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Prawn landings and their relationship with the extent of mangroves and shallow waters in western peninsular Malaysia

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Abstract

This study investigated changes in landings of all prawns, white prawns (mainly *Penaeus merguiensis*), mangrove extent, rainfall and the area of shallow water in western peninsular Malaysia. The most important state for both the landings of all prawns and white prawns was Perak where about 50% of all prawns and 35% of white prawns were landed. This is also the state with the largest, and most stable, extent of mangrove forest reserve (40 000 ha) and the largest area of shallow water (< 5 m deep). Juvenile prawns from Perak may contribute to the landings of the nearby, adjacent states of Penang and Selangor, where the second highest landings for white prawns and total prawns, respectively, were found. The area of shallow water accounted for the greatest proportion of variation in landings of both all prawns and white prawns, and was the most significant variable fitted to multiple regressions of landings and coastal attributes (area of shallow water, mangrove area, length of coastline). Although there was a significant linear relationship between the landings of total prawns and mangrove area in both the 1980s and 1990s, this was not the case for the mangrove-dependent white prawns where a significant relationship was found only for the 1990s. Furthermore, landings of all prawns and white prawns in Selangor and Johor, where large losses of mangrove forest reserve have been recorded, appear to have been maintained or increased in the 1990s. The lack of a clear relationship between mangrove loss and prawn landings may be due to the migration of prawns from adjacent areas or that other attributes of mangroves, such as the length of mangrove-water interface, may be more important for the growth and survival of prawn populations than total area of mangroves.

Keywords: mangrove; prawn; shallow water; fisheries

1. Introduction

In many developing countries, particularly in Asia and central America, prawns are caught by trawlers and also by people using traditional fishing methods. The white banana prawn *Penaeus merguiensis* is found in coastal waters from the Persian Gulf to Hong Kong, the western coasts of the Philippines, New Caledonia and northern Australia (Grey et al., 1983). (Note that this species was renamed *Fenneropenaeus merguiensis* by Pérez-Farfante and Kensley (1997). However, because phylogenetic analyses using molecular techniques do not support the previously created subgenera or genera (Lavery et al., 2004), we have used the older name). *P. merguiensis* is one of the most important commercial

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species in the Indo-Pacific region, and is mainly found in shallow waters, less than 30 m deep (Grey et al., 1983; Somers and Wang, 1997).

In general, prawns in the genus *Penaeus* spawn in offshore waters and the planktonic larvae are transported to shallow coastal areas where as postlarvae, they may settle in different habitats (Dall et al., 1990). Postlarval and juvenile *P. merguiensis* are found predominantly along mangrove-lined mudbanks (Staples et al., 1985; Vance et al., 1998) and start emigrating from these estuarine habitats to coastal waters two to four months after settlement.

In addition to stabilising sediments and slowing water movement, mangroves provide habitat for the juvenile stages of fish, crustaceans and birds (e.g. Robertson and Blaber, 1992; Röhnnback, 1999). In the Asian region, mangroves are used for the woodchip industry, in the construction of housing and making charcoal (Chan et al., 1993). In many areas of Asia, mangroves have been replaced by a variety of other land uses such as prawn ponds, rice fields, housing, roads or factories. In peninsular Malaysia, about 10% of the mangroves in forest reserves were removed between 1980 and 1990 for aquaculture, agriculture, urban development, wood chipping or clear felling (Chan et al., 1993).

The total prawn landings for all species in Malaysia and the banana prawn catch in Australia are both positively related to the extent of mangroves (Staples et al., 1985; Chong and Sasekumar, 1994). A positive relationship between prawn catch and the extent of mangroves has also been demonstrated in Indonesia (Martosubroto and Naamin, 1977) and through the south-east Asian region (Pauly and Ingles, 1986; Chong and Sasekumar, 1994). In all except the Australian study (Staples et al., 1985), total prawn landings or maximum sustainable yield, rather than that of mangrove-dependent prawn species, were used in regression analyses with measures of mangrove extent (see Baran, 1999; Manson et al., in press for summaries of mangrove–fisheries relationships).

Prawns are fished by a variety of methods in Malaysia, including trawling, trammel nets, pushnets and bagnets. They are also fished at several stages of the lifecycle from juveniles in estuaries to the sub-adults and adults in the coastal waters. Until the mid-1960s, there was little trawling for prawns in the waters of peninsular Malaysia. This study examines the relationship between prawn landings in western peninsular Malaysia and mangrove extent, change in mangrove extent over time, rainfall and the area of shallow water. The trends in landings have been investigated for all species, and those of the mangrove dependent white prawns (mainly *P. merguiensis*) to determine whether there has been a significant decline in prawn landings associated with the decline in extent of mangrove forest reserve. General changes in fishing effort for the region have also been described but not analysed in detail because information on the amount of fishing for prawns was not available.

2. Materials and methods

2.1. Rainfall, mangrove and shallow water data

Western peninsular Malaysia (WPM) is located close to the equator, extending from about 1° N, 104° 20′ E in the east, to 6° 30′ N, 100° E to the north-western border with Thailand, with a coastline of about 2 000 km in length (Fig. 1). The depth contours and coastline for WPM were digitised from hydrographic charts (1:100 000) and the area of different depth strata calculated (i.e. 0–5 m, 5–10 m, 10–20 m and >20 m).

Monthly data on rainfall were obtained from the Malaysian Bureau of Meteorology from two stations in six of the states of western peninsular Malaysia (no data were available for Perlis or Negeri Sambilan) between 1980 and 1996. These data were used to calculate the average monthly pattern of rainfall for western peninsular Malaysia, and the average annual rainfall (and coefficient of variation for rainfall) for each state in WPM and the whole of WPM.

In Malaysia, areas of mangroves are gazetted either in Stateland Mangroves (managed by the respective State Governments) or Mangrove Forest Reserves (managed by the Federal Government). Applications must be made to remove mangroves from Mangrove Forest Reserves. The extent of Mangrove Forest Reserves in each state has been documented by Chan et al. (1993), from various publications and reports for 1980 and 1990. Data for 1996 were also obtained from a report by the Malaysian Department of Forestry (H.T. Chan, Malaysian Department of Forestry, pers. comm.).

2.2. The prawn fishery of western peninsular Malaysia

Each month, commercial landings and data on the number of vessels operating are collected from the landing centres throughout peninsular Malaysia by the Department of Fisheries. In each State, the landings from a sample of boats or operators are recorded for each month and method. These data are used to estimate the total landings for the centre, month and state by the State Departments of Fisheries. The federal Department of Fisheries compiles the State data to produce annual summaries for broad regions (western peninsular Malaysia, eastern peninsular Malaysia, Sabah and Sarawak) that are published as the Annual Fisheries Statistics. In 1984 and 1985, data were not summarised for eastern and western peninsular Malaysia separately but grouped as peninsular Malaysia. Data on prawns from the landings centres are recorded in

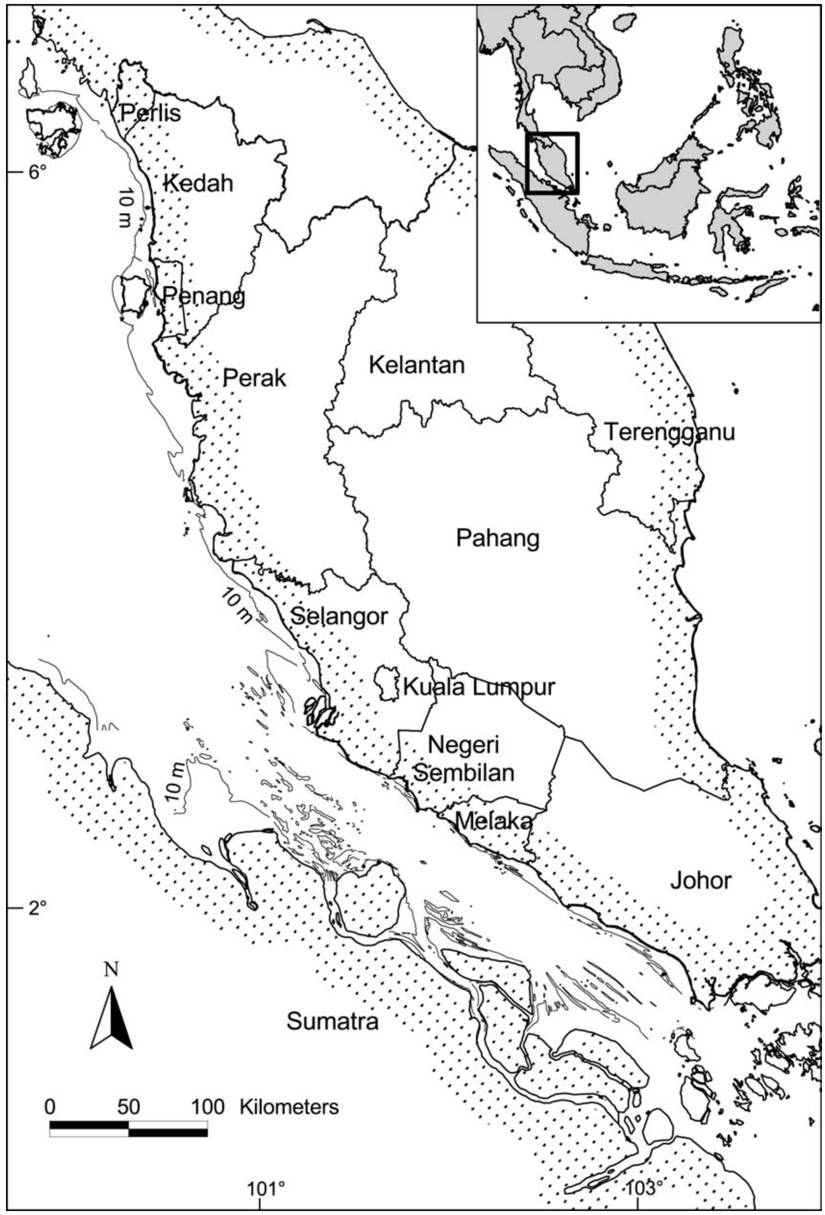

Fig. 1. Map showing the states of peninsular Malaysia and the 10 m depth contour for the west coast.

19 groups based on size and type of prawn, which are combined into six categories in the Annual Statistics. Data from the summary tables in the Annual Statistics from 1981 to 1997 were entered on an ACCESS database. Data on the landings of all species of prawns in the years before 1981 have been summarised by Ong and Weber (1972), Chong (1984) and Lui (1991).

Before 1983, prawn landings were grouped into large, medium and small prawns. Since then, the prawn catches in the Annual Fisheries Statistics have been summarised in the following groups: White prawns (*Penaeus merguiensis*, *Penaeus indicus*, *Penaeus penicillatus* and *Penaeus latisulcatus*); Sharp-rostrum prawns (*Parapeneopsis hardwickii*, *Parapeneopsis coromandelica*, *Parapeneopsis hungerfordii* and *Parapeneopsis gracilima*); Pink prawns/ Greasyback prawns (*Metapenaeus affinis*, *Metapenaeus ensis* and *Metapenaeus intermedius*); Rainbow prawns (*Parapeneopsis sculptilis*); Giant tiger prawn/Green tiger prawn (*Penaeus monodon* and *Penaeus semisulcatus*); and Other prawns. Independent research surveys have found that *P. merguiensis* accounts for over 90% of the white prawns on the west coast (Talib et al., 1995), except in the southern waters of Johor where *P. indicus* is also caught (Taupek and Ibrahim, 1990).

Data are also summarised under the following groups of fishing methods in the annual statistics: Bag nets; Drift/gill nets (including trammel nets); Other seines which for prawns refers to paired trawlers that tow a net between them and then purse the net; Push nets; and

Trawlers. Note that although push nets are illegal on the west coast of peninsular Malaysia, they are known to operate in one area of Perak and their landings are recorded. Some restrictions are imposed on the different methods e.g. trawlers are not allowed to operate within 5 nautical miles (nm) of the coast, except on the east coast during the monsoons (from about December to April). Prawns are fished throughout the year except during major festivals such as the Muslim and Chinese New Years. Landings from trawlers are recorded for vessels in different size categories (0–9.9 t, 10–24.9 t, 25–39.9 t, 40–69.9 t, $\geq$70 t).

The present method for sampling the landings centres has been used since 1987. Before then, another sampling design (the South China Sea Program) was used. However, FAO thought that the landings data from 1982 to 1986 significantly underestimated the actual landings and a change in sampling of landings centres was initiated following this finding from FAO. The data for the period 1982 to 1986 were revised by the Department of Fisheries to account for these underestimates.

2.3. Analysis of data

The total landings of all prawns and white prawns were calculated for each state and for the west coast of peninsular Malaysia. In three years (1989, 1990 and 1992) the landings of sergestids (*Acetes* spp.) were included with those of penaeid prawns in the annual statistics. For these years, the mean proportion of sergestids in the landings from the year before and the one after the affected year (two years after for 1989) were used to estimate the total landings of penaeid prawns.

The mean landings of all prawns and white prawns were calculated for each state over the history of the fishery (from 1981 until 1997), the 1980s (1981 to 1989) and 1990s (1990 to 1997). The mean proportions of the landings from each state of western peninsular Malaysia were also calculated for each of these time periods. The mean landings of all prawns and white prawns caught by each fishing method were also calculated.

2.4. Relationship between landings, rainfall, mangroves, and extent of shallow water

The mean landings, rainfall, and area of substrate in different depths were calculated for each state in the 1980s and 1990s. The relationships between mean landings (both total prawns and white prawns) and mean rainfall, area of substrate in different depth contours and extent of mangroves in each of the 1980s and 1990s, were investigated by calculating coefficients of determination (R^2) between pairs of individual variables and stepwise multiple regressions (searching both backward and forward simultaneously), fitted using *R* (Ihaka and Gentleman, 1996), with combinations of variables.

Initially, all coastal variables (total length of coastline, mangrove area, ratio of mangrove area:coastline, area of substratum in the 0–5 m depth contours, and area in the 5–10 m depths) were fitted to the multiple regressions and then different combinations of area of shallow water and mangrove area were fitted. The distribution of the data for each variable was examined and where necessary data were transformed before analysis by $\sqrt{(x+3/8)}$. Note that because rainfall data were only available for six of the eight states and the coefficients of determination for rainfall and landings were not significant, rainfall was not included in the multiple regression analyses.

3. Results

3.1. Rainfall

The average annual rainfall for western peninsular Malaysia (WPM) was greater than 2000 mm except in 1981 (1827 mm) and 1983 (1925 mm, Fig. 2a). The highest average rainfall was about 2400 mm in 1995. The coefficient of variation for annual rainfall was less than 15% in most years (range = 8.1–21.3%). The average monthly rainfall for WPM exceeded 140 mm in all months, except January and February, when it was about 100 mm (Fig. 2b). Peaks in monthly rainfall were found in April/May ($\cong$200 mm) and from August to November (200 to 250 mm). The mean rainfall for each state in western peninsular Malaysia was about 2200 mm per year, except in Perak ($\cong$1800 mm per year, Fig. 2c).

3.2. Coastline, shallow water and mangroves

The longest coastlines (including islands) were estimated for the states of Kedah and Selangor, where they extended over about 400 km (Fig. 3a). The coastline for Perak was about 290 km long and those of Johor and Penang were about 170 km in length, while those for Negeri Sembilan, Malacca and Perlis were less than 100 km long. The total length of coastline for western peninsular Malaysia, including islands, was about 1560 km.

The areas of water in the 0–5 m and 5–10 m depth strata were greatest in Perak (1466 km^2 and 634 km^2, respectively) followed by Selangor (944 km^2 and 553 km^2) (Fig. 3b). The total amount of shallow water (i.e. $<$10 m deep) was less than 265 km^2 in Perlis, Malacca and Negeri Semibilan (Figs. 1, 3b). The largest areas of deeper water ($>$ 20 m) were found in Johor, Selangor and Kedah.

By far the largest areas of mangrove forest reserves were in Perak ($\cong$40 000 ha, Fig. 3c). In 1980, the areas

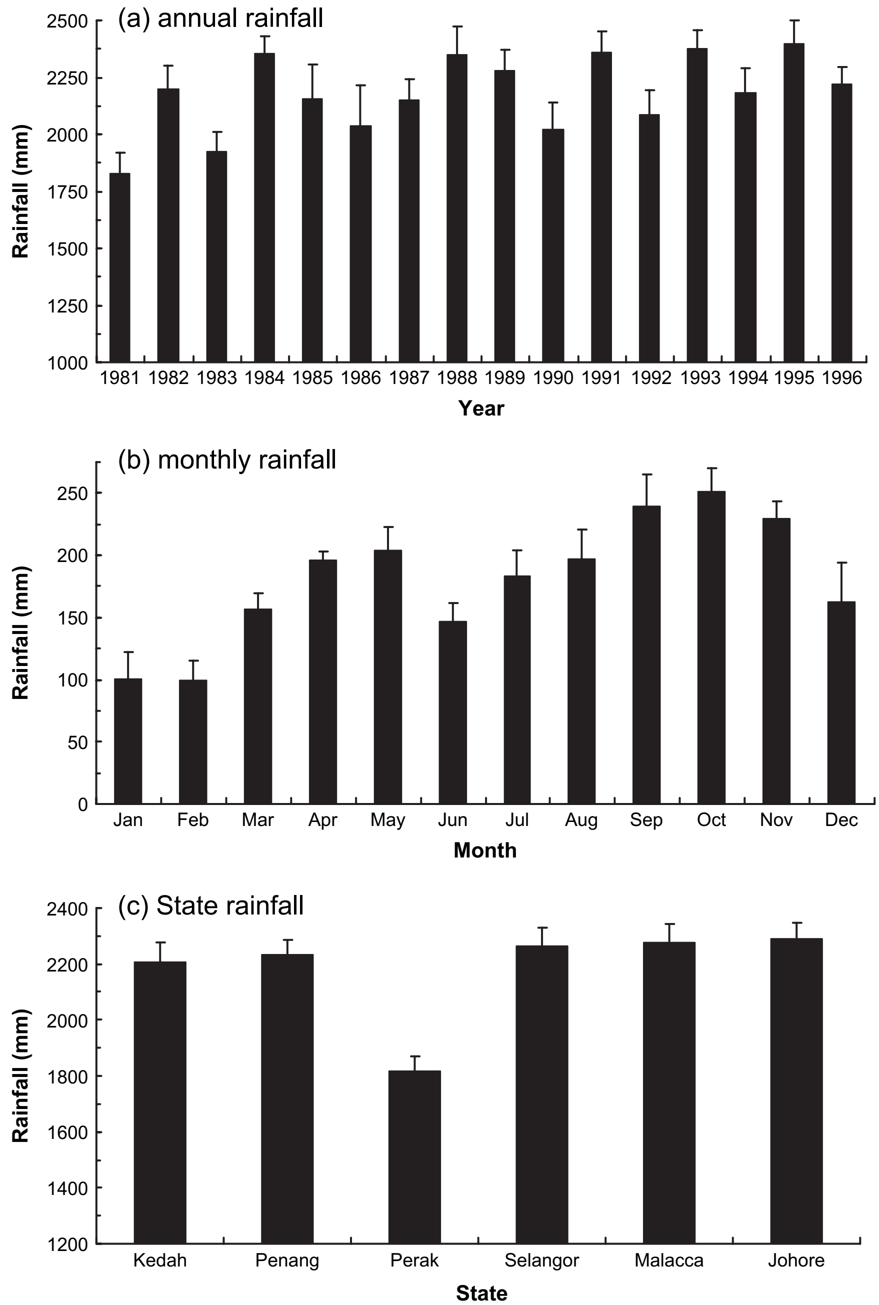

Fig. 2. Average rainfall (+1 SE) for western peninsular Malaysia in (a) in each year between 1981 and 1996, (b) each month and (c) each state.

of mangrove forest reserve in Selangor and west Johor were about 25 000 ha, with about 9000 ha in Kedah. The areas of reserves in all other states of western peninsular Malaysia were less than 1500 ha. The area of mangrove forest reserves in Perak remained virtually the same between 1980 and 1996. In contrast, the areas of reserves declined by over 20% in Johor (35%) and Selangor (22%) between 1980 and 1990, while those in Kedah declined by about 10% over the same time (Fig. 3c). In 1996, the areas of mangrove forest reserves in all states were similar to those in 1990, except in Selangor, where the area of mangrove forest reserves declined from about 22 000 ha in 1990 to 15 000 ha in 1996 (31% loss, Fig. 3c). The total area of mangrove forest reserve in western peninsular Malaysia declined from about 105 000 ha in 1980 to 89 000 ha in 1990 (15% loss) and 85 000 ha in 1996, i.e. an overall loss of 20% in area since 1980.

3.3. Landings by different methods

The mean total landings for prawns on the west coast of peninsular Malaysia were about 55 000 t for all prawns and 5800 t for white prawns between 1981 and

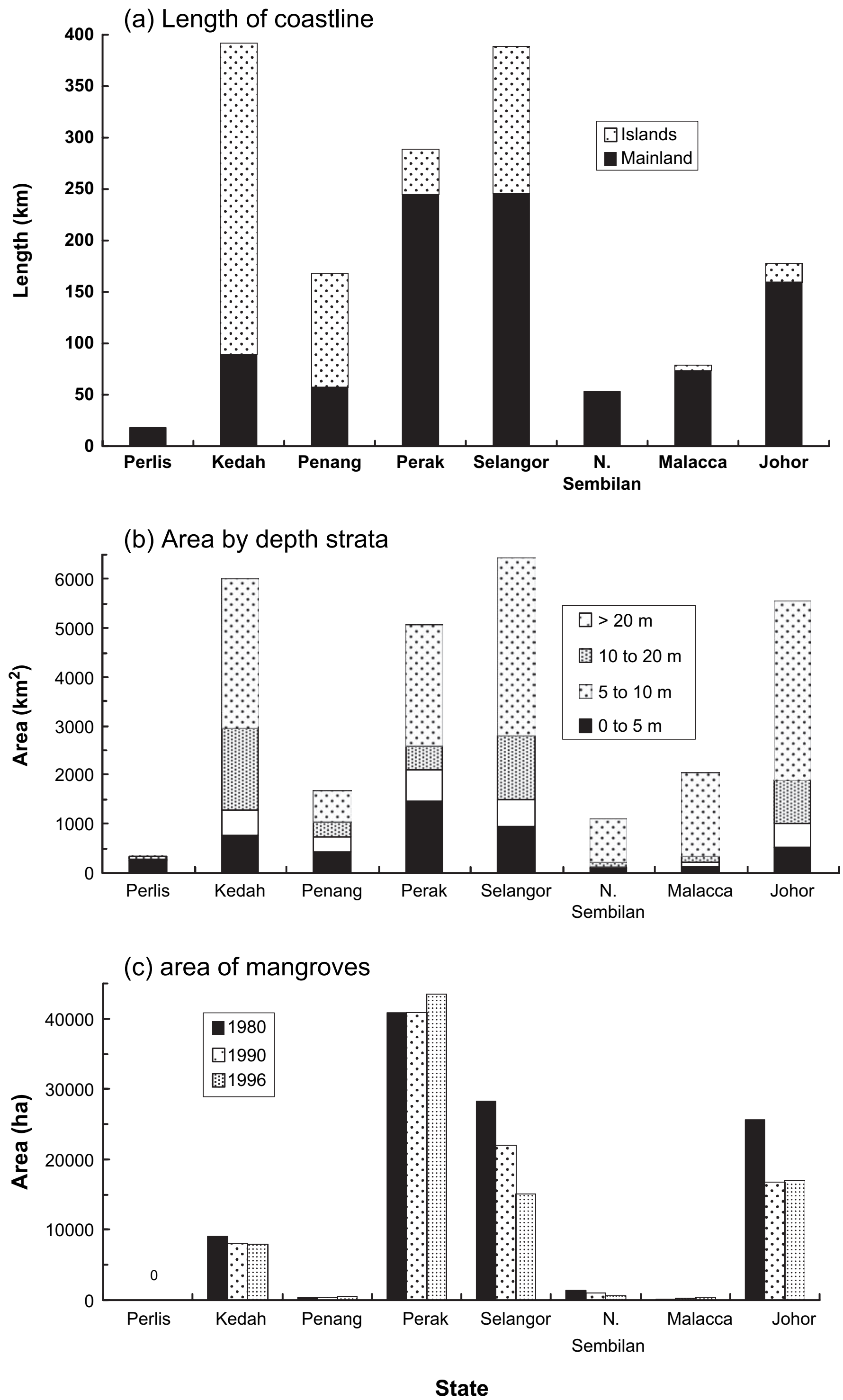

Fig. 3. The (a) Length of coastline, (b) area in different depth contours and (c) area of mangrove forest reserves (hectares) for the states of western peninsular Malaysia.

1997. The highest mean proportion of total prawn landings was recorded in the 10–25 t trawlers (31%), followed by bag nets (23%), paired trawls (15%), and drift/gill nets (including trammel nets, 11%). In contrast to the total prawn landings, the highest mean landings of white prawns was found in drift/gill nets (63%), followed by the 10–25 t trawlers (20%, Table 1). There was little difference in the proportion of landings taken by the different methods between the 1980s and 1990s, except that the proportion of total landings from the

Table 1
Mean percent (±1 SE) landings for all prawns and white prawns (mainly *Penaeus merguiensis*) for western peninsular, Malaysia between 1984 and 1997

Method	Mean percentage of landings	
	All prawns	White prawns
Bag net	22.5±1.07	2.1±0.57
Drift/gill net	11.2±0.85	63.4±1.54
Paired trawlers	15.1±0.62	1.8±0.23
Push net	3.7±0.32	2.7±0.89
Trawlers		
0–9.9 t	10.3±0.90	4.2±0.61
10–24.9 t	30.8±2.45	19.7±1.40
25–39.9 t	3.5±0.57	3.9±0.54
40–69.9 t	0.9±0.16	1.3±0.30
All trawlers	45.5±5.3	29.1±2.3
Total landings (tonnes)	54333	5895

10 to 25 t trawlers increased from about 32% in the 1980s to 40% in the 1990s (means not shown in Table 1).

The total number of trawler licenses was about 3900 boats in 1974, increasing to 5800 boats in 1984. The number of trawler licenses declined from 1985 until 1987 (4200 boats), but since 1993 has been relatively constant at about 3900 to 4000 trawlers. In recent years, about 2000 of the trawlers were in the 10–25 t category of vessel. Landings of white prawns are made throughout the year in western peninsular Malaysia.

3.4. Variation in landings between states

In both the 1980s and 1990s, the mean total landings in Perak (about 25 000 t) were about 2.5 times higher than those for the second highest state (10 000 t in Selangor, Fig. 4a). The mean total landings of white prawns in Perak (about 2000 t) were about 2 times higher than those in the next highest state of Penang

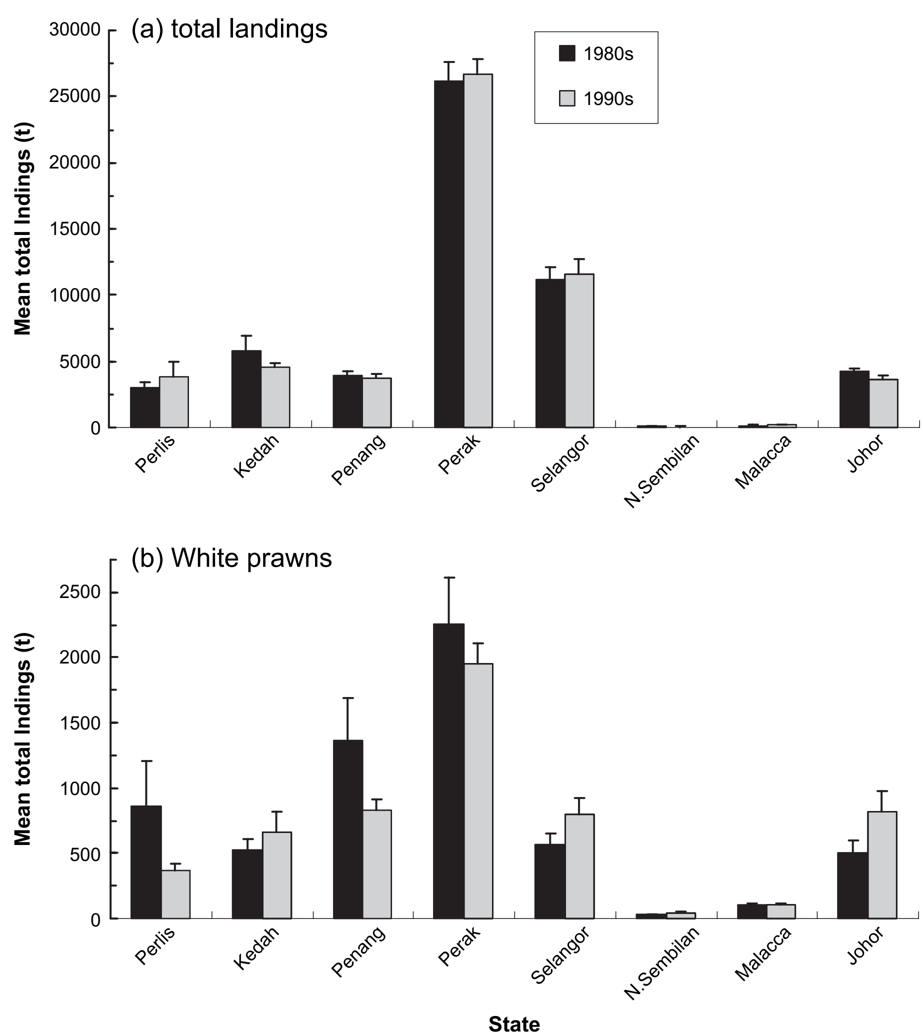

Fig. 4. Mean landings (+1 SE) for (a) all prawns and (b) white prawns in each state of western peninsular Malaysia for the 1980s and 1990s.

(Fig. 4b). Perak contributed about 50% to the mean total landings and 35% to the landings of white prawns in WPM in both the 1980s and the 1990s. The second most important state for white prawns was Penang (18%), with four states (Perlis, Selangor, Johor, and Kedah) contributing about 10% to the landings of white prawns on the west coast (Fig. 4b). Although prawn landings in Perak were at least 2.5 times higher than those in other states, the mean number of trawlers in Perak were about 1.7 times higher than those in Selangor and the mean number of drift/gill net boats in Perak were similar to those in Johor, Selangor and Penang (Fig. 5).

In Perak, both landings and mangroves showed little change between the 1980s and 1990s (Fig. 6). However, in Selangor and Johor, where the greatest losses of mangroves were recorded, landings of white prawns increased in the 1990s compared with the 1980s by about 60% and 90%, respectively (Fig. 6). In fact, the landings of white prawns increased by over 20% in all states south of Perak.

3.5. Relationships between prawn landings, mangroves, shallow waters and rainfall

The mean total landings of prawns in each state were positively correlated with the area of stratum in the 0 to 5 and 5–10 m depth substratums, the area of mangroves and the ratio of the area of mangroves:length of coastline, and negatively correlated with rainfall for each decade (Table 2). However, by far the highest correlations were obtained with area in the 0–5 m depth stratum, which accounted for about 90% of the variation in mean total landings in the 1980s and 1990s (Table 2, Fig. 7a). The area of mangrove forest reserve accounted for about 60% of the variation in mean landings for each decade (Table 2, Fig. 7b).

The area of water 0–5 m deep and the area in the 5–10 m stratum were the only variables fitted to the multiple regression equation for the mean total landings in both decades (Table 3). However, adding in the area in the deeper depth strata to the equation only increased the adjusted R^2 for the multiple regression by 5% in the

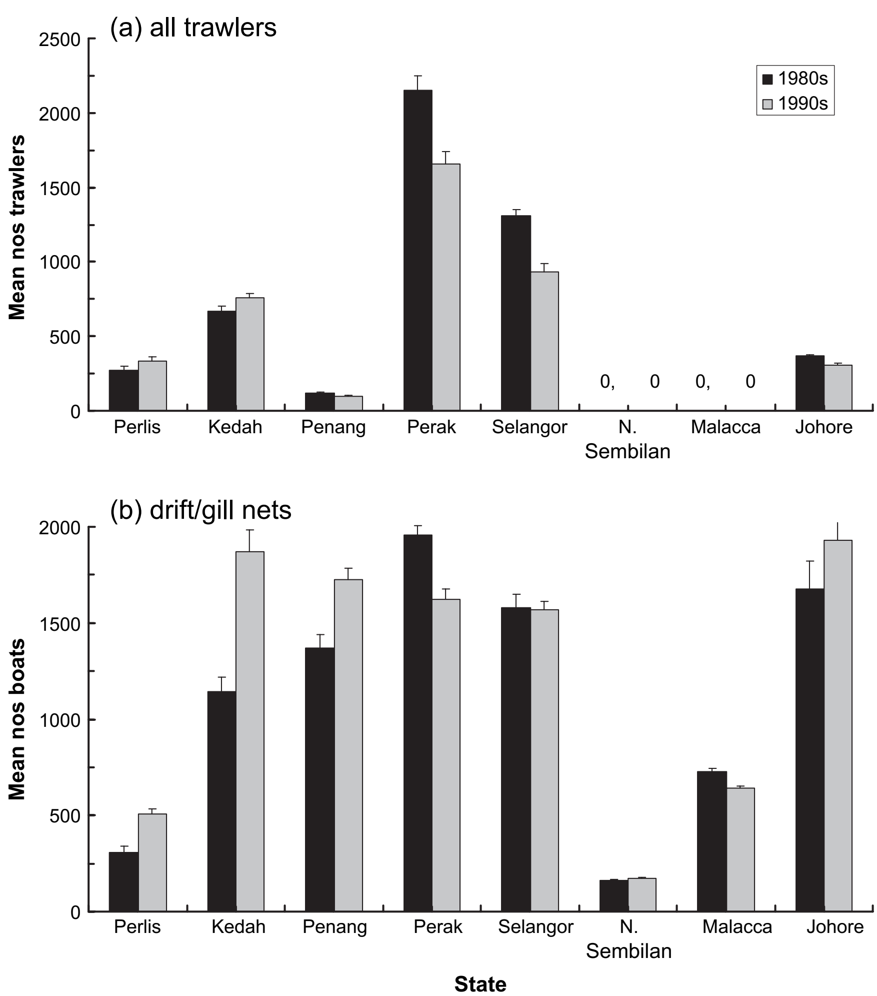

Fig. 5. Mean number of boats (+1 SE) for (a) 10–25 t trawlers and (b) drift/gill nets in each state of western peninsular Malaysia for the 1980s and 1990s.

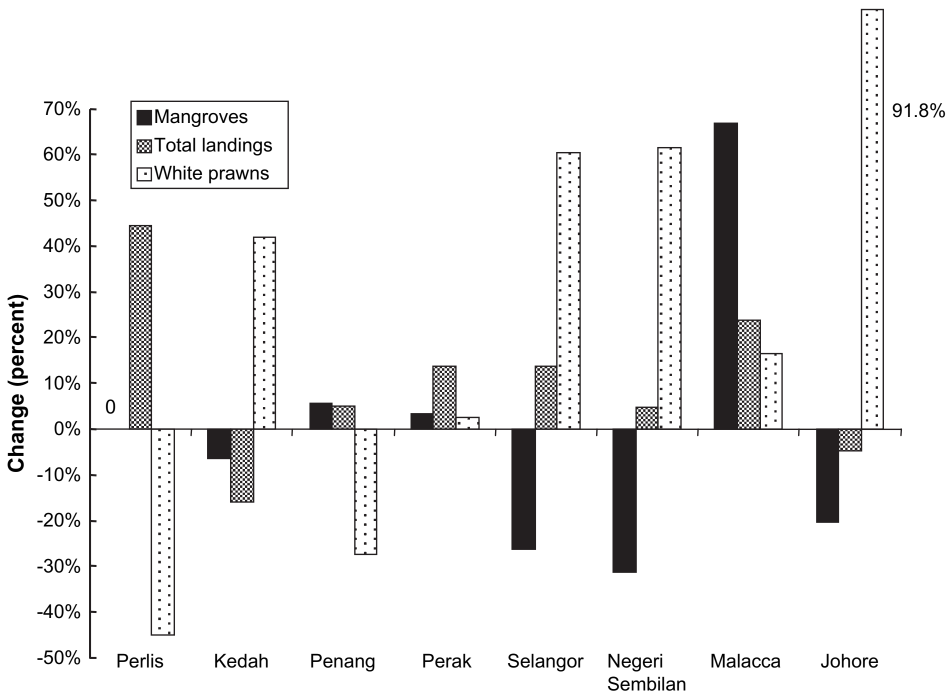

Fig. 6. Percentage change in mangroves and landings of both all prawns and white prawns between the 1980s and 1990s for the states of western peninsular Malaysia.

1980s (Table 3). When depth was excluded from the multiple regression for total landings in the 1980s, mangrove area and the ratio of mangrove area:coastline were both fitted to the multiple regression and accounted for 78% of the total variation in landings, while

Table 2
Coefficients of determination (R^2) and significance levels for the relationship between mean landings of prawns, length of coastline, extent of mangrove forest reserve and area in different depth strata for the 1980s and 1990s

Variable	Decade	
	1980s	1990s
Total landings		
Coastline	0.54	0.46
Mangroves	0.68*	0.68*
Ratio mang:coast	0.63^{+}	0.46
0–5 m	0.94***	0.89**
5–10 m	0.64^{+}	0.55
#Rainfall	0.64 (−)	0.54 (−)
White prawns		
Coast	0.20	0.50
Mangroves	0.22	0.63^{+}
Ratio mang:coast	0.11	0.48
0–5	0.60^{+}	0.87**
5–10	0.33	0.70*
#Rainfall	0.50 (−)	0.54 (−)

$n=8$ for all correlations, except rainfall (#), where $n=6$. All data, except rainfall, were transformed by $\sqrt{(x+3/8)}$. (−) indicates a negative relationship with landings. $^{+}0.05<P\leq0.10$; $*0.01<P\leq0.05$; $**0.001<P\leq0.01$; $***P\leq0.001$.

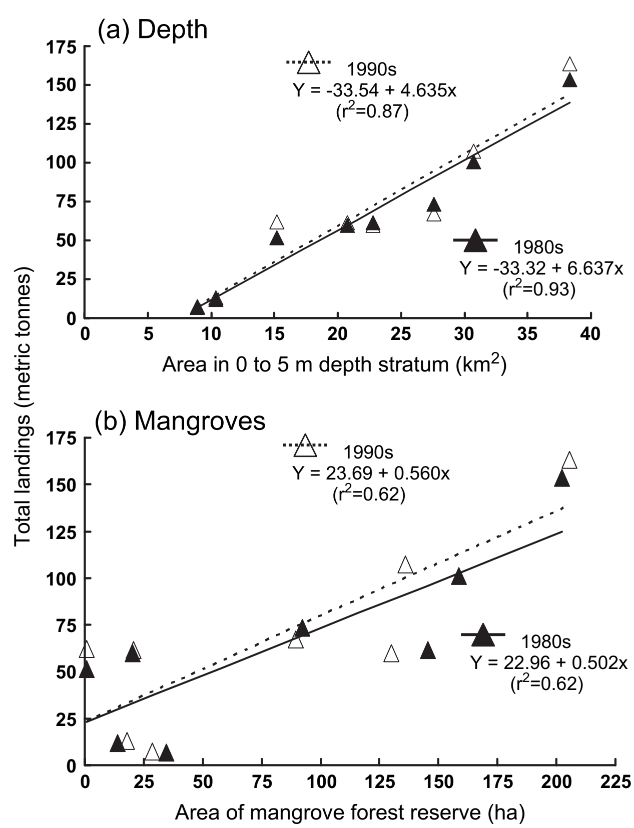

Fig. 7. Relationship between mean total landings and (a) area in the 0–5 m depth stratum (both square root transformed) and (b) mangrove area (square root transformed) for the 1980s and 1990s for the states of western peninsular Malaysia. All variables square root transformed.

Table 3
Mean squares, significance levels and parameter estimates for significant variables in stepwise multiple regressions relating total prawn landings to mangrove characteristics, length of coastline and area of substrate in different depth strata

Variable	1980s		1990s	
	Mean square	Estimate	Mean square	Estimate
All variables				
Intercept		-30.97 ± 5.61		-30.07 ± 8.27
Area of 0–5 m	$14703^{<0.001}$	6.637 ± 0.572	$15630^{<0.001}$	7.804 ± 0.843
Area of 5–10 m	$673^{0.009}$	-2.96 ± 0.72	$1474^{0.009}$	-4.382 ± 1.063
Residual MS, adj. R^2	39.9	$R^2_{2,5} = 0.98$	86.8	$R^2_{2,5} = 0.97$
Area 0–5 m only				
Intercept		-33.32 ± 10.65		-33.54 ± 15.75
Area of 0–5 m	$14703^{<0.001}$	4.495 ± 0.447	$15630^{<0.001}$	4.635 ± 0.661
Residual MS, adj. R^2	145	$R^2_{1,6} = 0.93$	317.9	$R^2_{1,6} = 0.87$
Excluding depth				
Intercept		37.17 ± 13.36		41.80 ± 13.13
Area mangroves	$10536^{0.006}$	1.336 ± 0.374	$11845^{\mathbf{0.003}}$	1.674 ± 0.417
Ratio mang:coast	$2618^{0.07}$	-15.11 ± 6.50	$3442^{\mathbf{0.04}}$	-20.24 ± 7.32
Residual MS, adj. R^2	484.2	$R^2_{2,5} = 0.78$	445	$R^2_{2,5} = 0.82$
Mangroves only				
Intercept		22.96 ± 15.64		23.69 ± 16.54
Area mangroves	$10536^{0.01}$	0.502 ± 0.142	$11845^{\mathbf{0.01}}$	0.560 ± 0.158
Residual MS, adj. R^2	839.8	$R^2_{1,6} = 0.62$	948.8	$R^2_{1,6} = 0.62$

All variables transformed by $\sqrt{(x + 3/8)}$.

mangrove area alone explained 62% of the variation (Table 3, Fig. 7b). The coefficient for the ratio of mangrove:area to coastline was negative, indicating that once mangrove area had been accounted for, landings decreased with an increase in this ratio (Table 3).

In the 1980s, the mean landings of white prawns were significantly correlated only with mean area in the 0–5 m depth stratum (Tables 2, 4, Fig. 8). In the 1990s, area in the 0–5 m depth stratum alone accounted for about 85% of the variation in white prawn landings, while area of mangrove forest reserve accounted for 57% of the variation in white prawn landings (Table 4, Fig. 8). The ratio of mangrove area: length of coastline was also fitted to the equation for landings excluding depth in the 1990s and like total landings, had a negative coefficient.

Table 4
Mean squares, significance levels and parameter estimates for significant variables in stepwise multiple regressions relating landings of white prawns to mangrove characteristics, length of coastline and area of substrate in different depth strata

Variable	1980s		1990s	
	Mean square	Estimate	Mean square	Estimate
All variables				
Intercept	NSR	NSR		-12.33 ± 9.79
Mangroves	$234.7^{0.12}$		$627.9^{0.006}$	-0.294 ± 0.213
Area of 0–5 m	$570.4^{0.04}$		$248.3^{0.03}$	1.883 ± 0.610
Area of 5–10 m	$39.2^{0.45}$			
Ratio mang:coast	$67.2^{0.34}$		$36.26^{0.26}$	3.488 ± 2.668
Residual MS, adj. R^2	52.1	$R^2_{4,3} = 0.66^{0.13}$	21.22	$R^2_{3,4} = 0.85^{0.013}$
Area 0–5 m only				
Intercept		2.392 ± 7.499		0.0164 ± 4.043
Area of 0–5 m	$635^{0.02}$	0.935 ± 0.315	$872^{<0.001}$	1.094 ± 0.170
Residual MS, adj. R^2	72.1	$R^2_{1,6} = 0.53^{0.02}$	21.0	$R^2_{1,6} = 0.85^{<0.001}$
Excluding depth				
Intercept	NSR	NSR		16.59 ± 4.69
Area mangroves	$235^{0.23}$		$627.9^{0.02}$	0.301 ± 0.149
Ratio mang:coast	$190^{0.28}$		$82.3^{0.29}$	-3.129 ± 2.614
Residual MS, adj. R^2	129	$R^2_{2,5} = 0.16^{0.28}$	57.4	$R^2_{2,5} = 0.60^{0.04}$
Mangroves only				
Intercept	NSR	NSR		13.79 ± 4.21
Area mangroves	$235^{0.24}$		$627.9^{0.02}$	0.129 ± 0.040
Residual MS, adj. R^2	139	$R^2_{1,6} = 0.18^{0.30}$	61.6	$R^2_{1,6} = 0.57^{0.02}$

All variables transformed by $\sqrt{(x + 3/8)}$. NSR, no significant regression.

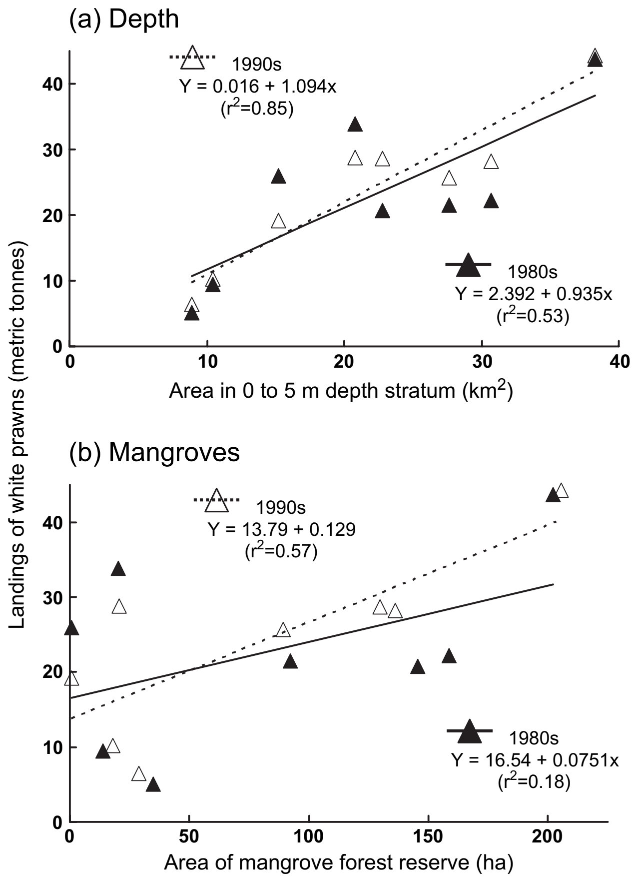

Fig. 8. Relationship between landings of white prawns and (a) area in the 0–5 m depth stratum and (b) mangrove area for the 1980s and 1990s for the states of western peninsular Malaysia.

4. Discussion

4.1. Importance of mangroves to prawns

Despite the unknown quality of the fishery data, and the lack of data on fishing effort to match the landings of prawns, the major contribution of Perak to the prawn fishery of western peninsular Malaysia for total landings (≅50%) and those of white prawns (≅35%) (Fig. 4), is consistent with the prominence of the fishery in this state (e.g. Chan et al., 1993; Ahmad Adnan et al., 2002). The largest landing centre in this region (Kuala Sepetang) is in the Larut Matang mangrove forest reserve, which has the largest area of mangroves in peninsular Malaysia (Gan, 1995). These forests have been managed for the sustainable harvesting of mangroves for over 100 years (Chan et al., 1993; Gan, 1995).

The total prawn landings from Perak, taken from only 270 km of coastline, are similar in magnitude to those for the whole of Australia (25 000 t, Preston et al., 1997). The landings of white prawns from Perak are about 50–60% of the annual banana prawn catch from Australia's Northern Prawn Fishery (3000 to 4000 t, Somers and Wang, 1997), a fishery which extends over about 6000 km of coastline. Landings of prawns in Malaysia in the 1970s, adjusted to the area of intertidal substrate (202 kg ha^{-1}), were the highest recorded in south-east Asia, followed by those in Indonesia (82 kg ha^{-1}, Turner, 1977), which also highlights the productivity of the waters of western peninsular Malaysia.

The highest correlations with landings for both total prawns and white prawns were with the area of water in the 0–5 m depth, which accounted for most of the variation in the multiple regressions for prawn landings. These shallow waters are the areas where the postlarvae settle (Dall et al., 1990; Rothlisberg et al., 1996; Condie et al., 1999) and are normally associated with high primary productivity (Hatcher et al., 1989; Robertson and Blaber, 1992; Blaber, 2000). Although the total landings of prawns for each state increased with the area of mangroves and the ratio of mangrove area: coastline length for both the 1980s and the 1990s, these variables accounted for much less of the variation in landings than that accounted for by shallow water. When only the landings of the mangrove-dependent white prawns were considered, a significant relationship between mangrove area and landings was only found in the 1990s.

The linear extent of mangroves is possibly a better estimator of prawn production than the total extent of mangroves, a variable that accounted for about 50% of the variation in catches of banana prawns in the Gulf of Carpentaria (Staples et al., 1985). Few studies have estimated the linear extent of aquatic habitat (see Staples et al., 1985; Browder et al., 1989; Manson et al., 2001, 2003 for exceptions), a procedure that requires either manual tracing of maps, or polygon data for both habitats and waterways in a Geographic Information System. Unfortunately, electronic data were not available to estimate the linear extent of mangroves in WPM and test whether this was more highly correlated with prawn landings than total mangrove area.

In some systems in Malaysia (e.g. Sungai Merbok estuary in Kedah), large areas of mangroves were removed for aquaculture in the 1980s but in most places a narrow band of fringing mangroves (5–10 m wide) were retained. In the Merbok estuary, catches of juvenile banana prawns at sites with a narrow band of fringing mangroves were similar to those at sites where the mangrove fringe was much wider (100–200 m). However, catches at a bare site, where all mangroves were removed to construct a prawn pond, were significantly lower than those at sites where a fringe of mangroves remained (Haywood et al., CSIRO Marine Research, unpublished data). No soft sediments were present at the bare site, while the sediments at sites with a narrow mangrove fringe were similar to those at sites with much wider fringes of mangroves i.e. soft and fine grained. These results suggest that the mangrove-water interface is a key attribute of mangrove forests for juvenile banana prawn populations. The importance of the interface zone has been identified in studies of saltmarsh and brown shrimp (*Penaeus aztecus*) production in Florida, United States. As saltmarsh habitat is lost and becomes fragmented, the length of marsh-water interface first increases before declining after further habitat loss. The trends in brown shrimp production were correlated with the change in the length of interface (Browder et al., 1989).

Populations of nekton in other marine habitats may also be influenced by the presence of nearby mangroves. A study of coral reef systems, with and without adjacent mangroves, found that the fauna of reefs close to mangroves had a higher biomass of fish and larger individuals, than in reefs with no adjacent mangroves. These results suggest that mangroves enhanced the growth and survival of juveniles that later colonised the reefs (Mumby et al., 2004).

In addition to the inconsistent relationship between white prawn landings and mangrove area in WPM, there was no evidence that total landings or landings of white prawns had declined in Selangor and Johor, despite a loss of 30–45% of mangrove forest reserves in these States between 1980 and 1996. The migration of prawns between areas, or changes in fleet movements and locations where prawns are landed, could contribute to the maintenance of landings in these States where vast areas of mangroves have been removed from reserves.

Juvenile *Penaeus merguiensis* from the mangroves in Perak could also contribute to the landings made in the adjacent states of Selangor in the south and Penang in the north. These two states had the second highest landings of total prawns and white prawns respectively. *Penaeus merguiensis* also appear capable of migrating from Sumatra to Johor and Selangor where the Straits of Malacca are less than 30 km wide and shallower than 50 m in depth. This is within the range of tagged *P. merguiensis* from the Gulf of Carpentaria, Australia, where most *P. merguiensis* were recaptured within 25 km of two release areas and within 80 km of a third release area (Lucas et al., 1979). The coastline of Sumatra had extensive areas of mangroves that supported prawn landings of about 16 000 t in the early 1970s (Martosubroto and Naamin 1977).

4.2. The prawn fishery of western peninsular Malaysia

The landings of white prawns in western peninsular Malaysia remained virtually constant throughout the year. This contrasts greatly with the highly seasonal fisheries for white banana prawns in regions where rainfall is markedly seasonal, such as eastern peninsular Malaysia, Sarawak and Australia (Hadil, 1994a,b; Somers and Wang, 1997). In Sarawak, landings during the northeast monsoon months of January, February and March, when rainfall is typically much higher than in other months, account for about 50% of the total prawns landed by trawlers. In northern Australia, where about 80% of the annual rainfall occurs in the summer wet season months of December to April, nearly 90% of the banana prawn catch is taken in the first 2 to 4 weeks of the fishing season that typically starts in April (Vance et al., 1985; Somers and Wang, 1997; Loneragan and Bunn, 1999). Rainfall during the wet season and its associated effects on sediments, salinity and river flow is thought to stimulate the emigration of juvenile prawns from their estuarine mangrove habitats (e.g. Staples and Vance, 1986; Vance et al., 1998).

In Australia, *P. merguiensis* form large schools or boils as sub-adults that can be identified from spotter planes and/or using colour depth sounders. Once located, the boils are fished in trawls of very short duration (e.g. 10–30 min). There is no evidence of this type of behaviour by white banana prawns in WPM, where migration appears to take place throughout the year, probably because of the much more consistent rainfall throughout the year (Ahmad Adnan et al., 2002, Fig. 2).

Trawling is a significant component of the prawn fishery in WPM as it is in other regions of the world. However, significant quantities of prawns are landed by other methods of fishing, e.g. the white prawns taken by drift/gill nets. The number of boats fishing in western peninsular Malaysia (2000 trawlers in the 10–25 t class, and nearly 11 000 drift/gill net boats) is much higher than in many regions, particularly western countries like Australia, where only about 95 trawlers now operate in the Northern Prawn Fishery. Although the number of trawlers has been reduced in WPM, the efficiency of the fleet has probably increased because of the use of more powerful engines. This has been the case in Vietnam where engine power increased following the change in fishing operations from those managed by cooperatives to free enterprise companies (de Graaf and Xuan, 1998).

4.3. Sources of data

This study has drawn on data from a number of sources including the Annual Fisheries Statistics published by the Department of Fisheries, the Bureau of Meteorology, and data on the distribution of mangroves, summarised by the Department of Forestry. Like most fisheries throughout the world, there are questions about the reliability and accuracy of the fisheries data. The potential sources of bias and error for the fisheries data are from the sub-sampling procedure used to estimate landings, the identification of prawns and their categorisation into different groups, the estimation of weight in a category when more than one species belongs to that category and the errors in reporting the landings. If these sources of bias and error are consistent over time, the landings data may still provide information on general trends in the fishery. Data from landings and log books may be under-reported to avoid giving information on prime fishing locations or to avoid tax. However, a recent investigation of FAO statistics for China found that the catches appear to have been substantially over-reported, probably to 'demonstrate' that government targets for fisheries production had been met (Watson and Pauly, 2001).

Prawn fisheries in Malaysia and other countries in the region are complex because of the number of species groups that are landed, the large size range over which prawns are exploited, the variety of fishing methods used to catch prawns and the number of people fishing for prawns. This complexity increases the difficulty in collecting consistent and representative data on the fishery and means that fishery independent surveys would be invaluable for enhancing the assessment of stocks and providing reliable indicators for recruitment. Currently, fishery independent surveys of fish and crustaceans are carried out by the Department of Fisheries in Malaysian waters at intervals of several years. Annual surveys would be needed to effectively monitor the status of the prawn populations in this region. Because of the significance of Perak to the prawn fishery of western peninsular Malaysia, greater sampling effort could be concentrated on surveys of prawns in this state.

The data on mangroves, length of coastline and rainfall are likely to be less biased and more reliable than the fisheries data. Prior to the 1980s, estimates of mangrove area were made from topographic maps. They are now being made from Landsat™ imagery that can give relatively accurate and repeatable measures of mangrove extent (Manson et al., 2001). Records for the extent and production of mangroves in the Larut Matang in Perak, where mangroves have been sustainably harvested for over 100 years, are likely to be the most accurate in western peninsular Malaysia.

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