2.3 Results

2.3.1 Water temperature, salinity[1] and σ_t

Figure 2.3 shows the horizontal distribution of water temperature and salinity, and also of σ_t observed at 2 m below surface. Figure 2.4 illustrates vertical section distribution in the north-south direction at around 50-200 m water depth (see Figure 2.1), and Figure 2.5 shows vertical profile at each observation station divided into north, central and south areas, and coastal and offshore areas (cut-off boundary: 20m water depth).

The results obtained from each observation period are summarized below. A general view of the oceanic environment integrated these results are described in section 2.4.2 with referring to existing reports.

<Phase 1 cold season>

- **Variation**
  - Water temperature : 10.4 - 22.4°C
  - Salinity : 35.3 - 39.2
  - σ_t : 25.3 - 27.3
- **Horizontal distribution at 2m below surface (see Fig. 2.3)**
  - Water temperature: High in the Northern coastal area. Low in the offshore west of Cape Blanc and offshore south of Cape Timiris.
  - Salinity : High in the Northern coastal area.
  - σ_t : Ditto.
- **Vertical section distribution in the north-south direction (see Fig. 2.4)**
  - Water temperature: High at surface in the Southern area, but homogeneous as a whole.
  - Salinity : High at surface in the Northern area, but homogeneous as a whole.
  - σ_t : Ditto.
- **Vertical profile (see Fig. 2.5)**
  - Water temperature, salinity and σ_t show a slight gradient from surface to bottom.

<Phase 1 warm season>

- **Variation**
  - Water temperature : 10.6 - 29.9°C
  - Salinity : 34.6 - 39.7
  - σ_t : 22.1 - 27.1
- **Horizontal distribution at 2m below surface (see Fig. 2.3)**
  - Water temperature : High in south of Cape Timiris. Low in the offshore west of Cape Blanc. Off the Cape Timiris, the tropical front where water temperature ranged between 22 and 24°C was clearly observed.
  - Salinity : High in the Northern and Central coastal areas.
  - σ_t : High in the Northern coastal area. Low in south of Cape Timiris.

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[1] Practical salinity without a unit defined by specific conductivity – PSU (Practical Salinity Unit).

- **Vertical section distribution in the north-south direction (see Fig. 2.4)**

  Water temperature : High (over 24°C) in the water column less than 50m deep in south, progressively cooling and thinning from south to north.

  Salinity : Slightly low in the water column less than 50m deep.

  σ_t : Low (under 25) in the water column less than 50m deep in south, progressively increasing and thinning from south to north.

- **Vertical profile (see Fig. 2.5)**

  Water temperature : A thermocline exists at around 50m deep in offshore, with a gradient increasing southwards. Difference between the upper and lower layers of thermocline is around 15°C. High from surface to bottom in the coastal area.

  Salinity : A slight gradient of less than 0.5 from surface to bottom in all areas.

  σ_t : A pycnocline exists at around 50m deep in offshore, with gradient increasing southward. Low from surface to bottom in the coastal area.

<Phase 2 *cold season*>

- **Variation**

  Water temperature : 12.0 - 22.8°C

  Salinity : 35.1 - 39.9

  σ_t : 24.5 - 27.2

- **Horizontal distribution at 2m below surface (see Fig. 2.3)**

  Water temperature : High in the Northern coastal area. Low in the offshore west of Cape Blanc and offshore south of Cape Timiris.

  Salinity : High in the Northern and Central coastal areas.

  σ_t : High in the Northern area. Low in and around the Banc d'Arguin and in the offshore of the Southern area.

- **Vertical section distribution in the north-south direction (see Fig. 2.4)**

  Water temperature : High at surface in the Southern area, but homogeneous as a whole.

  Salinity : High at surface in the Northern area, but homogeneous as a whole. Low at surface around 18°30'N.

  σ_t : High at surface in the Northern area, but homogeneous as a whole.

- **Vertical profile (see Fig. 2.5)**

  Water temperature, salinity and σ_t show a slight gradient from surface to bottom. But thermocline and pycnocline existed at different depths in the Southern area.

<Phase 2 warm season>

- **Variation**

  Water temperature : 10.7 - 30.0°C

  Salinity : 34.2 - 40.2

  σ_t : 21.5 - 27.3

- **Horizontal distribution at 2m below surface (see Fig. 2.3)**

  Water temperature : High in south of Cape Timiris. Low in the offshore west of Cape Blanc. Off the Cape Timiris, the tropical front where water temperature ranged between 22 and 24°C was clearly observed.

Salinity	:	High in the Northern and Central coastal areas.
σ_t	:	High in the Northern coastal area. Low in south of Cape Timiris. Lower in the Southern coastal area.

- **Vertical section distribution in the north-south direction (see Fig. 2.4)**

Water temperature	:	High (over 24°C) in the water column less than 50m deep in south, progressively cooling from south to north.
Salinity	:	Slightly low in the water column less than 50m deep.
σ_t	:	Low (under 25) in the water column less than 50m deep in south, progressively increasing northward.

- **Vertical profile (see Fig. 2.5)**

Water temperature	:	A thermocline exists at around 50m deep in offshore, with a gradient increasing southwards. Difference between the upper and lower layers of thermocline is around 15°C. High from surface to bottom in the coastal area.
Salinity	:	A slight gradient of less than 0.5 from surface to bottom in all areas.
σ_t	:	A pycnocline exists at around 50m deep in offshore, with gradient increasing southward. Low from surface to bottom in the coastal area.

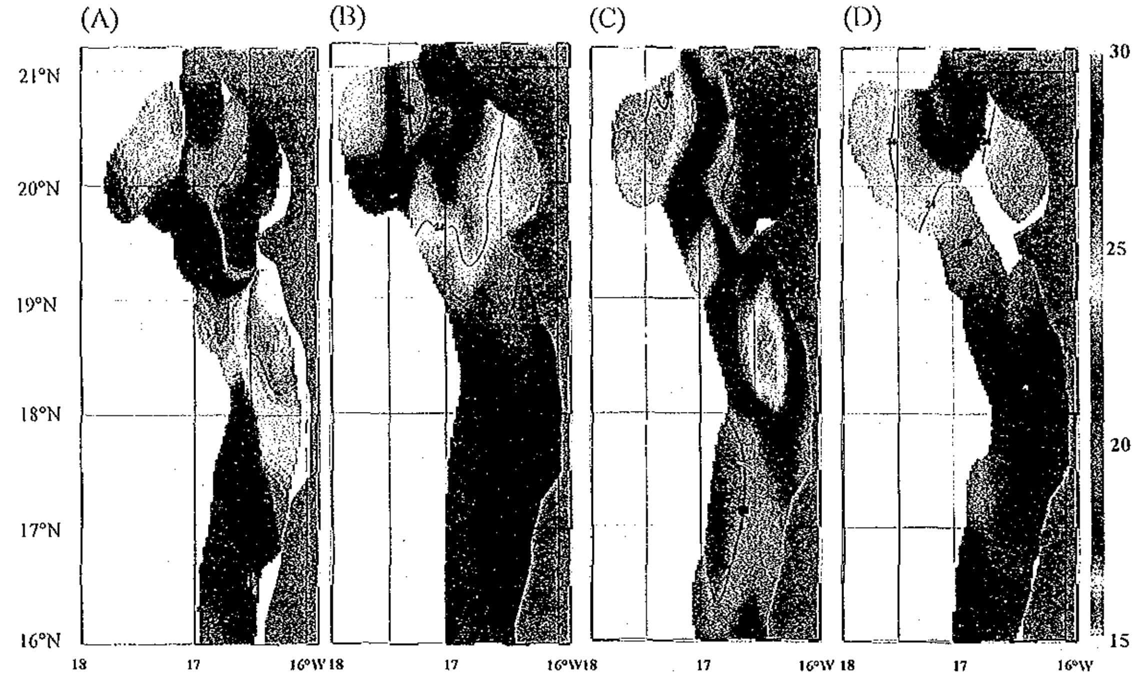
2.3.2 Water current direction and velocity

Figure 2.6 shows the horizontal distribution of water current vectors at 4 m below surface during the observation period, and Figure 2.7 illustrates the distribution of frequency of the water current direction.

As indicated by Figure 2.6, velocity at upper layer (4 m below surface) was 0–67 cm/s, without much variation between cold and warm seasons. Although great differences in current direction happened as tide varied according to observation time, in the Northern area, fast currents of 40–65 cm/s in the inshore-offshore direction (southwest to northwest) were observed next to the region over the continental slope. In addition, northward currents of a top velocity of around 50 cm/s were observed flowing parallel to the coastline in the Southern area, around 16 - 17° N.

As for the frequency of the current direction by layer in Figure 2.7, in the Northern area, except for the Phase 1 warm season, the frequency of west or southwest currents was high in the upper layer, and it of north current increased with depth. Also, the Phase 1 warm season showed a trend for southwest currents in all layers. In the Central area, many currents between south and west were observed in the cold season, as well as northwest currents in the upper layer; there were also many north currents in the bottom layer (about 70% of the water depth) in the warm season. In the Southern area, north currents were numerous, regardless of observation season or layer.

Temperature (°C)



Salinity (psu)

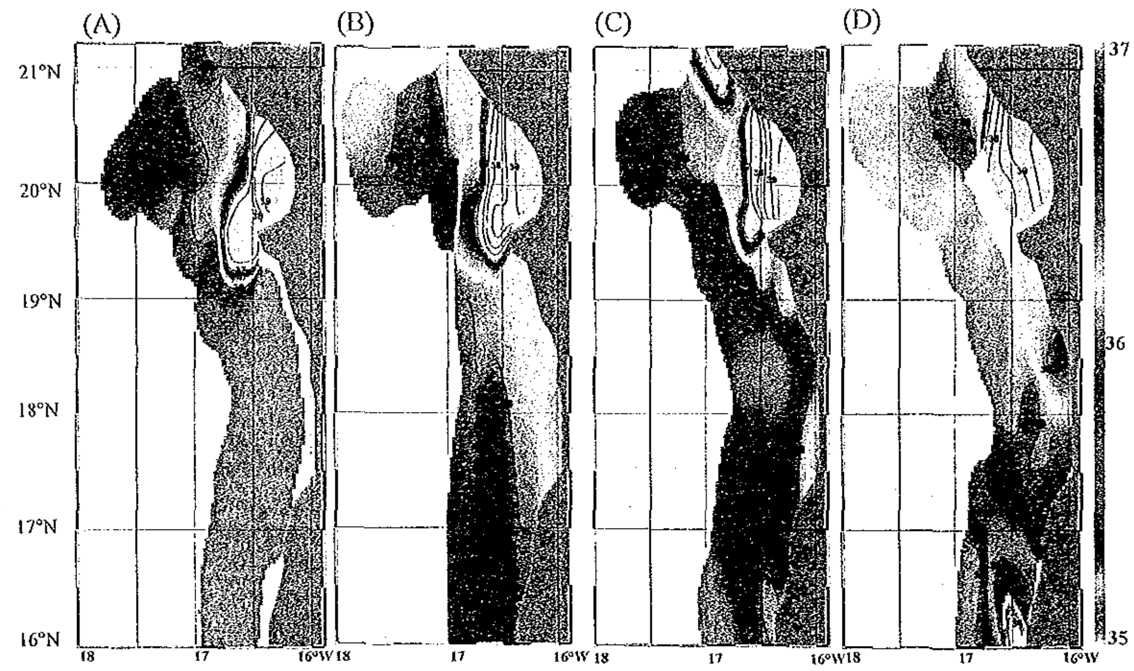
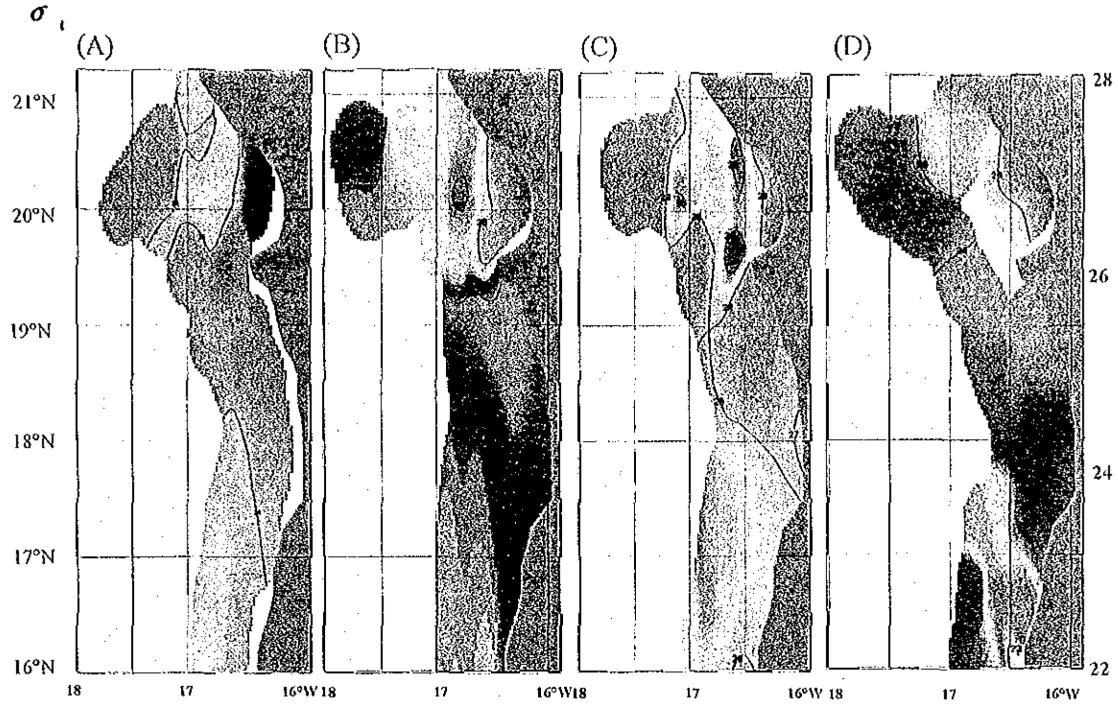


Figure 2.3 Horizontal distribution of water temperature, salinity and σ_t at 2 m below surface.
(A) Phase 1 cold season; (B) Phase 1 warm season; (C) Phase 2 cold season; (D) Phase 2 warm season.

Figure 2.3 continued



Temperature (°C)

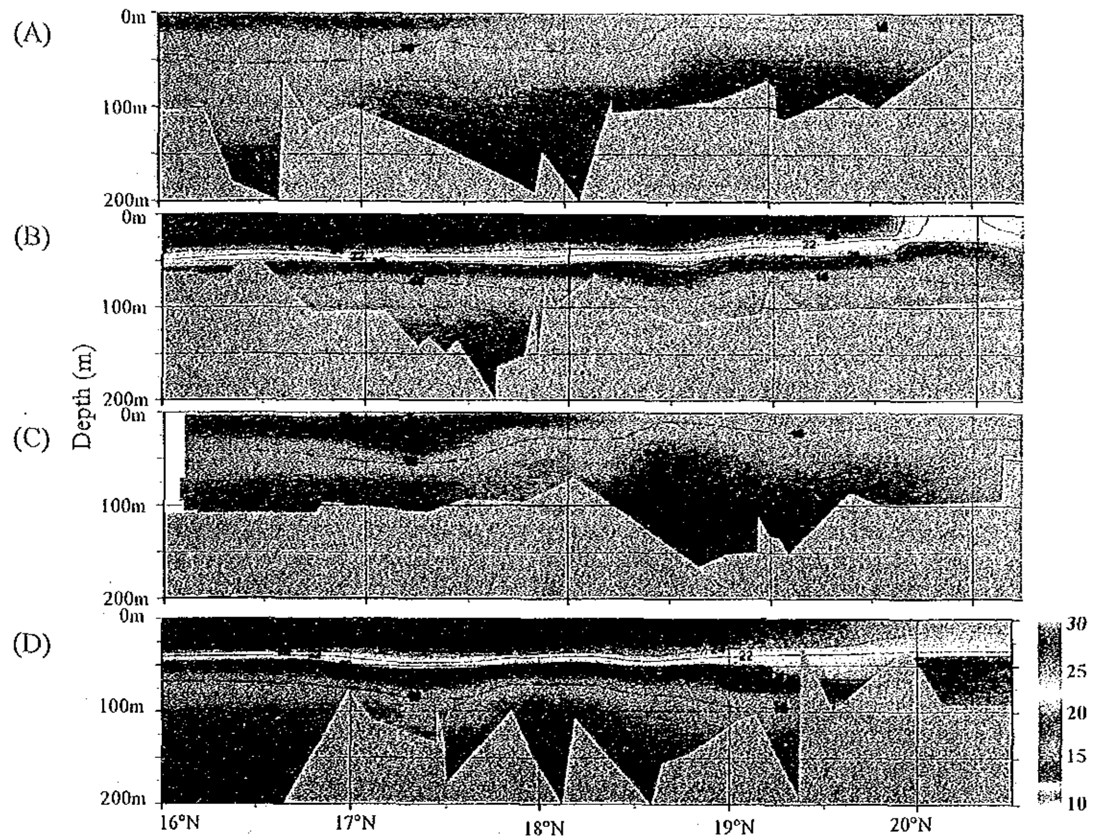
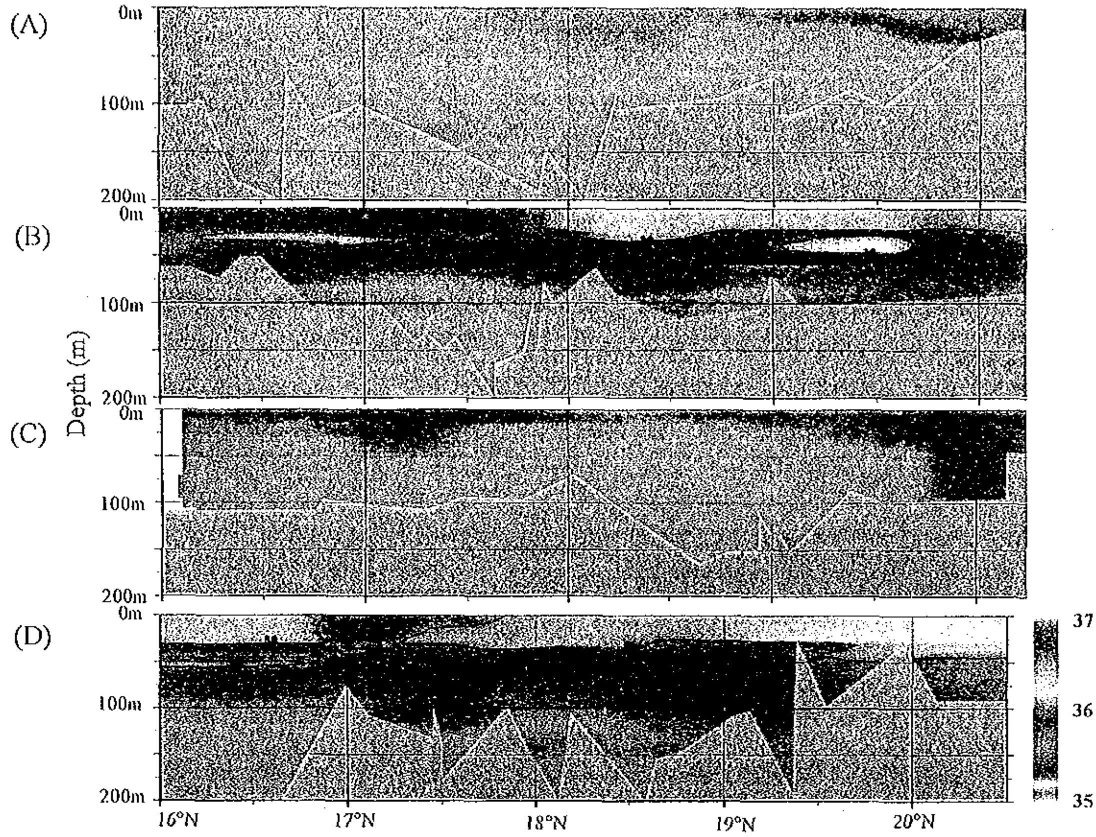


Figure 2.4 Vertical section distribution of water temperature, salinity and σ_t in the north-south direction at around 50-200 m water depth.

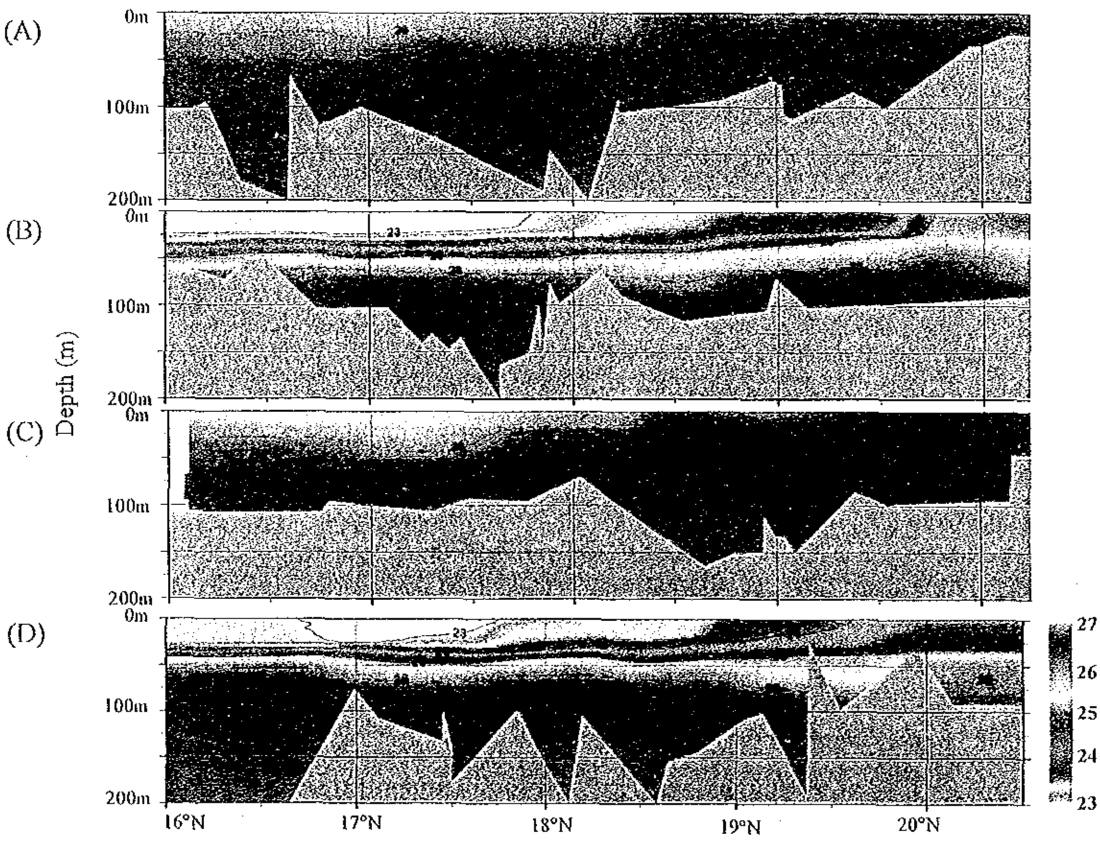
(A) Phase 1 cold season; (B) Phase 1 warm season; (C) Phase 2 cold season; (D) Phase 2 warm season.

Figure 2.4 continued

Salinity (psu)



σ_t



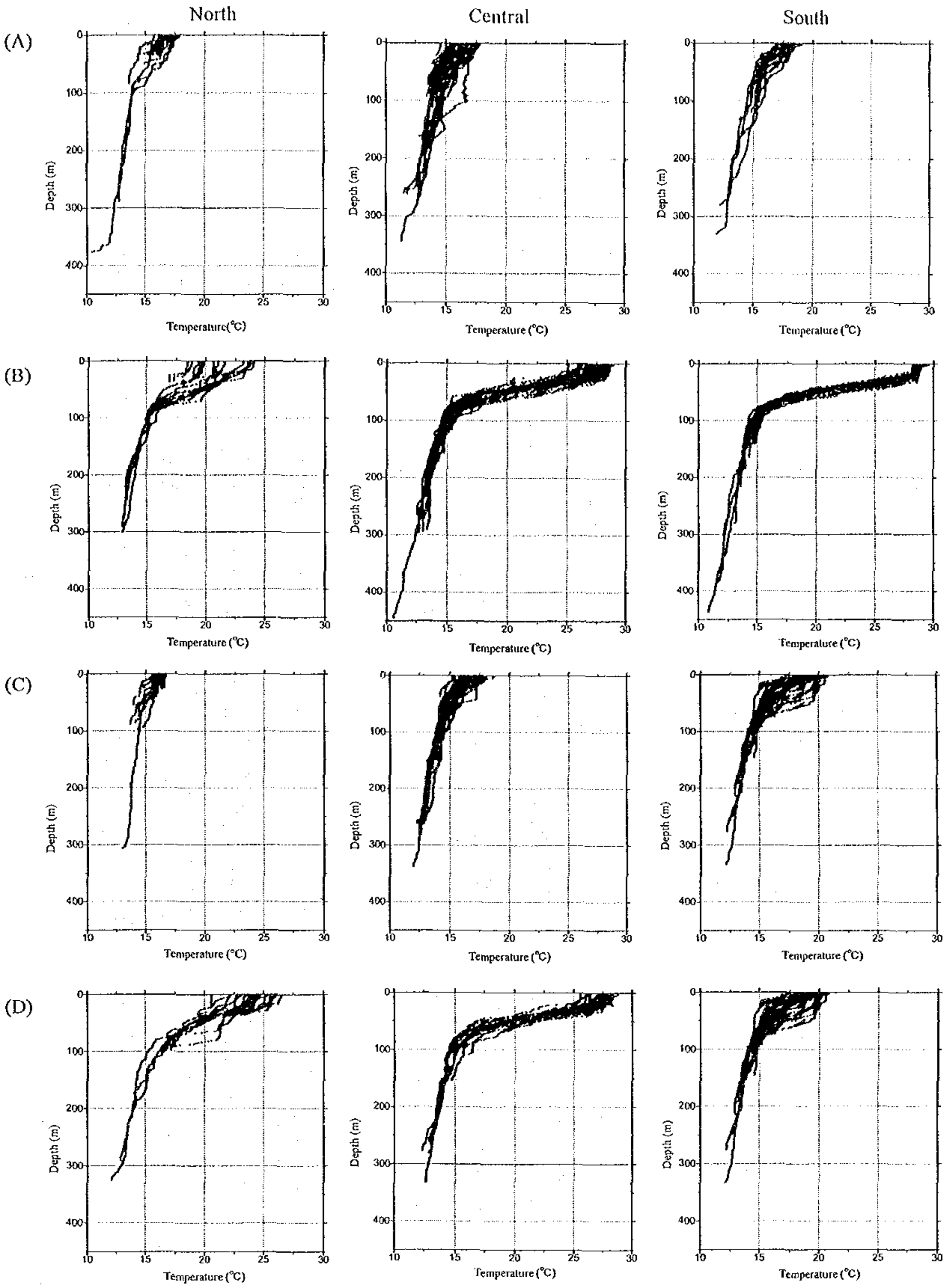


Figure 2.5.1 Vertical profiles of water temperature in offshore area by observation period and by subarea.

(A) Phase 1 cold season; (B) Phase 1 warm season; (C) Phase 2 cold season; (D) Phase 2 warm season.

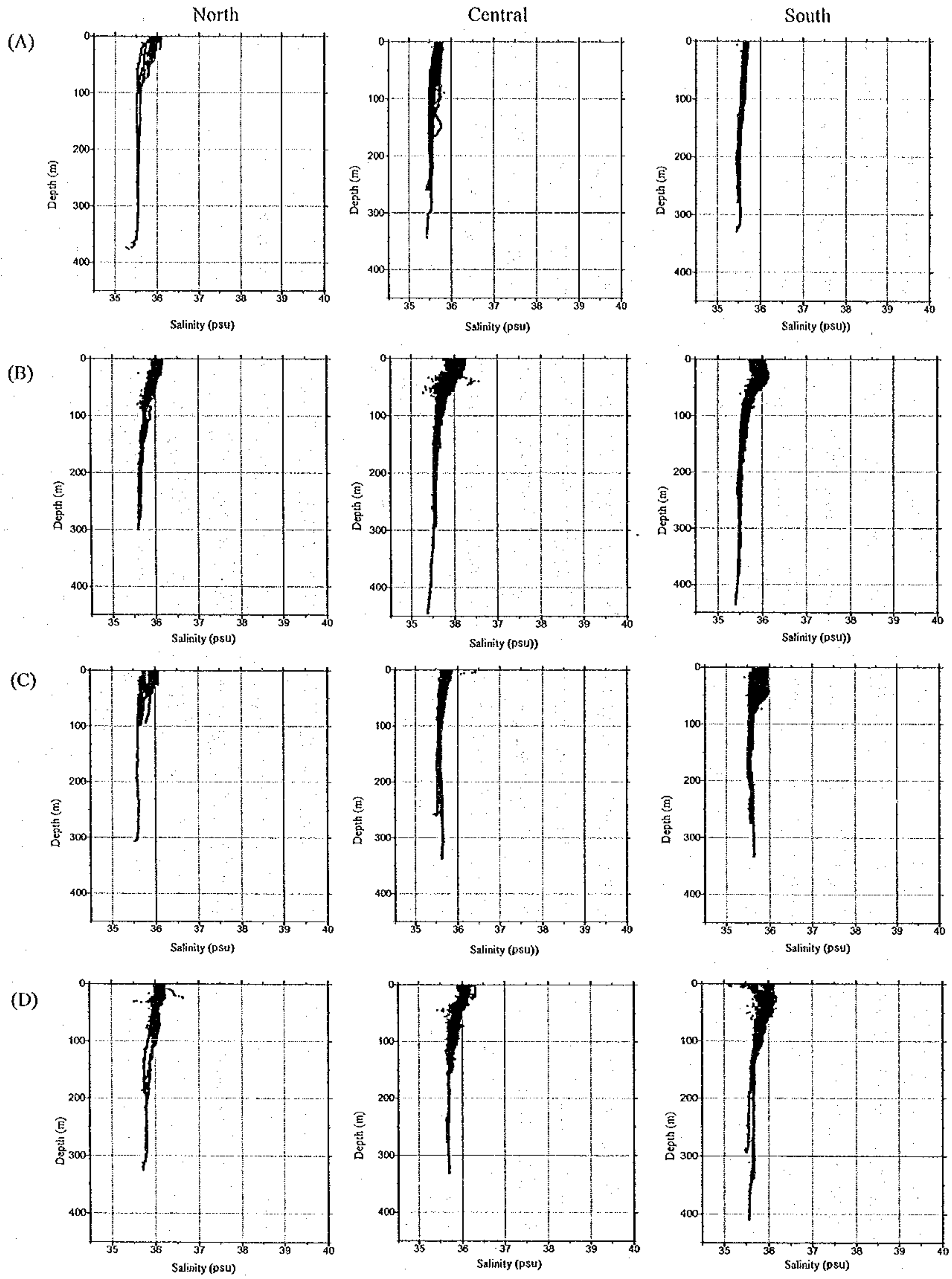


Figure 2.5.2 Vertical profiles of salinity in offshore area by observation period and by subarea .
(A) Phase 1 cold season; (B) Phase 1 warm season; (C) Phase 2 cold season; (D) Phase 2 warm season.

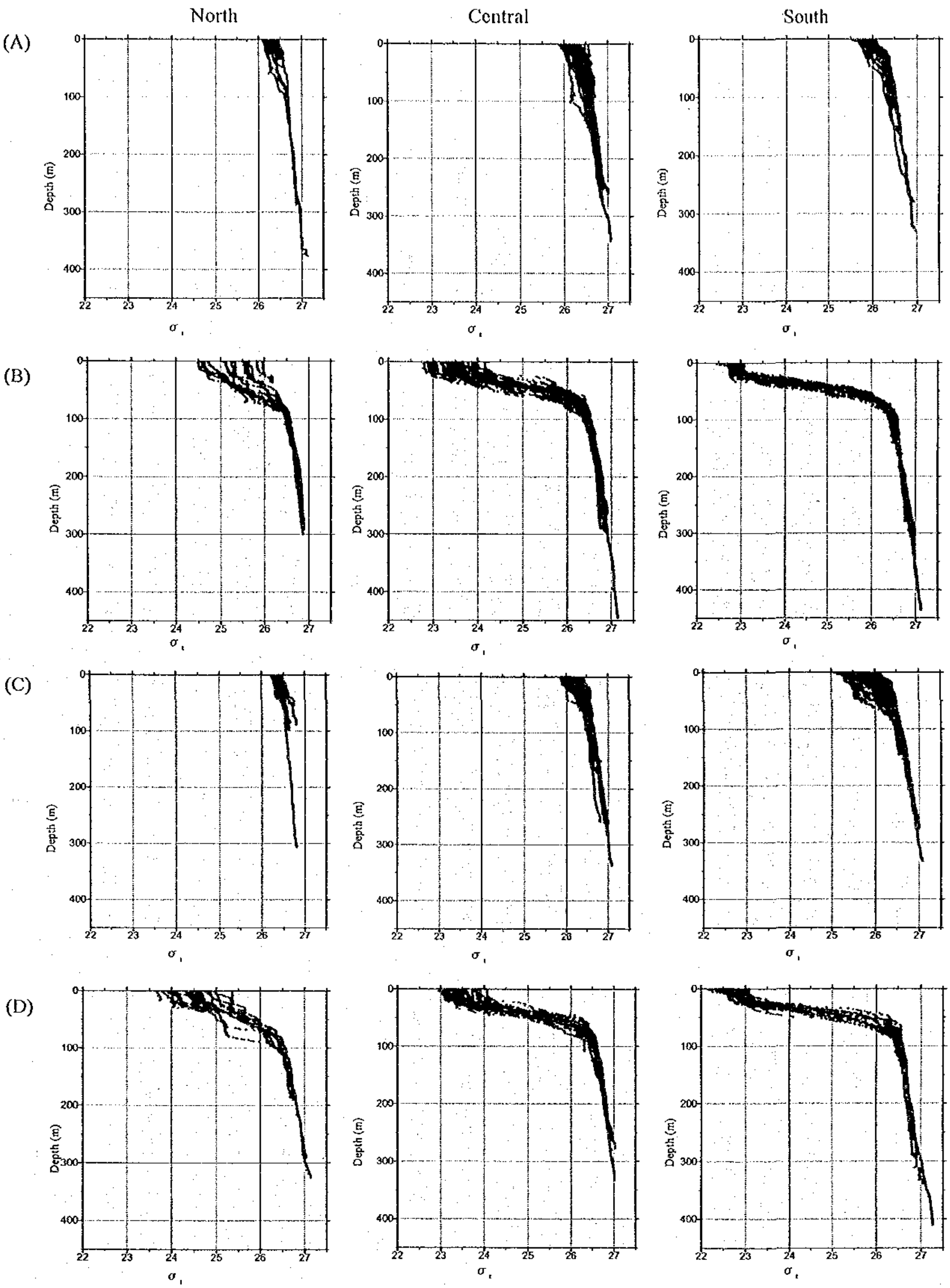


Figure 2.5.3 Vertical profiles of σ_t in offshore area by observation period and by subarea.

(A) Phase 1 cold season; (B) Phase 1 warm season; (C) Phase 2 cold season; (D) Phase 2 warm season.

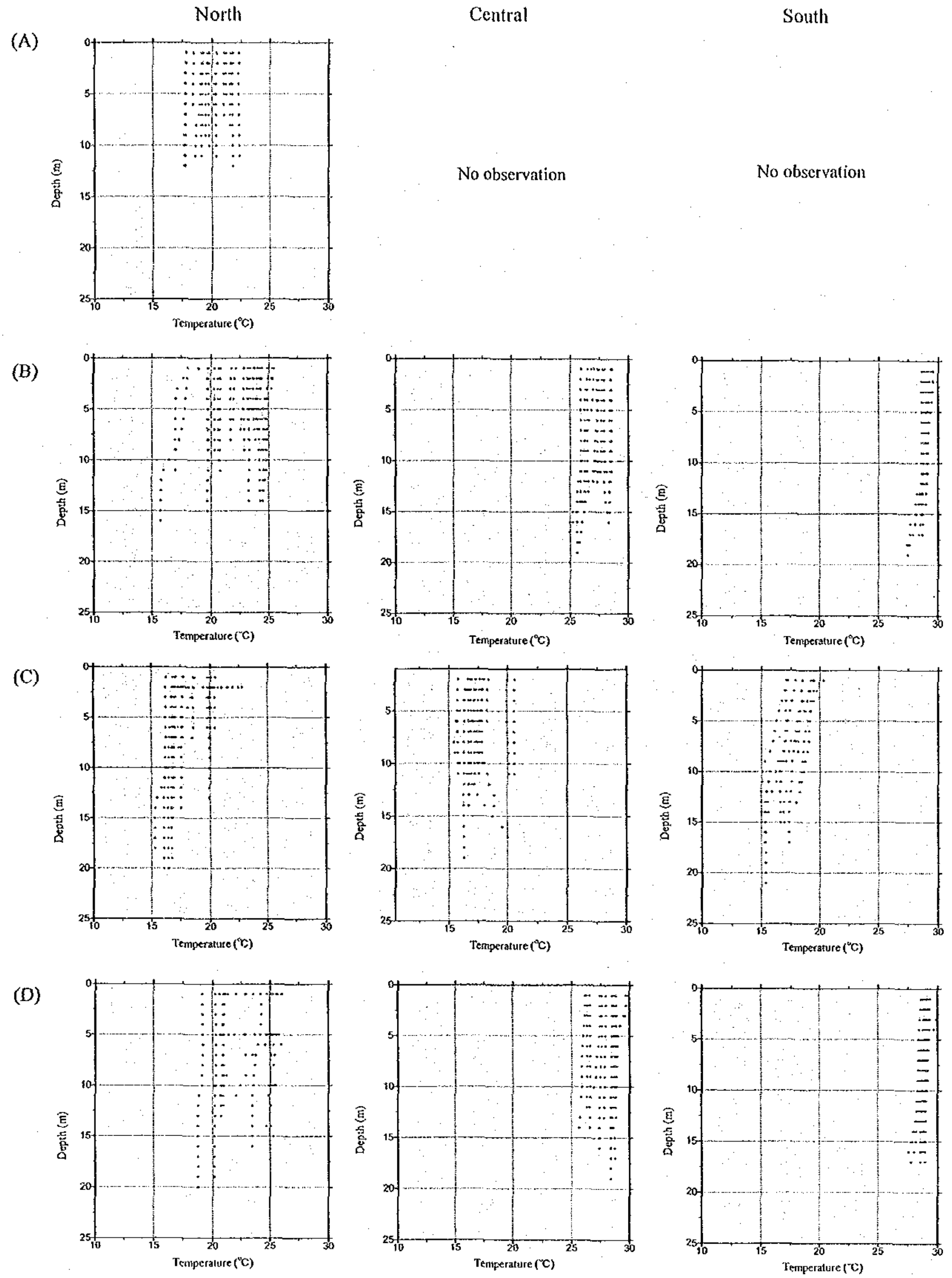


Figure 2.5.4 Vertical profiles of water temperature in coastal area by observation period and by subarea.

(A) Phase 1 cold season; (B) Phase 1 warm season; (C) Phase 2 cold season; (D) Phase 2 warm season.

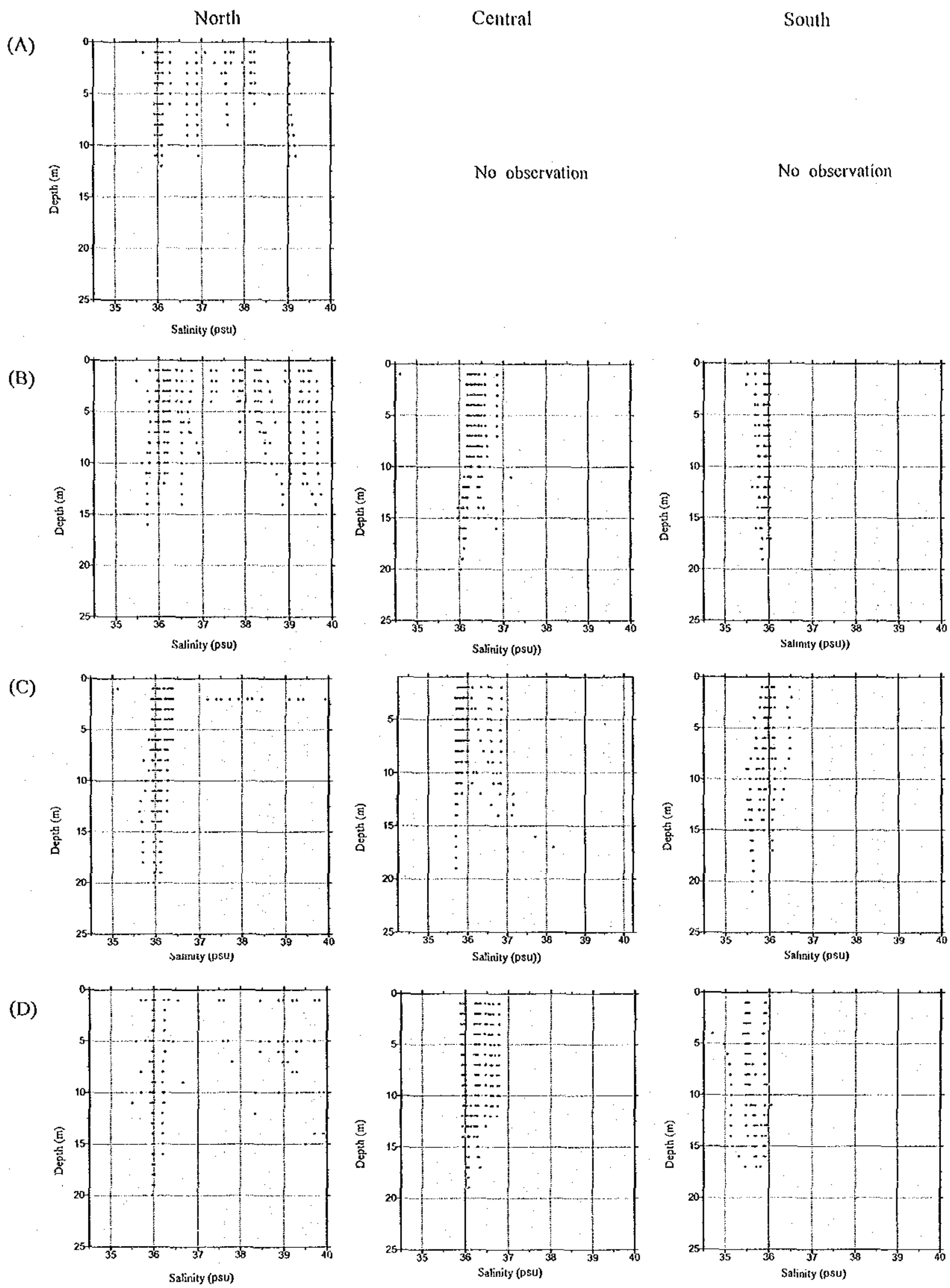


Figure 2.5.5 Vertical profiles of salinity in coastal area by observation period and by subarea .
(A) Phase 1 cold season; (B) Phase 1 warm season; (C) Phase 2 cold season; (D) Phase 2 warm season.

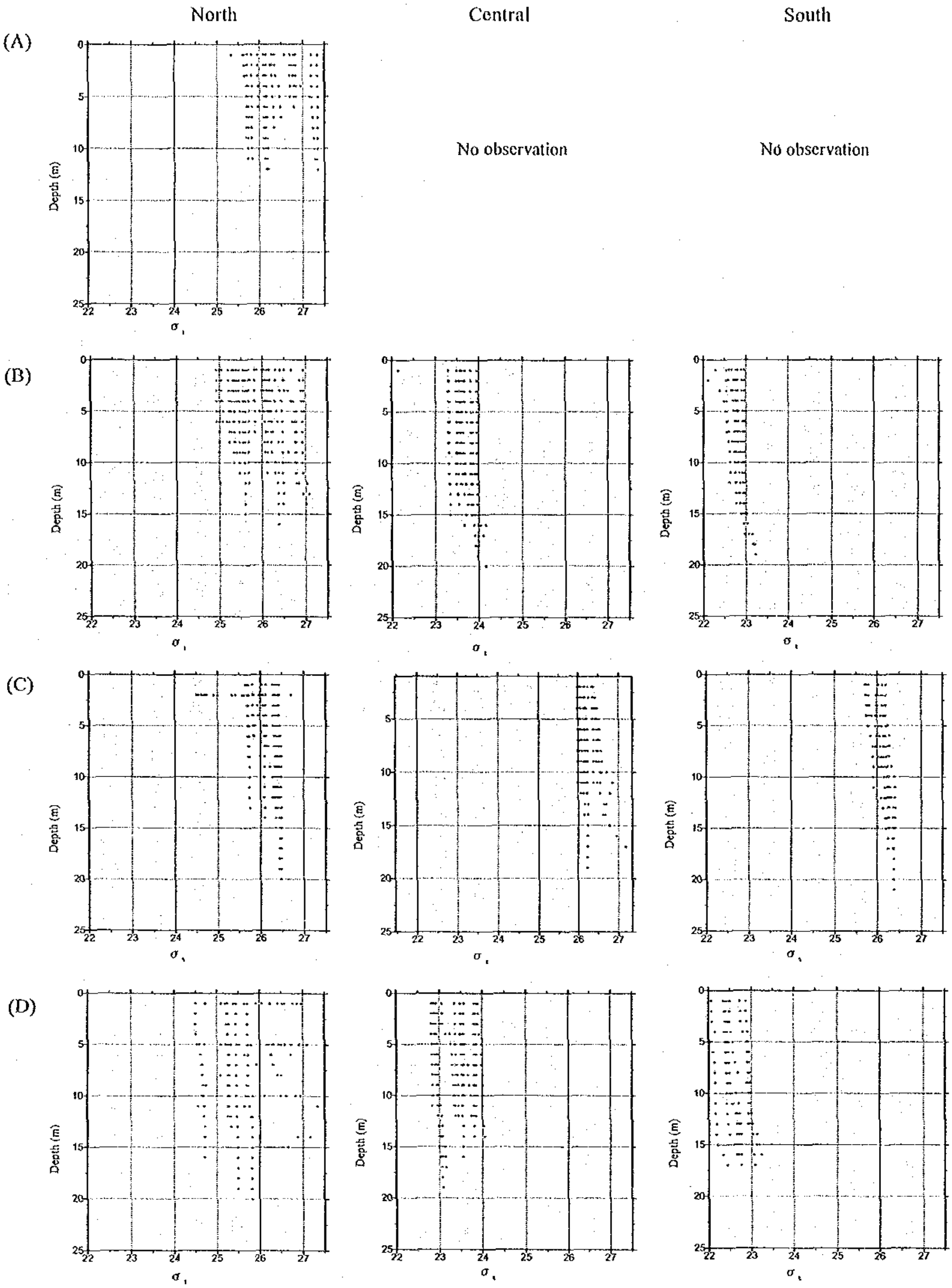
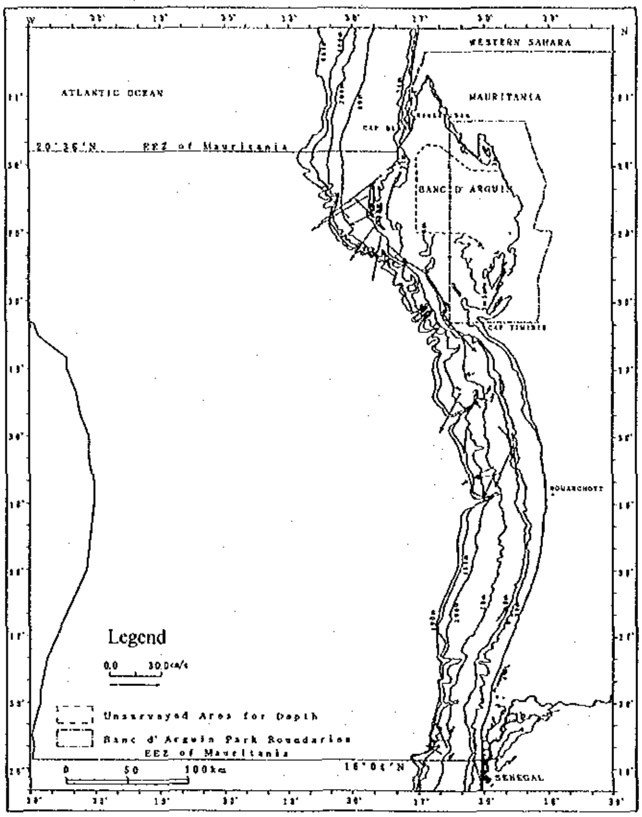
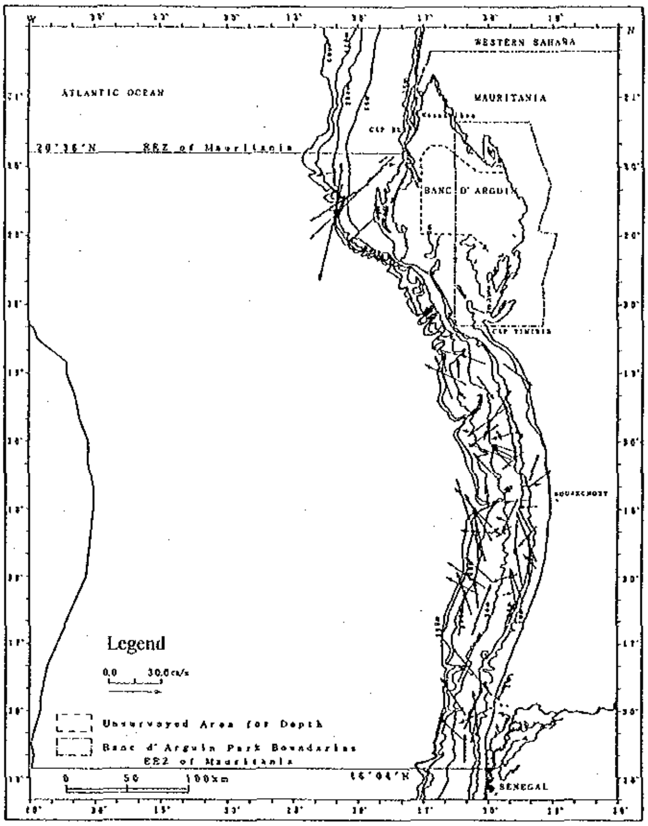


Figure 2.5.6 Vertical profiles of σ_t in coastal area by observation period and by subarea.
(A) Phase 1 cold season; (B) Phase 1 warm season; (C) Phase 2 cold season; (D) Phase 2 warm season.

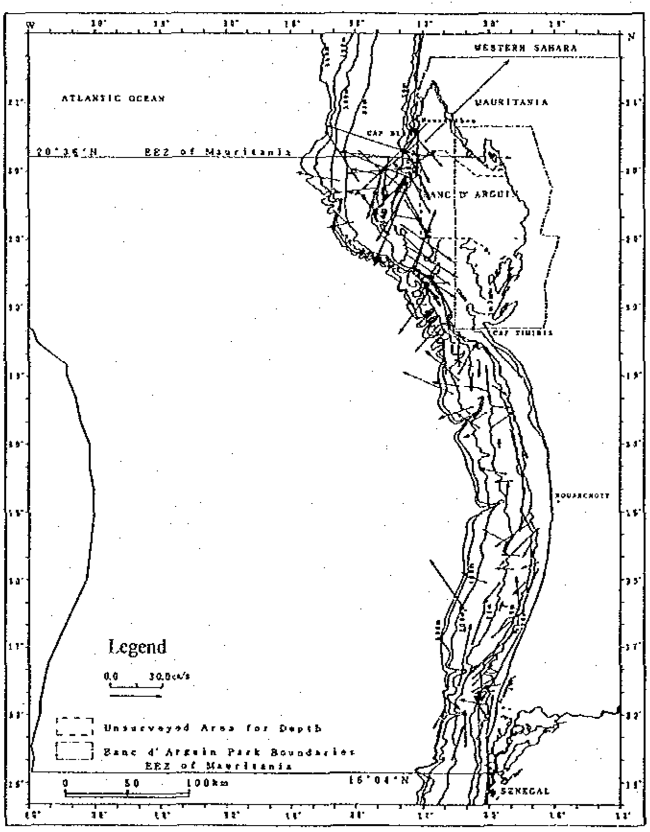
(A) Phase 1 cold season



(B) Phase 1 warm season



(C) Phase 2 cold season



(D) Phase 2 warm season

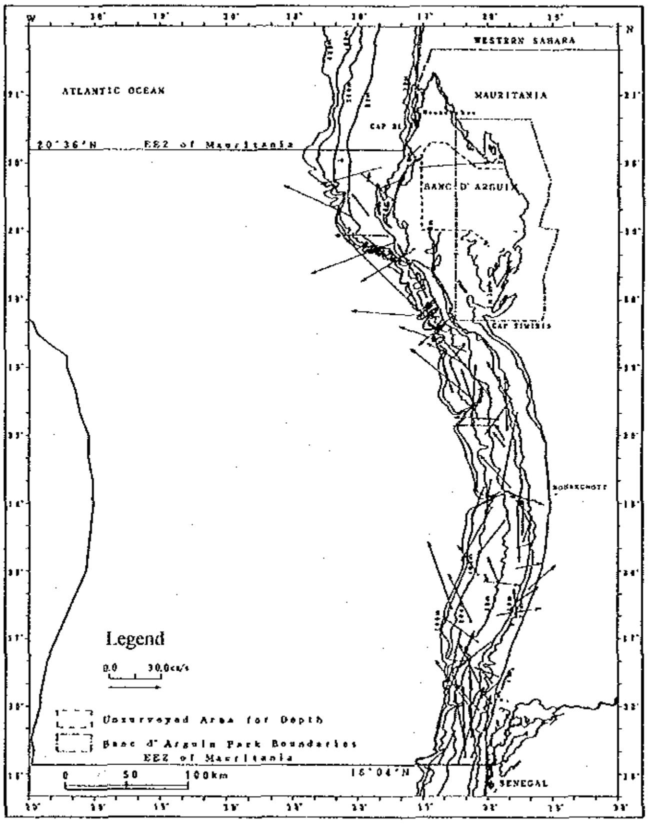


Figure 2.6 Horizontal distribution of water current vectors at upper layer (4 m below surface).

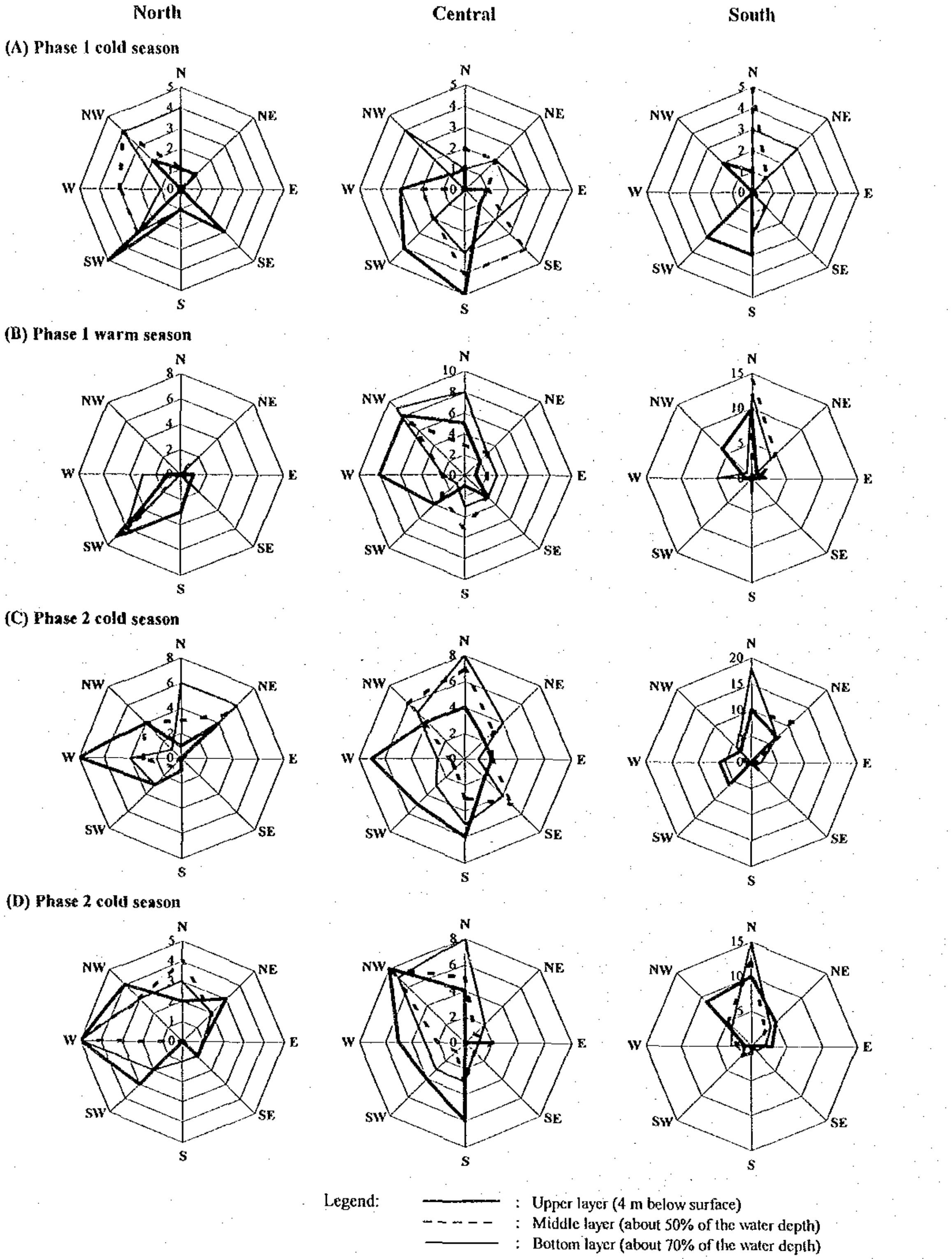


Figure 2.7 Frequency of distribution of current direction by layer, by observation period and by subarea.

2.3.3 Water mass structure

It is useful to analyze the oceanic structure, when the data with similar characters has been grouped up as one water mass. Here the water mass identification is attempted by difference of water temperature and salinity. First, a T-S diagram (Figure 2.8) was established from observed water temperatures and salinities, and an attempt was made to divide water masses based on existing data, characteristics and variations of temperature and salinity by depth (Figure 2.9). Since water masses were interacted in many cases by various factors, clear identification was difficult in the shallow sea such as the area for this study. The water mass identification was made by the sequence of the mode within a certain TS variations. Figure 2.10 shows the horizontal distribution of divided water masses at depths of 2 m, 25 m, 50 m and 100 m for all observation periods. Four water masses were defined for the cold season and 6 - 8 for the warm season. Table 2.1 shows their distribution and their characteristics. Dubrovine *et al.* (1991) reported on water masses distributed in the EEZ of the IRM. Table 2.1 also shows the results of the comparison between those results and the water masses identified in the present observation. LS water mass is not indicated in the above-mentioned report. Also the origin or the formation factor of LS water mass cannot be clarified in this study, but its low salinity and distribution shows that it may have the influence of the Senegal River.

Table 2.1 Summary of identified water masses.

Water masses	Distribution and characteristics of water masses identified in the present observation	Presumably corresponding water masses of Dubrovine *et al.* (1991)
BA	Distributed in the Northern coastal area. Temperature and salinity high. Quite possibly a differente water mass from that found in the Central and Southern coastal areas in Phase 2 cold season at the depth of 2 m. (Cold season : T:17.1-22.8, S:35.9-39.9, Warm season : T:19.8-26.1, S:36.1-40.4)	Banc d'Arguin water mass (T:8.0-17.5, S:35.1-36.4) (T:6.5-18.0, S:34.9-36.57)
CN	Widely distributed at 100 m depth. When the depth get shallower, the distribution gets narrower. (Cold season : T:10.4-19.5, S:35.1-36.1, Warm season : T:10.7-25.9, S:35.4-36.6)	Central North Atlantic water mass (T:18.0-20.0, S:36.38-36.50)
SN	Widely distributed at less than 50 m depth in the Northern area in the cold season. Quite localized in the warm season. Possibly a different water mass than that distributed at 100 m depth in the Phase 2 cold season. (Cold season : T:13.5-18.6, S:35.5-36.3, Warm season : T:12.1-25.4, S:35.4-36.7)	Northern surface water mass? (T:23.9, S:36.45) (T:22.7, S:37.17) or water mass from the upwelling?
SS	Appeared only in the warm season. Widely distributed at less than 25 m depth in the Central and Southern areas. Characteristics: high water temperature. (Warm season : T:24.0-30.0, S:35.3-36.3)	Southern surface water mass (T:26.85, S:35.38) (T:28.8, S:35.75)
A	Water mass considered a mixture of SN and SS, widely distributed at 2m below surface in the Southern area in the cold season, and near Cape Timiris and Cape Blanc, and also at the 50 m depth in the Central and Southem areas in the warm season. (Cold season : T:13.9-21.4, S:35.4-36.0, Warm season : T:15.6-26.0, S:35.3-36.4)	Water mass (A)
T	Distributed only inshore in the Central and Southem areas in the warm season. Temperature and salinity high. (Warm season : T:26.0-29.8, S:36.2-37.2)	Tropical water mass
LS	Distributed only near the Senegalese border, in the Southern coastal area in Phase 2 warm season. Water temperature high, salinity low. (Warm season : T:28.7-29.1, S:34.2-35.2)	-
CS	Distributed only at 100m depth of a limited zone of the offshore Southern area in Phase 2 warm season. Salinity tending to be lower than that of CN. This water mass is not shown in Fig 2.10. (Warm season : T:12.5-14.7, S:35.5-35.6)	Central South Atlantic waters? (T:5.5-17.8, S:34.65-35.78) (T:8.0-16.0, S:34.7-35.65)

Remarks: T: Water temperature (°C), S: Salinity

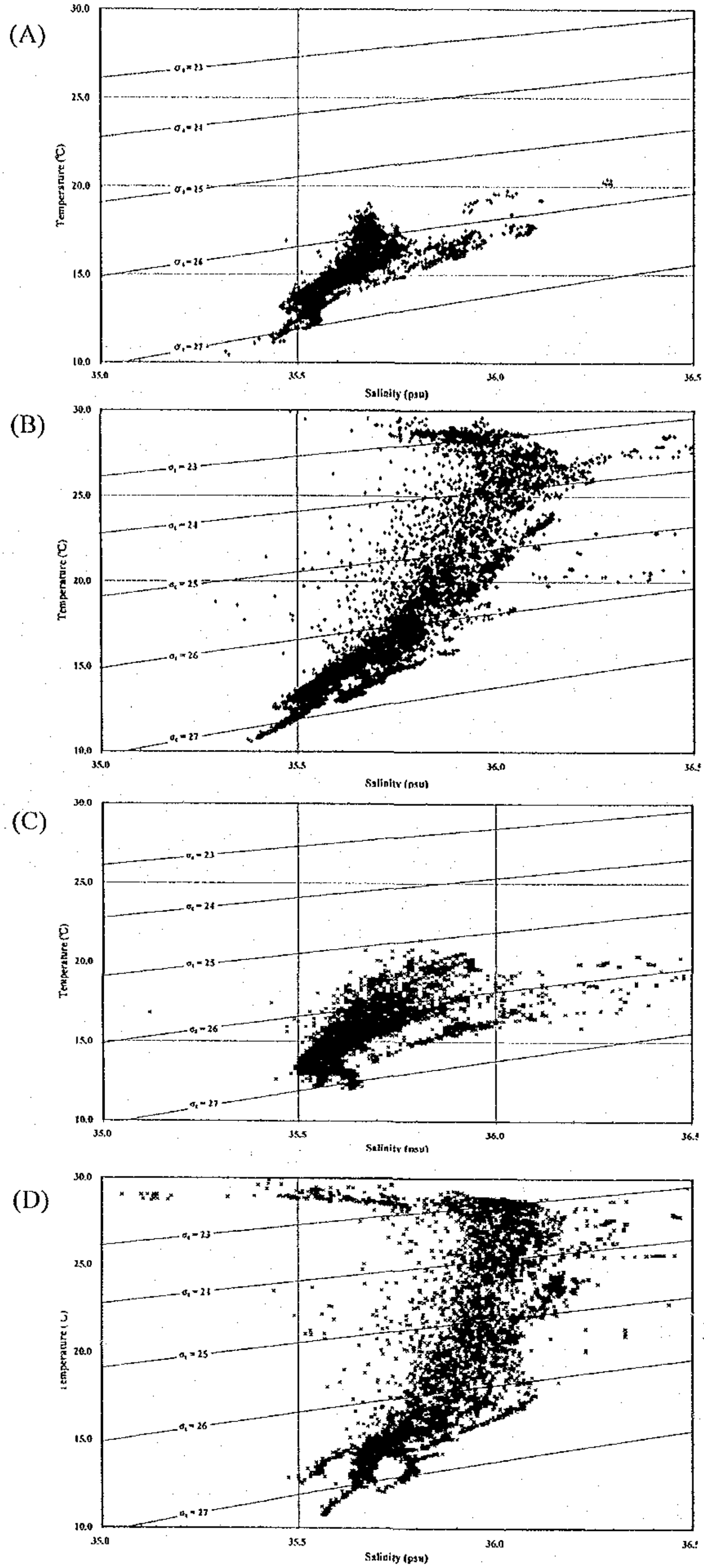


Figure 2.8 T-S diagram by observation period.

(A) Phase 1 cold season;
(B) Phase 1 warm season;
(C) Phase 2 cold season;
(D) Phase 2 warm season.

Remark.
Method of water masses identification by T-S diagram is indicated in ANNEX 2.

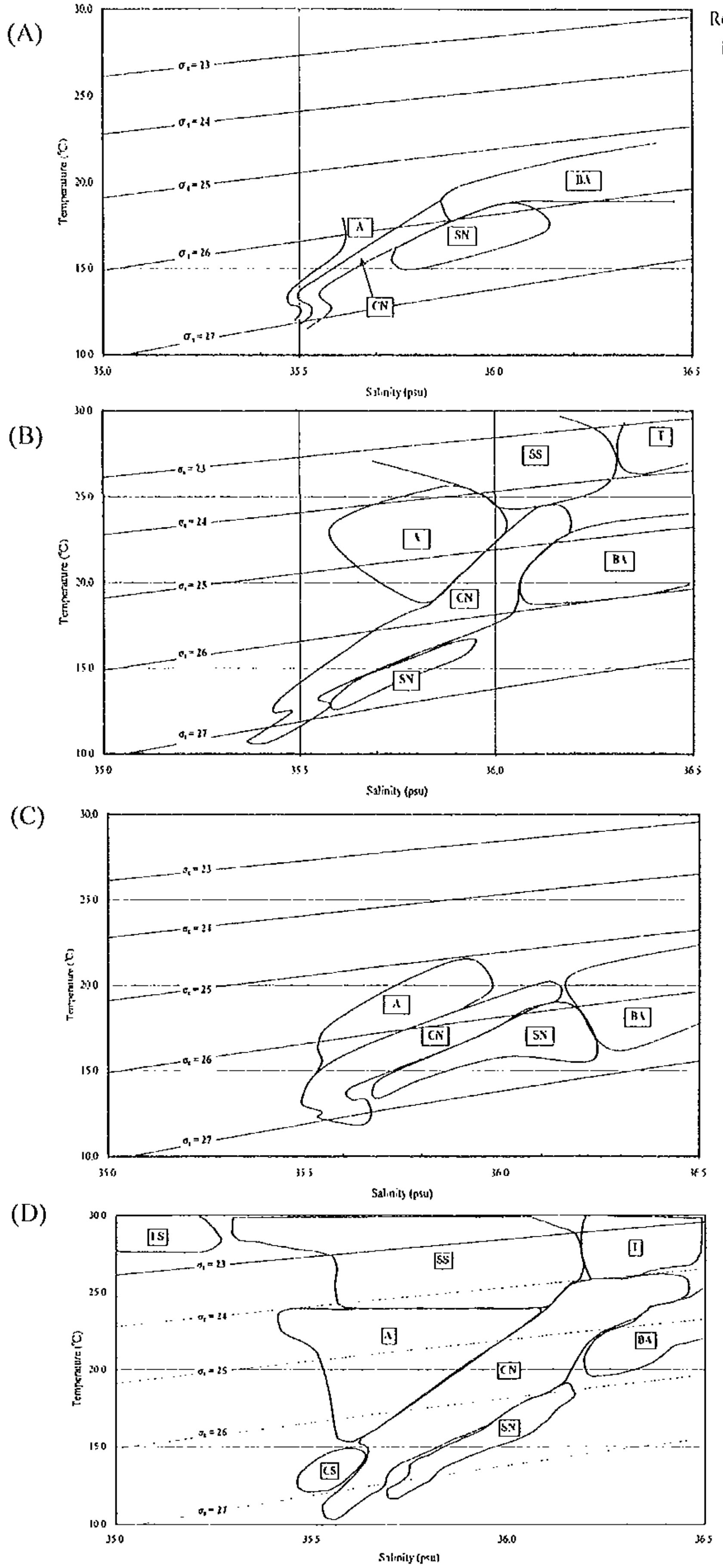


Figure 2.9 Water masses identified from the T-S diagram by observation period.

(A) Phase 1 cold season;
(B) Phase 1 warm season;
(C) Phase 2 cold season;
(D) Phase 2 warm season.

Water masses
BA: Banc d'Arguin water mass
CN: Central North Atlantic water mass
SN: Northern surface water mass
SS: Southern surface water mass
A : Water mass (A)
T : Tropical water mass
LS: Low salinity water mass
CS: Central South Atlantic water mass

(A) Phase 1 cold season

a. Depth : 2m   b. Depth : 25m   c. Depth : 50m   d. Depth : 100m

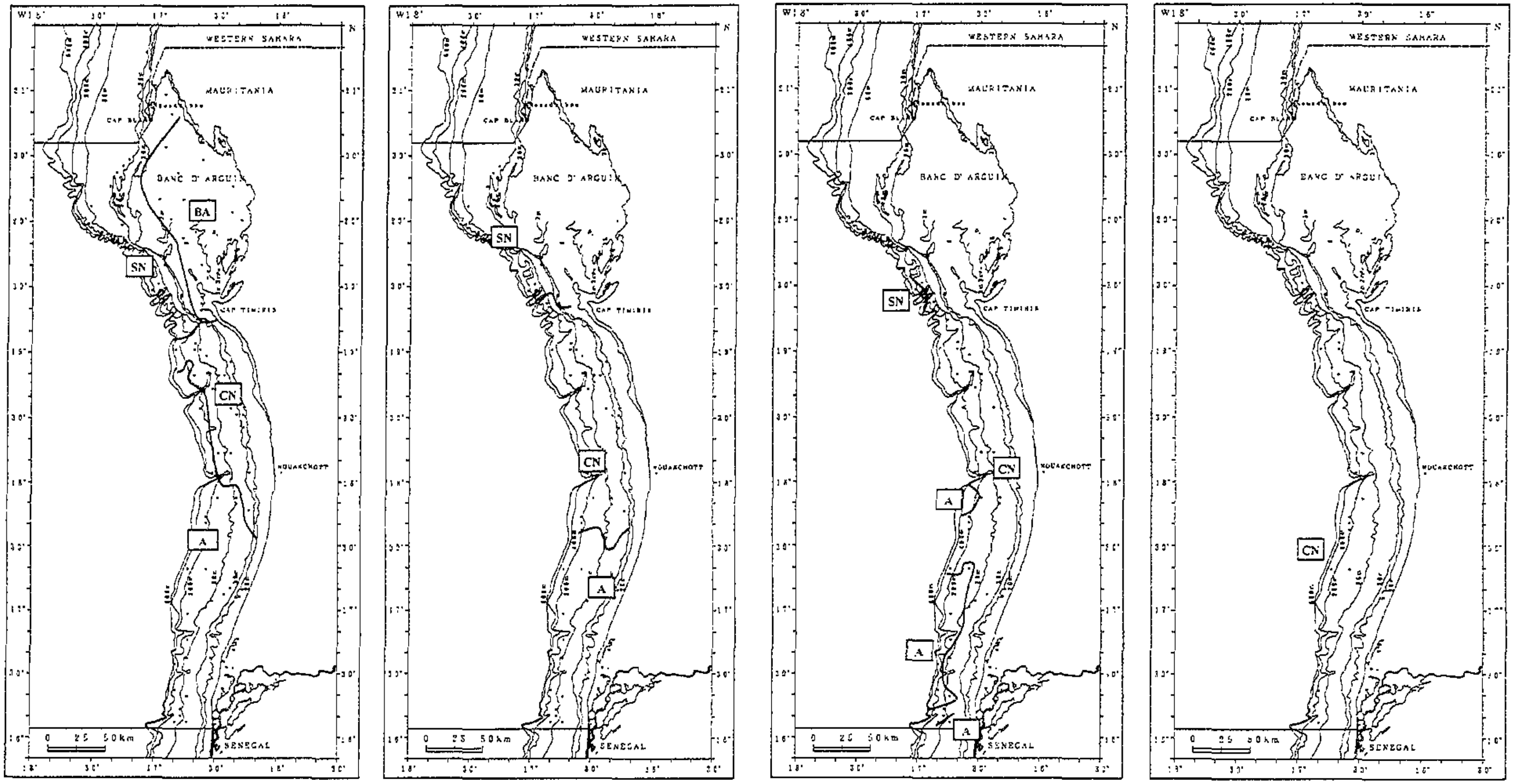
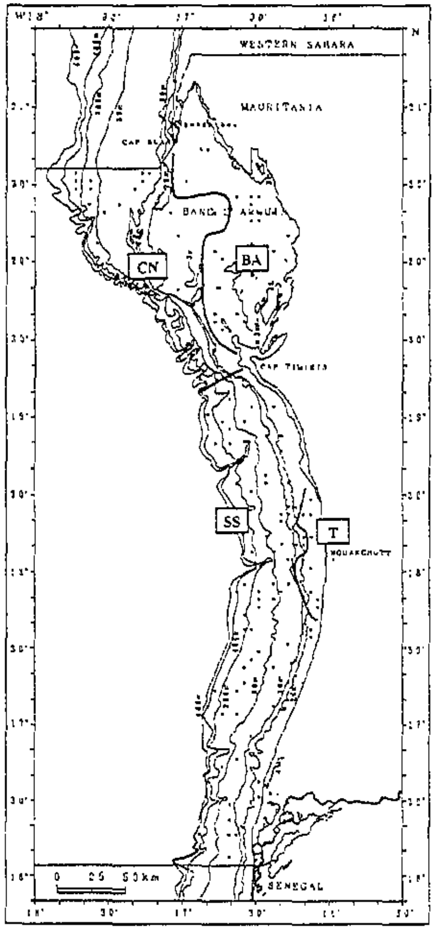


Figure 2.10 Distribution of water masses at specific depths.

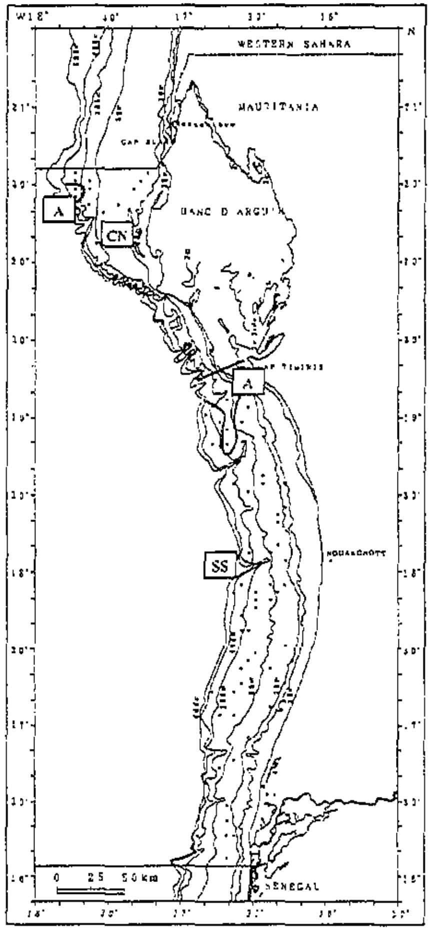
Figure 2.10 continued

(B) Phase 1 warm season

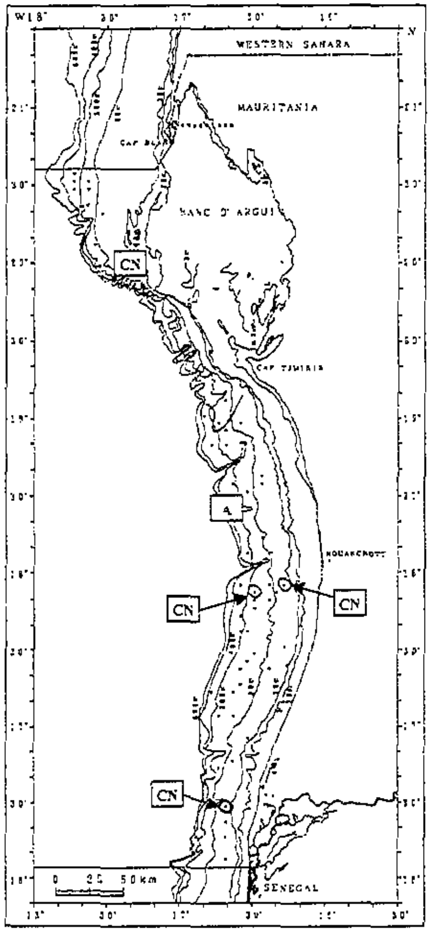
a. *Depth : 2m*



b. Depth : 25m



c. Depth : 50m



d. Depth : 100m

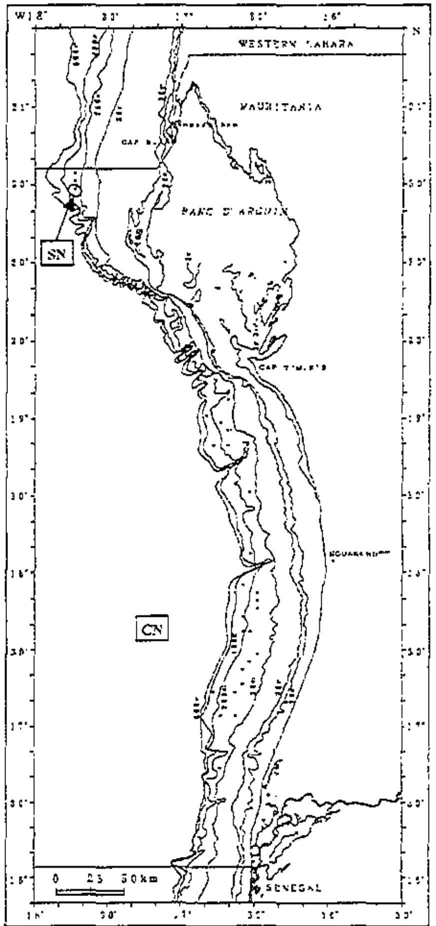
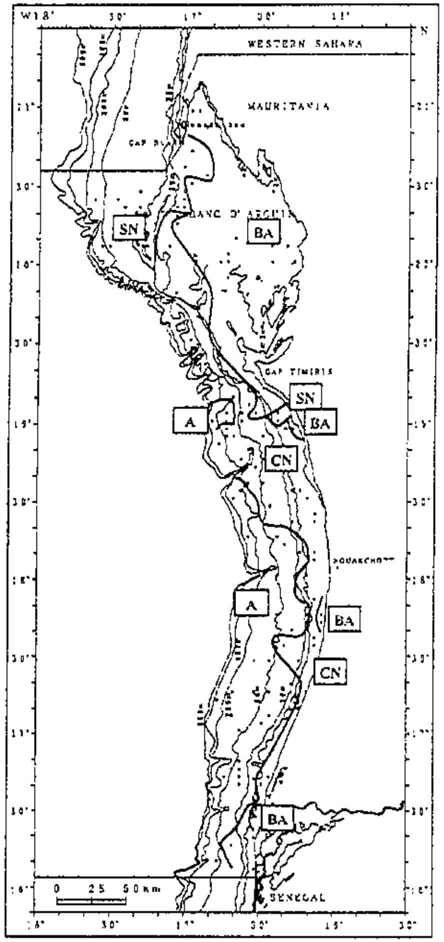


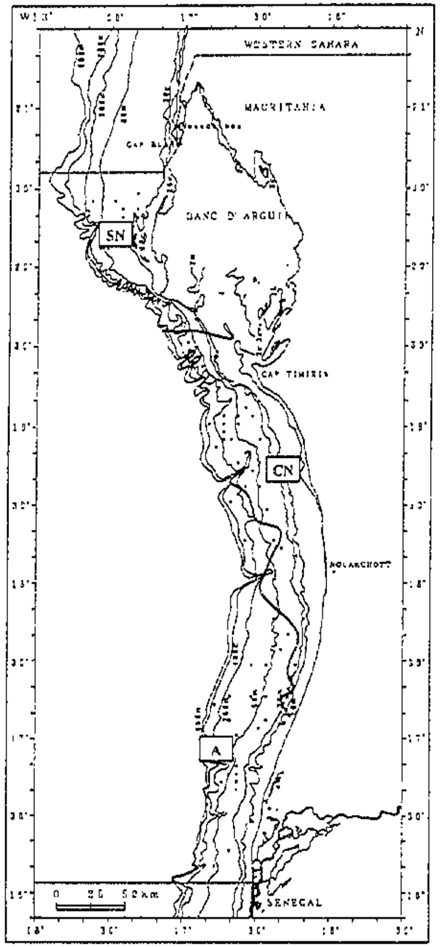
Figure 2.10 continued

(C) Phase 2 cold season

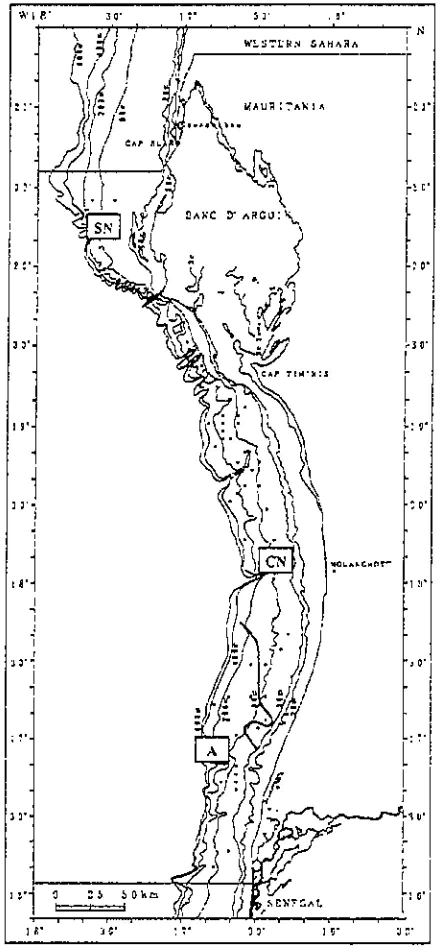
a. Depth : 2m



b. Depth : 25m



c. Depth : 50m



d. Depth : 100m

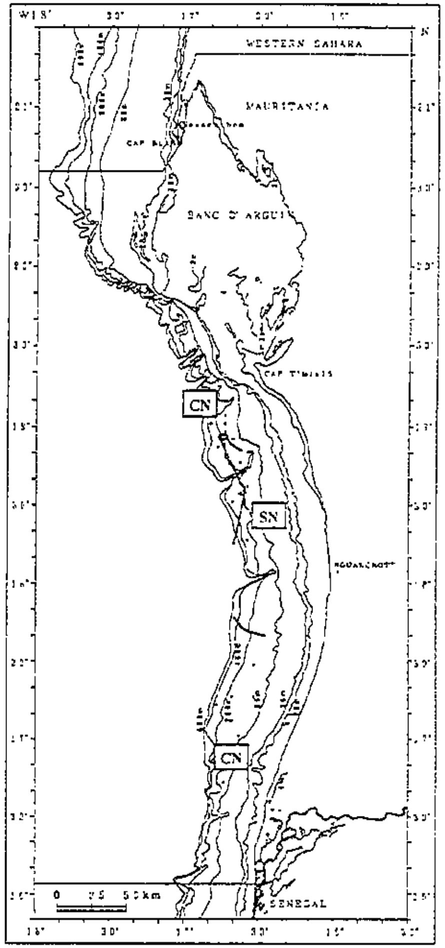
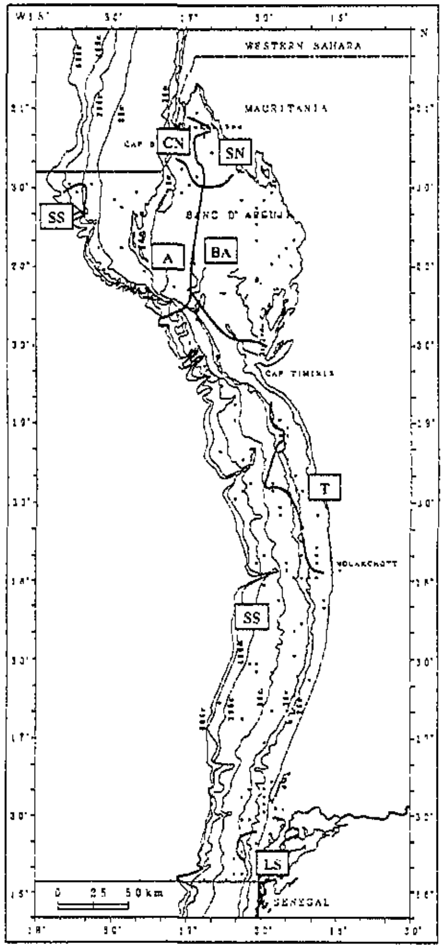


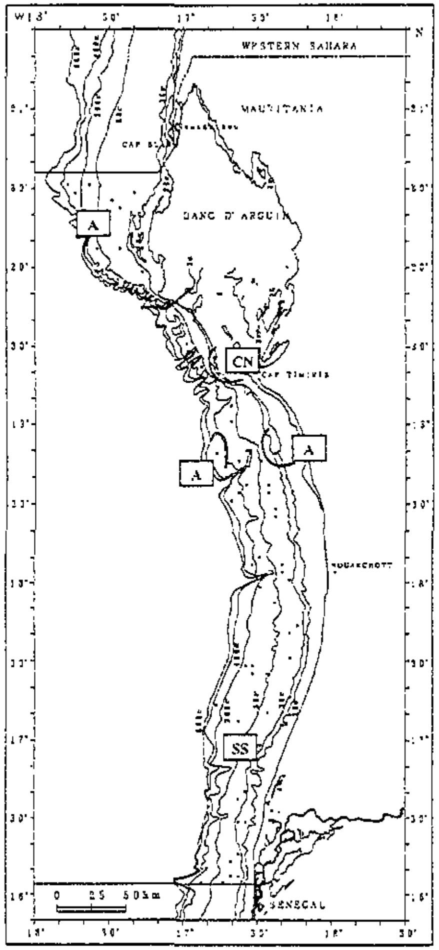
Figure 2.10 continued

(D) Phase 2 warm season

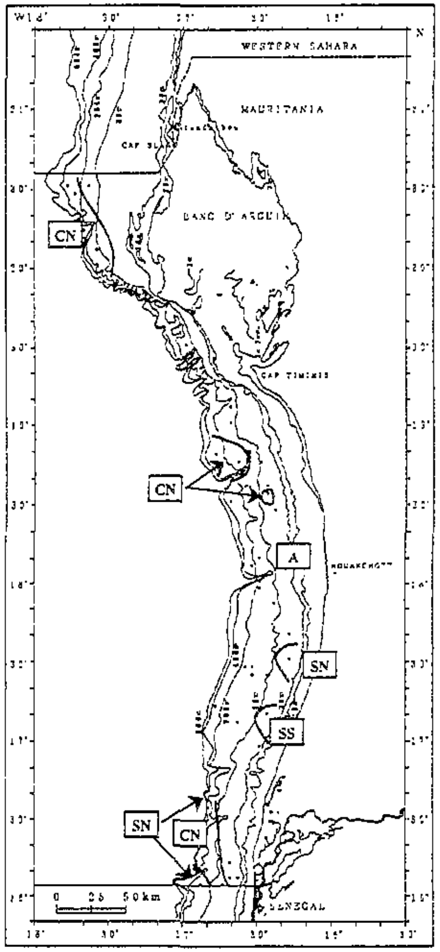
a. Depth : 2m



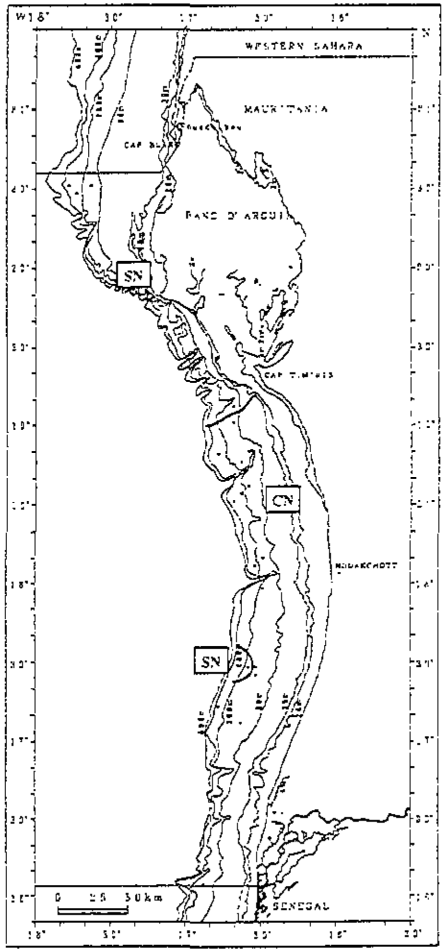
b. Depth : 25m



c. Depth : 50m



d. Depth : 100m



2.3.4 pH, chlorophyll-a, nutrient salts, etc.

Table 2.2 shows the results of the analysis of pH, chlorophyll-a and nutrient salts. Chlorophyll-a tended to be more abundant in the warm season than in the cold season, the peak of their abundance occurring respectively at 20 and 50 m depths and at 0m depth (surface). No particular characteristics were found with respect to the distribution of pheophytines by season or by depth. Nitrites (NO_2-N) tended to be more abundant in the cold season than in the warm season, maximum values for both seasons being found near the surface. On the other hand, nitrates (NO_3-N) exhibited no marked tendencies on its distribution by season or by depth. And pH was generally low in the cold season and high in the warm season, and tended to be higher near the surface and lower with depth.

Figure 2.11 shows the vertical section of water temperature, σ_t, pH, chlorophyll-a, NO_2-N and NO_3-N on the seven across-isobaths transects (see Figure 2.1). Distribution of salinity and pheophytins by vertical section often tended to be uniform and were not represented. The figure shows water temperature and σ_t practically have a stratified structure, but there are also cases in which inclination of contour lines seem to ascend toward shore side with vertical section distribution figure. Also, the range of water temperature and σ_t values is wider in the warm season than in the cold season. Distribution of pH is overall similar to that of σ_t. Chlorophyll-a, nitrites and nitrates have a patchy distribution, as their values exhibit maximal at a given depth. There are some cases where distribution of chlorophyll-a in the warm season shows a maximum layer at 20–50 m deep, close to the thermocline.

2.3.5 Meteorology at sea

Table 2.3 summarizes meteorology at sea during the observation period. Weather was often cloudy during the observation in Phase 2 warm season. In other periods it was sunny, even bright. Dominant temperature range was 22 - 28°C in the cold season and 26 - 32°C in the warm season. No significant variation of atmospheric pressure was observed in any season with two high frequency classes between 1012 - 1016hPa. Dominant wind direction was from northwest or northeast in the cold season, often with speed classes between 5 and 9 m/s. Northwest–northeast wind appeared often in the warm season, at a usual speed classes between 3 and 6 m/s or 7 and 9 m/s. Also, south winds with a speed of less than 7 m/s were more frequent in the warm season than in the cold season.

Figure 2.12 shows wind condition between January 2000 and October 2001 in NDB and NKC. Wind direction during the Sea-borne survey period was often north to northeast at NDB and northwest to north at NKC. Only northerly winds blowed in the cold season, but there were also south winds in the warm season.

Table 2.2 Results of water quality analysis.

(A) Phase 1 cold season

	Chlorophyll-a (μg/ℓ)				Pheophytin (μg/ℓ)				NO_2-N (μmol/ℓ)				NO_3-N (μmol/ℓ)				pH			
Depth	No.	Min.	Max.	Mean	No.	Min.	Max.	Mean	No.	Min.	Max.	Mean	No	Min	Max	Mean	No.	Min.	Max.	Mean
0	16	0.26	17.62	6.06	10	1.94	17.32	8.44	17	<0.05	3.00	0.39	17	2.30	26.71	11.71	13	7.59	7.93	7.77
10	12	0.60	17.35	8.26	13	0.84	17.32	6.78	18	<0.05	1.50	0.32	17	2.53	32.90	13.71	14	7.60	7.94	7.77
20	8	0.26	10.14	4.66	9	1.17	12.92	5.82	16	<0.05	0.80	0.25	15	1.80	21.32	12.79	11	7.59	7.89	7.73
50	3	1.60	4.00	2.84	5	0.24	10.17	5.22	12	<0.05	0.60	0.22	12	2.46	29.92	15.42	8	7.59	7.86	7.69
100	6	3.73	11.21	6.34	1	3.12	3.12	3.12	8	<0.05	<0.05	<0.05	8	1.09	36.98	20.55	5	7.56	7.72	7.63
200	2	0.53	3.68	2.11	3	0.48	5.25	2.27	5	<0.05	0.40	0.08	5	0.68	30.89	16.06	3	7.56	7.66	7.61
300	-	-	-	-	1	5.95	5.95	5.95	3	<0.05	0.20	0.07	1	32.40	32.40	32.40	2	7.55	7.73	7.64
400	-	-	-	-	1	20.82	20.82	20.82	2	<0.05	<0.05	<0.05	2	19.69	36.14	27.92	2	7.55	7.72	7.64
Total	47	0.26	17.62	6.04	43	0.24	20.82	6.69	81	<0.05	3.00	0.24	77	0.68	36.98	14.83	58	7.55	7.94	7.72

(B) Phase 1 warm season

	Chlorophyll-a (μg/ℓ)				Pheophytin (μg/ℓ)				NO_2-N (μmol/ℓ)				NO_3-N (μmol/ℓ)				pH			
Depth	No.	Min.	Max.	Mean	No.	Min.	Max.	Mean	No.	Min.	Max.	Mean	No.	Min.	Max.	Mean	No.	Min.	Max.	Mean
0	17	2.51	27.23	13.99	17	<0.1	1.87	0.11	15	<0.05	0.80	0.14	16	0.38	6.33	2.05	18	7.78	8.18	8.03
10	17	0.27	30.41	12.79	17	<0.1	2.72	0.27	17	<0.05	1.52	0.12	17	<0.05	30.00	5.40	18	7.84	8.15	8.04
20	17	2.94	62.93	14.76	17	<0.1	1.31	0.08	17	<0.05	1.52	0.21	17	<0.05	684.00	43.37	18	7.84	8.18	8.02
50	12	<0.1	39.78	6.40	12	<0.1	50.41	9.13	13	<0.05	0.80	0.19	13	<0.05	23.30	10.39	13	7.71	8.10	7.89
100	6	<0.1	2.94	1.16	6	<0.1	31.43	12.87	6	<0.05	0.40	0.12	7	15.07	28.36	23.81	8	7.65	7.89	7.72
200	5	<0.1	0.53	0.11	5	2.64	29.90	17.37	4	<0.05	<0.05	<0.05	5	3.11	27.18	18.23	6	7.43	7.69	7.62
300	3	<0.1	<0.1	<0.1	3	0.27	14.69	9.17	3	<0.05	<0.05	<0.05	4	0.60	29.77	14.51	4	7.59	7.71	7.63
400	3	<0.1	<0.1	<0.1	3	1.60	2.40	1.99	4	<0.05	<0.05	<0.05	4	<0.05	31.25	14.15	4	7.53	7.68	7.59
Total	80	<0.1	62.93	9.88	80	<0.1	50.41	3.93	79	<0.05	1.52	0.14	83	0.00	684.00	16.50	89	7.43	8.18	7.92

(C) Phase 2 cold season

	Chlorophyll-a (μg/ℓ)				Pheophytin (μg/ℓ)				NO_2-N (μmol/ℓ)				NO_3-N (μmol/ℓ)				pH			
Depth	No.	Min.	Max.	Mean	No.	Min.	Max.	Mean	No.	Min.	Max.	Mean	No.	Min.	Max.	Mean	No.	Min.	Max.	Mean
0	23	0.80	37.38	10.73	23	<0.1	9.24	2.17	23	<0.05	2.50	0.57	23	0.29	20.71	8.99	44	7.08	8.36	7.76
10	23	0.80	19.49	8.78	23	<0.1	13.00	2.41	22	<0.05	1.60	0.45	21	0.32	18.54	9.73	22	7.18	8.36	7.68
20	*22*	*<0.1*	*21.63*	*6.58*	*22*	*<0.1*	*38.60*	*3.27*	*22*	*0.06*	*1.44*	*0.50*	*22*	*0.40*	*25.16*	*9.42*	*19*	*7.13*	*8.20*	*7.67*
50	14	<0.1	14.95	2.46	14	<0.1	67.10	9.44	15	0.06	1.29	0.36	15	2.75	19.47	14.49	14	7.21	8.12	7.62
100	7	<0.1	8.81	1.34	7	<0.1	8.68	3.53	6	0.06	0.54	0.21	6	2.60	19.90	10.33	7	7.15	7.95	7.53
200	4	<0.1	<0.1	<0.1	4	1.76	65.68	20.49	3	0.06	0.46	0.21	3	18.77	28.93	23.14	4	7.28	7.76	7.58
300	2	<0.1	<0.1	<0.1	2	<0.1	1.34	0.67	2	0.22	0.30	0.26	2	12.13	20.12	16.13	2	7.62	7.68	7.65
400	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	95	<0.1	37.38	6.71	95	<0.1	67.10	4.39	93	<0.05	2.50	0.45	92	0.29	28.93	10.86	112	7.08	8.36	7.69

(D) Phase 2 warm season

	Chlorophyll-a (μg/ℓ)				Pheophytin (μg/ℓ)				NO_2-N (μmol/ℓ)				NO_3-N (μmol/ℓ)				pH			
Depth	No.	Min.	Max.	Mean	No.	Min.	Max.	Mean	No.	Min.	Max.	Mean	No.	Min.	Max.	Mean	No.	Min.	Max.	Mean
0	19	<0.1	12.02	3.52	19	<0.1	8.78	0.89	19	<0.05	0.70	0.10	19	5.05	14.32	9.65	19	8.16	8.29	8.25
10	18	<0.1	12.55	3.09	18	<0.1	3.87	1.08	19	<0.05	0.70	0.12	19	3.07	13.37	9.66	19	8.15	8.28	8.23
20	*19*	*<0.1*	*22.16*	*5.79*	*19*	*<0.1*	*3.40*	*0.71*	*19*	*<0.05*	*0.50*	*0.06*	*19*	*3.38*	*14.53*	*9.74*	*19*	*8.13*	*8.27*	*8.20*
50	12	<0.1	1068.00	92.40	12	<0.1	6.40	0.93	12	<0.05	0.50	0.18	12	<0.05	15.77	7.25	12	7.92	8.18	8.01
100	6	0.27	2.67	1.20	6	<0.1	1.07	0.20	6	<0.05	0.30	0.05	6	3.29	7.89	6.08	6	7.81	7.98	7.88
200	2	1.86	2.67	2.27	2	1.68	4.64	3.16	2	<0.05	<0.05	<0.05	2	2.96	4.53	3.75	2	7.78	7.83	7.81
300	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
400	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	76	<0.1	1068.00	17.80	76	<0.1	8.78	0.90	77	<0.05	0.70	0.10	77	<0.05	15.77	8.87	77	7.78	8.29	8.16

*Mean value was calculated by having set value of under limit of determination to 0.

Limit of determination: *Chlorophyll-a and Pheophytin: 0.1 μg/ℓ, NO_2-N and NO_3-N: 0.05 μmol/ℓ.*

(A) Phase 1 cold season

	Temperature (°C)	σ_t	pH
1. 20°30'N transect	No observation	No observation	No observation
2. 20°N transect	No observation	No observation	No observation

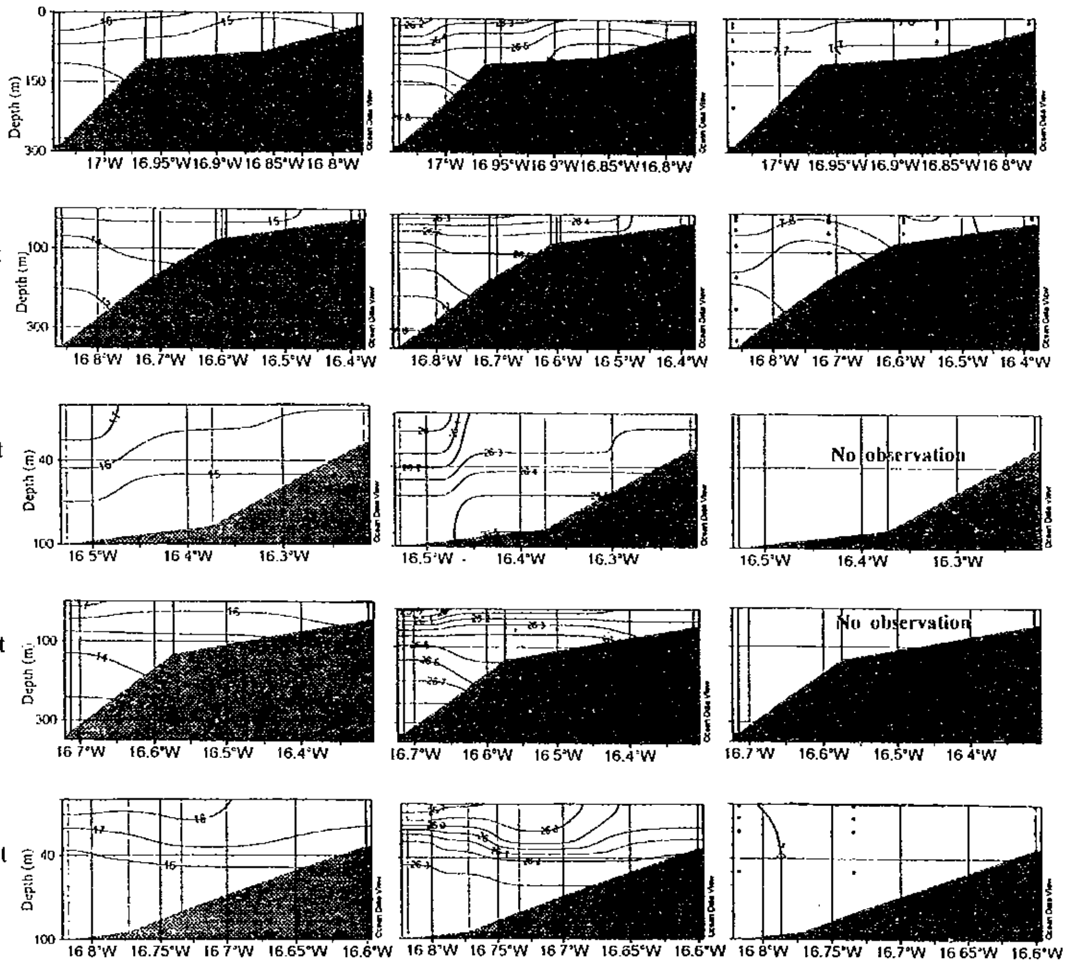
3. 19°30'N transect

4. 19°N transect

5. 18°N transect

6. 17°N transect

7. 16°N transect



Contour lines interval; Temperature:1°C, σ_t:0.2, pH:0.1.

Figure 2.11 Section of vertical distribution of water temperature, σ_t, pH, chlorophyll-a and nutrient salts from east to west.

Figure 2.11 continued

(A) Phase I cold season (cont.)

	Chlorophyll-a (μ g/ℓ)	NO_2-N (μ mol/ℓ)	NO_3-N (μ mol/ℓ)
1. 20°30'N transect	No observation	No observation	No observation
2. 20°N transect	No observation	No observation	No observation

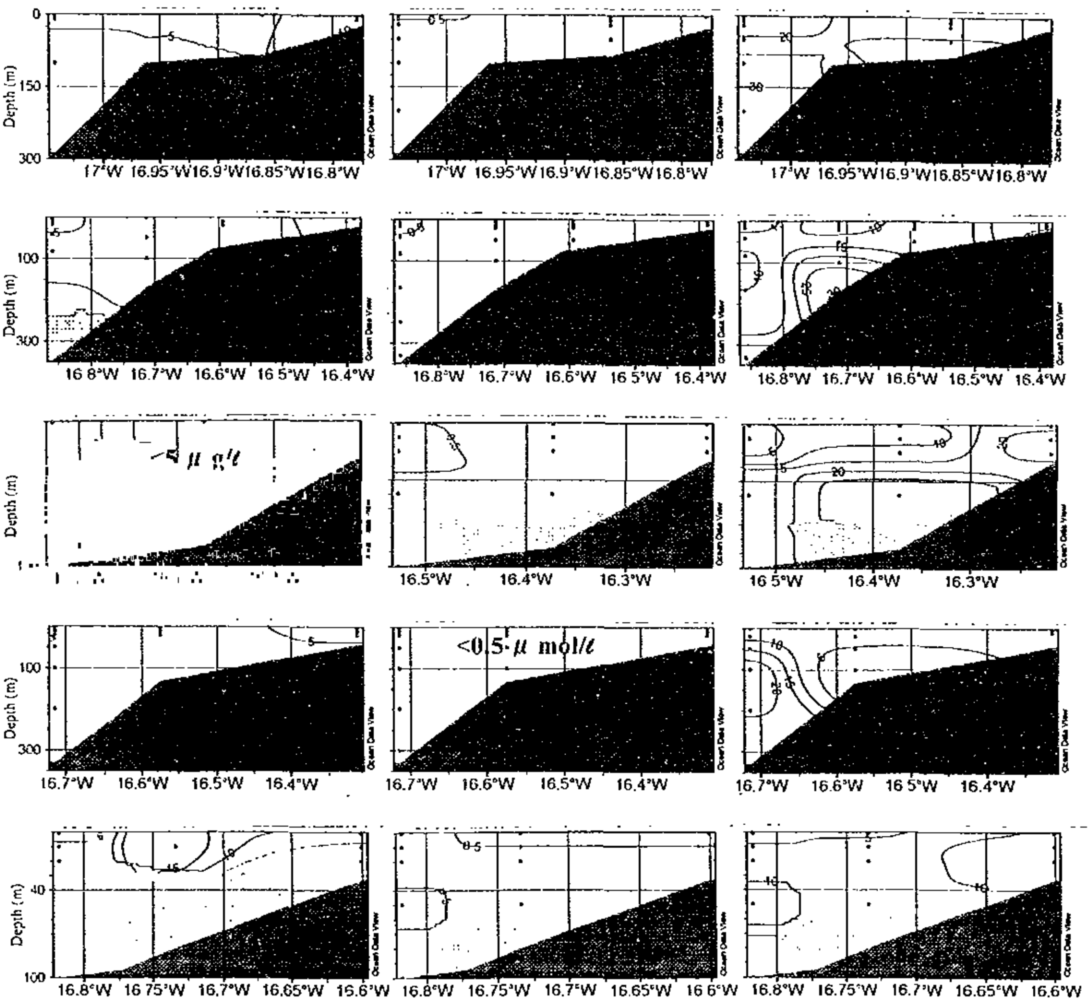
3. 19°30'N transect

4. 19°N transect

5. 18°N transect

6. 17°N transect

7. 16°N transect



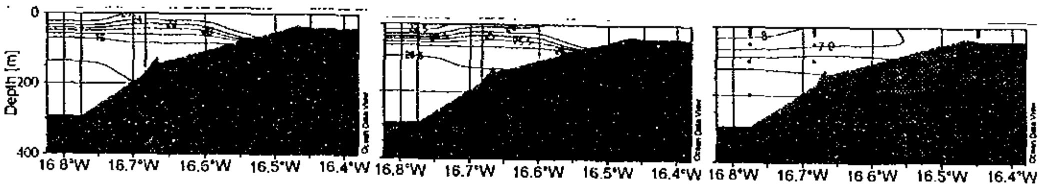
Contour lines interval; Chlorophyll-a:5 μ g/ℓ, NO_2-N:0.5 μ mol/ℓ, NO_3-N:5 μ mol/ℓ.

Figure 2.11 continued

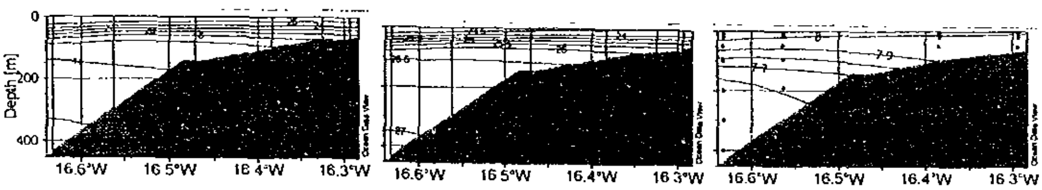
(B) Phase 1 warm season

	Temperature (°C)	σ_t	pH
1. 20°30'N transect	No observation	No observation	No observation
2. 20°N transect	No observation	No observation	No observation
3. 19°30'N *transect*	No observation	No observation	No observation

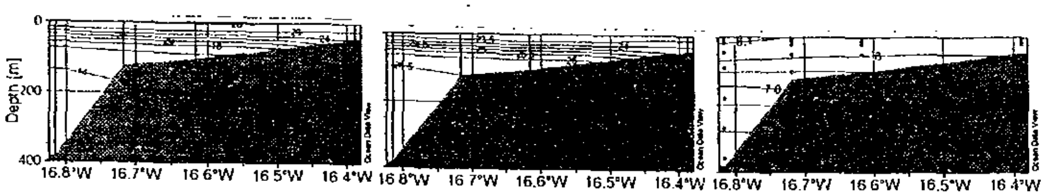
4. 19°N transect



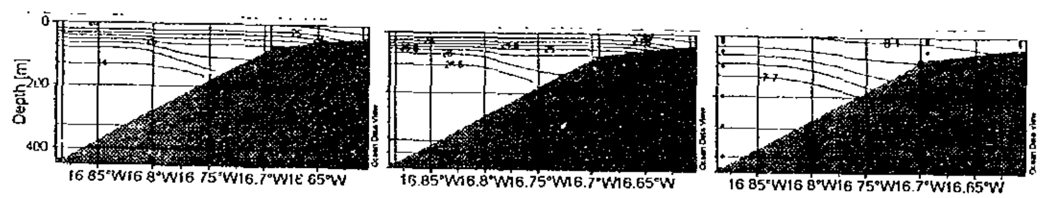
5. 18°N transect



6. 17°N transect



7. 16°N transect



Contour lines interval; Temperature:2°C, σ_t:0.5, pH:0.1.

Figure 2.11 continued

(B) Phase 1 warm season (cont.)

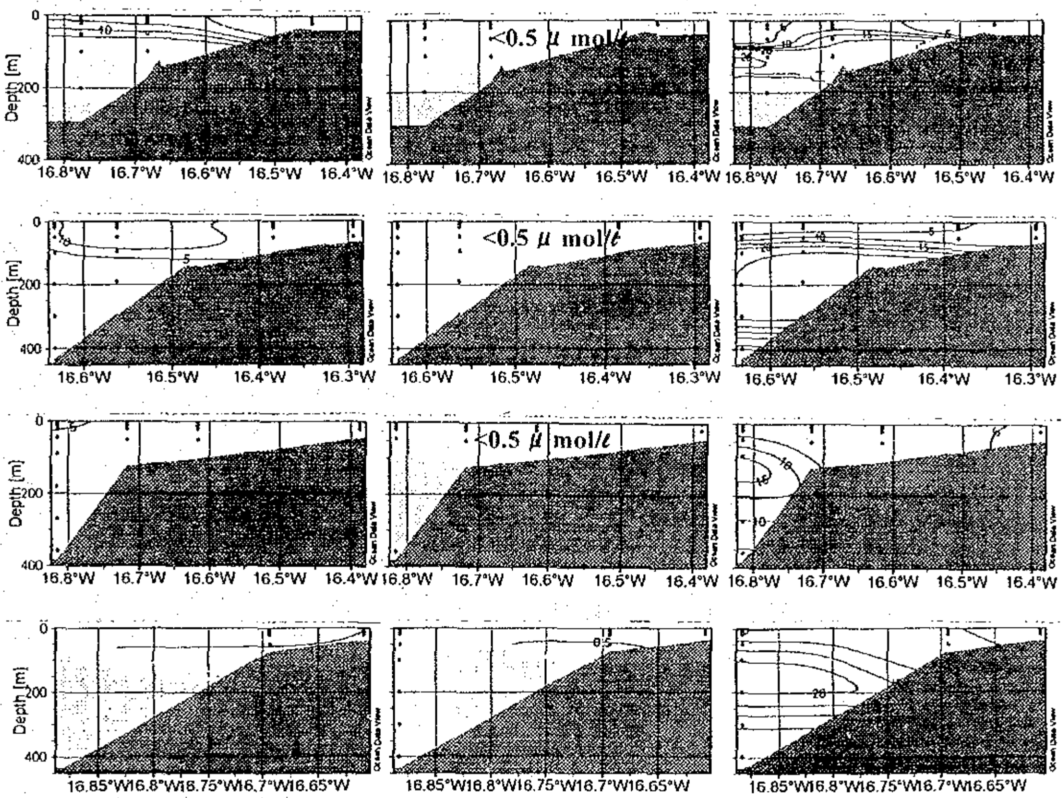
	Chlorophyll-a (μ g/ℓ)	NO_2-N (μ mol/ℓ)	NO_3-N (μ mol/ℓ)
1. 20°30'N transect	No observation	No observation	No observation
2. 20°N transect	No observation	No observation	No observation
3. 19°30'N transect	No observation	No observation	No observation

4. 19°N transect

5. 18°N transect

6. 17°N transect

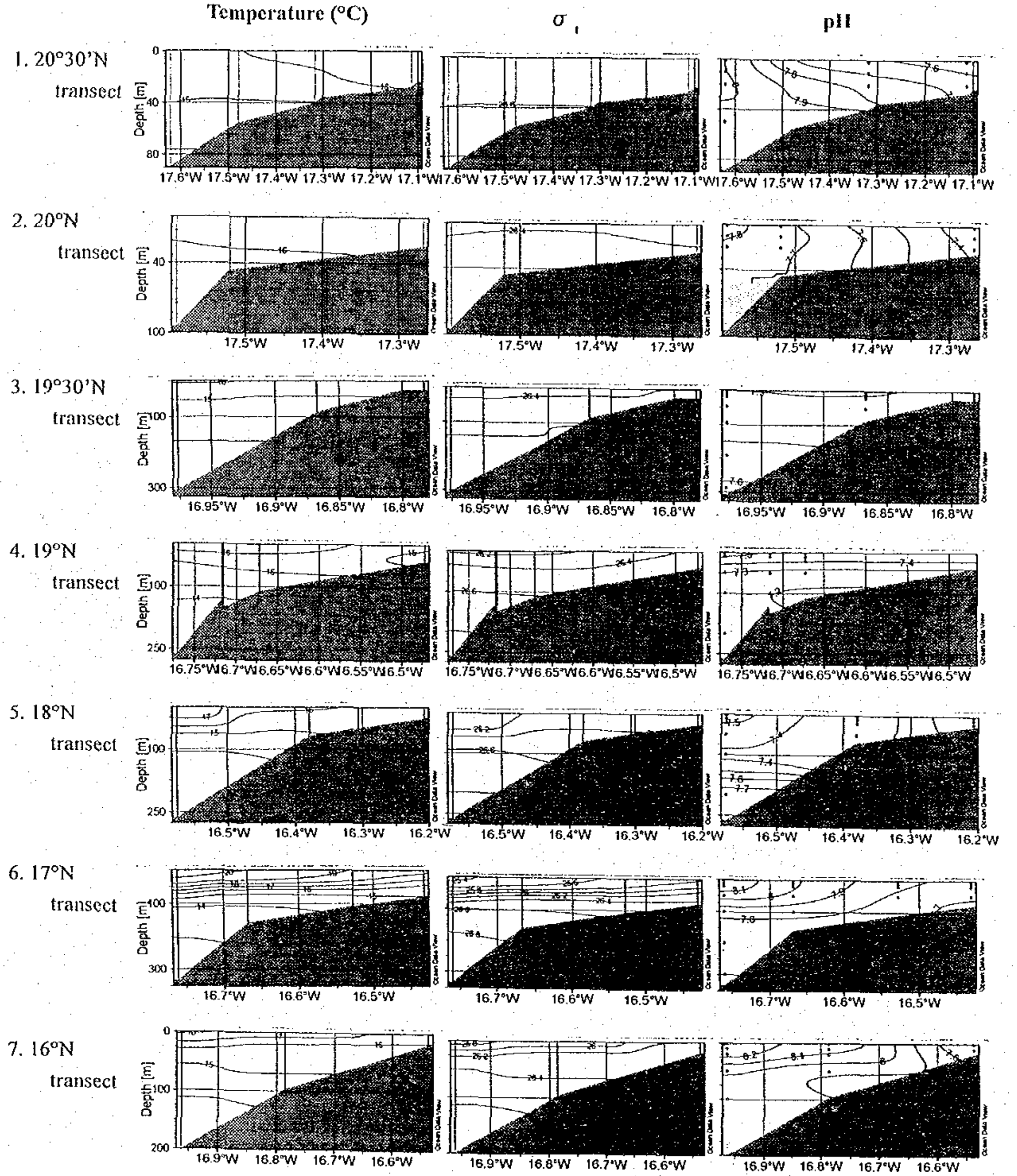
7. 16°N transect



Contour lines interval; Chlorophyll-a:5 μ g/ℓ, NO_2-N:0.5 μ mol/ℓ, NO_3-N:5 μ mol/ℓ.

Figure 2.11 continued

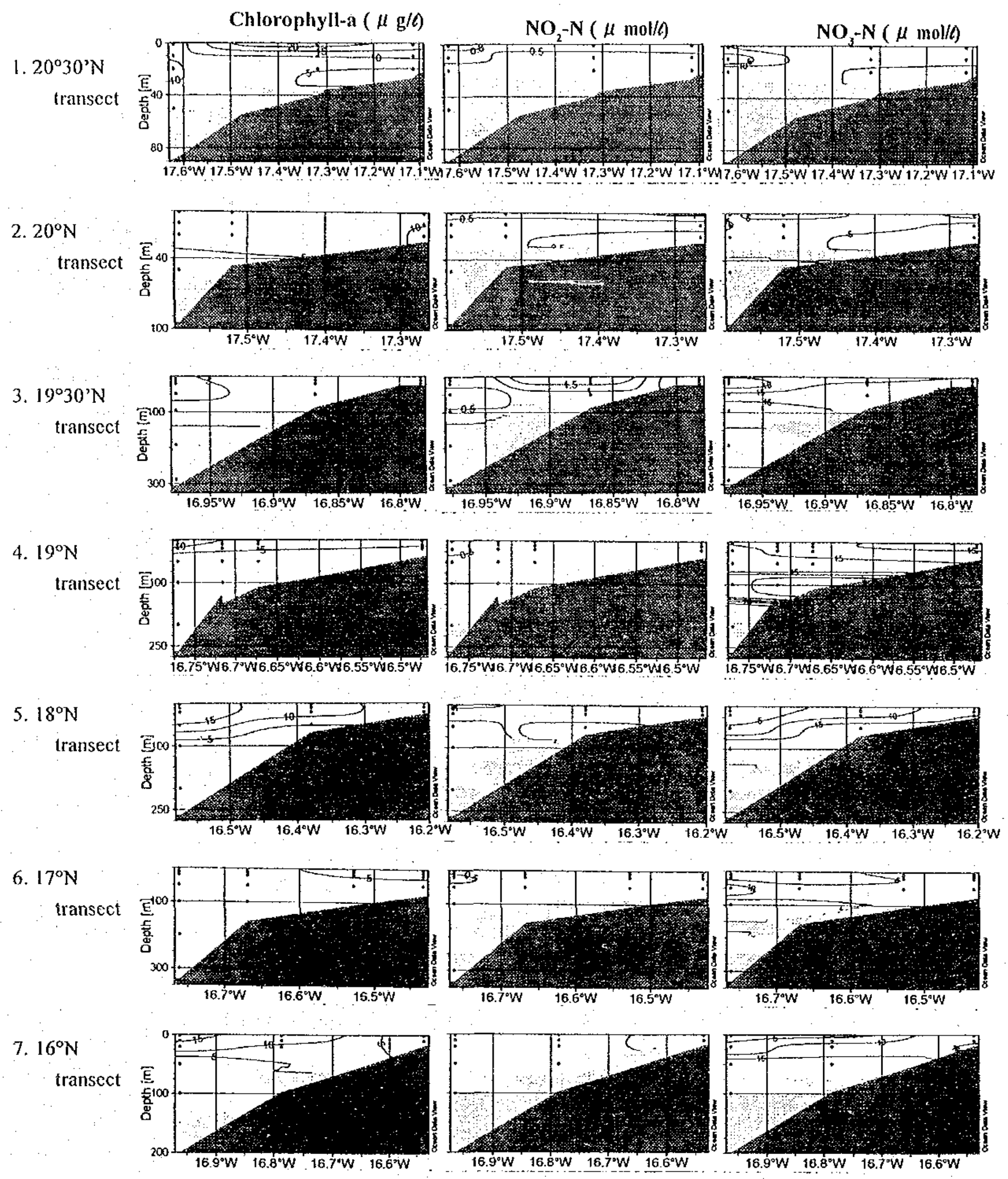
(C) Phase 2 cold season



Contour lines interval; Temperature:1°C, σ_t:0.2, pH:0.1.

Figure 2.11 continued

(C) Phase 2 cold season (cont.)



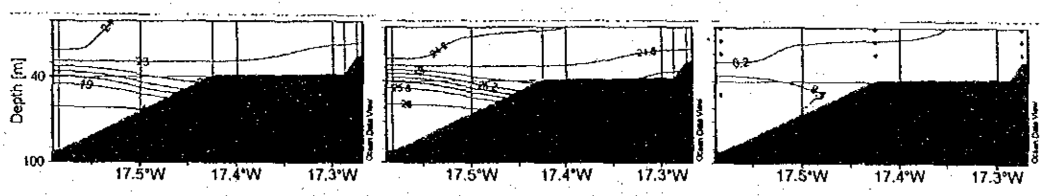
Contour lines interval; Chlorophyll-a:5 μ g/ℓ, NO_2-N:0.5 μ mol/ℓ, NO_3-N:5 μ mol/ℓ.

Figure 2.11 continued

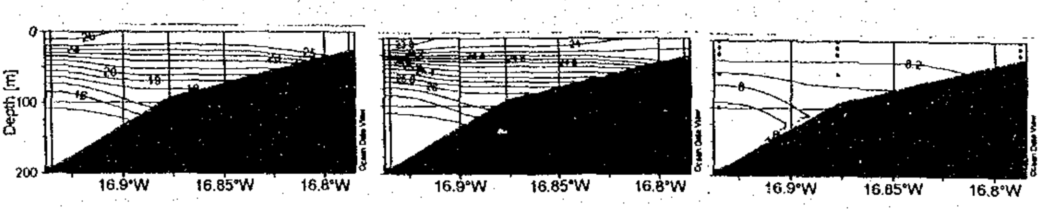
(D) Phase 2 warm season

	Temperature (°C)	σ_t	pH
1. 20°30'N transect	No observation	No observation	No observation

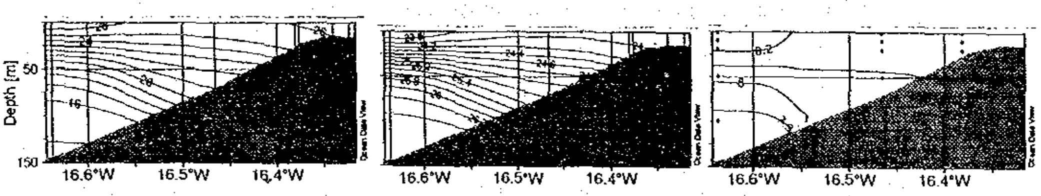
2. 20°N transect



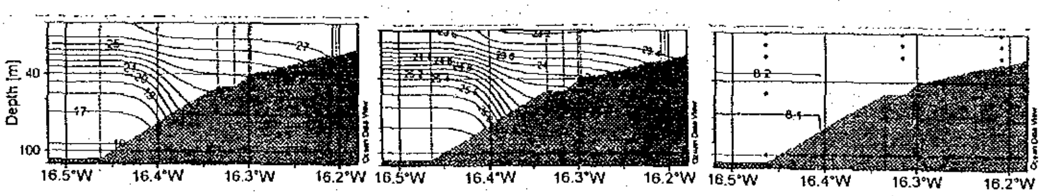
3. 19°30'N transect



4. 19°N transect



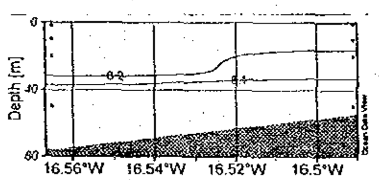
5. 18°N transect



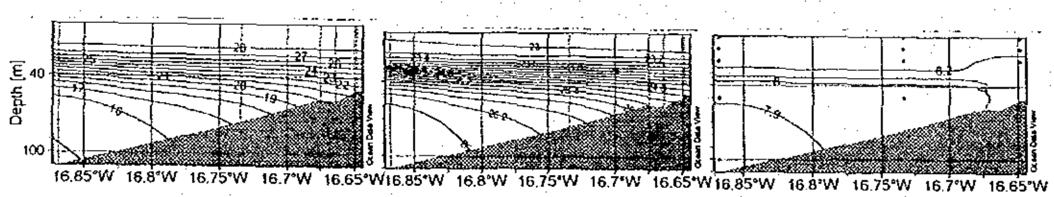
6. 17°N transect

No observation

No observation



7. 16°N transect



Contour lines interval; Temperature:2°C, σ_t:0.5, pH:0.1.

Figure 2.11 continued

(D) Phase 2 warm season (cont.)

	Chlorophyll-a (μ g/ℓ)	NO_2-N (μ mol/ℓ)	NO_3-N (μ mol/ℓ)
1. 20°30'N transect	No observation	No observation	No observation

2. 20°N transect

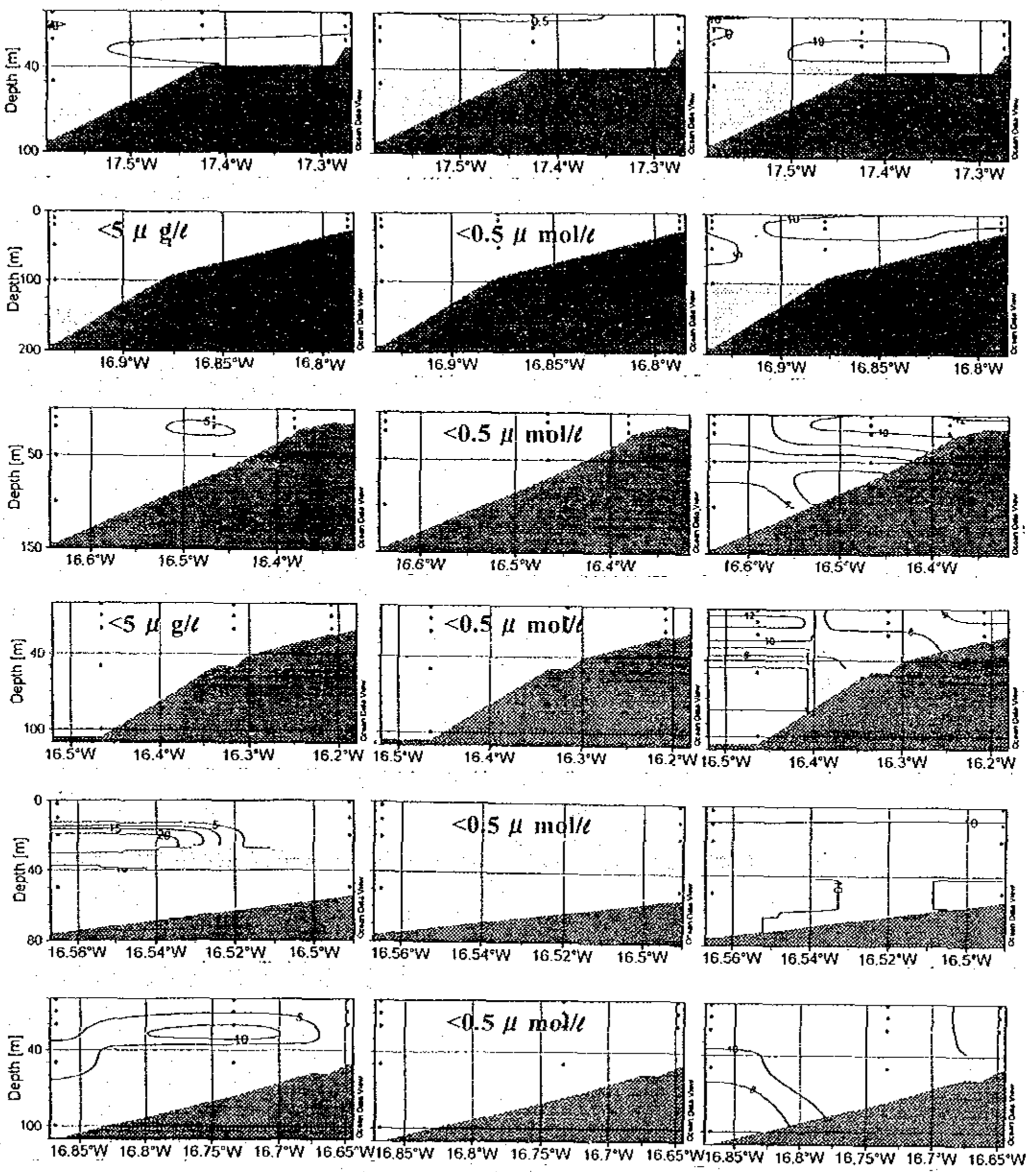
3. 19°30'N transect

4. 19°N transect

5. 18°N transect

6. 17°N transect

7. 16°N transect



Contour lines interval; Chlorophyll-a:5 μ g/ℓ, NO_2-N:0.5 μ mol/ℓ, NO_3-N:5 μ mol/ℓ.

Table 2.3 Summary of meteorology at sea during trawl operations.

1. Weather condition

Survey season			Phase 1		Phase 2	
			Cold season	Warm season	Cold season	Warm season
Number of data			88	126	133	116
Frequency (%)	Weather*	b	70.5	69.0	74.4	33.6
		bc	22.7	14.3	1.5	22.4
		c	6.8	16.7	6.8	44.0
		f	-	-	0.8	-
		(Unobserved)	6.8	16.7	16.5	-
	Air temperature (℃)	20≦A.T.<22	3.4	-	5.3	-
		22≦A.T.<24	38.6	0.8	37.6	-
		24≦A.T.<26	44.3	12.7	42.9	3.4
		26≦A.T.<28	12.5	22.2	10.5	28.4
		28≦A.T.<30	-	49.2	3.0	52.6
		30≦A.T.<32	1.1	15.1	0.8	14.7
		32≦A.T.<34	-	-	-	0.9
		Mean	24.1	28.0	24.2	28.3
		Min.	21.0	23.5	20.5	24.5
		Max.	30.0	31.5	30.0	32.0
	Atmosphere pressure (hPa)	1004≦A.P.<1006	1.1	-	-	-
		1006≦A.P.<1008	-	-	-	-
		1008≦A.P.<1010	3.4	0.8	3.8	-
		1010≦A.P.<1012	17.0	15.9	12.8	9.5
		1012≦A.P.<1014	38.6	37.3	36.1	35.3
		1014≦A.P.<1016	25.0	32.5	33.1	37.9
		1016≦A.P.<1018	13.6	13.5	14.3	12.1
		1018≦A.P.<1020	1.1	-	-	5.2
		Mean	1013.1	1013.6	1013.7	1014.2
		Min.	1004.0	1009.5	1008.2	1010.0
		Max.	1018.0	1017.7	1017.2	1018.6

*: b: blue sky, bc: blue sky with detached clouds, c: cloudy, f: fog

2. Wind condition

(A) Phase 1 cold season

Direction (Frequency (%))	Wind speed (m/s) 0	1≦ <2	2≦ <3	3≦ <4	4≦ <5	5≦ <6	6≦ <7	7≦ <8	8≦ <9	9≦ <10	10≦ <11	11≦ <12	12≦ <13	13≦ <14	Total
N					1.1	2.3	3.4	3.4	2.3	4.5		1.1			18.2
NNE				1.1		1.1	1.1		4.5						8.0
NE						1.1									1.1
ENE			1.1												1.1
E															0.0
ESE															0.0
SE															0.0
SSE															0.0
S															0.0
SSW															0.0
SW															0.0
WSW															0.0
W															0.0
WNW									1.1						1.1
NW					1.1	4.5	2.3	4.5	2.3	1.1	2.3				18.2
NNW						3.4	3.4	12.5	13.6	12.5	4.5	1.1	1.1		52.3
Calm															0.0
Total	0.0	0.0	1.1	1.1	2.3	12.5	10.2	20.5	23.9	18.2	6.8	2.3	1.1	0.0	100.0

(B) Phase 1 warm season

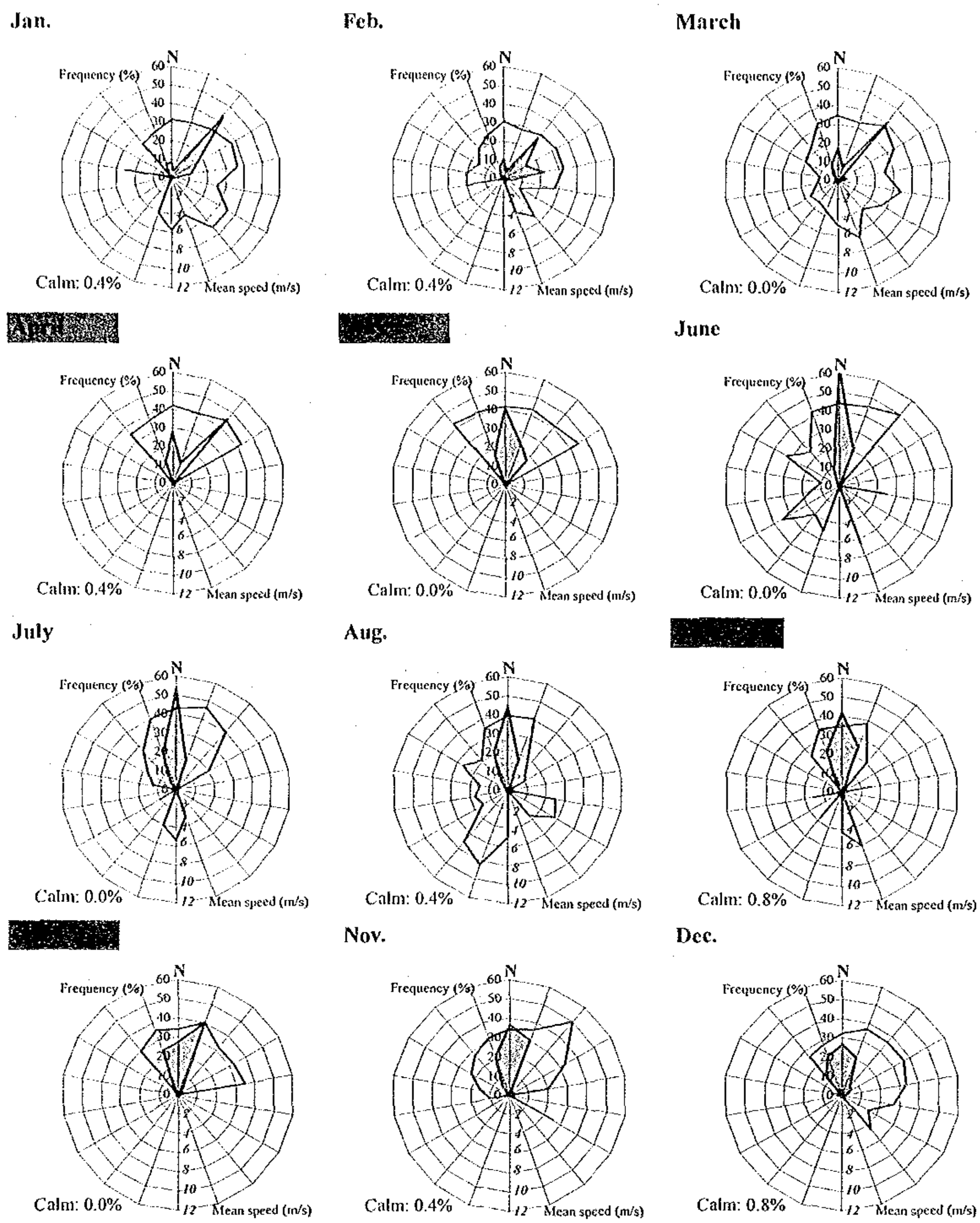
Direction (Frequency (%))	Wind speed (m/s) 0	1≦ <2	2≦ <3	3≦ <4	4≦ <5	5≦ <6	6≦ <7	7≦ <8	8≦ <9	9≦ <10	10≦ <11	11≦ <12	12≦ <13	13≦ <14	Total
N		0.8	1.6	4.8	0.8	5.6	3.2	4.8	7.9	2.4		1.6	0.8	0.8	34.9
NNE							0.8		0.8	0.8	0.8			0.8	4.0
NE			0.8		0.8	0.8			0.8		1.6	0.8	0.8		6.3
ENE															0.0
E				0.8		1.6									2.4
ESE															0.0
SE															0.0
SSE															0.0
S			0.8				1.6								2.4
SSW									0.8						0.8
SW										1.6					1.6
WSW															0.0
W			1.6		1.6	0.8	0.8	1.6	0.8	0.8	0.8				8.7
WNW															0.0
NW			1.6	3.2	2.4	5.6	0.8	3.2	7.9	2.4					27.0
NNW			1.6	0.8		2.4		0.8	3.2	1.6	1.6				11.9
Calm															0.0
Total	0.0	0.8	7.9	9.5	5.6	16.7	7.1	10.3	22.2	9.5	4.8	2.4	1.6	1.6	100.0

(C) Phase 2 cold season

Direction (Frequency (%))	Wind speed (m/s) 0	1≦ <2	2≦ <3	3≦ <4	4≦ <5	5≦ <6	6≦ <7	7≦ <8	8≦ <9	9≦ <10	10≦ <11	11≦ <12	12≦ <13	13≦ <14	Total
N			1.5	2.3	3.0	5.3	6.8	6.8	6.8	2.3	3.0	2.3	0.8	1.5	42.1
NNE						0.8		2.3	1.5						4.5
NE				0.8			0.8								1.5
ENE															0.0
E				0.8		1.5									2.3
ESE															0.0
SE				0.8											0.8
SSE															0.0
S			0.8												0.8
SSW															0.0
SW															0.0
WSW															0.0
W					0.8	1.5	0.8								3.0
WNW			0.8	0.8	0.8	0.8									3.0
NW				0.8	0.8	2.3	1.5		2.3	1.5		0.8			9.8
NNW		0.8	0.8		0.8	2.3	9.0	5.3	5.3	3.8	3.0	0.8			31.6
Calm	0.8														0.8
Total	0.8	0.8	3.8	6.0	6.0	14.3	18.8	14.3	15.8	7.5	6.0	3.8	0.8	1.5	100.0

(D) Phase 2 warm season

Direction (Frequency (%))	Wind speed (m/s) 0	1≦ <2	2≦ <3	3≦ <4	4≦ <5	5≦ <6	6≦ <7	7≦ <8	8≦ <9	9≦ <10	10≦ <11	11≦ <12	12≦ <13	13≦ <14	Total
N		5.2	6.9	5.2	0.9	1.7	2.6	6.3	2.6	4.3	3.4	0.9			40.0
NNE				0.9			0.9		0.9		0.9		0.9		4.3
NE				0.9	0.9	0.9									2.6
ENE					0.9		0.9								1.7
E			0.9	1.7											2.6
ESE				0.9			0.9								1.7
SE			0.9		1.7	0.9									3.4
SSE														0.9	0.9
S			1.7	0.9	2.6	0.9					0.9				6.9
SSW			0.9		1.7	0.9		0.9							4.3
SW		0.9	0.9	0.9	1.7										4.3
WSW															0.0
W															0.0
WNW								0.9							0.9
NW				3.4	0.9	0.9	1.7	1.7	2.6		0.9				12.1
NNW					0.9		2.6	1.7	4.3	2.6			0.9		12.9
Calm	0.9														0.9
Total	0.9	6.0	12.1	14.7	12.1	6.0	9.5	11.5	10.3	6.9	6.0	0.9	1.7	0.9	99.5



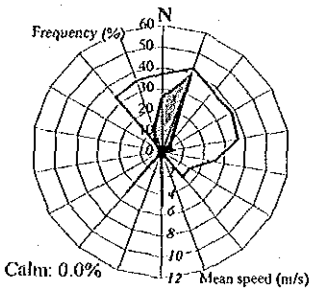
Frequency of wind direction: Painted, Mean wind speed: Line, Survey season: Halftone screening

Figure 2.12 Frequency distribution of wind direction and mean speed on land (Nouadhibou, 2000).

Source: ASECNA.

Figure 2.12 continued

Jan.



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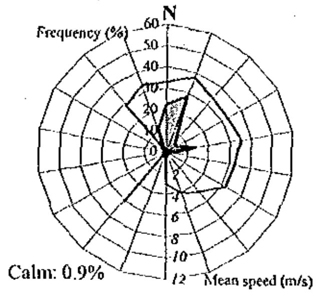

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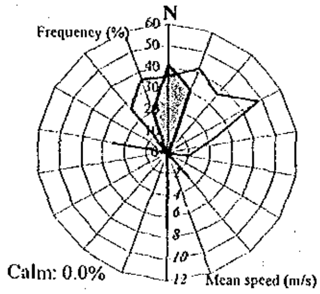

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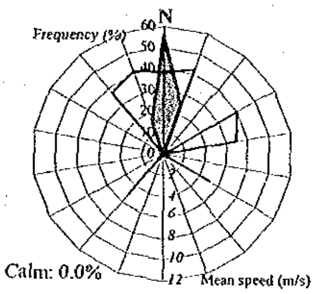

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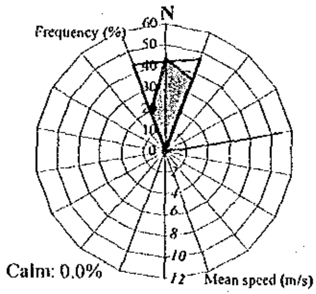

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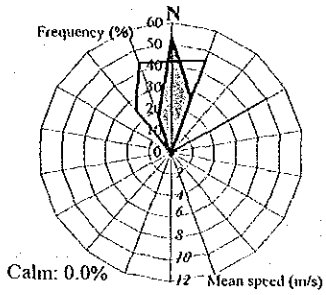

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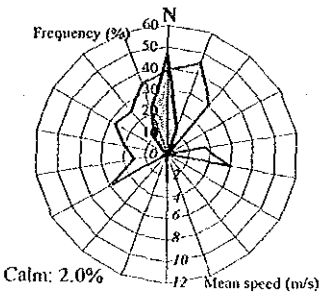

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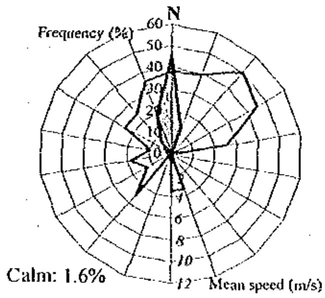

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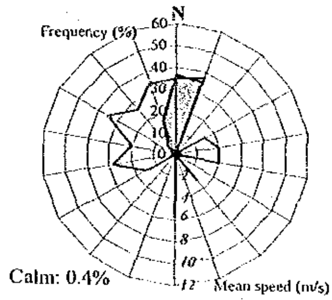

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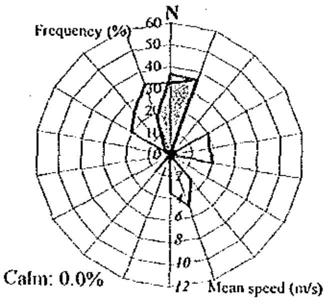
Nov.

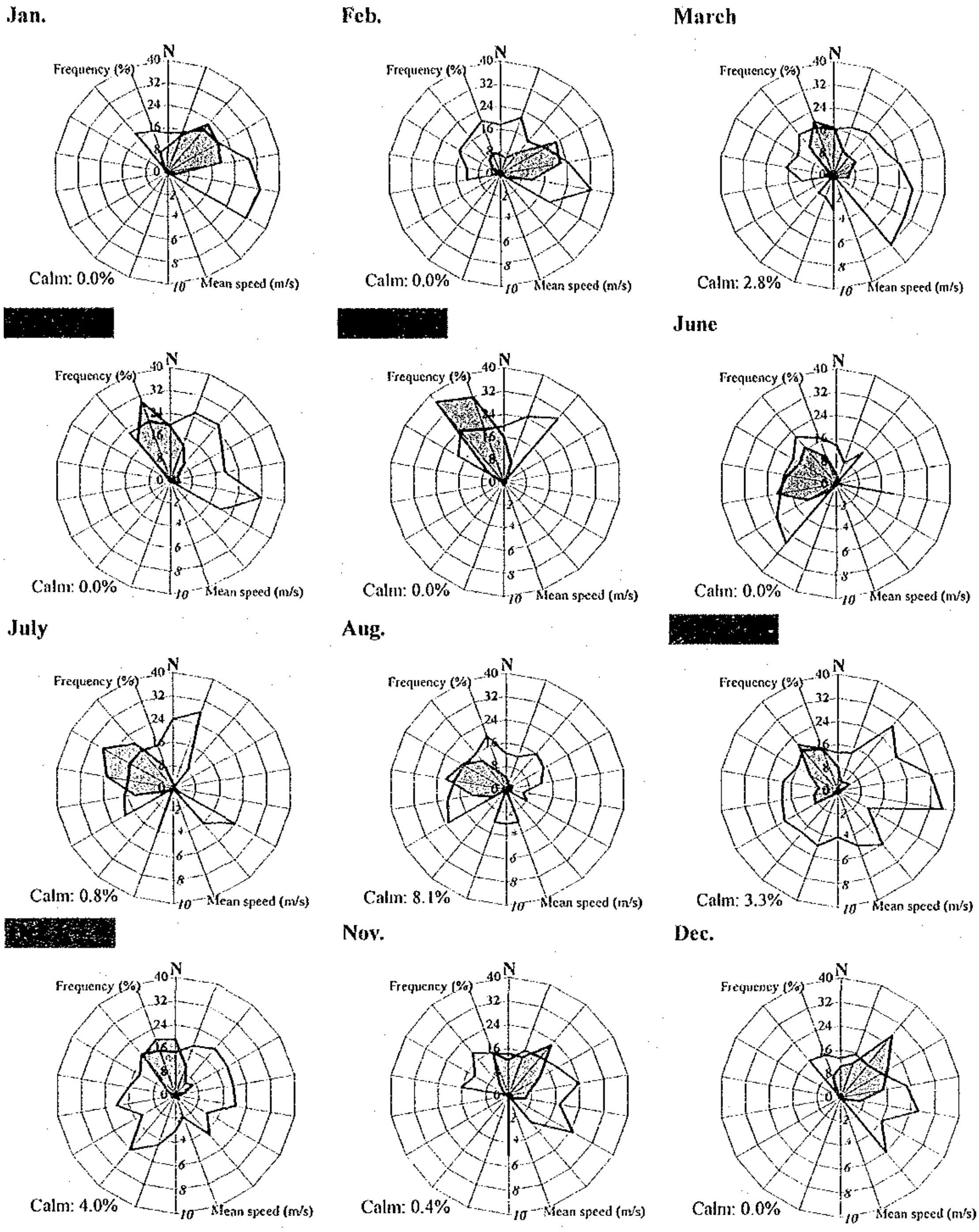
Dec.



Frequency of wind direction : Painted, Mean wind speed : Line, Survey season : Halftone screening

Figure 2.12 (cont.) Frequency distribution of wind direction and mean speed on land (Nouadhibou, 2001).
Source: ASECNA.

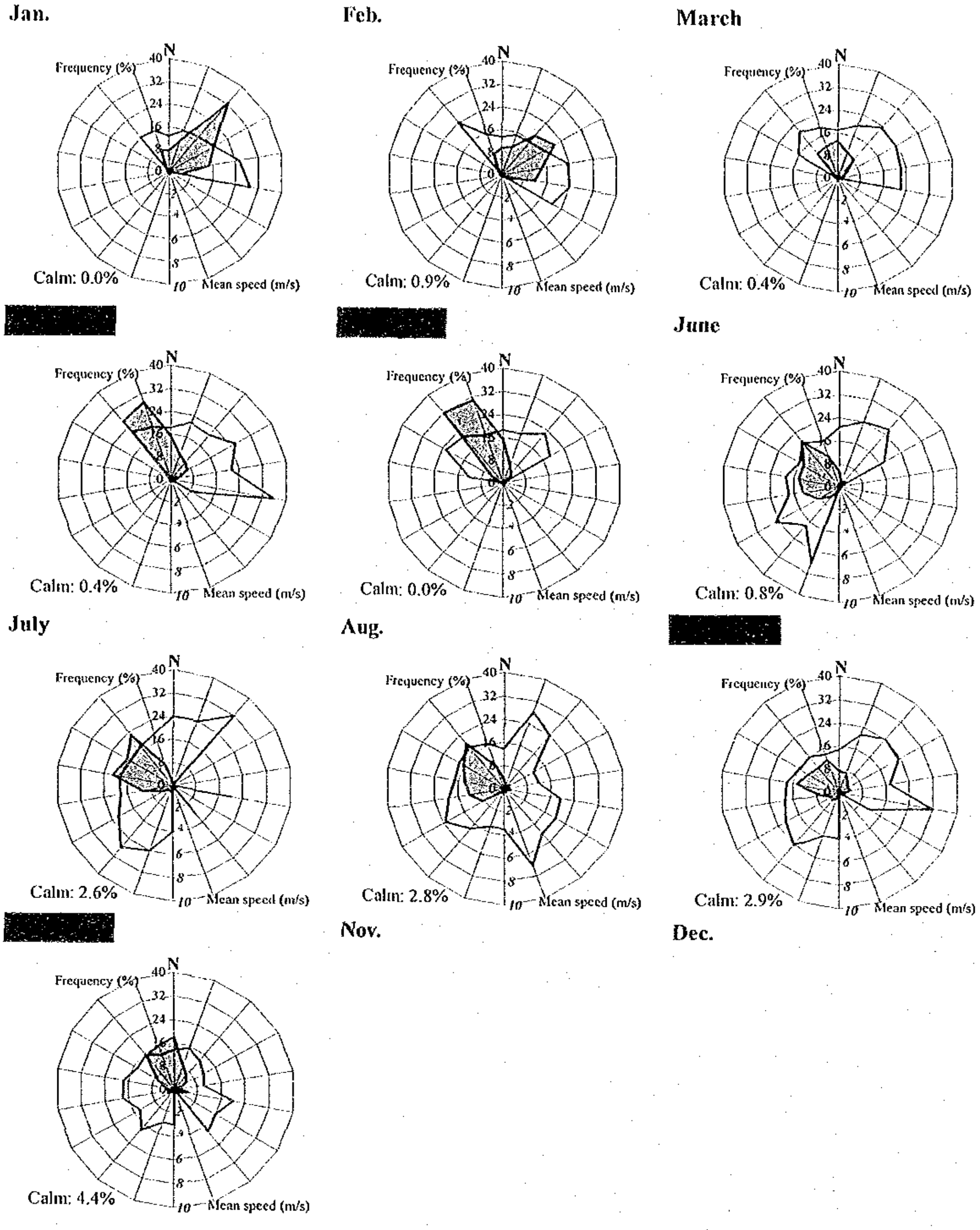
Figure 2.12 continued



Frequency of wind direction: Painted, Mean wind speed: Line, Survey season: Halftone screening

Figure 2.12 (cont.) Frequency distribution of wind direction and mean speed on land (Nouakchott, 2000).
Source: ASECNA.

Figure 2.12 continued



Frequency of wind direction: Painted, Mean wind speed: Line, Survey season: Halftone screening

Figure 2.12 (cont.) Frequency distribution of wind direction and mean speed on land (Nouakchott, 2001).
Source: ASECNA.

2.4 Oceanic environment of the survey area

2.4.1 Oceanic environment by data

Results of this oceanographic observation were obtained from observations conducted in two seasons in a year, or a total of four seasons, which is not enough considering the annual seasonal variations. For this reason, a simple review of existing reports on seasonal variations and upwellings was compiled.

(1) Seasonal variations in the survey area

Generally, the climate in IRM is determined by the function of the following three action centers (Bambaye, 2001):

- The Azores anticyclone center producing trade wind.
- The intertropical front producing rain and south or southwest winds.
- The warm cyclone producing east winds and harmattan (wind blown from the Sahara desert).

A transfer of these three action centers in a year has direct or indirect influence on the hydrographic conditions in the EEZ of Mauritania. For this reason, oceanic environment in the EEZ shows a certain seasonal variation.

Dubrovine *et al.* (1991) proposed four seasons based on seasonal variations of temperature in the EEZ of the IRM (offshore zone).

1. Cold season: January–May. Period in which the entire area is affected by the Canary Current. Water temperature 17.5 - 19.1°C.
2. Transitional season: June–July. Period in which the Canary Current and the Guinea Current mix near NKC. Water temperature 18.7–25.6°C.
3. Warm season: August–October. Period in which the entire area is affected by the Guinea Current. Water temperature 21.4–27.7°C.
4. Transitional season: November–December. Period in which the Canary Current and the Guinea Current mix near NKC. Water temperature 18.0–21.8°C.

Also, according to Hatanaka (1979), the temperature during octopus fishing ground in the Northern area was relatively low because of the influence of the Canary Current, and that except for some localized spots along the coast, surface water temperature was within 17–26°C. Additionally, as upwellings are formed every year north of Cape Timiris, the vertical gradient of water temperature is weak.

Figure 2.13 shows seasonal variations of surface water temperature in the Banc d'Arguin zone, according to Dubrovine *et al.* (1991). As it is indicated, minimum temperatures are in January-March, and maximum temperatures in August–October. Annual temperature differences are small near Cape Blanc, and significant in the bay-depth, the southern part of the bay and north of Lévrier Bay.

Hatanaka (1979) also reported that the range of annual variation of salinity was narrow in the Northern area of the EEZ of the IRM (35.8–36.4). Those values are relatively high throughout the year because there is little inflow of fresh water. Also, the halocline could not be observed year round north of Cape Timiris.

Based on those data, the present observation was planned and conducted during the cold and warm seasons indicated. The comparison between values of water temperature of the present observation and the annual observation is explained in full detail in 2.4.2.

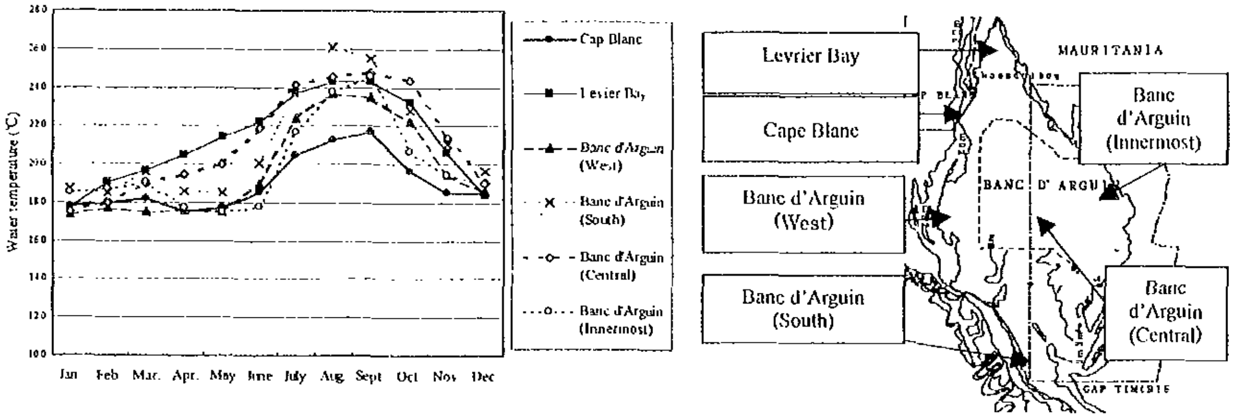


Figure 2.13 Mean temperature of surface water by month in the zone near Banc d'Arguin (1952-1988). Dubrovine *et al.* (1991).

(2) Upwellings

The existence of upwellings is considered a characteristic phenomenon of the oceanic environment of the survey area. A summary of those upwellings are presented below.

The upwellings on the northwesterrn coast of the African continent (Table 2.4) are considered wind-driven upwellings formed by the interaction between the offshore current and the compensation current. The former current area caused by the dominant wind that blows parallel to the continent toward the Equator (Nasu, 1975). On the upwellings in the IRM, Hatanaka (1979) reported that north–northeast winds of force 2 to 7 (annual mean : 4) blow almost every year, and that those seasonal rise and fall determine the strength or the weakness of the upwellings. Every year between 20° N and 25° N, upwellings appear and are more active around Cape Blanc in June, accompanied by a drop in water temperature and salinity. Under their action, the thermocline and the halocline are not formed. The February 1972 report of the joint Federal Republic of Germany/USA observations conducted between Cape Blanc and Cape Timiris (Voorhis *et al.*, WHOI) points out that the vertical current is not constant, but oscillating, that depth also varies upwards and downwards, and that the upwelling speed is of 0.56 cm/s. Also, upwellings being formed relatively close to the bottom, they are strongly influenced by submarine canyons (Uda, 1974).

Faure *et al.* (2000) referred to the oceanic stricture in the upwelling zone in the IRM attending to the intensity of upwelling, the turbulent flow by the wind and the residence on the coast. According to their report, the upwelling starts in October, reaches the maximum intensity in January to May and becomes the minimum intensity around September. Moreover, the residence phenomenon becomes the minimum in January and reaches the maximum in April to June. They reported that these oceanic structure on the coast was strongly related to the wind direction and velocity.

In the present observation as well, localized distributions of low water temperatures were observed at the surface layer offshore west of Cape Blanc and on the south coast of Cape Timiris in the cold season, suggesting the formation of upwellings. Also, the gradient of isopycnic in the section of vertical distribution from east to west (Figure 2.11), and the dome-shaped distribution of isopycnic surface between 18° N and 20° N in the vertical section from south to north, are considered due to the upwelling phenomenon.

Table 2.4 Scale of upwelling currents and annual basic production on the northwestern coast of Africa (Canary Current zone). Cushing, 1969: Modification by Nasu.

Sea area	Season (month)	Length (km)	Width (km)	Surface area (km^2)	Annual basic production (tonnes C/year)
Freetown – Dakar	10, 11, 12, 1, 2	800	50	40×10^3	$34{,}80 \times 10^6$
Dakar – Cape Blanc	10, 11, 12, 1, 2, 3, 4	700	150	105×10^3	$12{,}19 \times 10^6$
Cape Blanc – Canaries	4, 5, 6, 7, 8, 9	1.020	300	306×10^3	$31{,}40 \times 10^6$
Canaries – Casablanca	4, 5, 6, 7, 8, 9	1.000	150	150×10^3	$12{,}83 \times 10^6$
Cape St. Vincent – Vigo	6, 7, 8, 9, 10	600	150	90×10^3	

2.4.2 Oceanic environment during the survey period

In order to see the feature of surface water temperature distribution in this survey period, the anomaly of water temperature is shown in Figure 2.14. The value of the WOA 98 of NODC was used here as an usual year. The values in the cold and warm seasons were compared with those in April and September of WOA 98 respectively.

(1) Cold season

From the anomaly distribution of surface water temperature in the cold season, the high surface water temperature both in Phase 1 and Phase 2 was observed. This positive anomary was distributed from Cape Timiris to south of Banc d'Arguin. According to Mahfoudh *et al.* (in preparation), in the cold season of 2001, the surface water temperature in the Banc d'Arguin was typical of the seasonal character being thermo-homogeneous owing to decrease in the temperature gradient. The surface water temperature showed a tendency to increase north to south of Cape Timiris and east of Banc d'Arguin. Off north of Cape Timiris, the comparative high water of 21°C was observed. This phenomenon is considered due to the advection of oceanic warm water. Excepting the abovementioned areas the negative anomaly was prevailing over the continental shelf. The negative anomary in Phase 1 and Phase 2 reached -5°C and -3°C respectively. The remarkable decrease in the surface water temperature extending over two Phases suggested that the activity of upwelling had been raising during that period. The surface water temperature offshore in Phase 1 and Phase 2 ranged 14.5 to 19.0°C, 15.3 to 21.4°C respectively. The mean temperature was between 17.5 and 22.7°C (Doubrovine *et al.*, 1991) and 16.9 to 22.7°C of WOA 98 (April).

Except for the Northern coastal area, the structure of the oceanic environment in the survey area in the cold season was horizontally and vertically more uniform (low temperature, high density) than in the warm season (Figure 2.3-2.5). This is due to the influence of the Canary Current and upwellings characterize the oceanic environment in this area in the cold season with intesification of the trade wind. The effect of the Canary Current was also observed on the distribution of water masses north of Cape Timiris (except for the coastal area) (Figure 2.10). From the standpoint of water masses, the south of that area is where water masses of the Canary Current type mix with those of the Guinea Current type (SS shown in Table 2.1) from the south. However, there are no warm water masses of the Guinea Current type in the cold season (Figure 2.10). As no front was clearly identified in the cold season, the oceanic structure divide is considered as offshore Cape Timiris. In the Northern area, the sub-surface current (at 4 m below surface) flowing from the offshore to the continental slope was observed (Figure 2.6). This current was supposed to originate an upwelling water moving from the bottom layer to the surface layer in the shallow coastal area.

In the Northern coastal area, and particularly in the PNBA zone (east of 16°45' W), there was a water mass relatively warmer and strongly saliner than in other areas (Figure 2.10). Increase in water temperature and salinity is thought to be due to topographic characteristics of shallow waters and to the effect of the sun, thermohaline levels being considered in relation to the amount of exchange with offshore waters (or the residence time). This warm water mass observed off Cape Timiris and Cape Blanc (Figure 2.3, 2.6) was flowed offshore by the influence of the current observed south of Cape Blanc (Figure 2.6).

(2) Warm season

From the anomaly distribution of surface water temperature in the warm season of Phase 1 and Phase 2, the comparative low water temperature was observed in north of 19°N. In south of 19°N, the temperature was slightly high. This result suggested that the negative and positive anomalies were prevailing in north and south of 19°N respectively. In Phase 1, the negative anomaly offshore of Cape Timiris indicated -3°C. It suggested that the warm current flowing up northwards was dispersed than usual year. The surface water temperature offshore ranged 18.5 to 29.6°C in Phase 1 and 26.6 to 29.6°C in Phase 2. The mean temperature was in range of 17.5-22.7°C . According to Doubrovine *et al.* (1991), the mean water temperature in the warm season ranged from 21.9 to 28.2°C.

The oceanic structure in the survey area was more complex in the warm season than in the cold season. The water mass with water temperature above 28°C and low density not to be observed in the cold season offshore Cape Timiris and toward the south, was distributed near the surface layer (Figure 2.3-2.5). Its distribution was recorded at less than 50 m deep, close to the Senegalese border, the its thickness declining northward (Figure 2.4). Its characteristics and the dominant northward current led to believe it was a Guinea Current type water mass. Also, no significant difference from the oceanic structure in the cold season was observed north of Cape Timiris (Figure 2.10). In the warm season, the surface water temperature in the front area located off Cape Timiris ranged from 22°C to 24°C (Figure 2.10). Those water masses were distributed shallower than 50m depth in the Southern area. Also, high-density chlorophyll-a was distributed near this front, suggesting there was a favorable area for the primary and secondary productions (Figure 2.11). No significant difference from the cold season was confirmed for the oceanic structure for depths over 100 m (Figure 2.4, 2.10). This water mass was presumed to be Central North Atlantic waters. In Phase 2, a distribution of low salinity water, presumedly influenced by the inflow of freshwater from the Senegal River, was reported in the coastal area near the Senegalese border (Figure 2.3). In the Central coastal area, besides the warm water, an increase in salinity was observed, suggesting a stagnation of the water mass, as in the Banc d'Arguin.

Like in the cold season, a water mass relatively warmer and strongly saliner than in other areas existed in the Northern coastal area, particularly around Banc d'Arguin. Considering the southward extension of high temperature water seen at the surface layer off Cape Timiris (Figure 2.3) and the current near Cape Blanc (Figure 2.6), much like in the cold season, it was thought that water mass was placed over a current that moved clockwise, going toward the open sea off north of Cape Timiris.

Also, as the wind was weaker than in the cold season (Table 2.3, Figure 2.12), the influence of the upwelling restricted particularly in the Central and Southern areas.

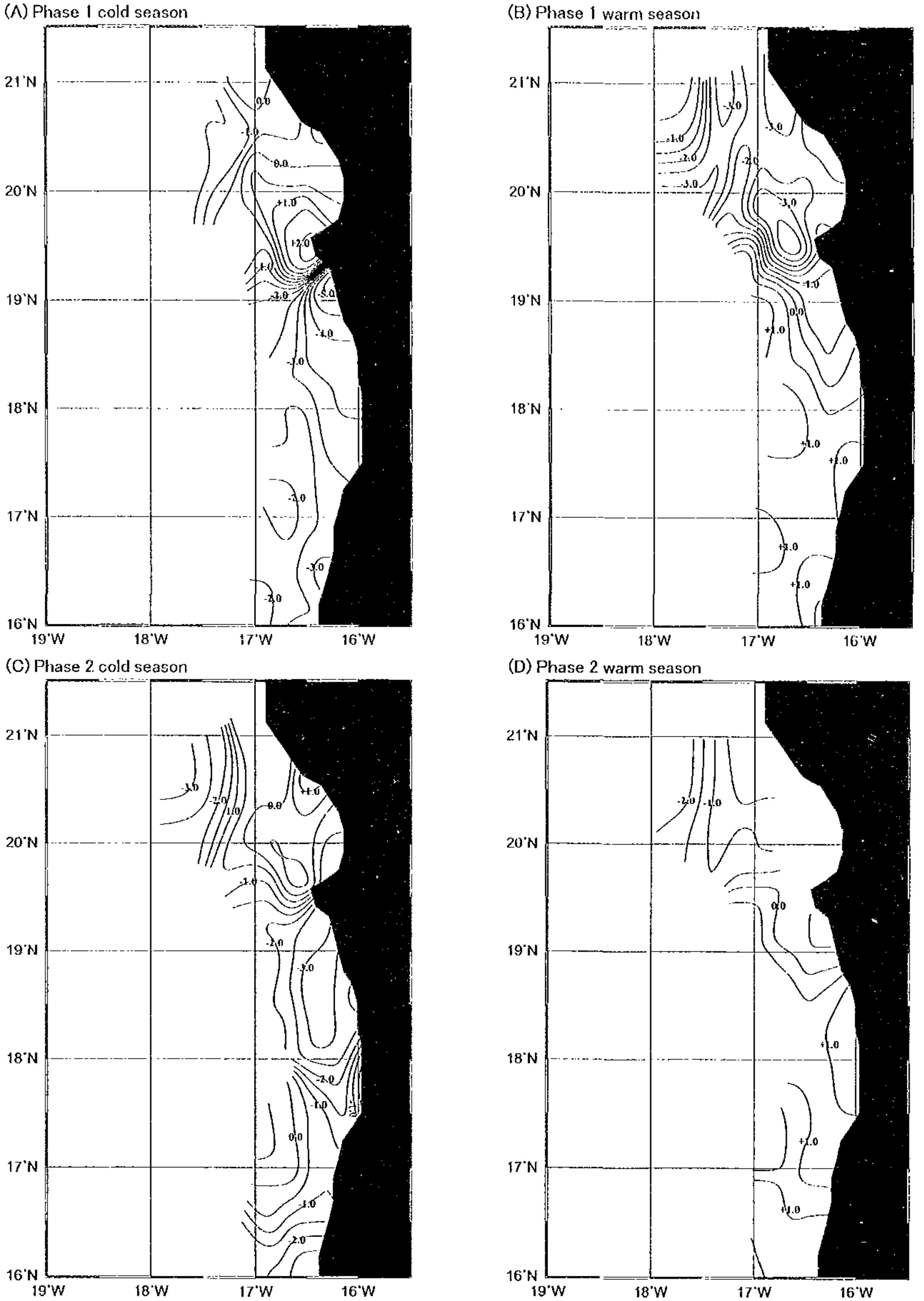


Figure 2.14 Anomaly of water temperature in this sucvey period.