EFFECT OF HARMFUL ALGAL BLOOM ON COASTAL WATER PROPERTIES AT SEPANGGAR BAY, SABAH

LOW SIN EE

DISSERTATION SUBMITTED TO FULLFILL PARTIAL REQUIREMENT FOR THE BACHELOR OF SCIENCE WITH HONORS

MARINE SCIENCE PROGRAMME
SCHOOL OF SCIENCE AND TECHNOLOGY
UNIVERSITI MALAYSIA SABAH

APRIL 2007

PUMS 99:1

UNIVERSITI MALAYSIA SABAH

BORANG PENGESAHAN STATUS TESIS@

JUDUL: Effect of Harmful Algal Bloom On Coastal Water Properties at Sepanggar Bay.

Ijazah: Sarjana Muda Sains Dengan Kepujian (Sains MARIN)

SESI PENGAJIAN: 04/07

Saya Low Sin Ee

(HURUF BESAR)

mengaku membenarkan tesis (LPS/Sarjana/Doktor Falsafah)* ini disimpan di Perpustakaan Universiti Malaysia Sabah dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hakmilik Universiti Malaysia Sabah.
2. Perpustakaan Universiti Malaysia Sabah dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (/)

[ ]	SULIT	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
[ ]	TERHAD	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
[/]	TIDAK TERHAD	

Disahkan oleh

(TANDATANGAN PENULIS)

(TANDATANGAN PUSTAKAWAN)

Alamat Tetap: 1612, Kampung Baru 43950 Sungai Pelek Sepang Selangor.

Dr. Md. Azharul Hoque
Nama Penyelia

Tarikh: 13/4/07

Tarikh: 13/4/07

CATATAN: * Potong yang tidak berkenaan.

** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT dan TERHAD.

@ Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (LPSM).

DECLARATION

I declare that this research is completed by me except for statements and summaries which each one of it had been statements and summaries stated its sources.

16 April 2007

LOW SIN EE
HS 2004-2578

AUTHENTICATION

Signature

1. SUPERVISOR

   (Dr. Md. Azharul Hoque)

2. EXAMINER 1

   (Dr. Sitti Raehanah Muhd. Shaleh)

3. EXAMINER 2

   (Dr. Normawaty Mohamad Noor)

4. DEAN

   (Supt/KS Prof. Madya Dr. Shariff A.K. Omang)

ACKNOWLEDGMENT

First of all, I wish to express sincere appreciation to my beloved and respected supervisor, Dr. Md. Azharul Hoque for his assistance and patience along the study period and in the preparation of this dissertation. Again, thanks for your encouragement and enthusiastic support for this research.

Next, a special thanks to Mr. Md. Rashed-Un-Nabi, Mr. Asri, Joanna, Madiha, who freely gave their valuable time in order to provide information, advice and help whenever I need. I would also like to thanks my friends, especially Siow Ling who always accompany me during laboratory works and all the knowledge have shared with me.

I am grateful to have my dearly loved family members who always support me throughout the journey of this study.

ABSTRAK

Peningkatan populasi alga berbahaya (HAB) menjadi suatu isu alam sekitar yang amat merisaukan di Sabah sejak kebelakangan ini. HAB yang disebabkan oleh *Cochlodinium* lebih kerap berlaku di perairan barat Sabah berbanding dengan 30 tahun yang lepas. Kepekatan *Cochlodinium* yang tinggi dalam air laut menyebabkan perubahan warna air laut dan kematian ikan dan invertebrata. *Cochlodinium* akan menyumbat dan merosakkan insang ikan dan haiwan tanpa tulang belakang. Peningkatan populasi *Cochlodinium* memainkan peranan penting dalam pengukuran kualiti air. Bilangan alga akan bertambah secara mendadak dalam keadaan optimum. Data analisis telah dijalankan dengan menggunakan program komputer, PRIMER 6 (Plymouth Routines In Multivariate Ecological Research). PRIMER 6 mengandungi pelbagai analisis yang menggunakan graf dan berbagai rutin untuk menganalisis kepelbagaian spesis atau matrik biojisim yang wujud semasa menguji kesan alam sekitar serta penyelidikan asas tentang komuniti ekologi yang bersekutu dengan data kimia-fizikal. *Cochlodinium* mempengaruhi kualiti air seperti suhu, oksigen terlarut, kemasinan, pH, dan kekeruhan air. Peningkatan populasi *Cochlodinium* meninggikan suhu kerana peningkatan aktiviti metabolisme *Cochlodinium*. Kemasinan air juga tinggi kerana kadar penyejatan yang disebabkan oleh suhu tinggi. Selain itu, air laut menjadi keruh kerana bilangan sel *Cochlodinium* yang tinggi dalam air laut. Kandungan oksigen terlarut dalam air adalah semakin berkurangan kerana aktiviti-aktiviti bakteria ketika proses pereputan. Bacaan pH meningkat semasa HAB disebabkan oleh kepekatan ion hidrogen yang tinggi dalam air laut.

ABSTRACT

Harmful algal bloom (HAB) becomes a most concerned environmental issue in Sabah recently. HAB caused by *Cochlodinium* occur more frequent in west coast of Sabah than previous. The water discolouration by high concentration of *Cochlodinium* in seawater causes mass mortality of fish and invertebrates. *Cochlodinium* clogging and damaging the fish and invertebrates gills. The coastal water properties play important roles during algal bloom. Algal will bloom when there is an optimum condition. Data analysis was done by using software named PRIMER 6 (Plymouth Routines In Multivariate Ecological Research) consists of a wide range of univariate, graphical and multivariate routines for analyzing the species abundance or biomass matrices that arise in biological monitoring of environmental impact and more fundamental studies in community ecology, together with associated physical-chemical data. From this study, *Cochlodinium* was found affecting the physical water properties, such as temperature, DO, salinity, pH and water transparency. Bloom of *Cochlodinium* made the temperature increase due to the rapid metabolic activity. The level of salinity rise because of the high temperature which promotes evaporation. Besides, decreases the light penetration due to the high density of cells in water. It also result low oxygen conditions as the huge activities of bacteria which responsible in decomposition activities. The pH value was found higher during bloom consequence of greater the hydrogen ion concentration in the seawater.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

HAB	Harmful Algal Bloom
PSP	Paralytic shellfish poisoning
DSP	Diarrhetic shellfish poisoning
CFP	Ciguatera fish poisoning
ASP	Amnesic shellfish poisoning
ANOSIM	Analysis of similarity
SIMPER	Similarity percentage
CA	Cluster analysis
MDS	Non-metric Multi-dimensional scaling
UMS	University Malaysia Sabah
BMRI	Borneo Marine Research Institute
ODEC	Out door development centre
GPS	Global position system
DO	dissolved oxygen
SPM	Suspended particulate matter
N	North
E	East
m	meter
nm	nanometer
ml	milliliter
L	Liter
g	gram
°C	degree Celsius

CHAPTER 1

INTRODUCTION

1.1 Introduction

Harmful algal bloom is a natural phenomenon caused by a relatively rapid increase in the population of phytoplankton in an aquatic system, imparting a red tinge to the surface of the water. It also called red tide, but it has nothing to do with tides. Red tides occur all over the world. Almost half of the red tides organisms are dinoflagellates. But it also caused by other organisms such as cyanobacteria, diatoms and chrysophytes (Castro and Huber, 2005). Not all red tides organisms are harmful. There are about one third of red tides organisms produces poisons, some of which are among the most powerful toxins known. These neurotoxins can be transferred through the food web where they affect and even kill the higher forms of life such as zooplankton, shellfish, fish, birds, marine mammals, and even humans that feed either directly or indirectly on them. Impacts of red tide phenomena include mass mortalities of wild and farmed fish and shellfish, human illness and death after consume contaminated shellfish or fish, death of marine mammals, seabirds, and other animals, and alteration of marine habitats or trophic structure (Anton *et al.*, 2000).

The main factor that contributes the algal bloom are water properties. For example, water temperature, salinity, nutrient level, light conditions and also other coastal processes such as upwelling, wind and tide. Red tides usually occur during a climate change which associated with physical processes (Dobson *et al.*, 2006).

Minister Datuk Chua Jui Meng said there were two people died in Sabah after eating shellfish which contaminated by red tide in the 1980s. "These toxic substances that exist during red tide can cause food poisoning, vomiting and diarrhea. In some cases, it can even affect the central nervous system," he said. He also mentioned the Fisheries Department had put up signboards at the affected areas and had come out with a list of seafood safe for consumption for the convenience of the people in these areas (Tan, 2000).

Of the three hundreds species of algae that are known to cause bloom, only one third of them produce toxins. Algae that are consumed by other marine life may accumulate toxins in their organs particularly in the bivalves. As a result they become contaminated and the toxin is concentrated as it moves up to the food chain. Fish and shellfish can tolerate high levels of toxins, thereby appearing health problem and posing a significant danger to man. Unfortunately, the toxins can not be detected by sight, smell, or taste and also not destroyed by cooking or freezing (Intergovernmental Oceanographic Commission, 2005). Thus man becomes an unsuspecting victim. Therefore, it is important to study the effect of harmful algal bloom on coastal water properties.

Malaysia is one of several countries affected by harmful algal blooms (HABs) and caused fish dead and seafood poisoning events. The first of HABs and shellfish toxicity in Malaysia was reported in 1976 when the marine dinoflagellate *Pyrodinium bahamense* var. *compressum* bloomed in Brunei Bay on the west coast of Sabah (Roy, 1976). Several people were poisoned during this event. The bloom eventually spread to other parts of Sabah, but since 1990 cases have emerged in Peninsula Malaysia as well. The number of toxin-producing microalgae species have also increased and there is evidence that these species are widely distributed in Malaysian waters. Proven and potentially toxic species have been detected in the waters of Sabah, Sarawak, Straits of Malacca, East coast of Peninsula Malaysia and Strait of Tebrau (Lim *et al.*, 2002).

Shellfish toxicity was a problem to the west coast of Peninsula Malaysia as well. In 1991, there were three people became sick after consuming green mussel, *Perna viridis,* cultured at a newly established mussel farm in Sebatu, a small fishing village facing the Strait of Malacca (Usup *et al.,* 2000). Results of tested extracts from mussels collected during the event confirmed the presence of algal toxins. The most likely toxins producer was isolated from the area and the clonal cultures were established in the laboratory. The species was successfully identified as *Alexandrium tamiyavanchii.* Toxin analysis of these cultures confirmed the dinoflagellate produced toxins similar to those in toxin mussels (Usup *et al.,* 2000).

Six people were ill after consuming benthic bivalve, 'lokan' (*Polymesoda sp.*) collected from a coastal lagoon on the east coast of Peninsula Malaysia. One of the victims died during this event in September 2001(Lim *et al.,* 2002).

The most important seafood poisoning due to algal toxins is paralytic shellfish poisoning (PSP). There are three species of PSP-toxin producing dinoflagellates currently known, *viz. Pyrodinium. bahamense* var. *compressum* in Sabah, *Alexandrium tamiyavanichii* in Sebatu, Malacca and *A. minutum* in Tumpat, Kelantan. More extensive survey may well reveal the presence of other PSP-toxin producing species. The primary vector for PSP toxins are bivalve mollusks, although planktivorous fish such as 'tamban', *Sardinella sp.* can also contain the toxins (Lim *et al.*, 2003).

Diarrhetic shellfish poisoning (DSP) is the second important seafood toxicity caused by HABs. There are several marine dinoflagellates that produced toxin such as Okadaic acid. This can cause stomach ache and diarrhoe when eaten in large amounts. This commonly caused by marine algae, *Dinophysis spp.* Experiences of several other countries showed that DSP emerged with the establishment of large mussel farms (Lembeye *et al.*, 1993).

Ciguatera fish poisoning (CFP) is solely tropical origin seafood poisoning. The toxins are produced by benthic epiphytic dinoflagellates, and the vectors are various species of marine fishes. Exporting fishes to other countries can result the development of CFP in places far from where the ciguatoxic fishes originated (Geller *et al.,* 1991). Several species of benthic dinoflagellates which may be involved in CFP have been identified, they are *Gambierdiscus toxicus, Ostreopsis ovata, O. lenticularis,* and *Coolia sp.* Toxicity screening based on hemolytic assay, antimicrobial and mouse bioassay has proven the existence of biological activities in aqueous and organic phase extract of these cultures. However, the toxins compound are yet need to be determined (Lim *et al.*, 2003).

Amnesic shellfish poisoning (ASP) is the other group of algal intoxication which remains little studied. *Pseudo-nitzchia* is common diatoms collected in most plankton samples from coastal areas in our waters. This may be due to the fact that difficulty in identification and toxins screening. However, some species of diatoms have been established in laboratory culture for identification and toxicity screening. (Lim *et al.*, 2003)

1.2 Objectives

The major objectives of this study are:

1. To compare the abundance of phytoplankton in the study area during red tide and non-red tide situation.

2. To investigate the variation of temperature, salinity, DO, pH and water transparency at the study area.

3. To model the effect of HAB on physical water properties through analysis of similarity (ANOSIM), similarity percentage (SIMPER), cluster analysis (CA) and non-metric multi-dimensional scaling (MDS).

1.3 Significant of study

Occurrences of HAB create serious threats to human health as well as to the development of aquaculture and seafood industries in Malaysia. Studies required to be carried out in term to understand the extent of distribution of the toxic phytoplankton species in Sepanggar Bay waters. How the modes of spreading, physiology and toxicity, and the factors that promote bloom formation. Studies are also needed to develop the methods to detect these species in water samples and the presence of toxins in seafood.

A major limitation in HABs studies in Malaysia at present is insufficient trained manpower. Graduates who have been trained in this field more often than not do not have the opportunity to apply the knowledge and skills that they have obtained. It is clear that an initiative to solve this problem is needed.

Through this study, the effect of HABs on coastal water properties will be known. Besides, this study is crucial in management and mitigation of HAB events. It also helps us to enhance public awareness and understanding about HABs as well as propose the way to mitigate the effect of HAB.

The lack of monitoring program in place might account for the sporadic occurrence of HAB events. The presence of HAB species imposes a severe burden to our country, so that the adoption of the techniques and management approaches, coupled with proactive measures from the related authority will better prepare the country in future occurrence of HAB events.

CHAPTER 2

LITERATURE REVIEW

2.1 Plankton

Just beneath the surface waters of the ocean is a breathtaking, miniature world of unique and beautiful wander-ers, the plankton (Greek: planktos "to wander"). Plankton are defined by their movements and size. Although they are capable of swimming vertically in the water, they have little ability to swim horizontally and thus are carried about by currents. They are usually small in size generally microscopic (micron, μ) (Garisson, 2005).

Plankton are the most abundant form of life in the ocean. In fact, all other marine life is dependent upon plankton. The plant forms and many protozoans are known as phytoplankton. The abundance of all marine life is directly related to the supply of phytoplankton in the ocean. The animals in the plankton community are known as zooplankton. Zooplanktons are important as a stable food source for fish and other animals (Svarney *et al.,* 2002).

Plankton can range in size from microns to millimeters. The smallest plants in the ocean are the phytoplankton, which vary in size from about 5 microns to 50 millimeters. Single-celled plants called diatoms, constitute more than half of the phytoplankton in the ocean. Phytoplankton is often referred to as "the grass of the ocean". By means of photosynthesis they convert chemical nutrients into their food. Phytoplankton absorbs nutrients such as phosphates, nitrates, and minerals directly from the ocean waters. The phytoplankton are consumed by the zooplankton and by some of the larger animals. Then the larger animals feed on the zooplankton. The chemical nutrients are replaced in the ocean by the excretion of animals and bacterial action in the decomposition of dead plants and animals. Thus, the ocean's food cycle is continuous, from chemical nutrient to phytoplankton to zooplankton to strong swimming animals to bacteria, which recycle the organic matter from dead animals and sloppy eating back into chemical nutrients used as food by phytoplankton (Buschbaum and Milne, 1960).

Phytoplankton needs water, carbon dioxide, sunlight and nutrients to grow. Sunlight in sufficient strength to permit photosynthesis penetrates only to a maximum depth of about 500 to 600 feet. This upper layer of the ocean's water is called the euphotic or photic zone. Within this zone, photosynthesis is limited by the supply of chemical nutrients. Under favorable conditions, phytoplankton may increase as much as 300 % in a single day. On a highly productive day, a cubic foot of ocean water may contain 20,000 plants. The biological process of creating high-energy organic material is called primary production. Being primary producers make them an important part of the aquatic food chain (Thurman, 1997).

2.2 Harmful algal bloom

Harmful algae are microscopic single-celled plants that live in the sea. Most species of algae or phytoplankton are not harmful and serve as the energy producers at the base of the food web. Occasionally, the algae grow very fast or "bloom" and accumulate into dense, visible patches near the surface of the water. "Red tide" is a common name for such phenomenon where certain phytoplankton species contain reddish pigment "bloom" in the water and appears to be colored red. The term "red tide" is thus a misnomer because they are not associated with tides and they are not always red. They are usually not harmful. And those species that are harmful may never reach the densities required to discolor the water (Wilson, 2005).

Unfortunately, a small number of species produce potent neurotoxins that can be transferred through the food wed where they affect and even kill the higher forms of life such as zooplankton, fish, seabirds, marine mammals and even humans that feed either directly or indirectly on them (Woods Hole Oceanographic Institution, 2006).

Phytoplankton develop into highly concentrated "bloom" conditions as a result of physical, chemical, and biological factors that are conducive to bloom formation most frequently along an optimum water condition at coastal region (Department of Natural Resources, 2006). The water must contain high levels of nutrients (nitrogen and phosphorus) for the phytoplankton to feed on. Also, water temperature and salinity levels must be within a certain range to be beneficial to phytoplankton growth.

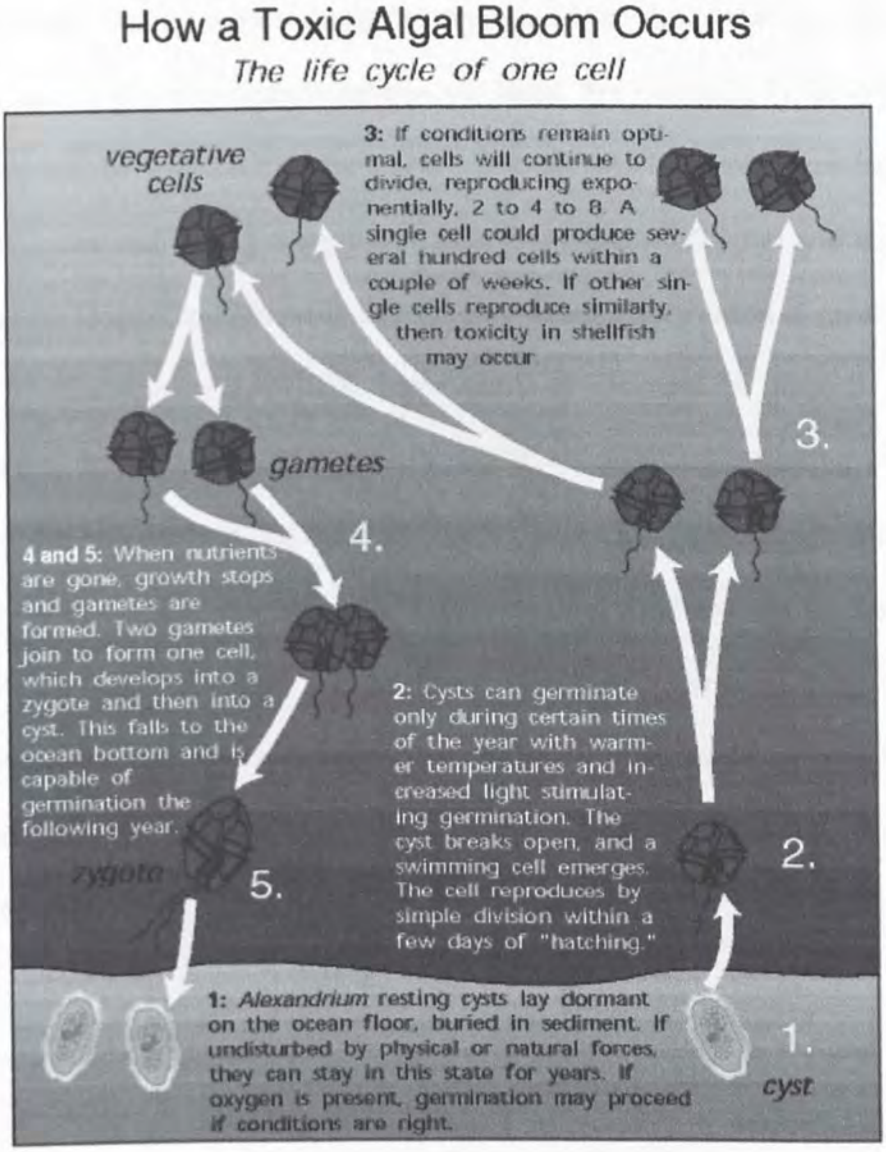

Figure 2.1 Formation of HAB.

(Source:http://www.whoi.edu/redtide/whathabs/whathabs.html)

2.3 Effects of coastal water properties

The populations of HABs species are distributed depending on temperature, salinity, or depth, pH and so on. The increased in human activities such as industrialization and aquaculture along the coastal waters may caused the drastic increase of nutrient (nitrogen, phosphorus and organic substances) input. For example, in the Philippines there are several bays which face the problem of outbreaks by *Pyrodinium bahamense* var. *compressum* and among these are Manila Bay where industrial and high urban population are located and Maqueda Bay where extensive cultivation of green mussels are located (Liew *et al.*,1999).The inner Gulf of Thailand is plagued with the occurrence of annual bloom of *Noctiluca scintillans*. Lirdwitayaprasit *et al.* (1995) attributed this phenomena to the increase in nutrients particularly, nitrate and phosphate from fishpond discharges around the Gulf of Thailand. On the other hand, most Southest Asian countries rely on the marine environment for protein source. Therefore, the impacts of harmful algal bloom should be reduced to acceptable health and economic levels through a "well focused HABs monitoring programme" (Andersen, 1996).

2.4 Dissolved oxygen (DO)

Dissolved oxygen (DO) concentrations are a measure of how well the water is aerated. This parameter is one of the best and most immediate indicators of an ecosystem's health. Because oxygen is needed to support animal and plant life, consequences of declining DO levels will affect the entire ecosystem. This immediate impact on plant and animal life makes measuring the level of oxygen an important means of assessing water quality. Additionally, at low oxygen conditions, nutrients (and other pollutants) will be released from sediments thereby exacerbating problems (Pihl *et al.*,1991).

Overall DO levels will generally increase as phytoplankton produce oxygen as part of the photosynthesis process at the day time. However, the DO levels will decrease rapidly during the night time as the phytoplankton consume oxygen (Mahoney and Gibson, 1983). Anthropogenic input and phytoplankton decay may also decrease oxygen levels as the bacteria that utilize organic matter for food consume oxygen.

As the nutrients become depleted, the algae can no longer survive and populations decrease sharply in what is called a "crash". As this crash is occurring, the dead phytoplankton sink to the bottom of the water column, where they are consumed by decomposers. Since these decomposers require oxygen to break down the algae, dissolved oxygen levels will decrease during this time period. Resulting low oxygen levels can be detrimental to fish health. Fish kills can be resulted if DO drop to below 3 mgl^{-1} (Pihl *et al.*, 1991).

2.5 pH

pH levels are also critical to survival of most marine plants and animals. They can be influenced by events such as algal blooms and acidic pollution from wastewater discharge and in this way function as preliminary indicators of potential problems. At low pH levels, toxic metals in sediments can be re-suspended in the water column (Millero, 1996).

REFERENCES

Andersen, P. 1996. Design and implementation of some harmful algal monitoring systems. *IOC Tech. Ser.* No. 44, UNESCO, Paris, 102~~.

Anderson, D. M., Kulis, D. M. and Blinder, B. J. 1984. Sexuality and cyst formation in the dinoflagellate *Gonyaulax tamarensis*: cyst yield in batch cultures. *J. Phycol.* **20**: 418-425.

Anton, A., Noor, M. N., Estim, A., Kurniasih, F., Wong, C. P. and Wendy, L. 2000. Red tides in Sabah, Malaysia. http://www.ums.edu.my/sst/redtide/index.html

Bray, J. R. and Curtis, J. T. 1957. An ordination of the upland forest communities of Southern Wisconsin. *Ecol. Monogr.* **27**: 325-349.

Buschbaum, R. and Milne, L. J. 1960. *The Lower Animals.* Doubleday and Co. New York.

Castro, P. and Huber, M.E. 2005. *Marine Biology.* Ed 5th . McGraw. Hill, New York.

Cembella, A. D. 1998. Ecophysiology and metabolism of paralytic shellfish toxins in marine microalgae. In: Anderson, D. M., Cembella, A. D., Hallegraeff, G. M. (Eds.), *Physiological Ecology of Harmful Algal Blooms.* NATO ASI Series. **41**: 381-403.

Chapman, M. G. and Underwood, A. J. 1999. Ecological patterns in multivariate assemblage: Information and interpretation of negative values in ANOSIM test. *Marine Ecology Progress Series.* **180**: 257-265.

Clark, I. and Rittenberg, D. 2005. The metabolic activity of hydrogen ion in red tide species. *The Journal of Biological Chemistry.* **112** (1): 18-28.

Clarke, K. R. and Warwick, R. M. 2001. *Change in Marine Communities: An Approach to Statistical Analysis And Interpretation.* Ed 2nd. Primer-E. Ltd., United Kingdom.

Cormack, R.M. 1971. A Review of Classification. *J. R. Statist. Soc. Ser. A.* **134**: 321-367.

Department of Natural Resources. 2006. Continuous Monitoring Archived Results: Phytoplankon Algae Blooms. Maryland. http--mddnr_chesapeakebay_net-newmontech-contmon-Images-bloom_din_dip_gif.mht

Dobson, A., Gulland, F., Kline, D., Lafferty. and Pascual, M. 2006. The rising tide of ocean plages: How humans are changing the dynamics of disease. http://www.eurekalert.org/pub_releases/2006-02/s-trt021206.php

Garrison, T. 2005. *An Invitation to Marine Science: Oceanography.* Ed 5th. Thomson Learning Inc, USA.

Geller, R. J., Olson, K. R. and Senecal, P. E. 1991. Ciguatera fish poisoning in San Francisco, California, caused by imported barracuda. *West. J. Med* **155**: 639-632.

Intergovernmental Oceanographic Commission. 2005. The IOC Harmful Algal Bloom Programme. http://ioc.unesco.org/hab/intro.htm.

Kashima, K. 2003. The quantitative reconstruction of salinity changes using diatom assemblages in inland saline lakes in the central part of Turkey during the Late Quaternary. *Quaternary International.* **105**: 13-19.

Kruskal, J. B. and Wish, M. 1978. *Multidimensional Scaling.* Sage Publication, Berverly Hills, California.

Lembeye, G., Yasumoto, T., Zhao, J. and Fernandez, R. 1993. DSP outbreaks in Chilean fjords. In Smayda T.J. and Shimizu, Y. (Eds.): *Toxic Phytoplankton Blooms in the Sea.* Elsevier, Amsterdam.

Liew, S. C., Lin, I. I, Kwoh, L. K., Holmes, M., Teo, S., Gin, K. and Lim, H. 1999. Spectral Reflectance Signatures of Case II Waters: Potential For Tropical Algal Bloom Monitoring Satellite Ocean Colour Sensors. http://www.crisp.nus.edu.sg/~liew/txt/LiewSC_JSPS99.PDF

Lim, P. T., Leaw, C. P. and Usup, G. 2002. First incidence of paralytic shellfish poisoning on the east coast of Peninsula Malaysia. In *Proceeding Asia Pacific Conference on Marine Science and Technology,* Kuala Lumpur.

Lim, P. T., Leaw, C. P. and Usup, G. 2003. Workshop on Red Tides Monitoring in Asian Coastal Waters. Status of HAB and Potential Remote Sensing Application in Detection of Events in Malaysia Water. http://fol.fs.a.u-tokyo.ac.jp/rtw/TOP/progrum030310.html

Lirdwitayaprasit, T., Vichangrangsan, T. and Sawetong, N. 1995. Occurrences of red tide phenomena in the inner Gulf of Thailand during 1991-1993. In *Snidvongs A.et al., (eds.), Proc. ,b'RCT-JSPSjoint Seminar in Marine Science,* 2-3 December 1993, Songkhla, Thailand. 106- 110.

Litchendorf, T. 2006. *The effect of lower pH on phytoplankton growth in the Galapagos Archipelago.* University of Washington, Seattle.

Liu, X. and Millero, F. J. 2002. The solubility of iron in seawater. *Mar. Chem.* **77**: 43-54.

Madiha, B. J. S. 2006. Effect of cage culture on physical water properties, plankton communities and macrobenthos assemblage in Sepanggar Bay, Sabah. M. Sc. Thesis. Borneo Marine Research Institute, University Malaysia Sabah. (Submitted)

Mahoney, R. K. and Gibson, R. A. 1983. Phytoplankton ecology of the Indian River near Vero Beach, Florida. *Florida Scientist* **46**: 212-231.

Millero, F. J. 1996. *Chemical Oceanography.* Ed 2nd. CRC Press, Baco Raton.

Odum, E. P. 1983. *Basic ecology of marine and coastal system.* CBS College Publishing, USA.

Peterson, D. H. and Festa, J. P. 1984. Numerical simulation of phytoplankton productivity in partially mixed estuaries. *Estuarine, Coastal and Shelf Science.* **19**: 563-589.

Pihl, L., Baden, S.P. and Diaz, R.J. 1991. Effects of periodic hypoxia on distribution of demersal fish and crustaceans. *Marine Biology* **108**: 349-360.

Roy, R. N. 1976. Red tide and outbreak of paralytic shellfish poisoning in Sabah. *Med. J. Malaya.* **31** (3): 247-251.

Shirota, A. 1966. *The Plankton of South Viet-nam. Fresh Water and Marine Plankton.* Overseas Technical Coorperration Agency, Japan.

Steidinger, K. A. 1997. *Dinoflagellates. In Tomas, C. R. (Ed.), Identifying Marine Phytoplankton.* Florida Department of Environmental Protection. Florida Marine Research Institute, St. Petersburg, Florida.

Svarney E., Thomas, and Barnes, P. 2002. *The Handy Ocean Answer.* Visible Ink Press, M. I.

Tan, C. K. 2000. Two People Died After Eating Poisoning Shellfish. *The Star*, 6 March, 9.

Thurman, H. V. 1997. *Introductory Oceanography.* Prentice Hall College. New Jersey, USA.

Usup, G., Teen, L. P., Pin, L. C. and Ahmad, A. 2000. Development of a receptor binding assay for shellfish toxicity monitoring. *Proceedings of the Malaysian Science and Technology Congress 2000*, COSTAM, Kuala Lumpur, 127-132.

Wilson, R. 2005. Red Tide. Surfrider Foundation. http://surfriderfoundation.typepad.com/shapingroom/2005/07/red_tides.html

Wofsy, S. C. 1983. A simple model to predict extinction coefficients and phytoplankton biomass in eutrophic waters. *Limnology and Oceanography.* **28**: 1144-1155.

Woods Hole Oceanographic Institution. 2006. Harmful Algae and Red Tides Primer. Woods Hole,MA.http://www.whoi.edu/institutes/coi/viewArticle.do?id=12506