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Nearshore and Offshore Comparison of Marine Water Quality Variables Measured During SESMA 1

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ABSTRACT Total suspended solids (TSS), dissolved oxygen (DO) and dissolved inorganic nutrient concentrations [ammonium (NH_4), nitrite (NO_2), nitrate (NO_3), phosphorus (PO_4) and silicate (SiO_4)] were measured in offshore sites covered by the first Scientific Expedition to the Straits of Malacca or SESMA 1 cruise. Both TSS and DO showed striking differences between nearshore and offshore sites. TSS was elevated nearshore (> 250 mg l^{-1}) but was < 100 mg l^{-1} offshore. DO was at healthy levels (> 300 µM or 9.6 mg l^{-1}) offshore but were low and sometimes exhibited hypoxia (< 125 µM or 4 mg l^{-1}) nearshore. Dissolved inorganic nutrients were generally higher nearshore and this reflected eutrophication. High TSS, low DO and eutrophication showed that anthropogenic activities are affecting the marine water quality in Malaysia.

ABSTRAK Dalam kajian ini, kami mengukur beberapa pembolehubah kualiti air marin di stesyen luar pantai semasa Ekspidisi Saintifik ke Selat Melaka atau pelayaran SESMA 1. Data yang diperolehi dibandingkan dengan stesyen dekat pantai. Jumlah ampaian pejal (TSS), oksigen larut (DO) dan kepekatan nutrien inorganik larut [amonium (NH_4), nitrit (NO_2), nitrat (NO_3), fosforus (PO_4) and silikat (SiO_4)] diukur. Kedua-dua TSS dan DO menunjukkan perbezaan ketara antara stesyen dekat pantai dan luar pantai. TSS adalah tinggi dekat pantai (> 250 mg l^{-1}) tetapi < 100 mg l^{-1} luar pantai. DO adalah pada tahap sihat (> 300 µM atau 9.6 mg l^{-1}) luar pantai tetapi adalah rendah dan kadang kala mempamerkan hipoksia (< 125 µM atau 4 mg l^{-1}) dekat pantai. Nutrien tak organik larut adalah pada amnya lebih tinggi dekat pantai dan ini mencerminkan eutrofikasi. TSS yang tinggi, DO yang rendah dan eutrofikasi menunjukkan bagaimana aktiviti antropogenik sedang memberi kesan terhadap kualiti air marin di Malaysia.

(inorganic nutrients, tropical coastal waters, eutrophication, suspended solids, dissolved oxygen)

INTRODUCTION

Tropical oceans cover about 40% of the global ocean [1], and yet knowledge of the structure and function of this ecosystem remains limited especially in the Southeast Asia region [2]. A pre-requisite to understanding the marine ecosystem is to determine the health of the marine habitat by carrying out marine water quality studies.

In this study, we sampled several stations along the Straits of Malacca during the first research cruise of the Scientific Expedition to the Straits of Malacca or SESMA 1 and measured some marine water quality variables. These offshore waters were located away from anthropogenic activities and pollution. Baseline data from these sites (especially offshore islands) are rare, and will be valuable reference points for marine water quality studies or impact assessments.

In order to determine the effects of human activities on marine water quality, our observations from SESMA 1 were compared with nearshore waters. At present, nearshore waters are in various stages of degradation as they are increasingly exploited by humans for food, recreation, transport and other needs [3]. Marine water quality data is also essential for the future development of a marine water quality standard that is at present not available in Malaysia.

MATERIALS AND METHODS

Study site

The Scientific Expedition to the Straits of Malacca or SESMA research cruise was first carried out aboard the MV 'Reef Challenger'. The research cruise was from 4 - 12 June, 2004, and we collected water samples from around the islands of Jarak, Sembilan and Perak, and along a line transect established from T1 to T4 (T1, T2, T3 and T4) (Figure 1). These SESMA stations were located farther from the coastline (up to 125 km offshore), and represented offshore sites that were less affected by pollution from rivers or land. Due to logistical constraints, sampling at these offshore sites was carried out only once. On two other occasions (July 2004 and June 2005), samplings were also carried out at the fringe waters of the Matang Mangrove Forest Reserve and these represented nearshore waters. Some marine water quality data from Klang (September 2004 to February 2005, n = 6) were summarized from [4], and used to represent nearshore waters.

Sampling and chemical analyses

Seawater was collected about 0.1 m below the surface, and was filtered onboard through pre-combusted (500ºC for 3 h) GF/F filters (Whatman, UK). The filtrate was kept frozen (-20ºC) until nutrient analysis in the laboratory. In-situ measurement of temperature and salinity was carried out using a

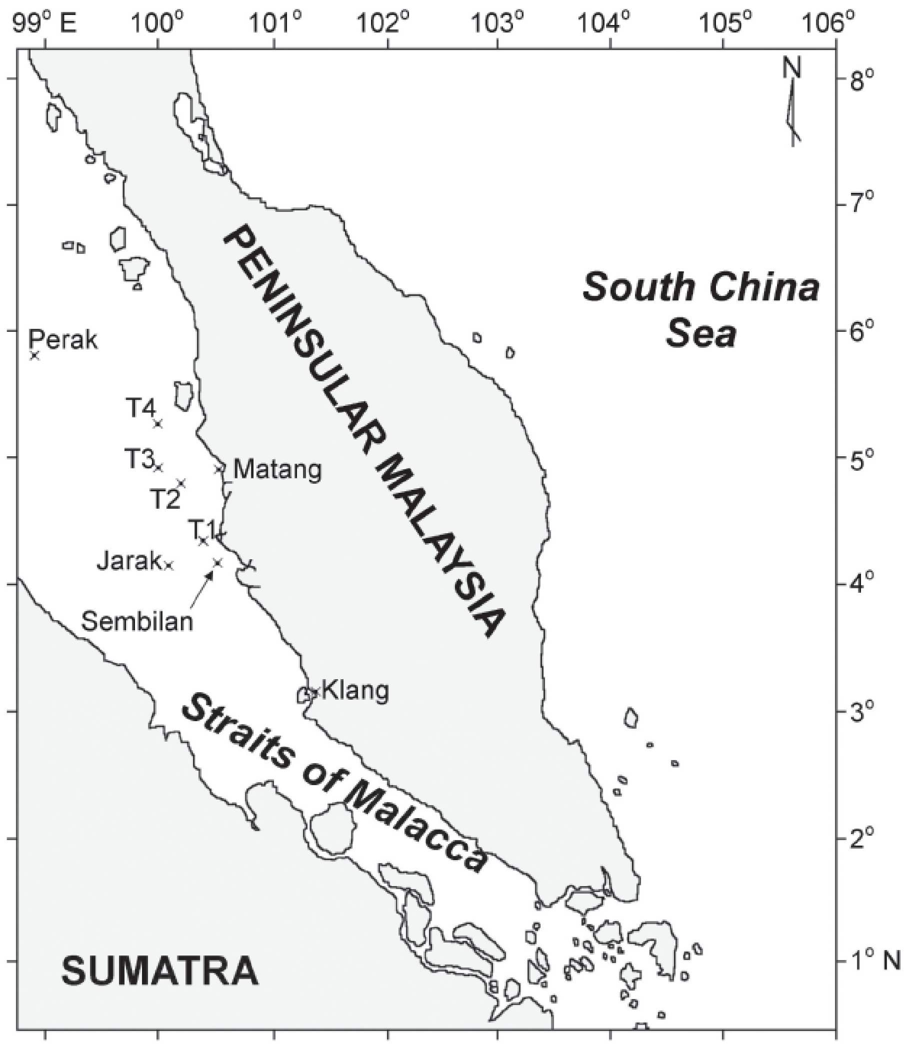

Figure 1. Map showing the location of the sampling sites in this study.

salinometer (YSI-30, USA), whereas pH was measured with a pH meter (Thermo Orion 4-Star, USA). For dissolved oxygen (DO), samples collected in 50 ml DO bottles were fixed immediately with manganous chloride and alkaline iodide solutions, and determined by the Winkler titration method [5].

The weight increase of the GF/F filter after drying at 70ºC (until no more weight loss) was measured as total suspended solids (TSS). The same filter was later combusted in a microwave furnace (CEM MAS7000, USA), and the weight loss after combustion was measured as particulate organic matter (POM). Dissolved inorganic nutrients [nitrate (NO_3), nitrite (NO_2), ammonium (NH_4), phosphate (PO_4) and silicate (SiO_4) were measured according to [6]. With the exception of TSS and POM, all measurements were carried out in triplicates. Coefficient of variation (CV) for NH_4, PO_4 and SiO_4 analyses were < 5%, and < 10% for NO_2 and NO_3 analyses. For DO measurements, the CV was < 6%.

RESULTS AND DISCUSSION

Water characteristics

Table 1 shows some of the characteristics of the surface seawater sampled during this study. Nearshore sites were shallow (< 5 m depth) whereas offshore sites had depths > 29 m, and reached 82 m at Perak Island. Average surface seawater temperature ranged from 28.6 to 32.0ºC, and was typical of tropical waters. Salinity ranged from 26 to 30 whereas pH was from 7.7 to 8.5. Average salinity and pH were generally lower nearshore, and this could be attributed to the influence of freshwater run-off or rivers. Freshwater generally has a lower salt content and pH than seawater [7].

TSS and DO

Figure 2 shows the distribution of TSS and DO for both nearshore and offshore sites. TSS was > 250 mg l^{-1} for nearshore sites but generally < 100 mg l^{-1} for offshore sites. Most of the TSS was non-biogenic as POM was < 6% of TSS (data not shown). High TSS level is a pervasive problem in Malaysia, and is often attributed to land clearing activities in construction projects, mining, agricultural and forest industries, and dredging operations [8]. In the past, e.g. 20 years ago, TSS level at Klang was only about 100 mg l^{-1}. The increase in TSS of about 132 mg l^{-1} from 1994 to 2003 coincided with the rapid development in the Klang valley upstream [4]. High suspended solid loading was however limited to nearshore waters as offshore sites had

Station	Location	Depth (m)	Temperature ºC	Salinity	pH
NEARSHORE					
Klang* − estuary	03º00.1'N, 101º23.4'E	2	30.0±0.8	26.4±5.1	7.7±0.4
Matang − mangrove waters	04º46.2'N, 100º35.4'E	5	29.7	29.5	7.7
OFFSHORE					
Jarak − offshore island waters	03º59.0'N, 100º05.8'E	40	30.0	30.0	8.1
Sembilan − offshore island waters	04º00.6'N, 100º33.8'E	29	28.6	28.7	8.0
T1 − offshore waters	04º12.6'N, 100º28.6'E	28	28.8	29.0	7.7
T2 − offshore waters	04º39.5'N, 100º14.6'E	48	30.3	28.0	8.4
T3 − offshore waters	04º47.8'N, 100º04.5'E	49	32.0	28.0	8.5
T4 − offshore waters	05º07.8'N, 100º00.5'E	50	30.0	29.0	8.2
Perak − offshore island waters	05º40.8'N, 098º56.2'E	82	29.9	29.0	8.3

Table 1. Location and type of sampling stations in this study. Mean (± Standard Deviation) of water depth, surface water temperature, salinity and pH measured in this study. * − data from [4]

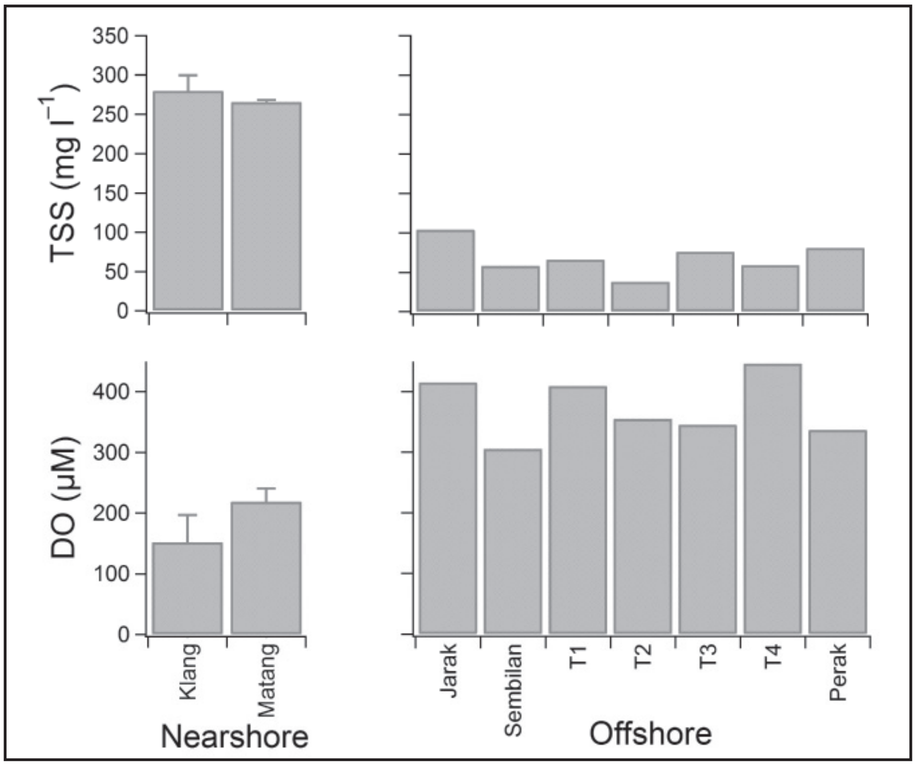

Figure 2. Average total suspended solids (TSS, mg l^{-1}) and dissolved oxygen (DO, μM) nearshore and offshore. Error bars (± Standard Deviation) for nearshore stations are also shown.

lower TSS concentrations (Student's *t*-test: $t = 23.8$, $df = 13$, $p < 0.001$).

Average DO (± Standard Deviation, S.D.) at Klang was 160 ± 20 μM (or 5.1 ± 0.6 mg l^{-1}), and at Matang, it was 220 ± 20 μM (or 7.0 ± 0.6 mg l^{-1}). Nearshore DO was significantly lower (Student's t-test: $t = 6.7$, $df = 15$, $p < 0.001$) than offshore sites which were > 300 μM (or 9.6 mg l^{-1}). DO concentration is a good indicator of aquatic health as all respiring organisms require oxygen. Low DO concentration (or hypoxia) can cause stress response in fish and other aquatic organisms. Although there is no universally accepted DO concentration to describe hypoxia, the consensus from laboratory or field observations is 125 μM (or 4.0 mg l^{-1}) [9]. In this study, DO concentrations offshore were at healthy levels whereas episodes of hypoxia have been recorded nearshore [4].

Many countries are now facing a common problem where increasing anthropogenic activity results in elevated TSS and formation of 'dead zones' (hypoxia and anoxia) in coastal waters [3, 4, 9, 10]. In this study, comparison between nearshore and offshore sites clearly showed the effects of development upon marine water quality. There should be better enforcement of existing laws regulating activities along rivers and coasts to prevent deterioration of marine water quality which could threaten fisheries and biodiversity.

Dissolved inorganic nutrients

Dissolved inorganic nutrients are essential for both heterotrophic and phototrophic processes and are known to limit biological activity when inadequate [11]. Figure 3 shows the distribution of dissolved inorganic nitrogen (DIN = NH_4 + NO_2 + NO_3) species for both nearshore and offshore sites. DIN was generally higher nearshore (8.11 – 21.80 μM DIN) than offshore (2.04 – 6.21 μM DIN). This could again be due to pollution prevalent in nearshore waters. Among the different nitrogen species measured, NH_4 was the dominant species nearshore (> 65% of DIN) whereas NO_3 was dominant offshore (> 59% of DIN). Average NH_4 was 13.76 ± 9.06 μM at Klang and 8.30 ± 1.70 μM at Matang, whereas for offshore sites NH_4 was < 1 μM. In this study, NH_4 significantly

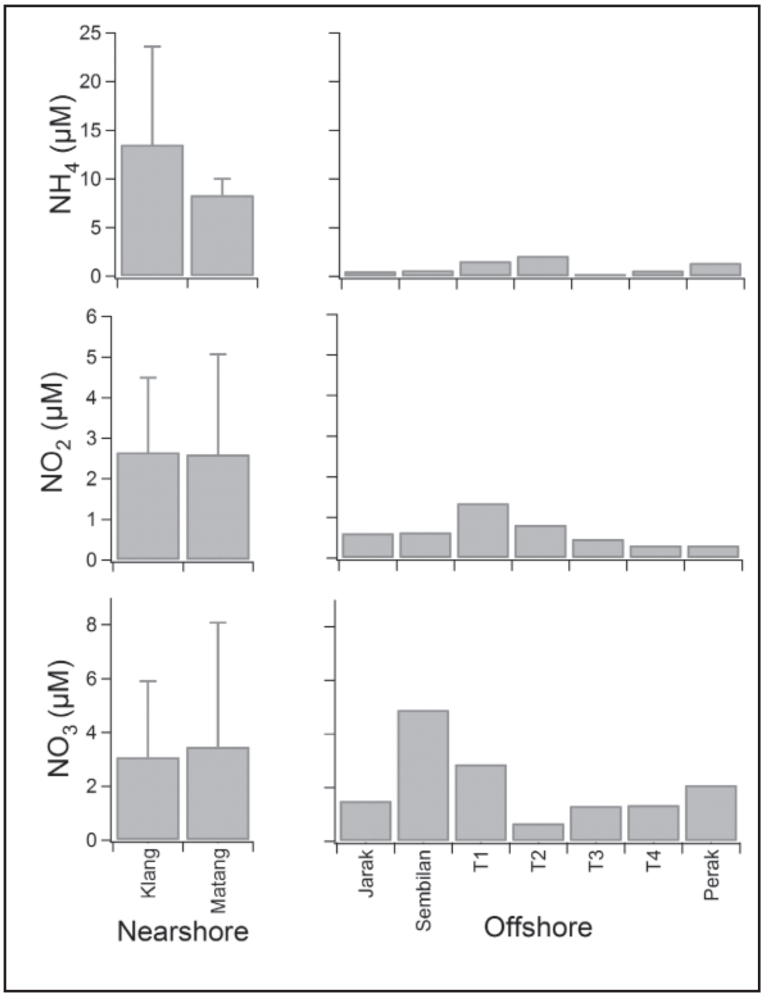

Figure 3. Average ammonium (NH_4, µM), nitrite (NO_2, µM) and nitrate (NO_3, µM) concentrations nearshore and offshore. Error bars (± Standard Deviation) for nearshore stations are also shown.

higher (Student's *t*-test: $t = 3.6$, $df = 7$, $p < 0.01$) nearshore. The prevalence or accumulation of NH_4 reflects a reducing environment or waters with low DO [10].

Similarly, NO_2 distribution was significantly higher nearshore (Student's *t*-test: $t = 2.7$, $df = 7$, $p < 0.05$) even though NO_2 was a minor fraction of DIN for both nearshore and offshore sites.

For NO_3 concentrations, there was no significant difference between nearshore and offshore sites. Since NO_3 concentration is affected by nitrification and denitrification processes [12], further studies are required to understand the NO_3 distribution observed here.

There was also no significant difference in the distribution of PO_4 and SiO_4 between nearshore and offshore sites (Figure 4) even though SiO_4 was generally higher nearshore (> 10 µM). This is typical of coastal waters with large river systems (for example the Klang River) as freshwater is a source of SiO_4 [13]. In this study, PO_4 also fluctuated over a higher range nearshore (0.41 − 5.67 µM) than offshore (0.49 − 2.10 µM). Nutrient concentrations are generally higher nearshore, primarily due to anthropogenic activities and surface run-off [12, 14, 15]. The eutrophication of the nearshore waters in turn supports higher biological activity as both phototrophic and heterotrophic biomass and activity are higher than offshore sites [16].

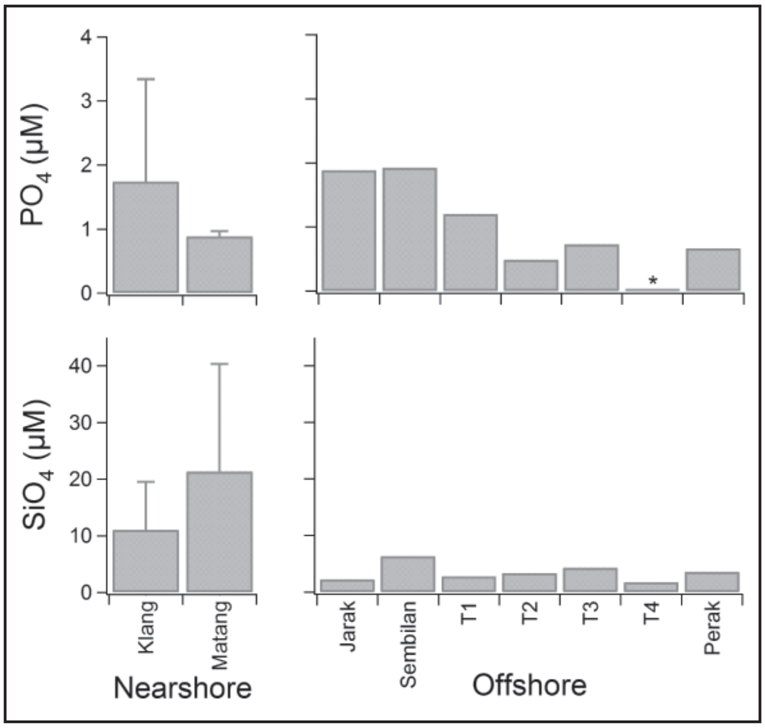

Figure 4. Average phosphorus (PO_4, µM) and silicate (SiO_4, µM) concentrations nearshore and offshore. Error bars (± Standard Deviation) for nearshore stations are also shown. * − data not available.

In this study, marine water quality nearshore was deteriorating as opposed to offshore waters. Other than increasing TSS and decreasing DO, the eutrophication of our coastal waters is of great concern. Continuous eutrophication of our nearshore waters raises concerns about the deteriorating marine water quality that could threaten recreational industry, tourism, fisheries and biodiversity.

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