RELATIONSHIP BETWEEN WATER MASSES AND ZOOPLANKTON

IN THE GULF OF THAILAND AND EAST COAST OF PENINSULAR MALAYSIA

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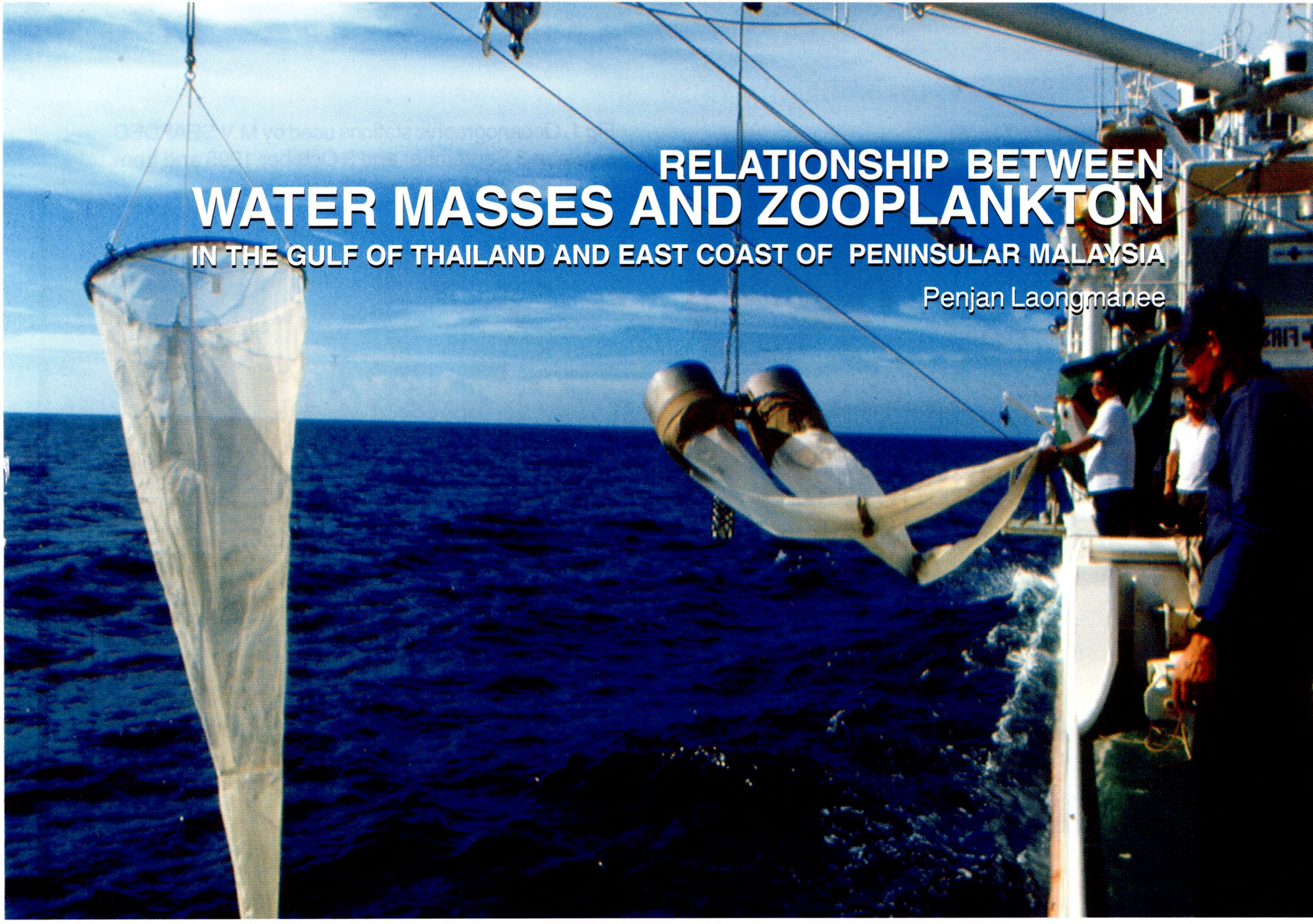

INTRODUCTION

Most of the studies on the relationship between the physical and chemical properties of water and biological data were done by studying the relationship between individual parameters with individual species or each group of marine life which might not be appropriate, as individual species usually relate to several parameters. The study on water masses, which tries to classify water by their properties and origins, may give a better answer than the each parameter study. Because each water mass can be composed of the same kind of organic or inorganic matter, minerals, trace metals etc., which are important for life. The objectives of this study are to classify and study the distribution of water masses in the Gulf of Thailand and East Coast of Peninsula Malaysia and to determine the relationship between those water masses and zooplankton in the area.

METHODOLOGY

The Southeast Asian Fisheries Development Center (SEAFDEC) carried out two intensive field observations in the western part of the Gulf of Thailand and the East Coast of Peninsular Malaysia in September 1995 and April-May 1996. It was the first systematic and intensive oceanographic measurement, since the Joint Thailand-Vietnam-US NAGA Expedition in 1959-1961 (Robinson, 1963). Unfortunately, the study areas could not cover all the Gulf of Thailand area because of the exclusive economic zone (EEZ) of a neighbor country. However, the SEAFDEC survey data was the most complete and accurate oceanographic data set in this area.

The Gulf of Thailand is a semi-enclosed Gulf with two sills at the southern most part. The first sill runs from the Camau Peninsula (08°42'N, 103°11'E) to the southwest about 100 km at a depth of less than 25 m. The second runs from Kota Bharu (06°15'N, 102°23' E) at a depth of less than 50 m to the northeast for 150 km. There is a channel connecting the deepest part of the Gulf to the South China Sea. This underwater channel is about 60 m in depth and about 50 km wide at the center of the mouth of the Gulf of Thailand (Piyakarnchana, 1989). The average depth is about 50 meters. The East Coast waters of the Malay Peninsular are a part of the South China Sea. The depth of the study area was between 22 and 78 meters. The average depth being 57.4 meters (Fig 1).

Sources of data

Data was obtained from two-survey cruises of M.V.SEAFDEC in the Gulf of Thailand and East Coast of Peninsular Malaysia under the Interdepartmental Collaborative Research Program in the South China

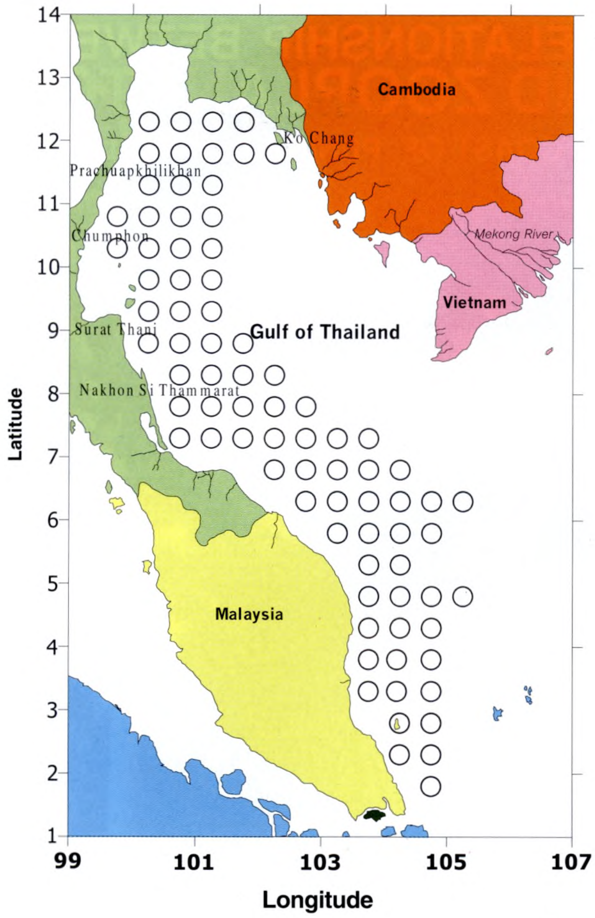

Fig 1. Oceanographic stations used by M.V.SEAFDEC between 3 September and 3 October 1995 and from 23 April to 23 May 1996

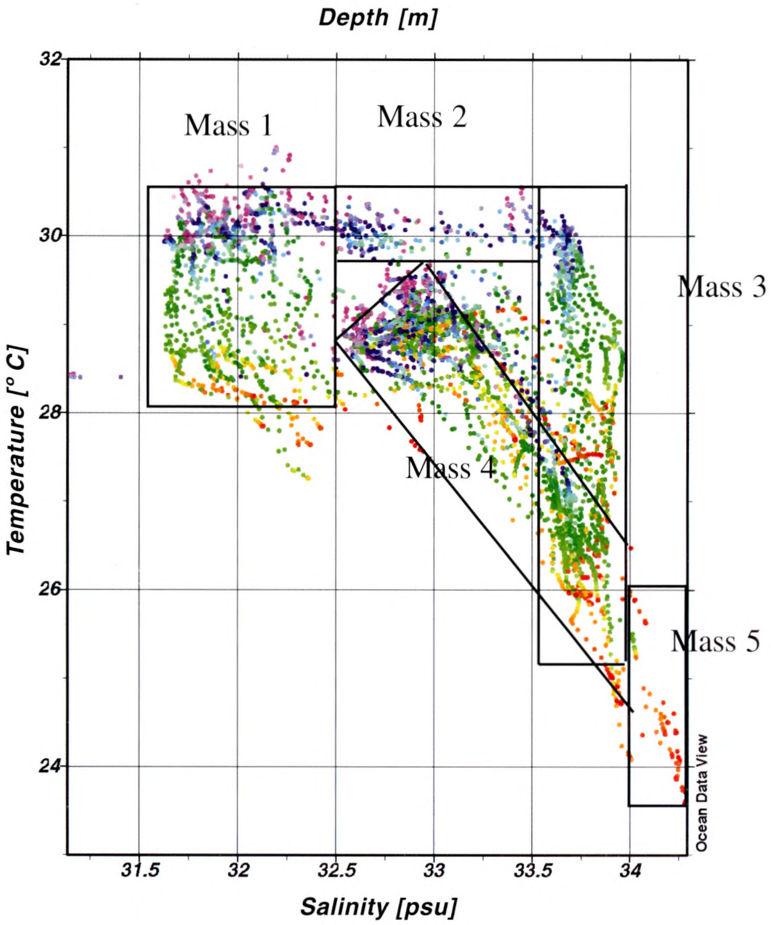

Fig 2. TS-diagram of all data

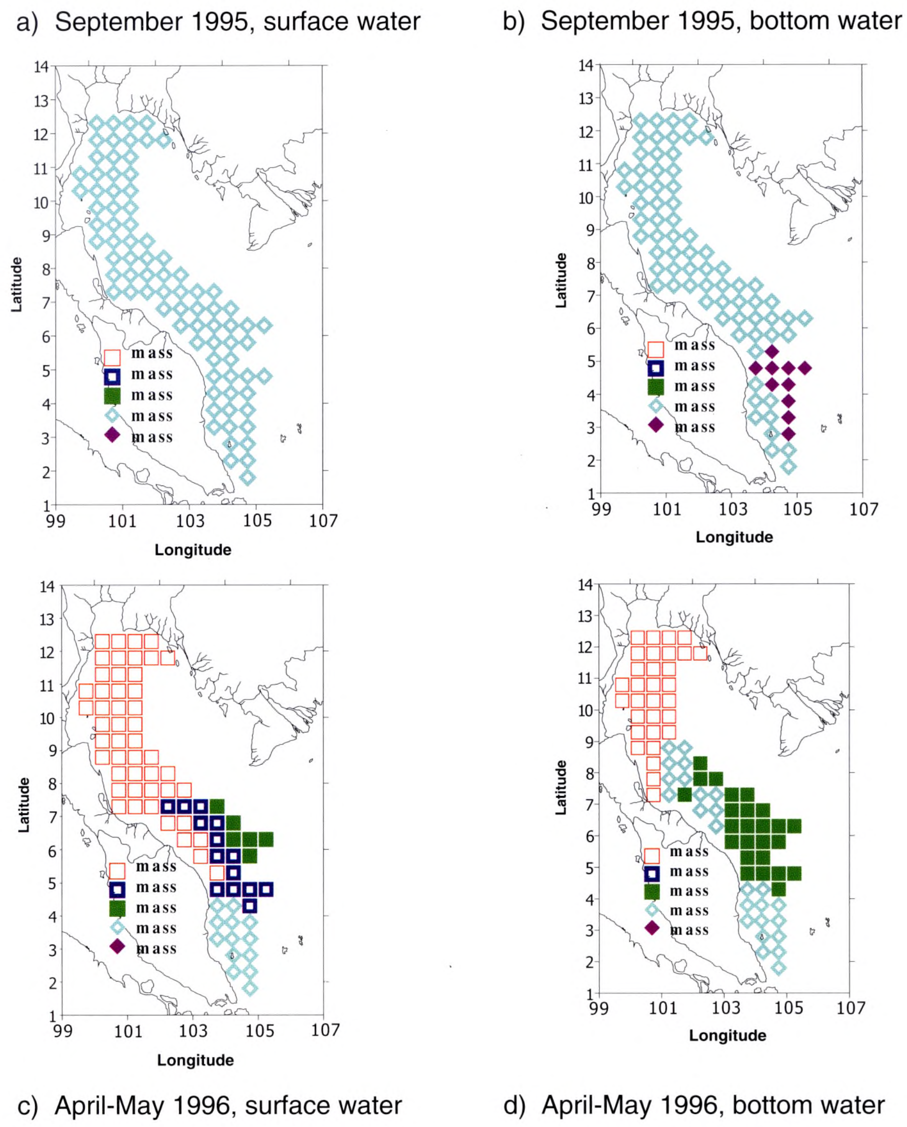

Fig 3. Distribution of water masses identified by TS-diagram

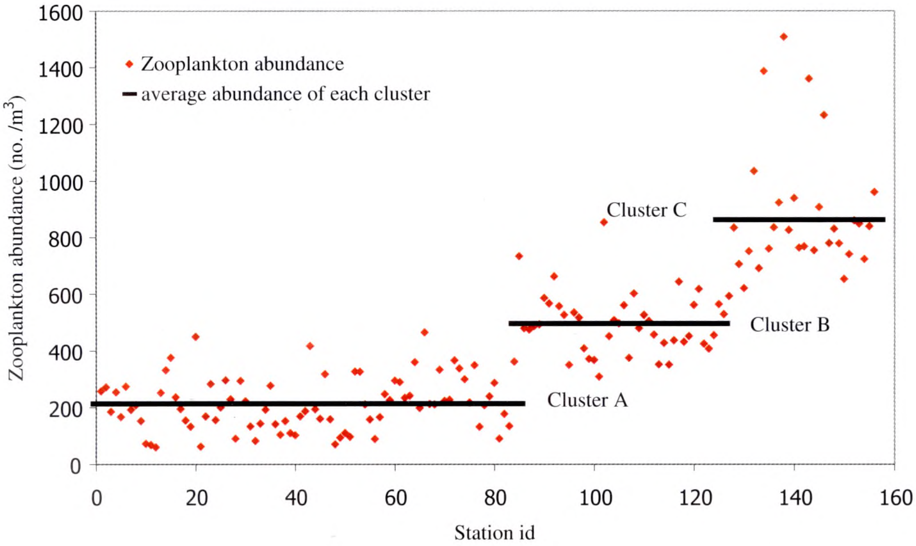

Fig 4. Comparison between total abundance of zooplankton in each station of each cluster

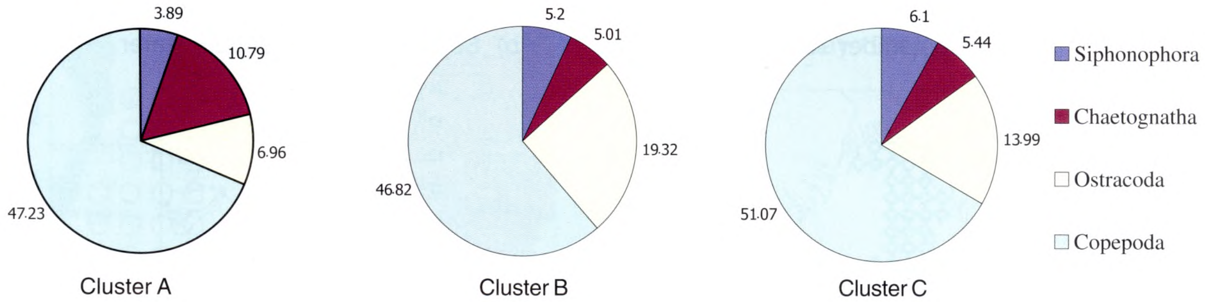

Fig 5. Average percentage of four main abundance species of zooplankton in each cluster

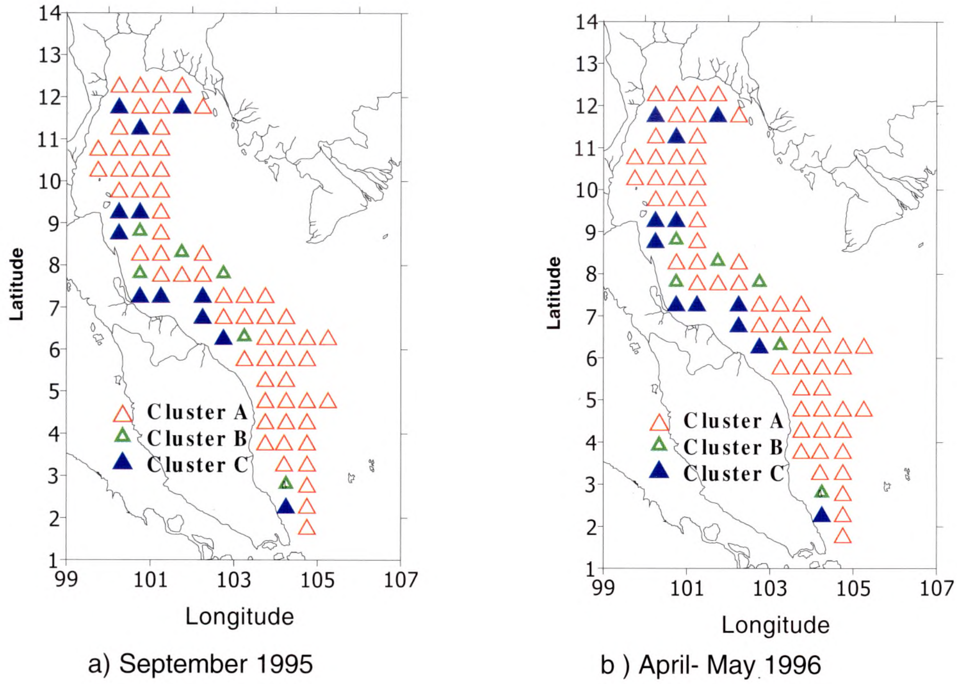

Fig 6. Distribution of zooplankton cluster

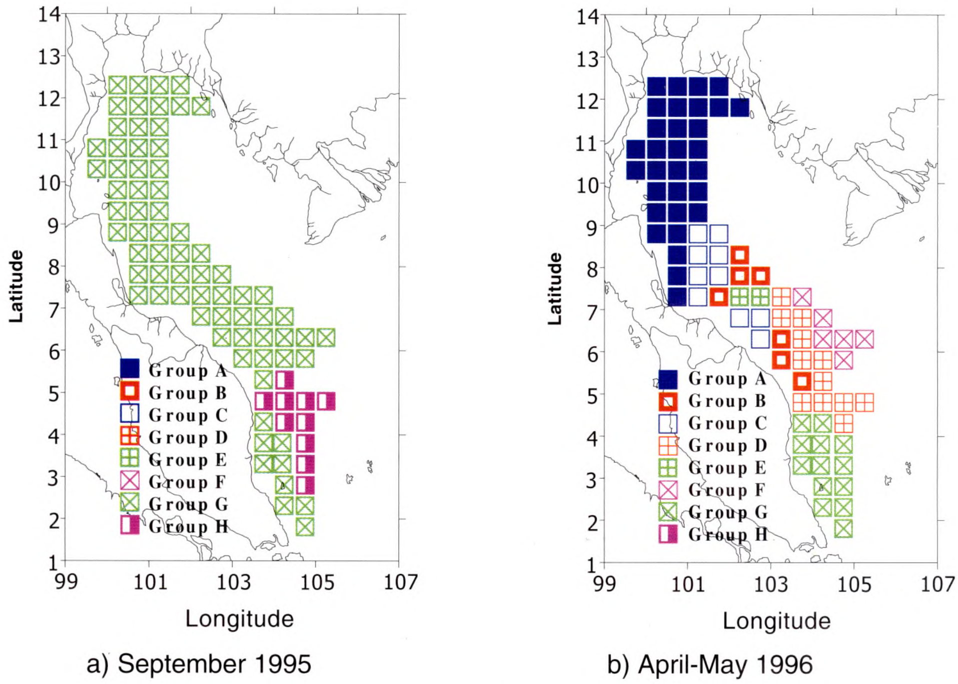

Fig 7. Distribution of composite water masses A to H (table 1)

Table 1 Type of water mass in mixing layers and bottom layers of composite water masses A to H

Group	Mixinglayer	Bottomlayer
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

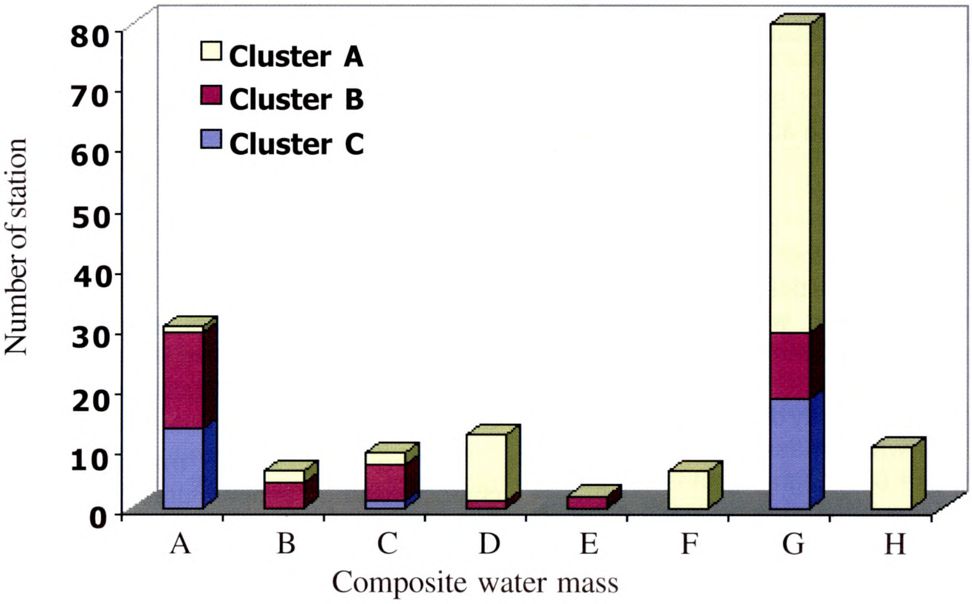

Fig 8. Number of clusters of A, B and C zooplankton in each composite water mass

Sea area of the Southeast Asian Fisheries Development Center. The first cruise was between 3 September and 3 October 1995. The second cruise was from 23 April to 23 May 1996, with a total of 81 oceanographic stations (Fig 1). Station no. 27 was surveyed only during the second cruise.

Oceanographic data were collected using the onboard Falmouth Integrated CTD instrument with conductivity, temperature and pressures sensors having an accuracy of ± 0.003 mmhn, ± 0.003 °C and ± 0.03%, respectively. Raw counts of each variable were recorded and averaged at every 1 meter interval using FSI post acquisition data analysis software.

Total abundance (no/m^3) and species composition of zooplankton from the study of Jivaluk (1999) were used in this study. Zooplankton samples were collected by Bongo net oblique hauls.

Water mass identification procedure

A water mass is defined as a body of water with a common formation history, usually based upon the observation that water renewal in the deep ocean is the result of water mass formation in contact with the atmosphere and spreading from the formation region. A point in the functional relationship of water mass is defined as a water type. Direction and quantity of the spreading and mixing of a water mass with other water masses can be tracked by analyzing the distribution

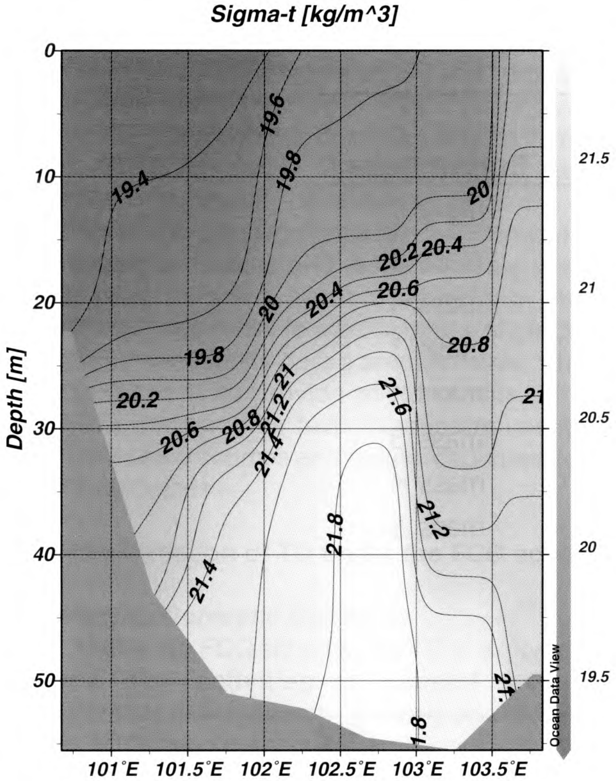

Fig 9. Vertical distribution of sigma-t along latitude 7°20'N (from station 40 to 46) in April - May 1996

of conservative properties, that is, they altered only by processes occurring at the boundaries of the ocean by mixing with the other water masses, like temperature, salinity, etc. (Open University, 1989).

The temperature-salinity diagram (TS-diagram) is a basic tool for water mass classification and analysis in deep-sea oceanography. It is the plot of two conservative properties against each other. A water mass with uniform temperature and salinity including water masses in mixed layers shows up in a TS-diagram as a single point. Other water masses, which present some variation of their properties with depth, are shown in the TS-diagram as curves.

The temperature and salinity data of all depths were plotted against each other using Ocean Data View Software (ODV). ODV presents depth as a Z-axis with colors for each X, Y coordinate. Results of the TS-diagram being presented as the range of temperature and salinity of each water mass.

Relationship between water mass and zooplankton data analysis

Zooplankton cluster analysis, function of S-PLUS 2000 Software, was applied to determine the group of stations with similar species composition and abundance of zooplankton. The squared Euclidean distance algorithm was used to calculate the inter-individual distance for clustering. The available zooplankton data was represented for the whole water column, therefore, results from cluster analysis determine the relationship with water masses classified by TS-diagram, which are applied for the whole water column data.

RESULTS

Water masses identification

Water masses in the study area from two seasons were identified by TS-diagram as five masses (Fig 2). The first water mass (mass 1) was characterized by high temperatures between 28-30.5 °C and low salinities between 31.5-32.5 psu. Mass 1 was found in the inner of the Gulf of Thailand during April-May 1996 (Fig 3 c and d).

The second water mass (mass 2) was characterized by temperatures between 29.5-30.5 °C and salinities 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 c).

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

The fourth water mass (mass 4) was characterized by temperatures between 25-30 °C and salinities between 32.5-34 psu. This type of water was found in the whole study area during September 1995 and in the southern and middle part of the study area during April- May 1996 (Fig 3 a - d).

The fifth water mass (mass 5) was characterized by temperatures between 23.5-26 °C and salinities of more than 34 psu. This was found at the bottom layer (more than 50 meters) offshore of eastern Peninsular Malaysia (st. 63-69, 73,74 and 78) in September 1995 (Fig 3 b).

The Relationship between water mass and 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 4). The average percentages of the top four high abundance zooplankton species are shown in Fig 5. The dominant species of zooplankton in both survey periods were copepod. Total zooplankton increased because of the increase in copepod abundance.

From Fig 4 and 5, the characteristics of cluster A were high abundance of chaetognatha (twice the abundance in cluster B and C) and low average total abundance. The ratio of dominant species of clusters B and C were similar. The different characteristic was the total abundance, in which cluster C was higher.

The distributions of clusters in each station are shown in Fig 6. Most of the stations during September 1995 displayed 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 6 b).

Six stations at the central and southern parts of the study area in September 1995 were cluster B zooplankton. Their distribution did not have any special pattern (Fig 6 a). In April-May 1996, large distributions of cluster B zooplankton (35 stations) were found throughout the study area, except near the mouth of the Gulf of Thailand (Fig 6 b). Cluster C zooplankton was found in both survey periods at the coastal area.

Zooplankton samples were collected by oblique haul, so it was not possible to find the species composition and abundance in each layer, while type of water mass at the lower and upper layers of some stations was different. Therefore, survey stations were grouped by considering both surface and bottom water masses as shown in Fig 7. for determining the relationship between water mass and zooplankton.

Distribution of cluster A zooplankton coincided with the presence of composite water mass G and H in September 1995 and D and F in April-May 1996 (Fig 6, 7 and 8). Cluster B zooplankton stations were observed mostly in composite water masses A, B and C (Fig 8). Cluster C zooplankton stations were observed at composite water masses G in September 1995 and A in April - May 1996 (Fig 6, 7 and 8) which are coastal areas.

DISCUSSION

Characteristics and distribution of water masses

Characteristics of water masses and their distribution suggest that there were five water masses in the study area. The water masses are named following their originating area.

1. Characteristics of water mass 1 (29.5-30.5 °C, 31.5-32.25 psu) were different from the characteristics of all other water mass in the adjacent areas (Rojana-anawat et al., 2000 and 2001). This water mass originates in the study area of the so called Gulf of Thailand water mass (GOT water mass).
2. Characteristics of mass 2 (29.5-30.5 °C, 32.5-33.5 psu) could be overlaid with the characteristics of the water mass near the Mekong river (Rojana-anawat et al., 2001). This water mass could be an inflow of Mekong water to the study area and is the so called Mekong water mass.
3. Characteristics of Mass 3 (27-30 °C, 33.5-34 psu) could be overlaid with the characteristics of the surface of the South China Sea water mass (surface water to 50 meter depth) from the study of Rojana-anawat (2000 and 2001). It shows the intrusion of a water mass from the surface layer of the South China Sea to the study area (Surface South China Sea water mass, SSCS).
4. Characteristics of Mass 4 (25-30 °C, 32.5-34 psu) were between the characteristics of the GOT and SSCS water masses. It should be a mixture of GOT water mass and SSCS water mass.
5. Characteristics of Mass 5 (23.5-26 °C, >34 psu) could be overlaid with the subsurface of the South China Sea water mass (SuSCS water mass) in the study of Rojana-anawat et al. (2000 and 2001). It was suggested that there was an intrusion of SuSCS water mass into the study area at 50 to 150 meter depths.

Seasonal variation of water mass distribution

The seasonal variation of the horizontal distribution of water masses in this area is mainly influenced by monsoon winds, different water densities and tidal currents. (Lowwittayakorn, 1998 , Snidvongs 1998 and Yanagi et al., 2001).

During September 1995, which is the Southwest monsoon season, there was a strong inflow of surface layer of the SCS water mass to the Gulf of Thailand at the west coast, the strong winds induce mixing with the local GOT water mass. This explanation was encouraged by the study of Yanagi et al. (2001) that stratification is weak in this season. The whole area except the bottom water of the East Coast of Peninsular Malaysia was occupied by a mixture of the GOT and SSCS water masses (Fig 3 a and b). The bottom water of the East Coast of Peninsular Malaysia (50-80 m) was occupied by the SuSCS water mass. This observation implies that there was an intrusion of SuSCS water mass from the South China Sea under the influence of wind and density difference.

In April-May 1996 which is a transition period between the Northeast to Southwest monsoon season, stratification occurred over the whole area at depths greater than 30 meter because of large sea surface heating and weak sea surface wind. The development of stratification separated high temperature and low salinity GOT water mass at the upper layer from the others beneath it (Fig 3 c and d).

It was observed in this study that the SSCS water flowed into the Gulf of Thailand at the bottom layer and both surface and bottom layers at the mouth of the Gulf of Thailand while GOT water flowed out of the Gulf of Thailand at the upper layer (Fig 3 c and d). The SSCS water mass at the bottom in the Gulf of

Thailand should flow from the South China Sea through the channel connecting the deepest part of the Gulf of Thailand and the South China Sea (Fig 9). Yanagi et al., 2001 suggested that it was because the density difference between the head of the Gulf of Thailand and the tip of Peninsular Malaysia which is about 2.0 sigma-t at 20 m below the water surface in this season. The intrusion was limited in horizontal distribution only at the deep area of the Gulf of Thailand (> 80 meter).

The Mekong water mass was found only at the surface layer of stations at the mouth of the Gulf of Thailand and east coast of Peninsular Malaysia (Fig 3 c). This water mass came from a coastal jet flowing southwestward along the southeast coast of Vietnam under the influence of the Northeast monsoon wind as indicated by Shaw and Chao (1994). The coastal jet water is from mixing between the South China Sea water mass and run off from the Mekong River. Although, there was no coastal jet during the survey period because of the weak NE monsoon wind but the Mekong water mass still remained in the area.

Mixing of GOT and SSCS water mass was found in two areas. The first was at the bottom layer of the centre of the study area between the area of the GOT water mass and the intrusion of the SSCS water mass. This water mass should originate from the turbulent mixing which is most pronounced along the isopycnal surface (Open University, 1989). Fig 3 d and Fig 8. showed that the GOT and SSCS water masses occupied the isopycnal surface of the first area. The second area was both surface and bottom water of the southern part of the study area. Mixing of the GOT and SSCS water masses in this area should be the remaining water mass from the Northeast monsoon season that stratification was not present because of sea surface cooling and the strong Northeast monsoon wind (Yanagi et al., 2001).

Ecological implication

The presence of the SSCS water mass either surface or bottom water or both layers (water mass group B, D and F) in TS-diagram coincided with the area of zooplankton cluster A, which was in a high abundance ratio of chaetognatha and low total abundance of zooplankton (Fig 6 and 7). This suggests the possibility to use SSCS water mass as the indicator of low total abundance of zooplankton with the high proportion of chaetognatha area. Jiwaluk (2001) also reported a high abundance ratio of chaetognatha in the area of open sea water mass in Vietnamese waters that has the same characteristics as the SSCS water mass (Rojana-anawat et al, 2001).

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