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WEST COAST OF PENINSULAR MALAYSIA

Acoustic, Fishery Oceanography and Bottom Substrate Surveys

DEPARTMENT OF FISHERIES MALAYSIA
MINISTRY OF AGRICULTURE AND AGRO-BASED INDUSTRY MALAYSIA

CHAPTER 1

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ACOUSTIC AND PELAGIC FISH RESOURCE SURVEY ON THE WEST COAST OF PENINSULAR MALAYSIA

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ABSTRACT

An acoustic and pelagic fish resource survey in the waters off Langkawi, Kedah; Penang; Perak and Selangor was carried out from 23rd February to 13th March 2006 to evaluate pelagic fish resources in the northern part of the west coast of Peninsular Malaysia. This survey was conducted simultaneously with other research components that included physical and biological oceanography and fish larvae studies. The total area of 27,838 km² surveyed covered coastal and offshore waters. The total pelagic fish biomass was estimated at 210,000 tonnes. Scombridae, dominated by Rastrelliger brachysoma, R. kanagurta, Auxis thazard and Euthynnus affinis and Carangidae, represented mainly by Decapterus maruadsi, formed the two major families of pelagic fish. The highest catch of R. kanagurta was observed in the the deeper waters of the northern area between Langkawi and Penang. The truss morphometric protocol and Random Amplified Polymorphic DNA (RAPD) analysis were applied to the two species of Rastrelliger; R. kanagurta and R. brachysoma to investigate the genetic variation between them. Five 10-base RAPD random primers were used in this study. The results obtained from this study suggested the probable existence of two morphologically significantly differentiated groups of R. kanagurta along the west coast of Peninsular Malaysia.

Keywords: Acoustic survey, Biomass estimation, Fish density, Pelagic fish, Genetic variation

1.0 INTRODUCTION

Pelagic fish resources contributed to about 45% of the total production of the west coast of Peninsular Malaysia (Annual Fisheries Statistics, 2004). The waters off Perlis to Selangor contributed up to 97% of the total fish landings of the west coast of Peninsular Malaysia. The pelagic species that dominate the landings of commercial gears such as fish trawls and fish purse seines are *Rastrelliger kanagurta* (Indian mackerel), *R. brachysoma* (Indo-Pacific mackerel), *Decapterus maruadsi* (Japanese scad), *D. russeli* (Indian scad) and *neritic tuna namely Euthynnus affinis* (Kawakawa), *Thunnus tonggol* (Longtail) and *Auxis thazard* (Frigate).

Mackerel comprises three main species i.e. *Rastrelliger brachysoma, R. kanagurta and R. faughni* (Island mackerel). Although the local name 'kembung' is used loosely to refer to this group of fish, a finer breakdown splits this genus into 'pelaling' *(R. brachysoma)*, 'kembung' (small to medium size of *R. kanagurta* and *R. faughni)* and 'mabung' (large size *R. kanagurta* and *R. faughni)*. These fish species inhabit coastal waters, form large schools and tend to aggregate around Fish Aggregating Devices (FADs). *R. brachysoma* is distributed in the more coastal near-shore areas while *R. kanagurta* and *R. faughni* are more oceanic (Chee, 2000). *R. brachysoma, R. kanagurta* and *R. faughni* can be found throughout the Pacific Ocean: Andaman Sea to Thailand, Indonesia, Papua New Guinea, Philippines, Solomon Islands and Fiji; Indo-West Pacific: Red Sea and East Africa to Indonesia, north to the Ryukyu Islands and China, south to Australia, Melanesia and Samoa, entering the eastern Mediterranean Sea through the Suez Canal; and Indo-West Pacific: India to Fiji, north to Taiwan, respectively (Froese and Pauly, 2005).

According to Chee (2000), pelagic fish resources including *Rastrelliger* sp. are already over-exploited on the west coast of Peninsular Malaysia. The contribution of pelagic fish to the total landings in this area was 32% in 2006, a reduction 15% over 25 years. This was mainly caused by over-fishing through the used of more efficient fishing gear and larger fishing vessels. The expansion of fishing grounds into new and non-traditional areas within the Malaysian Exclusive Economic Zone (EEZ) also contributed towards this problem as the additional fishing effort was also targeting to harvest the same fish stocks. The increasing level of pollution, the loss of suitable habitats to development activities, natural phenomena such as *El Nino* and *La Nina* and environmental catastrophes such as tsunamis may also affect the present state of pelagic fish resources in the area. To date, pelagic fish remains the backbone of the marine fisheries of the west coast of Peninsular Malaysia.

Since the small pelagic fish of the west coast has been contributing significantly to the total annual landings, proper management measures are essential to ensure the resources are exploited at a sustainable level. Therefore, a study on the fish biology and the stock assessment of commercially important species is needed. Johannes (1980) indicated that fluctuations in catches of pelagic fish species are due to changes in population abundance in relation to their survival rates. Sissenwine (1984) noted that the recruitment variability is the central fishery science and a major source of uncertainty in management.

One important fish stock assessment technique, using acoustic surveys, is widely used in the world recently. In the past, conventional methods that mostly depended on the swept area method, structured length frequency and tagging were used. However with technology advancement, many types of scientific echo sounders have been introduced for quantitative stock assessment especially on pelagic fish.

Although the acoustic technique has been extensively used in European and American waters for a long time, this technique was only introduced to Malaysia in the 1980s. The first acoustic survey in Malaysia was conducted in 1980 using the Norwegian Research Vessel Dr. Fridtjof Nansen which was equipped with the SIMRAD EKS 38 and EKS 120. The survey aimed to investigate the total pelagic fish biomass in the Exclusive Economic Zone off the west and east coasts of Peninsular Malaysia. The second survey was conducted in 1982 under a joint project between FAO and Malaysia. The third survey was carried out in the third quarter of 1983, using KK AYA which was equipped with an EKS 120 and a SIMRAD CM Sonar Scope. The fourth acoustic survey was carried out from late 1985 to early 1986 using RV RASTRELLIGER, a vessel from FAO. This survey covered the South China Sea and the Straits of Malacca. The survey was aimed at estimating the total biomass, species composition and distribution of pelagic and semi-pelagic fish.

In 1995, a collaborative program between SEAFDEC Training Department (TD) and Marine Fishery Resources Development and Management Department (MFRDMD) was undertaken. A series of acoustic surveys, covering the waters of the South China Sea, was implemented. This recent acoustic survey on the west coast of Peninsular Malaysia was aimed at estimating the total biomass of pelagic fish during the north-east monsoon.

The identification of the geographical ranges of unit stocks is fundamental for population dynamics and management of fisheries (Bailey, 1997). To date no relevant information on stock definition has been produced for the genus Rastrelliger in Malaysia. Thus, the determination of management units is deemed necessary for the management of the stocks of *Rastrelliger* in Peninsular Malaysia. Management units are distinct populations of fish that have different population sizes, recruitment patterns, spawning and nursery grounds, and therefore need to be managed separately for sustainable commercial fishing.

There are several approaches used to understand the population structure and the movement of fish (Garcia de Leo'n *et. al.*, 1997) though it is not often easy to determine the correct spatial scale to employ in identifying populations of fish (Larkin, 1981). These have included utilization of both molecular and non-molecular markers. An example of the latter is the multivariate analysis of morphometric characters. Morphometric characters provide information complementary to that derived from biochemical, physiological and life history studies, for identifying marine stocks and their spatial distribution. The land-mark based truss morphometric protocol (Strauss and Bookstein, 1982) is very effective in capturing information on the shape of a fish. This protocol prevents biases, which occur with traditional procedures, as the latter gives redundant measurements for certain axes of the body (Grimes *et. al.*, 1987).

While phenotypic variation is usually associated with the adaptive potential of populations, genetic markers such as DNA and protein, detect levels of genetic variation. This information is critical for conservation strategies as the long-term survival and evolution of every species depend on the maintenance of genetic diversity and are closely related to geographic distribution of genotypes. In the last few decades, the advancement of molecular marker techniques, bioinformatics and the use of geographical information systems (GIS) have greatly assisted in the survey, sampling and assessing genetic diversity (Rao and Hoskela, 2001) of populations and higher level taxa. Some of the molecular markers frequently utilized for population assessment (Williams *et. al.*, 1990) include restriction fragment length polymorphisms (RFLPs), random amplified polymorphic DNA (RAPDs), amplified fragment length polymorphism (AFLP) and single sequence repeats (SSR) also known as microsatellites.

The objectives of this study are to estimate the total biomass of pelagic fish on the west coast of Peninsular Malaysia to gather as much biological information from the samples obtained during the survey and to determine the genetic variation among the species that probably form a unit stock. These findings are crucial for better stock estimation upon which measures for sustainable management can be formulated.

Andrade, 2002) was utilised by transforming the data using the following formula:

$$M_{trans} = \log M - \beta(\log SL - \log SL_{mean})$$

where M_{trans} is the transformed measurement, *M* the original measurement, β the within-group slope regressions of the log *M* vs log SL, SL the standard length of the fish, and SL_{mean} the overall mean of the standard length.

A stepwise multivariate discriminant analysis (DFA) was then performed on the transformed morphometric variables to identify the combination of characters that optimize differentiation among the population. The output generated from this analysis was used to assess the discriminatory effectiveness from percentage of correct re-classification in discriminant analysis. Mahalanobis distance between population centroids and pairwise F statistics ($P \leq 0.05$) were computed to evaluate significant levels of population difference. The spatial separation between the centroids was represented by the generation of scatter plots. All statistical analysis was performed using SPSS v11.5.

2.3.2 RAPD analysis

Total genomic DNA from muscle tissue was extracted using the Tissue DNA Kit (Genispin). Five 10-base RAPD random primers were used for the RAPD-PCR. The PCR reaction consisted of 10 X PCR Buffer, 0.4 mm dNTPs mixture, 3.5 mM $MgCl_2$, 5 picomoles primer, 2.0 units *Taq* DNA polymerase, 30 ng template DNA and distilled water in a final volume of 25 µl. The amplification of DNA was conducted using the MJ-Research Peltier Thermal Cycler (PTC-200) that was programmed at 35 cycles for 30 seconds of denaturation at 94 °C, 30 seconds of annealing at 36 °C, one minute of extension at 72 °C and two minutes of final extension at 72°C.

The markers were scored by either the presence (1) or absence (0) at a particular position of a given amplification product of each individual. The data matrices were entered into the Multivariate Statistical Package (MVSP) v3.13, and pairwise comparisons of population were made. To analyse for phonetic relationships the scored data were used to calculate the genetic distance values and to construct the dendogram based on unweighted pair-group method of arithmetic (UPGMA). The index of similarity between individuals was calculated using the equation of Nei & Li (1979):

$$S_{xy} = 2n_{xy} / (n_x + n_y)$$

where n_{xy} is the number of fragments shared by individuals *x* and *y*, and n_x and n_y are the numbers of fragments scored for each individual. This method was chosen because of the greater emphasis placed on fragment matches versus that of non-matches.

■ Tissue extraction from the fish

3.0 RESULTS AND DISCUSSION

3.1 Acoustic Stock Assessment Survey

The raw back scattering strength was obtained solely by using FQ80 Data Analyzer. Data quality was considered quite high with some errors due to loss of echoes after an 800-ping interval. Echo verification was solely dependent on fish sampling activities using the high-opening bottom trawl. However the bulk of catches during sampling comprised mainly demersal fish with only a small percentage of pelagic fish. Thus the pelagic biomass reported here should be used with caution because of the species reference.

Table 4 indicates the average density of pelagic fish on the west coast of Peninsular Malaysia. The average density estimated was 7.5 tonnes/km². The minimum and maximum densities were 2.3 and 24.2 tonnes/km², respectively. Based on the output density, the pelagic fish biomass in the whole survey area was estimated at 209,798 tonnes.

The national acoustic survey in 1998 gave an average fish density in the west coast Peninsular Malaysian waters of 9.6 tonnes/km² (Raja Bidin *et. al.*, 2000). However, this recent survey only recorded a fish density of 7.5 tonnes/km². The current estimate shows a 23.8% reduction of the pelagic resources in comparison to the estimate made in 1998.

However, this biomass estimation requires further verification due to improper sampling using the high-opening bottom trawl instead of a mid-water trawl. Therefore, it is most likely that the species composition derived from the catch does not provide a good representation of pelagic fish resources in the area although mackerels and anchovy are the major pelagic fishes found in this area.

3.2 Fish Biology Study

A total of 296 samples of pelagic species were analysed for maturity stages for the fecundity study. Scombridae and Carangidae formed the two major families of pelagic fish which were dominated by *Rastrelliger brachysoma, R. kanagurta, Decapterus maruadsi, Auxis thazard* and *Euthynnus affinis*. Only 11 specimens of 3 selected species namely *R. brachysoma, R. kanagurta, D. maruadsi* were used for the fecundity study.

Table 5 shows the length information of pelagic species

sampled. *Rastrelliger kanagurta* (Indian mackerel or kembung) with a maximum length up to 255 mm and with an average of 217 mm indicated the specimens caught were already mature. The maximum and average lengths of *Rastrelliger brachysoma* (Indo-pacific mackerel or "pelaling") were 227 mm and 180.5 mm, respectively. Only a small number of neritic tuna were caught - seven frigate tuna *(Auxis thazard)* and one kawakawa *(Euthynnus affinis)*. A small sample of 34 fishes of *Decapterus maruadsi* (Japanese scad) gaves the maximum and average length as 192 mm and 159 mm, respectively.

Table 6 shows the fecundity and average size of eggs of the three abundant species; *R. brachysoma, R. kanagurta, D. maruadsi. R. kanagurta* having a long body length produced 33,000 – 34,000 ova at each spawning period. For *R. brachysoma*, the observed fecundity was 17,000 – 30,000 ova at each spawning. The diameters of the ova in *R. kanagurta* seemed to be even at 0.49 mm while in *R. brachysoma*, the size varied from 0.42 – 0.51 mm. Figure 4 shows the relationship between body weight and number of ova. It seems that the number of ova in the eggs has a direct relationship with body weight.

Figure 5 shows the catch distributions of *Rastrelliger kanagurta* along the Straits of Malacca during the survey. The higher catches were observed in the northern areas between Pulau Langkawi and Penang towards the deeper areas. The highest catch was 11.6 kg per half an hour at Station 4. *Rastrelliger brachysoma* was found in three stations. Two stations were located in the coastal areas off Kedah and one in the southern part of the survey area. The highest catch rate was 2.7 kg per half an hour at Haul 7 (Figure 6).

The percentage of mature fish of *R. brachysoma, R. kanagurta* and *D. maruadsi* were found to be above 80% of the total number caught. Fish were categorized as mature when the gonadosomatic index (GSI) was above 3.0. Figure 7 shows the percentage of mature fish. Most of them were found between Pulau Langkawi and Penang.

Most of the selected major pelagic species were found to be abundant in the northern waters off Kedah and Penang. *Rostrelliger kanagurta* in particular, showed a well distributed pattern when compared to *R. brachysoma* and *Decapterus maruadsi*. The areas where the pelagic fish were abundant are known to be the main fishing grounds not only for the purse seine vessels but also fish trawlers. However, the observation and analysis of the data for this survey were solely dependent on the fish samples caught by the high-opening trawl; the true sizes of the pelagic fish schools were not well represented.

Based on the body size and maturity stages of the fish species caught, it seemed that the period of February and March could be the spawning season of *Rastrelliger kanagurta, R. brachysoma* and *Decapterus maruadsi*. In the same area between Pulau Langkawi and Penang, the northeast monsoon season is the spawning period of most species of cephalopods such as *Loligo duvaucelli* and *Sepioteuthis lessoniana*.

3.3 Fish Genetics and Morphometric Study

3.3.1 *Truss morphometric analysis*

In the stepwise discriminant function analysis the first two functions which contributed significantly to the discriminant accounted for 84.1% of the between group variability. All 18 variables contributed significantly to the multivariate discriminant of the populations. Percent classification success (PCS) for each sample, the generalized Mahalanobis distances (D2) and F-statistics for the two species are presented in Table 7. The F-statistics indicated highly significant difference on the truss element Mahalanobis distances with a North-South geographical gradient. Two clusters of homogeneous groups were observed in *R. kanagurta*; i) Hauls 1, 3, 6, off the coast of Kedah and Penang in the North and Hauls 12, 14 and 15 off the coast of central Perak in central Peninsular Malaysia. ii) Hauls 19 and 20 located of the coast of the central Peninsular Malaysia but towards the south (Figure 8).

R. brachysoma showed asimilar gradient with the northern Hauls 4 and 7 showing some degree of distinction from the more southern Haul 23 found off the coast of Selangor. However, adjustment for multiple group comparison shows non significance for all comparisons. As noted in Table 7, Hauls 15 was significantly different from other populations in its cluster but after similar adjustment its group centroids is not significantly different from Hauls 1, 6 and 14. The overall total reclassification rate was high at 81.8% (Table 8). Based on DFI (which explained 70% of the variance) four truss elements were selected for the distinction of *R. kanagurta* from *R. brachysoma* (A1, A2, A6 and B3). Within each species differentiation was along DF2 (A2, A3, A5 and A6) as shown in Table 9. For both intra and inter species discrimination the head related and the anterior part of the body seem to be important for discrimination.

The results obtained from the truss morphometric analysis suggested the existence of two morphologically significantly differentiated groups of *R. kanagurta* along the west coast of Peninsular Malaysia, with some slight discrepancies in the placement of Haul 15. However this site was shown to be not significantly different from Haul 1, 6 and 14 (after statistical adjustment for multiple comparisons) based on Mahalanobis distance. The first group comprised populations in the north and the central region off the coast of Perak and the second of populations just further south off the coast of southern Perak. Within each area, the overlapping distribution of samples was probably attributable to extensive migration in these waters. The same trend was observed for *R. brachysoma* (though not significant but this was based on limited number of size of population). A parallel pattern of differentiation shown by both species suggested the presence of natural or artificial geographical barriers which could have contributed largely to the emergence of differences between populations existing between the areas north and south of the coast of central Perak.

Examination of the contribution of each morphometric character to discriminant functions saw association of the head related characters and anterior part of the body for stock differentiation. *R. kanagurta* and *R. brachysoma* share similar morphological characters but again show differences in head related variables and anterior part of the body. Such head related differences would normally suggest the influence of habitat differences between the populations. Variation in pattern of head morphology is often attributed to the exploitation of different ecological niches, as a result of food availability and type of prey (e.g. Hyndes *et. al.*, 1997; Delariva and Agostinho, 2001). Water temperature, prolonged swimming and currents have also been suggested to account for these differences although temperature may not have any bearing in this study. As morphology is especially dependent on environmental conditions during early life-history stages (Lindsey, 1988), phenotypic differentiation may indicate that majority of fish spend their entire lives in separate regions.

The detected high morphometric differentiation indicates that extensive mixing does not occur between the two zones to the north and south of the coast of central Perak. This is confirmed by the high significant Mahalanobis distance values observed between the areas. Nevertheless, in general, fishes demonstrate greater variance in morphological traits both within and between populations than other vertebrates, and are more susceptible to environmentally-induced morphological variation (Allendrof and Leary, 1988; Wimberger, 1992) as mentioned above. However, although environmental factors play a major role in phenotypic discreteness of aggregations, restricted movement may also lead to reproductive isolation resulting in genetic differentiation.

3.3.2 *RAPD analysis*

Of the 10 RAPD primers screened from Kits OPC (Operon Technology, USA), five produced repeatable amplification products that yielded a total of 47 scorable markers with molecular size ranging from 300 to 1200 base pair (bp). The number of scorable bands amplified by each primer varied from 8 – 9 in *R. brachysoma* and 8 – 10 in *R. kanagurta*. The percentage of polymorphic loci showed a high value of 87.2% in *R. kanagurta* but a low of 36.4% in *R. brachysoma*.

As expected, the UPGMA cluster analysis using the Nei similarity coefficient (Nei, 1972) showed (Figure 9) two main clusters comprising of *R. kanagurta* and *R. brachysoma*, respectively. Within the latter species a fair degree of structuring was observed, although with some overlap, most of which were between individuals in the northern area, Hauls 4 and 7. The extent of structuring was more evident in *R. kanagurta*, almost congruent with those observed in the morphometric analysis with those populations to the north and south off the coast of Perak forming separate cohesive groups. The main difference was with Haul 15. Unlike in the morphometric data where it grouped with the northern group, here three of its individuals introgressed with the southern cluster of 19 and 20 while a single individual was clustered with Hauls 12 and 14 in central west coast of Peninsular Malaysia. This suggests that Haul 15 was more genetically related to the southern populations although gene flow to the neighbouring Hauls 12 and 14 still occurs.

The PCOA chart (Figure 10) confirmed the findings as was shown by the UPGMA analysis. The first principal co-ordinate axis which accounted for 39.6% of the total variance, separated the two species but not at intraspecies level. However, the second co-ordinate axis which explained 11.7% of the total variation not only differentiated populations north of the coast of Perak from the more southern populations, but also to a large extent from the northern population (Hauls 1 and 3) and from the central population (Hauls 12 and 14). The moderate percentage of the variation (52%) explained by the first two axes could be attributed to evidence of genetic cohesiveness observed within areas.

The RAPD method suggests that there was a genetic component to the phenotypic differentiation observed between geographic regions. Analysis of the RAPD marker profiles obtained for the *R. kanagurta* samples from the sampling location shows similar trend to the morphometric studies, but population structuring being more evident and spatially corrected. Both the UPGMA and PCO analysis show the formation of three clusters.

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4.0 CONCLUSIONS

The estimated biomass for the current survey was 23.8% less compared to the survey conducted in 1998. This figure indicated that pelagic resources on the west coast had experienced a reduction and need special attention. Scombridae and Carangidae formed the two major families of pelagic fish which were dominated by *Rastrelliger brachysoma, R. kanagurta, Decapterus maruadsi, Auxis thazard* and *Euthynnus affinis*. Based from the body size of fish and maturity stages of the fish species caught, it seemed that February and March could be spawning season of *Rastrelliger kanagurta, R. brachysoma* and *D. maruadsi*. The truss morphometric and genetic study suggested the existence of two fairly self-contained stocks of *R. kanagurta* along the west coast of Peninsular Malaysia. The first group comprised populations in the north and the central region off the coast of Perak, and the second of populations just further south off the coast of southern Perak.

This study confirms the need for gathering and combining genetic with physiological, ecological and oceanographic information when assessing the genetic structure of highly abundant, widely distributed and high gene flow marine fish to facilitate the development of management recommendations. As such, conservation strateies should aim at preserving the diversity in each area, as there may already be local adaptations that will be lost if the population is mixed with others. In the case of *R. brachysoma* assessment on a wider population is required.

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Table 1: Full range of layer setting by FQ80 of MV SEAFDEC2 during the survey on the west coast of Peninsular Malaysia, 2006

Layer No	From (m)	To (m)	Range (m)	Layer Type
Layer 01	0	5	5	P
Layer 02	5	10	5	P
Layer 03	10	15	5	P
Layer 04	15	20	5	P
Layer 05	20	25	5	P
Layer 06	25	30	5	P
Layer 07	30	35	5	P
Layer 08	35	40	5	P
Layer 09	40	45	5	P
Layer 10	45	50	5	P
Layer 11	50	55	5	P
Layer 12	55	60	5	P
Layer 13	60	65	5	P
Layer 14	65	70	5	P
Layer 15	70	75	5	P
Layer 16	75	80	5	P
Layer 17	80	85	5	P
Layer 18	85	90	5	P
Layer 19	2	3	1	B
Layer 20	1	2	1	B

Note: P = Pelagic and B = Bottom

Table 2: Sampling details of *Rastrelliger kanagurta* and *R. brachysoma* used in the genetic and morphological studies on the west coast of Peninsular Malaysia, 2006

Species	Sample size	Location (Haul No.)	Date of capture
Rastrelliger kanagurta	2	No.1	24/02/06
	14	No.3	25/02/06
	4	No.6	27/02/06
	7	No.12	04/03/06
	4	No.14	05/03/06
	4	No.15	05/03/06
	9	No.19	08/03/06
	9	No.20	10/03/06
Total specimens	53		
Rastrelliger brachysoma	10	No.4	26/02/06
	4	No.7	27/02/06
	10	No.23	13/03/06
Total specimens	24		
Grand total specimens	77		

Table 3: Morphometric variables analysed

No.	Name	Description
1	A1	Distance between the tip of snout and the insertion of the first dorsal fin
2	A2	Distance between the insertions of the first dorsal and pelvic fins
3	A3	Distance between the tip of snout and the insertion of the pelvic fin
4	A4	Distance between the insertions of the first and second dorsal fins
5	A5	Distance between the insertions of the second dorsal and anal fins
6	A6	Distance between the insertions of the pelvic and anal fins
7	B1	Distance between the insertions of the first dorsal and anal fins
8	B2	Distance between the insertions of the pelvic and the second dorsal fins
9	A7	Distance between the insertions of the second dorsal and superior finlets
10	A8	Distance between the insertions of the first superior and inferior finlets
11	A9	Distance between the insertions of anal fins and inferior finlets
12	B3	Distance between the insertions of the second dorsal and inferior finlets
13	B4	Distance between the insertions of anal fins and superior finlets
14	A10	Distance between the insertions of the first and fifth superior finlets
15	A11	Distance between the insertions of the fifth superior and inferior finlets
16	A12	Distance between the insertions of the first and fifth inferior finlets
17	B5	Distance between the insertions of the first superior and fifth inferior finlets
18	B6	Distance between the insertions of the first inferior and fifth superior finlets
19	SL	Standard length

Table 4: Estimation of pelagic fish density during the survey on the west coast of Peninsular Malaysia, 2006

Station		Position		Average		Density	Biomass
From	To	LAT (N)	LONG (E)	TS (dB)	SA (dB)	Ton/km²	tonnes
1	2	06° 10'	99° 55'	-43.2	-55.0	9.9	3,405.97
2	3	06° 10'	99° 45'	-43.2	-56.4	7.2	2 467.41
3	4	06° 10'	99° 35'	-43.2	-57.0	6.3	2 149.02
4	5	06° 10'	99° 25'	-43.2	-57.3	5.8	2 005.58
5	6	06° 10'	99° 15'	-43.2	-56.0	7.9	2 705.46
6	7	06° 10'	99° 05'	-43.2	-59.5	3.5	1 208.48
8	9	06° 00'	99° 15'	-45.1	-55.0	13.9	4 782.86
9	10	06° 00'	99° 25'	-45.1	-57.0	8.8	3 017.78
10	11	06° 00'	99° 35'	-49.0	-62.0	6.5	2 239.20

Table 4: (Continued)

Station		Position		Average		Density	Biomass
From	To	LAT (N)	LONG (E)	TS (dB)	SA (dB)	Ton/km²	tonnes
11	12	06° 00'	99° 45'	-49.0	-59.0	13.0	4 467.79
12	13	06° 00'	99° 55'	-49.0	-61.0	8.2	2 818.98
14	15	05° 50'	100° 05'	-49.0	-59.2	12.4	4 266.70
15	16	05° 50'	99° 55'	-50.3	-58.4	10.2	3 502.48
16	17	05° 50'	99° 45'	-50.3	-59.1	8.7	2 981.09
17	18	05° 50'	99° 35'	-50.1	-60.0	11.8	4 058.40
18	19	05° 50'	99° 25'	-50.1	-61.1	9.2	3 150.32
19	20	05° 50'	99° 15'	-50.1	-60.3	11.0	3 787.52
21	22	05° 40'	99° 25'	-49.5	-59.1	13.6	4 676.50
22	23	05° 40'	99° 35'	-49.5	-60.4	10.1	3 466.74
23	24	05° 40'	99° 45'	-49.5	-63.0	5.5	1 905.11
24	25	05° 40'	99° 55'	-51.2	-62.0	5.2	1 778.03
25	26	05° 40'	100° 05'	-51.2	-58.0	13.0	4 466.21
27	28	05° 30'	99° 55'	-51.2	-58.7	11.1	3 801.37
28	29	05° 30'	99° 45'	-50.0	-57.0	21.2	7 275.53
29	30	05° 30'	99° 35'	-50.0	-59.2	12.8	4,383.94
30	31	05° 30'	99° 25'	-50.0	-60.0	10.6	3 646.40
32	33	05° 20'	99° 25'	-53.7	-59.3	6.9	2 366.41
33	34	05° 20'	99° 35'	-53.7	-57.8	9.7	3 342.64
34	35	05° 20'	99° 45'	-53.7	-61.0	4.7	1 599.89
35	36	05° 20'	99° 55'	-53.7	-62.0	3.7	1 270.84
36	37	05° 20'	100° 05'	-53.7	-64.0	2.3	801.84
38	39	05° 10'	99° 55'	-53.7	-62.6	3.2	1 106.85
39	40	05° 10'	99° 45'	-53.7	-63.0	2.9	1 009.46
40	41	05° 10'	99° 35'	-49.0	-61.1	7.5	2 572.57
41	42	05° 10'	99° 25'	-49.0	-56.0	24.2	8 324.69
43	44	05° 00'	99° 35'	-49.0	-59.0	12.1	4 172.23
44	45	05° 00'	99° 45'	-49.0	-60.1	9.4	3 238.68
45	46	05° 00'	99° 55'	-49.0	-65.0	3.0	1 048.02
46	47	05° 00'	100° 05'	-49.0	-62.2	5.8	1 996.95
48	49	04° 50'	100° 15'	-49.0	-63.0	4.8	1 660.99
49	50	04° 50'	100° 05'	-49.0	-61.4	7.0	2 400.87
50	51	04° 50'	99° 55'	-48.8	-62.7	5.1	1 750.09

Table 4: (Continued)

Station		Position		Average		Density	Biomass
From	To	LAT (N)	LONG (E)	TS (dB)	SA (dB)	Ton/km²	tonnes
51	52	04° 50'	99° 45'	-48.8	-63.0	4.8	1,633.27
52	53	04° 50'	99° 35'	-48.8	-60.0	9.5	3,258.81
54	55	04° 40'	99° 35'	-48.8	-64.0	3.8	1,297.36
55	56	04° 40'	99° 45'	-48.8	-57.0	18.9	6,502.18
56	57	04° 40'	99° 55'	-48.2	-61.4	3.4	1,182.71
57	58	04° 40'	100° 05'	-48.2	-60.0	4.8	1,632.59
58	59	04° 40'	100° 15'	-48.2	-62.0	3.0	1,030.10
60	61	04° 30'	100° 25'	-48.2	-62.8	2.5	856.80
61	62	04° 30'	100° 15'	-48.2	-58.3	7.0	2,414.78
62	63	04° 30'	100° 05'	-48.2	-60.0	4.8	1,632.59
63	64	04° 30'	99° 55'	-48.2	-58.0	7.5	2,587.49
64	65	04° 30'	99° 45'	-48.2	-59.2	5.7	1,962.81
65	66	04° 30'	99° 35'	-48.2	-56.8	9.9	3,410.97
67	68	04° 20'	99° 45'	-45.5	-58.0	5.6	1,932.63
68	69	04° 20'	99° 55'	-45.5	-59.0	4.5	1,535.14
69	70	04° 20'	100° 05'	-45.5	-54.0	14.1	4,854.55
70	71	04° 20'	100° 15'	-45.5	-65.0	1.1	385.61
72	73	04° 10'	100° 25'	-45.5	-55.0	11.2	3,856.11
73	74	04° 10'	100° 15'	-55.4	-66.7	4.2	1,436.91
74	75	04° 10'	100° 05'	-55.4	-64.2	7.4	2,555.22
75	76	04° 10'	99° 55'	-50.1	-60.0	4.1	1,413.76
76	77	04° 10'	99° 45'	-50.1	-57.7	7.0	2,400.91
79	78	04° 00'	99° 55'	-50.1	-61.3	3.0	1,048.03
80	79	04° 00'	100° 05'	-50.1	-59.0	5.2	1,779.82
81	80	04° 00'	100° 15'	-48.2	-63.3	2.3	796.55
82	81	04° 00'	100° 25'	-48.2	-57.4	9.0	3,098.92
85	84	03° 50'	100° 05'	-48.2	-60.2	4.7	1,626.34
84	83	03° 50'	100° 15'	-48.2	-59.4	5.7	1,955.29
83A	83	03° 50'	100° 25'	-48.2	-58.9	6.4	2,193.87
86	87	03° 40'	100° 15'	-48.2	-58.0	7.9	2,699.05
87	88	03° 40'	100° 25'	-48.2	-62.1	3.1	1,050.05
88	89	03° 40'	100° 35'	-48.2	-58.2	7.5	2,577.57
90	91	03° 30'	100° 45'	-48.2	-59.1	6.1	2,095.13

Table 4: (Continued)

Station		Position		Average		Density	Biomass
From	To	LAT (N)	LONG (E)	TS (dB)	SA (dB)	Ton/km²	tonnes
91	92	03° 30'	100° 35'	-48.2	-60.0	5.0	1,702.98
92	93	03° 30'	100° 25'	-48.2	-57.0	9.9	3,397.90
94	95	03° 20'	100° 35'	-48.2	-60.0	5.0	1,702.98
95	96	03° 20'	100° 45'	-53.5	-63.8	5.6	1,924.42
96	97	03° 20'	100° 55'	-53.5	-64.0	5.3	1,837.81
100	101	03° 10'	100° 45'	-53.5	-65.0	4.2	1,459.82
Total Area 1 nm = 343.676 km²		27,838 km²		**Biomass Total**		**7.5**	**209,797.71**

Table 5: Length information of selected pelagic species caught during the survey on the west coast of Peninsular Malaysia, 2006

Spesies	Sample No.	length (mm)		
		max	min	average
Restrelliger Kanagurta	117	255	167	217
Rastrelliger brachysoma	137	227	157	180.5
Decapterus maruadsi	34	192	192	159
Euthynnus affinis	1			255
Auxis thazard	7	350	220	272.6

Table 6: Fecundity of selected pelagic species obtained during the survey on the west coast of Peninsular Malaysia, 2006

Spesis	Haul no.	Total lenght (mm)	Body wt. (g)	Gonad wt. (g)	GSI	No of eggs	Diameter egg (mm)
Rastrelliger Kanagurta	3	230	135.1	7.2	5.63	33,896	0.4938
	3	212	109.5	6.0	5.80	31,824	0.4977
	6	217	112.5	7.0	6.64	33,032	0.4871
	6	228	129.9	7.8	6.39	32,636	0.4782
Rastrelliger brachysoma	4	181	68.4	7.1	11.58	29,948	0.4220
	4	180	65.0	4.5	7.44	19,000	0.4275
	4	176	65.1	5.4	9.05	17,884	0.5127
	4	195	82.1	5.7	7.46	28,548	0.4041
	7	205	96.8	5.9	6.49	25,514	0.4297
	7	176	61.6	4.5	7.88	17,918	0.4442
Decapterus maruadsi	5	175	65.0	3.2	5.18	10,956	0.3284

Table 7: Pairwise group comparisons based on generalized Mahalanobis distances and F-statistics for the linear discriminant functions for all truss characters for the eight populations of *Rastrelliger kanagurta* and three populations of *R. brachysoma* on the west coast of Peninsular Malaysia, 2006

Step	Haul		1	3	4	6	7	12	14	15	19	20	23
8	1	F		3.090	27.622	1.244	22.572	2.021	1.709	.537	8.349	9.530	18.272
		Sig.		.022	.000	.301	.000	.102	.159	.709	.000	.000	.000
	3	F	3.090		49.770	1.520	25.292	2.030	1.758	9.035	13.878	13.940	24.903
		Sig.	.022		.000	.207	.000	.101	.149	.000	.000	.000	.000
	4	F	27.622	49.770		33.538	2.043	42.529	30.948	58.371	51.135	47.278	5.651
		Sig.	.000	.000		.000	.099	.000	.000	.000	.000	.000	.001
	6	F	1.244	1.520	33.538		22.473	.360	.126	4.176	5.403	6.389	18.480
		Sig.	.301	.207	.000		.000	.836	.973	.005	.001	.000	.000
	7	F	22.572	25.292	2.043	22.473		25.804	20.903	41.050	26.157	23.083	2.166
		Sig.	.000	.000	.099	.000		.000	.000	.000	.000	.000	.083
	12	F	2.021	2.030	42.529	.360	25.804		.174	6.896	5.948	7.255	22.610
		Sig.	.102	.101	.000	.836	.000		.951	.000	.000	.000	.000
	14	F	1.709	1.758	30.948	.126	20.903	.174		5.480	4.220	5.262	16.590
		Sig.	.159	.149	.000	.973	.000	.951		.001	.004	.001	.000
	15	F	.537	9.035	58.371	4.176	41.050	6.896	5.480		20.094	21.967	40.253
		Sig.	.709	.000	.000	.005	.000	.000	.001		.000	.000	.000
	19	F	8.349	13.878	51.135	5.403	26.157	5.948	4.220	20.094		.453	24.971
		Sig.	.000	.000	.000	.001	.000	.000	.004	.000		.770	.000
	20	F	9.530	13.940	47.278	6.389	23.083	7.255	5.262	21.967	.453		21.707
		Sig.	.000	.000	.000	.000	.000	.000	.001	.000	.770		.000
	23	F	18.272	24.903	5.651	18.480	2.166	22.610	16.590	40.253	24.971	21.707	
		Sig.	.000	.000	.001	.000	.083	.000	.000	.000	.000	.000	

Note: Hauls 1, 3, 6, 12, 14, 15, 19, 10 = *Rastrelliger kanagurta*. Hauls 4, 7, 23 = *R. brachysoma*
Significant levels are adjusted for multiple comparisons by multiplying the number of comparisons (50)

Table 8: Percentage of individuals reclassified in each group in the validation of the discriminant analysis for the morphometric data

	LABEL	Predicted Group Membership										
		1	3	4	6	7	12	14	15	19	20	23
Count	1	2	0	0	0	0	0	0	0	0	0	0
	3	0	13	0	0	0	1	0	0	0	0	0
	4	0	0	10	0	0	0	0	0	0	0	0
	6	0	0	0	4	0	0	0	0	0	0	0
	7	0	0	0	0	4	0	0	0	0	0	0
	12	0	1	0	0	0	6	0	0	0	0	0
	14	0	0	0	0	0	2	2	0	0	0	0
	15	0	0	0	0	0	1	0	3	0	0	0
	19	0	0	0	0	0	2	0	0	5	2	0
	20	0	1	0	0	0	0	0	0	1	7	0
	23	0	0	0	0	3	0	0	0	0	0	7
%	1	100.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	3	.0	92.9	.0	.0	.0	7.1	.0	.0	.0	.0	.0
	4	.0	.0	100.0	.0	.0	.0	.0	.0	.0	.0	.0
	6	.0	.0	.0	100.0	.0	.0	.0	.0	.0	.0	.0
	7	.0	.0	.0	.0	100.0	.0	.0	.0	.0	.0	.0
	12	.0	14.3	.0	.0	.0	85.7	.0	.0	.0	.0	.0
	14	.0	.0	.0	.0	.0	50.0	50.0	.0	.0	.0	.0
	15	.0	.0	.0	.0	.0	25.0	.0	75.0	.0	.0	.0
	19	.0	.0	.0	.0	.0	22.2	.0	.0	55.6	22.2	.0
	20	.0	11.1	.0	.0	.0	.0	.0	.0	11.1	77.8	.0
	23	.0	.0	.0	.0	30.0	.0	.0	.0	.0	.0	70.0

Table 9: The first three eigenvectors and percentages of total variance explained by the eigenvalues obtained from DFA Function Coefficients

	1	2	3
A1TRAN	.769	.223	-.163
A2TRAN	-1.253	.508	-.273
B1TRAN	-.510	.036	-.024
B2TRAN	.396	.134	.556
A7TRAN	.268	-.448	.736
A8TRAN	-.231	-.215	.440
A9TRAN	.260	-.075	-.304
B3TRAN	.526	.330	.280
B4TRAN	-.055	-.069	-.014
A10TRAN	.439	-.611	.798
A11TRAN	-.023	-.075	.535
A12TRAN	.180	.238	-.193
B5TRAN	-.264	-.274	-.257
B6TRAN	.577	.352	-.086
Eigenvalue	14.68	2.94	0.86
% variance	70.00	14.1	4.1

Figure 1: Acoustic cruise tracks and sampling stations during the survey by MV SEAFDEC2 on the west coast of Peninsular Malaysia, 2006

Figure 2: Sampling sites of *Rastrelliger kanagurta* (●) and *R. brachysoma* (●) in the northern and central west coast of Peninsular Malaysia

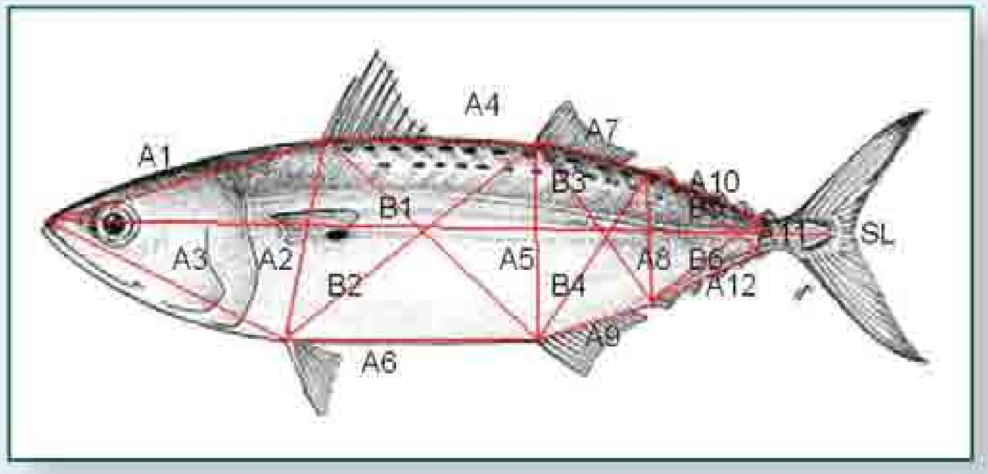

Figure 3: Diagram of *Rastrelliger* sp. showing the 18 variables (including standard length) measured

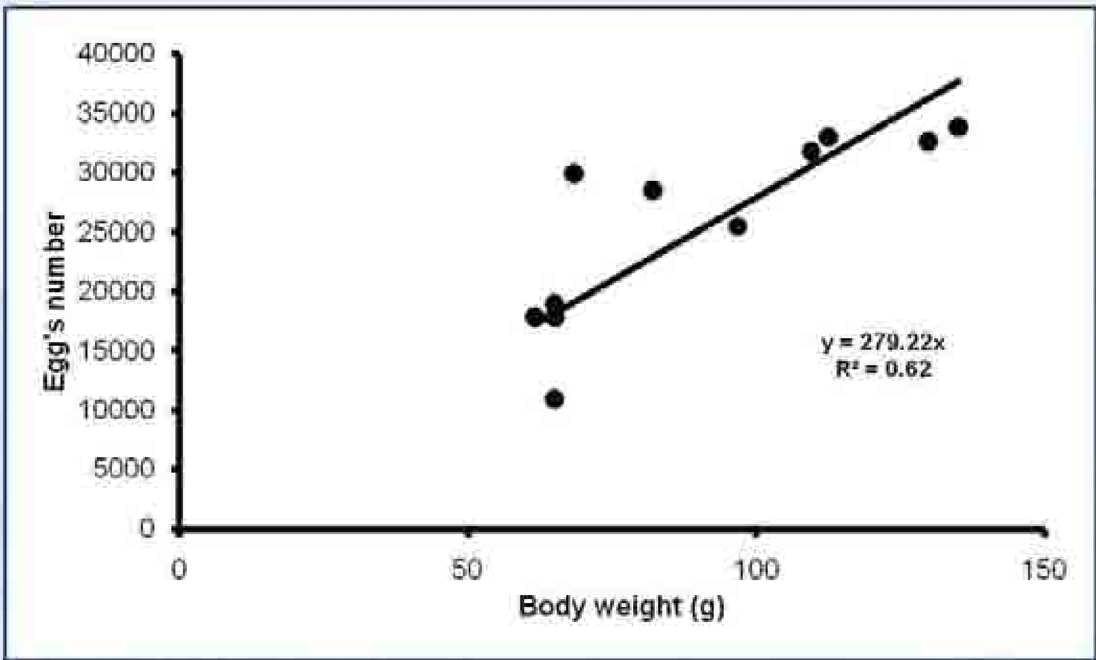

Figure 4: Number of eggs in relation to the body weight of *Rastrelliger brachysoma*, *R. kanagurta* and *Decapterus maruadsi* sampled from the west coast of Peninsular Malaysia, 2006

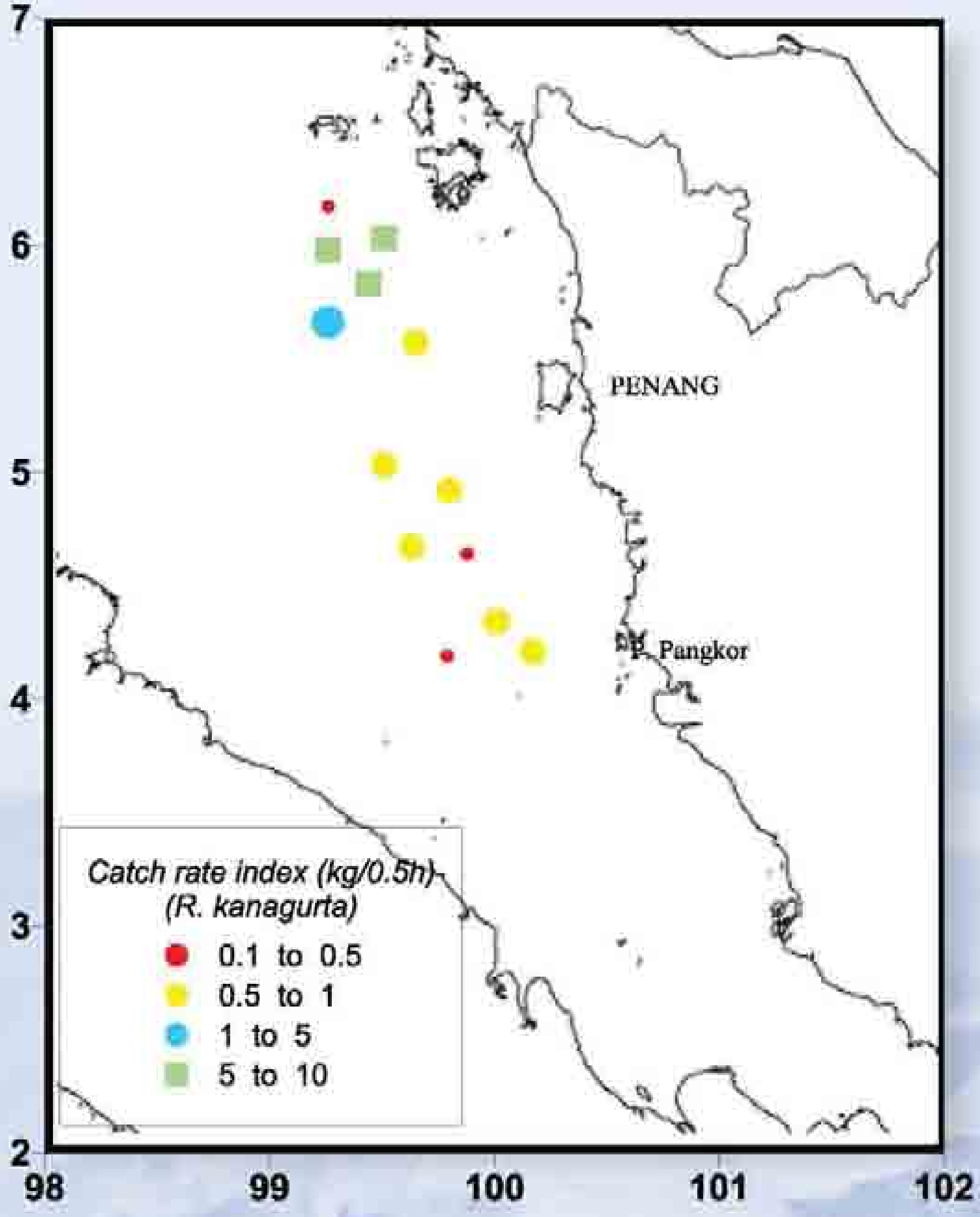

Figure 5: Catch distributions of *Rastrelliger kanagurta* on the west coast of Peninsular Malaysia during the survey in February-March, 2006

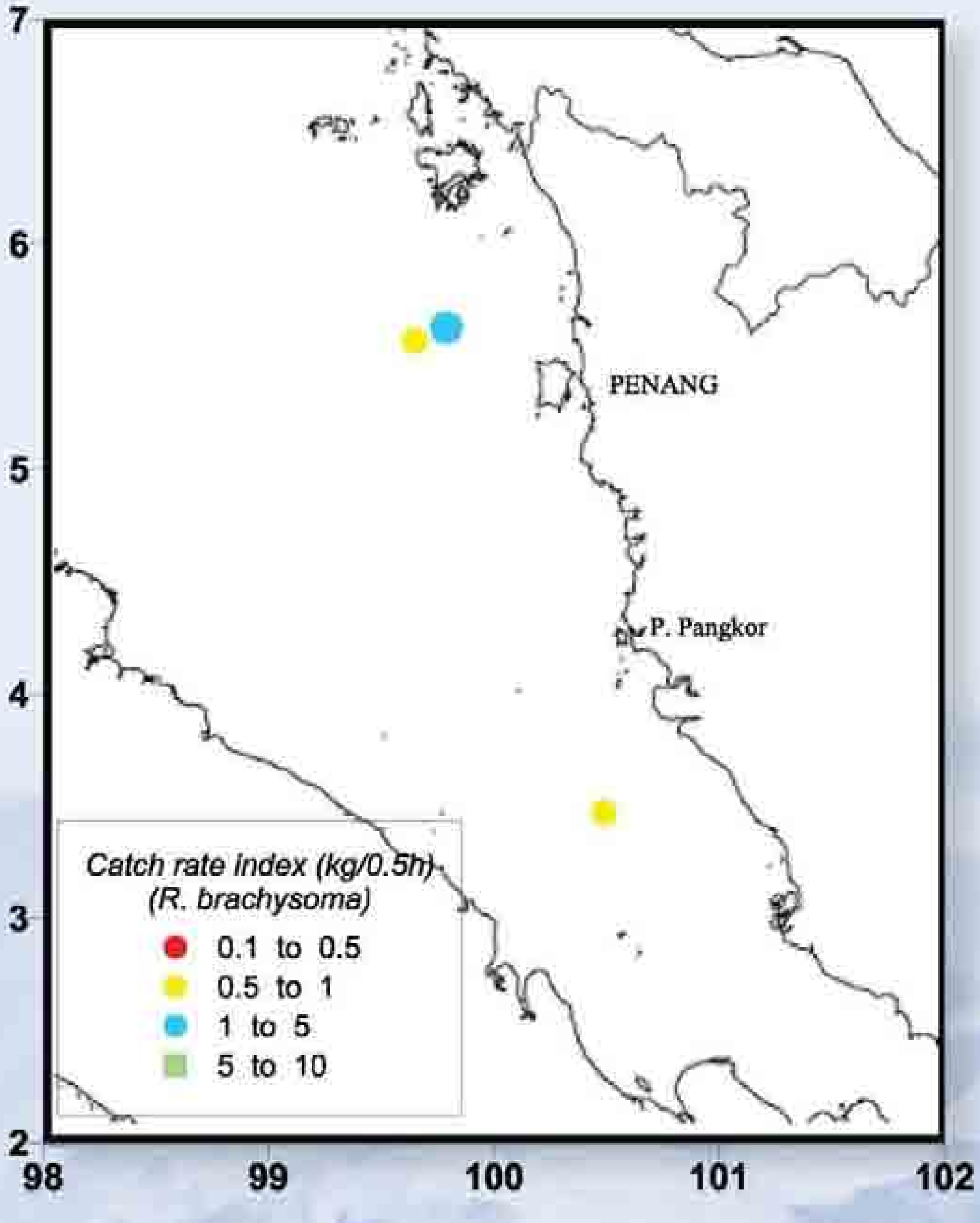

Figure 6: Catch distributions of *Rastrelliger brachysoma* in the Straits of Malacca during the survey in February – March, 2006

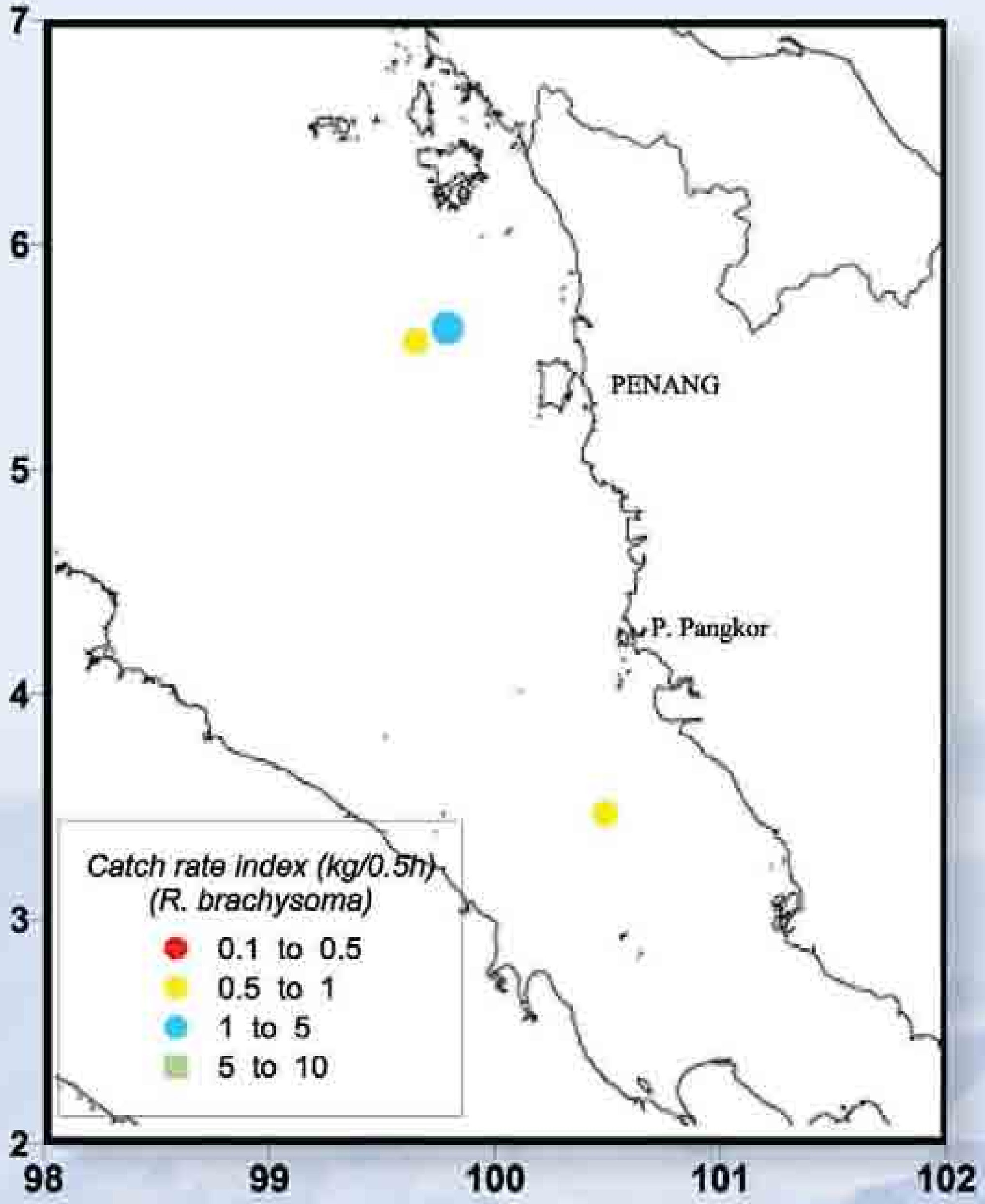

Figure 7: Maturity (%) of major pelagic species on the west coast of Peninsular Malaysia during the northeast monsoon, 2006

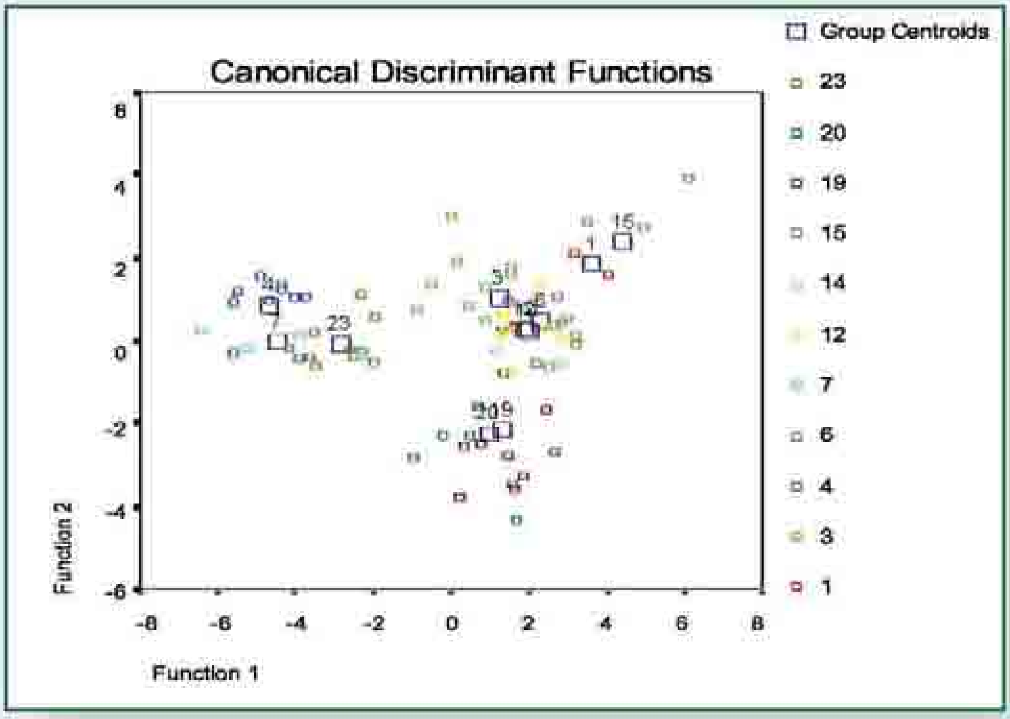

Figure 8: Plots of the coordinates of individuals of *Rastrelliger* sp. according to the first two discriminant functions (70% vs. 14.1% variation) obtained for morphometric data

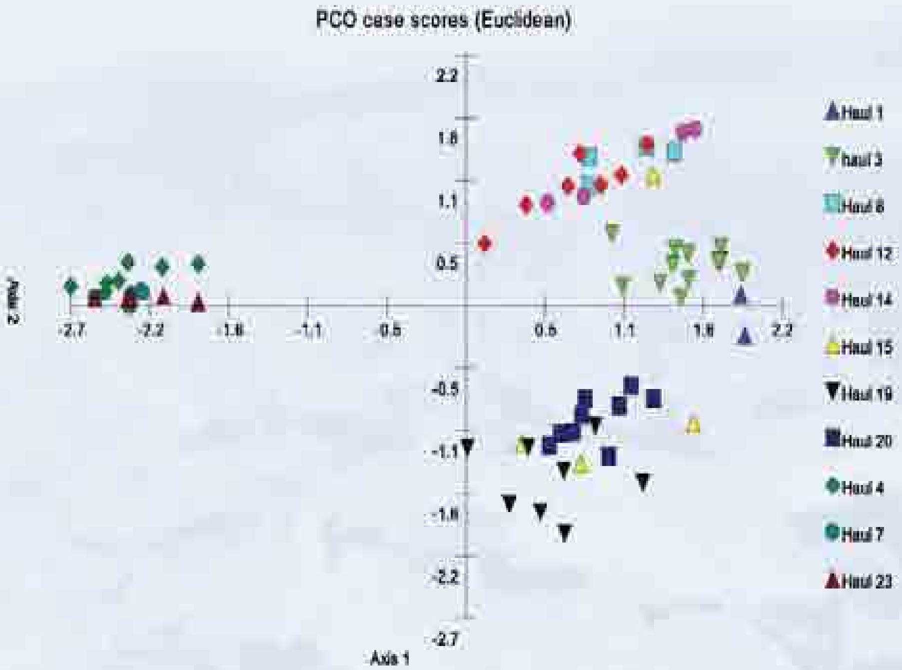

Figure 9: Principal co-ordinate analysis of RAPD data, based on RAPD profiles of 77 individuals of *Rastrelliger* sp. on the west coast of Peninsular Malaysia

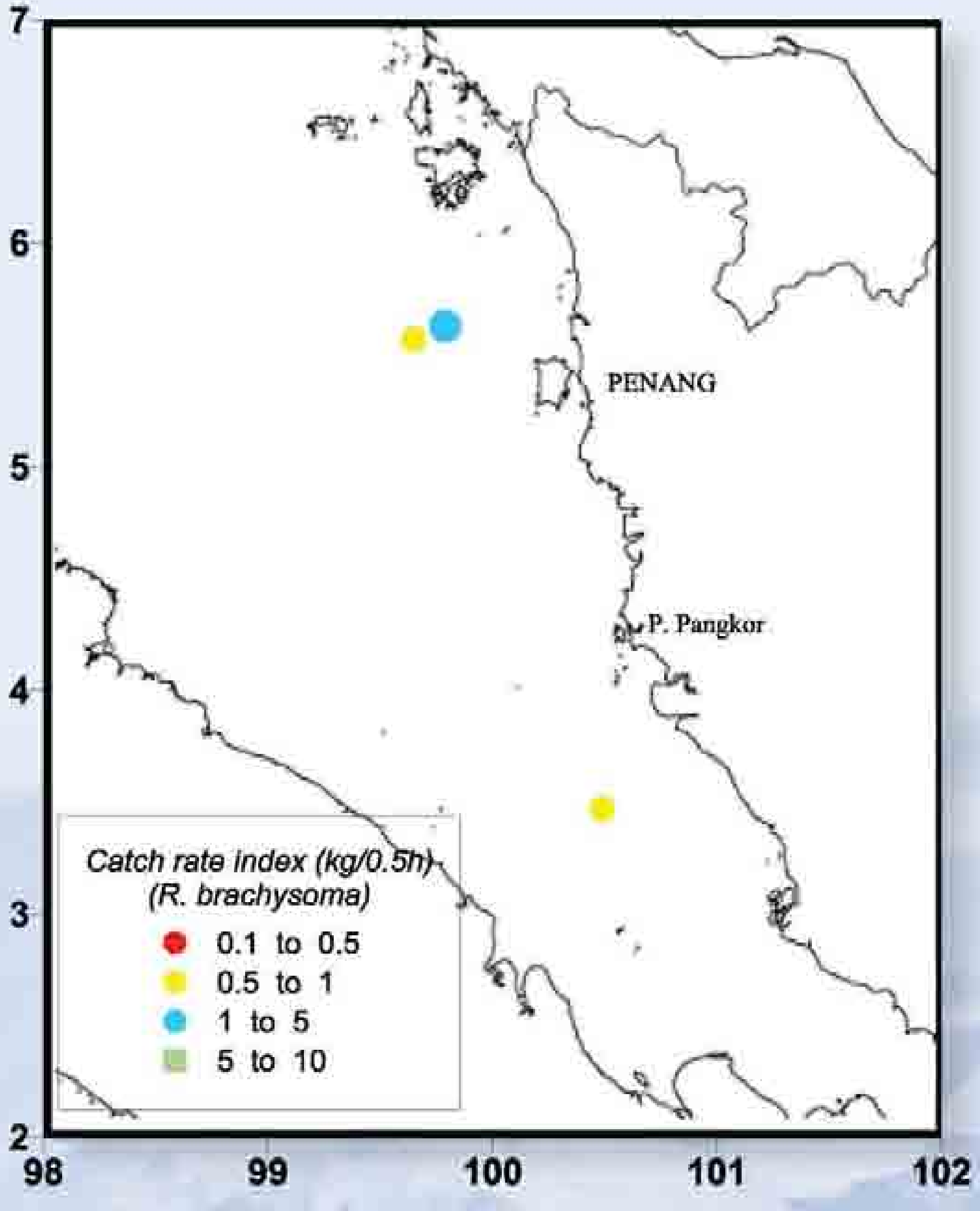

Figure 10: Maturity (%) of major pelagic species on the west coast of Peninsular Malaysia during the northeast monsoon, 2006

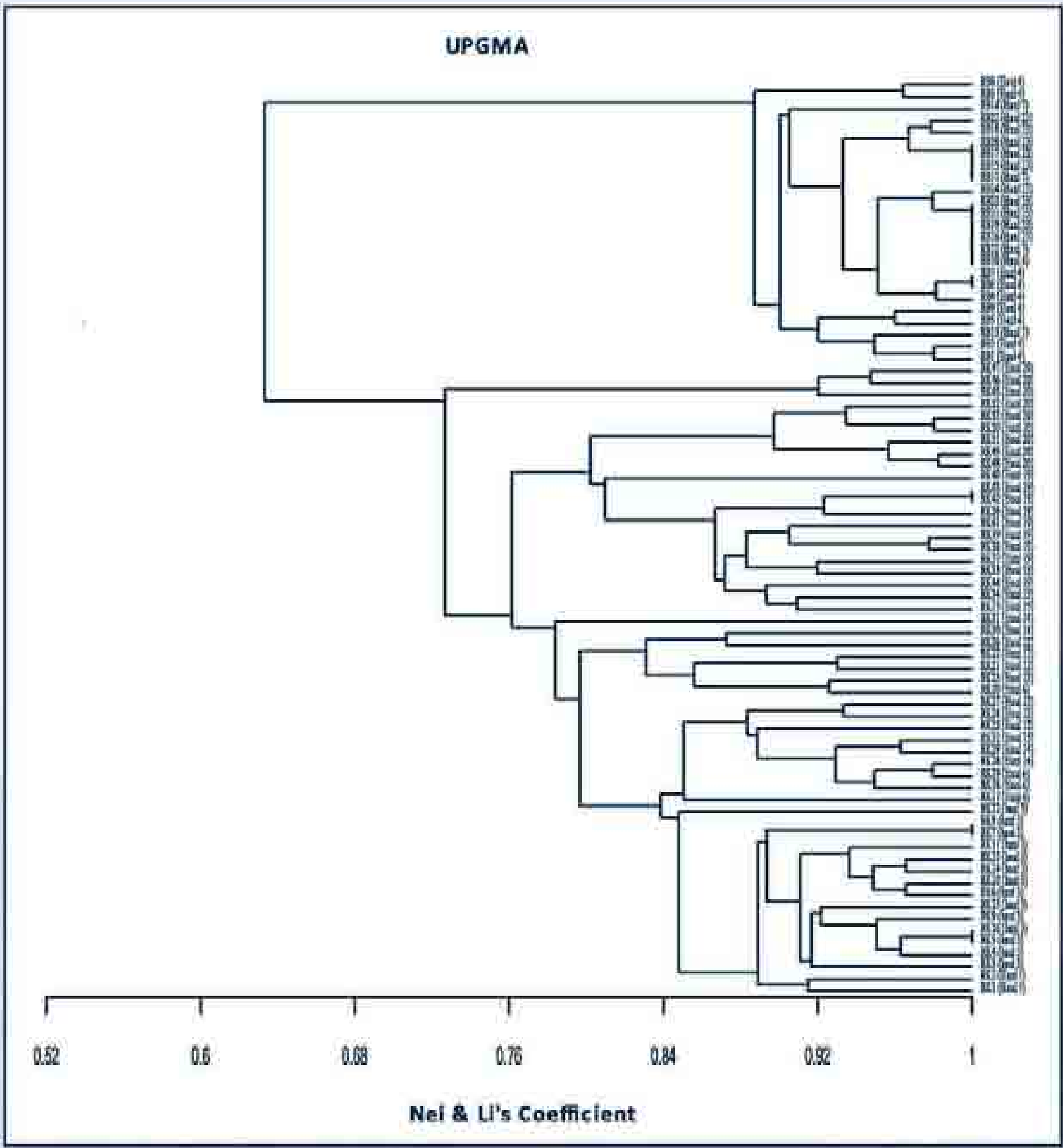

Figure 11: UPGMA dendogram of 77 individuals of 11 populations of two *Rostrelliger* sp. based on Nei and Li's Coefficient

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CONTENTS

FOREWORD

The west coast of Peninsular Malaysia is one of the four main regions for marine capture fisheries in the country. This area is one of the most productive in the country and barbours marine resources of great diversity, including pelagic fish species. The production from this area in the year 2006 amounted to 640,042 metric tons, which is equivalent to 46% of the total national production. The contribution of the pelagic fish resources in this area alone is 17% of the national production. They also contributed 37% of the total production from this area. Due to the schooling and migratory behavior of pelagic fishes, the annual production over the years shows fluctuating trends. Environmental factors also influence the temporal and spatial presence of this resource. Therefore, besides land-based pollution, habitat devastation and over-fishing are among the issues that need to be addressed to sustain the present level of production of this fish group.

Acoustic survey is the useful technique to determine the abundance and first estimation of the small pelagic fish stock biomass. Analysis of this data together with the present landings from commersial fishing provides a rough estimate of the resource potential for sustainable exploitation. Measuring some of the environmental parameters deemed to be of importance to pelagic fish during the conduct of survey provides better understanding on the factors affecting their distribution. All of this information are very important and formed the basis for the development of management measures that need to be undertaken by fisheries managers. All research findings, including those from resource surveys, will be taken into serious consideration in the decision-making process during the formulation of fisheries management plans.

By documenting all the findings from this survey into a book, important scientific information will not be lost and instead be available for future reference. This is particularly important in the case of pelagic fish resources as the ecosystem, or the environment, is a critical factor for its survival. Subsequently, the management of this resource should be based on the ecosystem approach. This means that the sustainable exploitation of the resource not only rest on managing the natural resources, but also the surroundings and the habitats where these resources depend on.

Finally, I wish to thank the researchers and the technical staff of the Fisheries Research Institute (FRI) and the Marine Fishery Resources Development and Management Department (MFRDMD) who have participated in this survey.

DATO' JUNAIDI CHE AYUB
Director-General Department
of Fisheries Malaysia
Putrajaya

PREFACE

The findings presented in this book came from the pelagic fish resource survey conducted off the west coast of Peninsular Malaysia from 23 February to 13 March 2006. The survey area covered were the waters of Perlis, Kedah, Penang, Perak and Selangor using MV SEAFDEC 2, a research vessel belonging to the Southeast Asian Fisheries Development Center (SEAFDEC) and based in Bangkok, Thailand. This 211 GRT trawler is capable of conducting fish resource surveys and is fully equipped with acoustic and oceanographic survey equipments.

Apart from conducting pelagic fish surveys by means of acoustic method, other related studies were also carried out, include oceanography and fishing. Due to the multidisciplinary nature of the studies involved and the limited expertise among the department's researchers, collaborative research was arranged with a number of local research organizations. Researchers from Universiti Sains Malaysia (USM), Universiti Malaysia Terengganu (UMT) and the Mineral & Geosciences Department participated in various components of the study. This collaborative effort provided a good avenue for the sharing of expertise among the different organizations, as well as enabling a wide range of research to be carried out. I hope this kind of collaboration would be continued and echanced in future undertakings.

This book presents the outcomes of the various data analysis and information obtained during the survey. It also provides recommendations for the proper development and management of the pelagic fishery resources in the west coast of Peninsular Malaysia.

Lastly, the Department of Fisheries Malaysia, particularly the Fisheries Research Institute, wish to record its gratitude to all who have made this survey a success; namely, researchers and technical staff of the Department of Fisheries Malaysia, the scientist from SEAFDEC, local universities; USM and UMT and from the Mineral & Geosciences Department. The wholehearted contribution from the captain and crew of MV SEAFDEC2 during the course of the survey are also very much appreciated.

Thank you.

Abu Talib Ahmad
Project Leader
Pelagic Fish Resource Survey

CHAPTER 3

WATER QUALITY, HYDROCARBON, HEAVY METALS AND MACROBENTHOS SURVEYS ON THE WEST COAST OF PENINSULAR MALAYSIA

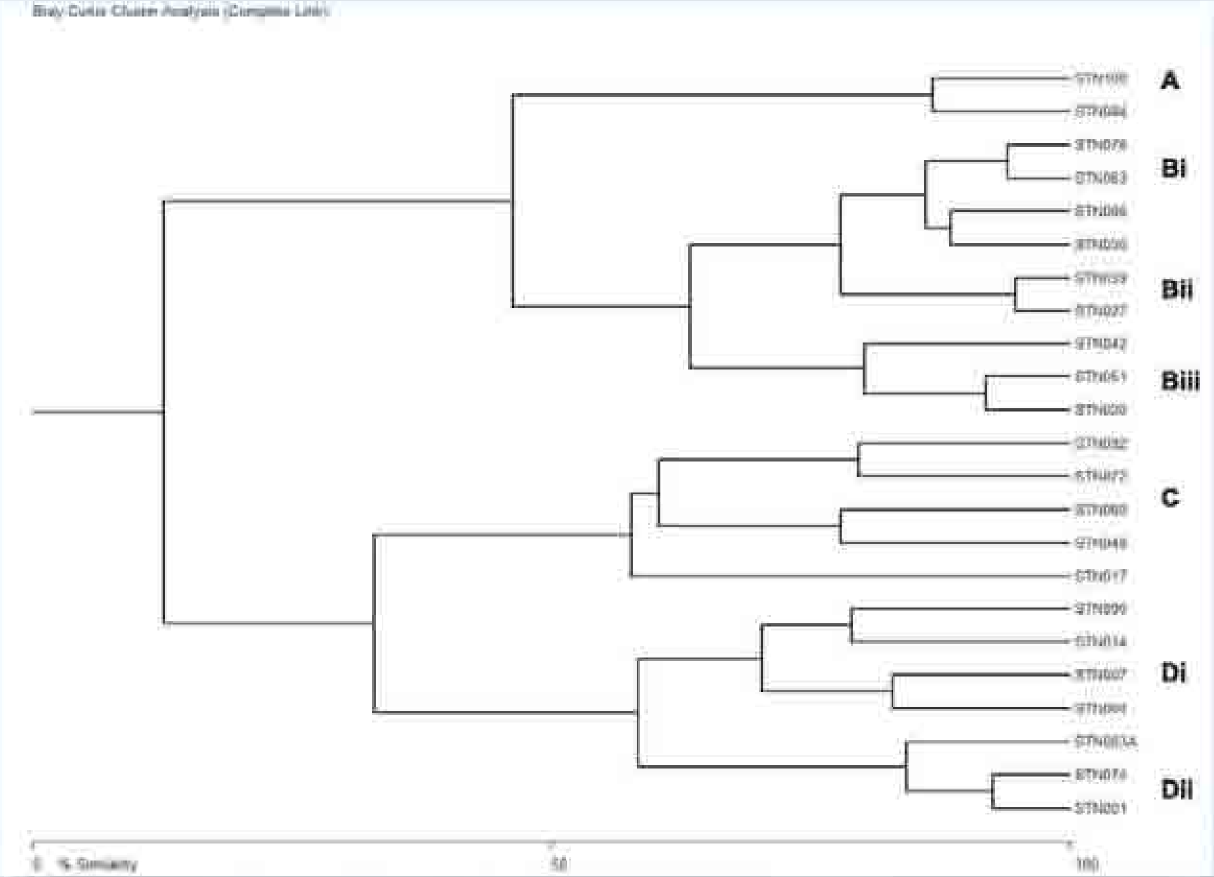

Figure 17: Cluster analysis of macrobenthos density (ind.m-2) according to station in the MV SEAFDEC 2 survey on the west coast of Peninsular Malaysia, 2006

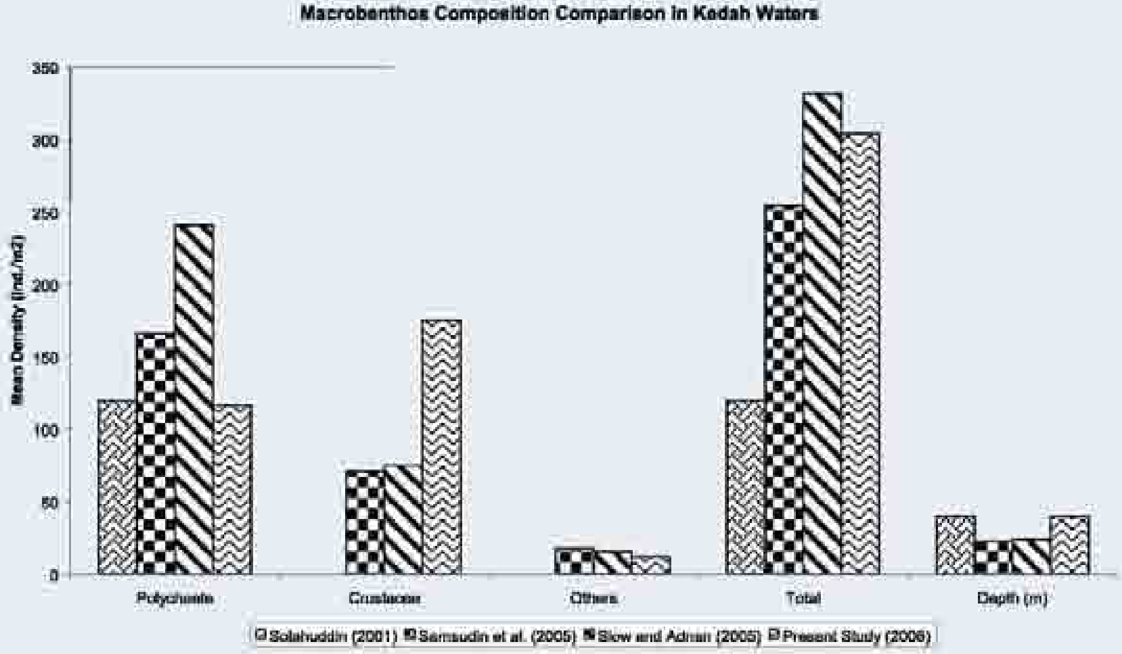

Figure 18: Comparison of major macrobenthos group mean densities (ind.m⁻²) and water depth (m) with previous studies conducted in Kedah water

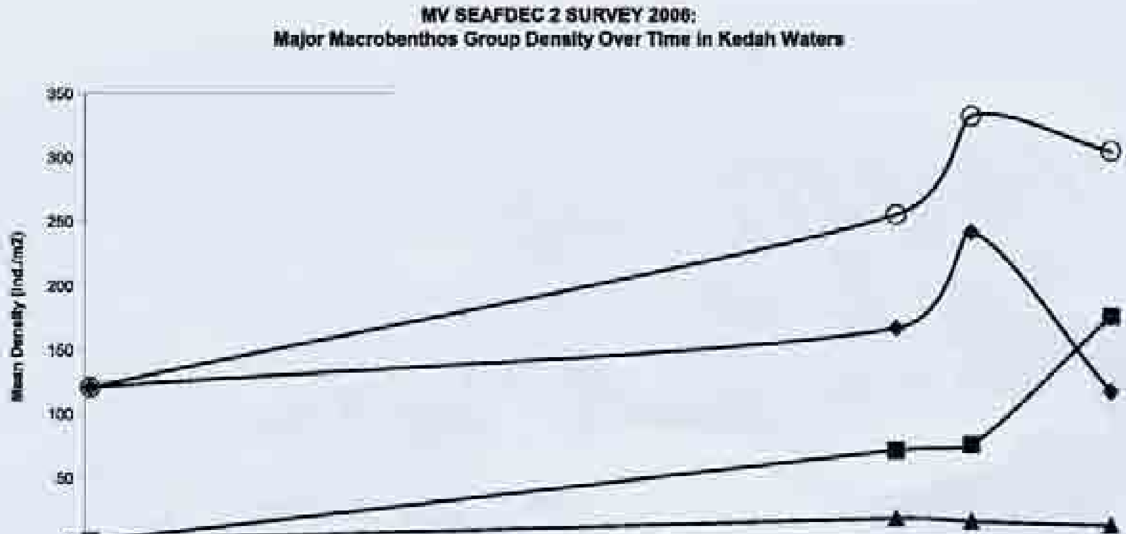

Figure 19: Comparison of major macrobenthos density (ind.m^{-2}) over time in Kedah water

WATER QUALITY, HYDROCARBON, HEAVY METALS AND MACROBENTHOS SURVEYS ON THE WEST COAST OF PENINSULAR MALAYSIA

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ABSTRACT

Water quality, total petroleum hydrocarbon, heavy metals and macrobenthos community studies were conducted in the Malaysian side of the Straits of Malacca, covering the areas from Langkawi Island in Kedah to Port Klang in Selangor. The studies were part of the acoustic and oceanographic survey programme on the west coast of Peninsular Malaysia and were carried out in late February 2006. Twenty three stations were pre-determined as oceanographic sampling sites in the study area. Generally, there were no obvious variations of ammonia, nitrite, nitrate, chlorophyll a and TSS concentrations even though a high amount of nitrite was recorded from the bottom at Station 93 and a high concentration of chlorophyll a was recorded at the bottom of Station 1. The concentration of ammonia increased as the sampling stations progressed to the south. The mean concentration of ammonia in the surface from all stations was 1.667 µg/l. From this research it was found that the amount of ammonia, nitrite and TSS increased as the stations progressed to the south. However the amount of orthophosphate decreased towards the southern part. The moisture content in the sediments had a wide range off 17% to 70 % of the total weight of sediment. Stations that were closer to the coast generally had a higher moisture content compared to the rest. Results from all 23 stations for total petroleum hydrocarbon level in water and sediment samples were below the level of reporting (LOR) i.e. 50 µg/L for water and for each fraction of the sediment samples the C6-C9 were < 5 mg/kg; C10-C14 were < 50 mg/kg; C15-C28 < 100 mg/kg; C29-C36 < 100 mg/kg. Although the concentrations were below their LOR, one station i.e. Station 20 (located off the coast of Kedah), had a higher concentration than the rest. The location of this station was farther from the coast and the finding was surprising considering the fact that pollution is usually encountered in near-coast locations. The total concentrations of Co, Cu, Cr, Ni, Mn, Fe, and Zn were measured in sediment collected from the study area. Concentrations of metals were generally lower than continental crust values and the values were comparable to previous studies in the Straits of Malacca and in near-shore sediment of the Straits of Johor and in the Penang-Juru areas. Zones of accumulation of metals in sediment were off Teluk Intan-Lumut extending north-west, following the dominant flow of current in the Straits of Malacca. For Fe, Ni and Zn, the sedimentary environment off Sg. Petani was another accumulation zone. Macrobenthos sampling was carried out using a Smith Mc-Intyre grab onboard MV SEAFDEC 2. The mean density of total macrobenthos derived from this study was 406 ± 293 ind.m^{-2}. The highest density was found at Station 84 (1,170 ind.m^{-2}) while the lowest density was found at Station 17 (60 ind.m^{-2}). The average depth recorded from the sampling stations was 52 ± 20 m. The benthic community was dominated by the following five groups in descending order (mean density in bracket); Amphipods (146 ind.m^{-2}), Polychaetes (136 ind.m^{-2}), Ostracoda (31 ind.m^{-2}), Thalassinidae (13 ind.m^{-2}) and Copepoda (12 ind.m^{-2}). Other organisms were also present but in low numbers or occurrence. Crustacean communities had increased significantly over the years and there were signs of diminished dominance of polychaetes and prominent occurrences of crustaceans such as amphipods, ostracods, ghost shrimps and copepods. Clear dominance of certain macrobenthos groups in specific regions in the Straits of Malacca were found in this study. The northern regions from the offshore waters of Langkawi to coastal waters of upper Lumut in Perak was dominated by the polychaete group. The coastal area of Penang Island and area from Lumut down to the border of Selangor were dominated by crustaceans such as amphipods and ostracods. Polychaetes again dominated the benthos community in Selangor waters except for the area around Port Klang.

Keywords: Water quality, Total petroleum hydrocarbons, Heavy metals, Macrobenthos, Distribution

1.0 INTRODUCTION

The Straits of Malacca is one of the most important water bodies for the marine capture fisheries production in Malaysia and is also one of the oldest and busiest shipping lanes in the world. The Straits is the shortest link for ships moving between the Indian Ocean and the Pacific Ocean. For this study, the sampling sites were located in the Malaysian side of the Straits of Malacca, spanning from Langkawi Island in Kedah to Port Klang in Selangor, with an estimated area coverage of 35,000 km^2.

Estuaries and coastal zones receive inputs of pollutants from point and non-point sources, most of which are eventually diluted at sea or deposited in estuarine sediments (Weis *et.al.*, 1992). Sediments act as sinks for metals and other pollutants and as such their concentrations in the sedimentary environment is indicative of the water column pollutant load and inputs from land-based pollution sources. Pollution by heavy metals deserves special attention because of their high toxicity and persistence in the aquatic environment, especially with respect to such ecosystems as seaports or other industrialized coastal areas that receive chronic inputs of these metals (Weis *et.al.*, 1992). Most of the studies in the Straits of Malacca environment were for near-shore sediments and very few studies have been done on offshore sediments. Studies on metal contents of offshore sediments, done in the Malaysian side of the South China Sea, have been reported by Shazili *et. al.* (1999a; 1999b). Most of these studies indicate that a number of metals are lower in concentration than in average earth crust material.

Petroleum hydrocarbons are commonly found in marine sediments in harbours and dockyards. The source of contamination is from spillages during transportation as well as ballast water discharges. They are a pollutant of concern as high concentrations have been reported to be toxic to marine life. Of prime concern are the volatile and aromatic fractions most of which are carcinogenic, mutagenic and embryotoxic.

The macrobenthos study is important as it will provide part of the oceanographic information that can be utilized in the management of fishery resources. The status of the macrobenthic communities is often used as an indicator of benthic environment health and condition. Macrobenthos communities play a vital role in the food web of the marine environment. In terms of ecological importance, invertebrates are directly involved in ecosystem stabilization, shoreline protection, energy and nutrient transfer and provision of habitat. They also help in climate stabilization and re-mineralization (Ponder *et.al.,* 2002).

Studies on water quality and benthos which cover the entire Straits of Malacca are very few and far between. Many of the recent studies only covered certain regions or were concentrated in coastal areas such as those done by Othman and Arshad (1994), Ong and Zubir (1997), Gopinath *et.al.* (2000), Samsudin *et.al.* (2005) and Siow and Adnan (2005). The only study in recent years that did cover the deeper waters of the Straits of Malacca was by Solahuddin (2001), who did a similar study under the Fisheries Resources Survey Program in the Exclusive Economic Zone (EEZ) of Malaysia back in year 1998. The lack of new studies may be due to the high expenditure and appropriation of suitable equipment and vessel required to conduct such a large scale survey. Thus, the opportunity to conduct such a study during the acoustic and oceanographic survey on the west coast of Peninsular Malaysia in late February 2006 was fully utilized and this had generated some new information pertaining to the oceanographic conditions, distribution and status of water quality, petroleum hydrocarbons, heavy metals and macrobenthos communities in the Straits of Malacca.

2.0 MATERIALS AND METHODS

Oceanographic observations were carried out from 23 February – 15 March 2006 by MV SEAFDEC 2 at 23 stations on the west coast of Peninsular Malaysia (from Langkawi to Port Klang) (Figure1 and Table 1). Two main activities, composing of the physical and biological oceanographic surveys, were conducted at each station.

2.1 *Vertical Profiles of Water Characteristics*

In order to obtain the vertical profiles of water characteristics, the ICTD system equipped with three main sensors for conductivity, temperature and depth and four auxiliary sensors for dissolved oxygen, pH, chlorophyll fluorometer and PAR was used. The ICTD was deployed from the sea surface to approximately 5m above sea bottom at a constant velocity 0.5 m/s and retrieved to the surface at a similar speed in order to study the water characteristics. All parameters at each station were divided into down cast and up cast and averaged into 1m intervals.

2.2 *Water Quality Study*

Carousel water samplers No. 7-12 of ICTD were used to collect water at three depths: surface, middle and bottom. One-litre water samples from each depth were then transferred into plastic sample bottles and frozen for nutrient analysis.

Analysis of nitrite, nitrate, ammonia, orthophosphate, silicate, total suspended solids (TSS) and chlorophyll-a were done according to APHA (1992). All samples were thawed at room temperature before analysis. One way ANOVA was done using SPSS version 11.5 to detect statistically significant interactions between stations and water levels.

The analysis in this report was conducted with reference to established methods of dividing the area in the Straits of Malacca into meaningful groups, areas or zones. The divisions show longitudinal and latitudinal characteristics of sampling stations. Latitudinal division comprised three zones; upper (Stations 1, 4, 7, 14, 17, 20, 27, 30), middle (Stations 39, 42, 48, 51, 60, 63, 66, 72, 74, 76) and lower (Stations 83, 84, 90, 92, 100). Longitudinal division was based on distances of sampling stations from the shorelines in nautical miles (nm). Near-shore stations were located less than 12nm while offshore stations were more than 12nm from shoreline (Figure 2).

2.3 *Distribution of Total Petroleum Hydrocarbons*

Sampling for total petroleum hydrocarbons in the Straits of Malacca was carried out using MV SEAFDEC 2 at positions shown in Figure 1. Water samples of one litre (1L) were collected 1m below sea surface using the Niskin Bottle sampler. Care was taken to collect water up to overflow and the bottles were sealed and stored at chill temperature (40°C) during the survey.

Sea bed sediment was collected using a Smith McIntyre sediment grab. Sub-samples of 500g from each sampling station were collected into glass bottles and stored chilled during the survey. At the completion of each survey trip i.e. three in all, the sample bottles were transported in ice to a private laboratory (ALS Technichem) for total petroleum hydrocarbon analysis following the methodology outlined in USEPA 3510C (extraction), 8015B (analysis). ALS Technichem is a laboratory accredited for petroleum hydrocarbon analysis in water and sediments (Akreditasi SAMM Malaysia, 2002).

2.4 Distribution of Heavy Metals

The methodology for sample collection, preparation and metal analyses adopted in the present study was similar to that used during previous work of Wood *et.al.* (1997) in the Straits of Johor.

Sediment samples were collected using a Smith McIntyre grab. The top 5cm of sediment were carefully collected with a clean plastic spatula and kept in acid-cleaned zip lock bag. The samples were preserved at –20°C until ready for analysis.

Samples were dried at 95°C then lightly ground to break up the particles. The sediment was sieved through a 63µm mesh and about 0.5g aliquots of this silt and clay fraction were then totally digested in a mixture of nitric, perchloric, hydrofluoric and hydrochloric acids in closed teflon vessels. Heating was carried out by microwave heating in a Milestone unit for 30 minutes at 210°C at 100bar. The digest was then made up to 50ml with deionized water.

Metals were analyzed using a Varian fast sequential flame atomic absorption spectrophotometer equipped with Deuterium corrector. For quality assurance, a standard reference material (1646a Estuarine Sediment) from the National Institute of Standards and Technology was digested as above and analyzed for metals. Analyses of NBS 1646a Estuarine Sediment (National Bureau of Standards) indicated good recoveries of most of the metals (Table 2) studied.

2.5 Study on Macrobenthos

Sampling was conducted in three sessions (cruises), beginning from 23 February 2006 to 15 March 2006. Twenty three stations were pre-determined as oceanographic sampling sites along the Malaysian side of the Straits of Malacca and macrobenthos sampling was carried out using a Smith Mc-Intyre grab with a mouth opening of 0.1m². One to three replicate samples were obtained from each station depending on weather and sea conditions. Sediment obtained by the grab was filtered with seawater on-site through a 450mm diameter sieve with a mesh size of #30 (600 µm). Materials retained on the sieve were fixed in 10% buffered sea water-formalin and brought to the laboratory for sorting and identification. Macrofauna found were sorted, enumerated and identified. The locations of the oceanographic stations where macrobenthos sampling was done is shown in Figure 1.

3.0 RESULTS AND DISCUSSION

3.1 *Vertical Profiles of Water Characteristics*

Temperature profiles at each station are shown in Figure 3. Water temperature at the surface (to 5m below the surface) ranged from 29-31°C for all the stations. Station 12 showed a clear thermocline layer at the depth of 30m.

Salinity profiles at each station are shown in Figure 4. Surface salinity for most of the stations ranged from 31-32 psu. Some of the stations showed a halocline layer at 15-20m deep.

The pH profiles at all stations were rather uniform, in the range of 8.5 to 9.0 as shown in Figure 5. Figure 6 provides the profiles for fluorescence. High fluorescence values at the depth of 20-30m indicated high chlorophyll concentrations.

3.2 Water Quality Study

3.2.1 *Ammonia*

The mean concentration of ammonia at all stations was 1.53 µg/L. The lowest concentration of ammonia was 0.254 µg/L (Station 20, middle) and the highest was 3.64 µg/L (Station 100, surface). There was a significant difference in ammonia between stations (Figure 7). There were two distinct groups of sampling stations that varied significantly (ANOVA, $p<0.05$). Group 1 consisted of Stations 1, 4, 7, 14, 17, 20, 27 and 30, while the second group consisted of Stations 39, 42, 48, 51, 6, 63, 66, 72, 74, 76, 83, 84, 90, 92 and 100. The amount of ammonia in the second group was significantly higher than the first group.

The mean concentration of ammonia at the surface for all stations was 1.667 µg/L. This value was lower than that recorded by Law *et.al.* (2000) and Nontji (2001) where the means were 19.572 µg/L and 130.2 µg/L, respectively. However, the findings in this study were similar to the previous study by Law *et.al.* (2001a, b) where the concentration of ammonia decresed with depth.

3.2.2 *Silicate*

Generally, the bottom water sample had a higher concentration of silicate followed by the middle-water sample (Figure 8). The same findings was made by Simantujak *et.al.* (1984). A higher concentration of dissolved silica at the bottom was due to the silica release from diatom skeletons deposited on the sea bottom (Kamatani, 1982). It was also reported that 80% of diatom skeletons dissolved in less than 10 days. A low amount of silicate at the surface may be caused by the assimilation of silica, in large quantities by diatoms, to synthesis their cell walls or frustules (Yusof *et.al.*, 2001).

There was no significant difference in the concentration of silicate between stations but there was a significant difference between levels. The mean concentration of silicate was 430.15 µg/L. The highest value recorded was 1,013.88 µg/L (Station 90, surface), while the lowest was 143.14 µg/L (Station 83, surface). ANOVA test by level showed that the amount of silicate on the surface and middle was significantly different from the bottom ($p<.05$). An unusually high concentration of silicate was recorded at the surface of Station 90.

3.2.3 *Orthophosphate*

Orthophosphate was generally high in the bottom, followed by the middle and the surface water samples (Figure 9). The concentration of orthophosphate at the surface, middle and bottom were significantly different. This is in agreement with previous research (Law *et.al.*, 2000) but contradicted with the findings made by Tengku and Yusoff (1998) which showed that orthophosphate decreased with depth. The concentration ranged from 0.31 µg/L (Station 48, surface) to 4.8 µg/L (Station 7, surface and Station 30, bottom) and the mean concentration was 2.35 µg/L.

The mean orthophosphate at the surface from the previous study was 7.495 µg/L which was much higher than the mean recorded for this study (1.563 µg/L). Even one of the earlier studies conducted in the EEZ off Sabah, Sarawak and Brunei (Tengku and Yusoff, 1998) also showed a higher orthophosphate concentration of 4.34 µg/L compared to this study. The low orthophosphate concentration at the surface in this study could have been caused by the active process of primary production by phytoplankton which reduced the orthophosphate level (Law *et.al.*, 2001a, b), while the high levels of orthophosphate at the bottom could be due to the active mineralization process that occured in the sediment of the Straits. As phytoplankton and other organisms die, phosphate is generated in the water column (Millero, 1996). The flux of orthophosphate from the sediment to the overlying bottom will enrich the water with phosphate (Law *et.al.*, 2001a, 2001b).

3.2.4 *Chlorophyll a*

There was no significant difference in the concentration of chlorophyll *a* between levels, but when compared by station, the difference was significant (Figure 10). Station 1 was significantly different from the other stations. The concentration of chlorophyll *a* varied from 0.00 µg/L (Station 4, middle, Station 7, bottom, Station 17, surface, Station 17, middle, Station 20, middle, Station 21, surface, Station 30, surface) to 2.83 µg/L (Station 1, bottom).

The mean chlorophyll *a* at the middle and bottom of near-shore stations were higher than stations located offshore. The mean chlorophyll a at the surface of offshore stations was much higher due to higher light penetration in near-shore stations. Lower chlorophyll *a* at the surface compared to middle and bottom suggests that there is a strong photo-inhibition at the surface. Gomes *et. al.* (1992) reported that phytoplankton photosynthesis is strongly inhibited at the surface at most stations in the Andaman Sea. Raihan and Ichikawa (1986) also observed that maximum chlorophyll *a* tends to occur near the bottom due to adaptation of most photosynthetic cells to low light intensity.

3.2.5 Total Suspended Solids, TSS

There was no significant difference in the amount of TSS between stations and levels ($p>0.05$). The amount of TSS varied from 0.009 g/L (Station 48, surface) to 0.132 g/L (Station 48, bottom) and the mean was 0.027 g/L (Figure 11). Generally Stations 1-48 recorded higher levels of TSS at the bottom, but TSS were higher at the surface at Stations 51-100.

The concentration of ammonia, nitrite and TSS increased as the stations progressed towards the south. The higher rainfall on land especially in the area near Port Klang could be a factor for the higher concentration of ammonia, nitrite and TSS. This could be caused by high organic pollution in this part of the Straits (Law *et.al.,* 2000). Heavy rainfall on land will bring more domestic waste to the sea (Law *et.al.,* 2001a, 2001b). The higher TSS value found at stations located towards the south could also be caused by the high shipping activity in that area. The movement of propellers of cargo ships could disturb the sediment at the seabed and increased the TSS especially in shallow water. A high amount of TSS in Station 48 (bottom) could have been partly contributed by the high phytoplankton biomass, which was related to the high concentration of chlorophyll a recorded. A high underwater current can also contribute to the high TSS by disturbing the seabed and increasing the bottom turbidity.

3.2.6 Nitrite

There was no significant difference in the concentration of nitrite (Figure 12) when compared by station and level ($p>0.05$). The concentration of nitrite varied from 0.06 µg/L (Station 1, surface and Station 1, middle) to 8.82 µg/L (Station 93, bottom) and the mean was 0.74 µg/L. Generally the surface water had a lower concentration of nitrite.

However the mean values of Law *et.al.* (2000) and Nontji (2001) were 1.582 µg/L and 7.28 µg/L. These were higher than the mean (0.448 µg/L) recorded in the study.

3.2.7 Nitrate

The mean nitrate level of surface water from Langkawi to Port Klang was 42 ± 75 µg/L, but two sampling stations, Station 48 and Station 83A, showed higher nitrate levels of 50.4 µg/L and 252 µg/L. Station 83A was adjacent to the Teluk Intan township.

In the mid-water column of the study area, the mean nitrate level was 15 ± 13 µg/L which was relatively lower than the sea surface. Only Station 72, which was located in offshore Lumut, showed a high nitrate level of 49.2 µg/L.

At the sea bottom, the mean nitrate level was 17 ± 15 µg/L which was comparable to the mid-water column, but a few stations, such as Station 48 off Kuala Kurau and Station 72 off Lumut, showed high nitrate level of 55.7 and 34.8 µg/L, respectively.

There was no significant difference in the concentration of nitrate (Figure 13) when compared by station and level ($p>0.05$).

3.3 Distribution of Total Petroleum Hydrocarbons

Total petroleum hydrocarbons in water were analyzed as four fractions i.e. C6-C9; C10-C14; C15-C28; and C29-C36. The results for total petroleum hydrocarbon level in water samples from all 23 stations showed they were below the level of reporting of 50 µg/L (Table 3).

Sediment samples were oven-dried prior to extraction with hexane. Results for percentage moisture are given in Table 4. The moisture content in the sediment had ranged widely from 17.3 to 70 % of the total weight of sediment. Stations that were closer to the coast (Figure 2) generally had a higher moisture content compared to the rest. Sediment from a coastal location would probably have more silt than clay, and hence a higher moisture content. Moisture content would also be linked to the texture of sediment. Sediment texture would thus be quite different depending on the location sampled and would also influence the content of contaminant analyzed. Sediments sampled in an earlier survey in 1997 in the Gulf of Thailand and off the east coast of Peninsular Malaysia (Wongnapapan *et.al.,* 1999) also had variable moisture content (26.6 to 51.8 %) but the circulation effects in the Gulf influenced the distribution. Moreover the data set was small; hence no obvious pattern was generated.

Again the hydrocarbon content was analyzed as four fractions similar to water samples. The results were all below level of reporting (LOR) for each fraction i.e. the C6-C9 were < 5 mg/kg; C10-C14 were < 50 mg/kg; C15-C28 < 100 mg/kg; C29-C36 < 100 mg/kg (Table 4). Although the concentrations were below their LOR, one station, i.e. Station 20, located off the coast of Kedah, had a higher concentration than the rest. The location of this station was farther from the coast and the finding was surprising considering the fact that pollution is usually encountered in near-shore locations. The picture however is similar to one reported in an earlier survey in 1999 where higher hydrocarbon concentrations were reported in offshore locations in the Gulf of Thailand (Wongnapapan *et.al.*, 1999). Possible reasons suggested included navigation activities along shipping routes or circulation patterns-causing the redistribution of hydrocarbons in surface waters settling onto sediments.

Owing to the rather high level of reporting (50 – 100 ppm) of the testing laboratory, certain hydrocarbon concentrations were non-detectable. One sample, from Station 100, was sent to another laboratory for a more accurate assessment. The result was 3.6 mg/kg for aliphatic hydrocarbons while aromatic hydrocarbons were not detected. This number was higher than the highest value of 1.36 mg/kg from sediment samples collected during the earlier survey in the Gulf of Thailand in 1977. Even though there was only one value, the result suggested that the level of contamination by dissolved hydrocarbons was probably much higher in the Straits of Malacca than the Gulf of Thailand and the east coast of Peninsular Malaysia as the Straits of Malacca is a busy shipping lane. The hydrography of the Straits of Malacca enables good mixing with a strong current flow in a north-south direction. It is very possible that the locations sampled were not near any port or harbour. Stations 90 and 100 were the closest to Port Klang but the exact location of sampling was not close enough to cover sediment receiving fuel or crude oil spillages from shipping traffic.

The laboratory conducting the analysis reported good recovery numbers for quality control spikes (63 – 107 %). Further work will need to be carried out with the sediments in storage to derive actual concentration values using pre-concentration techniques.

3.4 Distribution of Heavy Metals

The concentrations of heavy metal in the sediments of the study area (Table 5) were lower than their average continental crust values. Only Fe was within its average continental crust value. Continental crust values are 6.28% for Fe, 126 ppm Cr, 65 ppm Zn, 25 ppm Cu, 56 ppm Ni and 100 ppm Mn (Wedepohl, 1995). These values were also generally lower than in sediment of the Straits of Johor (Wood *et.al.*, 1997) and in Penang and Juru sediments (Wood *et.al.*, 1993). Cu values were comparable to a previous study by Yap *et.al.* (2002) in sampling sites similar to the present study. Cd and Pb concentrations were below the detection limit of the flame AAS. Down core metal concentrations in the core from Station 48 showed no particular trend in their distribution with depth in the core (Table 6).

Cu concentrations in the sediment of the study area in the Straits of Malacca is generally lower than in sediment from the South China Sea off Peninsular Malaysia and Borneo (Shazili *et.al.*, 1999a, 1999b). This may be due to the higher utilization of this nutrient element by phytoplankton in the environment in the Straits of Malacca.

Zones of accumulation of metals in sediment (Figure 14) were off Teluk Intan-Lumut extending north-west, following the dominant flow of the current in the Straits of Malacca. For Fe, Ni and Zn, the sedimentary environment off Sg. Petani was another accumulation zone.

3.5 Macrobenthos Study

The mean density of total macrobenthos derived from the survey was 406 ± 293 ind.m^{-2}. The highest density was at Station 84 (1,170 ind.m^{-2}) while the lowest was found Station 17 (60 ind.m^{-2}). The average depth recorded from the sampling stations was 52 ± 20 m. The macrobenthos density and water depth for every station in the survey area are shown in Figure 15. The breakdown of the major groups of macrobenthos is shown in Figure 16.

The benthic community was dominated by the following five groups in descending order (mean density in bracket): Amphipods (146 ind.m^{-2}), Polychaetes (136 ind.m^{-2}), Ostracoda (31 ind.m^{-2}), Thalassinidae (13 ind.m^{-2}) and Copepoda (12 ind.m^{-2}). Other organisms were also present but in low numbers or occurrence. The three most dominant benthos organisms for each station are shown in Table 7.

A cluster analysis was conducted using the macrobenthos density values (polychaetes, crustacean, other benthos, overall benthos) and station depth (m). The results showed that the 23 stations in the survey could be divided based on similarities (>50%) into seven major groups. The first group consisted of Station 84 and Station 100 which were dominated by crustaceans with high densities at 913 and 1,170 ind.m^{-2} respectively.

The second group consisted of stations with macrobenthos densities ranging from 397 to 767 ind.m^{-2}. This group could be further divided into three groupings. The first grouping consisted of Stations 76, 63, 66 and 30. These stations were dominated by crustaceans and had medium high densities of macrobenthos (480 to 613 ind.m^{-2}). Stations placed in this grouping were also located offshore near the border of Malaysia-Indonesia waters.

The next grouping consisted of Station 39 and Station 27. These two stations had macrobenthos densities of 767 and 697 ind.m^{-2}, respectively. The macrobenthos densities from this grouping were higher than those of the first grouping. Coincidently, members of this grouping were situated near Penang waters.

The third grouping in this Second Group consisted of Stations 42, 51 and Station 20. The macrobenthos densities from this grouping ranged from 397 to 580 ind.m^{-2}. However, the dominant taxa found in this grouping were polychaetes instead of crustaceans. Stations placed in this grouping were also located offshore near the border of Malaysia-Indonesia waters.

The next group consisted of five stations, namely Station 92, 72, 60, 48 and Station 17. The macrobenthos densities from this group were the lowest among the groups, and ranged from 60 to 120 ind.m^{-2}.

The last group consisted of two smaller groupings. The first grouping consisted of polychaete dominated communities with macrobenthos densities ranging from 160 to 277 ind.m^{-2}. The stations found in this grouping were Stations 90, 14, 7 and Station 4. The second grouping consisted of crustacean dominated communities with macrobenthos densities ranging from 275 to 370 ind.m^{-2}. The stations found in this grouping were Stations 83A, 74 and Station 1. The dendrogram of the cluster analysis is shown in Figure 17.

The results from this study were compared with the findings of another study done by Solahuddin (2001) in the same area in March 1998. In that study, macrobenthic sampling was done at 20 stations, in which 16 were in the same area as this present study. A comparison was made with the macrobenthos densities between the two surveys. It was found that the mean density of polychaetes had decreased over the eight year period. However, the mean densities of other benthic organisms and overall benthos density increased. The full comparison is shown in Table 8.

Nevertheless, a t-test analysis carried out indicated no significant differences ($p>0.05$) between the density values of both studies except for crustaceans ($p=0.006$). It should also be noted here that the t-test indicated borderline value ($p=0.06$) for the test for other benthos. There may be a slight increase in mean densities of organisms in the group "others" (which included echinoderms, nematodes, etc.).

A further comparison between the present study and that of Solahuddin (2001) indicated changes in dominance of major macrobenthos taxa. From the previous study, the benthic community was dominated by the following five groups in descending order (mean density in bracket); Polychaetes (238 ind.m^{-2}), Amphipods (53 ind.m^{-2}), Isopods (15 ind.m^{-2}), Shrimps (9 ind.m^{-2}) and Tanaidae (6 ind.m^{-2}). In contrast, the present benthic community was dominated by Amphipods (146 ind.m^{-2}), Polychaetes (136 ind.m^{-2}), Ostracoda (31 ind.m^{-2}), Thalassinidae (13 ind.m^{-2}) and Copepoda (12 ind.m^{-2}). Changes were indicated in the diminished dominance of polychaetes and prominent occurrences of other crustaceans such as amphipods, ostracods, ghost shrimps and copepods.

3.5.1 *Comparative study on macrobenthos communities in Kedah waters*

A case study was conducted on the macrobenthos communities in Kedah waters using data collected from the present study and those extracted from other studies (Samsudin *et.al.*, 2005; Siow and Adnan, 2005; Solahuddin, 2001). The study by Solahuddin (2001) was conducted in March 1998 (four stations), the study by Samsudin *et.al.* (2005) was conducted in June 2004 (16 stations) while the study by Siow and Adnan (2005) was conducted in January 2005 (11 stations) in the coastal waters of Kedah. A comparison of major macrobenthos group mean densities (ind.m^{-2}) and water depth (m) is presented in Figure 15. The changes in macrobenthos mean density (ind.m^{-2}) over time in Kedah waters can be seen in Figure 18.

Figure 19 shows a sharp decrease in polychaete density in Kedah waters after a drastic increase in early 2005. The decreased thereafter to the level lower than 1998 contributed to the decline in overall macrobenthos mean density in the present study. Contrary to that, the trend in crustacean density showed a steady increase since 1998 from 75 ind.m^{-2} to 175 ind.m^{-2} in 2005. However, no fluctuations in densities of other macrobenthos were recorded over the years.

Even though some fluctuations were seen in the macrobenthos densities, statistical analyses using both ANOVA and t-test indicated no significant differences ($p>0.05$) in macrobenthos densities between the studies. More studies are needed in this area to establish a stronger trend analysis.

3.5.2 *Distribution and dominance of macrobenthos*

Results obtained from this study showed a clear dominance of certain macrobenthos groups such as seen in polychaete-dominated and crustacean-dominated parts in specific regions of the study area. The northern region from the offshore water of Langkawi to the northern tip of Penang Island was dominated by polychaetes. The muddy sediment types found in this area may be one of the contributing factors for polychaete dominance. However, in the coastal areas between Alor Setar and Langkawi Island, crustaceans such as copepods showed more dominance.

Moving downwards to Penang water, the offshore was still dominated by the polychaete group while the coastal areas were dominated by crustaceans, particularly amphipods. The upper Perak region was