

WATER QUALITY IN PHUKET BAY

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ABSTRACT

Phuket Bay is located on the southwest of Phuket Island. Sewage discharged from Phuket town and Phuket fish harbour are drained into the bay as runoff via Bang Yai and Tha Chin Canals. Water quality of the bay was monitored monthly at 9 sampling stations, during January 1994 to February 1995. The results showed that variation of water quality in the bay was strongly influenced by runoff associated with tidal action. Generally poor and unstable water quality was found at the bay-canal transitional zone while relatively high and stable water quality was found in the outer bay areas. Trends of seasonal variation and the fate of organic waste that drained into the bay are discussed.

INTRODUCTION

Phuket Bay (Fig. 1) is an open bay, located at the southern part of Phuket Island. It is dominated by the dry northeast monsoon, November-March, and the wet southwest monsoon, May-October. The bay covers an area of about 10 km². The bay experiences a semi-diurnal tide with a mean tidal range of 1.75 m (Sojisuporn, 1994). There are two canals that flow into the bay, Bang Yai Canal and Tha Chin Canal. Bang Yai Canal originates at the point where Bang Tal and Ket Ho Canals join together, it passes through Phuket town into Phuket Bay. In 1994, Phuket municipality had a population of 55,847 citizens with a density of about 4,500 people/ km². Since there was no water treatment plant in Phuket town, Bang Yai Canal served as the main discharge route. Tha Chin Canal is a short canal where the main fishing port of Phuket Province and several fish processing factories are located on its banks. The fishing port provides landing facilities for over 400 fishing vessels with an average annual landing of about 70,000 tons (Ravikumar, 1994). Without water treatment, the organic rich waste waters from the fish industries are directly released into the canal and then carried to the bay. The inner bay, covers about 5 km² and is rather shallow (0.5 to 1.0 m) due to high sedimentation. An area of mangrove swamp covering about 0.4 km², fringed with a seagrass

bed is located in the southern part of the bay (Poovachiranon *et al.*, 1995). Boonruang and Sawangrerruks (1990) reported that juvenile commercial shrimp species were often found around Lam Tug Kae, in the northern part of the bay. Hence, the bay supports a complex ecological system and seems to be an important nursery ground for commercial marine organisms. Therefore, the water quality of the bay and its variability is a key issue.

MATERIALS AND METHODS

Nine sampling stations in the bay were chosen as shown in Fig. 1. Water samples were collected by Kitahara Transparent Plastic Water Bottle at the surface (0.5 m below surface), middle and bottom (0.5 m above bottom) of the water column. At shallow stations, samples were only taken at mid-depths as a representative of the whole water column. The samples were transferred to clean plastic bottles (2 L) prior to further analysis in the laboratory. A known volume of water sample was filtered through a GF/C filter. The filtrates were kept frozen in polyethylene bottles prior to nutrient analysis, which usually took place within one week after sampling. The filters were oven-dried at 105° C for 24 hrs and the particulate load was calculated from the volume of water used and weight retained on the dried GF/C. Nitrate, nitrite

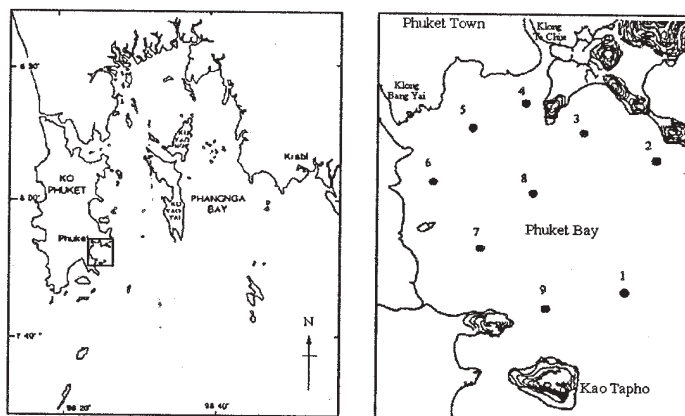


Figure 1. Sampling sites in Phuket Bay.

and phosphate were determined according to Strickland and Parsons (1972). Another aliquot of water sample was used for chlorophyll measurement by filtration through a GF/F filter, a few drop of $MgCO_3$ were added on top of the filter at the end of filtration to preserve the phytoplankton cells. Chlorophyll was extracted by 90% acetone and then determined using a spectrophotometer (APHA, 1992). Salinity, temperature, pH and dissolved oxygen content were measured in situ by DataSonde 3 Multiparameter Water Quality Data Logger (HYDROLAB). The HYDROLAB was calibrated before use each time. Biological oxygen demand (BOD) was determined following the Standard Method (APHA, 1992). Water samples for determination of coliform bacteria and faecal coliform bacteria were collected in sterilized glass bottles and a multiple tube fermentation technique was used (APHA, 1992). A Global Positioning System (GPS: Sony PYXIS) was used to locate sampling stations on each trip. Samples were taken monthly from January 1994 to February 1995 excepted in February, March, July, and September 1995 due to bad weather.

RESULTS AND DISCUSSION

1. Salinity

Salinity in the bay during the study period varied in the range of 28.5 to 33.0 ppt (Table 1).

The contour plots of salinity at low tide show that salinity of the inner bay (Stations 4, 5 and 6) was significantly lower than that of the outer bay (Figs. 2A and 2B). A similar pattern was shown by Box and Whisker plots (Figs. 3A and 3B). The low salinity water of the inner bay was obviously caused by runoff from the canals mixing with seawater. The difference became significantly greater during low tides. However, Sojisuporn (1994) anticipated that with small canals the effective runoff depended strongly on the amount of rain fall in the wet season. He also reported that in the dry season evapotranspiration rate were high in the inner bay leading to a slight elevation in salinity variation upstream. Hence, the inner bay water salinity fluctuated greatly while it was comparatively stable in the outer bay waters (31-33 ppt).

No significant seasonal differences of mean salinity in the bay water were observed (Table 2). The mean salinities in the wet and dry seasons were calculated between April-October and November-March, respectively. During the study period, maximum rain fall was observed in August and September resulting in low salinity. Unfortunately sufficient sampling could not be under-taken over that period due to bad weather. However, the low salinity tended to be prolonged until December, the end of the rainy season. Following this period salinity increased in the bay, with the highest salinities recorded during the dry season in January and

*Water quality in Phuket Bay*Table 1. The mean \pm standard deviation, maximum and minimum values of parameters measured in Phuket Bay at high and low tides.

Parameters	High Tide (n = 11)			Low Tide (n = 11)		
	Mean \pm sd	Min	Max	Mean \pm sd	Min	Max
Salinity (ppt)	31.78 \pm 0.86	30.20	32.90	31.68 \pm 0.98	28.50	33.00
Temperature (°C)	29.53 \pm 1.03	27.76	32.23	29.27 \pm 0.94	27.10	31.25
Total Suspended Solids (mg L ⁻¹)	19.03 \pm 9.94	6.90	87.60	23.45 \pm 13.01	4.90	67.20
Oxygen (mg L ⁻¹)	6.17 \pm 0.58	4.81	7.84	5.71 \pm 0.87	1.75	7.16
pH	8.12 \pm 0.14	6.97	8.29	8.09 \pm 0.12	7.68	8.26
Chlorophyll (mg m ⁻³)	2.60 \pm 3.68	0.25	30.19	4.75 \pm 6.19	ND	31.88
BOD (mg L ⁻¹)	1.23 \pm 1.05	0.27	4.63	1.30 \pm 1.06	0.25	4.63
Phosphate (μ M)	0.20 \pm 0.18	0.01	1.11	0.26 \pm 0.30	0.01	2.15
Nitrate (μ M)	0.27 \pm 0.30	ND	1.46	0.31 \pm 0.43	ND	2.83
Nitrite (μ M)	0.07 \pm 0.11	ND	0.77	0.12 \pm 0.16	ND	0.78
Coliform Bacteria (MPN/100ml)	40 \pm 98	2	540	729 \pm 1016	2	2400
Faecal Coliform (MPN/100ml)	10 \pm 15	2	78	409 \pm 757	2	2400

ND = Non-detectable

Table 2. Mean \pm standard deviation, maximum and minimum values of parameters measured at Phuket Bay in wet (April-October) and dry (November-March) seasons.

Parameters	Wet Season (n = 10)			Dry Season (n = 12)		
	Mean \pm sd	Min	Max	Mean \pm sd	Min	Max
Salinity (ppt)	31.68 \pm 0.84	29.8	31.90	31.8 \pm 1.00	28.50	33.00
Temperature (°C)	29.90 \pm 0.82	28.25	32.23	28.87 \pm 0.89	27.10	31.24
Total Suspended Solids (mg L ⁻¹)	22.99 \pm 11.81	8.3	67.20	19.14 \pm 11.41	4.90	87.60
Oxygen (mg L ⁻¹)	5.95 \pm 0.70	4.26	7.84	5.96 \pm 0.84	1.75	7.20
pH	8.14 \pm 0.05	7.87	8.25	8.07 \pm 0.18	6.97	8.29
Chlorophyll (mg m ⁻³)	3.59 \pm 4.95	ND	27.49	3.78 \pm 5.50	0.25	31.88
BOD (mg L ⁻¹)	1.34 \pm 1.32	0.25	4.63	1.18 \pm 0.61	0.27	3.33
Phosphate (μ M)	0.15 \pm 0.17	0.01	1.11	0.33 \pm 0.30	0.01	2.15
Nitrate (μ M)	0.22 \pm 0.27	ND	1.66	0.37 \pm 0.46	ND	2.83
Nitrite (μ M)	0.09 \pm 0.11	ND	0.71	0.10 \pm 0.17	ND	0.78
Coliform Bacteria (MPN/100ml)	492 \pm 892	2	2400	320 \pm 710	2	2400
Faecal Coliform (MPN/100ml)	264 \pm 645	2	2400	180 \pm 504	2	2400

ND = Non-detectable

February. Thus salinity in the bay water was likely lowest between August and December.

2. pH

The bay water pH varied from 6.97 to 8.29 (Table 1). The contour and Box and Whisker plots of pH (Figs. 2C, 2D, 3C and 3D) show that the pattern of change in pH follows that of salinity, as pH was lowest in the inner bay and increased seawards. The lowest value and the greatest variation in pH were observed at the canal - bay transition zone (station 4), especially at low tide. The pH value observed at the other stations always exceeded 8, except in January 1995 when the pH at all stations was, surprisingly, lower than 8 (Fig. 4B). There is no explanation for this phenomenon since low runoff was observed during the dry period. However, pH in the outer bay was stable, at 8.2, and no trend of seasonal variation was observed.

3. Temperature

Temperature of the bay water varied from 27.1 to 32.2 °C (Table 1). Contour plots of temperature in the bay (Figs. 2E and 2F) with Box and Whisker plot of each stations (Figs. 3E and 3F) show that higher temperature were usually found in the inner bay decreasing seawards. Water temperature at low tides and high tides were fairly similar. The inner bay is very shallow suggesting that elevated temperatures are attributed to solar heating. The mean temperature of the bay, plotted as a function of time in Fig. 4C and data in Table 2, indicates that the bay water temperature in dry season (27.1-31.2 °C) was slightly lower than in wet season (28.3-32.2 °C). Limpsaichol and Bussarawit (1991) reported that the mean water temperatures in Phangnga Bay were 28.62 ± 0.40 °C and 31.60 ± 0.50 °C in dry (January-February 1988) and wet (May-June 1988) seasons, respectively. Thus the water temperature in Phangnga Bay and Phuket Bay show a similar seasonal trend. Figure 4C shows mean water temperature in the Phuket Bay as a function of time together with the mean air temperature measured at the meteorological station in Phuket town. Between August and November the air temperature was about 28 °C while between April and July the air temperature measured 30-31 °C.

Hence, the water temperature in the bay seems to be influenced partly by the air temperature.

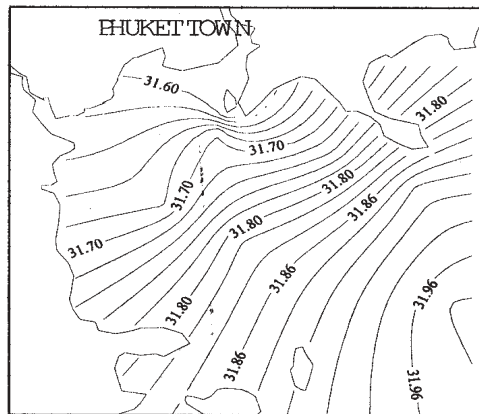
4. Total suspended solids.

Total suspended solids in the bay water varied from 4.9 to 87.6 mg L⁻¹ with an average of 21.24 mg L⁻¹ (Table 1). Contour plots and Box and Whisker plots of the total suspended solids in the bay (Figs. 2G, 2H, 3G and 3H) show that higher suspended solid contents were usually found in the inner part of the bay (Stations 4, 5 and 6) and decreased seawards. These plots show that the highest suspended solid content was located at the bay - canal (Tha Chin) transition zone (Station 4). The inner bay is shallow and turbulence caused by wind stress could lead to high suspended solids. Sojisuporn (1994) reported the concentration of suspended solids to be not higher than 15 mg L⁻¹ in Phuket Bay especially in the inner bay. A monthly plot of mean suspended solids content of the bay water (Fig. 4D) show no seasonal trends. The figure also shows that these recent findings have lower values than the previous results of Yamasmith (1981) and Bussarawit and Tinakul (1986). This may be due, in part, to the decline of tin mining activity in-land and offshore.

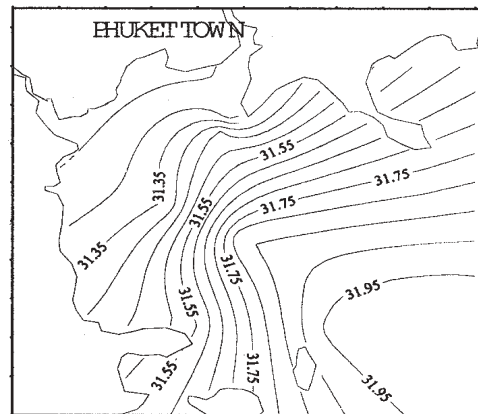
5. Biological Oxygen Demand (BOD).

The BOD in the bay water varied from 0.25 to 4.60 mg L⁻¹ (Table 1). Contour plots (Figs. 2I and 2J) and Box and Whisker plot of BOD (Figs. 3I and 3J) indicate the highest values, with greatest variation were located in the inner bay. This may be the result of organic loads from runoff mixing with the bay water during low tides. Bussarawit and Tinakul (1986) reported the BOD in Bang Yai Canal to be about 7 mg L⁻¹ during the dry season and about 4 mg L⁻¹ in the wet season. Previously, Yamasmith (1981) found that BOD in the bay ranged from non-detectable to 3.98 mg L⁻¹. Although the population density of Phuket town has increased from 3,886 persons km⁻² in 1984 to 4,500 persons km⁻² in 1994, the BOD in the bay did not show a significant increase. Study of water circulation in Phuket Bay by Sojisuporn (1994) showed that seawater generally entered the bay during high tides from the north and left the bay, during low tide, from the south. Thus bay water

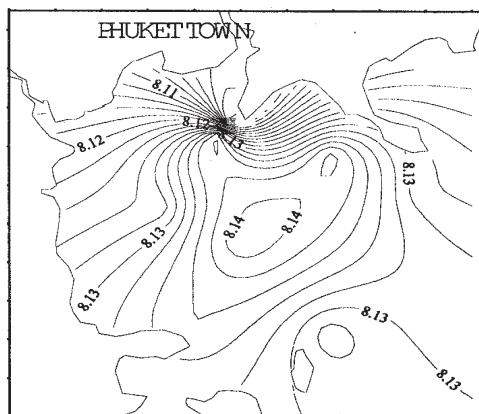
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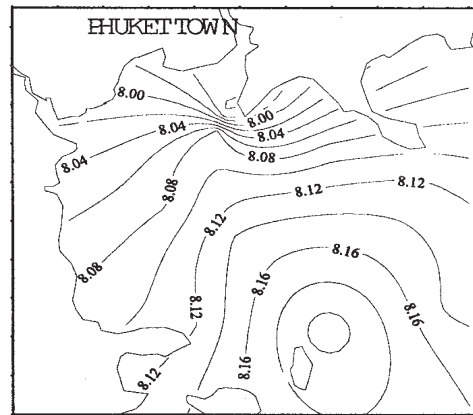
A Contour plot of mean salinity at high tide



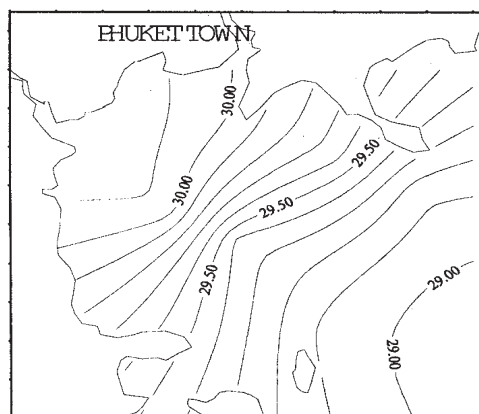
B Contour plot of mean salinity at low tide



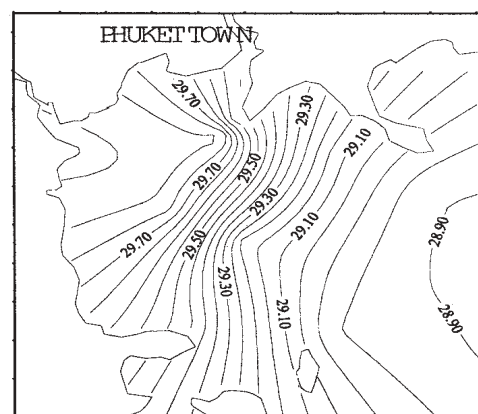
C Contour plot of mean pH at high tide



D Contour plot of mean pH at low tide

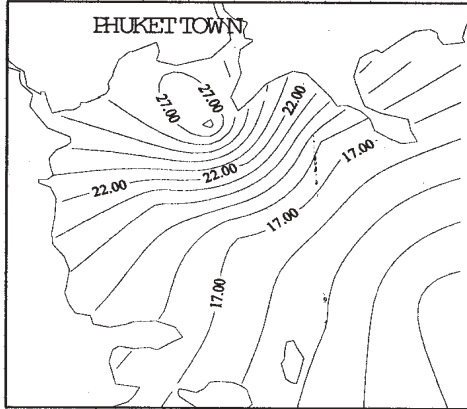


E Contour plot of mean temperature at high tide

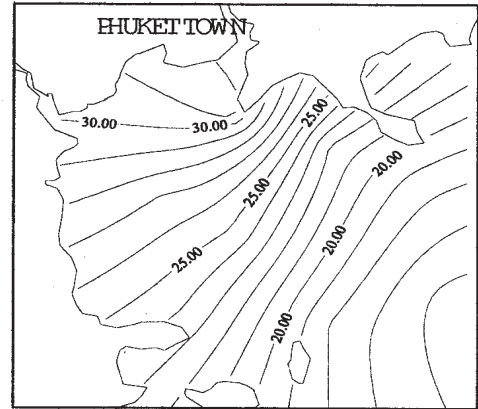


F Contour plot of mean temperature at low tide

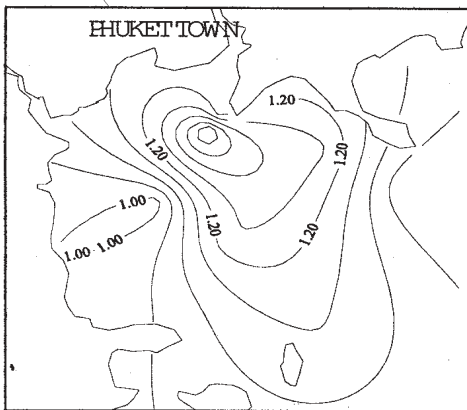
Figure 2. Contour plots of mean salinity (ppt), pH and temperature (°C) at high and low tide.



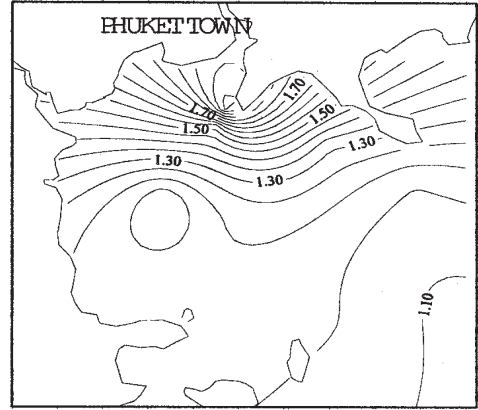
G Contour plot of mean TSS at high tide



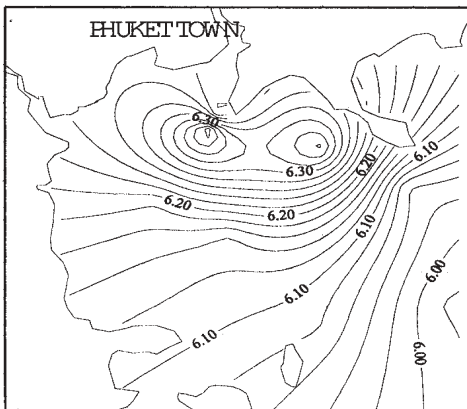
H Contour plot of mean TSS at low tide



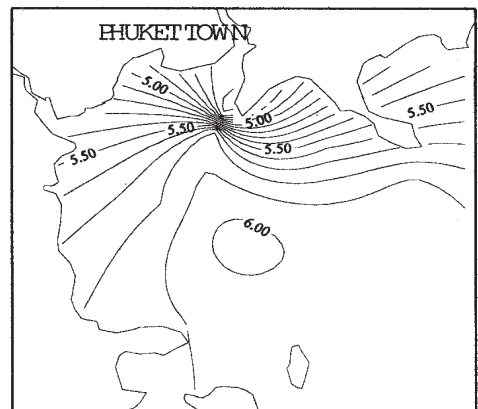
I Contour plot of mean BOD content at high tide



J Contour plot of mean BOD content at low tide



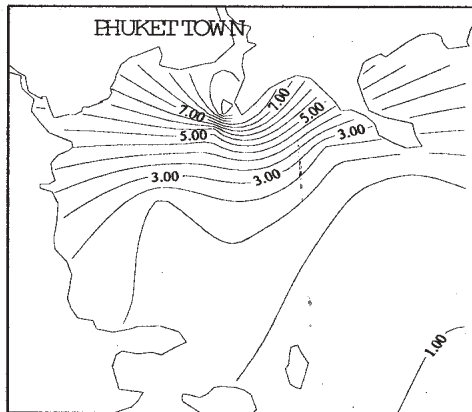
K Contour plot of mean oxygen at high tide



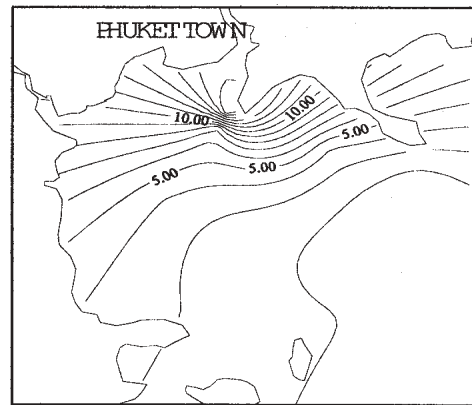
L Contour plot of mean oxygen at low tide

Figure 2 (continued). Contour plots of mean total suspended solid (TSS) (mg/l), BOD (mg/l) and oxygen (mg/l) at high and low tide.

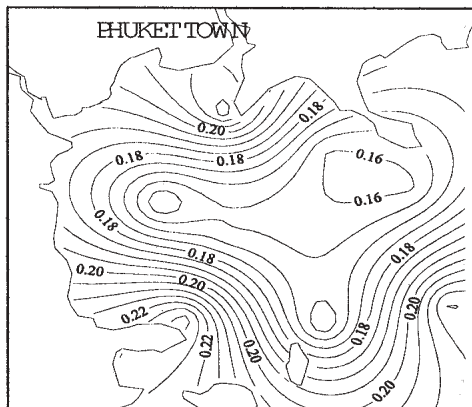
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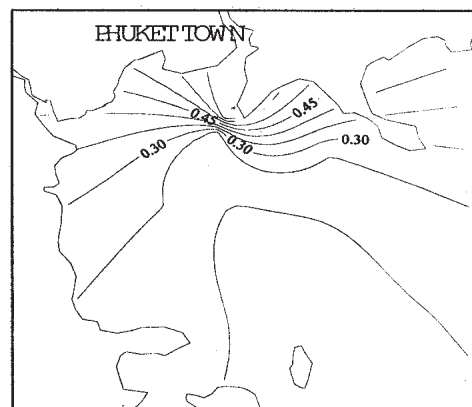
M Contour plot of mean Chl-a at high tide



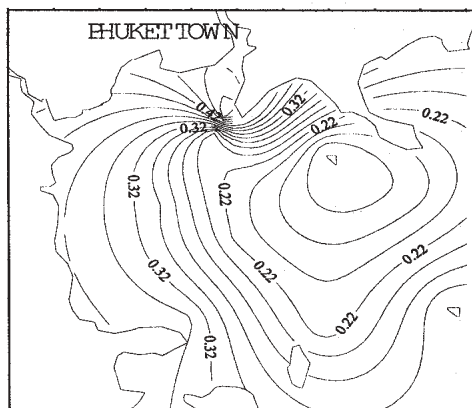
N Contour plot of mean Chl-a at low tide



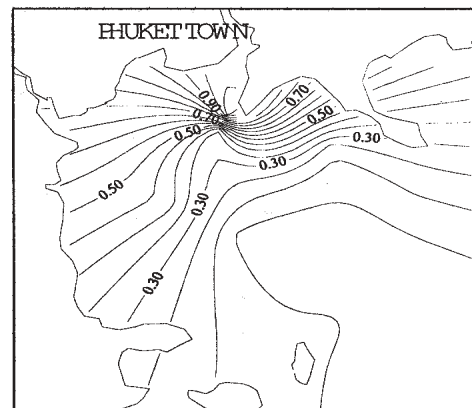
O Contour plot of mean phosphate at high tide



P Contour plot of mean phosphate at low tide

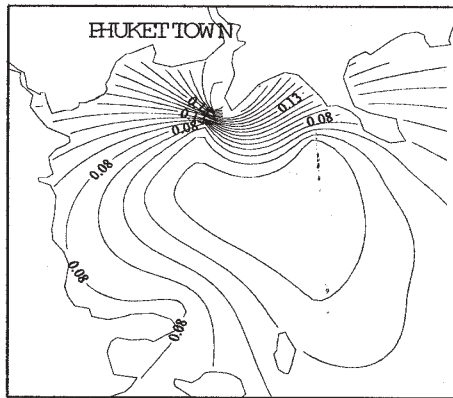


Q Contour plot of mean nitrate at high tide

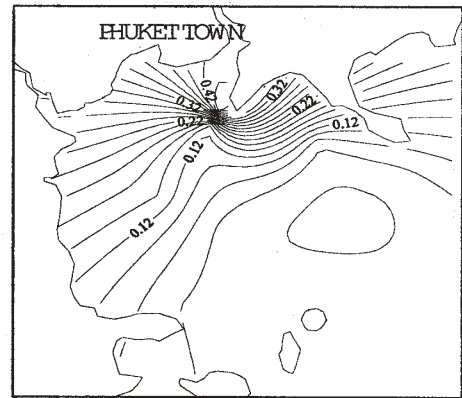


R Contour plot of mean nitrate at low tide

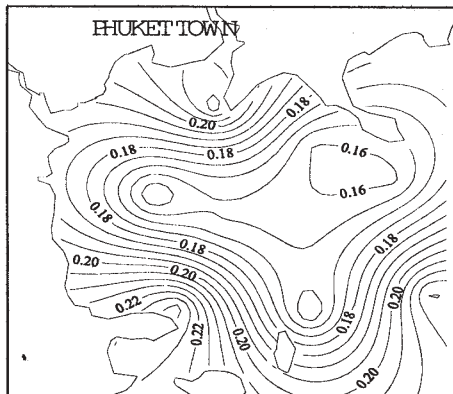
Figure 2 (continued). Contour plots of mean chlorophyll-a (mg/m^3), phosphate (μM) and nitrite (μM) at high and low tide.



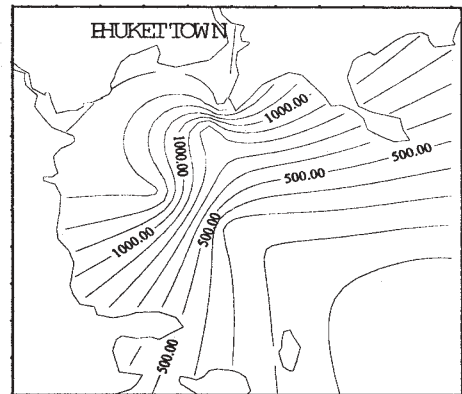
S Contour plot of mean nitrite at high tide



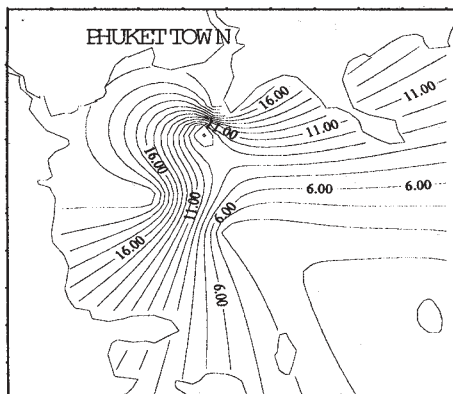
T Contour plot of mean nitrite at low tide



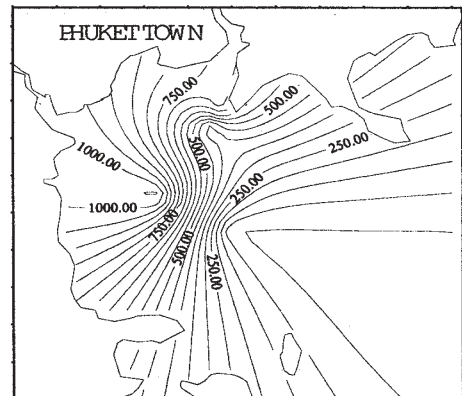
U Contour plot of mean coliform bacteria at high tide



V Contour plot of mean coliform bacteria at low tide



W Contour plot of mean faecal coliform bacteria at high tide



X Contour plot of mean faecal coliform bacteria at low tide

Figure 2 (continued). Contour plots of mean nitrite (μM), coliform bacteria (MPN/100 ml) and faecal coliform bacteria (MPN/100 ml) at high and low tide.

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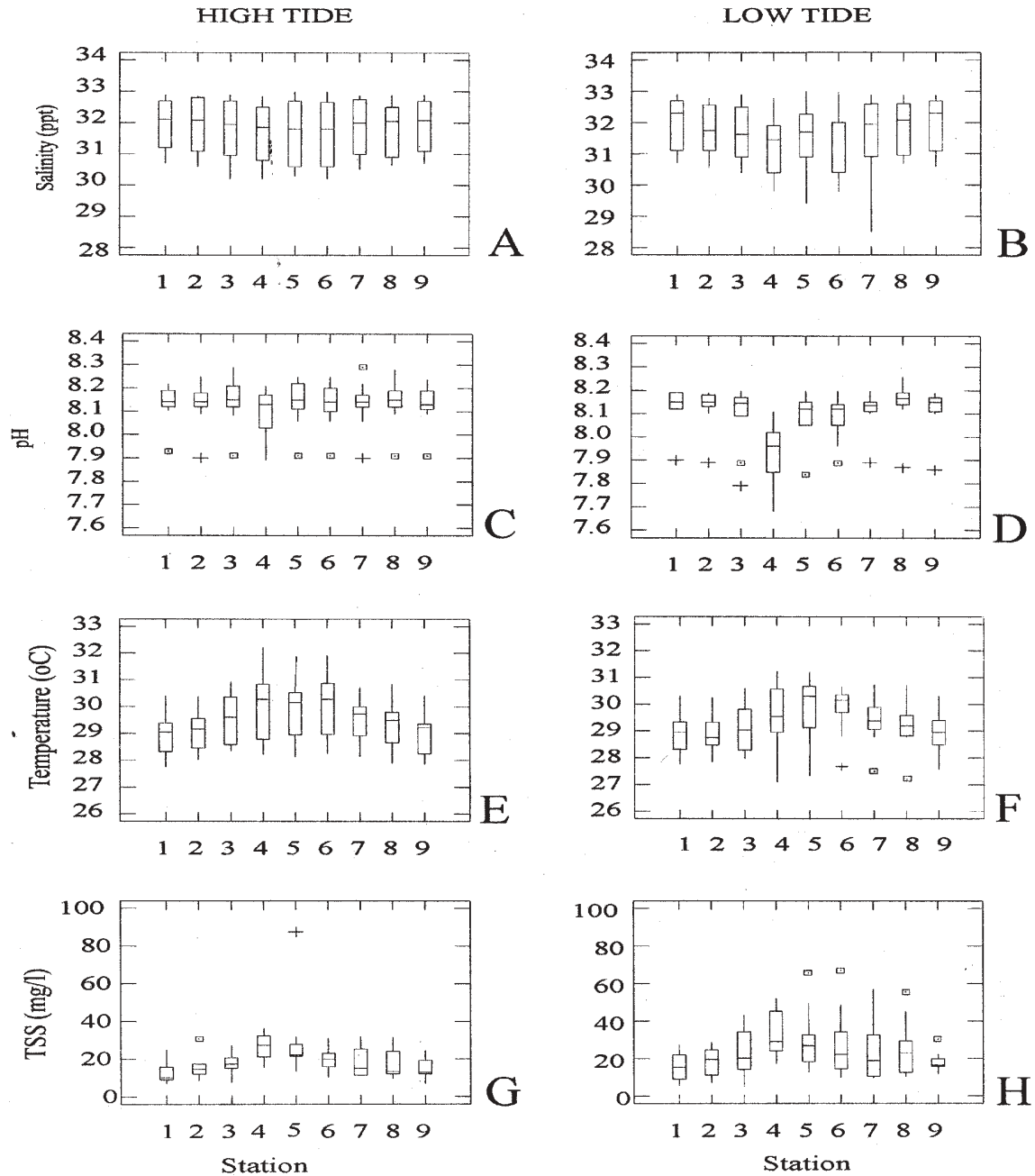


Figure 3. Box and whisker plots of salinity, pH, temperature and total suspended solid (TSS) in each station at high and low tides. The Lower and the upper end of the Box indicate interquartile of 25% and 75% respectively while the central line is for the median. The whisker indicates those points that are within 1.5 times the interquartile range, □ and + indicate extreme points beyond the length of the whisker.

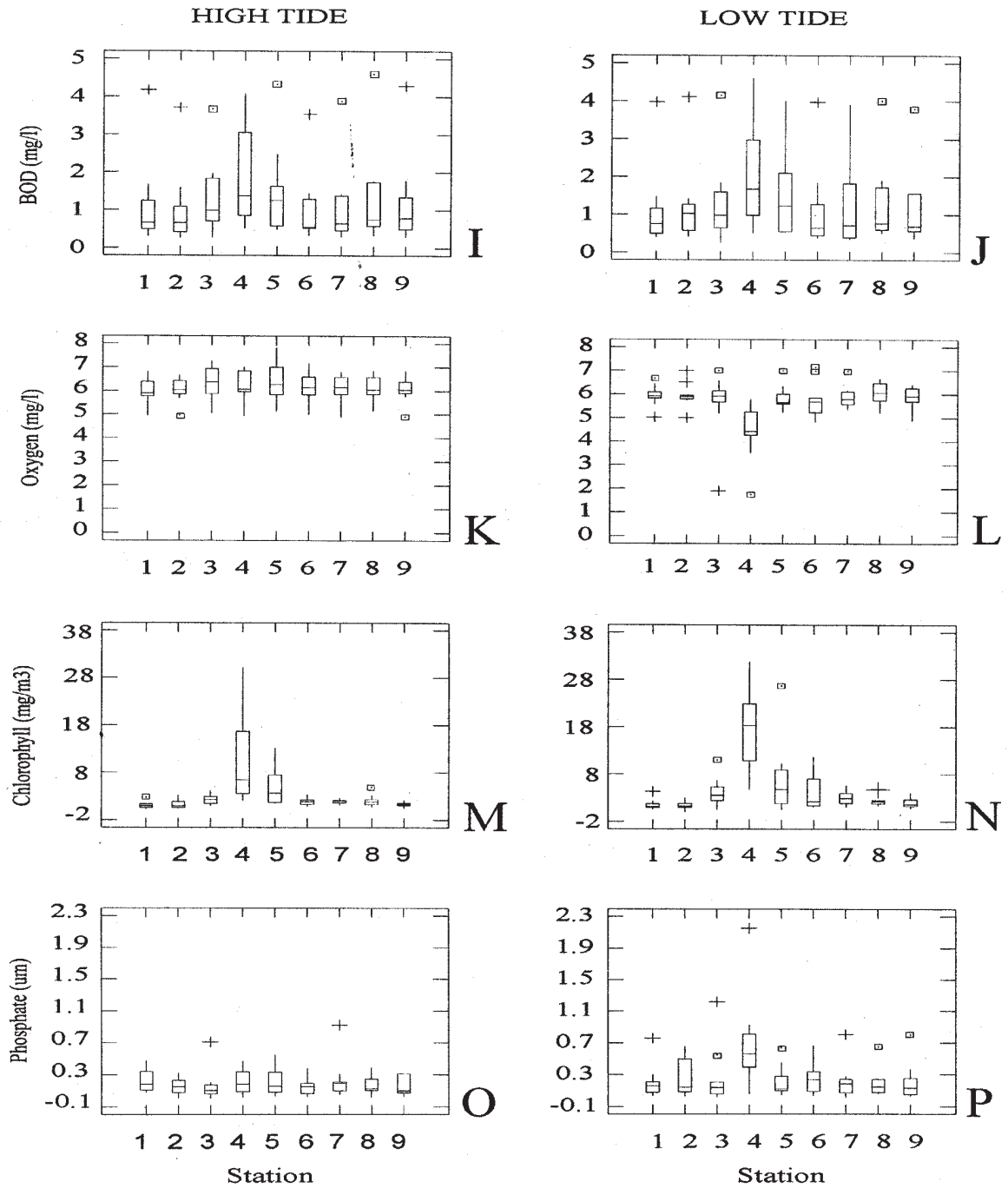


Figure 3 (continued). Box and whisker plots of BOD, oxygen, chlorophyll and phosphate in each station at high and low tides.

Water quality in Phuket Bay

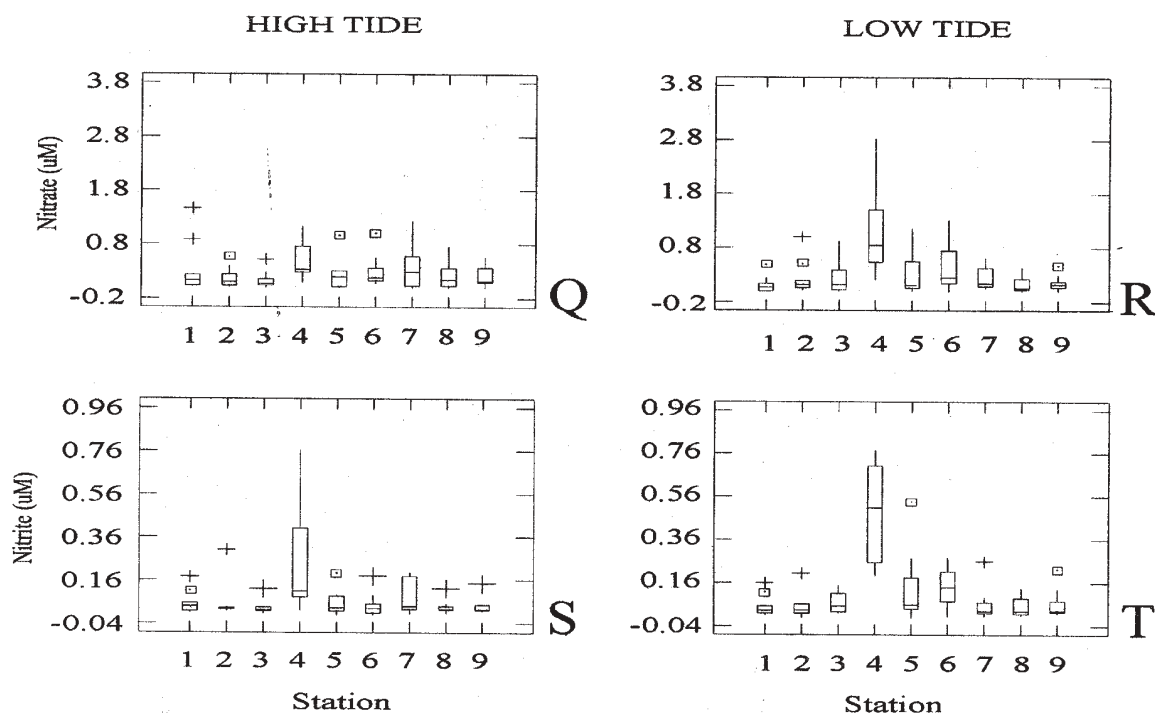


Figure 3 (continued). Box and whisker plots of nitrate and nitrite in each station at high and low tides.

containing high organic waste was conveyed to the south of the bay where mangrove swamp and seagrass beds are located.

The monthly plot of the mean BOD in the bay water as function of time (Fig. 4G) shows that water samples collected in June contained maximum BOD. During the same period, the highest levels of total suspended solids and chlorophyll-a contents were recorded with the lowest oxygen content. June was the beginning of the rainy season resulting in high runoff which transported a high concentration of organic compounds to the bay. Here they were microbiologically degraded leading to intensive nutrient regeneration, and resulting high Chl-a values in water.

6. Oxygen

Oxygen content in the bay water ranged from 1.75 to 7.84 mg L⁻¹ (Table 1). Contour plots of oxygen content at high and low tides (Figs. 2K and 2L) show opposite patterns. At high tide, the inner

bay water has a higher oxygen content than the outer bay water while at low tide a lower oxygen content was found in the inner bay. Box and Whisker plots (Figs. 3K and 3L) show that water with a low oxygen content dominated the inner bay especially at the canal - bay transition zone. The oxygen content in the Tha Chin Canal is characterized by low values of 2.0-4.6 mg L⁻¹ at low tide with slightly higher values observed at high tide (Panutrakul unpublished data). A similar pattern was observed in the Bang Yai Canal (Yamasmith, 1981). It was seen that during low tides, runoff with low oxygen content dominated the inner part of the bay while at high tide, high oxygen seawater dominated the inner bay. The shallow inner bay is strongly influenced by wind stress inducing turbulence which enhances oxygen content particularly during high tide. The plot of mean oxygen content in bay water as a function of time (Fig. 4H) shows that oxygen content correlated well with the highest BOD, total suspended solids and chl-a contents. The high concentrations of

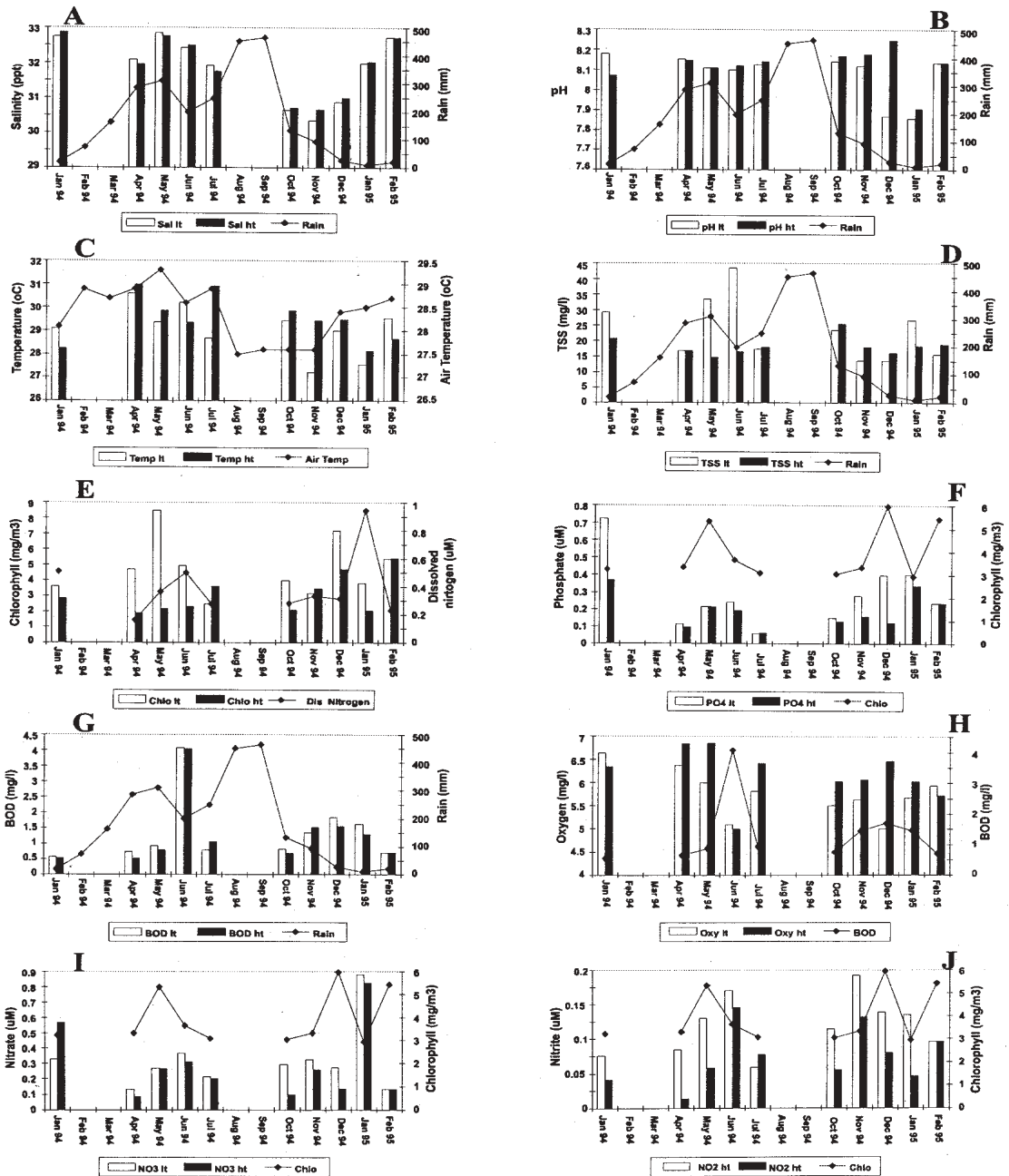


Figure 4. Monthly plots of salinity (A), pH (B), temperature (C), suspended solids load (D), chlorophyll (E), phosphate (F), BOD (G), oxygen (H), nitrate (I), and nitrite (J) from January 1994 to February 1995. Low tide (lt) and high tide (ht) measurements of each parameter are plotted.

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organic waste is indicated by the high BOD which is microbiologically consumed causing low oxygen in the water. However, no difference in oxygen content during the wet and dry seasons was observed (Table 1).

7. Chlorophyll-a (Chl-a)

Chlorophyll-a concentration varied in the bay water from 0.25 to 31.88 mg m⁻³ (Table 1). Contour plots of Chl-a at high and low tides are shown in Figures 2M and 2N, respectively. Similar to BOD, total suspended solid content and nutrients, high Chl-a content was found in the inner part of the bay especially at the mouth of the Tha Chin Canal. From Box and Whisker plots (Figs. 3M and 3N) the maximum Chl-a was found, at both high and low tides, at station 4. The maximum Chl-a content found in the inner shallow part of the Phangnga Bay (highly productive bay) by Janekarn and Hylleberg (1989) was 17.66 mg m⁻³ which accounts for about half of the maximum Chl-a content (31.88 mg m⁻³) found in Phuket Bay. Tinakul (1981) observed a high productivity value in Phuket Bay, especially at the mouth of the canals, comparable to the present findings. Boonruang and Sawangraruks (1990) observed that post larvae of *Penaeus* spp., *Mysid*, *Parapenaopsis* spp., and *Acetes* spp. were abundant in Phuket Bay. Sawangraruks and Boonruang (1990) also reported the abundance of adult Penaeid shrimp in the bay. The monthly plot of mean Chl-a content in the bay water (Fig. 4E) shows that the highest Chl-a contents occurred in June and December in accordance with nutrient content.

8. Nutrients

Contour plots of mean phosphate, nitrate and nitrite concentrations show high concentrations in the inner bay especially close to Lam Tuk Kae at the bay - canal transition zone (Figs. 2O to 2T). Box and Whisker plots (Figs. 3O to 3T) indicate high contents of these parameters especially at station 4 at low tide with values up to 0.300, 2.831 and 0.778 μM for phosphate, nitrate and nitrite, respectively. Hence, organic waste in runoff is the main source of nutrient supply to the bay. The nutrient contents in the bay did not exceed the values reported by Tinakul (1981) and Bussarawit and

Tinakul (1986) and are not distinctively higher than the nutrient contents found in the offshore and coastal area of the west coast of Thailand (Janekarn and Hylleberg, 1989; Limpsaichol *et al.*, 1994).

Mean phosphate, nitrate and nitrite of the bay water plotted as function of time (Figs. 4 F, I and G) show two peaks of high nutrients which can be observed in May-June and December-January. The nutrient peaks found in May-June were lower than in December-January in accordance with peaks of high Chl-a and BOD in the bay. Nevertheless, no strong conclusion can be made on temporal variation and the relationship between nutrients and Chl-a content since the data were insufficient. In a previous study (Panutrakul unpublished data) ammonia were shown to vary at the mouth of Tha Chin Canal from 2 to 75 μM. It was shown that high ammonia content is a very important controlling primary productivity (Boyer *et al.*, 1994; Mohlenberg, 1995).

The present study suggests that the monsoon influence may induce nutrient variations in Phuket Bay resulting in significantly higher nutrients during the dry season than in the wet season at a 95% confidence level (F-test).

9. Coliform bacteria and faecal coliform bacteria

Both coliform and faecal coliform bacteria in Phuket Bay were found in the range of 2 to 2400 MPN/100 ml (Table 1). Contour plots of total coliform bacteria and faecal coliform bacteria (Figs. 2U to 2X) show a high number of bacteria at the transitional zone. However, they rapidly decrease seawards indicating these bacteria are probably of runoff origin. The high number of bacteria can be found down to station 8, located in the middle of the bay. No significant seasonal differences were recorded (Table 2). Similar to other parameters, bacteria were flushed out from the polluted canals to the bay at low tide and were pushed back at high tide. High concentrations of bacteria were found all year round in the inner part of the bay especially at the mouth of the canals. On average the inner bay was dominated by a number of total coliform bacteria greater than 1000

MPN/100 ml exceeding the standards of water quality for coastal and estuarine sites. Thus the inner bay is not suitable for water sport or aquaculture. Limpsaichol and Bussarawit (1991) reported mean coliform bacteria in the Phangnga Bay in concentrations of 9 to 260 MPN/100 ml while Limpsaichol *et al.* (1994) reported that the number of total coliform bacteria in Patong Bay, an important tourist area, was as high as 240,000 MPN/100 ml. Comparing Kata, Karon (other important tourist areas), Phuket Bay and Patong Bay it was seen that Patong Bay is the most contaminated bay in Phuket. One of the main reasons may be the water circulation in each bay. Limpsaichol *et al.* (1994) suggested that the water circulation of Patong Bay created a sink of released waste at the northern part of the bay which led to high nutrient content and coliform bacteria in the area.

CONCLUSION

The results from this study suggest that variations in water quality of the bay for parameters such as salinity, pH, total suspended solids, oxygen content, BOD, nutrients, and coliform and faecal coliform bacteria are strongly influenced by input of organic wastes from runoff associated with tidal actions. The Tha Chin and Bang Yai Canals are polluted mainly by fish industries and domestic waste respectively. During ebb tides, runoff water dominates the bay water causing a lowering of water salinity, pH and oxygen content at the inner bay while BOD, total suspended solids, nutrients, chlorophyll-a and coliform bacteria increased. Since the canals are small with a low water discharge during the dry season, the amount of runoff depends very much on the amount of rain fall. Therefore salinity, pH and other parameters of the inner bay were only slightly lower than the outer bay where they were rather stable during the study period. At flood tide, seawater was pushed inward into the canals, thus at high tide water quality in the bay was influenced by

seawater. As a result, at high tide the bay was characterized by better water quality than at low tide.

Comparison of water quality of the present and the studies carried out in 1981 and 1986 shows that the BOD, total suspended solids and nutrient contents recorded in this study did not exceed the previous studies. Hence the waste input to the bay at its present load does not seem to accumulate in the bay. Water circulation in the bay must play an important role in transporting the waste loads out to the open sea. The mangrove swamp and seagrass beds at the southern area of the bay may absorb a proportion of the waste and regenerated nutrients. Water quality in terms of faecal bacteria, particularly at the bay - canal transitional zone, was lower than water standard criteria for coastal water. Thus, utilization of the inner bay water is not recommended for water sport and aquaculture. The high Chl-a content in the bay water and abundance of shrimp larvae reported in a previous study indicate that the bay is productive. It is therefore necessary for a further study to be carried out on the fluxes of organic wastes from the canals and their behaviour in the bay in order to achieve a better understanding of their fate in such a productive bay.

ACKNOWLEDGEMENTS

The author wishes to thank the Institute of Environmental Research, Chulalongkorn University for partial funding of the project, Mr. Somsak Chulasorn (Former Director of Phuket Marine Biological Center), Mrs. Nipavan Bussarawit and Mr. Somkiat Khokiattiwong for supporting the work, Mr. Prawin Limpsaichol (Director of Phuket Marine Biological Center) for finalising the manuscript. Special thanks to Ms. Daras Roungsaritsak, Mr. Songrit Chotithammo and the staff of the Fisheries Oceanography Sub-division for helping both in the field and laboratory.

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