Biomass Estimation by Hydro-acoustic Methods in the Gulf of Thailand and Peninsular Malaysia.

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ABSTRACT

The abundance of fisheries resources and their structure in the Gulf of Thailand and East coast of Peninsular Malaysia were investigated during the SEAFDEC Collaborative Research Survey. Hydro-acoustic surveying using a scientific echo sounder model FQ-70 was conducted to estimate the fish abundance and biomass. Two survey cruises were carried out by M.V.SEAFDEC during the pre and post-northeast monsoon seasons. The scientific echo-sounder was equipped with an echo-integrator and two quasi-ideal beam transducers with operating frequencies of 50 and 200 kHz. The volume back scattering strength (SV) of the fish schools were collected from the layer of water at a depth from 10 m to the bottom along the track of survey cruise. The estimated biomass measured by high frequency shows clearly that a high concentration is observed at the upper and middle part of the Gulf of Thailand and the boarder area between Thailand and Malaysia waters during the pre-northeast monsoon season. Whereas, high biomass concentration shows only in the middle part of the Gulf of Thailand during the post-northeast monsoon season.

Key words: Biomass estimation, Acoustic survey, Gulf of Thailand

Introduction

At present, quantitative acoustic methods are known to represent a powerful tool for fisheries management. Fisheries biologists are interested in the numbers of fish per unit volume or per unit area because it forms the basis of their analysies of population, and the catch or catch per unit of effort of a fishing vessel (Cushing, 1973). Acoustic surveys of fish are mostly based on the assumption that total echo intensity from a fish school is equal to the arithmetic sum of echo contributions from individual fish. In order to convert data collected in acoustic surveys into population estimations, it is essential to have as precise an estimates as possibles of a fish target strength (Johnnesson and Mitson, 1983). Due to the external and internal geometry of a fish, its target strength can vary widely with its size, the insonifying frequency and the insonified aspect. Hence, empirical approximations to the target strength of an individual fish are required as a function of size, frequency and aspect. These approximations may then be applied to fish school models in order to predict school volume back scattering strength (Love, 1977).

Marine fisheries resources migrate according to the change of season and their maturity state. The abundance estimation of such migratory species are needed to design the survey which covers all that particular area. The Gulf of Thailand and east coast of Peninsular Malaysia are adjacent waters with fish migrating along and across the exclusive economic zone between the two countries.

The first estimation of the abundance of the small pelagic resources by acoustic survey in the Gulf of Thailand was carried out from June to October 1979 by research vessel "Fishery Research No. 2" of the Department of Fisheries of Thailand (DOF Thailand, 1979). The objective of the survey was to make a quick quantitative assessment of fishery resources, especially pelagic fish in the Gulf of Thailand. The survey results showed that the dominant small pelagic species found during survey were *Sardinella* spp., *Rastrelliger* spp., *Caranx* spp., and *Decapterus* spp. The highest fish density were found in shallow waters at the upper gulf and middle part of the Gulf of Thailand.

Southeast Asian Fisheries Development Center (SEAFDEC) was proposed to conduct the Collaborative Research Survey on the marine fisheries resources and the environmental factors in the South China Sea off SEAFDEC member country's waters. Two survey cruises were performed by M.V.SEAFDEC during the pre-northeast monsoon season from 4 September to 4 October 1995 and the post-northeast monsoon season from 23 April to 23 May 1996. The objective of the survey being to estimate the abundance of fisheries resources and their structures in the Gulf of Thailand and East Coast of Peninsular Malaysia, and to study the variation of abundance during the pre-northeast monsoon and post-northeast monsoon season.

Materials and Methods

The survey area was divided into 81 oceanographic survey stations (Fig 1). The stations were located 30 nautical miles apart. The hydro-acoustic survey using a scientific echo-sounder, model FQ-70, was carried out parallel to the cruise track of 30 nautical miles. The scientific echo-sounder was equipped with dual frequencies by using two quasi-ideal beam transducers with frequencies of 50 kHz and 200 kHz. This acoustic survey system was equipped with an echo integrator, calibration system and data recorder. The system was designed so that a vast amount of data could be stored onto floppy disk memory and processed by a data analyzer.

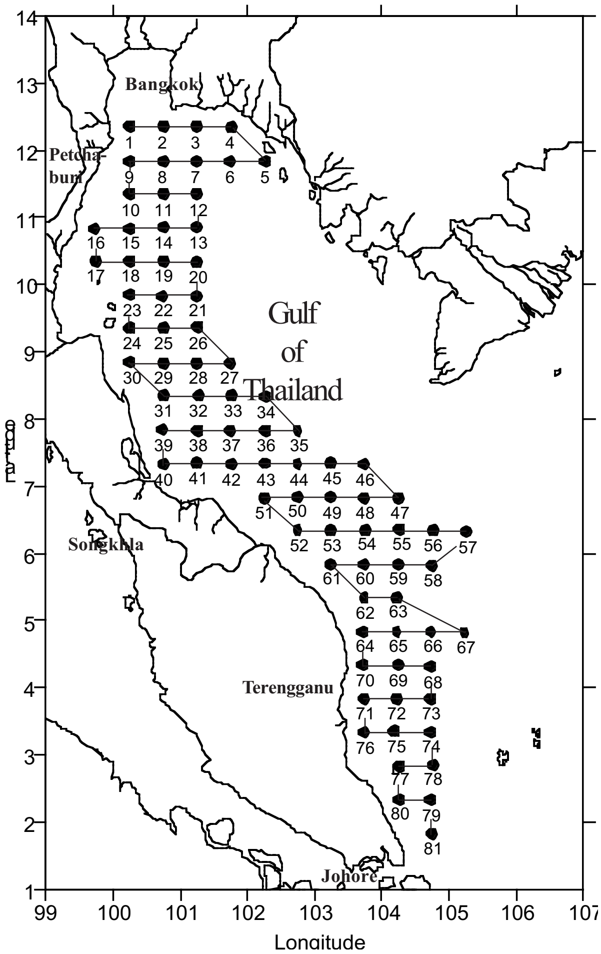


Fig. 1. Area and stations of collaborative research survey in the Gulf of Thailand and East Coast of Peninsular Malaysia.

The data of the hydro-acoustic survey during the cruises of M.V. SEAFDEC No. 26-8/1995 and No. 34-4/1996 recorded from the scientific echo sounder were analyzed by the author-edited computer programs. The raw data from Furuno FQ-70 software in the form of K3 ASCII code are used for the calculations. The volume back scattering strength (SV) of low frequency (50 kHz) and high frequency (200 kHz) were calculated from data recorded from the surface to the bottom layer.

Calibration of FQ-70 Scientific Echo Sounder

The calibration of FQ-70, conducted one day before the survey cruise was performed on 4 September 1995 and 23 April 1996 at Ko phai in the Gulf of Thailand. M.V.SEAFDEC was anchored in a water depth of 35 metres in a calm sea and weak current of 0.2 knots. The calibration was performed using a standard hydrophone model TW-9103-S attached 1 metre under the transducer sound beam axis. Both low (50 kHz) and high frequency (200 kHz) transducers were calibrated. The calibration items are shown as the followings:

- Transmitting Power
- Main Attenuation and Gain
- Transmitting Sensitivity of the Transducer
- Receiving Sensitivity of theTransducer.

The calibration result from both survey cruises showed a similar performance. The calibration on the first survey cruise are shown in table I to IV of Appendix.

Hydro-acoustic Data Collection

The hydro-acoustic data of fish schools in the area of the Gulf of Thailand and East Coast of Peninsular Malaysia are recorded using a scientific echo sounder (FQ-70) which is installed on board M.V.SEAFDEC. The total distance of the survey was 2495 nautical miles with a parallel track of 30 nautical miles. The data of mean volume back scattering were recorded by low (50 kHz) and high (200 kHz) frequency with the transmission rate of 160 ping/min. The ship cruising speed was 10 knots. During the survey cruise, the raw data of reflected echo signal from fish schools was also recorded on to VHS Video tape for data bank reservation. The processed echo information from the echo integrator with a distance interval of 0.1 nautical mile were calculated by echo integrator and data analyzer. The integration of volume back scattering strength (SV) of fish schools were calculated from the water depth layer of 10 m to 80 m with an interval of 10 m for each integration layer. Two bottom integration layers were calculated at 1 m to 5 m and 5 m to 10 m above the sea bottom. The integration of SV and density of fish were recorded on floppy disk as well as printed out on a printer and also plotted on the echogram. The recorded data on floppy disk was used for re-calculation for biomass estimation of fisheries resources and their distribution in the survey area. The parameter setting for echo integrator unit are shown below:

The Parameter Setting for the Echo Integrator Unit

Range

1. REC RANGE		0 - 80 m
2. LAYER	1	10 - 80 m
	2	10 - 20 m
	3	20 - 30 m
	4	30 - 40 m
	5	40 - 50 m
	6	50 - 60 m
	7	60 - 70 m
	8	70 - 80 m
	9	B10 - B5 m

10 B5 - B1 m

SONAR PARAMETER

1. Calculation	SV-H	SV-L
2. SL	219.5	215.3
3. ME	-194.9	-185.8
4. Absorption	92.7	9.9
5. 10 Log ψ	-16.1	-14.5
6. AMP Gain	50.1	49.0
7. Pulse Length	1.2	1.2
8. Sound Velocity		1500

SYSTEM PARAMETER

1. Threshold	-76.0		-76.0
2. Interval			0.1
3. VDC Range	-80	–	-30
4. Record Mode			DUAL
5. Position			SATNAV + DR
6. Speed			SATNAV + DR (Log)
7. Date, Time			MANUAL
8. Draft			4.5
9. Bottom	10.0	-25.0	0.5
10. Print Out			ENABLE

TRANSDUCER

CAL. K.P.	2
MODE	NORM
Tx. OUT	HIGH - D
	LOW - D

Calculation of Volume Back Scattering Strength (SV)

The volume back scattering strength (SV) of a fish school is obtained from the following equation;

$$SV = 20 \log V_{sv} - (SL + ME) + 20 \log r + (2\alpha r/1000) - 10 \log (c\tau/2) - 10 \log\psi$$

where SV : Volume Back scattering Strength, (dB)
V_{sv} : Voltage output (Vrms)
SL : Source Level, (dB)
ME : Receiving Sensitivity, (dB)
r : Range of target (m)
α : Absorption Coefficient (dB)
c : Underwater Sound speed (m/sec)
τ : Pulse duration (ms)
ψ : Equivalent beam width

The scientific echo sounder FQ-70 automatically calculated the mean volume back scattering strength (Sv_{avg}) in a particular layer width and log interval of the ship cruising. The calculation can be performed with pre-setting parameters by the following equation;

$$SV_{avg} = (S_{\Delta r} S_l sv_i)/\Delta r\, l$$

where Δr : Layer width
l : Log interval

During the survey cruise of M.V.SEAFDEC, the layer width and log interval were set at 10 m for the pelagic layer and 0.1 nautical mile, respectively. The fish density can be calculated as the following formula;

$$N = 10^{(SV-BSV)/10}$$

where N : Density of fish in the integrated layer (n/m^3)
BSV : Back scattering strength of a single fish per unit volume (=TS)

Averaging the Vertical SV Values

The average of SV of each transmission along the vertical layer of the log interval can be calculated using the following equation:

$$SV_{avg} = 10 \log \left(\frac{\Sigma (L_i\, 10^{(SVi/10)})}{\Sigma L_i} \right)$$

where SV_{avg} : SV value after averaging
SV_i : SV value of layer i
L_i : width of layer i

The calculation of SV was performed by averaging the SV from the 2nd layer which started at 10 m depth down to the bottom layer. The layer at which the sea bottom appeared was excluded from the calculation and substituted by SV values from the two layers of layer 9 and 10.

Averaging the SV Value in Sections of the Distance Run

The average of SV value in section of the distance run can be calculated using the following equation:

$$SV_{avg} = 10 \log \left(\frac{\Sigma\, 10^{(svi/10)}}{K} \right)$$

where SV_{avg} : SV value after averaging
SV_i : SV value of the layer Vi
K : Number of integrals per section of distance run

The integrated average SV from the FQ-70 were manually checked and the high SV value caused by the interference from the ship electronic equipment was eliminated.

Biomass estimation

Biomass is defined as the density of fish (Tones per square nautical mile) in the area surveyed, derived from the integrated echoes. The biomass estimation can be performed by using Algebraic Method (Johannesson and Mitson,1983). The basic principle is schematically illustrated in Fig. 2. Each sample observation (ai) is assigned to a corresponding rectangular area, here called "Elementary Statistical Sampling Rectangle" (ESSR). For a parallel survey grid with equidistant inter-transect spacing (Dt) (30 nautical mile) all ESSR's will have equal area sizes given by

$$ESSR = Dt \times (ESDU) \text{ mile}^2$$

where ESDU is the selected "Elementary Sampling Distance Unit". When the inter-transect spacing equals one ESDU, it follows that the ESSR becomes a square of size $(ESDU)^2$. The abundance of biomass in each ESSR is obtained by multiplying the population density (N) in the ESSR to the mean weight of a single fish. The total biomass in the survey area is estimated from the biomass in each ESSR area.

The estimation of biomass was calculated by using the Algebraic Method estimating the mean SV of each Elementary Statistical Sampling Interval (ESSR) which covers area of 30x30 nautical miles. The population density (fish/m^2) was calculated by using the parameter of mean SV in each ESSR and fish target strength (TS). The average TS of fish was calculated by the equation (Miyanohana et al, 1987; Furusawa, 1990) as follows;

$$\mathbf{TS} = \mathbf{20 \log l - 66} \quad \text{(dB)}$$

where l is fish length in cm.

Since, the maximum cath of pelagic species in the Gulf of Thailand is contributed by sardine with an annual catch ranging between 113,860 tons to 142,634 tons from 1991 to 1994 (SEAFDEC 1993, 1994, 1995, 1997), thus sardine was selected as the representative species for determining the TS of single fish for biomass estimation. The target strength (TS) of sardine (*Sadinella gibbosa*) with the first capture body length of 10 cm and weight of 10 gm (Somjaiwong, 1991) gives -46.0 dB which is used for the calculation. The abundance of biomass in each ESSR is obtained by multiplying the population density in the ESSR to the mean weight of sardine.

Result and Discussion

The hydro-acoustic survey for biomass estimation in the Gulf of Thailand and Peninsular Malaysia were carried out during pre-northeast monsoon and post-northeast monsoon season. The data recorded from the scientific echo sounder FQ-70 were analyzed by the author-edited computer programs. The volume back scattering strength (SV) of high frequency (200 kHz) and low frequency (50 kHz) were calculated from the surface layer at 10 m down to the bottom layer. The total running survey distance was 2489 nautical miles with a minimum water depth of 12 metres, where-as , the maximum depth is 80 metres, and the average depth is 53.2 metres. Fig.3 shows the echogram of a

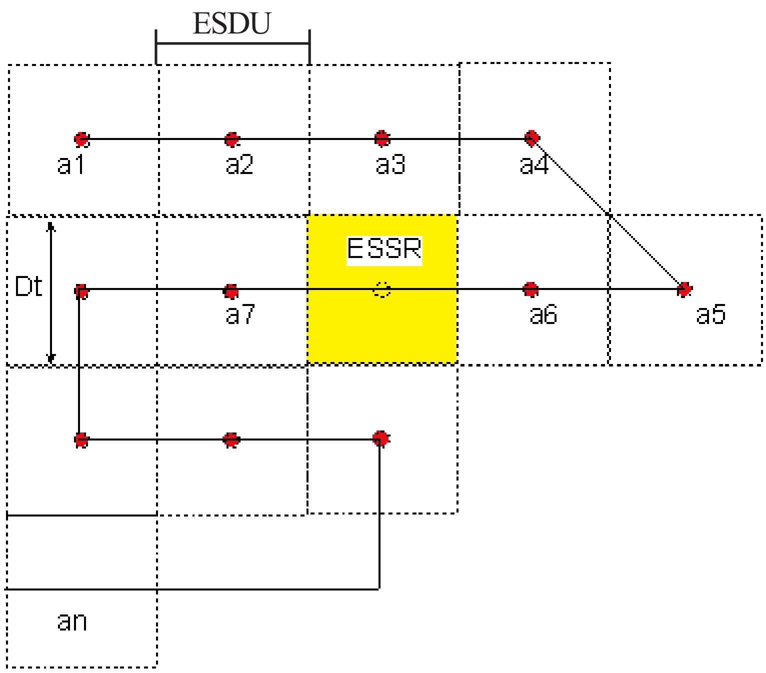


Fig. 2. Elementary statistical sampling interval (ESSR) along the cruise track when the inter-transect (Dt) equals one elementary sampling distance unit (ESDU). Tatal biomass estimation is the summation of all the abundance of the ESSR area.

fish school and plankton layer presented on the monitor of the display unit with upper screen and lower screen representing 50 kHz. and 200 kHz., respectively. The pelagic and demersal fish schools presented with the plankton layer are shown in Fig. 3 a) and b), respectively. The vertical migration of plankton layer from surface down to the bottom are shown in Fig. 3 c) to f). Fig.4 shows the echogram of pelagic and demersal fish schools detected by 200 kHz. and 50 kHz. The echogram also shows the vertical distribution curve (VDC) with the scale ranging from -80 dB to -30 dB. The VDC detected by 50 kHz. shows a high reverberation level from the surface to the bottom. Where-as VDC detected at 200 kHz. showing reduced values. The samples of average volume back scattering strength (SV) and density of fish (N) in each depth layer with integration for each 0.1 nautical mile of 200 kHz. and 50 kHz. are presented in Table 1.

The results of the pre-northeast monsoon survey showed that the average volume back scattering strength (SV) from station 1 to 33 (off shore Petchaburi to Songkhla Province, Thailand) were -61.2 dB for high frequency and -54.4 dB for low frequency. The average SV from station 34 to 66 (off shore Songkhla to Terengganu) were -62.9 dB for high frequency and -56.6 dB for low frequency. The average SV from station 67 to 80 (off shore Terengganu to Jahor) for high and low frequency were -66.4 and -57.3 dB, respectively (Fig.5). The SV difference between low and high frequency fluctuated from 0 to 30 dB. Thus showed that the low operating frequency (50 kHz) can detect plankton layers (Deep Scattering Layer) better than high frequency (200 kHz). The SV level showed high values in the area of the inner Gulf of Thailand, but decreasing southward to Peninsular Malaysia.

The observed SV level during the post-northeast monsoon season from station 1 to 33 were -63.1 dB for high frequency and -51.3 dB for low frequency. The average SV from station 34 to 66 were -69.0 dB for high frequency and -56.0 dB for low frequency. The average SV from station 67 to 79 for high and low frequency were -68.0 and -54.4 dB, respectively (Fig.6). The SV difference between low and high frequency fluctuated from 0 to 35 dB. The SV level shows the highest value in the upper Gulf of Thailand and the area between Terengganu to Jahor of Malaysia.

Fig.7 and Fig.8 showed the biomass distribution presented by means of the SV at each 0.1 nautical mile measured using 200 kHz during the pre-northeast monsoon and post-northeast monsoon seasons, respectively. The SV showed highest value for both seasons in the shallow water especially the upper Gulf of Thailand down to the coastal of the Southern part of Thailand with a water depth of not more than 40 m. Also, high SV values were observed in the coast area at the border between Thailand and Malaysia (Station 52,53,60 and 61) and also off the coast of Jahor in both seasons. The high SV present in the middle of the Gulf of Thailand during the pre-northeast monsoon season, showed a low level during post-northeast monsoon season.

Fig.9 and Fig.10 also show the biomass distribution presented by mean SV measured using 50 kHz during the pre- and post-northeast monsoon seasons, respectively. The SV measured using 50 kHz showed was higher levels than the SV measured by 200 kHz in both seasons. The highest concentration of SV was present in the upper Gulf of Thailand and along the coastal area of Peninsular Malaysia. The distribution of biomass (SV) measured using 50 kHz seemed not to be different between pre and post-northeast monsoon seasons.

The summary of biomass estimation by high and low frequency during the pre-northeast monsoon and post-northeast monsoon seasons are shown in Table 2 and 3, respectively. The total estimated biomass during the pre-northeast monsoon season measured by high and low frequencies were 2,754,773 tons and 13,136,860 tons, respectively. The maximum and minimum biomass measured by high frequency (200 kHz) were 390,906.80 tons at station No.47 and 1,688.03 tons at station No.34, respectively. The maximum and minimum biomass measured by low frequency (50 kHz) were 530,809.60 tons at station No.36 and 30,091.80 tons at station No.73.

The total estimated biomass during the post-northeast monsoon season measured by high and low frequencies were 1,323,154 tons and 20,942,590 tons, respectively. The maximum and minimum biomass measured by high frequency (200 kHz) were 170,998.50 tons at station No.18 and 416.30 tons at station No.34. The maximum and minimum biomass measured by low frequency (50 kHz)

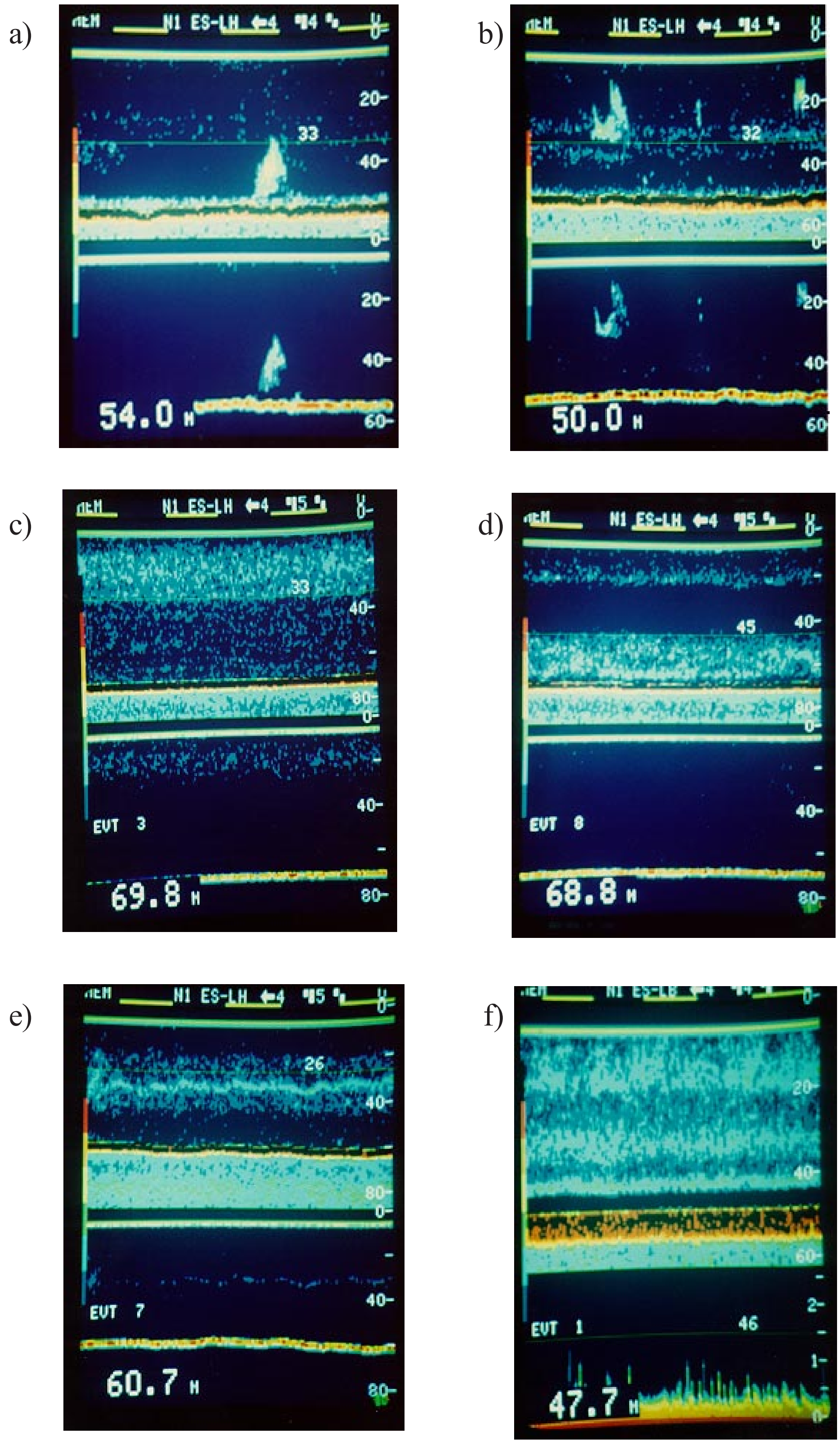


Fig. 3. The echogram of fish schools and plankton layers presented on the monitor of display unit with the upper screen and the lower screen present for 50 kHz. and 200 kHz., respectively. a) pelagic fish schools superimposed with plankton layers, b) demersal fish schools, c) plankton layers presented at the upper water layer in night time, d) plankton separated in to three layers, e) plankton layer concentrated on the mid water, and f) plankton layer present at bottom in the day time.

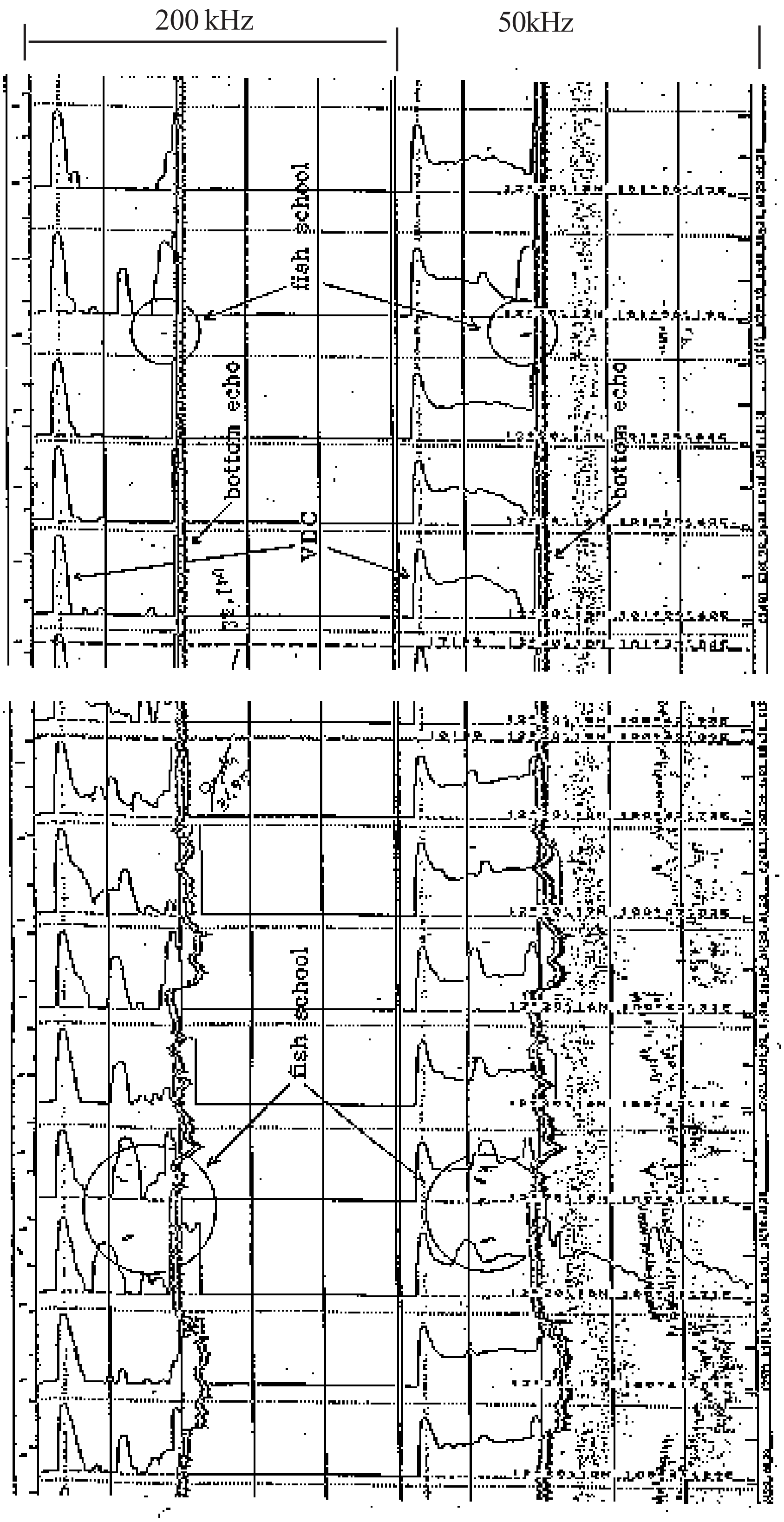


Fig. 4. The echogram of pelagic and demersal fish schools superimposed with Vertical Distribution Curve (VDC) detected by 50 kHz. and 200 kHz.

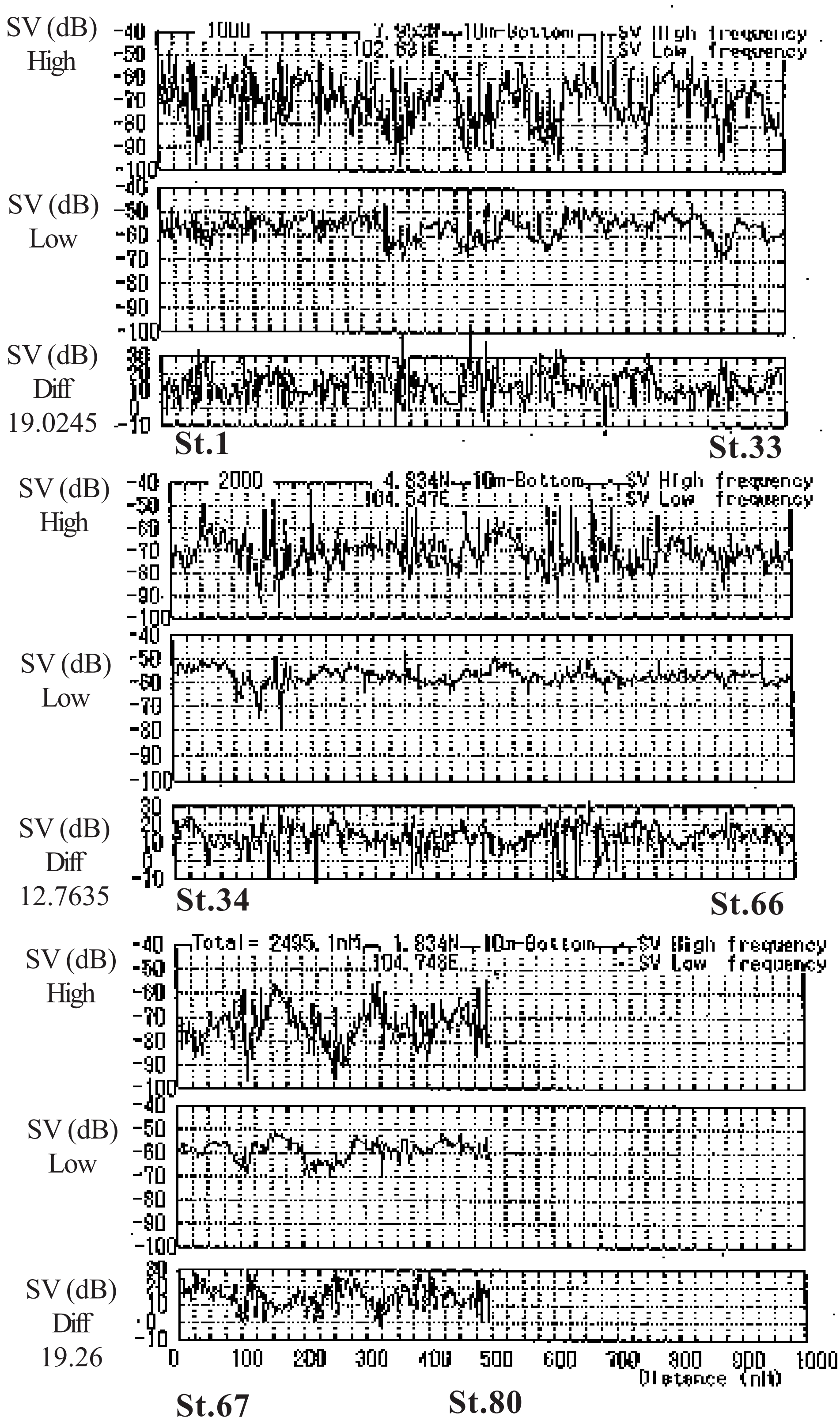


Fig. 5. The average volume back scattering strength (SV) measured by high (200 kHz.) and low (50kHz.) frequency during the pre-northeast monsoon season.

Table 1. The average volume back scattering strength (SV) and density of fish (N) in each layer with integrated for each 0.1 nautical mile for 200 kHz. and 50 kHz.

Layer		1	2	3	4	5	6	7	8	9	10
Upper		5	10	20	30	40	50	60	70	B10.0	B5.0
Lower		80	20	30	40	50	60	70	80	B 5.0	B1.0
Log (nm)	Time	Latitude		Longitude		Ship -spee	Current		Water Ten	Depth	B. LVL
0	11:37	1:50:07N		101:44.64E		9.5 268.	**.*	***.*	28.9	52	-19.9
(001) 0.1	11:38	1:50.07N		101:44.54E		9.5 273.(	**.*	***.*	28.9	52	-14.8
ATT = 30dB	SV	-50.5	-68.7	-67.7	-72.2	-70.9	-46.3	-99.9	-99.9	-70.5	-74.6
TH = 76dB	N	0.351	0.005	0.007	0.002	0.003	0.919	0	0	0.003	0.001
ATT = 30dB	SV	-51.3	-54	-54	-51.9	-49.9	-46.9	-99.9	-99.9	-49.3	-52.2
TH = 76dB	N	0.293	0.157	0.157	0.255	0.4	0.414	0	0	0.461	0.237
(002) 0.2	11:38	1:50.08N		101:44.44E		9.8 274.(	**.*	***.*	28.9	52	-7.2
ATT = 30dB	SV	-50.6	-69.2	-70.7	-74.2	-73.8	-46.4	-99.9	-99.9	-71.9	-77.7
TH = 76dB	N	0.341	0.005	0.003	0.001	0.002	0.912	0	0	0.002	0.001
ATT = 30dB	SV	-51.8	-54.7	-52.9	-51.81	-51.3	-47.7	-99.9	-99.9	-50.9	-52.5
TH = 76dB	N	0.263	0.135	0.201	0.258	0.293	0.671	0	0	0.32	0.223
(003) 0.3	11:39	1:50.09N		101:44.33E		9.9 275.(	**.*	***.*	28.9	52	-1.1
ATT = 30dB	SV	-50.2	-66.6	-70.5	-72.8	-72	-45.9	-99.9	-99.9	-72	-76.7
TH = 76dB	N	0.377	0.009	0.004	0.002	0.002	1.016	0	0	0.002	0.001
ATT = 30dB	SV	-51.9	-53.3	-51.7	51.5	-51.8	-49.3	-99.9	-99.9	-51.5	-53.2
TH = 76dB	N	0.252	0.184	0.264	0.279	0.26	0.467	0	0	0.281	0.188
(004) 0.4	11.39	1:50.10N		101:44.23E		9.8 275.(	**.*	***.*	28.9	52	-9.3
ATT = 30dB	SV	-50.2	-66.6	-71.2	-72.3	-66.9	-46.2	-99.9	-99.9	-68.5	-65.2
TH = 76dB	N	0.375	0.009	0.003	0.002	0.008	0.945	0	0	0.006	0.012
ATT = 30dB	SV	-50.2	-53	-52.8	-52.1	-49.9	-47.1	-99.9	-99.9	-50	-50.5
TH = 76dB	N	0.297	0.198	0.208	0.243	0.399	0.762	0	0	0.389	0.351
(005) 0.5	11:40	1:50.10N		101:44.14E		9.4 270.(	**.*	***.*	28.9	53	-14.6
ATT = 30dB	SV	-51.2	-66.2	-72	-72.9	-66.3	-46.5	-99.9	-99.9	-65.6	-66.1
TH = 76dB	N	0.301	0.009	0.002	0.002	0.009	0.871	0	0	0.011	0.01
ATT = 30dB	SV	-51.3	-53	-52.1	51.6	-49.7	-47.6	-99.9	-99.9	-49.7	-49.7
TH = 76dB	N	0.294	0.197	0.243	0.27	0.422	0.688	0	0	0.423	0.42
(006) 0.6	11:41	1:50.10N		101:44.04E		9.3 267.(	**.*	***.*	28.9	53	0.7
ATT = 30dB	SV	-51.1	-69.7	-73.2	-77.2	-73.7	-46.5	-99.9	-99.9	-71	-80.4
TH = 76dB	N	0.305	0.004	0.002	0.001	0.002	0.875	0	0	0.003	0
ATT = 30dB	SV	-52.7	-55.4	-53.7	-52.6	-53.6	-48.9	-99.9	-99.9	-53.7	-54.7
TH = 76dB	N	0.21	0.114	0.169	0.216	0.172	0.512	0	0	0.17	0.133

were 1,203,375.00 tons at station No.24 and 36,963.81 tons at station No.54.

The average weight of fish (biomass) measured by high and low frequency during the pre- and post-northeast monsoon season are presented in Fig. 11 and 12. The estimated biomass measured by high frequency show clearly that the high concentration of biomass was observed at the upper Gulf of Thailand and the boarder area between Thailand and Malaysia during the pre-and post-northeast monsoon seasons. However, the observation of biomass by low frequency did not show significant differences over the whole survey area during the pre- and post-northeast monsoon seasons.

The layers of plankton (Deep Scattering Layer) were observed over the survey area. Most of the plankton found during the survey were classified as Copepod and Tunicate. The echo sounder operating at 50 kHz seemed to be more effective at detecting the plankton layers than at 200 kHz. The

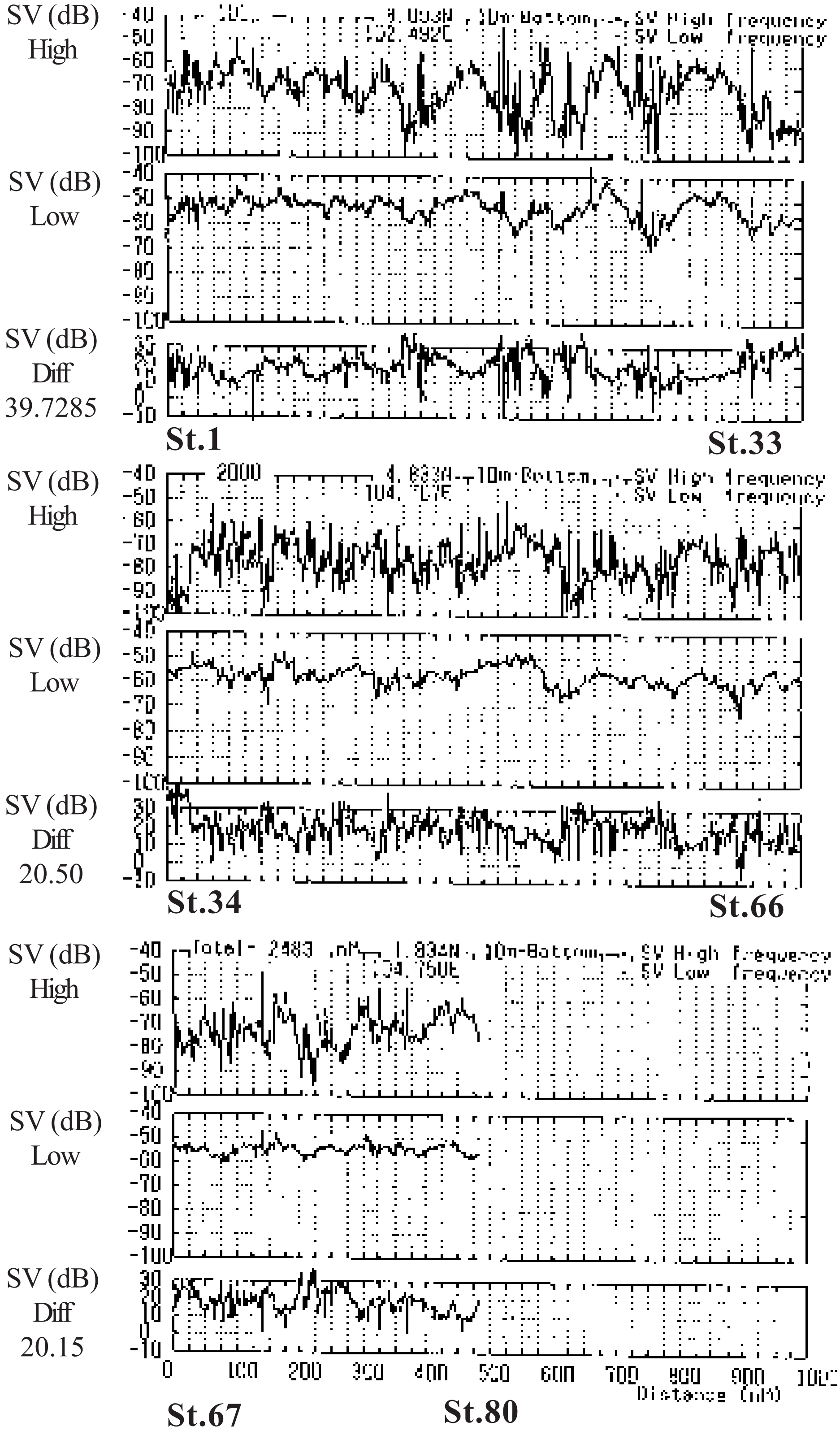


Fig. 6. The average volume back scattering strength (SV) measured by high (200 kHz.) and low (50 kHz.) frequency during the post-northeast season.

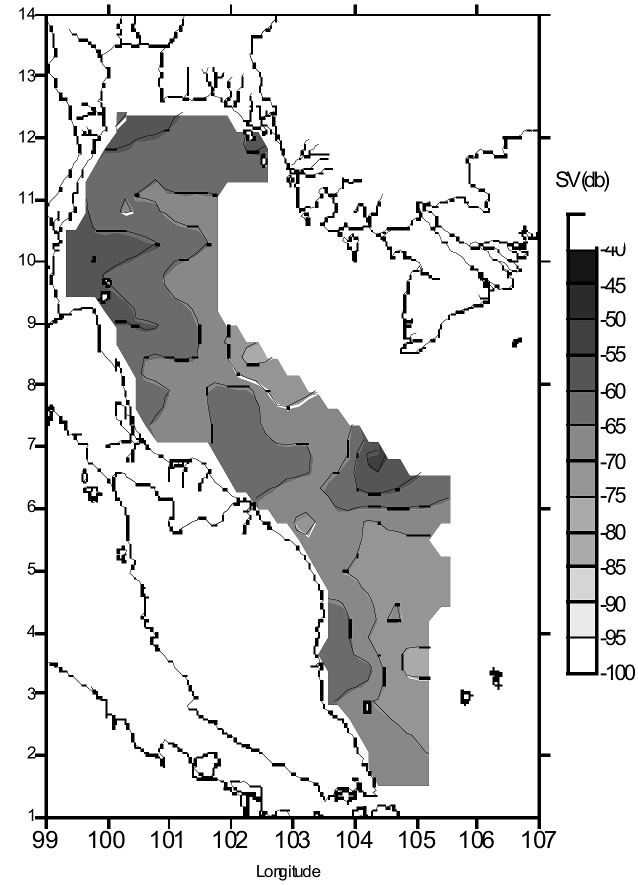


Fig.7. Distribution of volume back scattering strength (SV) of fish biomass measured using 200 kHz. during the pre-northeast monsoon season in the Gulf of Thailand and East Coast of Peninsular Malaysia.

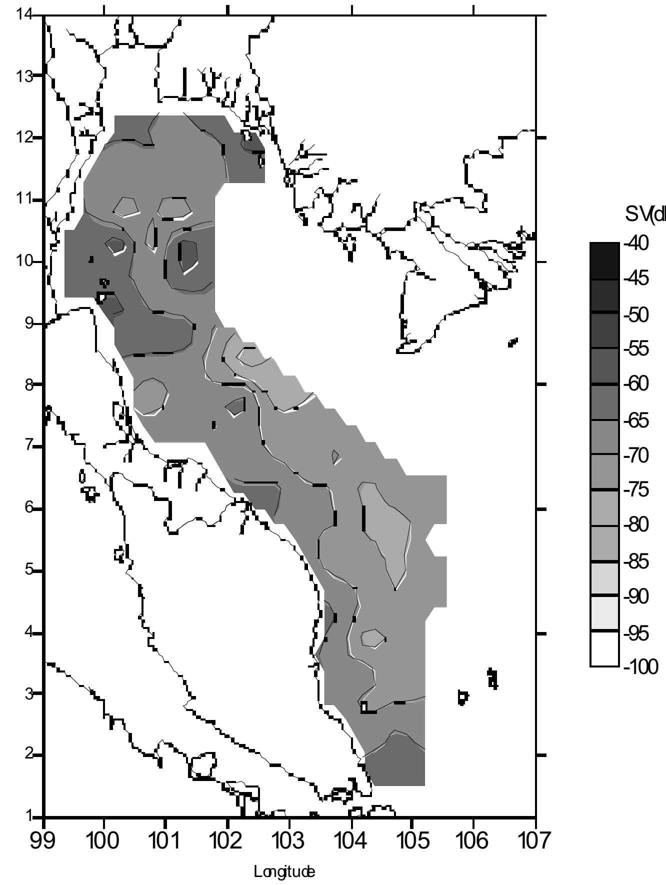


Fig.8. Distribution of volume back scattering strength (SV) of fish biomass measured using 200 kHz. during the post-northeast monsoon season in the Gulf of Thailand and East Coast of Peninsular Malaysia.

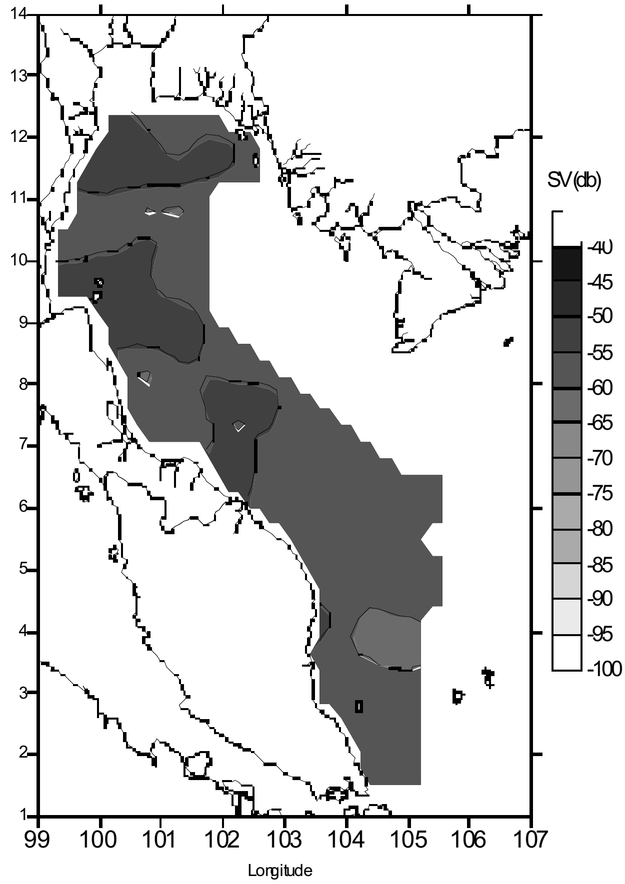


Fig.9. Distribution of volume back scattering strength (SV) of fish biomass measured using 50 kHz. during the pre-northeast monsoon season in the Gulf of Thailand and East Coast of Peninsular Malaysia.

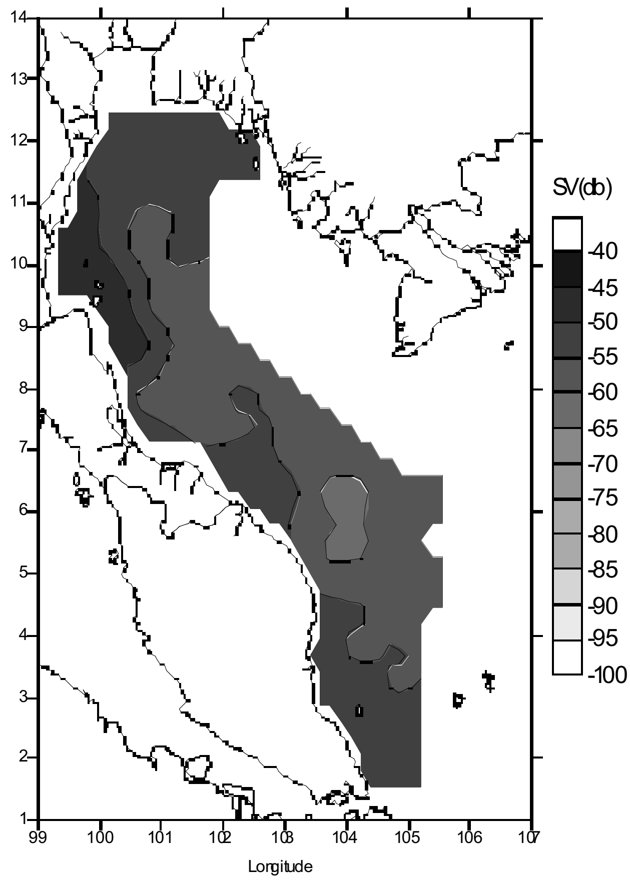


Fig.10. Distribution of volume back scattering strength (SV) of fish biomass measured using 50 kHz. during the post-northeast monsoon season in the Gulf of Thailand and East Coast of Peninsular Malaysia.

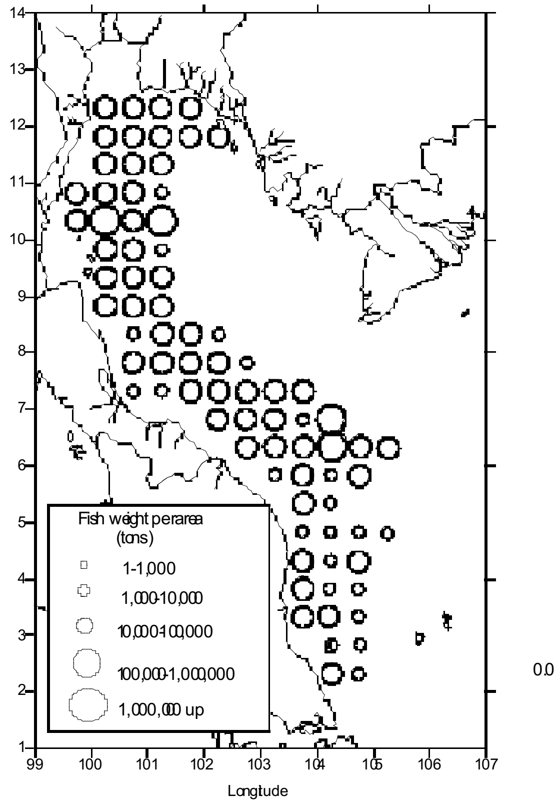
Table 2. Summary of biomass estimation by high frequency (200 kHz) and low frequency (50 kHz) during the pre-northeast monsoon season survey in the Gulf of Thailand and Peninsular Malaysia. The table shows the estimation for each station (ESSR) which covers an area of 30x30 nautical miles.

Station No.	Means SV High Freq.(dB)	Means SV Low Freq.(dB)	Depth (m)	Weight (High Freq. (tons)	Weight (Low Freq.) (tons)
1	-60.46	-54.36	27.6	15,236.63	62,066.29
2	-58.22	-55.54	29.6	54,722.12	101331.10
3	-60.32	-56.91	34.8	39,673.79	87,073.88
4	-61.61	-56.84	28.9	24,522.06	73,594.64
5	-59.24	-55.12	37.9	55,532.68	143436.20
6	-65.29	-53.45	52.8	19,197.32	293533.60
7	-62.31	-56.31	51.2	36,914.91	147219.50
8	-61.06	-53.40	45.2	43,583.01	254227.80
9	-59.63	-52.80	39.8	53263.00	257218.90
10	-62.74	-54.17	48.8	31,911.16	229387.60
11	-65.41	-52.89	54.7	19,347.94	345182.10
12	-60.21	-53.00	61.6	72,224.68	379760.80
13	-70.53	-61.25	63.0	6,853.92	58,079.12
14	-64.29	-60.88	57.9	26,510.85	58,096.43
15	-66.24	-55.59	50.1	14,652.28	170040.80
16	-59.70	-55.95	52.7	69,472.39	164522.30
17	-60.03	-56.75	53.4	65,186.63	138819.80
18	-56.46	-57.67	65.3	181368.40	137379.40
19	-59.27	-53.27	66.0	96,067.34	382230.40
20	-59.07	-55.54	69.2	105424.40	237375.30
21	-69.78	-60.13	61.9	7,998.53	73,823.52
22	-63.75	-54.07	48.6	25,185.12	234000.40
23	-61.70	-50.75	27.7	22,989.67	286114.20
24	-59.15	-52.31	40.1	59,920.43	289320.30
25	-62.36	-53.95	60.0	42,859.53	297073.00
26	-64.70	-54.13	59.3	24,709.64	281800.10
28	-62.17	-52.08	42.8	31,902.44	325698.60
29	-58.85	-51.49	28.9	46,343.92	252307.20
30	-60.82	-52.49	27.0	27,503.92	187039.50
31	-67.80	-61.06	42.1	8,585.28	40,529.33
32	-65.52	-55.05	64.4	22193.30	247176.30
33	-65.44	-55.54	75.5	26,496.29	258935.30
34	-77.45	-58.82	76.4	1,688.03	123240.80
35	-72.45	-54.23	74.3	5,197.14	344797.30
36	-59.49	-52.00	68.5	94,697.55	530809.60
37	-64.41	-53.68	50.6	22,493.49	265992.10
38	-65.78	-60.22	37.6	12,196.87	43893.70
39	-62.51	-59.39	25.2	17,409.31	35,687.95
40	-65.31	-58.01	27.0	9,755.48	52395.00
41	-69.61	-59.02	47.7	6419.40	73,455.61
42	-64.22	-55.30	49.3	22,939.33	178688.00
43	-63.35	-55.70	53.9	30,675.25	178505.10
44	-67.63	-54.73	55.4	11,756.64	229264.30
45	-65.50	-57.22	59.7	20,685.47	139285.50
46	-67.41	-57.46	53.8	12,017.42	118625.20
47	-52.88	-56.45	61.8	390906.80	171990.30
48	-70.12	-59.59	56.2	6,716.32	75,990.46
49	-63.91	-58.15	52.8	26,378.23	99,379.02
50	-63.47	-56.62	49.1	27167.90	131430.50
51	-61.10	-52.82	47.5	45,326.94	305186.20
52	-65.22	-55.85	49.2	18,151.65	156938.90
53	-65.95	-58.27	59.5	18,554.53	108784.20
54	-61.46	-59.14	67.4	59,120.89	100980.20
55	-57.00	-56.28	60.8	149182.50	176301.90
56	-60.12	-57.61	59.9	71,568.59	127590.50
57	-62.77	-58.23	60.5	39,301.99	111688.00
58	-67.66	-58.58	62.6	13,172.56	106763.10
59	-70.77	-57.71	63.6	6,554.84	132405.40
60	-65.83	-56.85	53.7	17,225.68	136363.60
61	-71.84	-57.44	54.8	4,408.46	121410.70
62	-67.09	-57.29	60.3	14,484.46	138232.20
63	-71.18	-56.70	63.1	5917.20	165846.00
64	-70.72	-58.26	64.1	6,678.94	117535.10
65	-70.75	-59.17	66.2	6,849.81	98,606.53
66	-75.71	-58.48	72.4	2,388.88	126162.40
67	-74.39	-57.24	75.5	3,374.92	175318.00
68	-67.81	-59.01	71.4	14,513.35	110269.20
69	-69.81	-59.78	60.4	7,759.72	78,080.86
70	-61.94	-54.13	39.2	30,854.85	186284.10
71	-62.44	-55.33	42.4	29,650.41	152684.90
72	-70.35	-62.76	62.7	7112.90	40,850.89
73	-75.13	-64.59	70.4	2,656.97	30091.80
74	-75.20	-59.20	64.9	2,407.31	95,985.61
75	-61.80	-55.49	42.7	34676.80	148244.70
76	-64.28	-57.49	32.0	14,642.07	69,995.52
77	-70.44	-58.00	52.7	5,853.05	102716.00
78	-72.10	-57.54	64.9	4,919.29	140561.90
79	-69.02	-55.10	50.0	7,703.25	189940.40
80	-66.07	-57.09	40.5	12,306.16	97,212.39
			Total =	2754773.00	13136860.00

Table 3. Summary of biomass estimation by high frequency (200 kHz) and low frequency (50 kHz) during the post-northeast monsoon season survey in the Gulf of Thailand and Peninsular Malaysia The table shows the estimation for each station (ESSR) which covers an area of 30x30 nautical miles.

Station No.	Means SV High Freq.(dB)	Means SV Low Freq.(dB)	Depth (m)	Weight (High Freq.) (tons)	Weight (Low Freq.) (tons)
1	-62.18	-55.04	27.9	10,372.43	53,750.02
2	-64.99	-52.96	29.0	11301.60	180290.10
3	-65.96	-52.27	30.3	9429.00	220841.80
4	-61.27	-52.11	32.0	29,371.95	242177.90
5	-59.36	-50.04	37.8	53,879.44	460022.60
6	-68.67	-51.22	52.3	8,735.19	484613.30
7	-67.12	-49.93	50.6	12,051.58	631487.90
8	-64.75	-51.65	41.9	17,227.55	352213.70
9	-66.24	-51.97	39.2	11,437.34	305529.70
10	-66.76	-50.87	48.3	12517.00	485338.00
11	-68.63	-52.83	52.7	8,886.23	337965.50
12	-65.11	-50.03	60.1	22,745.33	733071.10
13	-73.99	-54.85	64.3	3,155.24	258745.20
14	-69.24	-52.10	59.5	8,709.68	179429.80
15	-72.51	-51.47	54.0	3,723.48	473511.80
16	-64.82	-48.36	50.2	20,343.99	901040.10
17	-63.28	-48.58	49.5	28,567.79	843304.90
18	-56.43	-52.10	61.1	170998.50	462840.80
19	-72.80	-59.38	62.9	4059.20	89,113.78
20	-57.83	-53.05	71.1	143897.50	433242.90
21	-58.72	-55.20	67.3	111144.00	249723.90
22	-69.95	-54.74	58.3	7,247.77	240435.50
23	-63.52	-48.54	35.1	19,185.65	604238.80
24	-58.49	-45.23	32.7	56,769.93	1203375.00
25	-66.52	-54.67	49.0	13,413.05	205520.50
26	-68.17	-61.41	61.0	11,426.26	54,231.18
28	-60.19	-55.36	53.1	62,440.61	189887.80
29	-62.31	-48.73	32.5	23,487.23	535287.40
30	-62.59	-48.18	26.0	17,569.38	484492.30
31	-66.74	-50.43	33.8	8,795.62	376399.00
32	-69.29	-58.01	54.8	7,921.09	106331.90
33	-71.68	-57.05	71.6	5,982.68	173656.70
34	-83.53	-56.90	76.3	416.30	191674.20
35	-78.51	-55.52	74.4	1,288.47	256657.20
36	-61.56	-53.52	71.5	61,364.93	390406.50
37	-67.83	-56.78	54.8	11,106.37	141190.70
38	-67.87	-57.53	44.3	8,889.92	96,010.47
39	-73.27	-57.34	25.7	1,485.27	58,306.16
40	-67.98	-52.36	22.7	4,451.81	162326.90
41	-66.48	-54.95	41.5	11,485.83	163123.60
42	-64.82	-57.09	48.6	19,674.83	116689.30
43	-67.75	-56.64	51.2	10,572.92	136483.60
44	-72.53	-54.37	54.1	3,720.13	243323.50
45	-71.24	-58.57	56.9	5,253.67	97171.30
46	-70.88	-58.90	56.6	5,682.91	89,502.18
47	-71.68	-58.33	58.4	4,867.88	105297.30
48	-69.55	-56.66	58.1	7,925.98	153978.60
49	-73.6	-57.55	54.1	2,899.22	117009.70
50	-70.01	-54.19	51.2	6273.10	239406.60
51	-67.18	-51.70	48.6	11,455.98	403855.30
52	-63.43	-50.25	44.5	24,845.85	516491.10
53	-69.23	-54.95	52.8	7,748.62	207446.90
54	-70.20	-63.16	62.3	7,303.96	36,963.81
55	-76.75	-60.72	66.0	1,713.68	68,767.15
56	-71.01	-56.18	60.2	5,859.37	178237.20
57	-71.89	-57.99	58.9	4,684.93	114950.30
58	-76.45	-58.45	61.3	1704.70	107653.30
59	-75.77	-60.01	66.0	2,149.41	80,958.34
60	-69.26	-59.37	58.5	8,532.68	83,205.41
61	-68.91	-56.39	51.8	8171.80	146012.20
62	-73.29	-61.29	57.7	3,324.69	52784.70
63	-73.84	-60.58	62.7	3,183.19	67,516.83
64	-69.74	-56.51	62.0	8,085.02	170404.30
65	-71.05	-57.35	67.6	6,518.27	152811.80
66	-76.55	-54.95	73.0	1,985.25	287117.60
67	-70.44	-56.03	74.2	8,244.57	227517.00
68	-72.33	-57.48	68.4	4,909.69	150048.30
69	-71.50	-54.07	51.3	4,463.47	246813.40
70	-63.63	-53.06	36.7	19,566.68	223103.60
71	-66.59	-53.62	48.6	13,102.01	259779.30
72	-77.95	-57.17	68.1	1,342.68	160504.30
73	-74.24	-54.39	68.5	3173.90	306568.00
74	-74.76	-55.28	58.8	2,416.83	214199.40
75	-65.63	-52.92	32.6	10,977.21	204480.40
76	-65.98	-54.65	37.5	11,652.78	158066.00
77	-71.87	-54.43	58.6	4,683.73	259660.10
78	-69.63	-54.86	62.7	8,385.77	252029.40
79	-64.12	-52.18	39.5	18,814.61	293975.50
			Total =	1323154.00	20942590.00

a)



b)

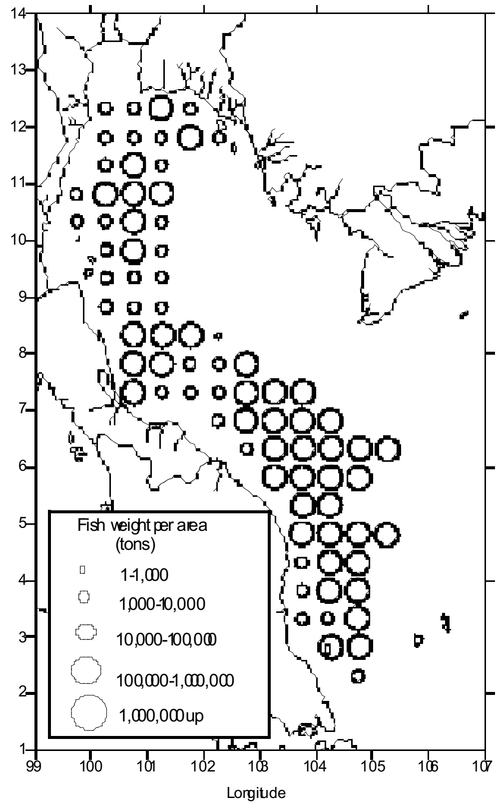
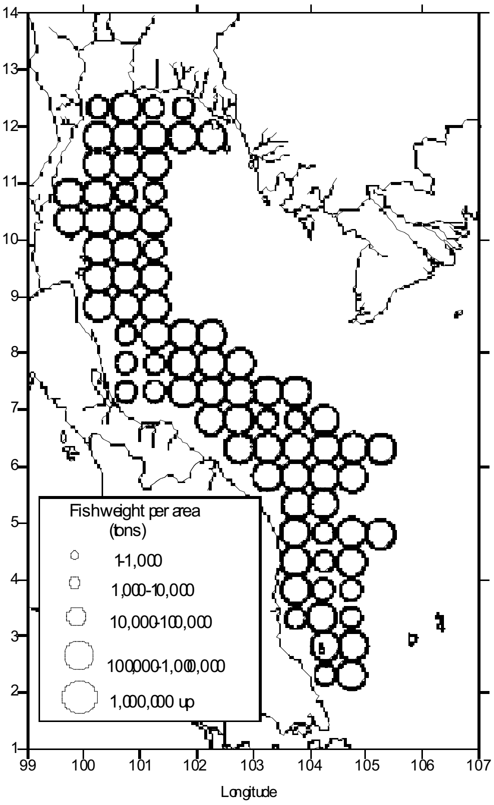


Fig.11. An average weight of fish (tons/900nm^2) in the Gulf of Thailand and East Coast of Peninsular Malaysia observed by 200 kHz. during a) pre-northeast and b) post-northeast monsoon season.

a)



b)

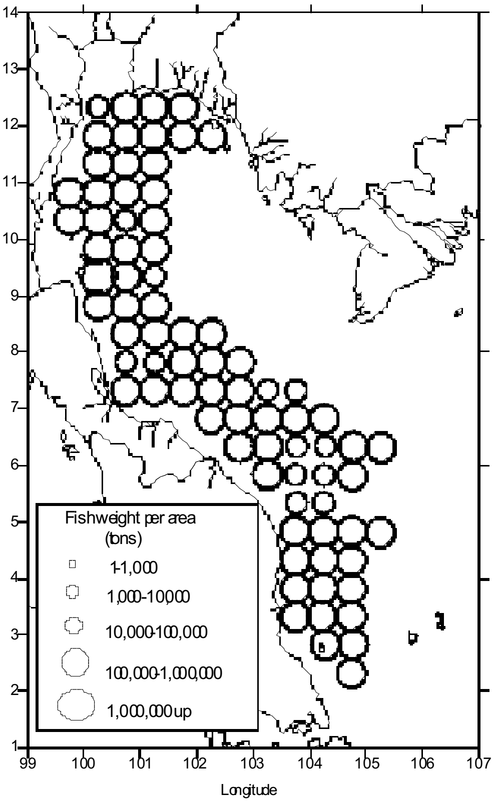


Fig.12. An average weight of fish (tons/900nm^2) in the Gulf of Thailand and East Coast of Peninsular Malaysia observed by 50 kHz. during a) pre-northeast and b) post-northeast monsoon season.

biomass estimation of fish schools using a frequency of 50 kHz seem to suffer more interference from the echo signal from the plankton layers. The biomass estimation results by low frequency showed the same amount during both seasons may be caused by the plankton layers present all year round.

The estimation by using a frequency of which 200 kHz seemed to be more effective at detecting the fish schools and less sensitive to plankton layers. The biomass estimation by high frequency can represent a better result than low frequency for this area. However, this estimation of fish biomass is the combination of the biomass of fish schools themselve as well as the biomass of high density plankton layers. The elimination of echo signal, from plankton layers can be achieved by increasing the threshold level, but it could also eliminate the echos from fish schools at the same time. Then, to eliminate the interference of plankton layers from the estimation, special equipment and techniques are required to separate the echo signal of fish schools from the plankton layers. The pure echo signal from fish schools will result in a better solution for fish school biomass estimation.

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Appendix

Table I Source level (SL) for low frequency (50 kHz).

Power Selection	SL	Vtx	Vmic	MES	SE
A (100 dB)	100.0 dB				
B (190-210 dB)	196.3 dB	180 Vpp	0.40 Vpp	-126.5 dB	161.6 dB
C (200-220 dB)	205.8 dB	540 Vpp	1.04 Vpp	-216.5 dB	160.4 dB
D (210-230 dB)	215.3 dB	1600 Vpp	2.50 Vpp	-216.5 dB	158.6 dB

Average SE (160 to 180 dB) = 160.2 dB

Table II Receiving sensitivity (ME) for low frequency (50 kHz.).

Vmic	ATT	Vpre	Gain	SES	ME
1 Vpp	0 dB	0.22 Vpp	49.6 dB	121.3 dB	-185.9 dB
1 Vpp	10 dB	0.07 Vpp	39.6 dB	121.3 dB	-185.8 dB
3 Vpp	0 dB	0.66 Vpp	49.6 dB	121.3 dB	-185.7 dB
3 Vpp	10 dB	0.21 Vpp	39.6 dB	121.3 dB	-185.8 dB
10 Vpp	10 dB	0.70 Vpp	39.6 dB	121.3 dB	-185.8 dB
10 Vpp	20 dB	0.23 Vpp	29.9 dB	121.3 dB	-185.8 dB

Average ME (-175 to -195 dB) = MEA - 185.8 dB

Table III Source level (SL) for high frequency (200 kHz).

Power Selection	SL	Vtx	Vmic	MES	SE
A (100 dB)	100.0 dB				
B (190-210 dB)	201.6 dB	170 Vpp	0.68 Vpp	-213.7 dB	165.7 dB
C (200-220 dB)	210.4 dB	470 Vpp	2.00 Vpp	-213.7 dB	166.3 dB
D (210-230 dB)	219.5 dB	1340 Vpp	5.60 Vpp	-213.7 dB	166.1 dB

Average SE (160 to 180 dB) = 166.0 dB

Table IV Receiving sensitivity (ME) for high frequency (200 kHz).

Vmic	ATT	Vpre	Gain	SES	ME
1 Vpp	0 dB	1.08 Vpp	50 dB	145.3 dB	-194.6 dB
1 Vpp	10 dB	0.34 Vpp	40 dB	145.3 dB	-194.7 dB
3 Vpp	0 dB	3.10 Vpp	50 dB	145.3 dB	-195.0 dB
3 Vpp	10 dB	0.94 Vpp	40 dB	145.3 dB	-195.4 dB
10 Vpp	10 dB	3.40 Vpp	40 dB	145.3 dB	-194.7 dB
10 Vpp	20 dB	1.02 Vpp	30 dB	145.3 dB	-195.1 dB

Average ME (-175 to -195 dB) = MEA - 194.9 dB