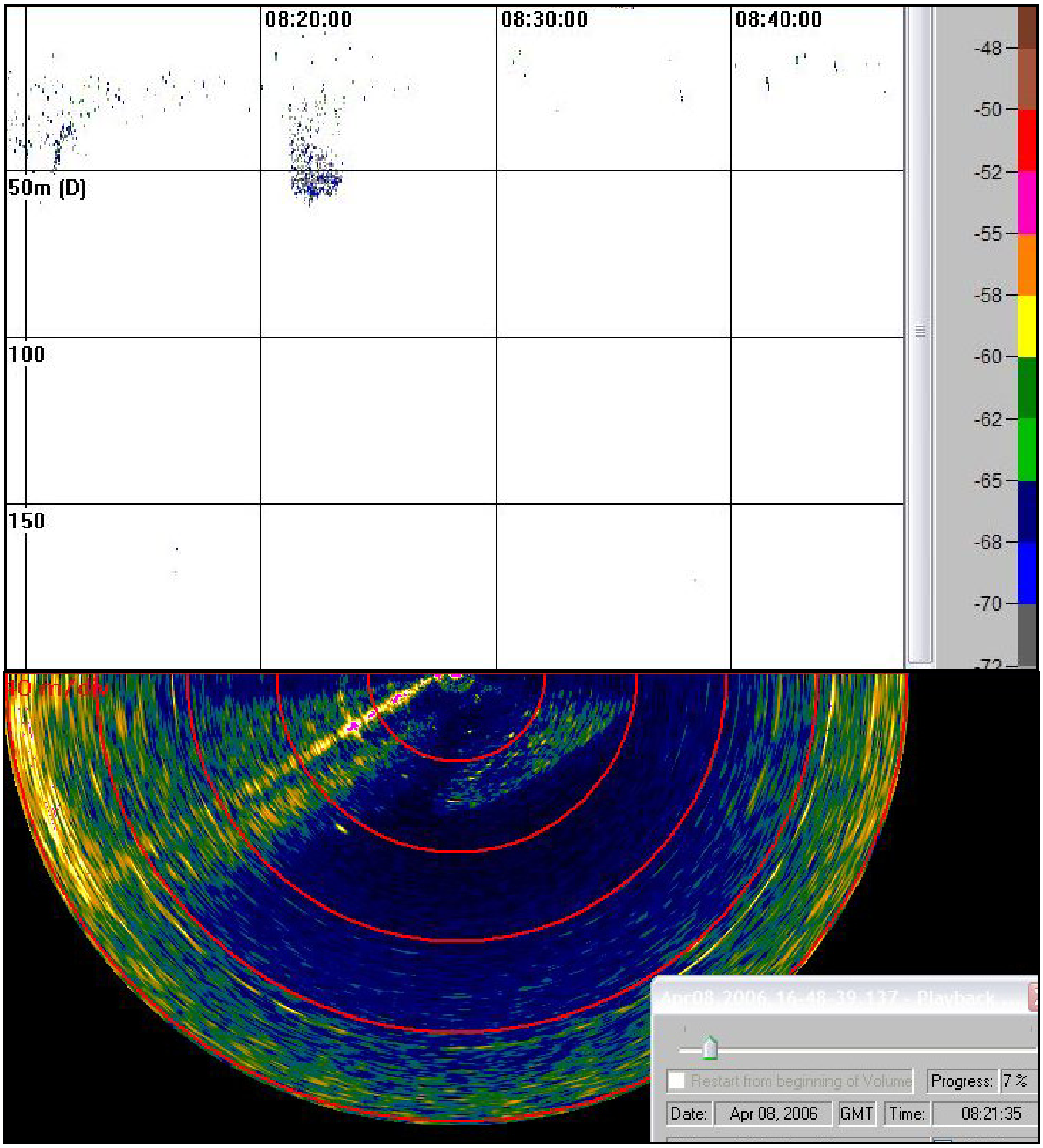


Figure II.29. An aggregation of acoustic scatterers resembling a fish school, possibly sardines (sardine eggs were caught concurrently), was imaged by the 200 kHz echosounder (a) and the SM20 (b) at 31 40.96 N, 120 39.15 W along Transect Line 91.7 between Station 80 and 70. The school is directly below the vessel with a nearly triangular shape with a broad base and vague peak. The school spanned a depth range from approximately 35 to 60 m and had a maximum width athwartship of approximately 80 m. The high intensity line is the sea surface.

On 10 April (20060410) at 1150 GMT (0350 PST) the SM20 echogram revealed two scattering layers, from approximately 0 to 12 m and 18 to 40 m, that were consistent with the ES200-7C echogram (Fig. II.30).

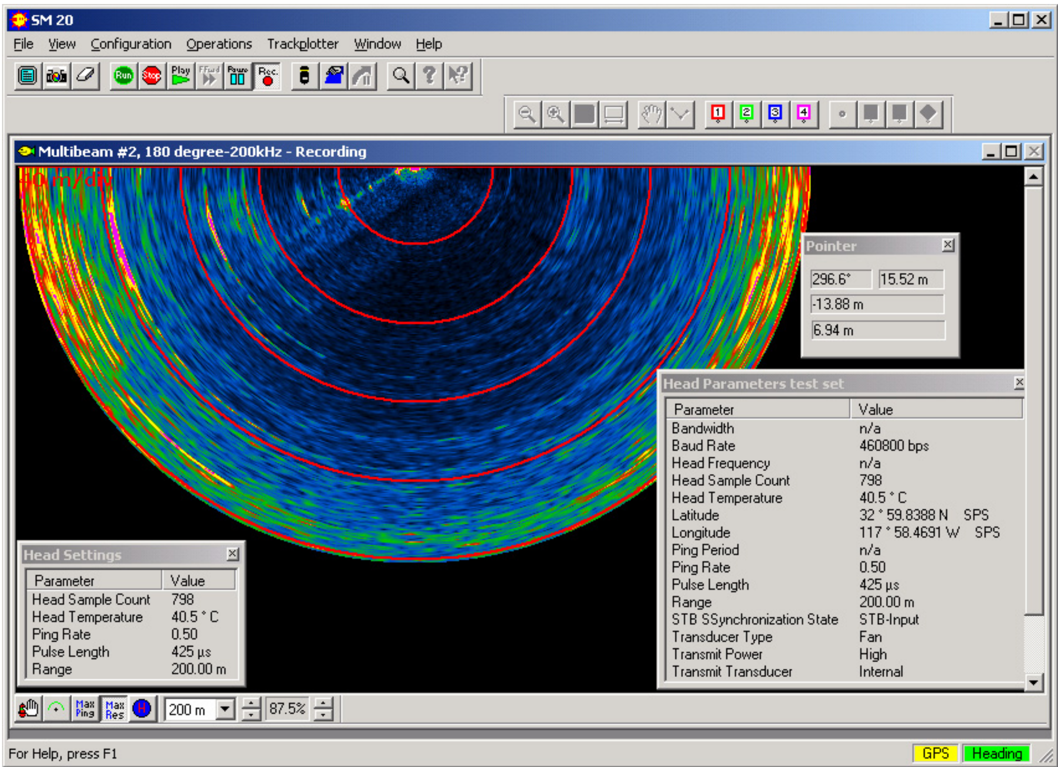


Figure II.30. Two scattering layers, from approximately 0 to 12 m and 18 to 40 m, were imaged by the SM20 and also observed in EK60 echograms.

On 15 April (10:14 GMT), a dense surface layer of scatterers from 0 to 30 m was evident in 200-kHz ES200-7C, and that layer was also evident in the SM20 echogram. In addition, the SM20 echogram showed several scattered small groups of targets that resembled anchovy schools (Fig. II.31), at location 33 24.1819 N, 117 57.6023 W.

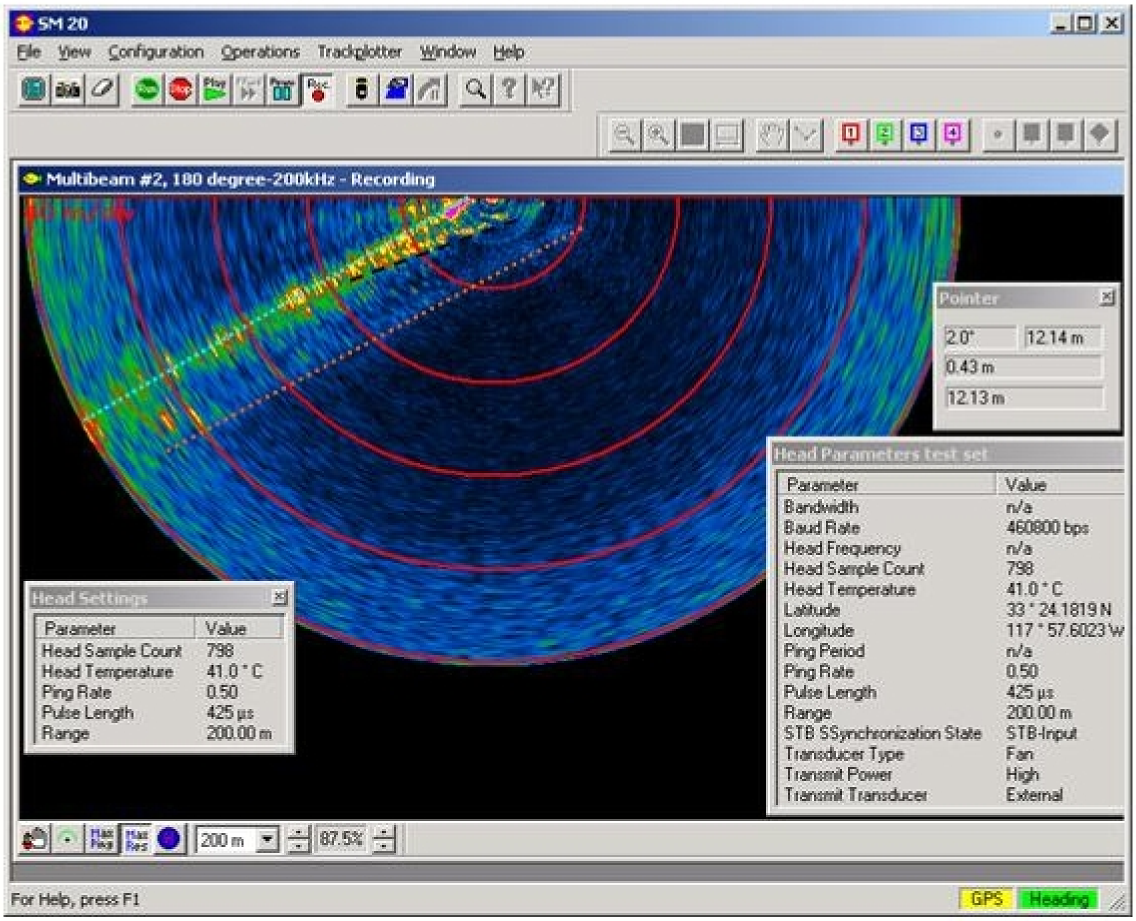


Figure II.31. SM20 data showing the sea surface (followed by the blue, dashed upper line) surface layer of scatterers from about 0 to 35 m (orange, dashed lower line), and several apparent small fish schools (underlined by black dashed line) from a location where CUFES was collecting moderate to high numbers of anchovy eggs. In this instance the schools seem to be at or near surface 60 m away from the ship, and down to 10 m under the ship (below transducer). Note that the vessel (*David Starr Jordan*) was slow to stopped at this time to deploy a bongo net to collect anchovy eggs. Each radial grid line in the figure represents a range-interval of 40 m from the SM2000 transducer face.

On 16 April, 2006, a strong return layer was evident in the 38 and 70 kHz EK60 echograms and seen as a dense aggregation by the 120 and 200 kHz EK60s and the SM20 (Fig. II.32). In addition, the SM20 revealed several isolated targets just beneath the layer. The strong targets that were evident in the SM20 echogram beneath the layer tend to resemble small schools of fish. Perhaps this image represents the spatial distribution of organisms from two trophic levels at a particular time.

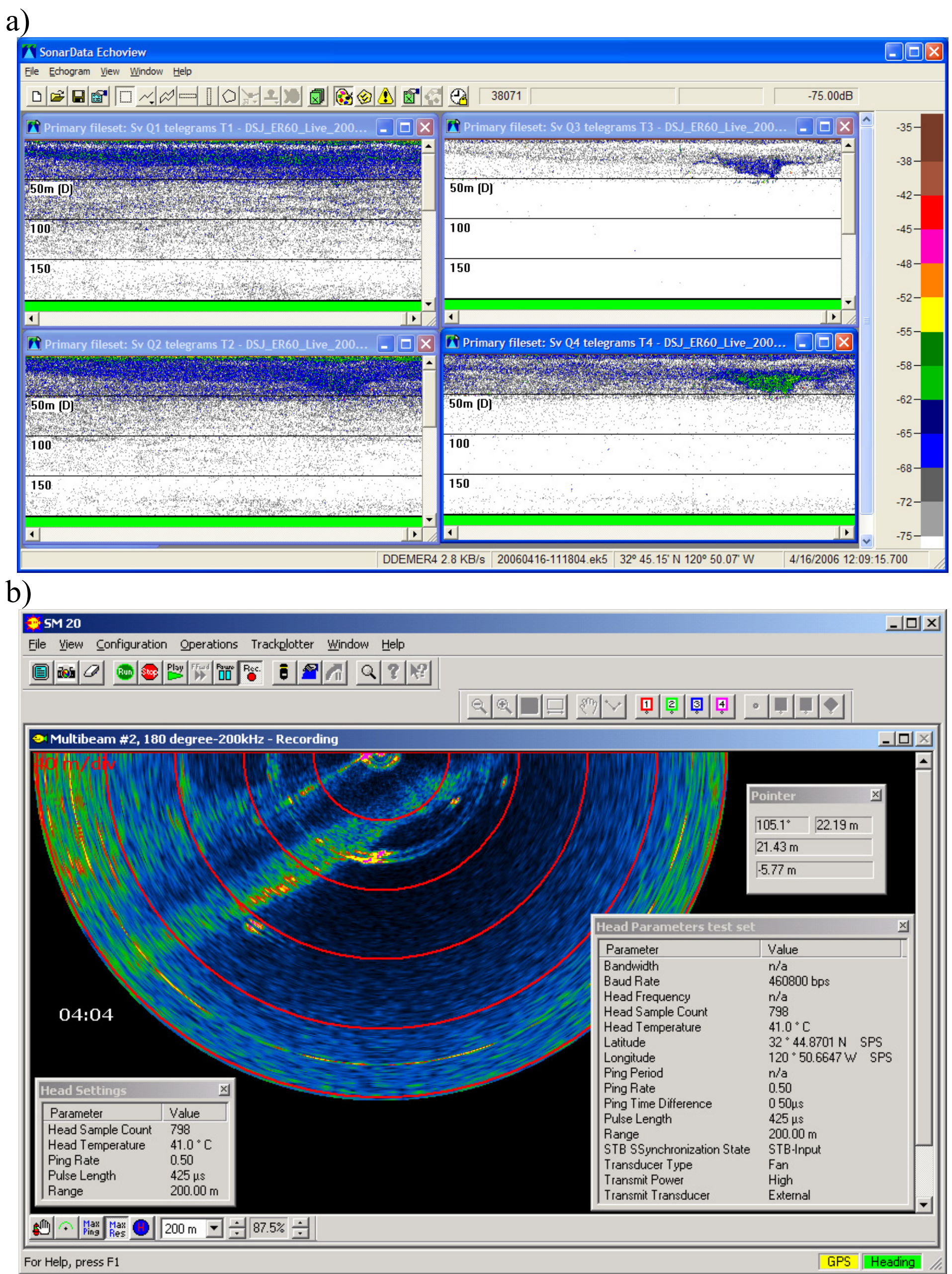


Figure II.32. A distinct aggregation from approximately 25 to 45 m below the transducers was evident amidst the upper 50 m scattering layer in (a) the echograms from the ES120-7, ES200-7C split-beam and in (b) the SM20 multi-beam echosounders. In addition to the general aggregation, there were three or four strong, isolated targets just below it. The range lines on the SM20 image are at 40 m/division.

II.3.3 ADCP

The RD Instruments, Model VM-150-18HP, 150 KHz broad band acoustic doppler current profiler (ADCP), permanently installed aboard the FRV *David Starr Jordan,* was operated by the ship's Electronic Technician and used to collect data throughout the survey.

II.3.2.1 ADCP System calibration

The ADCP system was not calibrated for absolute backscatter intensity or water velocities.

II.3.2.3 ADCP Triggering

To minimize interference with the five split-beam EK60s and the multi-beam SM20 echosounder systems, the ADCP was triggered and fired synchronously using the trigger pulse generated by the EK60 system every two seconds. No interference from the ADCP was detected on the EK60 or SM20 systems.

II.3.2.4 ADCP Data Collection and Archive

The ADCP was controlled by RDI's VMDAS software. Raw data were not properly stored during the survey and were lost.

II.3.2.5 ADCP Data processing

No processing of the ADCP data was done aboard.

II.4 Tentative Conclusions

II.4.1 EK60 multi-frequency echosounders

The highest densities of epipelagic fish were located in the southern portion of the study area, along Lines 95, 91.7, 86.7, and 81.7. These high densities corresponded with SST ranging from 11-16 °C. A positive relationship was observed between the largest densities of fish (as indicated by high values of the nautical area scattering coefficient, NASC) and the number of anchovy and sardine eggs collected by CUFES (Fig. II.5). One exception to the pattern of higher fish densities in the southern area and in warmer water was that high densities were observed approximately 100 n.mi offshore on Line 56.7, west of San Francisco.

The distributions of epipelagic fish off the west coast of the United States are highly skewed (i.e. most of the biomass is concentrated in a small number of schools). This patchiness is generally characteristic of coastal pelagic species. Barange and Hampton (1997) noted that sardines are more patchily distributed than anchovies, and that fewer than 20% of the data points contributed over 90% of the biomass. This survey suggested similar results.

Multiple coastal pelagic species with swimbladders (ie. anchovy, sardine, and Pacific and jack mackerel) can be the source of 38 kHz acoustic backscatter in the depth range from 12 to 70 m. Consequently, the trawl, egg pump, and SST information need were used to better apportion the integrated acoustic backscattering coefficients (NASC; $m^2/n.mi.^2$) to these candidate species.

For the area where eggs were found, the ratio of the anchovy spawning biomass to the sardine spawning biomass R can be estimated as:

$$R = \left[\frac{\sum e_{anchovy}}{\sum e_{sardine}} \right] \times \left[\frac{e_{sardine}}{w_{sardine}} \Big/ \frac{e_{anchovy}}{w_{anchovy}} \right] = \frac{300\,(e_{sardine}/g)}{500\,(e_{anchovy}/g)} = \left[\frac{\sum e_{anchovy}}{\sum e_{sardine}} \right] \times 0.6 \qquad \text{(Eq. 3)}$$

where *e* represents the number of eggs, *w* represents average weight of the fish, and *g* represents fish mass in grams. Assuming the ratio of immature fish of anchovy and sardine is the same as for mature fish, the same ratio can be applied. This, coupled with consideration of the trawl catches, should be used to apportion the total epipelagic fish biomass to the four candidate species.

Even so, biomass estimates of epipelagic fish surveyed with a down-looking echosounder are susceptible to large biases due to diel vertical migratory and schooling behavior. Barange and Hampton (1997) reported that anchovy near South Africa form high-density schools during the day, breaking into larger low-density aggregations at night. In contrast, sardine in the same region remain in relatively high-density schools throughout the day. All CPS species in this area appear to reside deeper in the water column during the daytime and shallower at night, as none of the daytime trawls caught CPS. Moreover, the ship speed (typically 12-14 kts) and the ping interval (2 s) were too large to accurately survey highly patchy fish schools. Also, especially for shallow depths, the echosounder pings do not overlap, leading to a negative bias. That is, there is multiple meters between pings are not insonified with a 7° beam width transducer, transiting at speeds of 6-7 m/s.

Another potentially large source of error is target strength (TS; dB re 1 m^2). TS depends on several aspects, such as the physiological state of the fish (stage of sexual maturity and fat content), its behavior and the time of day (Ona, 1999). In this study, measurements were made at all times of day, but only during spring. Thus, diel variations are likely, but variations due to seasonal factors should have been minimal. During the day, the sardines gather in schools and descend, even close to the bottom in shallow water areas. Consequently, their swim bladders may have a smaller volume and lower TS at day versus night. These changes can lead to both systematic and random errors in the estimated biomasses of each CPS.

II.4.2 SM20 multi-beam sonar

The SM20 multi-beam echograms aid interpretation of the EK60 echograms by providing perspective from an additional spatial dimension. For instance, the multi-beam echogram can be used to determine which part of a school was imaged by the split-beam echosounders, whether the central portion or an edge.

Many of the aggregations evident in the multi-beam echosounder data might represent organisms other than fish. The SM20 multi-beam operates at 200 kHz. Some invertebrates such as krill and squid and non-gas-bearing small fish can cause significant backscattering at that frequency, or higher frequencies. Spatial patterns or patterns in the returns by beam incidence angles in the multi-beam volume scattering data might provide a way to distinguish fish schools from aggregations of other organisms.

II.4.3 ADCP

The ADCP functioned reasonably well, collecting data for the duration of the cruise. It showed no signs of crosstalk interference between the split-beam and multi-beam echosounder systems.

II.5 Problems and Suggestions

II.5.1 EK60 multi-frequency echosounder

The NOAA FRV *David Starr Jordan* should be fitted with contemporary scientific echosounders echosounders (Simrad EK60s), operating at 18, 38, 70, 120 and 200 kHz, using hull-mounted transducers (Simrad ES18-11, ES38-B, ES70-7C, ES120-7C and ES200-7C). The transducers blister should be extended to reduce bubble noise and attenuation.

II.5.2 SM20 multi-beam sonar

The pole-mount for the SM2000 sonar head was large, rather difficult to raise and lower, and noisy (to the ship's personnel). The integrity of the plastic fairing on the SM2000 head was compromised by turbulence and drag that caused a crack and tearing. None of the problems affected the data. A hull-mounted, mechanically steered multibeam sonar transducer would be a valuable asset. Fish schools might be better-resolvable if SM20 data were to have a higher ping rate, however storing and processing the enormous amounts of data from the SM20 (or other full water-column multibeam sonars) is a problem that needs to be addressed if such devices are to be regularly deployed for surveys. The SM20 is primarily limited by operating at a single-frequency and inability to maintain a high ping rate.

II.5.3 ADCP

Occasionally, the ADCP would experience computer system failure and have to be rebooted by the ET. Transferring the ADCP data requires substantial effort by the ET because of the age of the controller PC and lack of interconnectivity with modern computers or storage devices.

II.5.3 General Notes

Acoustic data collected on the *Jordan* are relatively noisy, probably due to the ship's radiated propeller and engine noise, and possibly also to bubble wash. This survey was compromised because of the *Jordan's* equipment failures that prevented trawling operations. Hence, the acoustic data collected from the *Jordan* could not be verified by trawl sample data.

II.6 Disposition of Data

Archived on DVDs and computer hard disk are approximately 250 GB of raw and processed data from the EK60 and SM2000. Contact: David Demer (address: Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037, U.S.A.; phone: 858-546-5603; email: david.demer@noaa.gov) or Randy Cutter (address: Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037, U.S.A.; phone: 858-546-5691; email: george.cutter@noaa.gov).

II.7 Acknowledgements

We thank Dave Griffith for coordinating the attachment of the bracket for the multi-beam pole. We thank Doug Krause for his help with mobilization and calibration. Also, appreciate very much the efforts of the crew of the *David Starr Jordan*. In particular, Jose Coito provided invaluable assistance with the effort to attach and secure the SM2000 pole, allowing for a successful deployment of the multi-beam sonar.

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