1. INTRODUCTION

Objectives

The survey programme covered the exclusive economic zone (EEZ) of Pakistan from 20 m depth contour out to the 200 nautical mile (nm) limit using combined acoustic and trawl methods for pelagic, demersal and deep-sea species. It also included oceanographic observations such as CTD, O_2 and nutrient measurements. The scientific programme was designed through consultations amongst the Food and Agriculture Organization of the United Nations (FAO), IMR, NIO and MFD.

The specific objectives were to:

- obtain acoustic biomass estimates for the major small pelagic and mesopelagic fisheries resource species;
- obtain acoustic/swept-area biomass estimates for continental shelf demersal fisheries resource species;
- obtain oceanographic observations of the marine environment as related to the fisheries resources;
- obtain exploratory fishing information on the demersal fisheries resources in deep sea areas such as the Murray Ridge and deep continental slope; and
- conduct 3D mapping of specified areas in the Indus Swatch and the Murray Ridge.

Participation

The scientific staff consisted of:

2010408 – Pelagic survey (12–31 October 2010)		
Paul Fanning	FAO	Chief Technical Advisor/Cruise Leader
Gavin Macaulay	IMR	Acoustic Scientist
Magne Olsen	IMR	Instrument Engineer
Moazzam Ali	NIO	Oceanographer
Waqar Ahmed	NIO	Oceanographer
Ibrahim Zia	NIO	Oceanographer
Saira Ishaq	NIO	Oceanographer
Manzoor Ahmed	PN	Navy Hydrographer
M. Wasim Khan *	MFD	Project Director
Muhsan Kalhoro	MFD	Acoustic Specialist
Tariq Hanif	MFD	Acoustic Specialist
Dildar Shafi	MFD	Fisheries Specialist.
Hina Mansoor	MFD	Fisheries Specialist
Deedar Ali	MFD	Fisheries Specialist
Arif Mahmood	MFD	Fisheries Specialist
Hamid Badar Usmany	MFD	Fisheries Specialist
M. Iqbal Khan	DoF	Sindh Fisheries
Aslam Ansari *	MFD	Fisheries Specialist

* Due to illness, Wasim Khan was replaced by Aslam Ansari on 17 October 2010

2010409 – Demersal survey (2–21 November 2010)

Paul Fanning	FAO	Chief Technical Advisor/Cruise Leader
Thomas Wenneck	IMR	Acoustic Scientist
Diana Zaera	IMR	Fisheries Specialist
Mohsin Tabrez	NIO	Oceanographer
Waqar Ahmed	NIO	Oceanographer
Khalid Mehmood	NIO	Oceanographer
Samina Kidwai	NIO	Oceanographer
Rao Ghulam Dastagir	PN	Navy Hydrographer
M. Wasim Khan	MFD	Project Director
Muhsan Kalhoro	MFD	Acoustic Specialist
Tariq Hanif	MFD	Acoustic Specialist
Dildar Shafi	MFD	Fisheries Specialist
Liaquat Haroon	MFD	Fisheries Specialist
Deedar Ali	MFD	Fisheries Specialist
Aslam Ansari	MFD	Fisheries Specialist
Hamid Badar Usmany	MFD	Fisheries Specialist
Shakeel Ahmed	DoF	Balochistan Fisheries

Overview of activities

The survey programme for Pakistan was conducted in two legs. Survey 2010408 was a pelagic/acoustic survey which covered the entire Pakistan EEZ from approximately the 20 m contour on the shelf out to the 200 nm limit. Survey 2010409 was a swept-area trawl survey for demersal species on the shelf area (20–200 m) only.

Overall the surveys proceeded as planned however the survey activities were subject to scheduling and area constraints from the Pakistan Navy (PN). In general, the PN liaison officers carried aboard were able to advise and coordinate minimal impact on the survey programme. There were two interruptions to the survey programme. On 17 October 2010, the ship diverted to Karachi to land a seriously ill staff member and pick up a replacement. The survey transects were resumed that night. A second diversion to Karachi was required on 16 November 2010, this time to land two ill crew members for medical examination and treatment. The ship waited at anchor until their return from medical treatment and resumed the demersal survey on 17 October 2010.

The survey programme on the shelf at night was often hampered by fishing vessels and in particular by gillnets. This was most significant on the Balochistan shelf where night transects were simply not possible (Figure 1). In the final week of the pelagic survey, it was necessary to skip transects as there was insufficient time remaining to wait until the fishing gear was hauled in the morning. During the demersal survey, night-time trawl stations or hydrographic work on the shelf required extensive manoeuvring when it was possible at all.

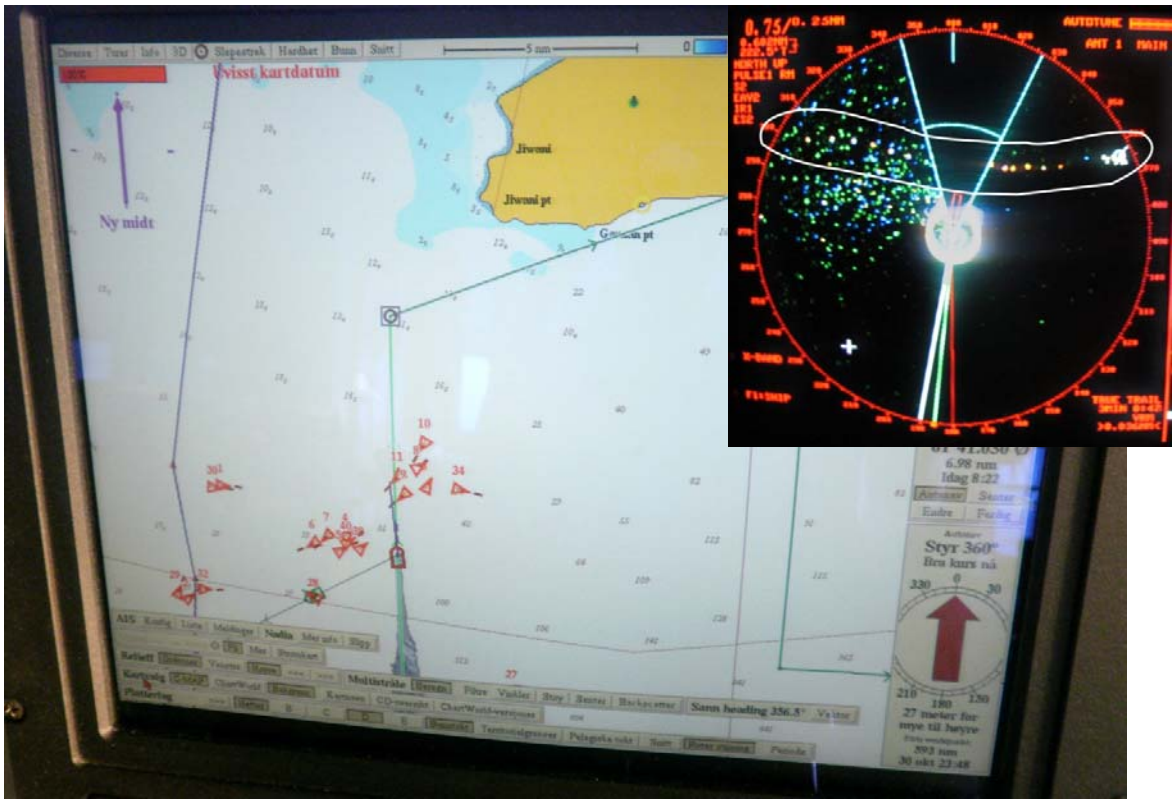

Figure 1: Navigation plot showing fishing vessels anchored at night. Many have gillnet gear set, extending to the westward of the vessels (inset: radar image highlighting gillnet vessel and line of floats)

Multibeam mapping using the EM710 multibeam echosounder was run continuously throughout both surveys when water depths were less than ~1400 m as data quality was too degraded for use below that. Except when specifically mapping pre-selected areas (Murray Ridge and The Swatch), the echosounder priority was assigned to the EK60 to prevent interference from the EM710.

Three different trawls were available on board, the “Harstadtrawl” pelagic trawl, the larger “Åkrahamn” pelagic trawl and the “Gisund Super” bottom trawl. Brief specifications of each trawl are given in Annex 1. The vessel is equipped with a Multisampler for the larger pelagic trawl, the “Åkrahamn”-type. This system is intended to allow up to four discrete samples to be collected on a single tow, preventing contamination of deeper catches with specimens from shallower layers. Unfortunately the acoustic communications link for this system would not function and this device could not be used.

2. METHODS

Fish sampling

All trawl catches (demersal and pelagic) were sampled for species composition by weights and numbers. Catches were sorted to species (or lowest taxon possible) using taxonomic identification sheets (Fischer and Bianchi, 1984) and a field guide (Bianchi, 1985). Large catches were subsampled by mixed baskets

after large specimens were collected separately. Raising factors were applied as required to estimate total catch (weights and numbers) per species/taxon. Station by station records of catches are given in Annex 2. Length frequency samples, or subsamples, were taken for all species of fish (total or fork length) and squid (mantle length), and for many decapod crustaceans (carapace length or width) on every station. Individual weights were collected on a stratified basis (1 per cm grouping) from the length frequency samples. In cases where individuals were too small for accurate weighing (<~5 gm) a pooled mean weight was estimated for each length. Other taxa were recorded in aggregate weights and/or numbers (jellyfish, gastropods, echinoderms and snakes). All catch data and biological sample data were entered into the Nansis database.

Acoustic sampling and analysis

Acoustic equipment

Acoustic data were recorded using a Simrad ER60 scientific echosounder equipped with drop-keel-mounted transducers at nominal operating frequencies of 18, 38, 120 and 200 kHz. Few locations along the Pakistan coast are favourable for transceiver calibration (essentially only the area east of Cape Monze near Karachi), and the survey was therefore started without *a priori* calibration. A post-survey calibration was completed on 20 November 2010 for the 18 and 38 kHz transducers only. Calibration results are given in Annex 1.

Acoustic data were logged and post-processed using the latest acoustic data post-processing software, the Large Scale Survey System (LSSS) Version 1.3.2. The technical specifications and operational settings of the echosounder used during the survey are given in Annex 1.

Design

There are two distinct areas of pelagic waters in the Pakistan EEZ, the on-shelf area and the off-shelf area. On-shelf is the area between the minimum sampling depth (approximately 15 m) and the 500 m offshore contour. Off-shelf is from the 500 m contour to the EEZ boundary. Sampling was restricted from approaching within 8 km of international boundaries. On-shelf strata for Balochistan and Sindh were based on the different natures of the continental shelf in each area. The specific boundary is the 24°50’ parallel as is used in the demersal stratification. The off-shelf area was divided into western, central and eastern strata. The central stratum covered the Murray Ridge and adjoining trough while the western and eastern strata cover the continental shelf margins from 500 m and outwards (Figure 2).

Sampling allocation to strata (Table 1) was based on stratum area however the sampling intensity (track miles per unit area) was reduced in the offshore strata due to the very large size of these. There is also little question that the shelf areas should be sampled more intensively than the off-shelf waters. The exact proportionality selected (2.5x greater on-shelf) was arbitrary.

A hybrid design was adopted, using zigzag transects for efficiency offshore, and parallel transects for improved mapping and distribution information on-shelf. The offshore zigzags were adjusted to align with oceanographic transect lines however it is assumed that no discernible bias would be introduced by this.

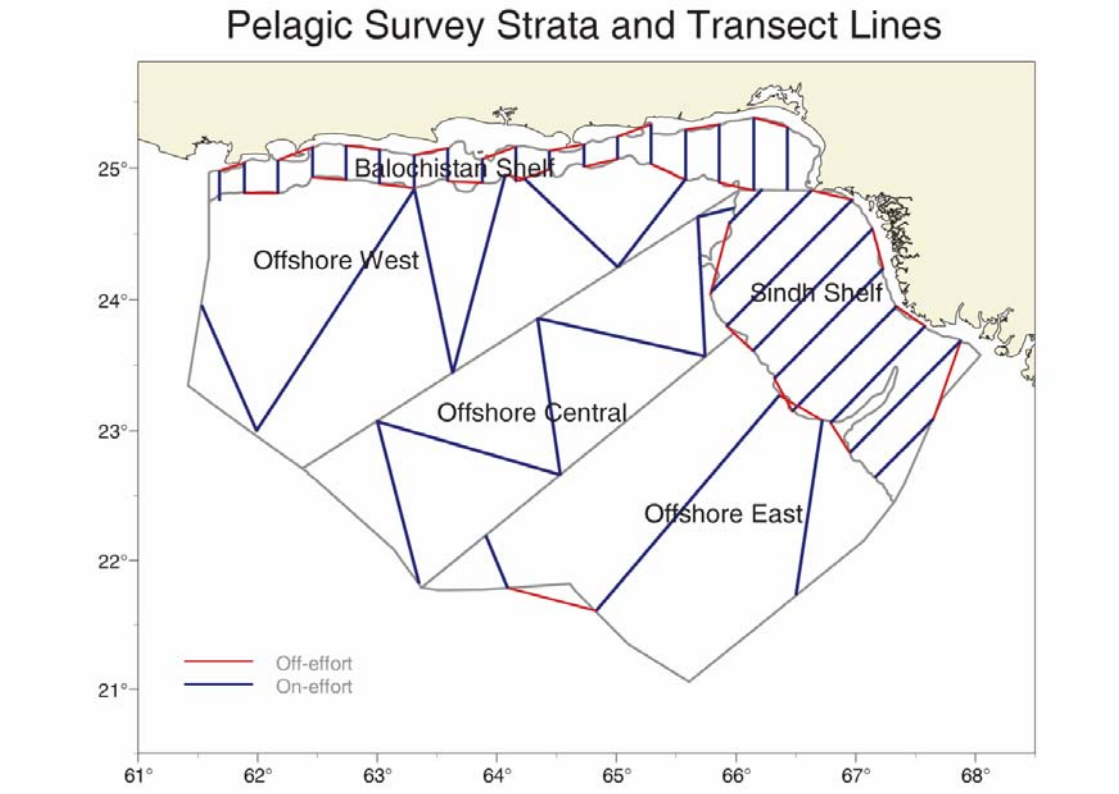

Figure 2: Acoustic survey strata and transect lines

Planned transects totalled 2500 nm (4625 km) of acoustic track lines in the study area required approximately 15 hours per day of on-effort steaming to complete. The remaining time was used for pelagic trawling, oceanographic sampling and multibeam mapping.

Table 1: Acoustic sampling effort allocation to strata based on 4600 km (2500 nm) total effort

Hybrid – adjusted sampling design

Stratum	Area (km^2)	Weight	Wt %	On-effort (km)	Total (km)	Percent on-effort	Km track /km^2
Balochistan	15466	2.5	13.8	566.5	1067.9	53.0	0.037
West offshore	65231	1	23.2	897	913.7	98.2	0.014
Sindh	30579	2.5	27.2	1034.2	1299.7	79.6	0.034
Central offshore	44632	1	15.9	740.9	773.3	95.8	0.017
East offshore	55984	1	19.9	444.1	565.4	78.5	0.008
				3682.7	4620	79.7	

Allocation of acoustic backscatter to species category

The acoustic data were scrutinized using LSSS v1.3.2 of 2009 (Korneliussen *et al*. 2006)from the 38 kHz display only. The mean 1 nm area backscattering coefficient S_A (m^2/nm^2) was allocated to a predefined set of species groups on the basis of established echogram features. Acoustic groups and respective

species are listed in Table 2. Samples for species and group identification, and estimation of mean length and weight, were obtained by targeted pelagic trawling.

Table 2: Taxa (families) conventionally assigned to acoustic categories and the principal species identified in Pakistan waters

Acoustic category	Family	Principal species
Pelagic 1	*Clupeidae*	*Dussumieria acuta*
		Sardinella spp. (includes 3 species)
		Anaduntostoma chacunda
	Engraulidae	*Thryssa vitriorostris*
		Thryssa dussumieri
		(and 2 more species)
Pelagic 2	*Carangidae*	*Decapterus russelli*
		Decapterus spp. (2 more species)
		Carangoides spp. (5 species)
		Scomberoides commersonnianus
		Megalaspis cordyla
		Alectis spp. (2 species)
	Scombridae	*Scomberomorus guttatus*
		Scomberomorus spp. (2 more species)
		Rastrelliger kanagurta
	Sphyraenidae	*Sphyraena obtusta*
		Sphyraena putnamae
		Sphyraena jello
	Trichiuridae	*Lepturacanthus savala*
		(includes 2 more species)
Mesopelagics	*Myctophidae*	*Benthosema* spp.
	Champsodontidae	*Champsodon* spp.
	Bregmacerotidae	*Bregmaceros* spp.
	Myctophidae	*Diaphus* spp.
		(and 3 more species)
Demersals	*Nemipteridae*	*Nemipterus randalli*
		Nemipterus japonicus
		Parascolopsis spp. (includes 3 species)
	Haemulidae	*Pomadasys kakaan*
		Pomadasys maculatum
		Pomadasys stridens
		(and 3 more species)
		Priacanthus spp. (includes 2 species)
	Serranidae	*Epinephelus diacanthus*
	Sciaenidae	*Atrobucca alcocki*
		Johnius spp. (3 more species)
		Otolithes spp. (2 species)
	Ariidae	*Arius* spp. (include 5 species)
	Synodontidae	*Saurida* spp. (includes 3 species)
Plankton		*Plankton*
	Acropomatidae	*Synagrops adeni*
	Loliginidae	*Uroteuthis duvauceli*
	Sepiidae	*Sepia* spp. (includes 4 species)
		Jellyfish
	Portunidae	*Charybdis* spp.
		Charybdis feriata

The plankton acoustic category was allocated differently between day and night. During the night, when mesopelagic fish had migrated into the top 100 m, the plankton category was used for this region and hence is more accurately a mesopelagic/plankton mix categorisation. During the day, when the mesopelagic fish had migrated down to about 300 m, the surface plankton categorisation then only contained plankton and a separate mesopelagic category was used for the deeper mesopelagic layers.

Target strength data were collected on two occasions during the night when single targets were observed above strong scattering layers that were at 20 m depth. In both cases, the trawl samples gave mixed catches of jellyfish and myctophids.

Distribution

Distribution plots were post-stratified into areas of similar densities using the following pre-defined ranges:

1: S_A = 0–300;
2: S_A = 301–1 000;
3: S_A = 1 001–3 000;
4: S_A > 3 001 (m^2/nm^2).

The post stratification boundaries of classified fish aggregations were determined by means of manual contouring guided by the inner and outer zero-value limits of the transect lines using Nansis 1.5.1.

Estimation of biomass

Acoustic backscatter (S_A) was summed over all transects within the 5 pre-defined survey strata. Day/night and depth categories were assigned after inspection of echograms to determine the apparent boundaries. Classified S_A was partitioned into time-depth strata accordingly.

The target strength (TS) function used to convert mean area backscattering coefficient S_A (m^2/nm^2) at 38 kHz to number of fish is generalized as:

$$TS = C \log L - I \text{ (dB)} \qquad (1)$$

where L is the mean total fish length and the coefficient (C) and the intercept (I) are species dependent regression parameters. This target strength function with C=20.0 and I=-72.0 was originally established for North Sea herring, but has been widely applied to clupeids in general (Foote *et al*., 1986; Foote, 1987).

Although species-specific target strength data is not available for many species seen in Pakistan waters, a collection of target strength at length parameters from the literature was assembled for related and similar species (Annex 1). These were compiled into several classes based on shape and presence/absence of a swimbladder (Table 2) and the great majority of species/taxa observed in the catches were assigned parameters based on the most similar group. The mean length and mean weight in the catch was calculated for each species/taxon and the average TS for the taxon was calculated from equation 1. Each species/taxon was assigned into an acoustic category in Table 2 and the species and size specific TS estimates were averaged (weighted by numbers in the catch) into the species groups corresponding to the acoustic categories. The corresponding mean weight in the acoustic category was also calculated following Simmonds and MacLennan (2007). The group's mean target strength is then used in the conversion from TS to backscattering cross-section by:

$$\sigma_{bs} = 10^{TS/10}$$

which is then used with the mean weight in the category (w) to convert from S_A (m^2/nm^2) to areal density (kg/m^2) by:

$$\rho = \frac{s_A}{4\pi\sigma_{bs}} w .$$

Table 3: Coefficient and intercept of published target strength to length relationships

Shape	Swimbladder	Intercept	Coefficient	Fixed TS
perch	yes	-50	20	
eel	yes	-50	20	
eel	no	-93.1	30.6	
elongate	yes	-76	20	
flounder	no	-77	20	
tuna	yes	-50	20	
crustaceans	no	-70.3	9.45	-85.0
tapered	no	-77	20	
jelly	no			-64.7
tuna	no	-60	20	
chond	no	-77	20	
squid	no	-76.2	20	
puffer	yes	-50	20	

Demersal sampling and analysis

Design

Following Abildgaard *et al.* (1986) the shelf area from 10 m inshore contour to the 200 m contour was partitioned into eight strata (Figure 3). Each of the four coastal regions (Makran, Sonmiani, Sindh and Kori) was divided into an inshore (10–50 m) and an offshore (50–200 m) depth zone.

A total of 95 trawl stations (assuming 5 trawl sets per day for 19 days) were allocated proportional to stratum area (Table 4). A standard trawl tow was 30 minutes towing at 3.5 kts for a total of 1.75 nm distance (approximately 3.24 km; 1 km = 0.539957 nm). Stations were randomly selected by defining a 6 km grid overlaying the strata. A 10 percent random selection from the grid points produced 229 grid points (Figure 4). From the selected points within each stratum the required numbers of stations were randomly selected as primary sampling stations. The remaining stations were available as alternates.

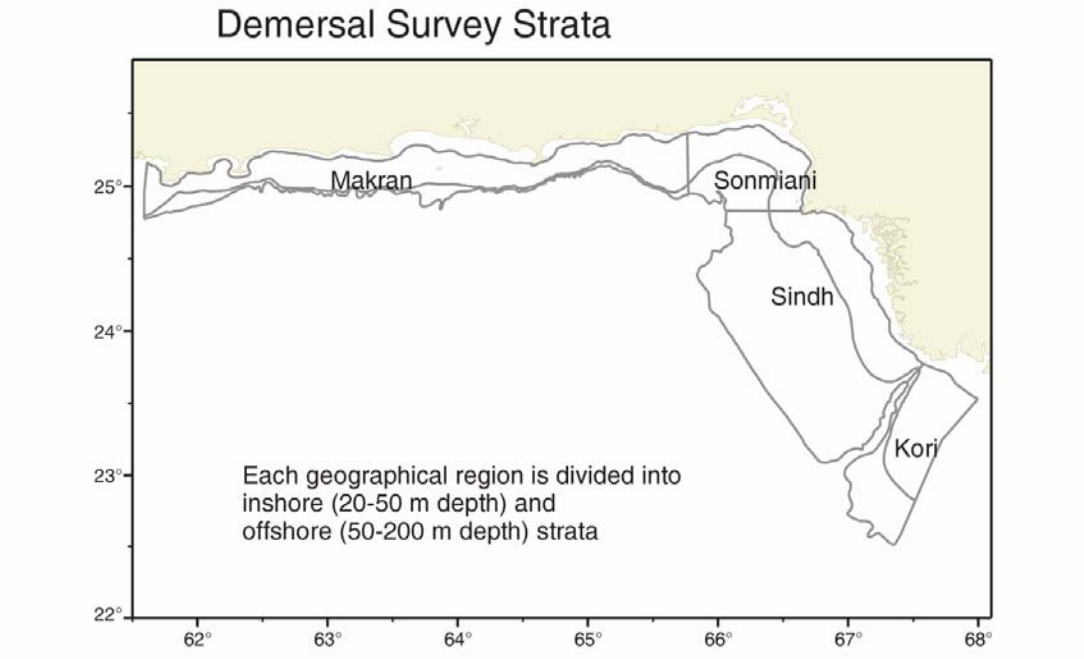

Figure 3: Demersal survey strata defined by geographical area and depth range

Table 4: Demersal stratum area and effort allocation

Statum	No	area-km	area-nmi	Stratum weight (W).	Sets
Makran inshore	9103	9482	2765	22.19%	21
Makran offshore	9104	1814	529	4.25%	4
Sonmiani inshore	9105	2917	850	6.83%	6
Sonmiani offshore	9106	2098	612	4.91%	5
Sindh inshore	9107	4747	1384	11.11%	11
Sindh offshore	9108	15269	4452	35.74%	34
Kori inshore	9109	3809	1111	8.92%	8
Kori offshore	9110	2587	754	6.06%	6
		42723	12456	100.00%	95

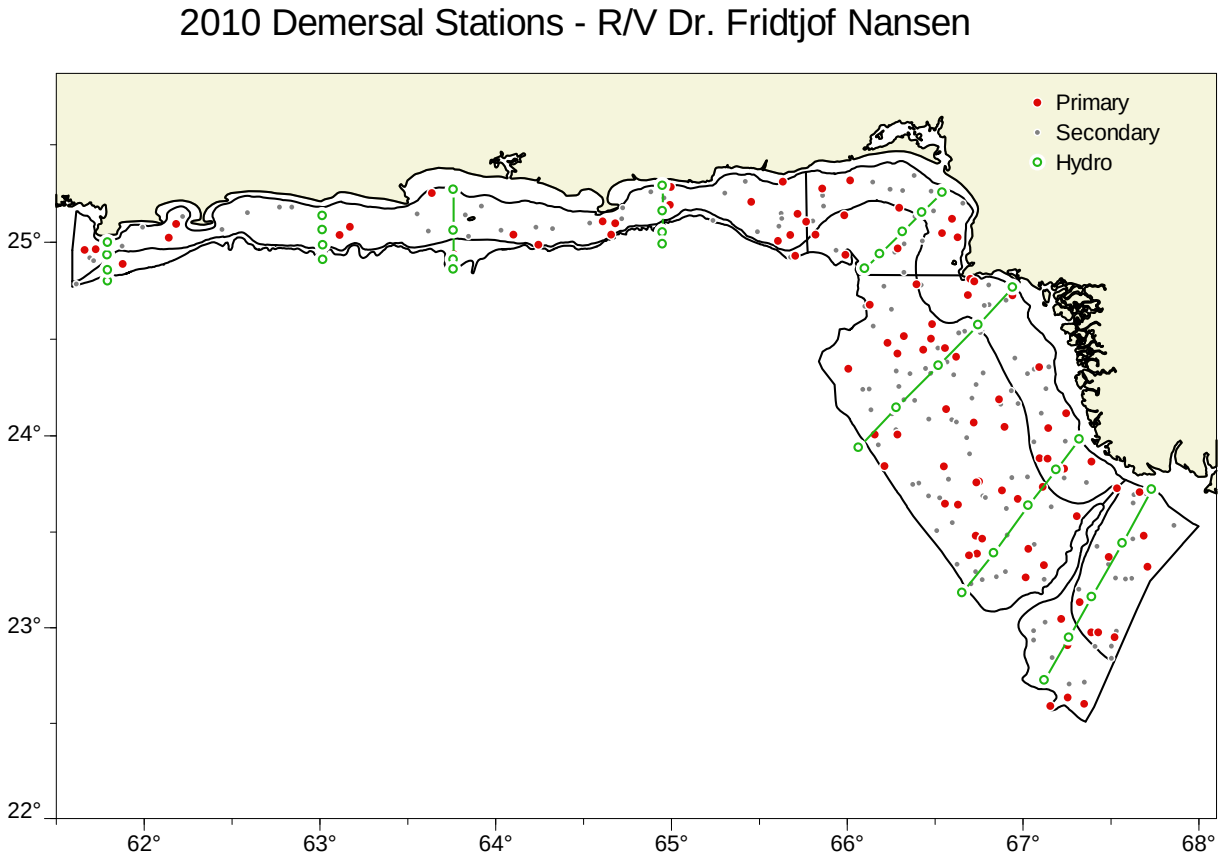

Figure 4: Demersal survey sampling stations randomly selected by strata. Oceanographic sampling stations are included

Biomass estimation

Swept area biomass estimates were computed using the standard stratified estimation (Cochrane, 1977). Catches in weight and numbers were standardized to a 1.75 nm tow by:

$$Y^{*}_{sih} = \frac{D_{ih}}{1.75} \cdot Y_{sih}$$

where D_{ih} is the distance (n. mi.) towed on the i^{th} set in stratum h and Y_{sih} is the observed catch (in weights or numbers) of species s in the given set. The stratified estimate of the mean catch per standard tow for species s is then given by:

$$\bar{Y}_S = \sum_h \frac{N_h}{N} \cdot \sum_i Y^{*}_{shi} = \sum_h W_h \cdot \sum_i Y^{*}_{shi}$$

where N_h is the stratum size and N is the total size of all strata i.e. W_h is the stratum weight given in Table 4.

Oceanographic sampling

The oceanographic tracks constituted transects with 4 in the offshore deep Arabian Sea consisting of 17 hydro-stations, and 8 shelf transects with 37 hydro-stations to cover the entire Pakistan EEZ of 240 000 square kilometres (Figure 5).

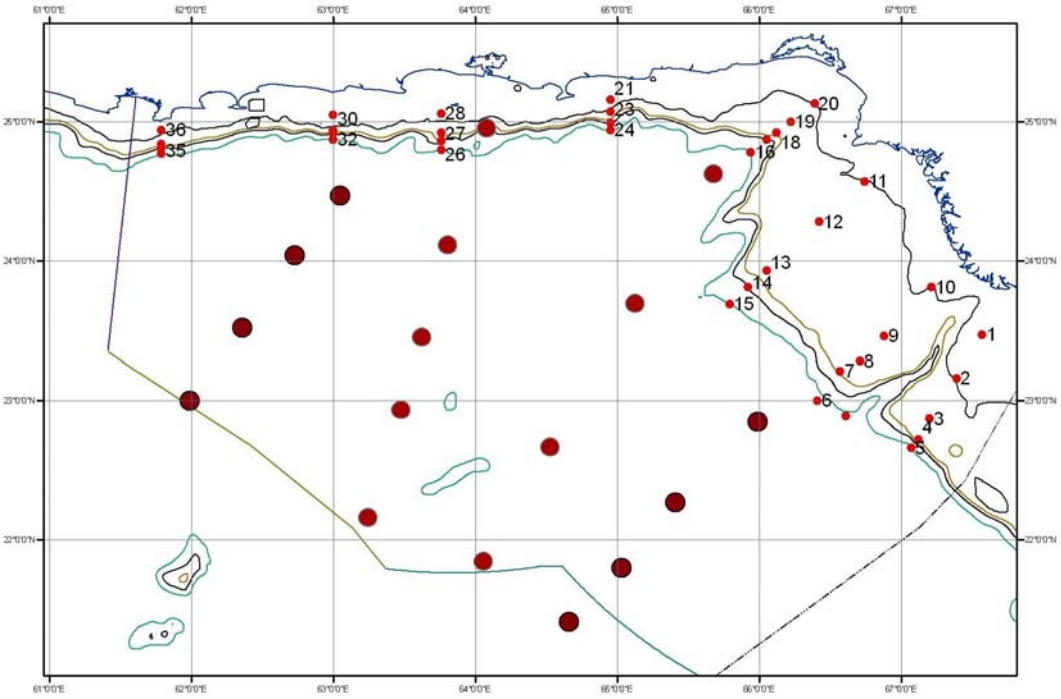

Figure 5: Locations of oceanographic stations with small circle denoting demersal stations and large circle denoting pelagic stations

At each of the hydro stations, a CTD rosette cast was completed for temperature, salinity, oxygen, fluorescence and water samples. Plankton net tows were also carried out. Almost all of the hydro stations were done in the night, keeping in view of the day-night variability, avoiding the transition periods of sunrise and sunset. Additional CTD casts were taken following each of the trawl stations, and an additional water sample was taken from the surface water to get chlorophyll observations for the day.

CTD

A Seabird 911+ CTD probe was used to obtain vertical profiles of the temperature, salinity and oxygen. Real time logging was carried out using the PC based Seabird Seasave software.

The casts were stopped a few meters above the bottom, and at a maximum of 1 500 m depth. The oxygen sensor has shown to be very stable, and bottle samples from all hydrocasts will be used for confirmation of the stability of the sensor. No calibration was conducted during the survey.

Attached to the CTD was also a Chelsea flourometer of the type Mk III Aquatrack. It measures chlorophyll A in $\mu gm\ l^{-1}$ with an uncertainty of 3 percent. Factory slope and offset was 0.921 and -0.02.

Thermosalinograph

The SBE 21 Seacat thermosalinograph was running routinely during the survey, obtaining samples of sea surface salinity and relative temperature and fluorescence (5 m depth) every 10 second. An attached in-line Turner Design SCUFA Fluorometer was continuously measuring Chlorophyll levels [RFU] at 5 m

below the sea surface while underway during the entire cruise. The instrument was configured with a bright blue photodiode, a 420 nm Excitation filter and a 680 nm Emission filter. It was calibrated against the secondary orange standard dye. The maximum output was equivalent to 5 Volt = 100 percent. It had a linear temperature compensation of 2.14 percent/°C.

Meteorological observations

Meteorological data logged from the Norwegian Meteorological Institute (DNMI) meteorological station included air temperature, humidity, air pressure, wind direction and speed, and sea surface temperature (SST). All data were averaged by unit distance sailed (1 nm).

Plankton

The zooplankton sampling was conducted by means of Hydrobios Multinet (5 nets of 405 µm), at three depths, 50, 100 and 200 m, at predetermined positions along the survey track. Data from the flow meter was recorded electronically from the Multinet receiver unit. A SCANMAR depth sensor gave real-time information of the depth. The nets were opened and closed remotely from the bridge of the vessel. The samples were preserved in 4 percent formalin.

A phytoplankton sample was taken at each predetermined hydro station with a vertical haul of a 50 µm ring net and preserved in 4 percent formalin.

Multibeam bathymetric data collection

The NIO requested two blocks for multibeam bathymetric survey, the near-shore end of the Indus Swatch and the western edge of the Murray Ridge. These were selected to extend existing Multibeam datasets.

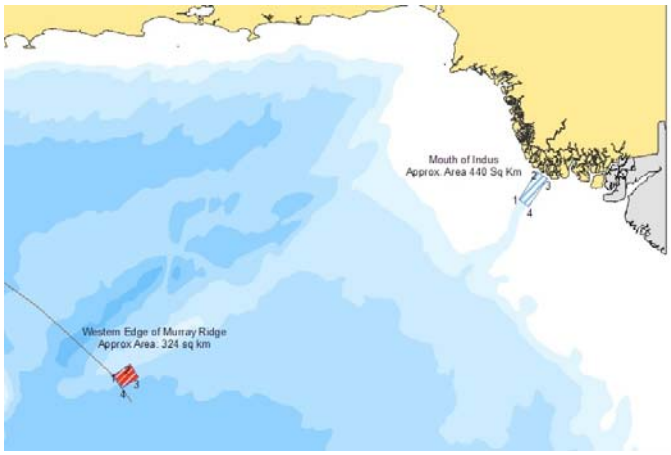

Figure 6: Preselected blocks for multibeam bathymetric survey

The vessel is equipped with the Kongsberg Marine EM 710 multibeam echosounder with the transducer array producing beams of 1°x2°. This is a high to very high resolution seabed mapping system which is interfaced with the ships OLEX chart mapping post-processing system. The system is rated to more than 2 000 m however increasing noise in the data at depths below 1 400 m made 1 400 m the functional limit recorded during the surveys. The multibeam was turned off in greater depths although single beam bottom depths from the ER60 sounder were recorded. The across track coverage (swath width) was approximately twice the water depth. Data from the OLEX system were edited at sea to remove spurious values and the results were provided in ASCII files in XYZ format.

3. PELAGIC SURVEY

Pelagic survey narrative

The vessel departed Karachi on 12 October 2010 at 13.00 hours local time (08.00 hours UTC). A planned acoustic calibration near Karachi was postponed due to excessive swell and the first acoustic transect was begun near dusk (14.00 hours UTC). The second transect had to be truncated due to Pakistan Navy exercises in the area.

The first survey region was the Sindh (eastern province of Pakistan) shelf from 20–500 m depth. The shelf regions were covered using parallel, evenly-spaced transects (28 km spacing, random starting track) perpendicular to the coast (Figure 2). Tracks were steamed 24 hours per day and pelagic trawl tows were made on selected acoustic targets. When the Sindh shelf region was completed the survey continued into the offshore Eastern, Central and Western strata and finally in the Balochistan shelf stratum.

The survey programme on the shelf at night was often hampered by fishing vessels and in particular by gillnets. This was most significant on the Balochistan shelf where night transects were simply not possible. As a result two transects were skipped completely and four others were truncated to less than 50 percent of the planned length resulting in about a 30 percent reduction in on-effort track in the stratum. This is not considered to impose any significant constraints on the analysis.

Survey effort

Three different trawls were used during the survey (Annex 1). Most of the trawl tows were with the "Harstadtrawl" pelagic trawl. A few tows were made with the larger "Åkrahamn" pelagic trawl. For shallow tows (<10 m below the surface) the "Harsadtrawl" was fitted with four floats (1 m diameter) on 1–10 m lines to limit depth near the surface. The bottom trawl ("Gisund Super") was also used as a pelagic trawl for shallow tows. Table 5 summarizes the survey effort by regions and Figure 7 shows the cruise tracks with fishing and hydrographic stations.

Table 5: Summary of survey effort by strata, including number of pelagic trawl hauls, CTD casts, plankton sampling stations (phytoplankton and 2–5 multinet zooplankton samples per station) and distance surveyed acoustically (nautical miles)

Area	Pelagic Trawls	CTD casts	Plankton stations	Plankton samples	Nautical miles	
					Total	Scrutinized
Balochistan Shelf -	5	6			576	496
Sindh Shelf -	12	11			720	634
Offshore West -	13	18	7	35	843	559
Offshore Central -	13	12	5	25	446	346
Offshore East -	2	7	5	25	561	445
Total	45	54	17	85	3146	2480

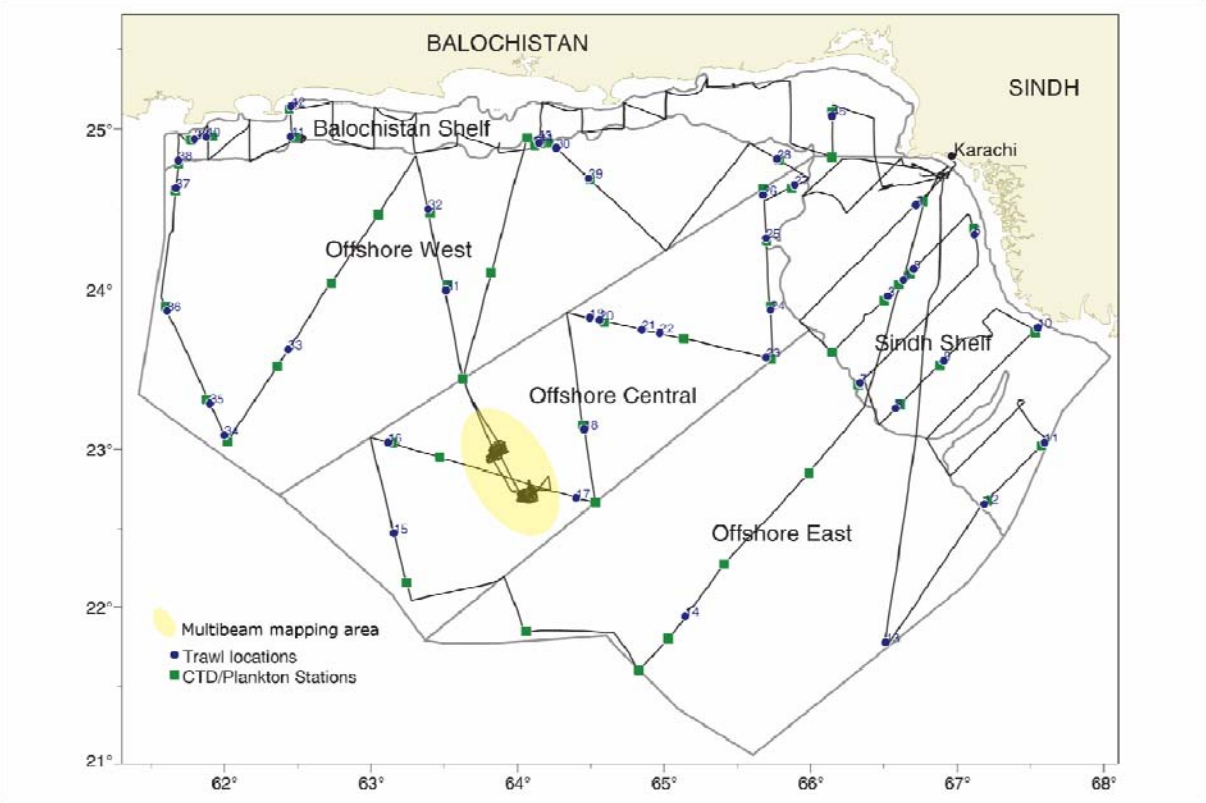

Figure 7: Survey track with hydrographic and trawl stations. Multibeam data was logged during all transects in depths <1400 m as well as on two sea mounts of the Murray Ridge

Results

Catch rate estimates

Catches from each set are included in the Nansis reporting format in Annex 2. In this case all catches are standardized by towing time to one hour rather than distance towed. The mean catch per hour towing is produced by the Nansis database based on species and taxa groupings specified. These were defined based on the observed catches and taxonomic relationships for the groups of greatest interest to fisheries. The set-by-set and stratum mean catches for these groups are included in Annex 3. The groups defined were *Benthosema* which includes *Benthsema pterotum* and *B. fibulatum*; Carangids all species in the family Carangidae; Cephalopods which includes squid and cuttlefish; Clupeoids which includes Clupeidae and Engraulidae; Trichurids all species in the family Trichuridae; Scombrids all species in the family Scombridae; Jellyfish which includes a wide range of gelatinous species; Other Mesopelagics includes Champsodontidae, Bregmacerotidae, Gempylidae, and Nomeidae; and all other groups are included in the category Others.

Distribution

The Sindh inshore strata contained a few concentrated schools and a widespread diffuse scattering layer. The Balochistan stratum contained the highest amount of backscatter from schools but extensive light scattering layers were also present (Figure 8) on the shelf areas.

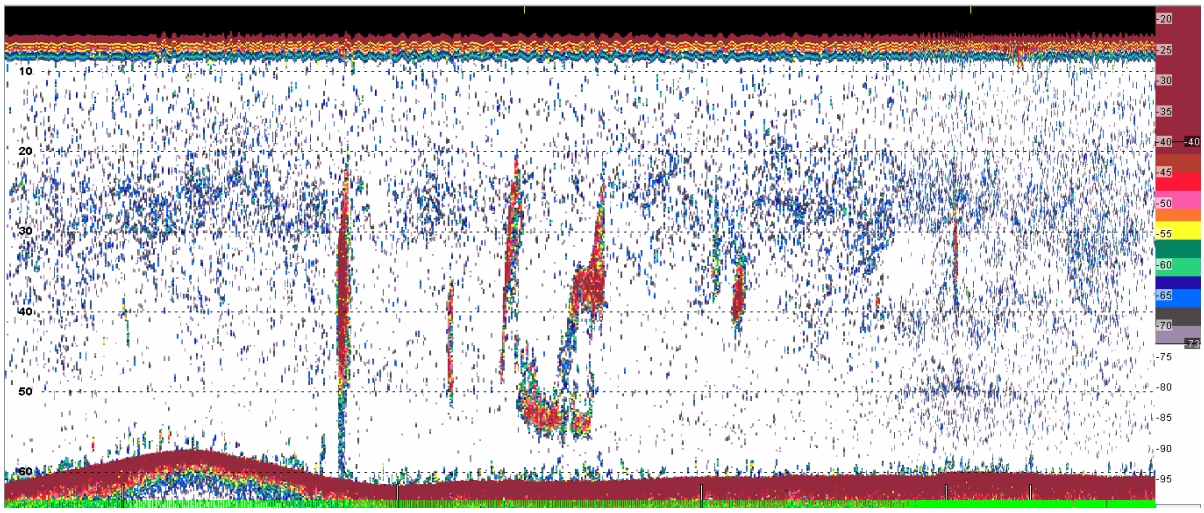

Figure 8: Example of dense pelagic schools and scattering layers in shallow water on the Balochistan shelf

Pelagic 1 (PEL-1) category marks were found over much of the inshore region, with a concentration in the western end of the Balochistan stratum (Figure 9). Pelagic 2 (PEL-2) category marks were weak with concentrations in the vicinity of Ormara and the Indus Delta (Figure 10). These results are based solely on acoustic classification and do not reflect any information from the trawl catches. No biomass estimates were made for these groups during the survey.

The offshore strata contained extensive scattering layers that migrated from mesopelagic depths to within 100 m of the surface during dusk and descended back to 300–700 m at dawn (Figure 11). This is characteristic of myctophids and other mesopelagic fish and was confirmed by trawling on the various layers. At times, dense clumps of myctophids were also observed (Figure 12) mostly near the continental shelf edge

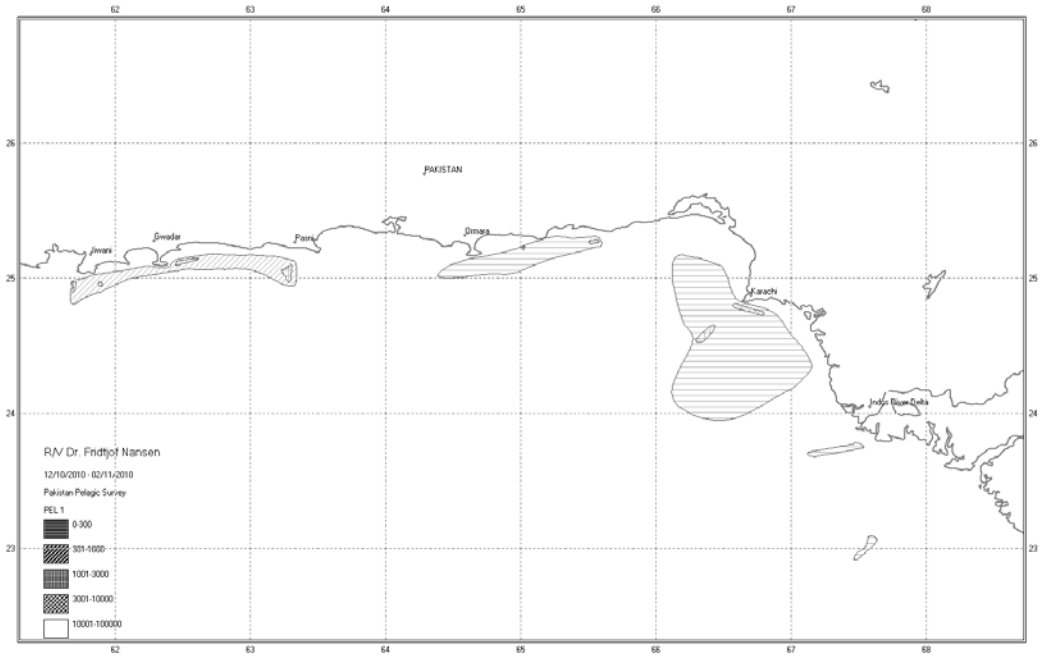

Figure 9: Distribution of acoustic backscatter assigned category PEL-1

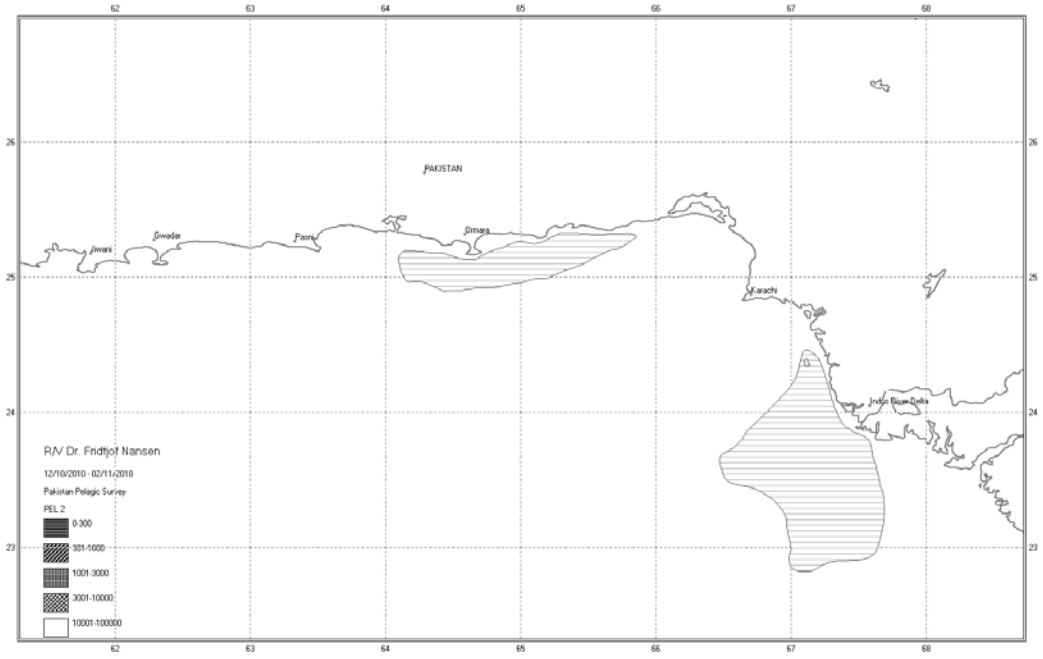

Figure 10: Distribution of acoustic backscatter assigned as category PEL-2

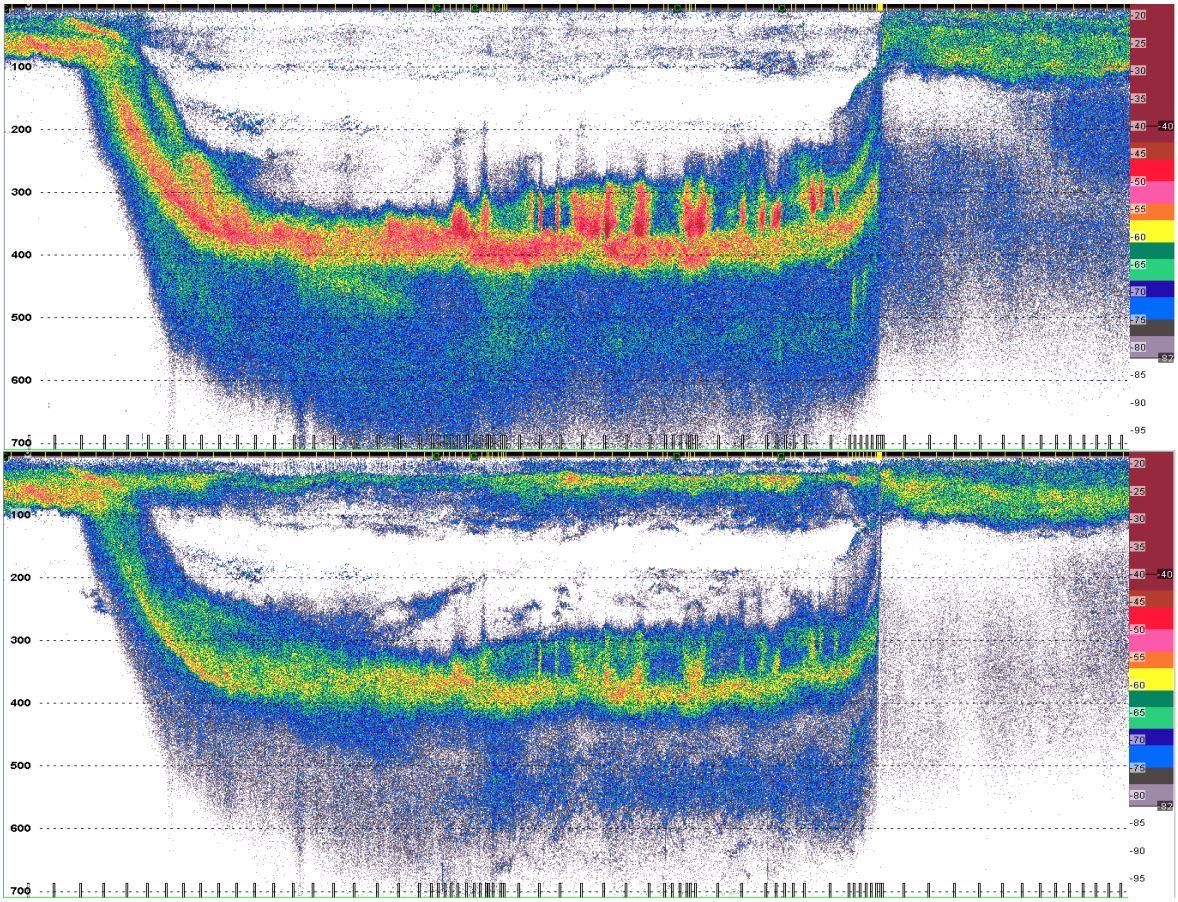

Figure 11: Diurnal migration of mesopelagic fish descending during dawn and ascending during dusk. Upper panel is 18 kHz, lower panel 38 kHz showing marked frequency-specific scattering

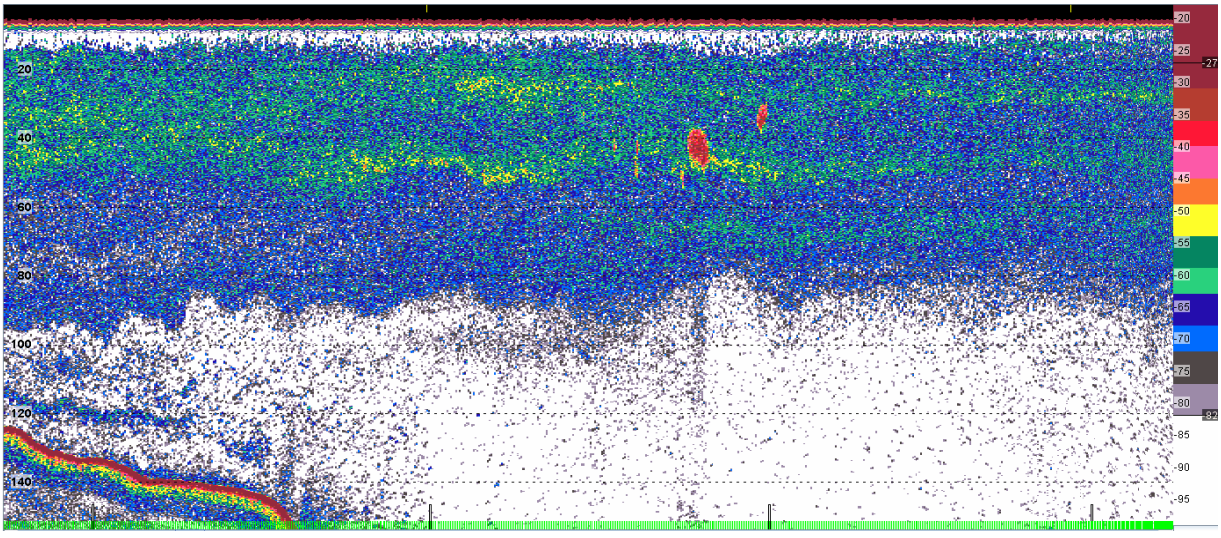

Figure 12: Example of dense clumps of myctophids off the Sindh shelf edge

The plankton-fish (PL-FI) category marks were evenly distributed over the entire survey area except for shallow inshore regions, approximately 25 m or less. The mesopelagic category (MESO) was only separate from the plankton-fish mixture at night and was included with the plankton-fish in the day. As a result the distribution of S_A classified as mesopelagic is discontinuous, depending on where the ship surveyed by day or night. In spite of this artefact, it is apparent that the mesopelagic biomass is present essentially uniformly over the offshore area. There is virtually no mesopelagic biomass on the shelf proper (<200 m water depth), day or night.

Mesopelagic biomass estimation

The scrutinized data from the three offshore strata were divided by depth zones and into day, night and the dawn/dusk intervals based on the mesopelagic species vertical migrations presented schematically in Figure 13. Approximate timing of the four periods (Table 6) was estimated by reviewing echograms to determine both timing of the migration and the depth intervals.

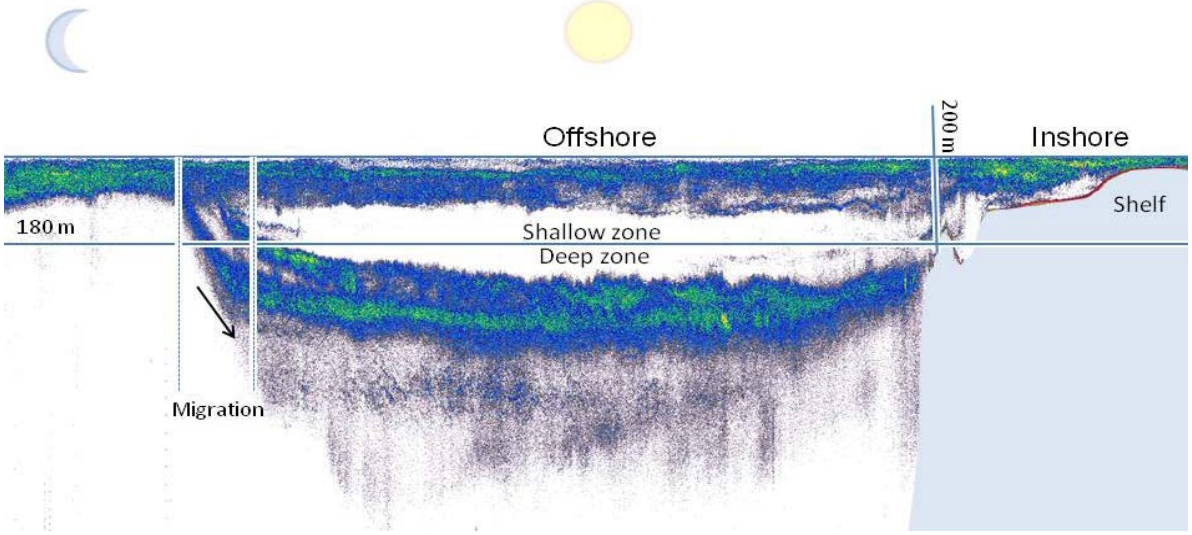

Figure 13: Post-stratification by day-night and depth for offshore strata. Inshore areas (<200 m) were not stratified by depth and day-night differences were smaller

Table 6: Timing (UTC) of day, night and migration intervals based on inspection of echograms. Local time was UTC+5 hours

Part of day	From	To	Duration	Nm
Migrates down	00:45	02:30	01:45	160
DAY	02:30	12:00	09:30	1054
Migrates up	12:00	14:00	02:00	253
NIGHT	14:00	00:45	10:45	1110
			Total	2577

For each depth zone offshore (above and below 180 m), the mean backscatter for plankton and mesopelagic fish from EK60 38 kHz were computed during daytime, night time and during the migration periods. Although the mesopelagic and plankton groups were generally acoustically indistinguishable in the night it is reasonable to assume that the actual total biomass of the two groups in the entire water column does not vary by time of day. This is apparent for daytime (MESO and PLANKTON separate) and the migration periods (groups mixed) but the mean S_A at night, when the two groups are largely mixed, is 15 percent higher. This difference may be due to changes in TS with depth.

Table 7: Mean backscattering area per track mile partitioned by depth and time of day intervals

Frequency	Depth	Area	Daytime			Migration	Nigthtime		
kHz	m		Meso	Plankton	Total	Mes/Pla	Meso	Plankton	Total
38	< 180	Offshore	2	560	562	2293	87	2642	2729
38	> 180	Offshore	1465	265	1730		0	117	117
		Total	1467	825	2292	2293	87	2759	2846

The daytime proportions of MESO in the total mean S_A (64 percent) was used to estimate the biomass of mesopelagic fish. The size-specific mean TS was -44.4299 for all species assigned to the MESO category weighted by abundance (>98 percent *Benthosema* spp.) and this was used to estimate the total number of mesopelagic fish. The mean individual weight, also weighted by numbers, of all species in the MESO category was 0.954 g which was applied to estimate biomass in t/nm^2 (Table 8).

Table 8: Estimation of mesopelagic biomass (t/nm^2) for the offshore strata

Frequency	Depth	Area	Daytime mesopelagic biomass		
kHz	m		S_A	Numbers	Biomass
38	< 180	Offshore	2	55 465	0.0529
38	> 180	Offshore	1 465	40 628 481	38.7708
Total			1 467	40 683 947	38.8238

Given the offshore stratum area of 165 847 km^2 (48 458 nm^2) the total biomass of mesopelagic fish is estimated to be 1 881 317 tonnes of which 1 846 254 tonnes would be *Benthosema* spp.

These results are more consistent with the adjusted estimate of 3 million tonnes given by Sætersdal *et al* (1999) than they are with the earlier estimates by Gjøsæter (1981) which were in the range of 5 to 8 million tonnes.

4. DEMERSAL SURVEY

Narrative

The demersal survey departed Karachi at 14.00 hourslocal time and steamed for the western part of the Makran shelf (Figure 3). Naval exercises prevented starting in the area nearest to Karachi. The Makran shelf area was surveyed first, followed by the near-shore portions of the shelf off Sindh and then the offshore portion of the Sindh shelf. The pre-selected stations for biomass estimation were all fished in daylight hours (tows starting between 06.45 and 17.45 hours local time). A subset of stations were fished twice, in the day and at night as well, to provide a data set of paired tows for day-night comparisons. These data were not used for biomass estimation.

Because of the daylight only limit on the trawl sampling for biomass estimation other sampling activities (oceanographic sampling, multibeam mapping) were concentrated in the night. As with the pelagic survey, the numerous boats and gear in the Balochistan inshore stratum limited night activities but it had less impact as the night-time sampling programme was more adaptable.

Survey effort

A total of 71 primary survey tows were completed out of a planned maximum of 95 (Figure 14, Table 9). Part of the shortfall was due to loss of a full day due to illness when two crew members had to be taken into hospital in Karachi. An additional 19 replicate tows were conducted at night on trawl locations previously sampled by day. The presence of fishing gear and boats at night limited operations, more seriously in Balochistan than in Sindh. Two nights were spent on multibeam mapping in the inner parts of the Swatch.

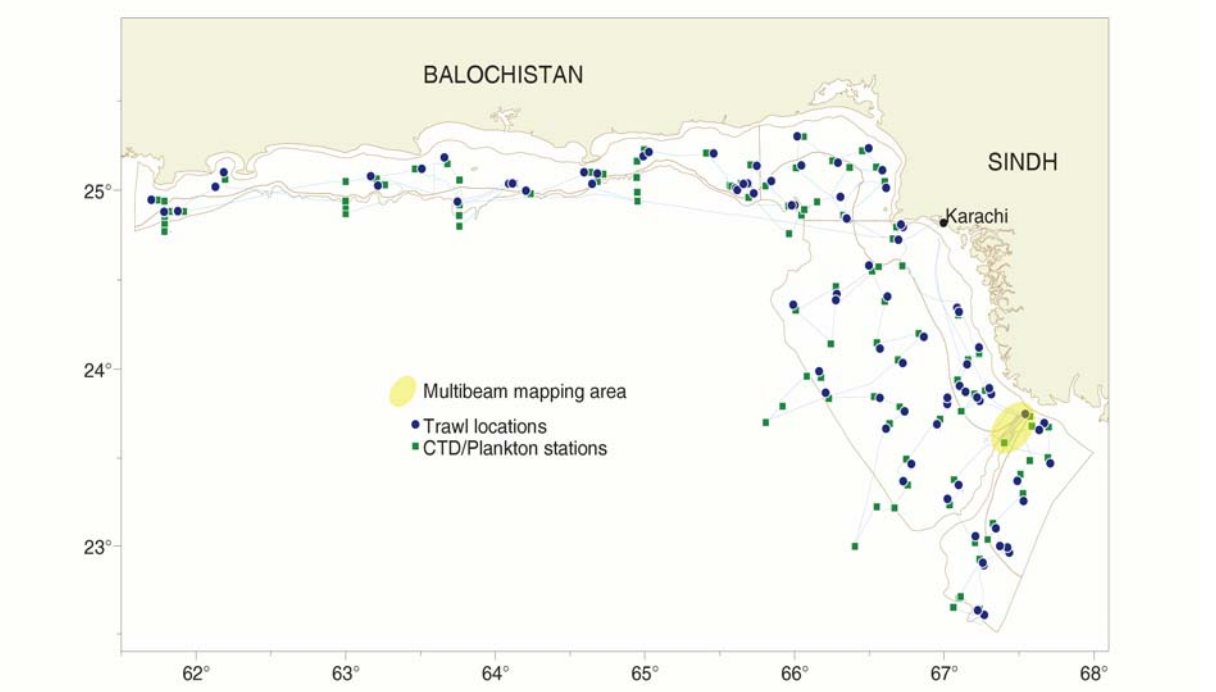

Figure 14: Cruise track and sampling locations during the 2010 demersal survey

Table 9: Demersal survey sampling effort by stratum

Area	Primary trawls	Night trawls	CTD casts	Plankton stations	Plankton samples
Makran inshore - 9103	19	3	22	4	14
Makran offshore - 9104	3	3	12	6	41
Sonmiani inshore - 9105	4	0	4		
Sonmiani offshore - 9106	6	3	9	5	24
Sindh inshore - 9107	11	3	8	1	3
Sindh offshore - 9108	16	4	24	6	33
Kori inshore - 9109	8	2	10	2	2
Kori offshore - 9110	4	1	6	2	14
Off-shelf			12	10	67
Total	71	19	107	36	198

Results

Catches from each set are included in the Nansis reporting format in Annex 4. In this case, all catches are standardized by towing time to one hour rather than distance towed. These results are summarized in the following sections.

Catch rate estimates

The mean catch per hour towing is produced by the Nansis database based on species and taxa groupings specified. These were defined based on the observed catches and taxonomic relationships for the groups of greatest interest to fisheries. The set-by-set catches for these groups are included in Annex 5. The groups defined were Carangids all species in the family *Carangidae*; Cephalopods which includes squid and cuttlefish; Clupeoids which includes *Clupeidae* and *Engraulidae*; Croakers the family *Sciaenidae*; Groupers the family *Serranidae*; Grunts the family *Haemulidae*; Scombrids the family *Scombridae*; Shrimps which includes all shrimp families, primarily *Penaeidae* and *Solenoceridae*; Soles which includes the families *Soleidae*, *Psettodidae*, *Bothidae* and *Cynoglossidae*; Threadfin breams which includes two species of Nemipterus; and all other groups are included in the category “Others”.

Stratum means and standard deviations are given in Table 10 as well as the stratified estimates of the catch rates and standard deviation for each group. Coefficients of variation are in the range 12–55 percent which is quite reasonable for demersal trawl surveys. Biomass estimates using swept area expansion are dependent on assumptions made concerning trawl catchability, *q* and the effective width of the swept area. Following the practice of previous Nansen surveys, *q* is assumed to be 1.0 and the swept area width is assumed equal to 18.5 m.

Distribution

The distribution and abundance of selected groups is given in the maps and tables in Annex 6. In each case, the standardized catches (adjusted to the standard distance of 1.75 nm) for groups of species are plotted as expanding pie charts.

Table 10: Demersal survey stratum and overall mean catch per hour with standard deviation and coefficient of variation (C.V.) and biomass estimates for selected species groupings

			Mean catch (kg) per hour											
Stratum	Weight	Stations	Carangids	Cephalopods	Clupeoids	Croakers	Groupers	Grunts	Scombrids	Shrimps	Soles	Threadfin breams	Other	Total
9103	22.19%	18	39.5	11.3	48.4	2	9	19.1	1.2	0.7	4.8	30.6	257.4	423.9
9104	4.25%	4	361	13.1	0.3	4.9	38.6		0.5	0.1	0.1	64.1	69.8	552.5
9105	6.83%	5	75.4	12.3	11	3.2	0.2	107.5	11.7		0.2	17.1	136.1	374.9
9106	4.91%	5	85.3	6.4	0.1	39.4	1.3	2.1	0.2	0.2	0.1	89.2	38.7	262.8
9107	11.11%	11	105.4	17.9	22.6	1.1	0.3	18.5	12.8	4.3	1.3	2.4	116.5	303.2
9108	35.74%	16	20.9	9.2	6.2	13.2	3.5	2.1	1	1.7	0.2	30	71.6	159.6
9109	8.92%	8	38.6	33.3	8.7	6.6	0.2	10.8	22.8	4.4	0.7	0.9	256.4	383.5
9010	6.06%	4	15.3	9.4	6	96.9	8.7		4	3.3	0.2	14.6	155.1	313.6
		Mean	57.0	13.0	17.4	14.1	5.5	15.5	5.2	1.8	1.4	27.0	142.1	300.0
			Standard deviation											
9103	22.19%	18	115.6	13.4	176.7	8.3	18.9	39.5	2.6	2.7	6.8	56.1	336.1	486.1
9104	4.25%	4	710.4	18.7	0.5	6	38.8		1.1	0.1	0.2	59.5	62	852.2
9105	6.83%	5	61.4	22.9	17.9	6.9	0.3	236.7	19.6		0.2	23.4	164.9	440.6
9106	4.91%	5	92.2	6.1	0.1	69.8	1.1	4.6	0.4	0.3	0.2	87.9	24.5	179
9107	11.11%	11	189.8	14.5	40.5	2.9	0.7	49.5	11.9	13.4	1.9	2.4	155.7	229.6
9108	35.74%	16	34.5	9.2	11	22.7	5.2	6.6	2.7	6.6	0.4	21.1	68.8	69.6
9109	8.92%	8	27.5	22.4	7.4	12	0.4	18.3	44.5	6.3	1.2	1.6	187.9	240.6
9010	6.06%	4	22.7	11.3	7.8	175.2	11.7		6	3.1	0.2	18.1	167.3	246.5
		Std.Dev	18.0	1.6	9.4	5.9	1.4	7.7	1.6	0.8	0.4	4.3	21.5	37.2
		C.V.	0.315	0.126	0.542	0.420	0.255	0.501	0.313	0.425	0.265	0.158	0.151	0.124
	Area (nm^2)		Biomass (tonnes)											
9103	2 765	18	3 124	894	3 828	158	712	1511	95	55	380	2 420	20 357	33 524
9104	529	4	5 462	198	5	74	584	0	8	2	2	970	1 056	8 360
9105	850	5	1 833	299	267	78	5	2614	284	0	5	416	3 309	9 115
9106	612	5	1 493	112	2	690	23	37	4	4	2	1 561	677	4 600
9107	1 384	11	4 172	709	895	44	12	732	507	170	51	95	4 612	12 002
9108	4 452	16	2 661	1 172	789	1 681	446	267	127	216	25	3 820	9 117	20 323
9109	1 111	8	1 227	1 058	276	210	6	343	725	140	22	29	8 148	12 187
9010	754	4	330	203	129	2 090	188	0	86	71	4	315	3 345	6 763
	12 456	Total	20 303	4 644	6 191	5 024	1 975	5 504	1 835	658	491	9 626	50 621	106 874

5. OCEANOGRAPHIC CONDITIONS

The oceanographic information collected on the two surveys (pelagic and demersal) have been combined with the offshelf areas covered in the pelagic survey (2010408) and the coastal/on shelf areas covered in the demersal survey (2010409). These two data sets have been combined to get four transects, extending from the shelf to the deep basins. They will be described as Transect A (offshore from Makran); Transect B (west of the Murray Ridge); Transect C (east of the Murray Ridge); Transect D (off Indus). Profiles from the four main CTD observations (temperature, salinity, oxygen, fluorescence) are reported here.

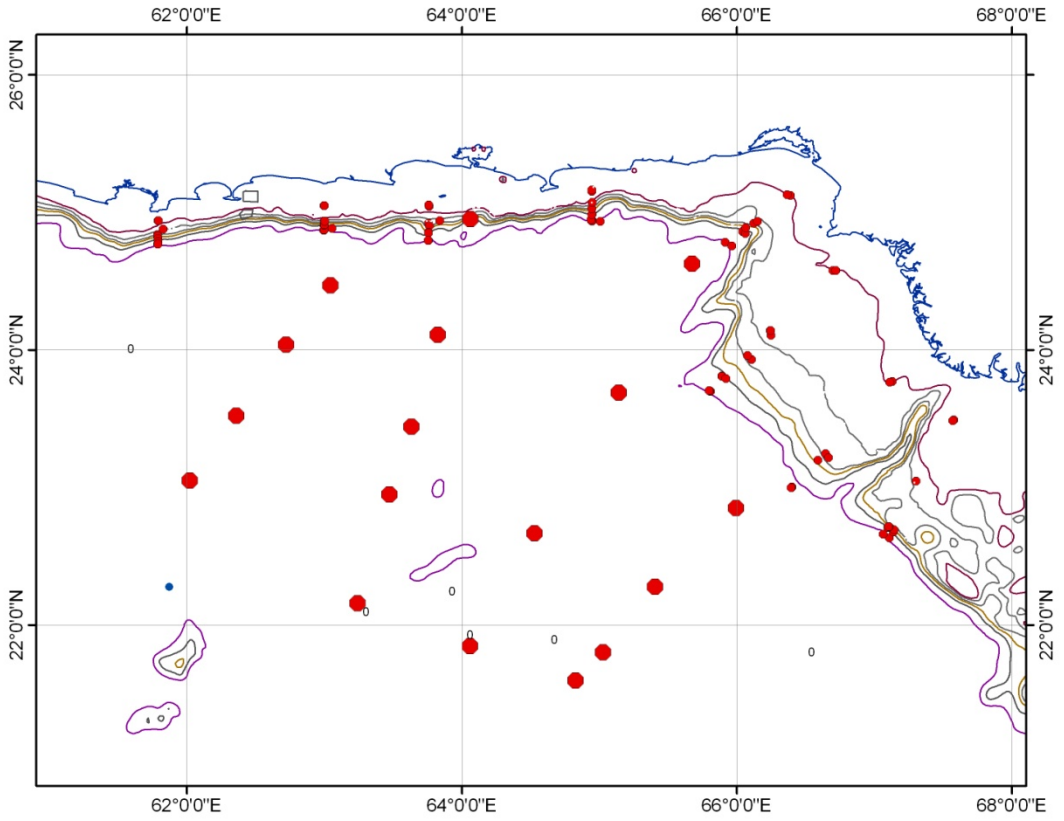

Figure 15: Oceanographic sampling stations completed as described in the results

Transect A (Shelf and deep offshore from Makran)

This westernmost area of the Pakistan coast has the narrowest shelf and steepest continental margin dropping to depths exceeding 3000 m very rapidly. The sections constructed from the four oceanographic profiles are given in Figure 16 (temperature, salinity, oxygen and fluorescence in order from top to bottom). The surface temperatures were more or less uniform and high at about 29 °C. The thermocline was observed as a sharp decline in the temperature (from 29 to 25 °C), generally around 54 m. The salinity was generally higher in the surface layers, especially closer to the shore. A low salinity area was observed at ~50–150 m depth at the outermost station. This was an interesting finding that was observed in the other transects as well, but was not so clear in the temperature profile and therefore needs further investigation. The oxygen near the surface (0–25 m) ranged between 3.90–4.49 ml L^{-1} and decreased with the depth. Low oxygen (<1 ml L^{-1}) was observed from depths between 60 and 100 m downwards. High fluorescence values were observed near the surface over and near the shelf while the Deep Chlorophyll Maximum (DCM) in the range 19–29 m depth was more pronounced in the deeper stations.

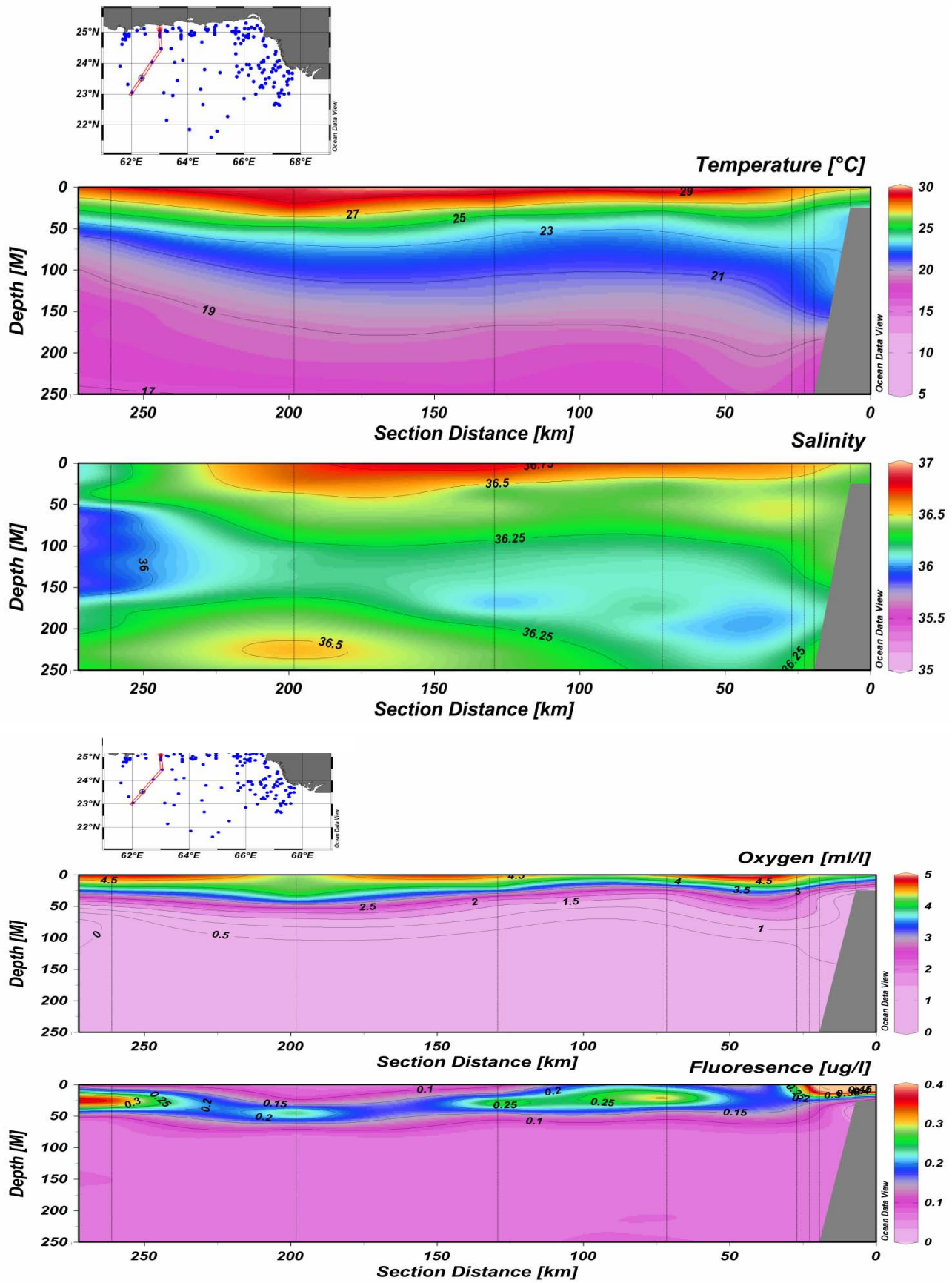

Figure 16: Oceanographic sections off Makran (Transect A)

The Murray Ridge divides the offshore Pakistan basin into two parts and the two transects B and C, run west and east of the Murray Ridge respectively.

Transect B (west of the Murray Ridge)

As with Transect A there is a narrow continental shelf and a steep continental margin in this area. The sections constructed from the four oceanographic profiles are given in Figure 17 (temperature, salinity, oxygen and fluorescence in order from top to bottom). The surface temperature ranged between 27–29 °C and the thermocline (~5 °C decrease in temperature) was observed between 23–60 m. Below the thermocline, the temperature gradually decreased to <17 °C at 250 m. The salinity was highest (~37) at the surface and the low salinity water mass at the outermost end was also observed in this transect between 100–180 m. The salinity of this water was similar to that further west which suggests that these may be an extension of the same water mass. Oxygen near the surface ranged from 4.12–4.61 ml L^{-1} and decreased to <1 ml L^{-1} at around 70 m and then declined to almost anoxic levels at 200 m. The peak fluorescence values were higher over the shelf and far offshore and lower in the intermediate areas. The DCM was shallower (~25 m) in the shelf area and deeper (~50 m) in the deep stations.

Transect C (east of the Murray Ridge)

The shelf is still relatively narrow in this area however the slope of the continental margin is more gradual. The sections constructed from the four oceanographic profiles are given in Figure 18 (temperature, salinity, oxygen and fluorescence in order from top to bottom). The surface temperature ranged between 27.5–29.5 °C. The thermocline was observed between at 30 m (29 °C) and 50 m (24.78 °C), below which the temperature gradually declined to 14 °C at 250 m. This section had generally higher surface temperatures with no strong differences between the shelf and offshore areas. Temperatures were somewhat lower in the deeper water. The surface salinity ranged between 36.4 and 37. The low salinity water mass observed at about 125 m depth in the outermost parts of the two western sections extends much closer to the continental shelf where a second low salinity (~36) water mass overlay the continental slope at about 200 m depth. Oxygen near the surface (0–50 m) ranged between 4.0 and 4.5 ml L^{-1} with little variation from the continental shelf edge outwards. Low oxygen levels (<1 ml L^{-1}) were found below 100 m depth across the entire section. The DCM varied between 30 and 50 m over deep waters and was shallower near the shelf edge and over the shelf. Fluorescence was more intense in the deep areas.

Transect D (off Indus)

The shelf is widest in this area and the slope of the continental margin is quite gradual. The sections constructed from the four oceanographic profiles are given in Figure 19 (temperature, salinity, oxygen and fluorescence in order from top to bottom). The temperature generally increased from the shelf to the offshore stations ranging between 25 and 29 °C. In deep waters, the thermocline was relatively uniform between 25 and 50 m but was much weaker over the continental slope and shelf.. The salinity generally ranged between 36.5 and 38 although a low salinity water mass was observed between 100–200 m near the continental margin. This may reflect low temperature water sinking to the same low salinity water mass observed to the west and further diluting the salinity to ~35, a decrease of ~2 units. Patches of low salinity water were also seen at the surface over the shelf and at about 200 km offshore. These various low salinity observations may all be linked to the recent floods in Pakistan and resulting peak in fresh water outflow through the Indus. This area is of particular interest with reference to the oxygen minimum zone in the Pakistan waters. The oxygen concentrations over the shelf were less than 4 ml L^{-1} and on the bottom it was below 3 ml L^{-1}. Low oxygen (<1 ml L^{-1}) was observed below 65–100 m. The DCM was observed at 40–50 m in the offshelf area. However, over the shelf productivity was very high at the surface corresponding to the slug of low temperature, low salinity water perhaps linked to the influx of floodwaters entering from the Indus creek system.

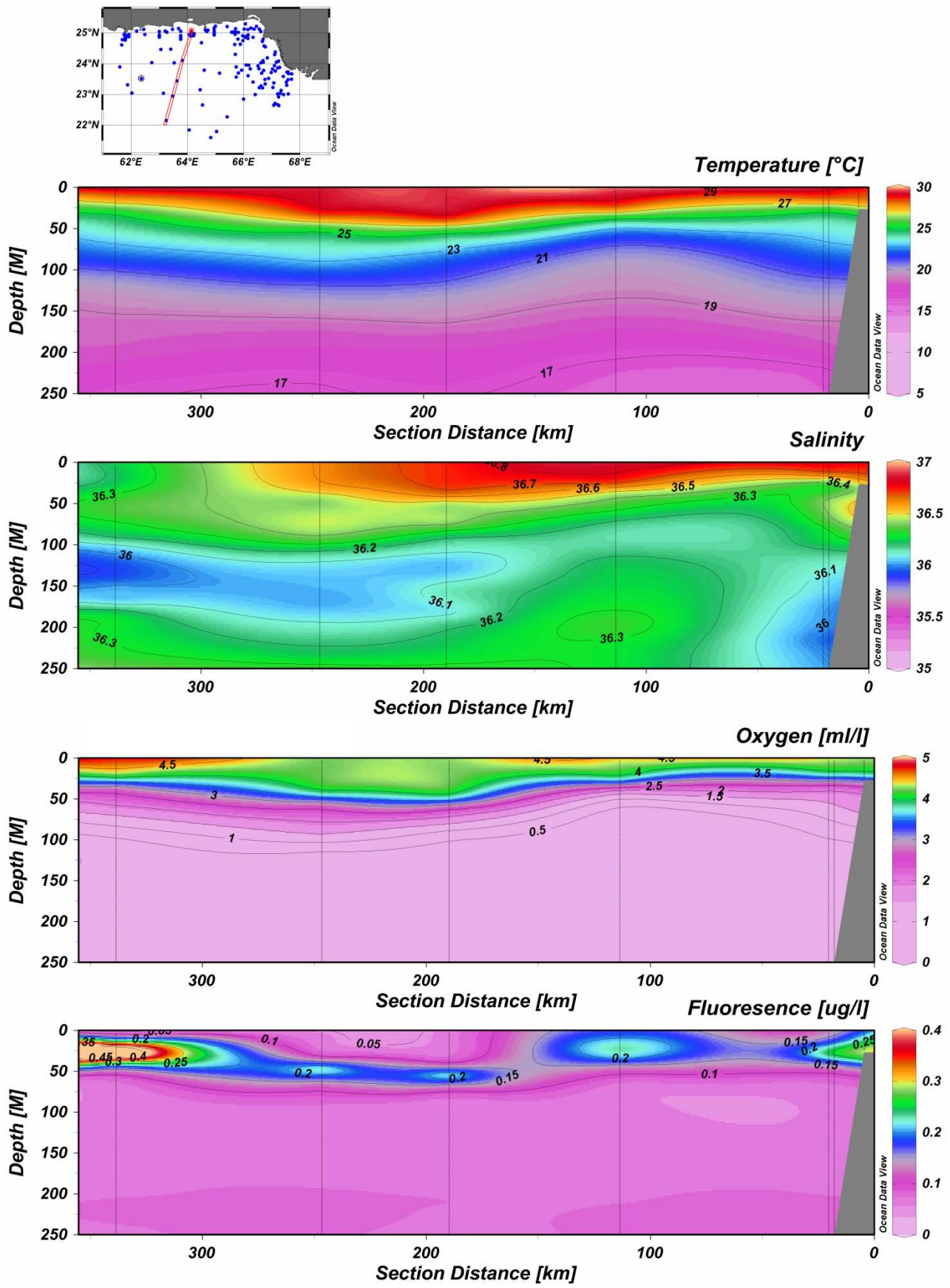

Figure 17: Oceanographic sections west of Murray Ridge (Transect B)

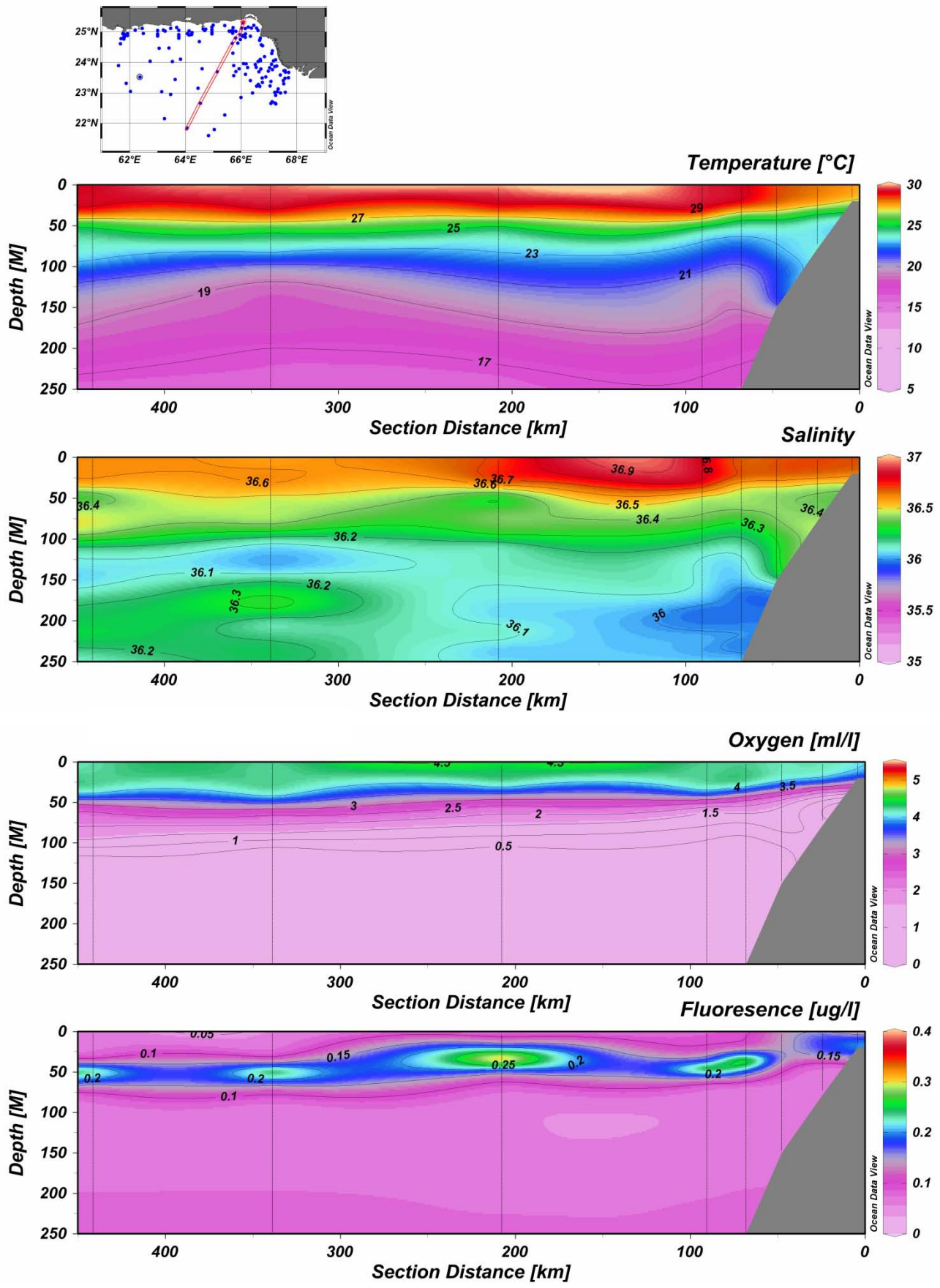

Figure 18: Oceanographic sections east of Murray Ridge (Transect C)

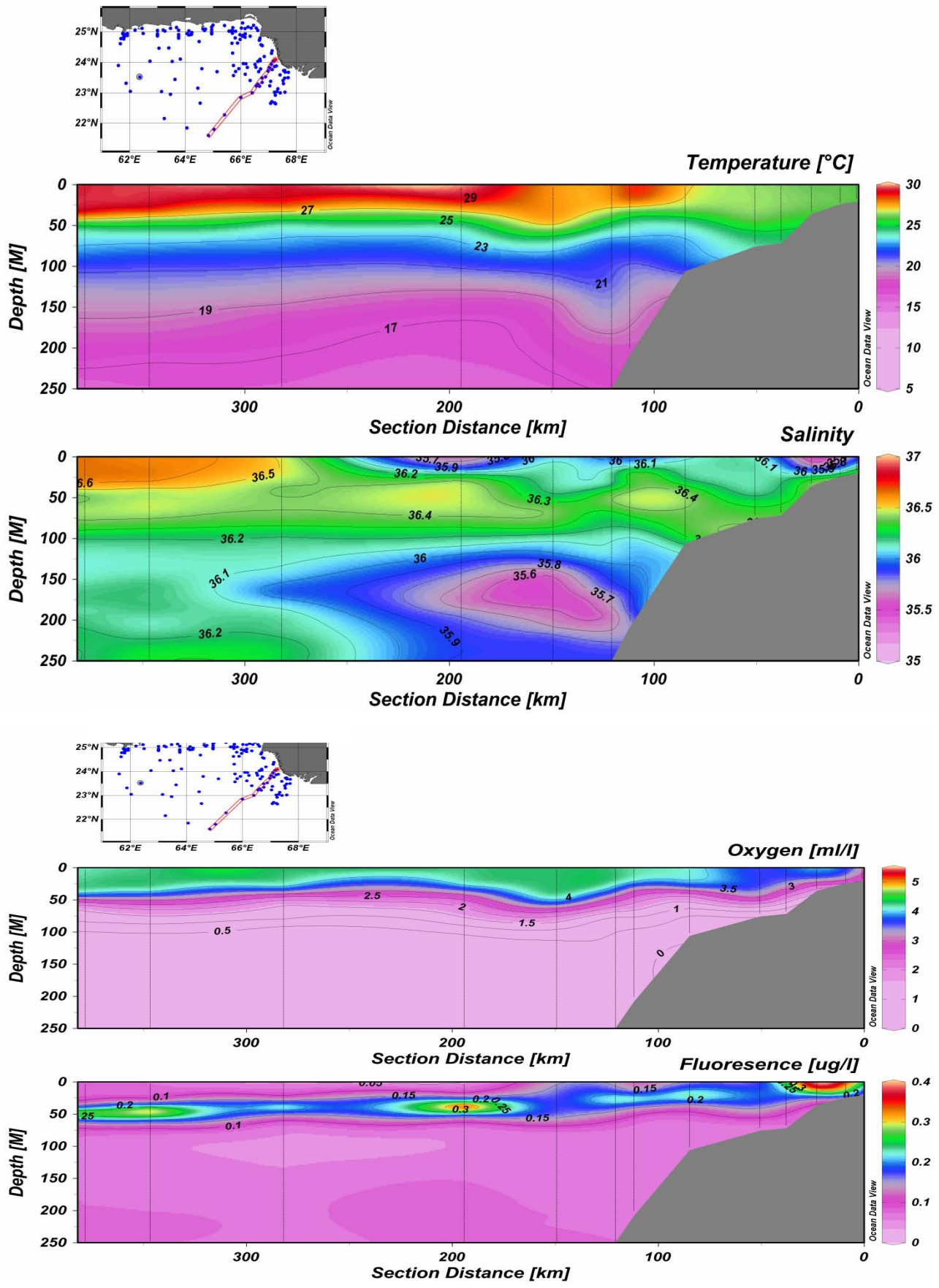

Figure 19: Oceanographic sections off Indus (Transect D)

6. MULTIBEAM BATHYMETRY

Multibeam bathymetry data were collected whenever the water depth was less than approximately 1 400 m throughout both surveys using the Kongsberg EM710 echosounder. When depths exceeded 1 400 m, the single beam bottom track was recorded from the ER60. In addition to the tracks covered during the course of the fisheries survey operations, there were two blocks of dedicated bottom surveying using the multibeam system one block on each survey leg.

During the pelagic survey (2010408), the pre-selected block west of the Murray Ridge was found to be almost entirely below 1 400 m, the effective depth limit for data quality reasons. An alternative area on the central seamounts of the Murray Ridge was selected and surveyed.

On the demersal survey, the selected area was surveyed although the shallow water meant the swath width was quite narrow and because of time constraints the survey was only able to cover a relatively small area. Effort was concentrated on the central canyon and high relief portions of the block.

Post-processing using OLEX removed spurious data and provided both shaded 3D and contoured visualization of the multibeam data. Sample OLEX results for the Indus Swatch area are shown in 3D and contoured format in Figure 20 left and right respectively.

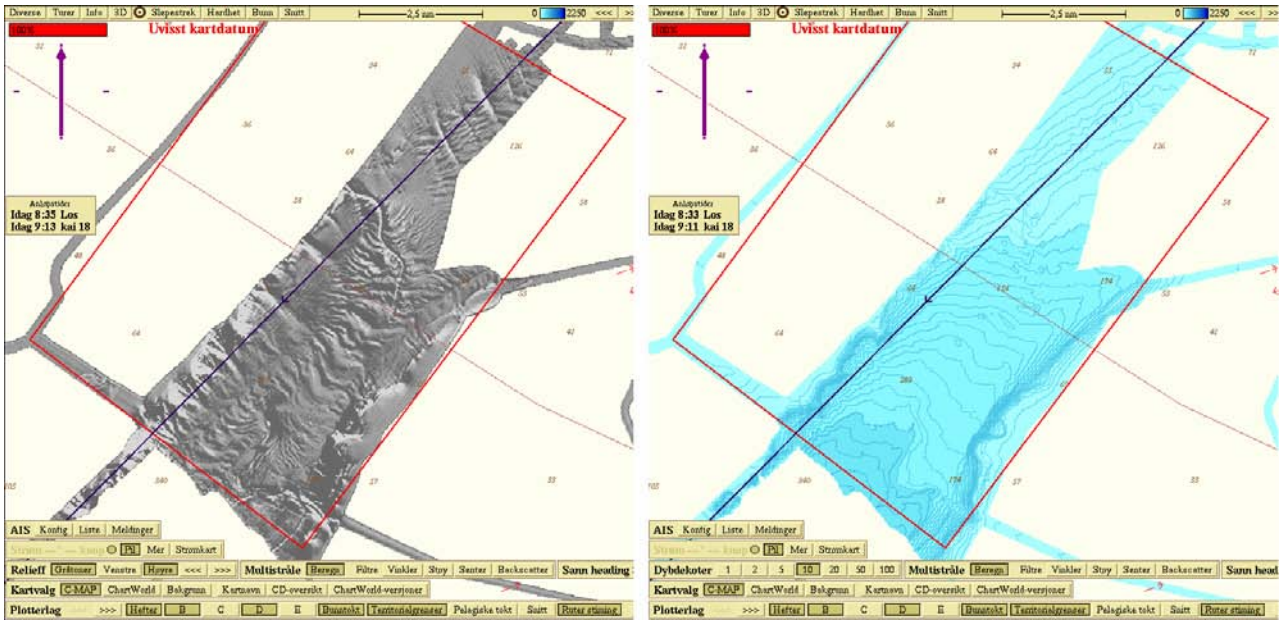

Figure 20: OLEX visualizations of multibeam survey of the Swatch in shaded 3D (left) and contours (right)

The resulting XYZ dataset (ASCII format file of longitude, latitude and depth) is over 800 Gb in compressed format. These data are held at the NIO National Oceanographic Data Centre. Incorporation of these data with pre-existing multibeam survey data will extend the overall bathymetric coverage of Pakistan's shelf.

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