Chapter 3

Results

3.1 Estimation of Chlorophyll-a from fluorescence data

Since phytoplankton data was available only at surface layer, fluorescence data and Chlorophyll-a data were used to assume phytoplankton abundance in the water column. Relationship between chlorophyll-a and fluorescence data in the corresponding water sample of September 1995 and April-May 1996 data set can be explained by equations 3.1 and 3.2, respectively. Calculated chlorophyll-a data were show in Appendix B and C.

An equation of September 1995 data set (Fig. 3.1) was

$$\text{Calibrated chlorophyll a (mg chl m}^{-3}\text{)} = 0.0144\ V + 0.0358 \qquad \text{—— (3.1)}$$

$N = 68$, r^2 0.3148, $P < 0.01$

Equation of data set of the April 1996 (Fig. 3.2) was

$$\text{Calibrated chlorophyll a (mg chl m}^{-3}\text{)} = 0.2646\ V - 0.0338 \qquad \text{—— (3.2)}$$

$N = 41$, r^2 0.5818, $P < 0.001$

V = fluorescence in unit volt from fluorometer measurement

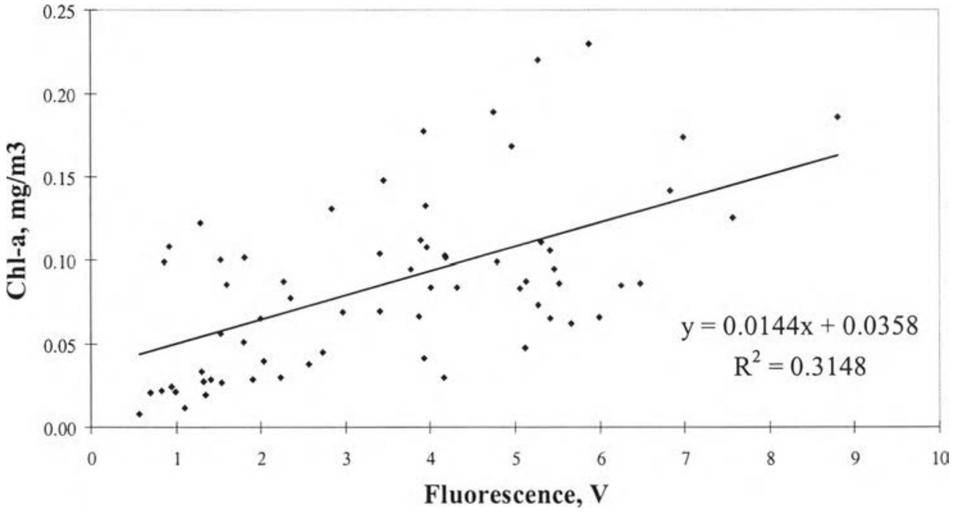


Figure 3.1 Relationship between chlorophyll-a (mg/m³) and fluorescence (V) of the September 1995 data set.

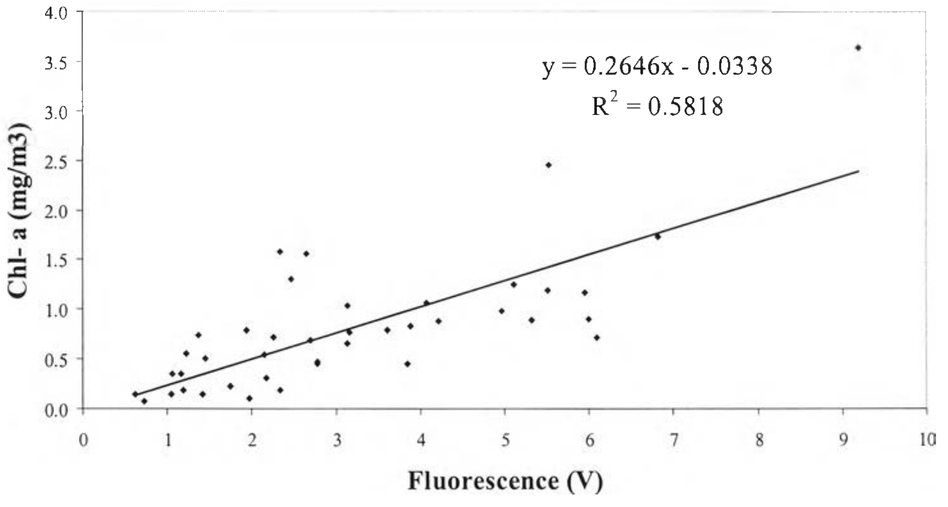


Figure 3.2 Relationship between chlorophyll-a (mg/m^3) and fluorescence (V) of the April-May 1996 data set.

3.2 AOU and Preformed Nitrate

AOU and preformed nitrate were calculated following equation 2.1 and 2.3 respectively. Calculated results were shown in Appendix B.

AOU was low at surface and increase with an increasing of depth in both seasons. The average of AOU at bottom layer of September 1995 was higher than of April 1996 (Fig. 3.3 a-f). In September, the ranges of AOU at surface (0-10 m), mid depth (10-40 m) and bottom (>40 m) were –0.184 to 0.045, -0.368 to 0.604 and –0.166 to 1.701, respectively. High AOU was observed at bottom of off shore of Surat Thani and Nakhon Si Thammarat province and Southern part of Peninsular Malaysia (Fig. 3.3 c).

In April, the range of AOU at surface, mid depth and bottom were –0.762 to 0.425, -0.642 to 0.543 and –0.432 to 2.275, respectively. High AOU was observed at bottom of off shore of Chumporn province (Fig. 3.3 c).

Distribution of preformed nitrate was opposite to AOU. High preformed nitrated was observed at surface layer especially in the southern of East Coast of Peninsular Malaysia in April 1996 and decrease with decreasing the depth. However, there was a different pattern at the southern most of Peninsular Malaysia in September 1995 that high preformed nitrate was observed at bottom. Ranges of preformed nitrate at surface, mid depth and bottom of September 1995 were –0.005 to 1.649 μM, -1.267 to 2.085 μM and –3.818 to 8.588 μM respectively. And in April 1996 were –1.960 to 5.290 μM, -2.310 to 3.950 μM and –6.780 to 3.490 μM, respectively (Fig. 3.4 a-f).

The difference of AOU and preformed nitrate in each area could support the possibility to use AOU and preformed nitrate as parameters to identify water mass.

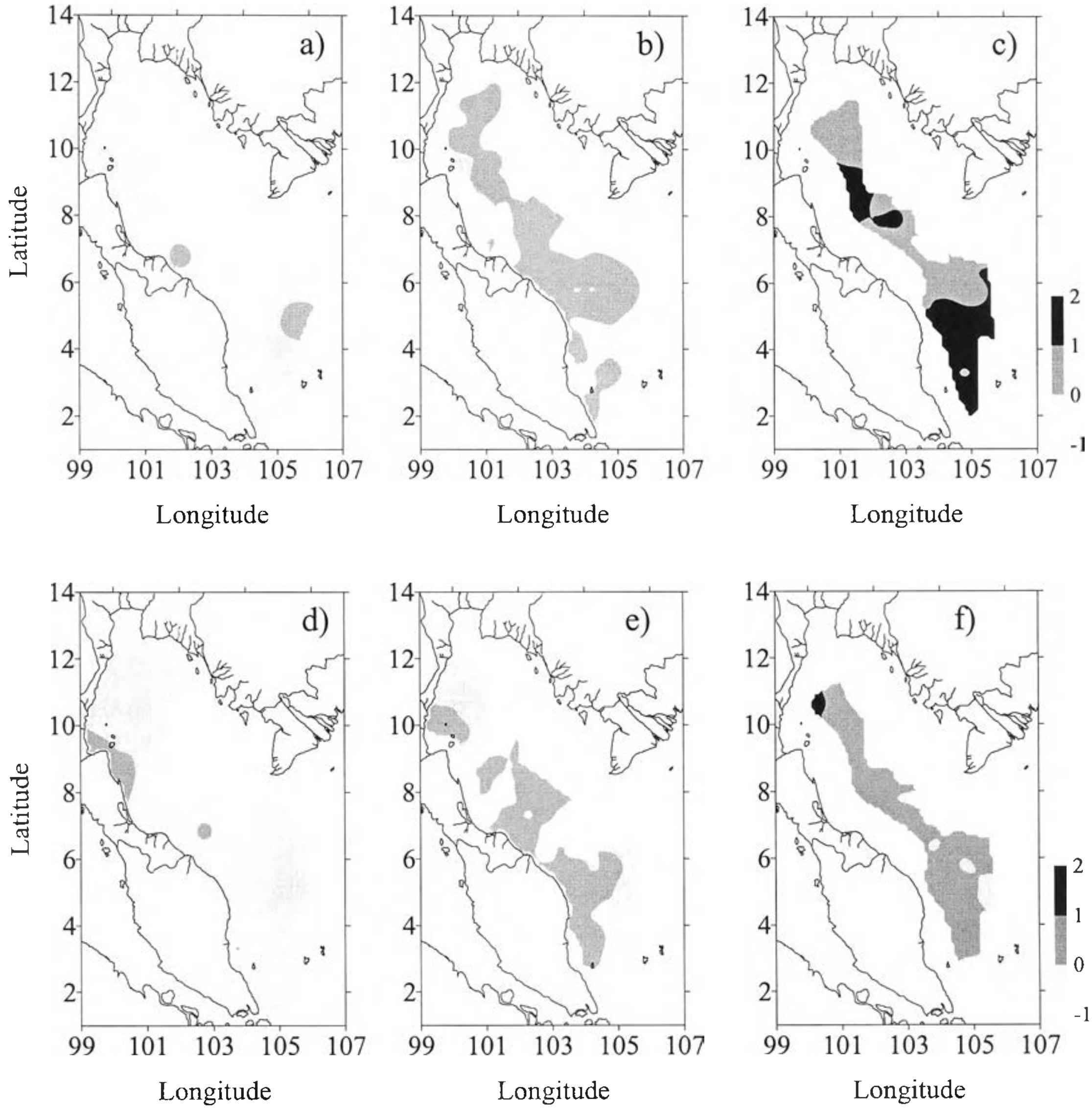


Figure 3.3 Horizontal distribution of AOU in September 1995 at a) surface (0-10 m), b) mid depth (10-40 m) and c) bottom (<40 m) and in April- May 1996 at d) surface, e) mid depth and f) bottom

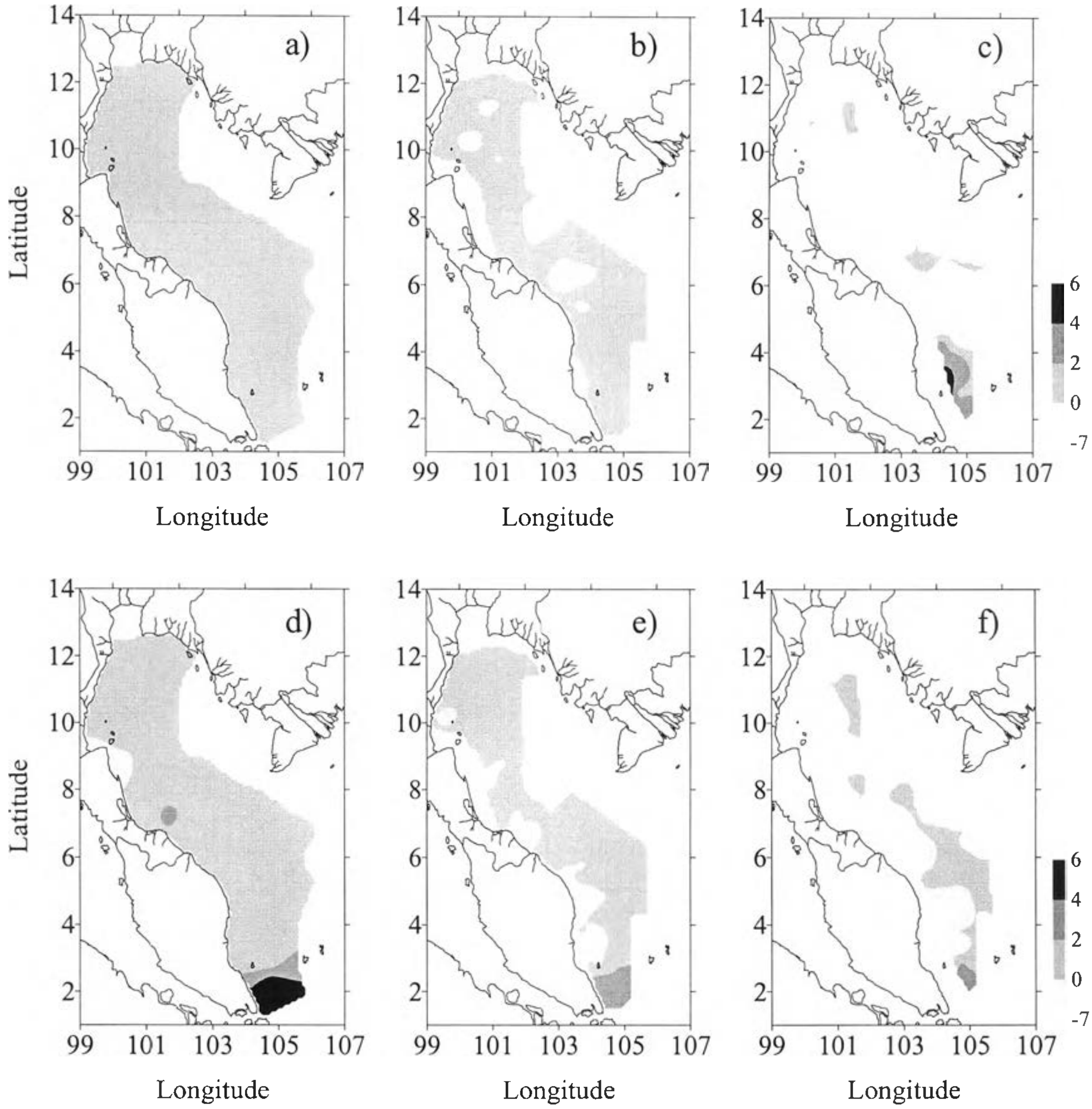


Figure 3.4 Horizontal distribution of preformed nitrate (μM) in September 1995 at a) surface (0-10 m), b) mid depth (10-40 m) and c) bottom (<40 m) and in April- May 1996 at d) surface, e) mid depth and f (bottom)

3.3 Water masses identification

3.3.1 By TS-diagram

Water masses in the study area from two seasons were identified by TS-diagram as five masses (Fig.3.5). The first water mass (mass 1) was characterized by high temperature between 28-30.5 °C and low salinity between 31.5-32.5 psu. Mass 1 was found in the inner of the Gulf of Thailand during April-May 1996(Fig. 3.6 c and d).

The second water mass (mass 2) was characterized by temperature between 29.5-30.5 °C and salinity between 32.5-33.5 psu. This water mass was found at the mixed layer water near the mouth of the Gulf of Thailand during April-May 1996 (Fig. 3.6 c).

The third water mass (mass 3) was characterized by temperature 27-30.5 °C and salinity 33.5-34 psu. It was found at the area of the mouth of the Gulf of Thailand (Fig.3.6 c and d).

The fourth water mass (mass 4) was characterized by temperature between 25-30 °C and salinity between 32.5-34 psu. This type of water was found in the whole area of study in September 1995 and the southern and Middle part of the study area during April- May 1996 (Fig. 3.6 a - d).

The fifth water mass (mass 5) was characterized by temperature between 23.5-26 °C and salinity more than 34 psu. It was found at the bottom layer (more than 50 meter) of off shore of eastern Peninsular Malaysia (st. 63-69, 73,74 and 78) in September 1995 (Fig.3.6 b).

3.3.2 By TS-time diagram

TS-time diagram was used to identify water mass in the mixed layer (Fig.3.7). Three water masses can be identified. The characteristic of the three water masses (table 3.2) and their distribution were as follow:

1. Surface mass 1 was characterized by high temperature between 29.5-30.5 °C and low salinity between 31.5-32.25 psu. It was found at all stations in the study area of April - May 1996 except the station at the boundary between the Gulf of Thailand and the southern most of Peninsular Malaysia (Fig. 3.8 b).

2. Surface mass 2 was characterized by temperature between 29.5 to 30.5 °C and salinity more than 33.25 psu. It was found during April-May 1996 at the mouth of the Gulf of Thailand, station no. 46, 47 and 55 to 58 (Fig. 3.8 b).

3. Surface mass 3 was characterized by low temperature between 28.5-29.5 °C and salinity between 32.5-33.25 psu. It was found at the all stations of September 1995 and the southern most of Peninsular Malaysia station no. 64, 65 and 68 to 81 during April-May 1996 (Fig.3.8 a and b).

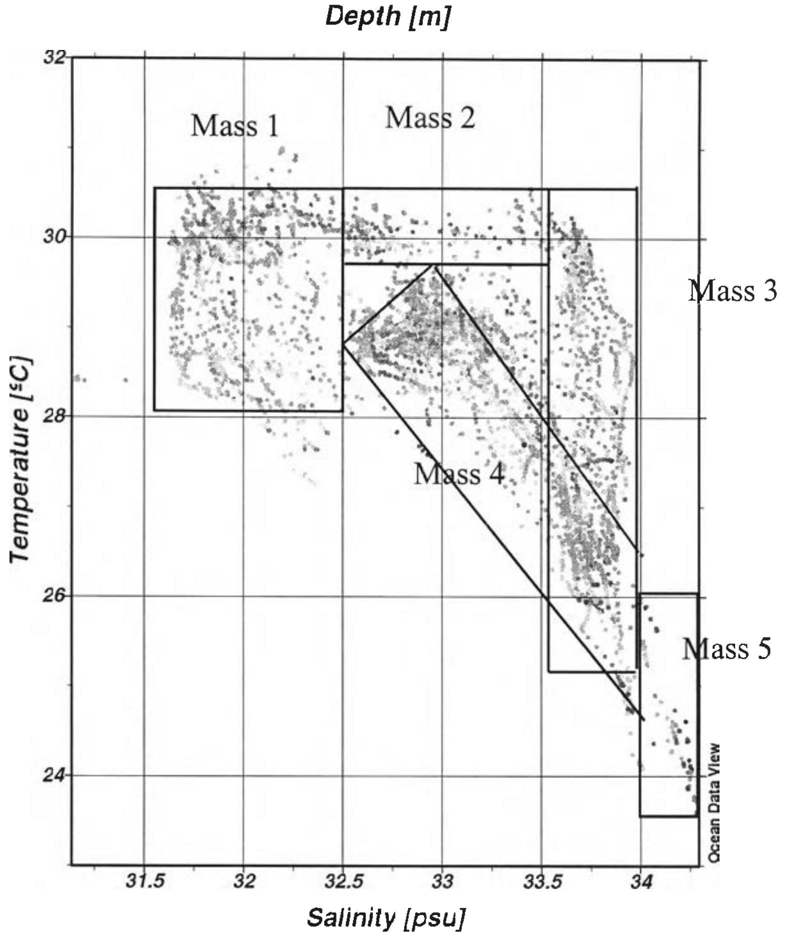
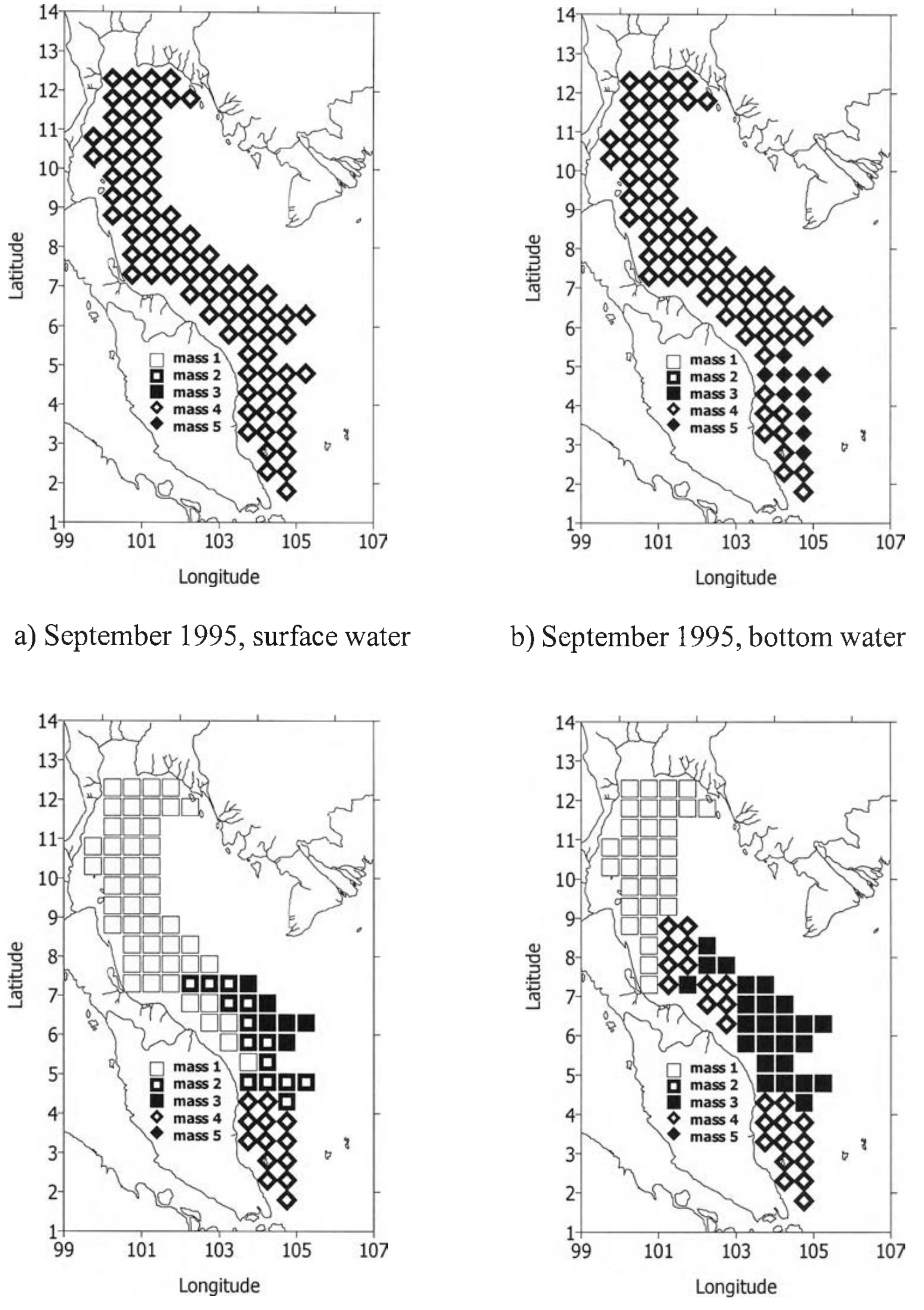


Figure 3.5 TS-diagram of all data.

Table 3.1 Type of water masses identified by TS-diagram

Type of water mass	Temperature range (^{o}c)	Salinity range (psu)	period	Area
mass1	28-30.5	31.5-32.5	Apr-May 1996	Inner Gulf of Thailand
mass 2	29.5-30.5	32.5-33.5	Apr-May 1996	Surface layer of the mouth of the Gulf of Thailand
mass 3	25-30.5	33.5-34	Apr-May 1996	Surface and bottom layer of the mouth of the Gulf of Thailand
mass 4	25-29.5	32.5-34	Sept 1995 Apr-May 1996	All over the study area Southern and Middle of the study area
mass 5	23.5-26	34-34.5	Sept 1995	Bottom layer of the southern of study area



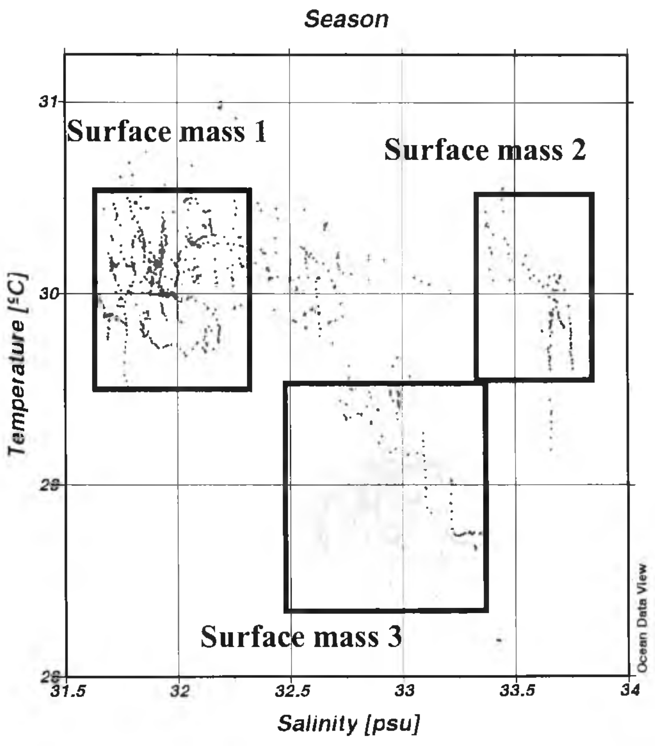
a) September 1995, surface water

b) September 1995, bottom water

c) April-May 1996, surface water

d) April-May 1996, bottom water

Figure 3.6 Distribution of water masses identified by TS-diagram



● Surface layer of September 1995
Surface layer of April 1996

Figure 3.7 TS-time diagram of mixing layer from two data sets.

Table 3.2 Type of water masses identified by TS-time diagram

Type of water mass	Temperature (^{o}c)	Salinity (psu)	Period	Area
Surface mass 1	29.5-30.5	31.50-32.25	Apr 1996	Gulf of Thailand and northern part of Peninsular Malaysia
Surface mass 2	29.5-30.5	>33.25	Apr 1996	Boundary between the Gulf of Thailand and South China Sea
Surface mass 3	28.5-29.5	32.5-33.25	Sept 1995 Apr 1996	All observation area Southern part of Peninsular Malaysia

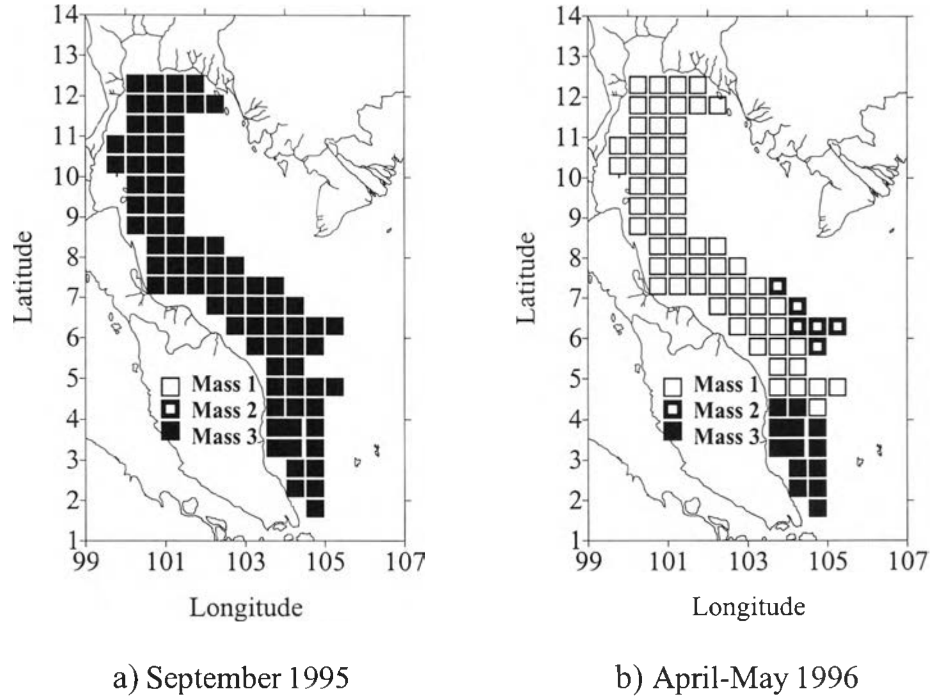


Figure 3.8 Distribution of type of water masses from TS-time diagram

3.3.3 By OMP-analysis

Only bottom layer water (under stratification layer) were identified by OMP-analysis.

3.3.3.1 Source of Water masses

The area of inner Gulf of Thailand, South China Sea and southern most Peninsular Malaysia were assumed from the feature of study area as a source of water mass (Fig.1.1). All available parameters of those three areas were plotted against temperature to find the water type definition. (Fig. 3.9, 3.10 and 3.11).

Six water types were found from OMP-analysis. Water type definitions, including the computed weights for the observed parameters were in table 3.3 and schematic representation of the typical TS, T-AOU and T-preformed No_3 were shown in Fig. 3.12.

1.Watermass of the Gulf of Thailand (GOT water mass) was represented by data from April 1996 st. no. 8, 9, 11, 12, 13, 14, 15 and 16.

Linear equation of the GOT water mass (Fig. 3.9)

$T = -2.0431S + 94.214$, $r^2 = 0.4538$, $n = 25$, $P < 0.05$ —— (3.3)

$T = 0.2865Pn + 28.87$, $r^2 = 0.5847$, $n = 25$, $P < 0.005$ —— (3.4)

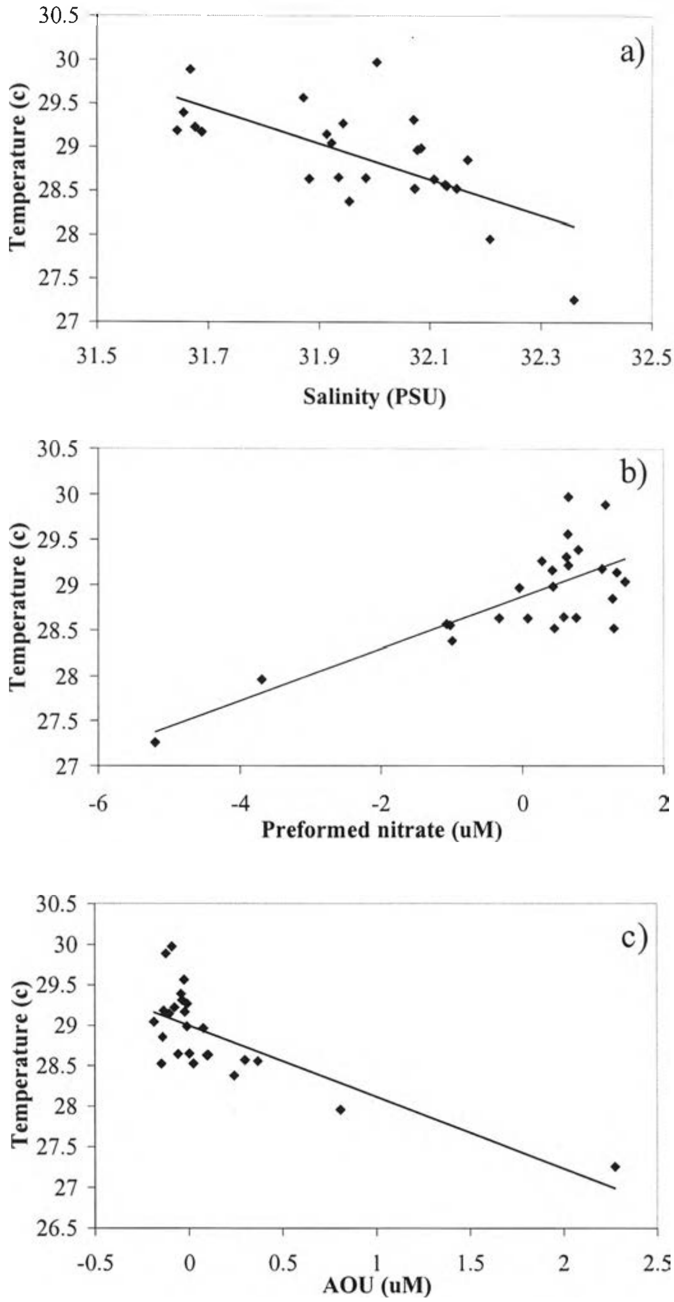
$T = -0.8815AOU + 28.999$, $r^2 = 0.5657$, $n = 25$, $P < 0.005$ —— (3.5)

where T —> Temperature (°C)

S —> Salinity (psu)

Pn —> Preformed nitrate (μM)

AOU —> Apparent Oxygen utilization (ml/l)



$T = -2.0431S + 94.214$
$r^2 = 0.4538$

$T = 0.2865Pn + 28.87$
$r^2 = 0.5847$

$T = -0.8815AOU + 28.999$
$r^2 = 0.5657$

Figure 3.9 Relationship between a) temperature and salinity, b) temperature and preformed nitrate and c) temperature and AOU of the stations represent GOT water mass.

2.Watermass of the southern most Peninsular Malaysia (S-PM water mass) was represented by data from of September 1995 st no. 73, 74, 75, 78, 79 and 81(Fig. 3.10)

Linear equation of the S-PM water mass

$T = -4.5295S + 179.19$, $r^2 = 0.9466$, $n = 14$, $P < 0.001$ —— (3.6)
$T = -0.5391Pn + 27.204$, $r^2 = 0.2334$, $n = 14$, $P < 0.5$ —— (3.7)
$T = -2.6877AOU + 28.346$, $r^2 = 0.8672$, $n = 14$, $P < 0.001$ —— (3.8)

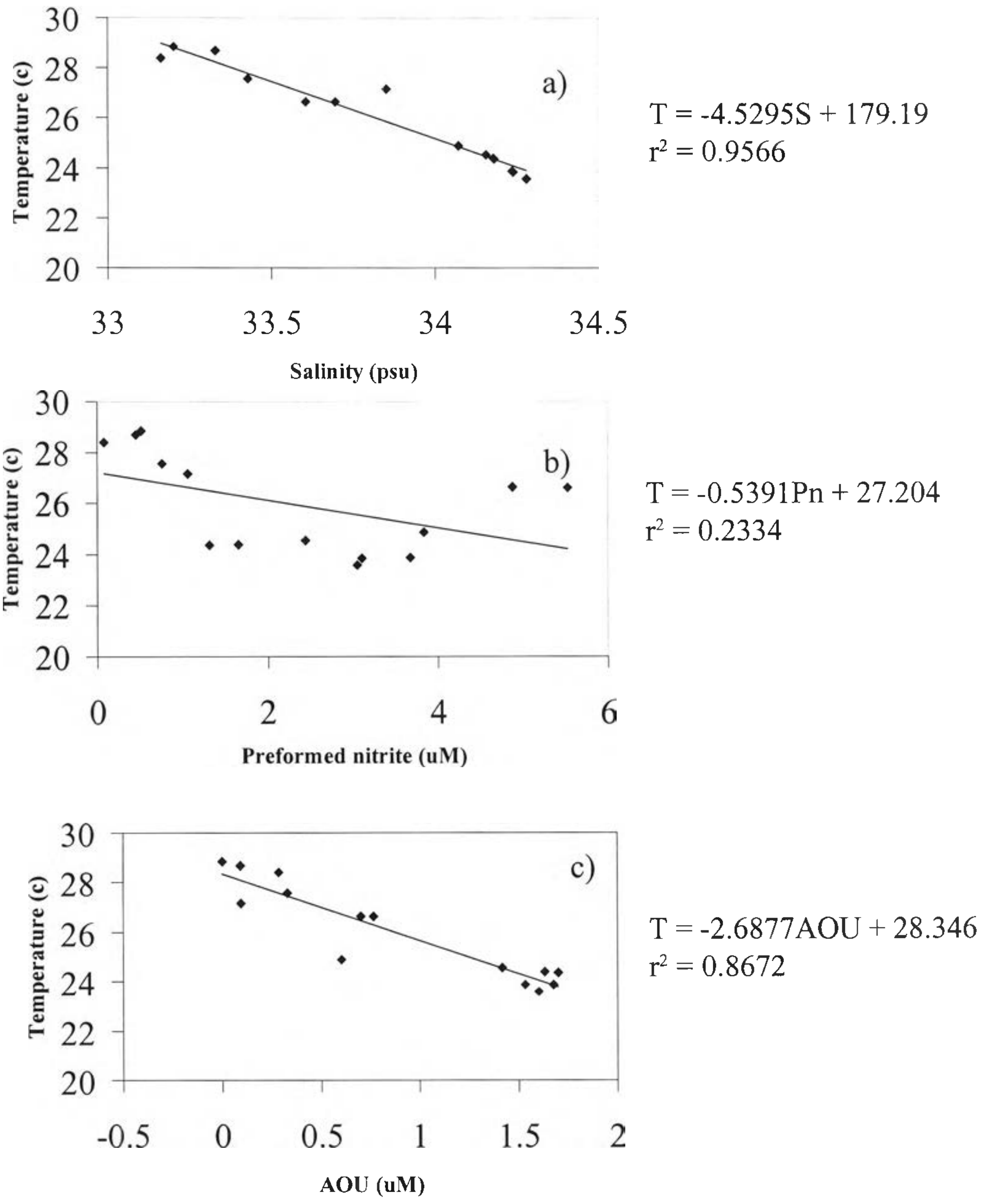
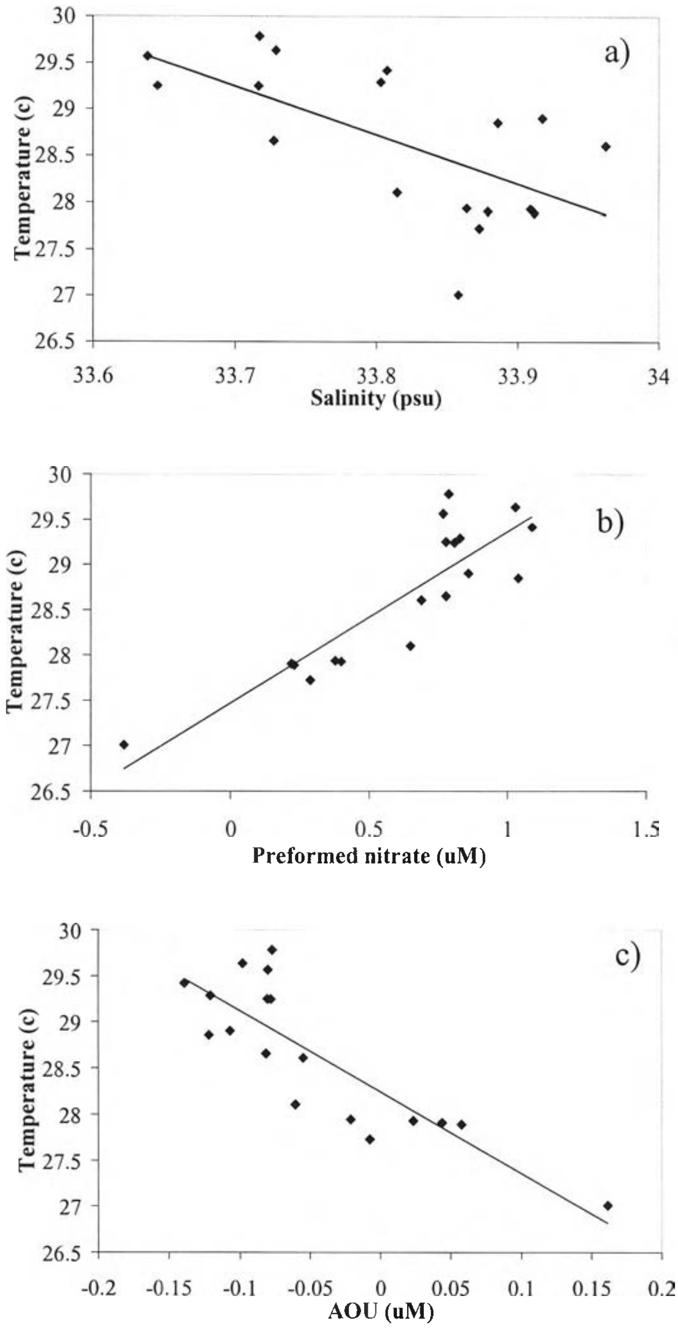


Figure 3.10 Relationship between a) temperature and salinity, b) temperature and preformed nitrate and c) temperature and AOU of the stations represent S-PM water mass.

3.Water mass of the South China Sea water mass (SCS water mass) was represented by data from of April 1996 st no. 45, 46, 47, 48 and 49 (Fig. 3.11)

Linear equation of the SCS water mass

$T = -5.2345S + 205.65$,	$r^2 = 0.4056$, $n = 18$, $P < 0.1$	—— (3.9)
$T = 1.8976Pn + 27.464$,	$r^2 = 0.7708$, $n = 18$, $P < 0.001$	—— (3.10)
$T = -8.7944AOU + 28.242$,	$r^2 = 0.7164$, $n = 18$, $P < 0.001$	—— (3.11)

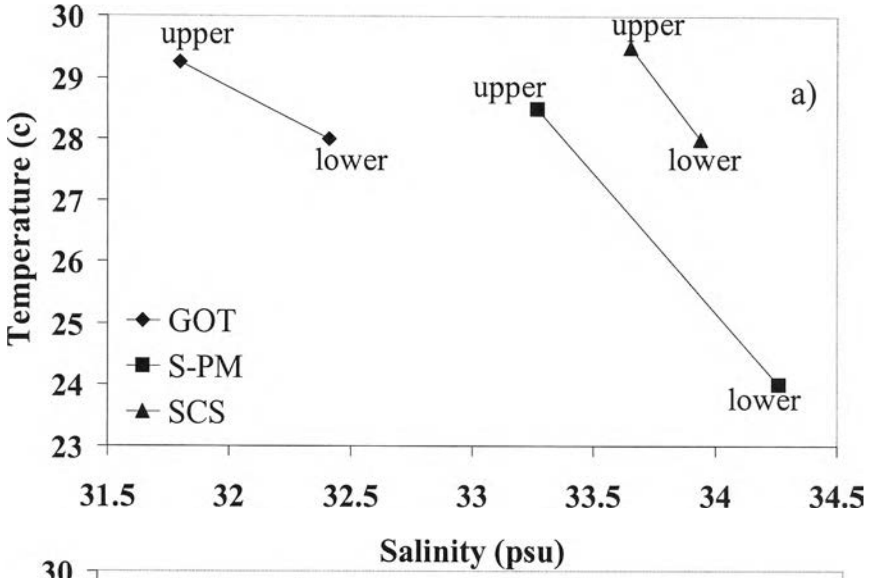


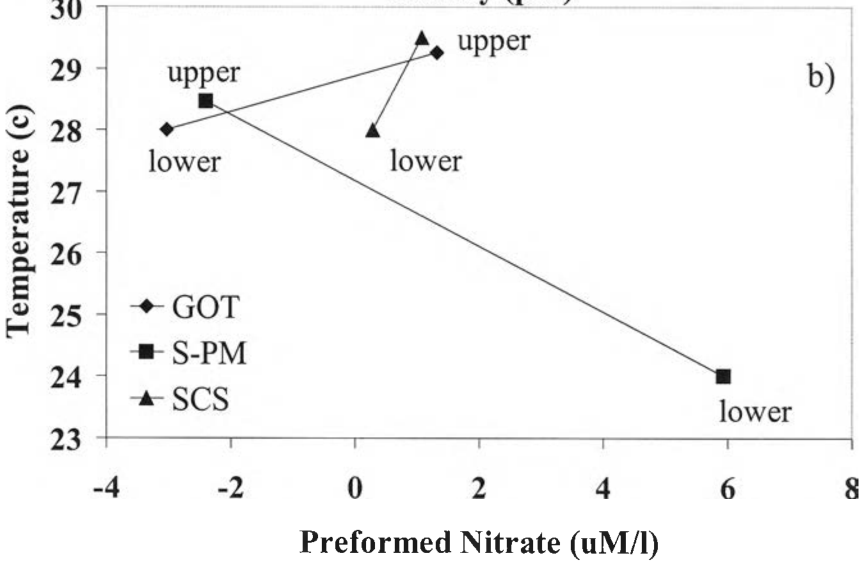
T = -5.2345S + 205.65
r^2 = 0.4056

T = 1.8976Pn + 27.464
r^2 = 0.7708

T = -8.7944AOU + 28.242
r^2 = 0.7164

Figure 3.11 Relationship between a) temperature and salinity, b) temperature and preformed nitrate and c) temperature and AOU of the stations represent SCS water mass.





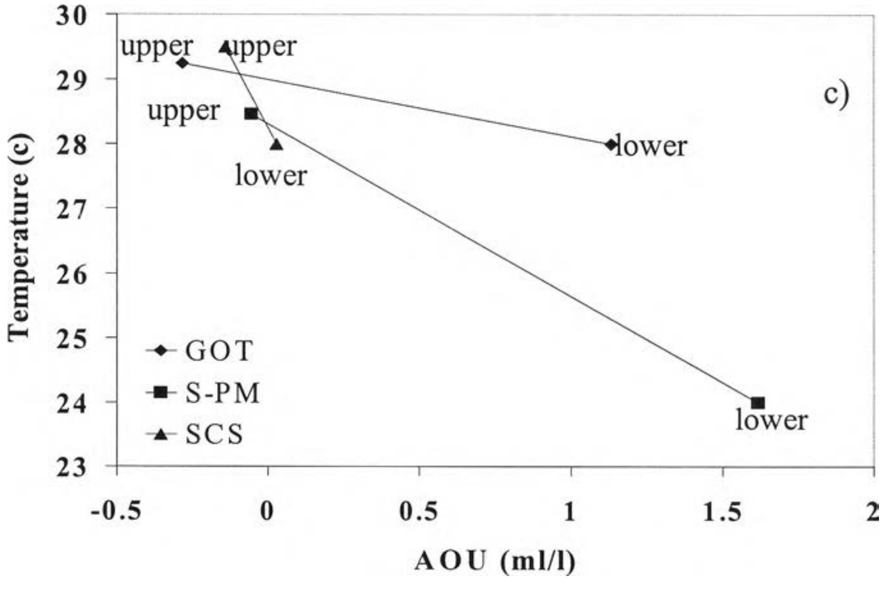


Figure3.12 Characteristic of a) temperature-salinity, b) temperature-Preformed Nitrate and c) temperature-AOU for the water masses in the lower layers of the Gulf of Thailand and East Coast of Peninsular Malaysia.

Table 3.3 Water type definition and parameter weights

Parameters \ Water Types	GOT		S-PM		SCS		Weights
	Upper	Lower	Upper	Lower	Upper	Lower	
Temperature (^{o}c)	29.25	28	28.5	24	29.5	28	49.31
Salinity (psu)	31.797	32.409	33.269	34.262	33.652	33.939	49.31
Preformed nitrate (uM)	1.326	-3.037	-2.404	5.943	1.073	0.283	21.458
AOU (ml/l)	-0.285	1.133	-0.057	1.617	-0.143	0.028	36.717

Remarks: GOT = Gulf of Thailand water mass
S-PM = Southern most Peninsular Malaysia water mass
SCS = South China Sea water mass

3.3.3.2 Water masses distribution

The result of OMP-analysis presented the relative contribution, or fraction, of each water type and water mass on each isopycnal surface by pie chart (Fig. 3.13 and 3.14). The summation of upper and lower water type fractions were a water mass fraction. For example, the summation of GOT upper and lower fraction were the fraction of GOT water mass. There were no fraction solution for some stations, because the lack of nutrient and dissolved oxygen information. The results gave an overview over the large - scale distribution of water masses.

Sigma-theta of water in September was between 20.00-23.30 kg/m^3 and 19.09 - 22.87 kg/m^3 in April-May 1996. Future discussion in this study, the sigma-theta 20 kg/m^3 will be translated as sigma-theta from 20.00 to 20.99 kg/m^3.

<u>September 1995</u>

Fig. 3.13a, b, c and d showed water masses fractions of the survey in September 1995 found on the isopycnal surface at sigma-theta = 20, 21, 22 and 23 kg/m^3 respectively. Missing water masses fractions was due to missing data or insufficient depth.

- On 20-kg/m^3 isopycnal surface

GOT water mass was the dominant water masses and reached the maximum ratio (60.5%) at station near Ko Chang (Fig. 3.13 a). The GOT upper water type presented in every station while GOT lower water type presented in every station except station near Ko Chang. On 20 kg/m^3, S-PM upper water type fraction presented only at the central (in term of North-South) of the observation area with 16.25 % in average. Fraction of SCS upper water type was found in the Gulf of Thailand area only this isopycnal surface.

- On 21-kg/m^3 isopycnal surface

The 21-kg/m^3 isopycnal surface was dominated by GOT lower water type (Fig. 3.13 b). The average fraction of GOT water mass decreased with an increasing of sigma-theta. S-PM lower type fraction was also observed on this isopycnal surface with the maximum fraction (55.84%) at the southern most station. Large fraction of SCS water was observed at the southern part of the study area.

- On 22 and 23 kg/m^3 isopycnal surface

S-PM lower was the dominant water type on 22 and 23 kg/m^3 isopycnal surface (Fig. 3.13 c and d). There were some small fraction of GOT and SCS water mass on these isopycnal surface.

April - May 1996

Fig. 3.14 a, b, c and d showed the water mass fraction on the isopycnal surface at sigma-theta = 19,20,21 and 22 kg/m^3 respectively of the survey on April-May 1996.

- On 19 kg/m^3 isopycnal surface

The 19 kg/m^3 isopycnal surface was dominated by GOT water mass (Fig. 3.14 a). The major fraction of GOT water mass was an upper type for 50.89 % to 99.55 %. Very Small fraction of S-PM and SCS water mass were observed on this isopycnal surface.

- On 20 kg/m^3 isopycnal surface

The GOT upper layer type was also a major fraction on 20 kg/m^3 isopycnal surface (Fig. 3.14 b). It was excepted only at the station off Prachuapkhilikhan and Chumporn province of Thailand which were dominated by the lower type. Fractions of GOT water mass decreased with an increasing of sigma-theta. There were some fractions of S-PM water mass at the central Gulf of Thailand. Small fractions of SCS water mass was observed at all the observation area excepted at coastal of the Gulf of Thailand.

- On 21 kg/m^3 isopycnal surface

All water mass gave their fraction to the water in this isopycnal surface (Fig. 3.14 c).

- On 22 kg/m^3 isopycnal surface

The 22 kg/m^3 isopycnal surface was dominated by S-PM water mass (Fig. 3.14 d). The maximum fraction of S-PM upper and lower water type were 61.56 % and 52.15 %, respectively. The GOT upper water types totally disappeared on this isopycnal surface. The SCS water mass fraction of four stations in the Gulf of Thailand on 22 kg/m^3 isopycnal surface was lower type. These fractions should came from the South China Sea on 21 kg/m^3 isopycnal surface because there was no connection to the South China Sea on this isopycnal surface.

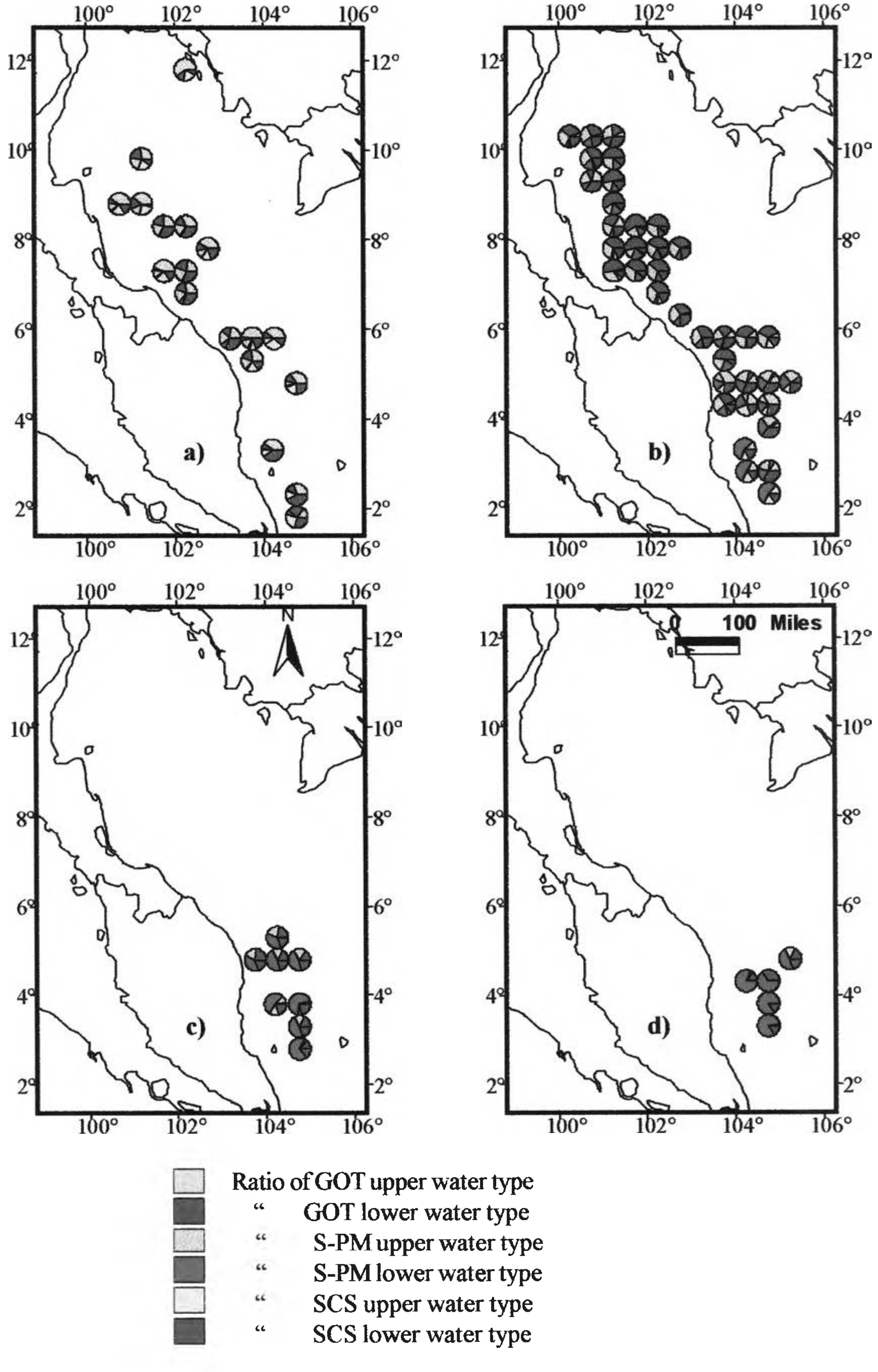
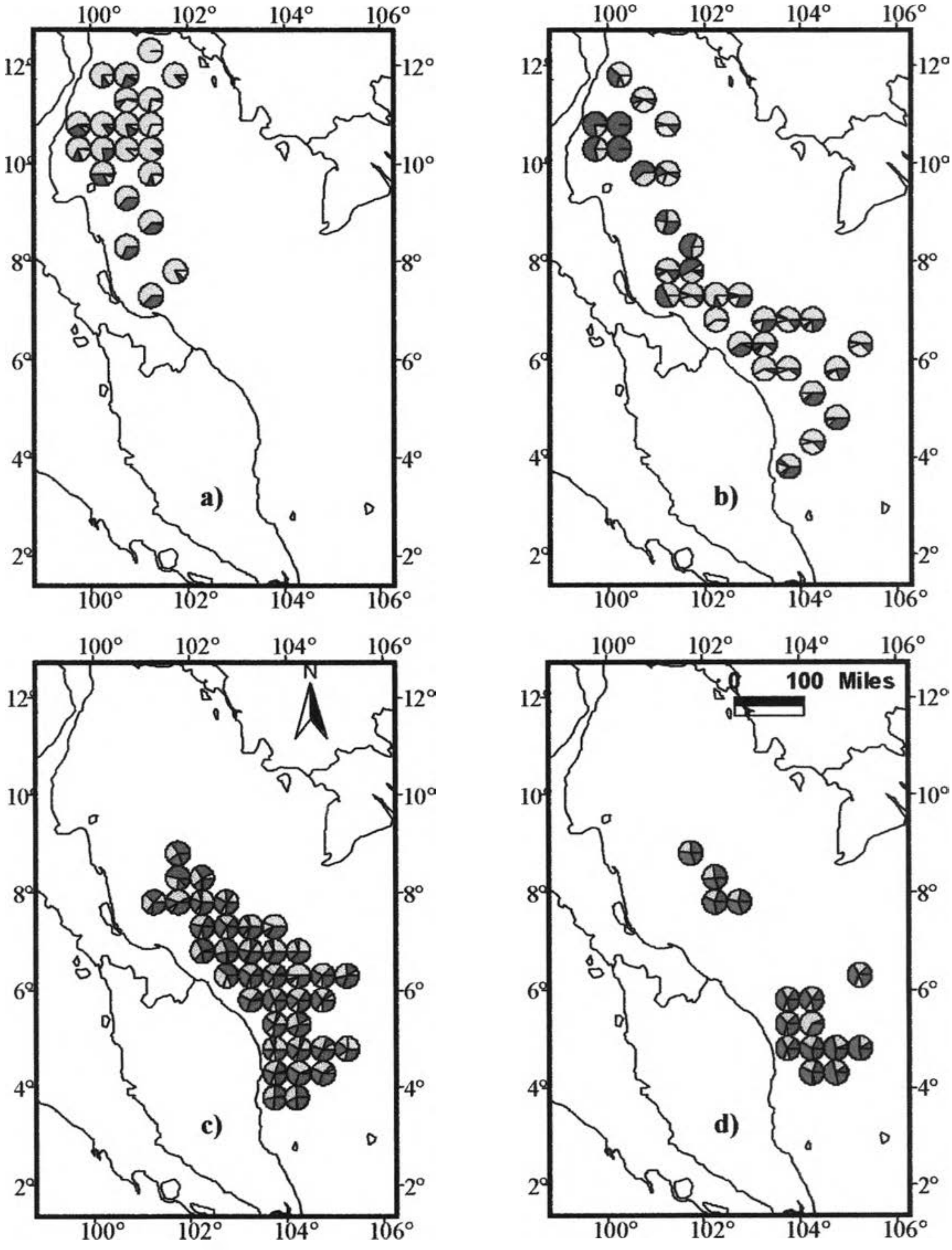


Figure 3.13 Contribution of GOT upper, GOT lower, S-PM upper, S-PM lower, SCS upper and SCS lower water type over the study area in September 1995 on a) 20 kg/m^3 isopycnal surface, b) 21 kg/m^3 isopycnal surface, c) 22 kg/m^3 isopycnal surface and d) 23 kg/m^3 isopycnal surface



Ratio of GOT upper water type
" GOT lower water type
" S-PM upper water type
" S-PM lower water type
" SCS upper water type
" SCS lower water type

Figure 3.14 Contribution of GOT upper, GOT lower, S-PM upper, S-PM lower, SCS upper and SCS lower water type over the study area in April-May 1996 on a) 19 kg/m^3 isopycnal surface, b) 20 kg/m^3 isopycnal surface, c) 21 kg/m^3 isopycnal surface and d) 22 kg/m^3 isopycnal surface

3.4 Relationship between water mass and biological data

3.4.1 Zooplankton

Cluster analysis was used to group survey stations by similarity of species composition and abundance of zooplankton into three clusters.

Average total abundance of each station in cluster A, B and C were 214, 497 and 862 no/m^3, respectively (Fig. 3.15). The average percentages of top four high abundance zooplankton species were shown in Fig. 3.16. Dominant species of zooplankton in both survey periods were copepod. Total zooplankton increased because of the increasing in copepod abundance.

From Fig. 3.15 and 3.16, characteristics of cluster A were high abundance of chaetognatha (2 time of abundance in cluster B and C) and low average total abundance. Ratio of dominant species of clusters B and C were similar. The different characteristic was the total abundance, which cluster C was higher.

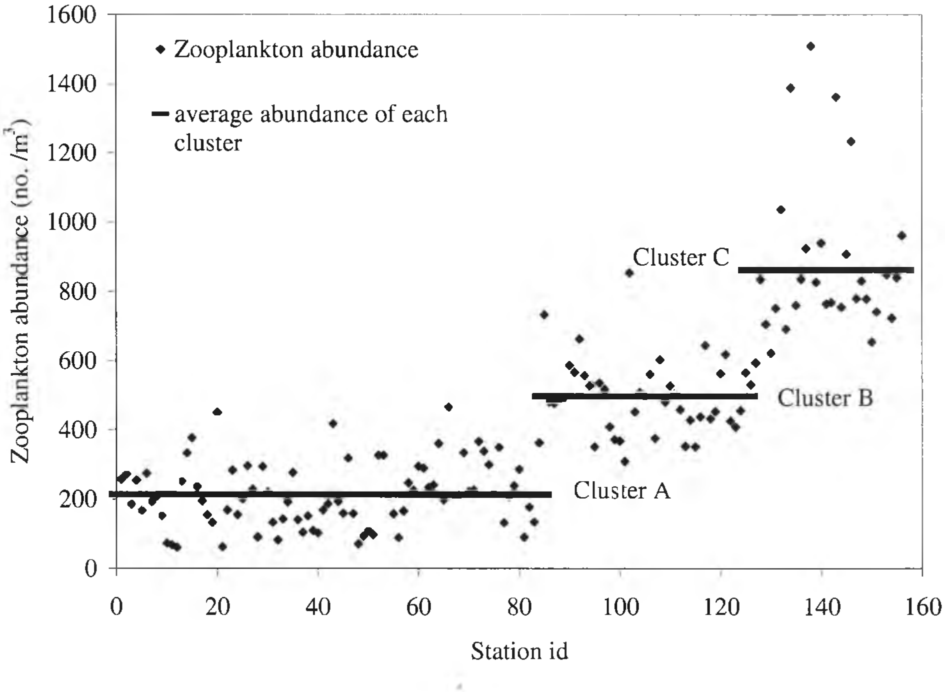


Figure 3.15 Comparison between total abundance of zooplankton in each station of each cluster.

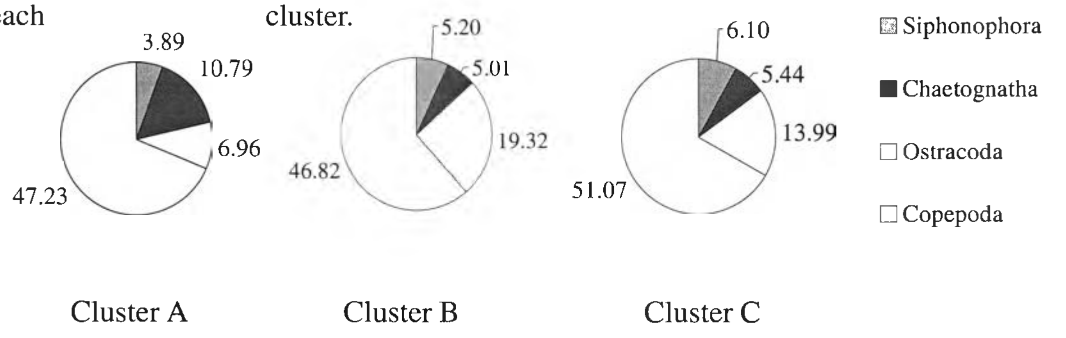
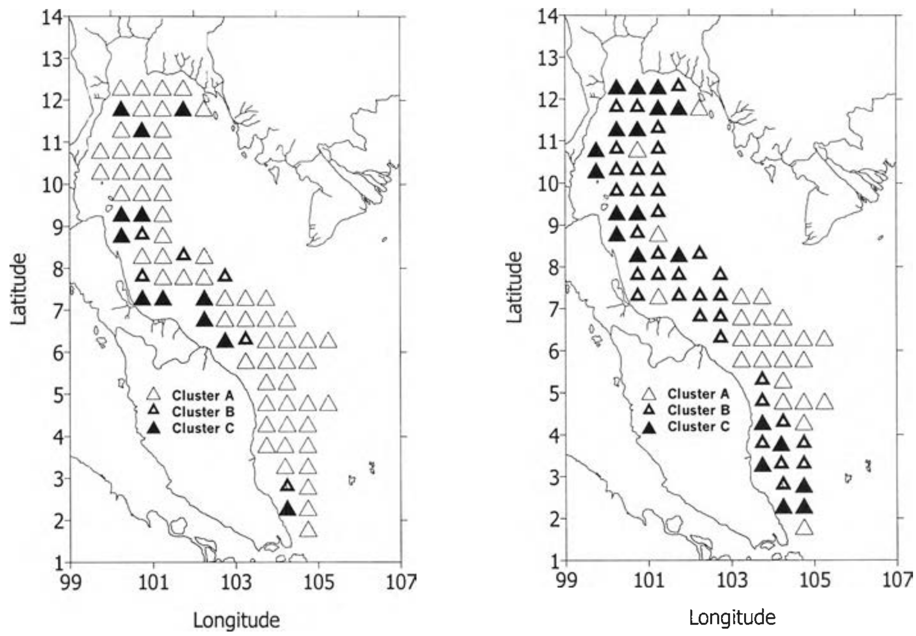


Figure 3.16 Average percentage of four main abundance species of zooplankton in each cluster.

The distributions of stations in each cluster were showed in Fig. 3.17. Most of stations during September 1995 were cluster A zooplankton. Cluster A zooplankton were also found in April-May 1996 at the boundary between the Gulf of Thailand and the South China Sea (Fig. 3.17 b).



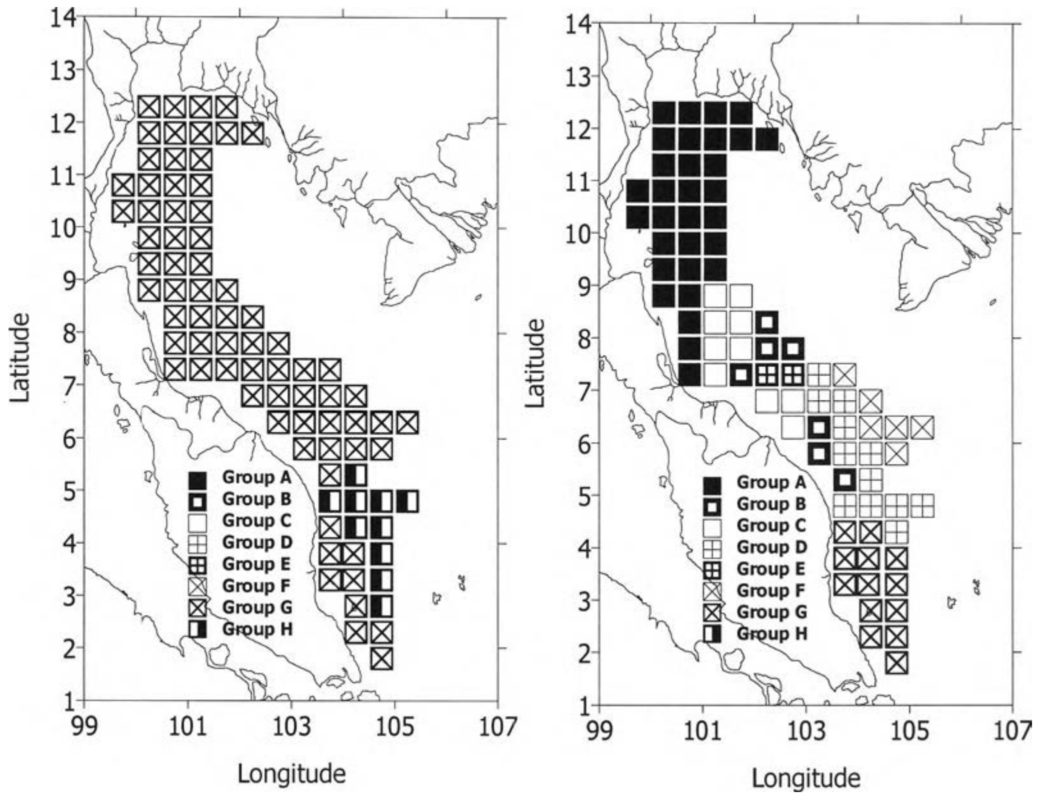
a) September 1995 b) April- May 1996

Figure 3.17 Distribution of zooplankton cluster

Six stations at the central and southern of the study area in September 1995 were clusters B zooplankton. Their distribution did not have any special pattern (Fig. 3.17 a). In April-May 1996, Large distributions of cluster B zooplankton (35 stations) were found all over the study area, except near the mouth of the Gulf of Thailand (Fig. 3.17 b). Cluster C zooplankton was found in both surveys period at the coastal area.

Zooplankton samples were collected by oblique haul, so it was not possible to find their species composition and abundance in each layer, while type of water mass at lower and upper layer of some stations was different. Therefore, survey stations were grouped by consider both surface and bottom water masses as shown in Fig. 3.18 for determining relationship between water mass and zooplankton.

Distribution of cluster A zooplankton coincided with the presented of composite water mass G and H in September 1995 and D and F in April-May 1996 (Fig. 3.17, 3.18 and 3.19). Cluster B zooplankton stations were mostly observed at composite water mass A, B and C (Fig.3.19). Cluster C zooplankton stations were observed at composite water mass G in September 1995 and A in April - May 1996 (Fig 3.17, 3.18 and 3.19) which were coastal area.



a) September 1995 b) April-May 1996

Figure 3.18 Distribution of composite water masses A to H (table 3.4).

Table 3.4 Type of water mass in mixing layer and bottom layer of composite water masses A to H

Group	Mixing layer	Bottom layer
A	mass 1	mass 1
B	mass 1	mass 3
C	mass 1	mass 4
D	mass 2	mass 3
E	mass 2	mass 4
F	mass 3	mass 3
G	mass 4	mass 4
H	mass 4	mass 5

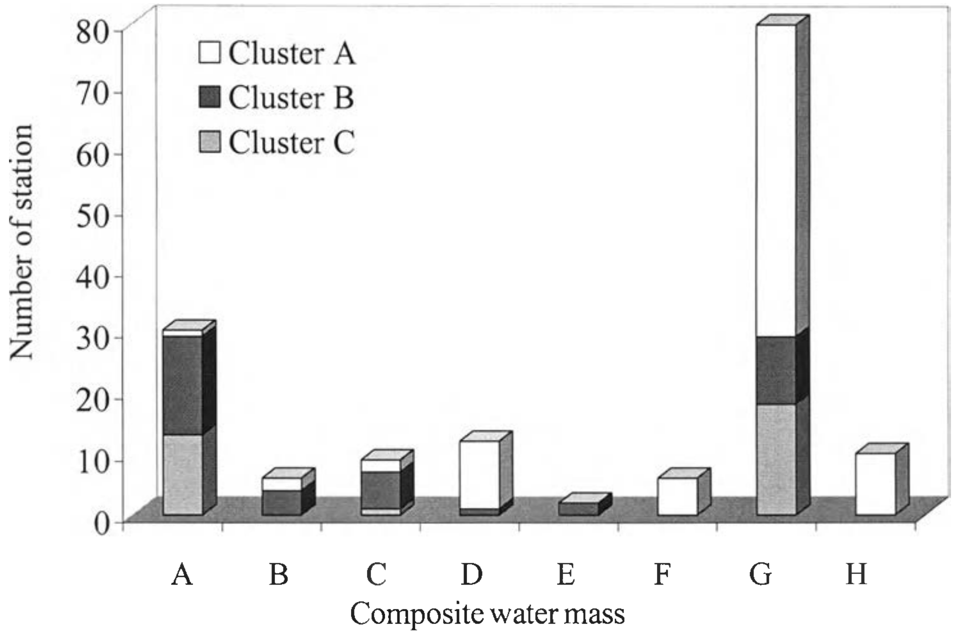


Figure 3.19 Number of cluster A, B and C zooplankton in each composite water mass.

3.4.2 Phytoplankton

Phytoplankton data

Surface phytoplankton collecting stations from two study periods were grouped by cluster analysis using the similarity of dominant and associate species and percentage of three groups of phytoplankton: Blue green algae, Diatom, and Dinoflagellate into three clusters.

Dominance species of cluster A phytoplankton was *Thalassionema fruenfeldii* while B and C was *Oscillatoria erythraea*. Relative abundance of Blue green algae, Diatom and Dinoflagellate of clusters A, B and C were shown in Fig. 3.20

The distribution of each cluster was showed in Fig. 3.21. There were some stations missing from the cluster distribution map, due to the kind of dominance and associate species and their percentages could not be grouped into any cluster.

The only relationship between phytoplankton clusters and water masses was surface mass 2 and cluster C phytoplankton and only in April-May 1996 (Fig. 3.8 and 3.21). The others did not show any significant relationships.

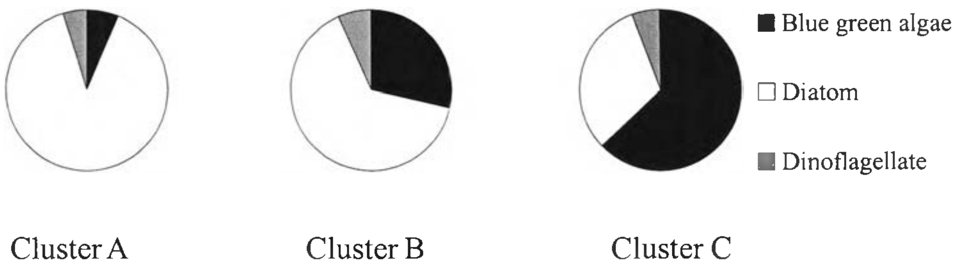
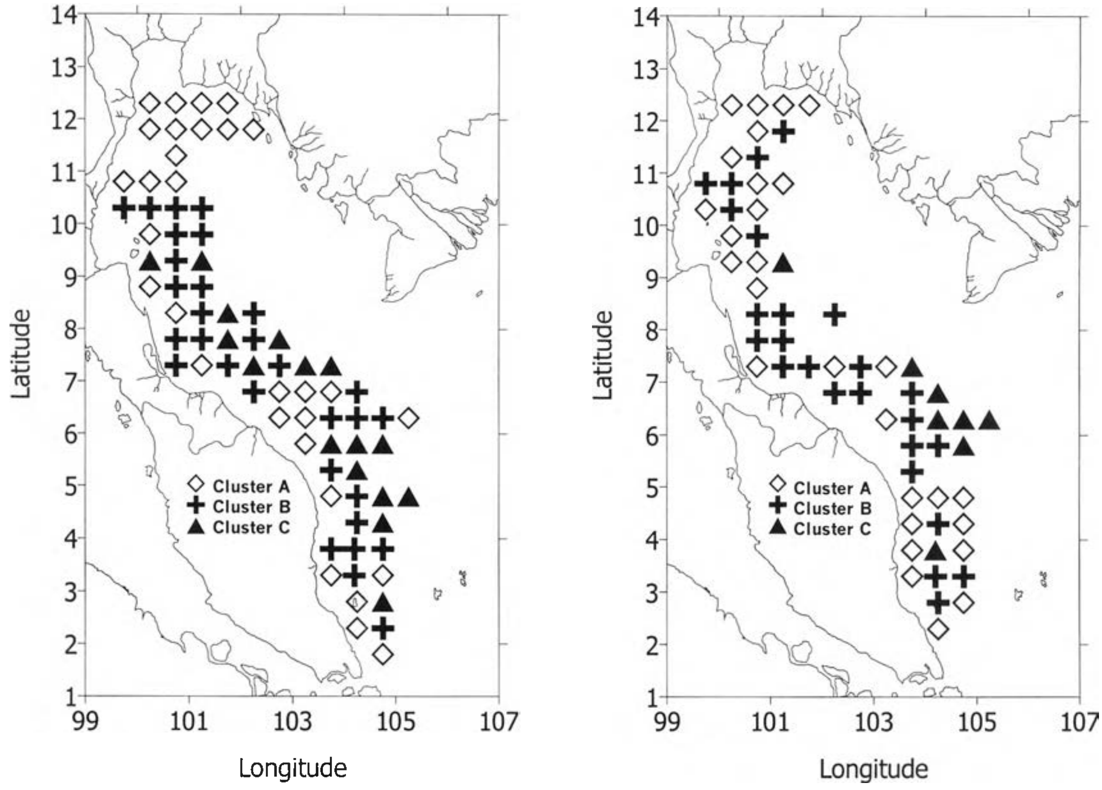


Figure 3.20 Relative abundance of three groups of phytoplankton in each cluster.



a) September 1995 b) April-May 1996

Figure 3.21 Distribution of phytoplankton cluster A, B and C

Chlorophyll-a data

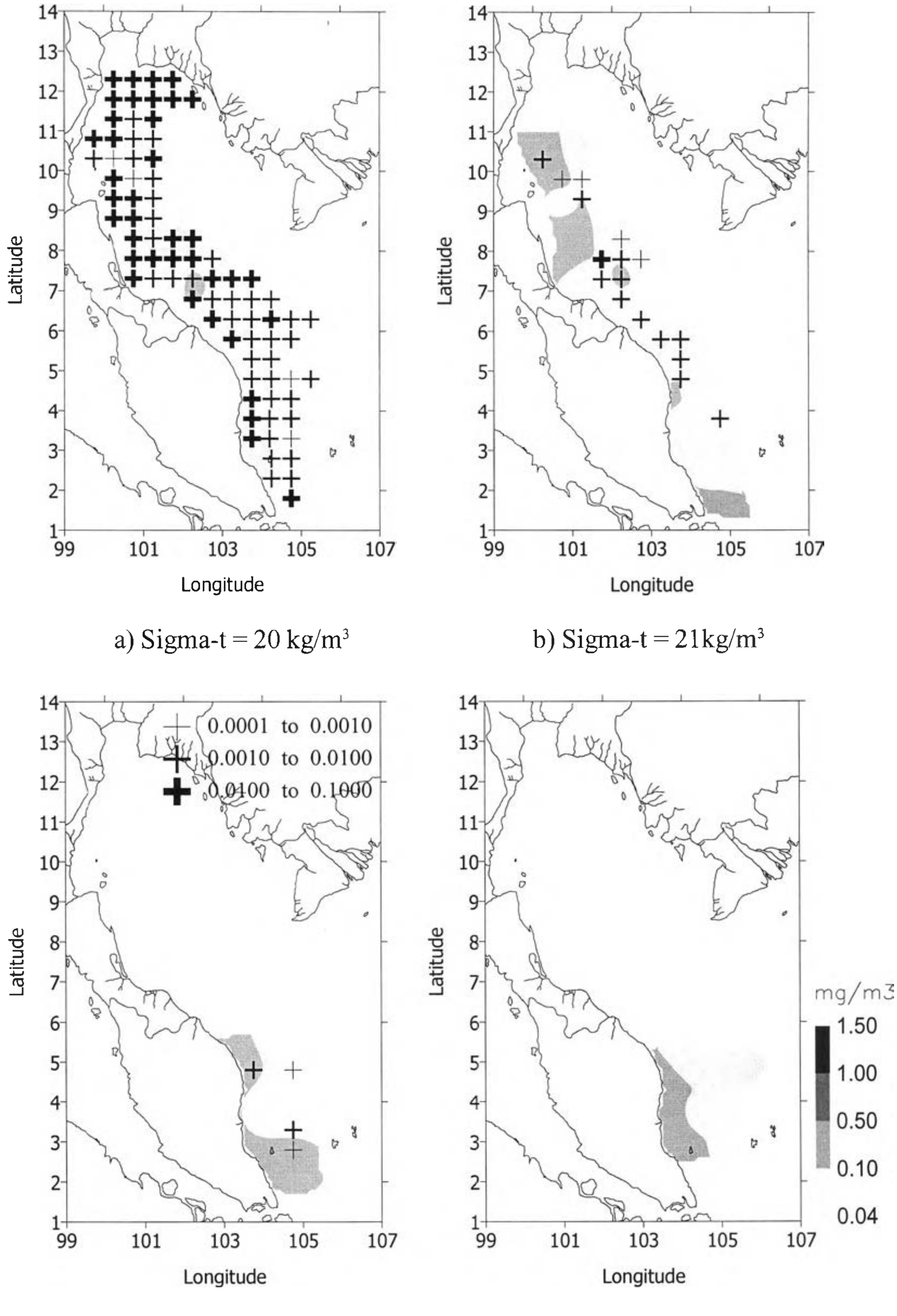
Chlorophyll-a data of two survey period were contoured on the same isopycnal surface as the one used on OMP-analysis (Fig. 3. 22 and 3. 23). Chlorophyll-a concentration in the September 1995 was 0.04-0.30 mg/m^3 in all layers over the observation area, which about 2 to 5 time lower than in April-May 1996. Chlorophyll-a concentrations were low on the shallowest layer and the near shore areas were mostly higher than off shore. The area that large proportion of GOT upper water type was the area of low chlorophyll-a concentration. While the area that large proportion of GOT lower water type coincided with the area of high chlorophyll-a concentration.

Chlorophyll-a concentrations of both survey period could be calculated from percentage of GOT upper, GOT lower, S-PM upper, S-PM lower and SCS upper water type. The multiple regression model at the 99% confidential interval that could explained their relation was

$$Y = -0.0691+0.0028X_1+0.0070X_2+0.0033X_3+0.0070X_4+0.0013X_5 \qquad \text{——3.12}$$

Y = Chlorophyll-a concentration (mg/m^3) X_3 = ratio of S-PM upper water type
X_1 = ratio of GOT upper water type X_4 = ratio of S-PM lower water type
X_2 = ratio of GOT lower water type X_5 = ratio of SCS upper water type

Chlorophyll-a concentration data were plot versus Chlorophyll-a concentrations from equation 3.12 in Fig. 3.24.



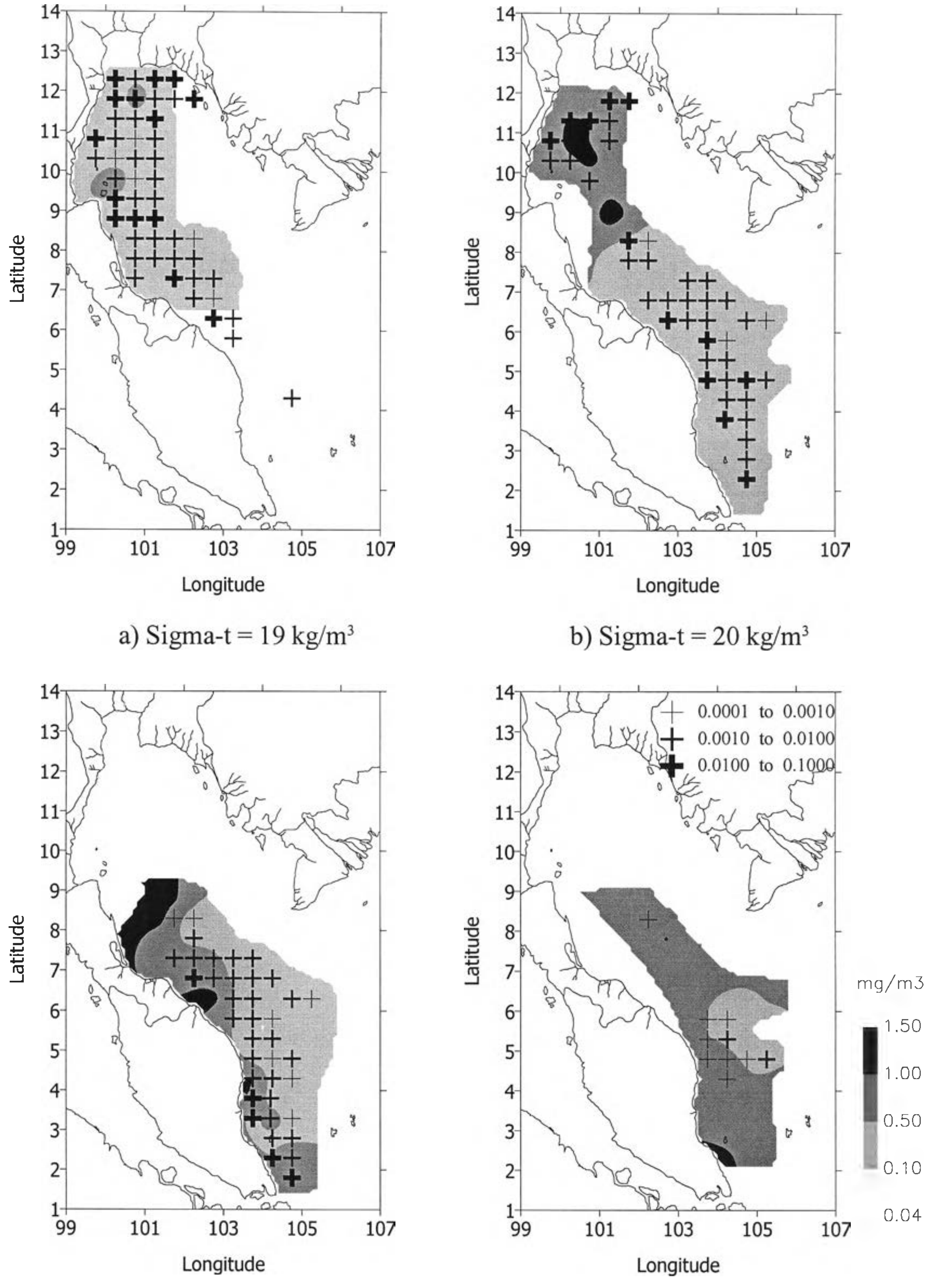
a) Sigma-t = 20 kg/m^3

b) Sigma-t = 21kg/m^3

c) Sigma-t = 22 kg/m3

d) Sigma-t = 23 kg/m3

Figure 3.22 Contours of Chlorophyll - a (mg/m^3) and relative abundance of pelagic fish (number of fish / ton) of each station at isopycnal surface 20,21, 22 and 23 kg/m^3 of the survey in September 1995.



a) Sigma-t = 19 kg/m³

b) Sigma-t = 20 kg/m³

c) Sigma-t = 21kg/m³

d) Sigma-t = 22 kg/m³

Figure 3.23 Contours of Chlorophyll a (mg/m^3) and relative abundance of pelagic fish (number of fish / ton) of each station at isopycnal surface 19,20,21 and 22 kg/m^3 of the survey in April 1996.

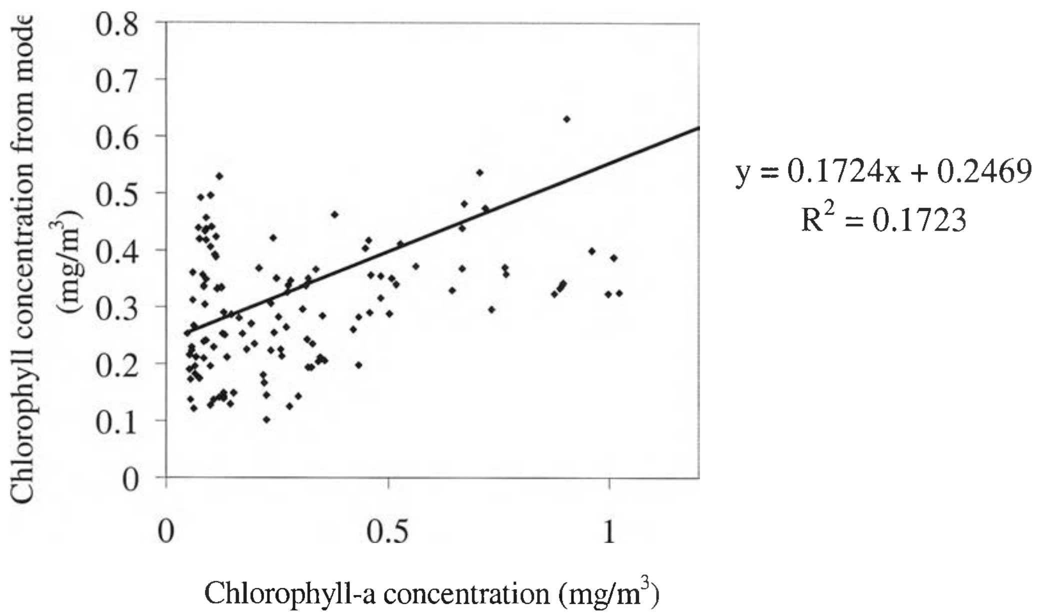


Figure 3.24 Scattering plot of chlorophyll-a concentration (mg/m^3) data versus chlorophyll-a concentration (mg/m^3) from equation 3.12

3.4.3 Relative abundance of Pelagic fish

Relative abundance of pelagic fish from two survey periods was plotted as classed symbol in Fig. 3.22 and 3.23. High relative abundance was observed at the low isopycnal surface (20 kg/m^3 in September 1995 and 19 and 20 kg/m^3 in April 1996) and at the coastal area. The area that large proportion of GOT lower water type was the area of low pelagic fish abundance.

Relative abundance of pelagic fish of both survey periods could be calculated from percentage of GOT upper, S-PM upper, S-PM lower and SCS upper water type. The multiple regression model at the 95% confidential interval that could explained their relation was

$$Y = 0.0108 - 0.00004X_2 - 0.0002X_3 - 0.0002X_4 + 0.00004X_5 \qquad \text{———3.13}$$

Y = Relative abundance of pelagic fish (fish no./ton)
X_2 = ratio of GOT lower water type
X_3 = ratio of S-PM upper water type
X_4 = ratio of S-PM lower water type
X_5 = ratio of SCS upper water type

Abundance of pelagic fish data was plot versus the calculated one from equation 3.13 in Fig. 3.25.

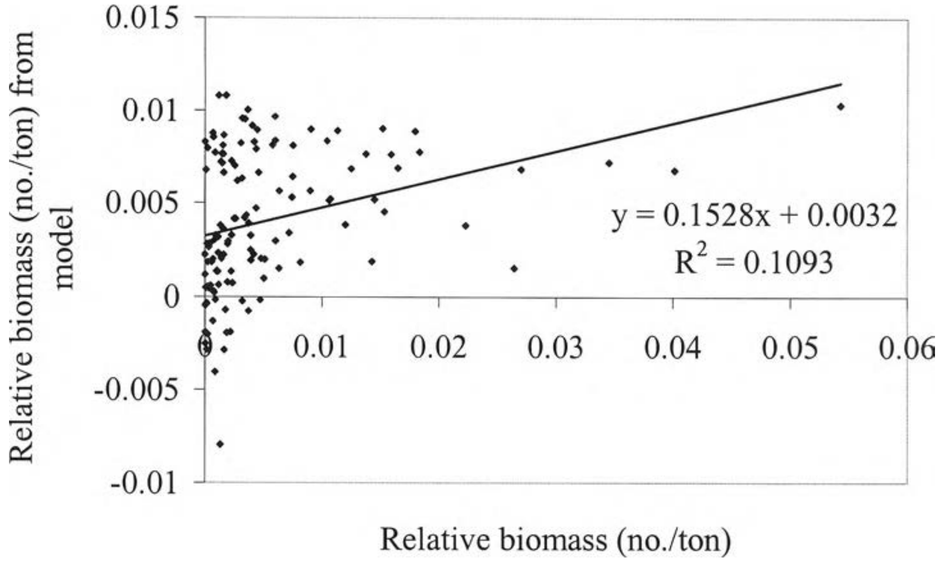


Figure 3.25 Scattering plot of pelagic fish abundance data versus the calculated abundance from equation 3.13