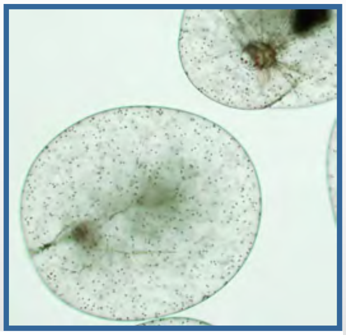
# Harmful Algal Blooms
# in
# ASIA



## A Regional Comparative Programme

GEOHAB

Global Ecology and Oceanography of Harmful Algal Blooms

UNESCO

United Nations Educational, Scientific and Cultural Organization

Intergovernmental Oceanographic Commission

International Council for Science

SCOR

Scientific Committee on Oceanic Research

# GEOHAB *Asia*

## Global Ecology and Oceanography of Harmful Algal Blooms in Asia: *A Regional Comparative Programme*

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*Based on contributions by the participants of the 1st and 2nd Asian GEOHAB Meetings 2007, 2008*

*April 2010*

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Title page photos are scenes from Vietnam and Hong Kong. Photos by P. Glibert.

Photos on the Table of Contents are from the Tokyo Fish Market. Photos by P. Glibert.

# GEOHAB *Asia*: A Regional Comparative Programme

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*Karenia mikimotoi* bloom in the East China Sea 2005 .
Photo by J. Li.

# Executive Summary

**Harmful algal blooms** (HABs) pose serious threats to both coastal ecosystems and human activities in Asia, including aquaculture, public health and coastal management. Both types of HABs—the toxin producers and the high biomass producers—occur in the region, and damages caused by blooming of these species lead to huge economic losses. The frequency and severity of HAB events are increasing, and, furthermore, their distribution within the region appears to be expanding. In this situation, the importance of exchange of information and cooperative research has become obvious among people working on HABs in Asia.

In this context, two Asian GEOHAB Meetings were held. The first meeting was held in Tokyo, Japan on Mar. 15 and 16, 2007, aiming to review HAB research activities in Asia, and the Second Asian GEOHAB Meeting was held in Nha Trang, Vietnam on Jan. 31 and Feb. 1, 2008 and was more focused on identifying key questions and research components to include in a plan for cooperative research in the region. A wide range of species was highlighted during the both meetings, including *Prorocentrum donghaiense*, *Cochlodinium polykrikoides*, *Karenia mikimotoi*, *Noctiluca scintillans*, *Pyrodinium bahamense* v. *compress*, *Alexandrium minutum*, *Dinophysis* spp., and benthic dinoflagellates. During both meetings, the importance and usefulness of the comparative ecosystem approach were well recognized, which is the fundamental concept of GEOHAB (GEOHAB, 2001). During the second meeting an international editorial team was formed from participants to prepare the present report. This report outlines and justifies research priorities for the study of HABs in Asia on the basis of reviews of regional HAB issues.

Scene from Vietnam illustrating the challenge of water quality. Photo by P. Glibert.

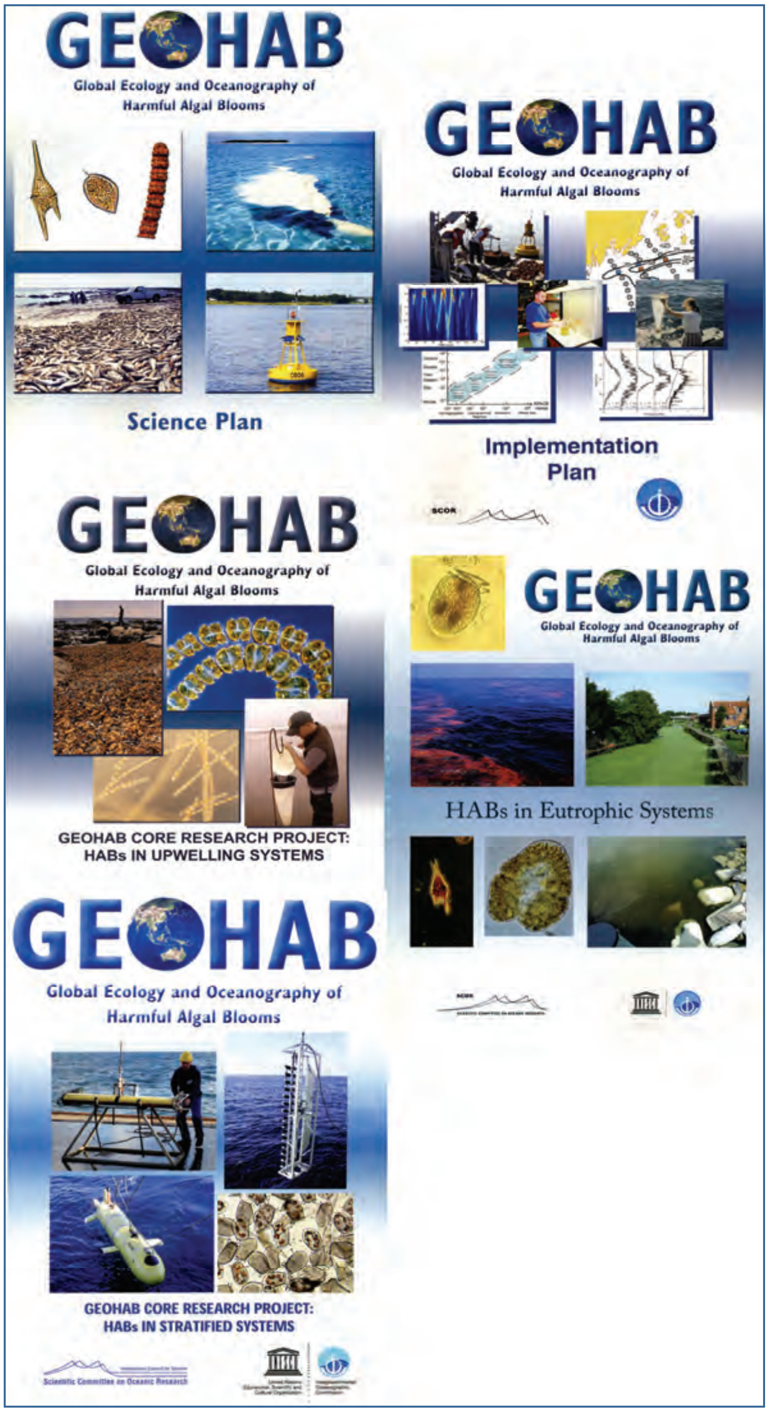
# Introduction to GEOHAB and the Regional Programme in Asia

**GEOHAB**, The Global Ecology and Oceanography of Harmful Algal Blooms Programme, sponsored by the Scientific Committee on Oceanic Research and the Intergovernmental Oceanographic Commission (IOC) of UNESCO, is an international programme to foster and promote co-operative research directed toward improving the prediction of harmful algal bloom (HAB) events. GEOHAB has recognized the impacts of HABs throughout all waters of the world, but has emphasized events in marine and brackish waters because of the global significance of these problems and the need for collaborative, international studies to address them.

HABs have been associated with fish and shellfish kills, human health impacts, and ecosystem damage throughout the world. Concurrent with escalating influences of human activities on coastal ecosystems, the environmental and economic impacts of HABs and consequent challenges for coastal zone management have increased in recent years. HABs have been expanding in recent decades in Asia, with new dominant species emerging, expanding geographic areas affected, and economic fishery and aquaculture interests seriously impacted.

GEOHAB is an international programme to co-ordinate and build upon national, regional and international efforts in HAB research. The GEOHAB Programme assists in bringing together investigators from different disciplines and

GEOHAB has produced Science and Implementation Plans along with reports of each of the Core Research Projects. The reports outline the rationale and key questions for each core project.




countries to exchange technologies, concepts and findings. This takes the form of workshops and meetings, or more specific teams of collaborating scientists sharing experimental approaches and data. GEOHAB is not a funding programme per se, but instead helps to facilitate those activities that require cooperation among nations and among scientists working in comparative ecosystems. The central challenge is to understand the key features and mechanisms underlying the population dynamics of HABs in a range of oceanographic regimes and influences by a range of natural and anthropogenic factors. The underlying mission and scientific goal of GEOHAB have been identified to reflect these needs.

The overall strategy of GEOHAB is to apply the comparative approach. The comparative method assembles the separate realizations needed for scientific inference by recognizing naturally occurring patterns, and temporal and spatial variations in existing conditions and phenomena (Anderson et al. 2005, GEOHAB 2005). Understanding the responses of harmful algae to the increasing anthropogenic perturbations of the world's coastal zones will assist in predictions of future patterns as well.

The GEOHAB *Science Plan* (2001) outlines five Programme Elements that serve as a guide to establish the programme's research priorities. These elements and their overarching questions include:

***Biodiversity and Biogeography***. What are the factors that determine the changing distributions of HAB species, their genetic variability, and the biodiversity of associated communities?

***Nutrients and eutrophication***. To what extent does increased eutrophication influence the occurrence of HABs and their harmful effects?

The ***mission*** of GEOHAB is to foster international cooperative research on HABs in ecosystem types sharing common features, comparing the key species involved, and the oceanographic processes that influence their population dynamics.

The ***scientific goal*** of GEOHAB is to improve prediction of HABs by determining the ecological and oceanographic mechanisms underlying their population dynamics, integrating biological, chemical, and physical studies supported by enhanced observational and modeling systems.

***Adaptive strategies***. What are the unique adaptations of HAB species and how do they help to explain their proliferation or harmful effects?

***Comparative ecosystems***. To what extent do HAB species, their population dynamics, and community interactions respond similarly under comparable ecosystems?

***Observation, modeling and prediction.*** How can we improve the detection and prediction of HABs by developing capabilities in observation and modeling?

The integration of findings from the individual programme elements described in more detail in the *Science Plan* (2001) is required to achieve not only an understanding of HAB organisms and associated events but also to improve predictive capabilities.

## Categories of Research

For the purposes of implementation, GEOHAB has adopted a 3-category system for defining and endorsing research.

***Core Research*** is comparative, multidisciplinary, and international, and directly addresses the overall goals of GEOHAB as outlined in the *Science Plan.* Core research comprises oceanographic field studies conducted in, and application of models to, comparable ecosystems, supported by identification of relevant organisms, and measurements of the physical, chemical and biological processes that control their population dynamics. To date, GEOHAB has developed Core Research Project Reports on Upwelling Systems, Eutrophic Systems, and Stratified Systems.

***Targeted Research*** addresses specific objectives outlined in the *Science Plan*. Targeted Research may include, but is not limited to, the development and comparison of specific models and observational systems, studies on the autecological, physiological, and genetic processes related to HABs, and studies on sub-grid formulations of physical, chemical and biological interactions affecting HABs. Targeted Research differs from Core Research in


The participants of the First (upper photo) and Second (lower photo) Asian GEOHAB workshops. Photos by K. Furuya (upper) and N.N. Lam (lower).

scope and scale. Whereas Core Research is expected to be comparative, integrative, and multifaceted, Targeted Research activities may be more tightly focused and directed to a research issue or element. It is expected that such research activities will facilitate wider and larger-scale studies.

***Regional/National Projects*** are those research and monitoring activities relevant to the objectives of the *Science Plan* and which are coordinated at a regional or national level. The Regional Comparative Programme on HABs in Asia is thus a Regional Project.

## The Process of Developing GEOHAB Asia

GEOHAB *Asia* was developed through two workshops (Appendices 1 and 2). The first workshop was held in Tokyo in 2007, while the second workshop was held in Nha Trang, Vietnam, in 2008. The information contained in this report was developed largely from these two meetings.

The report develops an overview of Asian HAB problems, based largely on the presentations from these meetings, then provides a framework for guiding priorities for research based on 5 Programme Elements of GEOHAB, followed by the key objectives and questions that can and should be studied on a regional comparative basis. Lastly, an overview of ongoing framework activities is provided to ensure that GEOHAB research is well integrated with other ongoing capacity building efforts.

# Overview of the Asian HAB Problem

Aquaculture activities compose one of the most typical landscapes in Asia. Tiger shrimp, *Penaeus monodon*, is extensively cultured on the coast of Cam Ranh Bay, Vietnam. Photo by Y. Fukuyo.

**Harmful Algae** are those proliferations of algae that cause massive fish kills, contaminate seafood with toxins, and alter ecosystems in ways that humans perceive as harmful. The term is used generically, recognizing that some species cause toxic effects even at low cell densities, and that not all HAB species are technically "algae". A broad classification of HAB species distinguishes two groups: the toxin producers, which can contaminate seafood or kill fish, and the high-biomass producers, which can cause hypoxia or anoxia, and indiscriminate mortalities of marine life after reaching dense concentrations (GEOHAB 2001). Some HAB species have characteristics of both.

The need to develop a comparative, international programmes on HABs in Asia is particularly compelling for several reasons. Asia is characterized by: 1) the highest production of aquaculture fish and shellfish in the globe, and thus the greatest impacts from HABs on these resources; 2) a diversity of harmful syndromes and causative organisms; 3) an apparent trend of increasing HABs throughout the region; and 4) an increasing trend toward regional eutrophication. The ecological and economic impacts of HABs in Asia are thus great and apparently increasing.

## Dependence on Aquaculture

Both types of HABs — the toxin producers and the high-biomass producers — pose significant impacts on aquaculture, the latter causing massive mortalities of fish and reductions in yields in deteriorated environments, and the former, shellfish poisonings and potential human health impacts.

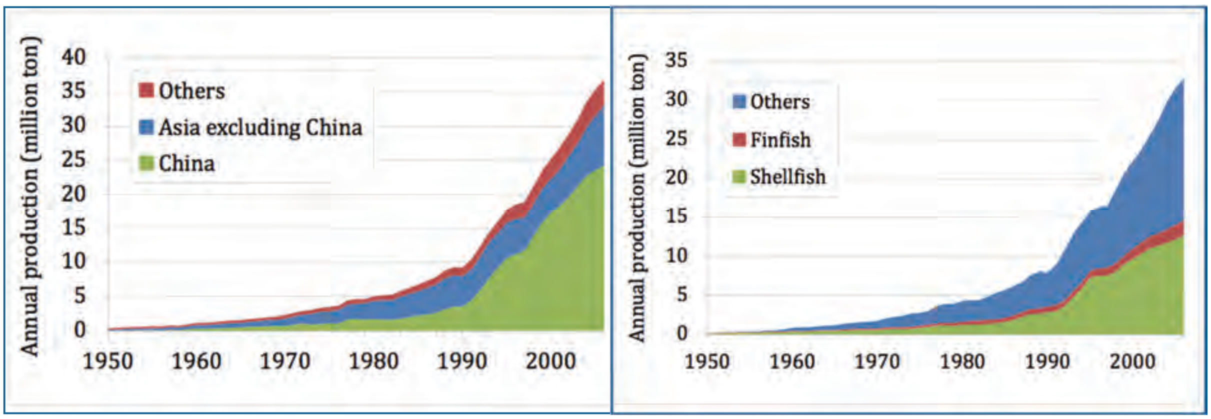
Thus, HABs pose impacts on both public health and ecosystems. Low oxygen conditions — hypoxia or anoxia — can be produced as the bloom biomass decays, and cultured fauna which cannot escape from cages suffer from oxygen stress. Mucilage released by some high-biomass producers also causes hypoxia by covering the surface of gills. Suspension feeding shellfish including mussels, scallops, oysters and clams accumulate toxins produced by toxic phytoplankton, sometimes at levels potentially lethal to humans. Toxins and other compounds released by the toxin producers can cause mortality of marine life directly. These damages lead to economic losses, and increase operational costs of aquaculture farms due to expenses for monitoring of causative organisms, and testing to detect algal toxins, and for countermeasures. Since HABs are annually recurrent phenomena, and their frequency and severity show increasing tendencies, the associated costs of operation are generally increasing in Asia.

Pacific oyster (*Crassostrea iredalei)* and green mussel (*Perna viridis)* are the most popular aquaculture organisms in tropical Asia. The culture of these organisms covers extensive intertidal areas in Manila Bay (top). Photo by E.F. Furio. Most of the harvest is sold in markets and consumed locally (middle and bottom). Photos by Y. Fukuyo.

Fish cage culture is widely conducted in enclosed and semi-enclosed embayments in Asia. Yellow tail (*Seriora quinqueradiata*) is the most common cultured fish in the Seto Inland Sea, Japan. Photo by Suisan Aviation.

World aquaculture has grown significantly during the past two decades, and the growth rate has outpaced capture fisheries, and other production of animals for food (FAO 2007). This rapid growth primarily reflects activities in Asia, in particular in China. The contribution of aquaculture to global supplies of aquatic animals occupied 32% of total fisheries production in weight in 2006. Marine aquaculture accounts for a major portion of global aquaculture production, occupying 55% in 2006. Asian coastal waters produce 89% of global marine aquaculture production. Products are not only consumed locally, but also are important for exports. For example, on a global scale, Asian waters produce 87% of the penaeid shrimp, and 93% of the oysters.

Among marine aquaculture, shellfish (including clams, abalones, oysters, mussels, pearls, and scallops) dominate by weight. The production of fish cage aquaculture in Asia increased more than 2-fold from the early 1990s to the early 2000s. While fish production is relatively small in weight, its market value is high. In particular, East Asia is characterized by aquaculture of high-value marine fish. Therefore, while the amount of production is relatively small, fish culture is an important industry.

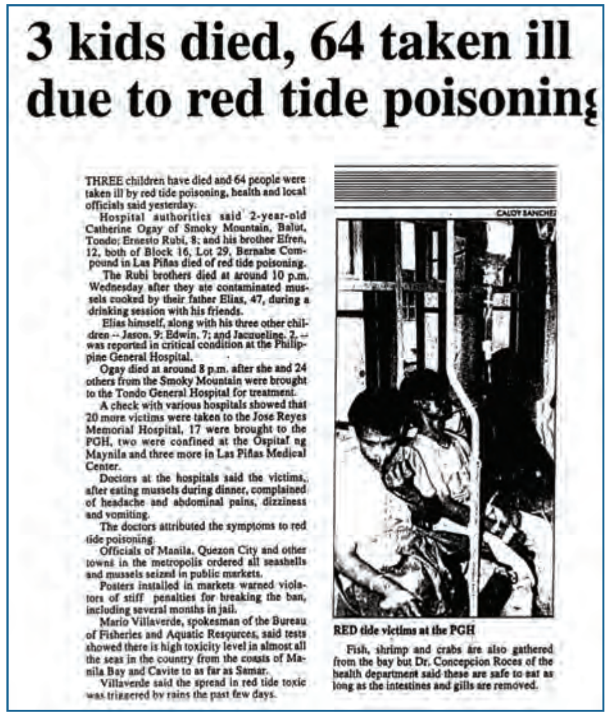



Marine aquaculture production (left panel) rapidly increased during the last two decades, indicating Asian coastal waters have become highly exploited for aquaculture activities. Data source: Aquaculture production (FAO 2008, ftp://ftp.fao.org/FI/STAT/Windows/FISHPLUS/AQUACULT.zip). Relative composition of cultured organisms (right panel) in Asian marine aquaculture. Shrimp, prawns, crabs, turtles and seaweeds are included in the category "Others", among which shrimps, prawns and seaweeds occupy major portions. Harvested shrimp and prawns are primarily exported to developed countries. Data source: Aquaculture production (FAO 2008, ftp://ftp.fao.org/FI/STAT/Windows/FISHPLUS/AQUACULT.zip). After K. Furuya and Y. Sakai.

Mega-scale shrimp culture farm (18,000 ponds) in Indonesia. Photo from IOC/Westpac-HAB.

# Diversity of Harmful Syndromes and Causative Organisms

Toxicity of Asian seafood due to HABs is of great concern. Poisoning cases number in the hundreds to thousands annually. The number of people affected by shellfish contamination is highest in the Philippines.



## 3 kids died, 64 taken ill due to red tide poisoning

THREE children have died and 64 people were taken ill by red tide poisoning, health and local officials said yesterday.

Hospital authorities said 2-year-old Catherine Ogay of Smoky Mountain, Balut, Tondo; Ernesto Rubi, 8; and his brother Efren, 12, both of Block 16, Lot 29, Bernabe Compound in Las Piñas died of red tide poisoning.

The Rubi brothers died at around 10 p.m. Wednesday after they ate contaminated mussels cooked by their father Elias, 47, during a drinking session with his friends.

Elias himself, along with his three other children -- Jason, 9; Edwin, 7; and Jacqueline, 2, -- was reported in critical condition at the Philippine General Hospital.

Ogay died at around 8 p.m. after she and 24 others from the Smoky Mountain were brought to the Tondo General Hospital for treatment.

A check with various hospitals showed that 20 more victims were taken to the Jose Reyes Memorial Hospital, 17 were brought to the PGH, two were confined at the Ospital ng Maynila and three more in Las Piñas Medical Center.

Doctors at the hospitals said the victims, after eating mussels during dinner, complained of headache and abdominal pains, dizziness and vomiting.

The doctors attributed the symptoms to red tide poisoning.

Officials of Manila, Quezon City and other towns in the metropolis ordered all seashells and mussels seized in public markets.

Posters installed in markets warned violators of stiff penalties for breaking the ban, including several months in jail.

Mario Villaverde, spokesman of the Bureau of Fisheries and Aquatic Resources, said tests showed there is high toxicity level in almost all the seas in the country from the coasts of Manila Bay and Cavite to as far as Samar.

Villaverde said the spread in red tide toxic was triggered by rains the past few days.

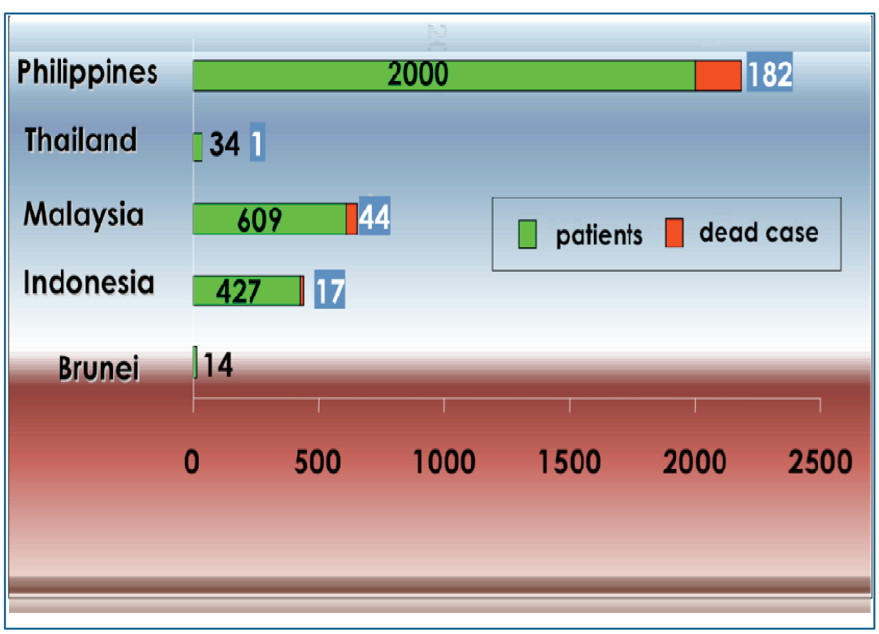
**RED tide victims at the PGH**

Fish, shrimp and crabs are also gathered from the bay but Dr. Concepcion Roces of the health department said these are safe to eat as long as the intestines and gills are removed.

Article from the *Philippine Daily Inquirer* on May 19, 1995, reporting victims who ate green mussels collected from Manila Bay. Used with permission.

Virtually all the common HAB toxin syndromes are present in Asia. Paralytic shellfish poisoning (PSP) is the most serious, with the number of affected people significant in the 1980s and the 1990s, but there have been fewer documented cases since the year 2000. However, the geographic area affected by PSP has increased even though the number of cases has not. The dinoflagellates responsible for Diarrheic Shellfish Poisoning (DSP) have been detected in Asian waters, but routine monitoring for DSP in Asia is rare. Similarly, the diatoms that are responsible for Amnesic Shellfish Poisoning (ASP) have been detected, but routine monitoring for ASP does not occur in Asia. The dinoflagellates known to cause Neurotoxic Shellfish Poisoning (NSP) also have been detected, but few studies on NSP have been conducted.

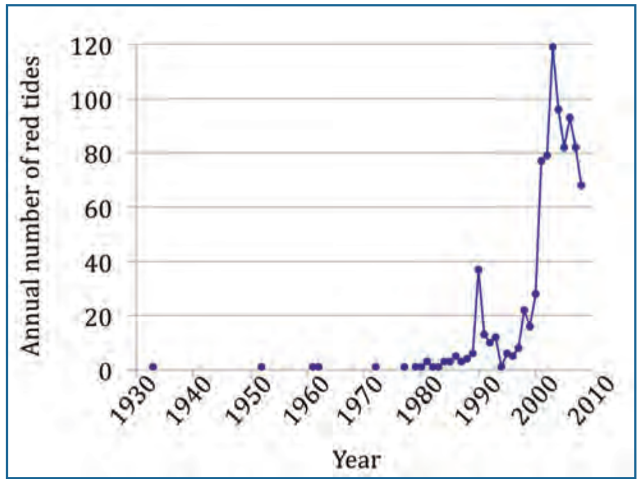
Ciguatera has long been recognized in the South Pacific and Australia, but has been rare in Asia, except for Okinawa, Japan. However, since the late 1990s, ciguatera has become common in Asia, particularly in the Philippines and in Hong Kong (Sadovy 1999). Studies on the causative benthic dinoflagellates have been been undertaken (e.g., http: //fishbase.se/manual/English/ FishbaseThe_CIGUATERA_Table.htm), but there have been far fewer studies on the toxicity in fishes.



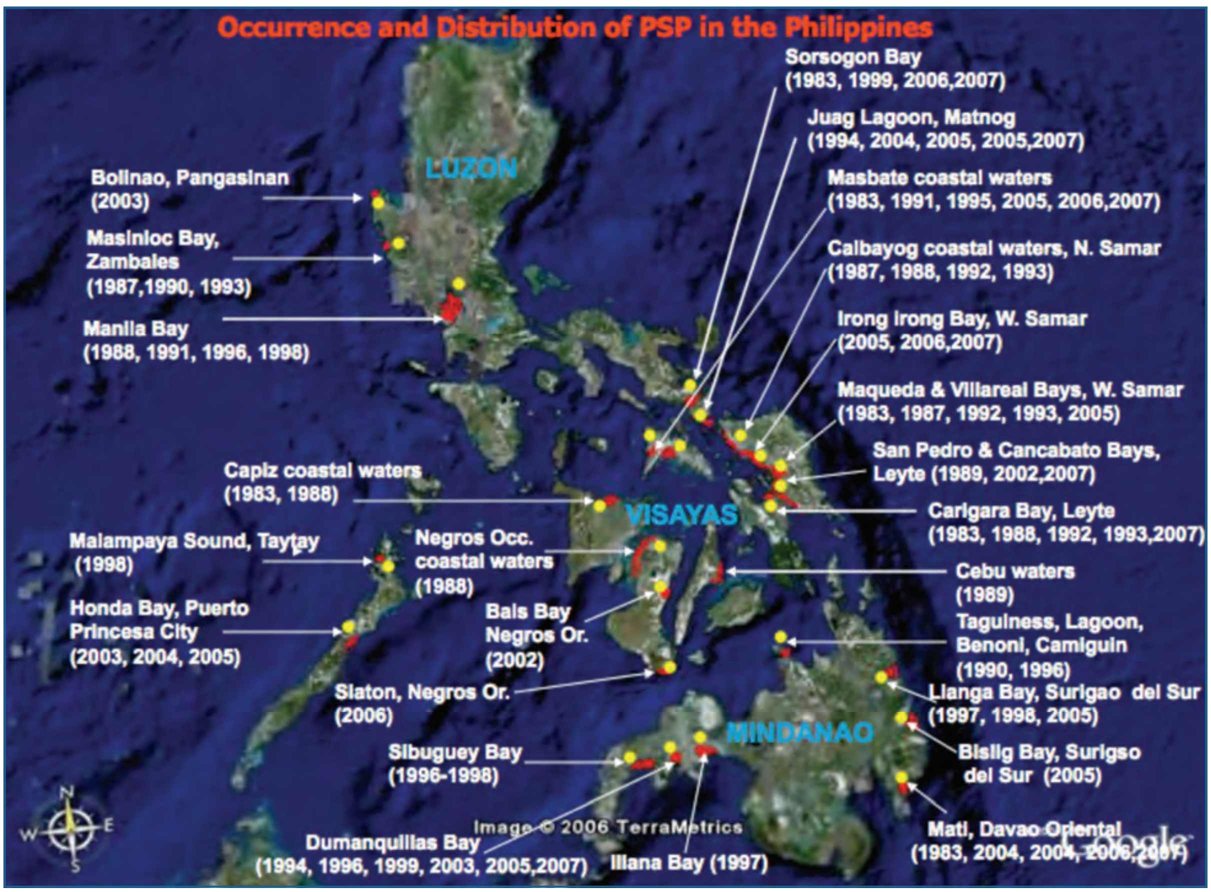

PSP incidents are most common in the Philippines, Saba in Malaysia and Indonesia. Its occurrence was most serious in 1980s and 1990s, and the annual number of poisonings has been low during the last decade due to successful monitoring of shellfish toxins. Courtesy of E.F. Furio.

# An Apparent Regional Trend of Increasing HABs

HABs are increasing in frequency, distribution, severity, and variety in Asia. PSP is the most well documented example of expansion throughout the region. In 1970 there were virtually no recorded cases of PSP in Asia except Japan, but by the year 2000, the presence of PSP-causing organisms and poisoning was documented throughout all of Asia (GEOHAB 2001). The increasing trend is also obvious in red tides in Asia.




In Chinese waters red tide events became frequent in 1980s, and increased even further by the year 2000. Data source: State Oceanic Administration (China).



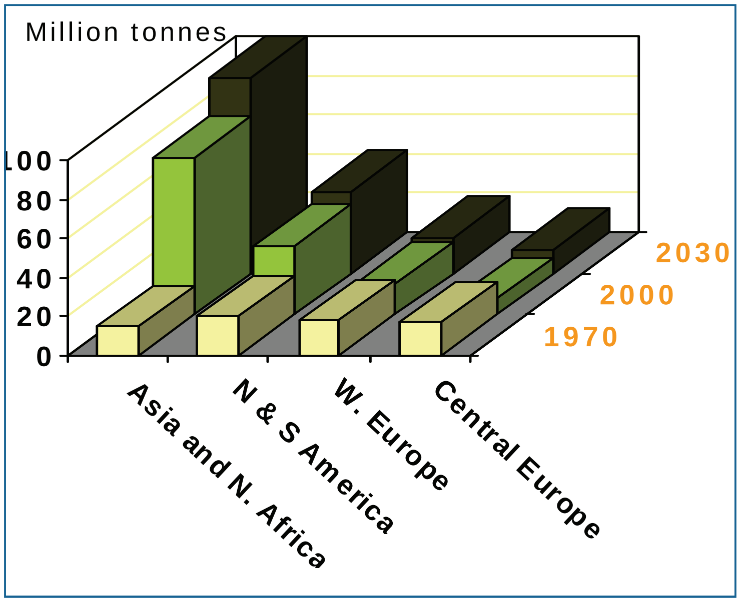

In the Philippines, PSP first attracted attention of people in 1983, when a total of 279 cases of serious intoxication occurred in western Samar and Leyte Islands. While the first shellfish poisoning occurred prior to the discovery of the bloom of *Pyrodinium bahamense*, this species was identified to be the causative organism, and monitoring activity of this species by a governmental organization started in the same year. After a brief interval between 1984 and 1986 when no PSP incidents occurred, an outbreak of PSP occurred again in 1986 in Masinloc, Luzon, and western Samar. The outbreak expanded to Manila Bay area, Cebu and Negros Islands in 1988 and 1989, and consequently PSP caused by *P. bahamense* became a nation-wide problem (Bajarias et al. 2006). Courtesy of J. Relox, Jr.

# An Increasing Trend Toward Regional Eutrophication

The increases in nutrient loading in Asia have been well documented through direct measurements and through global modeling of nutrient fluxes. Collectively, Asia now consumes about half of the world's nitrogen fertilizer, and the rate of increase in fertilizer use over the next two decades is projected to be largest for Asia (Glibert et al. 2005). Global models of riverine nitrogen export also show that this region of the world will have the largest increases in nitrogen export (Seitzinger and Kroeze 1998).

The Seto Inland Sea experienced increasing numbers of harmful blooms in the 1960s and 1970s. However, nutrient controls were put in place in the early 1970s and a reduction in HABs ensued. This demonstrates that regional recovery from escalating harmful algal or red tide events is possible with nutrient reduction (Okaichi 2003). The case of the Seto Inland Sea is also interesting because the increase in HAB events in the past decades also paralleled the rapid rise in the production of yellowtail fish aquaculture. Since the 1980s, the number of annual red tide events has decreased due to governmental control and reduction of nutrient loading from both industries and municipalities. While yellowtail fish aquaculture has been relatively constant since 1980s, total aquaculture production of other fish has been increasing (Ministry of Agriculture, Forestry and Fisheries, 2007). Thus, these observations demonstrate the importance and necessity of long-term time-series data for understanding HAB dynamics associated with anthropogenic impacts on coastal systems.

In Tolo Harbour, Hong Kong, the human population within the watershed grew 6-fold between 1976 and 1986, during which time the number of red tide events increased 8-fold (Lam and Ho 1989). The underlying mechanism was presumed to be the increase in nutrient loading from the human population. During 1994–1997, sewage was diverted from Tolo Harbour to Victoria Harbour for treatment, and red tide events have now been reduced because of the reduction in nutrients (Environmental Protection Department 2007).

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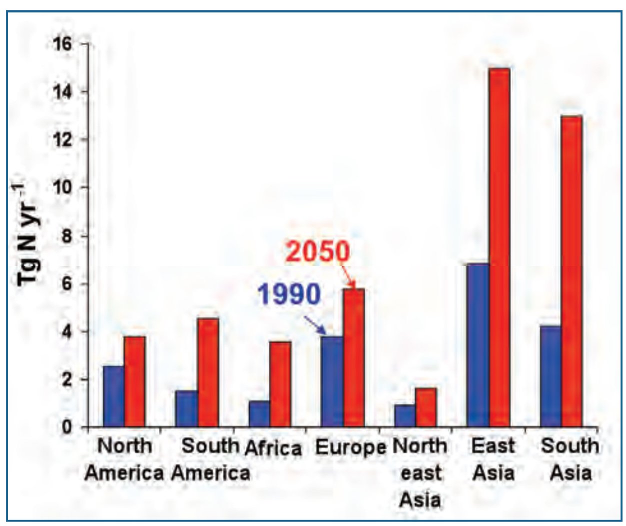


Global models of riverine nitrogen export also predict that Asia will have the largest increase in nitrogen export in the coming decades (from Seitzinger and Kroeze 1998).

The recent increase in HAB events off the coast of China is related to the increase in nitrogen-based fertilizer use over the past two decades (from Heisler et al. 2008).

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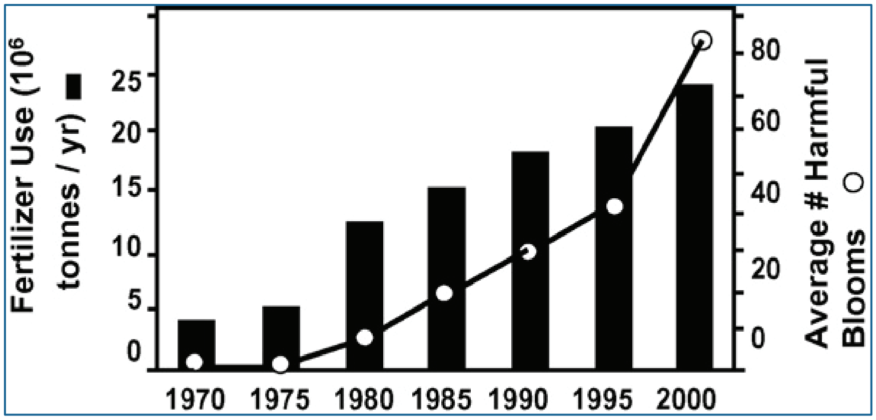
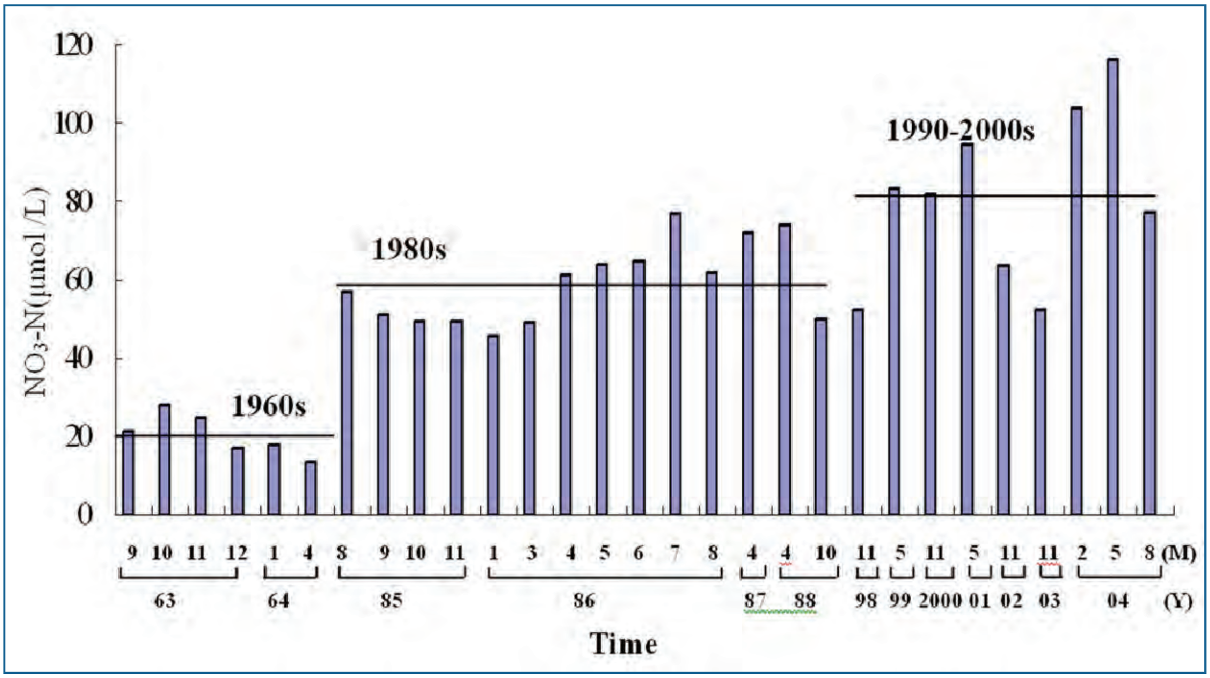
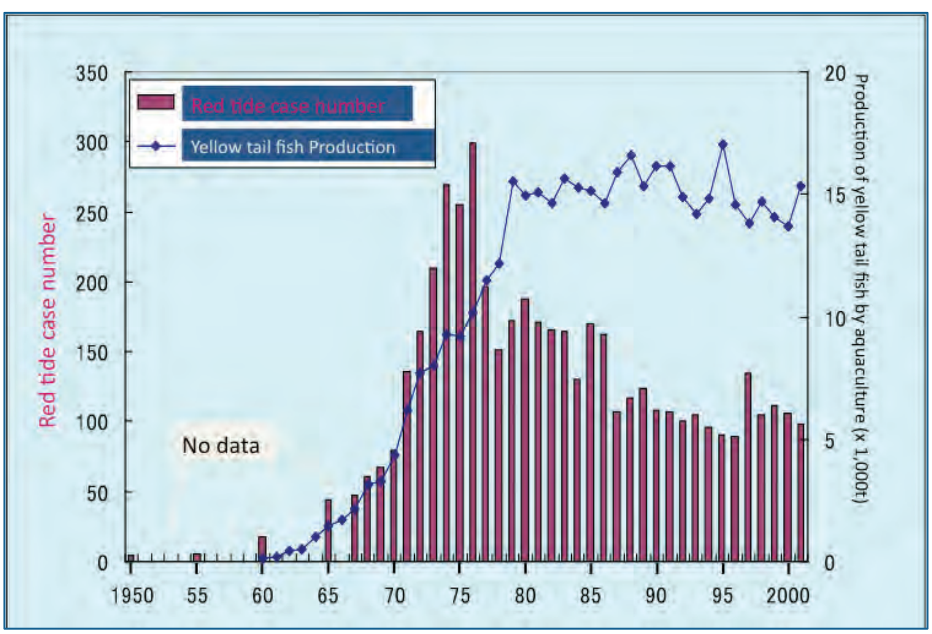



Long-term variation in nitrate concentration at the mouth of the Changjiang River shows a steady rise in riverine inputs of nutrients (Zhou et al. 2008). (Y) and (M) are the year and the month of sample collection, respectively.




Parallel increase of red tide occurrences and yellowtail fish aquaculture industry in Seto Inland Sea, Japan. Courtesy of Y. Fukuyo.

*Cochlodinium polykrikoides* collected in Korean waters. Photo by K. Matsuoka.

# Regional Background and Challenges for Advancing the Understanding of Asian HABs

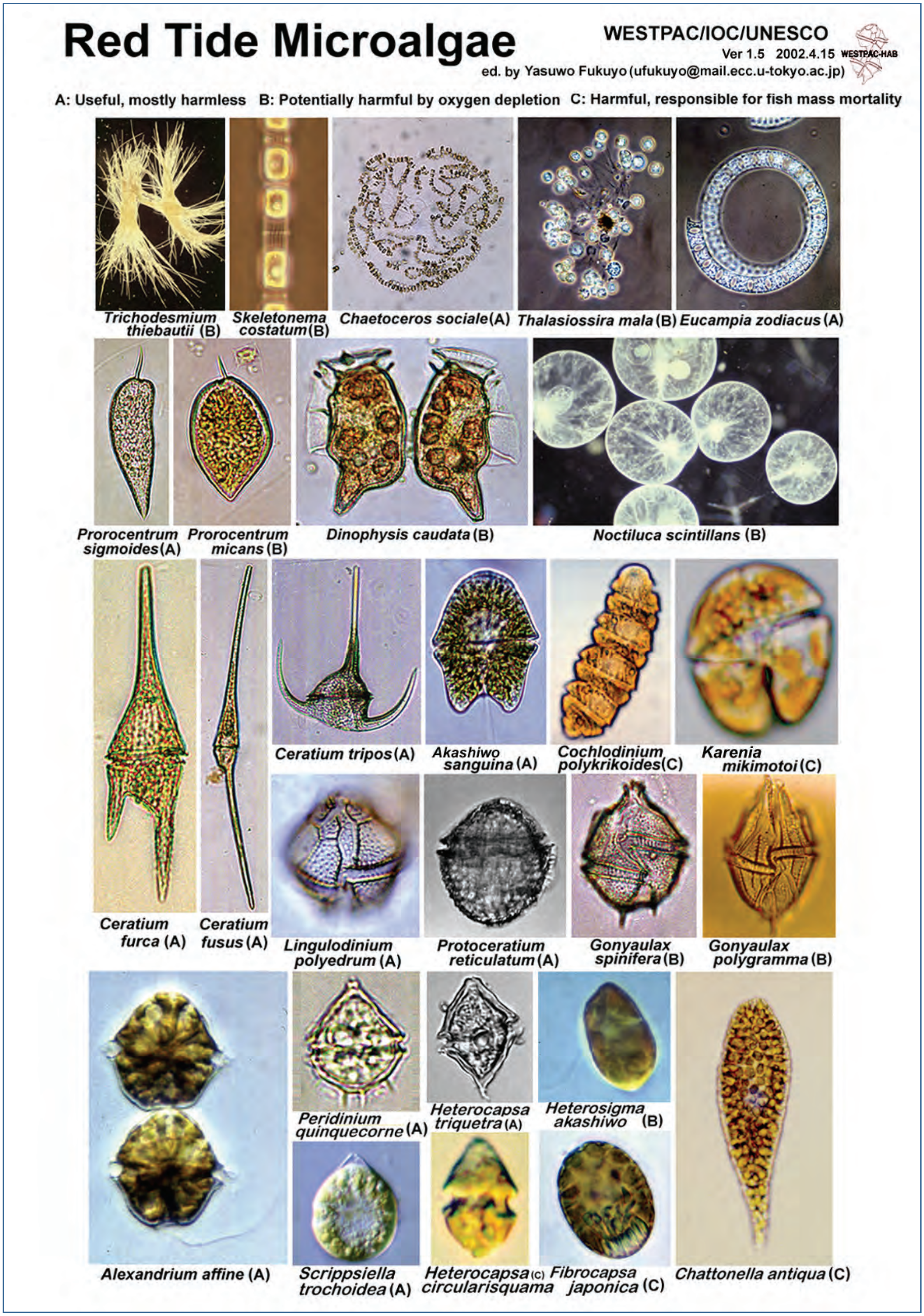
**GEOHAB** has defined five programme elements that serve as a framework for guiding priorities and research. The priorities and challenges for Asia are thus organized around these programme elements: Biogeography and Biodiversity; Nutrients and Eutrophication; Adaptive Strategies; Comparative Ecosystems; and Observation, Modelling and Prediction.

## Biogeography and Biodiversity

Globally, there is evidence of changes in the distribution of HAB species. Understanding the reasons for the change in the distribution of key HAB species in Asia represents one of the important challenges for GEOHAB *Asia*. Most of the important HAB species known to date occur in Asian waters (IOC-UNESCO Taxonomic Reference List of Harmful Micro Algae, http://www.marinespecies.org/hab/index.php). The important species, their effects and changes in their distributions are briefly described here. The larger goal is to eventually relate biogeography to climatic, oceanographic and anthropogenic processes in order to identify the mechanisms driving these change.

### *Cochlodinium*

*Cochlodinium polykrikoides* is a chain-forming dinoflagellate associated with massive fish kills in Asia. The first occurrence of a bloom of *C. polykrikoides* in the Yatsushiro Sea, west Japan in 1979, caused about 180 million yen (US$ 0.8 million) in




Red tide-causing species (left) and toxic species (right) detected in Asian waters (from IOC/WESTPAC-HAB).

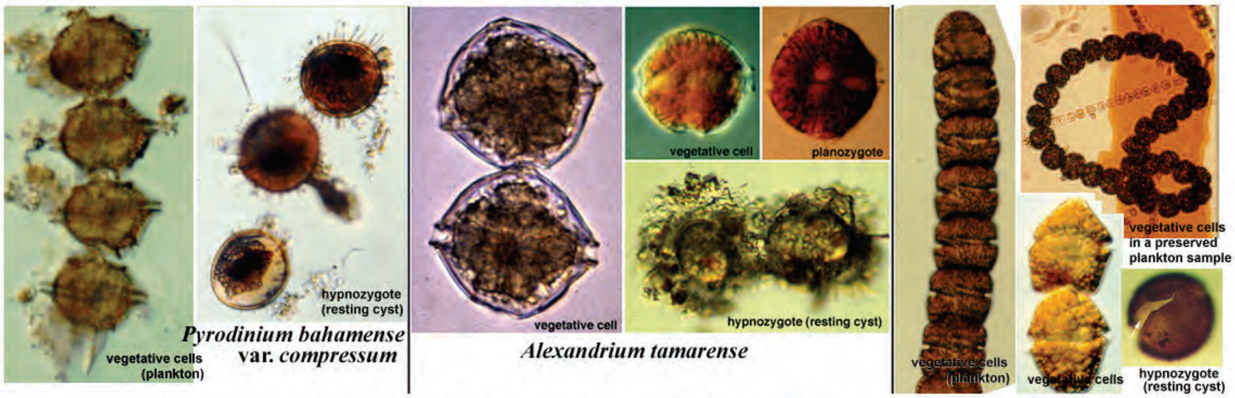
# Toxic Microalgae

**WESTPAC/IOC/UNESCO**

Ver 2.3 2002.4.15 WESTPAC-HAB

ed. by Yasuwo Fukuyo (ufukuyo@mail.ecc.u-tokyo.ac.jp)

## Species Responsible for Paralytic Shellfish Poisoning




*Pyrodinium bahamense* var. *compressum*

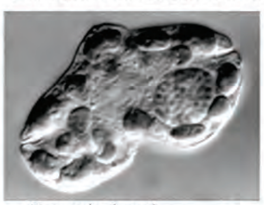
*Alexandrium tamarense*

*Gymnodinium catenatum*

## Species Responsible for Diarrhetic Shellfish Poisoning

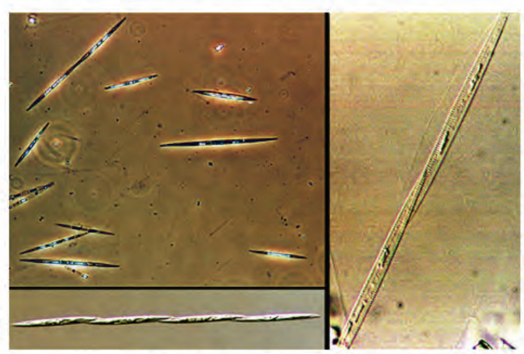
*Dinophysis fortii* *Dinophysis acuminata* *Dinophysis mitra* *Dinophysis caudata* *Dinophysis miles*

## Species Responsible for Neurotoxic Shellfish Poisoning



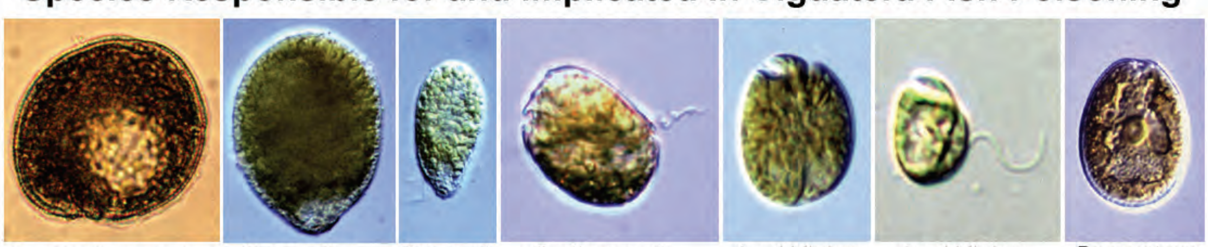
*Karenia brevis* (*Gymnodinium breve*)

## Species Responsible for Amnesic Shellfish Poisoning

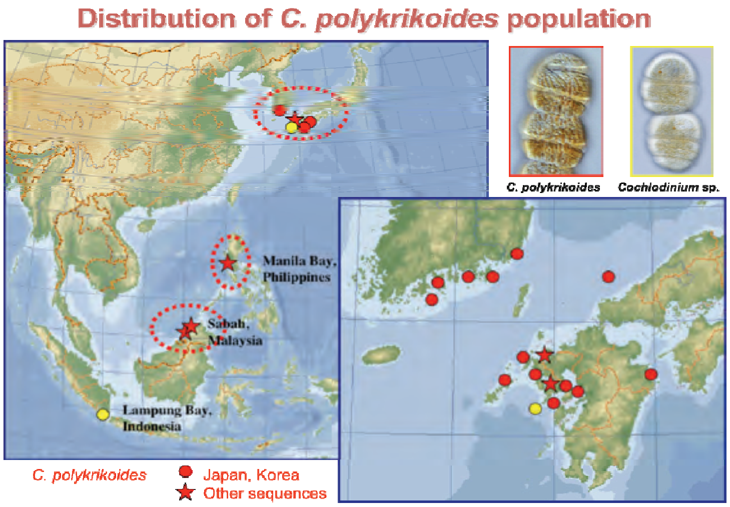


*Pseudonitzschia* spp.

## Species Responsible for and implicated in Ciguatera Fish Poisoning

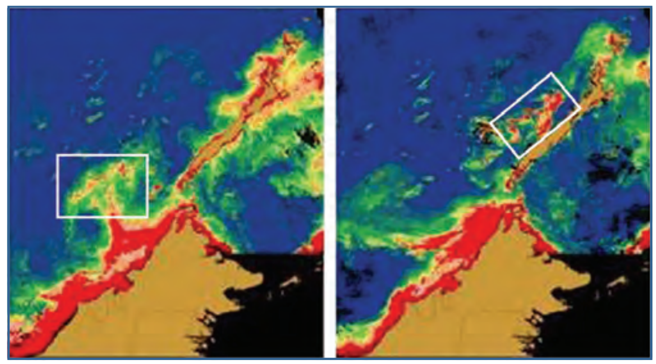


*Gambierdiscus toxicus* *Ostreopsis lenticularis* *Ostreopsis ovata* *Coolia monotis* *Amphidinium klebsii* *Amphidinium carterae* *Prorocentrum lima*




Distribution of harmful chain-forming *Cochlodinium* species occurred in East and Southeast Asian coastal waters. Red and yellow indicate *C. polykrikoides* and *C. fulvescens*, respectively. Phylogenetics based on partial LSU rDNA sequences revealed that the *C. polykrikoides* distributed in southern Korea and western Japan are distinguished from those in South East Asian waters (Iwataki et al. 2008). Figure courtesy of M. Iwataki and K. Matsuoka

The distribution of *C. polykrikoides* in Asia has apparently been expanding. The first record of its occurrence came from Japan in 1978 (Matsuoka and Iwataki 2004). It has subsequently been observed in Korea in 1985 (Kim 2005), in Malaysia and the Phillipines in 2005 (Anton et al. 2008, Relox and Bajarias 2003), in Hong Kong in 2007, and in the Persian Gulf and Oman Sea in 2008. Over the past two decades there has been an increase in the frequency of *C. polykrikoides* blooms, and there is a possible association between the frequency of the blooms and eutrophication. However, there is a large annual variation in the intensity and extent of these blooms.

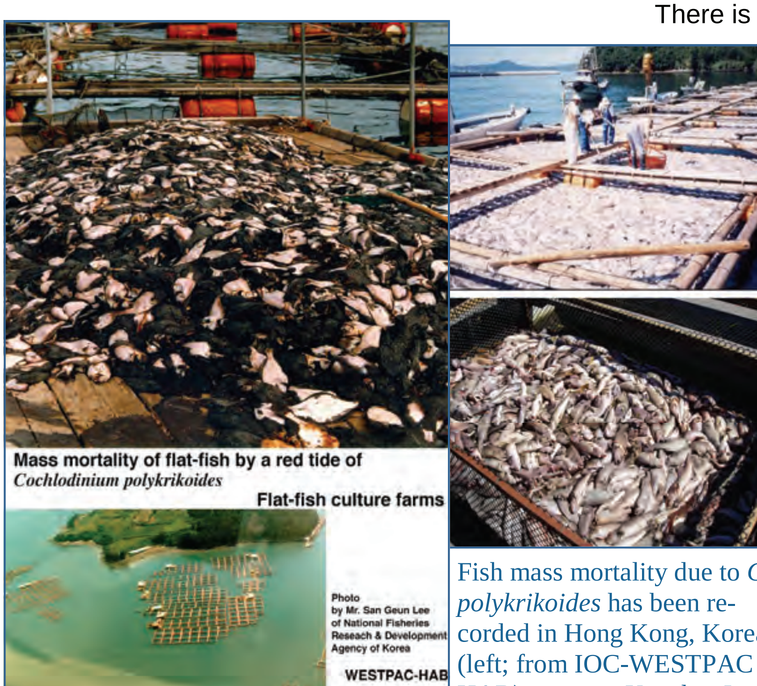


MODIS-aqua chlorophyll images indicate that a plume of high chl *a* extending from the Sabah coast into adjacent offshore waters in late January 2005 (square in the left panel) was likely transported to Palawan coast in late February 2005 (square in the right), where *C. polykrikoides* formed a dense bloom (Azanza et al. 2008).

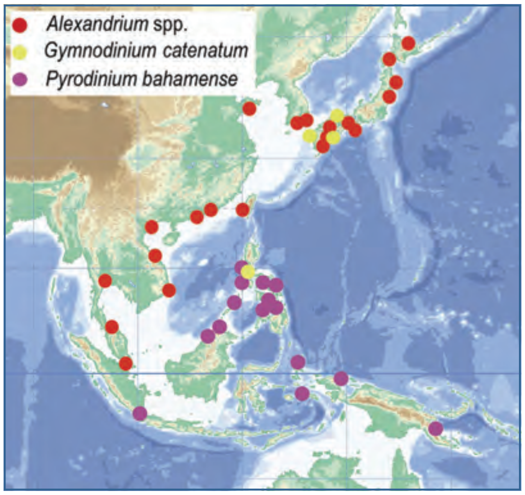
damage. Since then, other blooms of *C. polykrikoides* have also caused economic damage, including 8 billion yen (US$ 66 million) in Imari Bay in 1999 and 40 billion yen (US$ 330 million) in Yatsushiro Sea in 2000. In Korea, the first harmful bloom of *C. polykrikoides* caused damages of 76.5 billion Korean won (US$ 96 million) in 1995, followed by 2.1 billion won (US$ 2.4 million) in 1996, and 1.5 billion won (US$ 1.25 million) in 1998 (Yoon 2001).

There is satellite evidence for the advection of *C. polykrikoides* blooms from the Korean Peninsula to western Japan (Miyahara et al. 2005). A large bloom that occurred along Palawan Island, Philippines, is considered to have been transported from Brunei across Malaysian waters to Philippines (Azanza et al. 2008). Biogeographic evidence suggests further transport links across the region, yet currently there is no direct evidence.

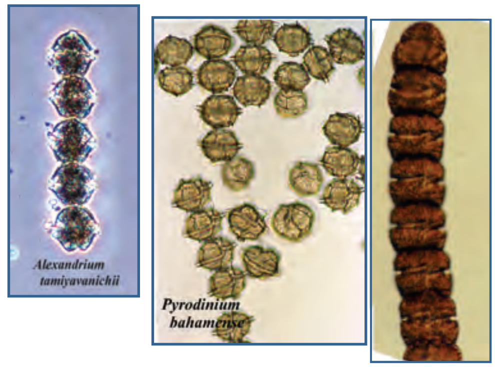
Damages caused by *C. polykrikoides* is not only restricted to fish, but also to various benthic organisms such as corals (e.g., *Pocillopora* spp., *Porites lobata* and *Pavona gigantean)*, shellfish (e.g., *Batillus cornutus*, *Haliotis discus*, and *Chlorostoma lischkei)*, and other animals (e.g., *Octopus vulgaris*, and *Anthocidaris crassizpina).*




Fish mass mortality due to *C. polykrikoides* has been recorded in Hong Kong, Korea (left; from IOC-WESTPAC HAB), western Kyushu, Japan (upper right; photo by Yamatogi) and Saba, Malaysia (right lower; photo by A. Anton).




*Alexandrium spp,, Pyrodinium* spp. and *Gymnodinium catentatum* can cause PSP incidents in the East and Southeast Asia. Figure after K. Matsuoka, Y. Fukuyo and K. Furuya. Photos by Y. Fukuyo.




## *Pyrodinium*

*Pyrodinium bahamense* var. *compressum* produces PSP toxins. It is one of the chain-forming dinoflagellates and has a tropical distribution across the region from the Indian Ocean to the Pacific. *P. bahamense* (probably var. *compressum* based on its apico-antapical compression) also occurs in the Persian Gulf, but examination of its toxicity is needed. The toxins that *Pyrodinium* produce have caused human mortalities after the consumption of contaminated shellfish. Similar incidents are still occurring, for example, in 2007, in localities around the Philippine Islands, where the geographical distribution of PSP incidents is widespread (E.F. Furio, pers. comm.).

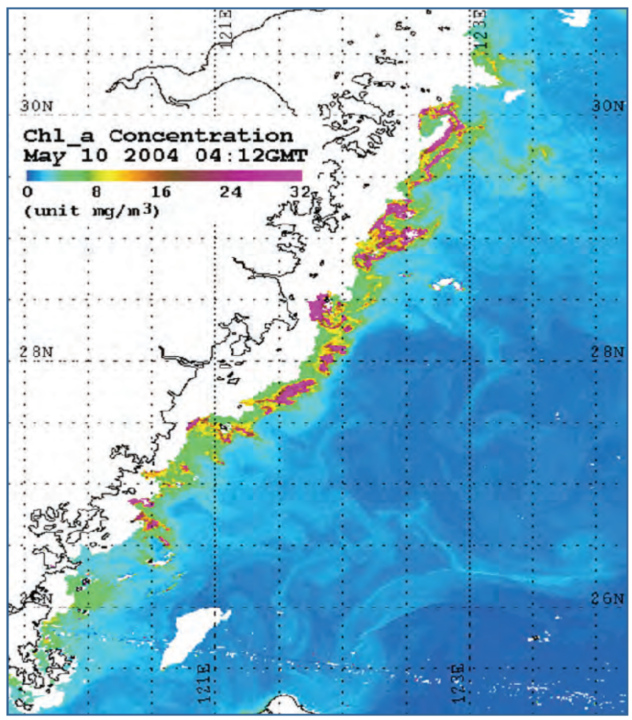
## *Alexandrium*

*Alexandrium* is another dinoflagellate genus which, along with *P. bahamense* and *Gymnodinium catenatum*, contains PSP toxin-producing species. Numerous species of this genus have been recorded in Asia, among which *A. tamiyavanichii*, *A. tamarense*, *A. catenella*, and *A. minutum* are known causative organisms of PSP incidents.

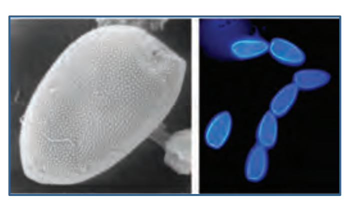
## *Prorocentrum*

*Prorocentrum minimum* causes mass mortality of aquaculture fish in Japan, Philippines, and Singapore due to anoxia in the bloom water after its dense blooms. Toxin production by this species was suspected, but there is no clear evidence.

*Prorocentrum donghaiense*, first described by Lu and Goebel (2001), is a dinoflagellate which has formed extensive high-biomass blooms in the East China Sea since 1998. Although it is neither a toxin producer nor a species associated with fish kills, it alters the ecosystem by forming dense blooms and the zooplankton abundance in the vicinity of these blooms is substantially reduced. Current evidence shows that zooplankton preferentially graze other phytoplankton, suggesting poor nutritional quality for this species. Blooms are initiated in the beginning of April and last until June. They are large scale, on the order of 10,000 km$^2$ from the Changjiang to the Nanji archipelago (28~35°N), and at a depth of 20 to 50 m. *P. donghaiense* is highly dominant in the plankton during these blooms, comprising >90% by numerical abundance.




A dense bloom of *P. donghaiense* expressed as chlorophyll *a*, occurs along Chinese coast in the East China Sea. Figure courtesy of CCAR/HKUST.



SEM (left) and fluorescence (right) images of *P. donghaiense*. Morphology of *P. donghaiense* is similar to that of *P. shikokuense*. Photos by D.D. Lu.

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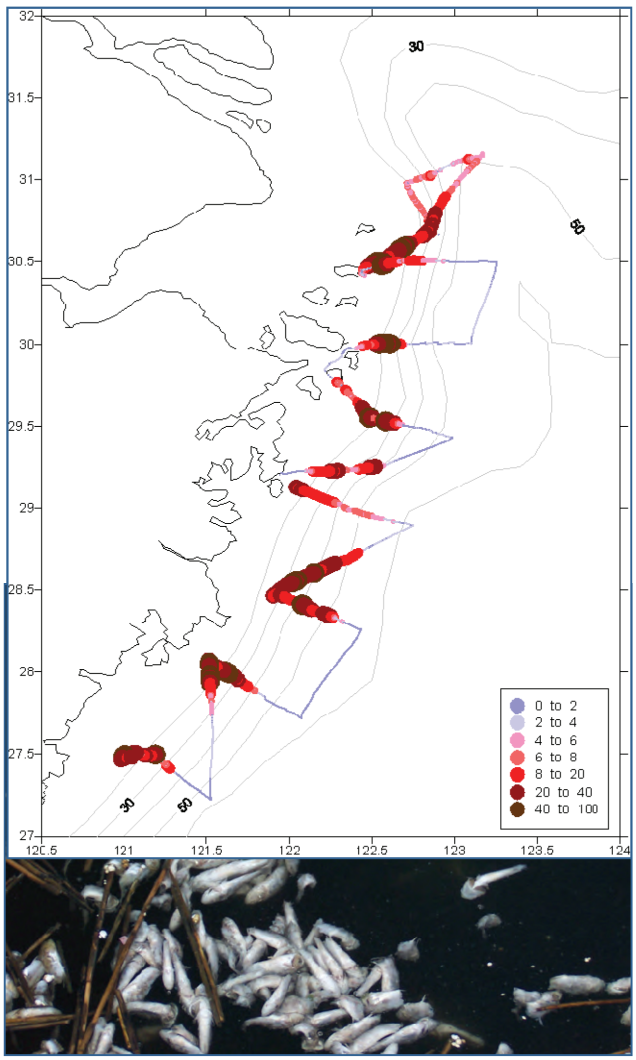
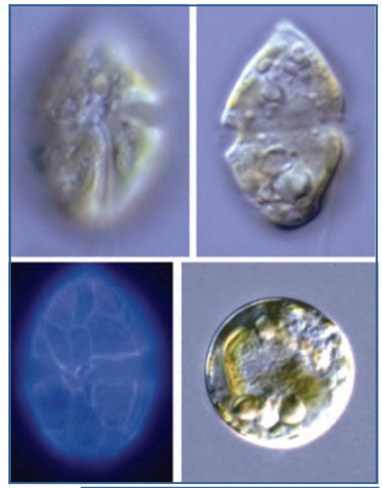
## *Karenia*

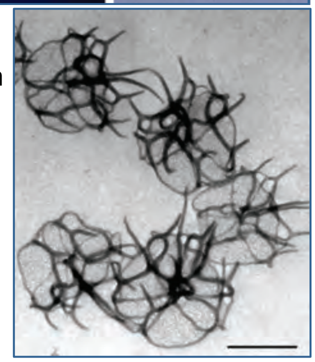
Although *Karenia mikimotoi* has been known to occur in Japan since 1934, it was previously described as *Gymnodinium mikimotoi* (Oda 1935), and has been observed to form red tides in western Japan since 1965 (Takayama 1990); its occurrence in other waters in Asia is rather recent (Yang and Hodgkiss 1999). It formed a harmful bloom in 1998 in Hong Kong waters and Guangdong Province. This extensive bloom was associated with huge fish kills nearby worth RMB 0.4 billion (US$ 48 million). In 2005, another extensive bloom occurred near the Changjiang River estuary, locally causing damage estimated at RMB 30 million (US$ 3.6 million) (Jiang et al. 2006). This is the region in which a *P. donghaisense* had bloomed continuously for the previous seven years , but which in 2005 also had a *K. mikimotoi* bloom. Subsequently, both species have bloomed virtually simultaneously, but bloom intensities have been relatively low and variable (Matsuyama 2003).




Distribution pattern of a large scale bloom caused by *Karenia mikimotoi* in the Changjiang River estuary and its vicinity, and related fish kills in 2005. Figures courtesy of Y.F. Wang and S.H. Lu.

## *Heterocapsa*





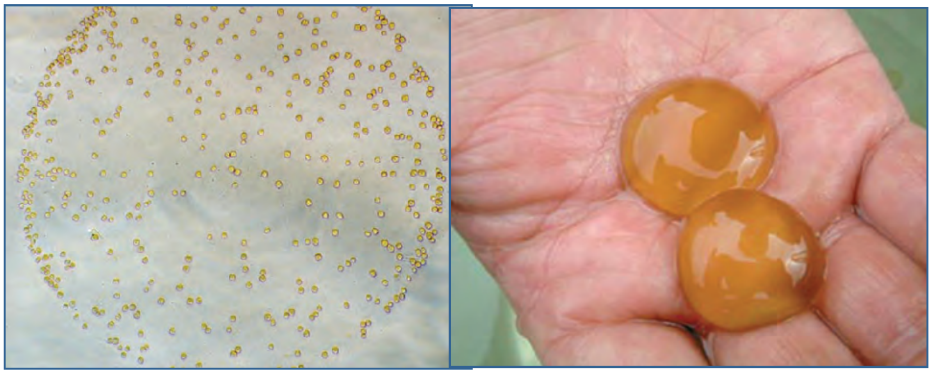
Top panel: light and fluorescence microscopy of *Heterocapsa circularisquama*, motile cell and temporary cyst (lower right). Lower panel: *H. circularisquama* possesses characteristic scales on its surface. Scale bar: 200

*Heterocapsa circularisquama* is a dinoflagellate which has caused mass mortality of bivalves in Japan, including the pearl shell, Pacific cupped oyster and
Manila clam (Matsuyama 2003), and has also caused mass mortality of mussels in Hong Kong (Iwataki et al. 2002).This species forms high-biomass blooms.

In the presence of *H. circularisquama*, blue mussels stop feeding and firmly close their shells (Matsuyama et al. 1997). About 50% of juvenile pearl oysters died within 48 h with 5x$10^3$ to 1x$10^4$ cells/mL (Nagai et al. 1996). Negative impacts of this species on growth are noted in athecate species, ciliates, rotifers, and jellyfish. Economic loss due to mass mortality of oysters was 3 to 4 billion yen (2 to 2.7 million US$) in Hiroshima Bay, Seto Inland Sea, Japan (Matsuyama 2003). A total of >10 billion yen damage to fisheries has been recorded in Japan since its first incident in 1988.

## *Phaeocystis*

*Phaeocystis globosa* is a prymnesiophyte which occasionally causes extensive blooms, leading to fish kills and mortality of the caged fish and lobster in Chinese and Vietnamese waters.

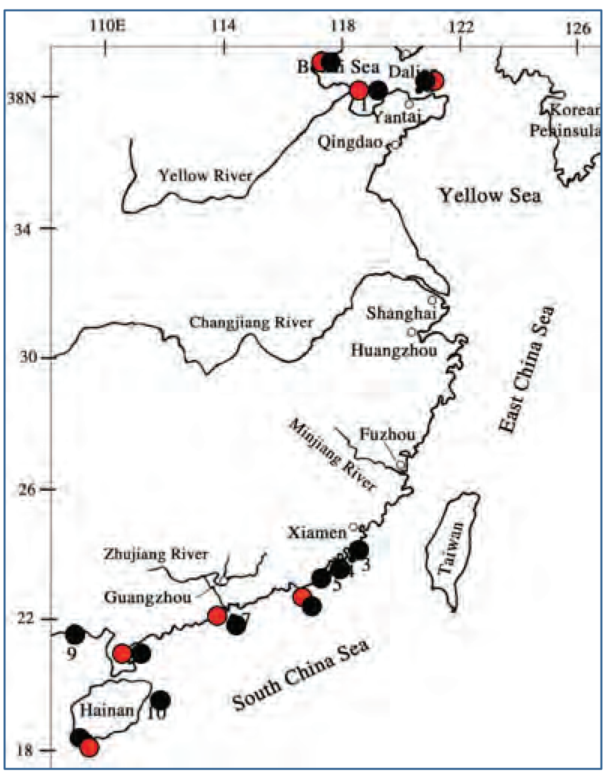


*Phaeocystis* can form very large colonies. Photos by Y.Z. Qi.

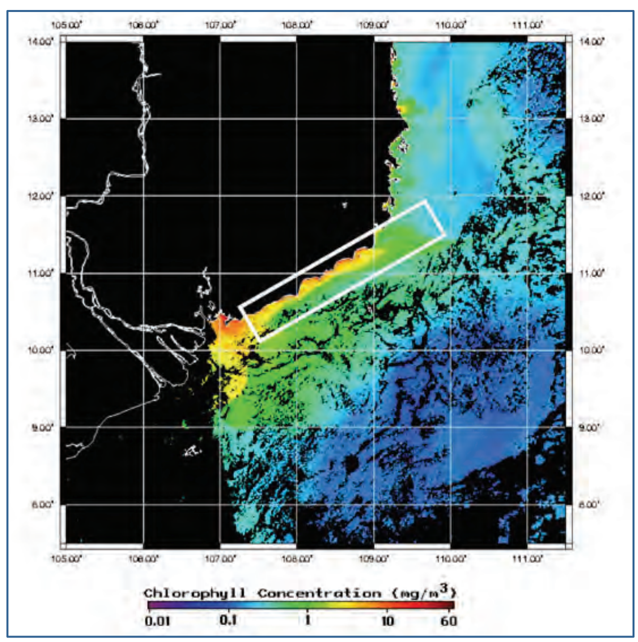
*P. globosa* forms spherical gelatinous colonies, up to several centimeters in diameter. *P. globosa* produces haemolytic substances, a mixture of liposaccharides, whose structures are similar to that of digitonin, a non-conventional non-ionic surfactant (Peng et al. 2005) This species is known as a DMS/DMSP producer as well (Stefels 2000)

Blooms of *P. globosa*, in coastal waters of Binh Thuan Province, Vietnam are associated with upwelling phenomenon during the southwest monsoon (Tang et al. 2004). In July 2002, about 90% of animal and plant species in tidal reefs of Phan Ri Bay were eliminated by a bloom. The loss was estimated to be more than VND10 billion (ca. $US 0.65 million). During this bloom, low diversities of both phytoplankton and zooplankton were reported (Doan et al. 2003). An extensive survey conducted in 2007-2008 indicate a regular pattern of development of the bloom with change in plankton communities and nutrient stoichiometry. The bloom formation is likely influenced by a combination of upwelling activity, nutrient regime, and species competition (National Institute of Oceanography, unpublished).

In a dense bloom, sea surface waters are often covered by thick foam along the south Vietnamese coast. Photo by N.N. Lam.



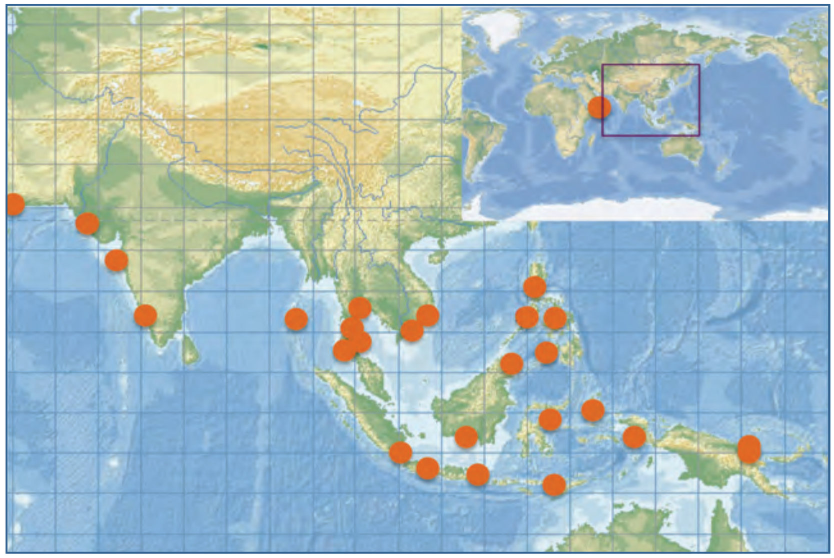

In China *P. globosa* red tide occurred along the coasts of Fujian and Guangdong Provinces from Oct. 1997 to Feb.1998 for the first time. Since then, the distribution (black circle) and blooming (red circle) of this species in China has been reported from the Bohai Sea in northern China and Guangdong Province in the southern China, but no bloom formation has been reported between these two areas.



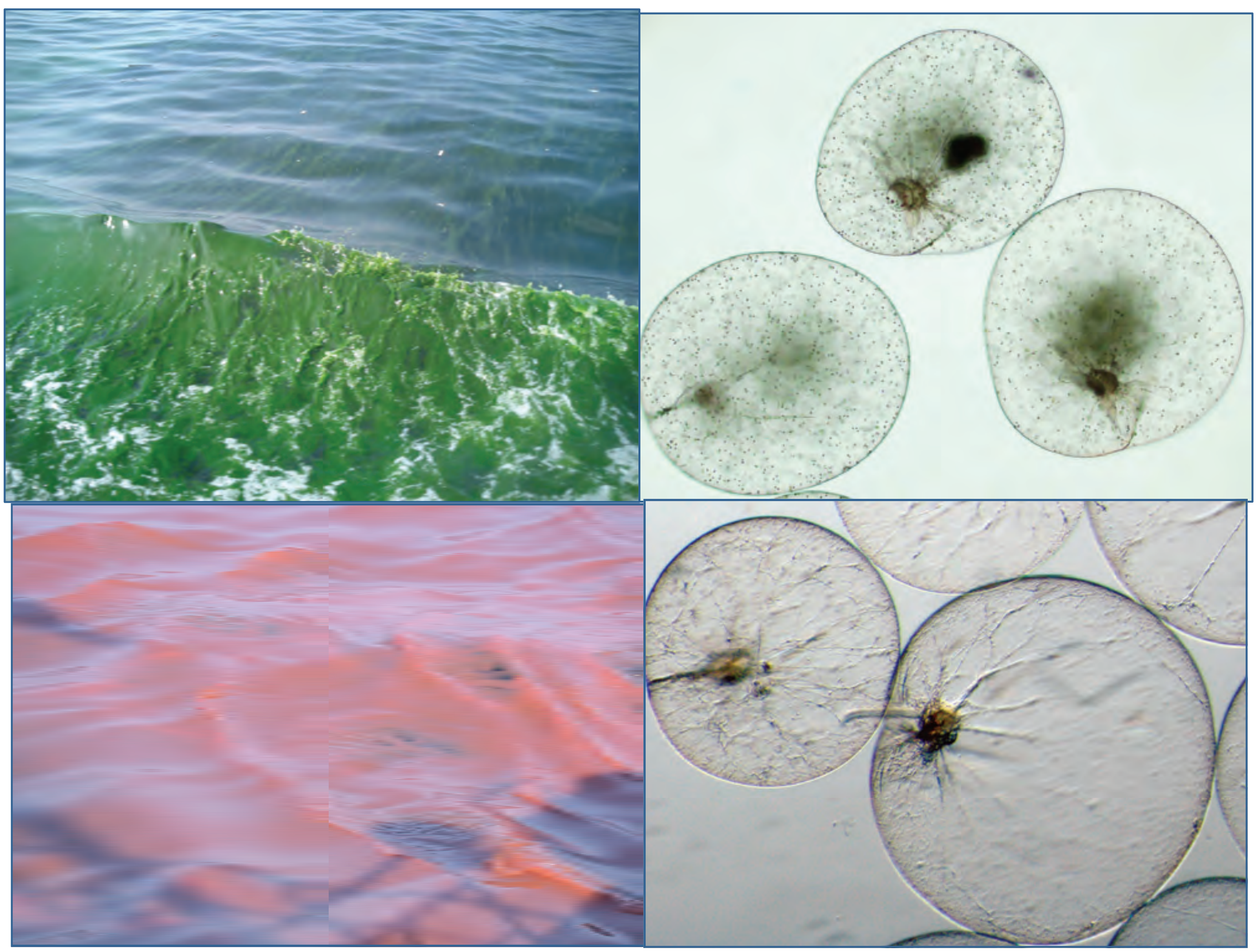

SeaWiFS chlorophyll image of blooming of *P. globosa* (white square) in September 2006 along the south Vietnamese coast. From GSFC/NASA.

## *Noctiluca*

*Noctiluca* is a monospecific genus of large unarmoured heterotrophic dinoflagellates. The species *N. scintillans* has two forms, one green and one red, which discolour seawater. While the red form has a fairly ubiquitous global distribution, the green form is limited to the western tropical Pacific and the Indian Ocean (Saito and Furuya 2006). The difference between the two forms is the presence (green) or absence (red) of the endosymbiont *Pedinomonas noctilucae* (Sweeney 1976). *Noctiluca* is less harmful than most of the species described here, but fish yields in aquaculture areas are sometimes decreased with mass occurrence of the green form. *Noctiluca* may have some impact on HABs by grazing on them in field samples. The green form has been found to contain *Gymondinium catenatum* (K. Furuya unpubl. data) and can graze *Pyrodinium* in culture (Hansen et al. 2004).



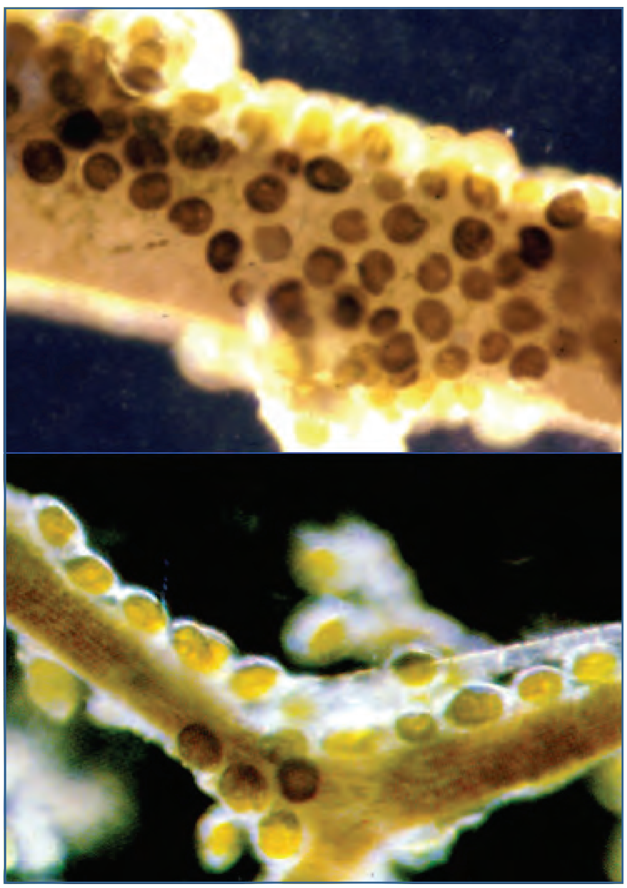
Green *Noctiluca* is distributed in tropical coastal waters of the western Pacific and the Indian Oceans. Modified from Saito and Furuya (2006).



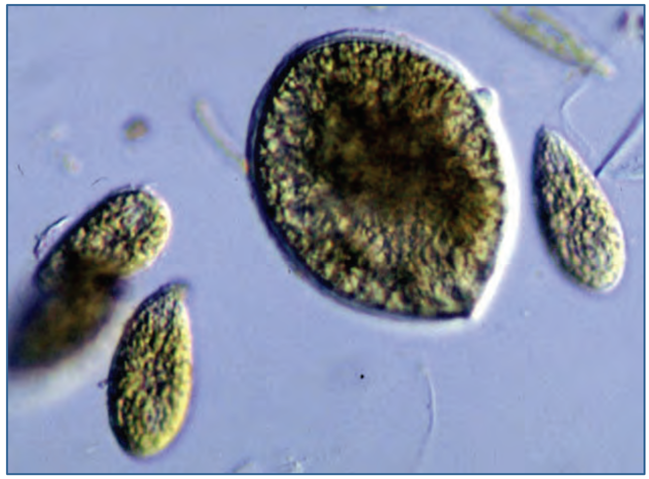
Two forms of *N. scintillans*, green and red, occur in Asian waters. Due to the presence of the endosymbiont *Pedinomonas noctilucae*, the green *Noctiluca* can survive without an external food supply, but it also conducts phagotrophy like the red heterotrophic form does (Saito et al. 2006). Upper and lower right photos by K. Furuya; lower left photo by J. Li.

## Benthic HABs

This group of dinoflagellates include the genera *Gambierdiscus*, *Ostreopsis*, *Coolia*, as well as *Prorocentrum*. These species generally are found epiphytically on seaweeds, in sandy beaches or on dead corals. The most well known toxins that are produced by this group are ciguatoxins and maitotoxin of *Gambierdiscus,* causing ciguatera fish poisoning (Bagnis et al. 1980). *Ostreopsis* can produce palytoxins and *P. lima* produces okadaic acid (Murakami et al. 1982, Penna et al. 2005). Taxonomic confusion and difficulties in standardization of sampling methods have impeded our understanding of the ecology of these species. For example, while ten species have been described in the genus *Gambierdiscus*, morphological criteria to distinguish some species are unclear and therefore identification is difficult. This is also the case with the genera *Ostreopsis*, *Coolia*, and *Prorocentrum*.



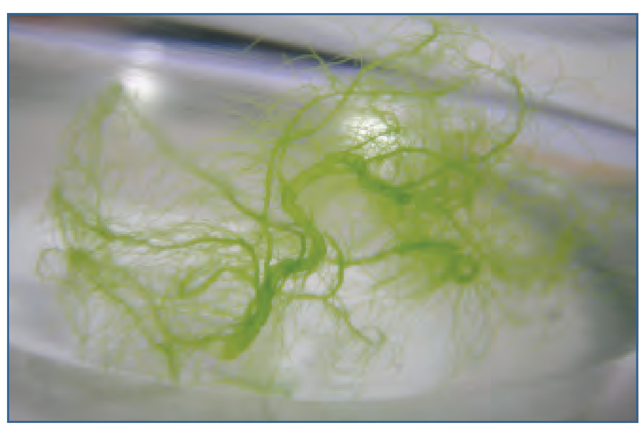
*Gambierdiscus toxicus* is generally found on seaweeds in low density in subtropical and tropical waters. However, high abundance of these benthic HAB species has been poorly documented. While these photos were taken about 30 years ago in Gambier Island, Tahiti, no areas where high biomass of this species occurs have been reported since then. Such a situation makes investigations of population dynamics and its association with toxin poisoning extremely difficult. Photos by Y. Fukuyo.



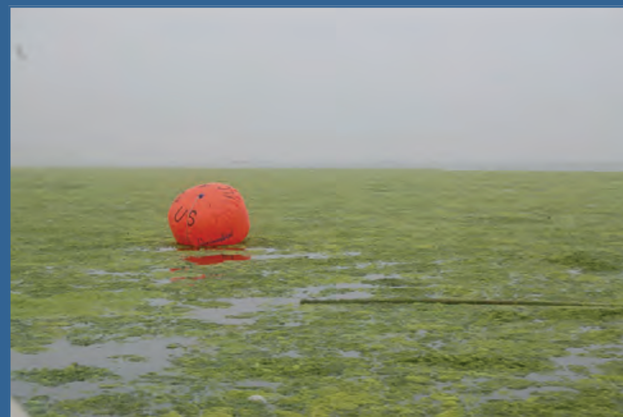
*Ostreopsis lenticularis* (large cell) and *Ostreopsis ovata* (small cells) collected in Okinawa, Japan. Photo by Y. Fukuyo.

### *Enteromorpha* (*Ulva*)

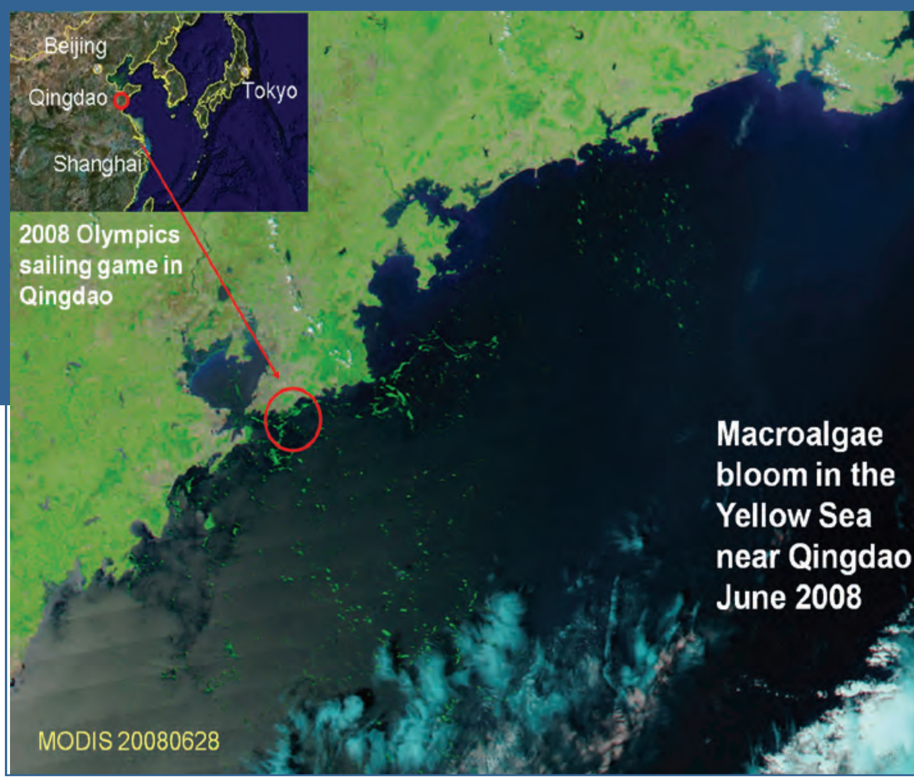
In 2008 a bloom of the macroalga *Enteromorpha prolifera (Ulva prolifera)* occurred at the venue of the sailing competition for the Olympic Games in Qingdao, China. The bloom was first observed in the Yellow Sea, and was transported into the Qingdao region. It required about 15,000 members of the Army to help the effort to remove the algae. Some 1 million tonnes of algae was removed before the sailing competition. Some studies have been carried out to understand the causes of the bloom, although the detailed mechanism needs further investigations (Sun et al. 2008). The causes of the bloom are unknown, but previous macroalgal blooms have been related to nutrient loading. For example, in Boston Harbor, USA, sea lettuce (*Ulva*) formed dense populations for many years near sewage outfalls (Sawyer 1965). Along the intertidal area of the Baltic Sea, sewage inputs have been related to overgrowth of formerly dominant brown seaweeds (*Fucus* spp.) by opportunistic macroalgae (Heisler et al. 2008). A relationship with seaweed aquaculture has also been suggested (Liu et al. 2009).



*Enteromorpha* is a filamentous macroalga. Photo by M.J. Zhou.



In 2008 a bloom of *Enteromorpha* occurred in the sailing venue for the Olympics games in Qingdao creating enormous challenges for competitors. The algae required a massive clean up effort prior to the Olympic sailing competition. Upper left photo www.sailjuice.com; right photo by Nancy Rios.




MODIS-aqua image of massive green algae blooms in the Yellow Sea near Qingdao on June 28, 2008. From M.J. Zhou redrawn from GSFC/NASA.

## Nutrients and Eutrophication

Of particular interest to the understanding of Asian HABs is the potential relationship between HABs and the growing eutrophication of coastal waters. Although it may seem reasonable to assume a causal relationship between human activities and an expansion of HAB events, the specific factors that contribute to the proliferation of individual species is far from well understood. The relationships are complex because the sources of nutrients are many, and nutrient loads are not evenly distributed. Moreover, the responses to nutrient enrichment depends on the physiology of the organisms at the time of nutrient delivery, whether nutrients are delivered in pulsed or continuous mode, and the composition and ratios of nutrients at the time of delivery (Glibert et al. 2005, Glibert and Burkholder 2006, Heisler et al 2008). The relationship between nutrients and the toxin content of species is even more complex. However, in spite of the complexities, various indices have proven to be useful in defining the extent to which eutrophication may be related to individual species. These issues are explored in more detail below.

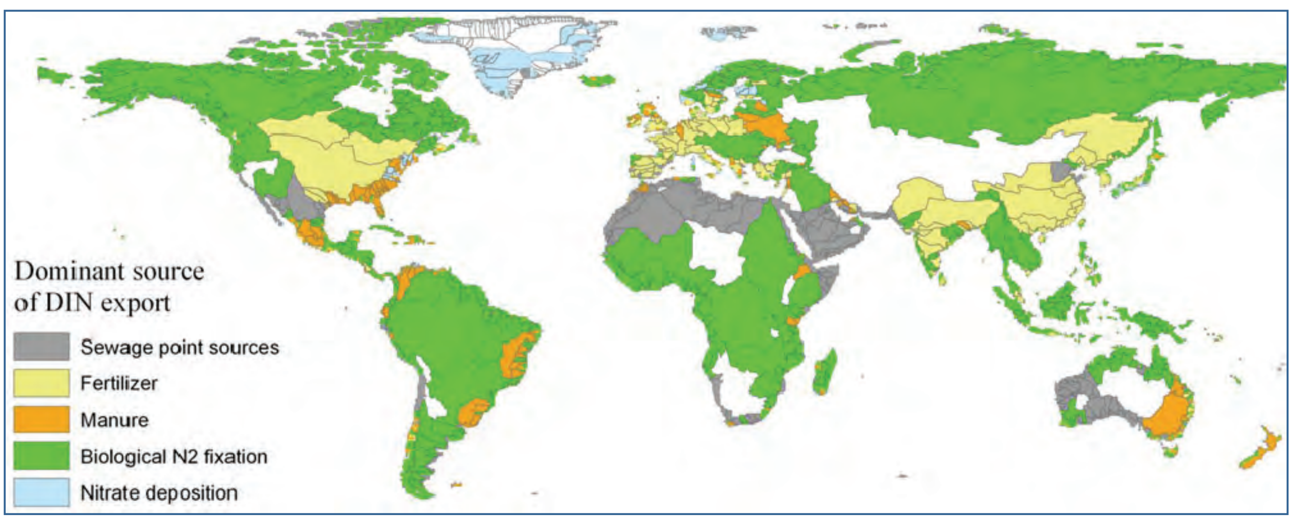
## Nutrient Loads and Forms

The sources of nutrients that may stimulate blooms are many, from sewage to atmospheric and ground-water inputs, to agricultural and aquaculture runoff and effluent. The rapid development of agriculture and aquaculture in Asian countries have dramatically altered the nutrient loads to land, and presumably also to the sea. For example, China, which used less than 5 million metric tonnes of nitrogen fertilizer annually in the 1970s, now uses more than 20 million metric tonnes per year, representing 25% of global nitrogen fertilizer consumption (Glibert et al. 2005). Aquaculture ponds and cage culture systems, as described previously, also represent an important source of nutrients, as nutrients are often provided as feed or fertilizer and are rapidly transformed by the biological processes occurring within these dynamic systems.

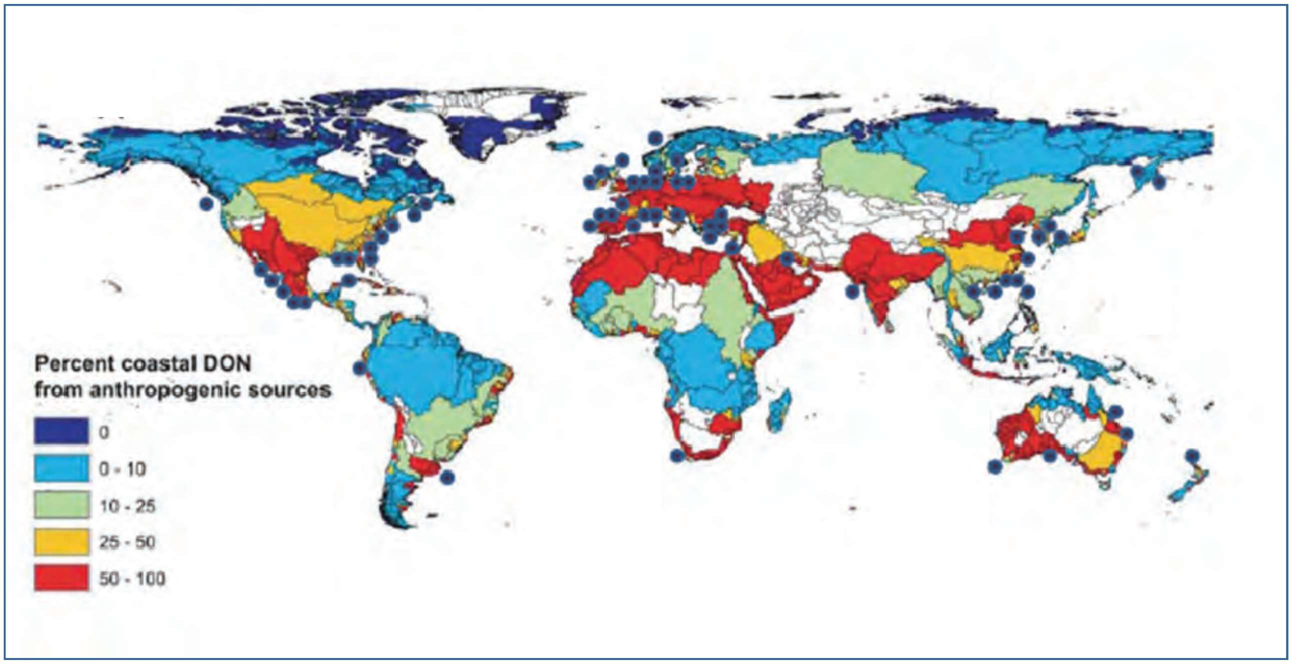
Atmospheric inputs are also important sources of nutrients to Asian waters. Atmospheric deposition of nitrogen comes from both fossil fuel combustion and from volatilization from agricultural systems, and its magnitude is likely to be underestimated in many cases, since gaseous dry nitrogen deposition is seldom measured (Galloway et al. 2004, Howarth et al. 2002, 2005). Blooms in the Yellow Sea of China, which have escalated in frequency over recent decades, have been related to atmospheric deposition in addition to direct runoff (Zhang 1994).

Global models of both inorganic and organic nutrient export are now available (Seitzinger and Kroeze 1998, Seitzinger et al. 2002, Harrison et al. 2005a,b). These models take into account both natural nutrient sources (e.g., nitrogen fixation and phosphate weathering) as well as anthropogenic inputs based on fertilizer usage by watershed, by specific crop grown, nitrogen fixation by the crop, atmospheric deposition and manure production by animal species, and human input from sewage (as point or non-point and by known treatment level). The models then account for hydrological and physical differences in the watershed and for in-river processing (Seitzinger et al. 2005). Such models show that nitrogen and phosphorus export is greatest from European and Asian lands, followed by the United States. These models also allow estimates of the percent contribution of different sources of nutrients to nutrient export. For example, it can be seen that in Asia the dominant source of inorganic nitrogen export from China is fertilizer, whereas the dominant source of nitrogen in southern Asia is biological nitrogen fixation (Dumont et al. 2005). In addition, the percent of anthropogenic organic nitrogen export has been estimated using this modeling approach (Harrison et al. 2005a), and a comparison of this global pattern and the global distribution of *Prorocentrum minimum* shows a high degree of correspondence (Glibert et al. 2008).

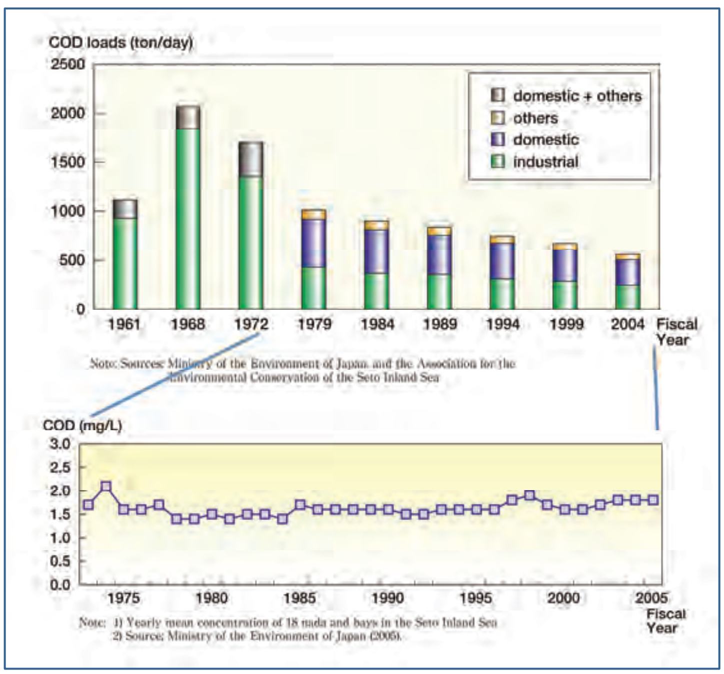
While increasing monitoring and enhanced modeling have improved our understanding of nutrient loads, the relationships between nutrient loads and water column concentration is not direct. There is no known direct relationship for any water quality parameter between load and in situ concentration, since in situ concentrations are a function of water column physics and biological and chemical




According to the Global NEWS model, $N_2$ fixation constitutes the dominant source of DIN export to the coast in many tropical, subtropical and boreal basins. Anthropogenic N, especially from fertilizer, is the dominant source of DIN export in southern and eastern Asia, western Europe, and the central United States. Fertilizer is the dominant source of exported DIN in two-thirds of the basins (Dumont et al. 2005)




Percent dissolved organic nitrogen (DON) from anthropogenic sources discharged into coastal areas (Harrison et al. 2005a). Humans have an important impact on river DON export, particularly in South Asia and northern China. The dots superimposed on the DON export map represent the global distribution of *Prorocentrum minimum* (Glibert et al. 2008).




The change in nutrient loads in the Seto Inland Sea during the past several decades due to direct management action resulted in well-documented decreases in red tide events, but a reduction in the loading of chemical oxygen demand (COD) had no effect on the in situ water column concentrations of COD (International EMEC Center 2008). Such an example underscores the fact that in situ measurements of a single water column parameter do not adequately reflect the rate of loading.

transformation processes. For example, in the Seto Inland Sea, western Japan, more than 300 cases of harmful algal blooms, mainly caused by *Chattonella antique,* frequently occurred in the 1970s (Okaichi 2003). After controlling the waste-water quality drained from factories and aquaculture industries, harmful algal blooms drastically decreased to around 100 events, but *Karenia mikimotoi, Heterocapusa circuralisquama*, and *Heterosigma akashiwo* took over from the previous *C. antiqua* blooms instead (International EMES Center 2008).

Another interesting observation is the case where the reduction of nutrient loads is considered to have led to a decrease in Nori culture (red alga *Porphyra*) in the Seto Inland Sea (Fujiwara and Komai 2009, Nishikawa and Yamaguchi 2009). This example indicates a difficulty in reducing red tide occurrence through the water quality control in the context of competition on nutrients in extractive aquaculture such as seaweed farming.

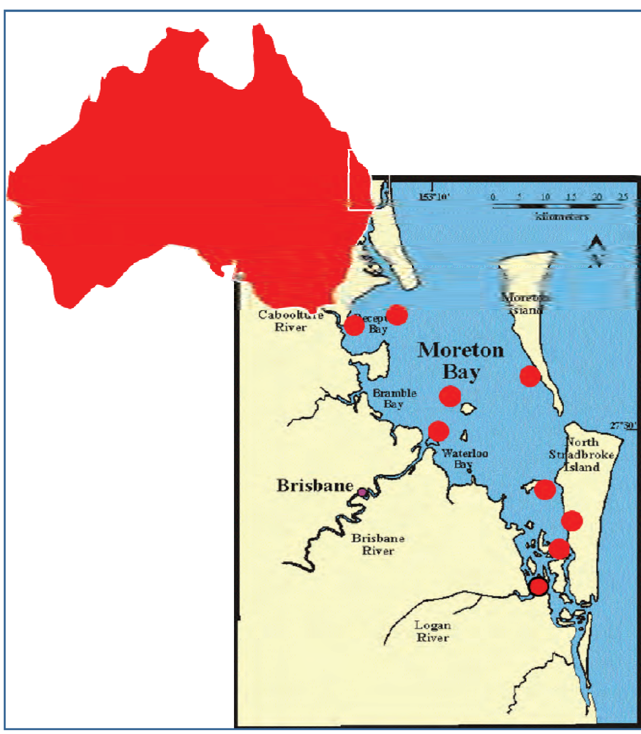
## Nutrient Enrichment, Nutrient Limitation and Nutrient Quality

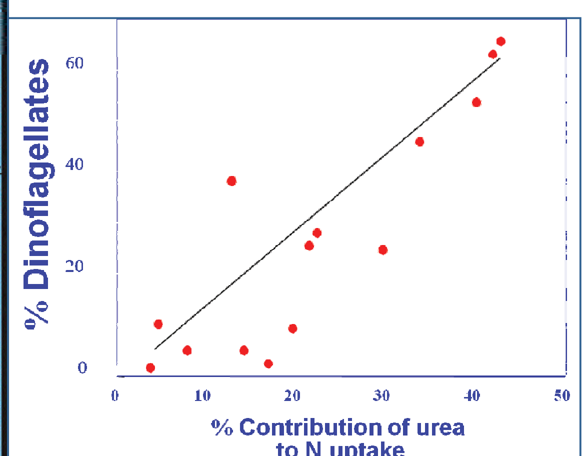
The concept of limiting nutrients in a eutrophic system actually is very complex. The ecosystem response to nutrient enrichment, or eutrophication, is a continual process rather than a static condition or a trophic state (Cloern 2001, Smayda 2005). Nutrient limitation of phytoplankton growth is a fundamental factor that restricts the accumulation of biomass and may determine the outcome of competition among species in mixed assemblages. Nutrient limitation is often expressed as an alteration in nutrient ratios, leading to an imbalance from proportions identified by Redfield (Redfield 1934, Tilman 1977, Samyda 1990, 1996). In terms of HABs, increases in nitrogen and phosphorus may result in proportional reduction of silica, a requirement for diatoms. Since silica is not abundant in sewage effluent or agriculture wastewater runoff, but nitrogen and phosphorus are, the N:Si or P:Si ratios in coastal waters have increased in regions receiving sewage effluent.

Red tides of Tolo Harbor in Hong Kong exemplify this effect. From 1976 to 1989, there was an 8-fold increase in dinoflagellate-dominated red tides coincident with a 6-fold increase in human population and a 2.5-fold increase in nitrogen and phosphorus loading (Lam and Ho 1989). Moreover, it was further demonstrated for Tolo Harbor that when N:P ratios fell below ~10:1, dinoflagellates such as *Prorocentrum micans*, *P. sigmoides* and *P. triestium* increased in abundance (Hodgkiss 2001).

It is increasingly recognized that inorganic nutrient loads, concentrations or ratios do not reflect the full suite of nutrients available to phytoplankton in general, and to HABs in particular. Some species use organic nutrients for their sole nutrient requirements, while others may use organic compounds to supplement their uptake of inorganic substrates (e.g, Graneli et al. 1997, 1999, Jones 1994, Stoecker 1999, Jeong et al. 2005, Glibert and Legrand 2006). Some species may, in fact, be obligate mixotrophs or heterotrophs, requiring organic forms of nutrient (Jones 1994). Indeed, there is considerable evidence that mixotrophy may be a strategy used in a high proportion by algae in eutrophic environments (Burkholder et al. 2008).

The chemical composition of dissolved organic matter exported from agricultural watersheds is not known, but up to 50% of this material can be taken up directly or indirectly by estuarine plankton communities (Seitzinger et al. 2002). The chemical composition, bioavailability, and effects of dissolved organic matter on coastal plankton communities vary depending on the source, the plankton community, and the season (Bronk 2002). Organic nutrients have been shown to be important in the development of blooms of various HAB species, in particular cyanobacteria and dinoflagellates (e.g., Paerl 1988, Glibert et al. 2001, 2006a). As a example of the importance of the relationship between organic forms of nutrients and blooms, in Moreton Bay, Australia, the fraction of dinoflagellates in the water column was found to be directly related to the proportion of nitrogen taken up as urea (Glibert et al. 2006a,b). In the East China Sea, differences in the proportional use of organic nitrogen was found between *Karenia mikimotoi* and *Prorocentrum donghaiense*, which bloomed in succession in 2005 (Li et al. 2009).



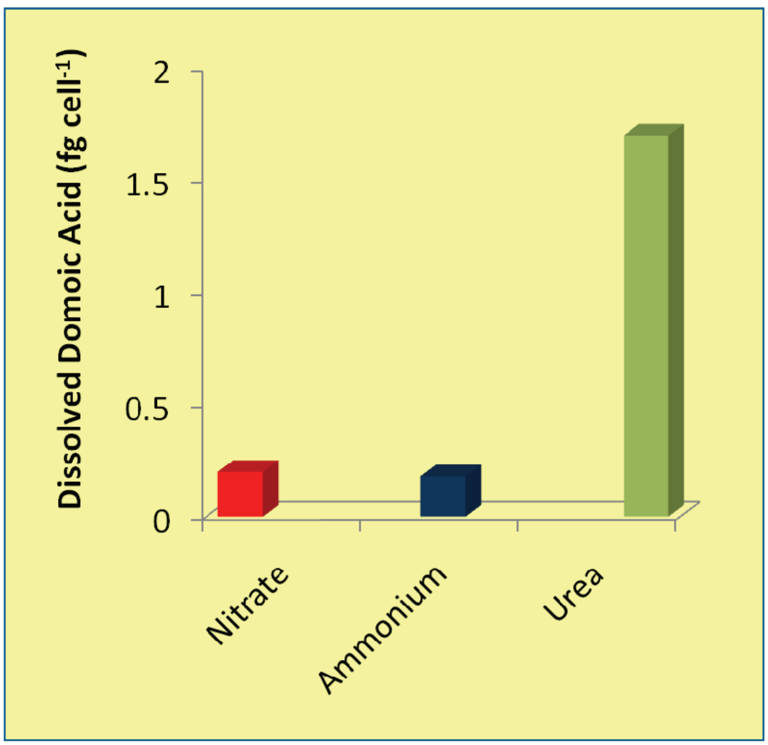

Moreton Bay, located on the northeast coast of Australia, is a shallow, well-mixed estuary that receives inflow from two dominant river systems, the Brisbane River and the Logan River. The fraction of dinoflagellates in the water column was found to be directly related to the proportion of nitrogen taken up as urea (Glibert et al. 2006a).

## Nutrients and Cellular Physiology

Determination of the overall role of nutrient quantity and quality in affecting HAB species composition requires a fundamental understanding of physiological differences within and between species groups, their nutritional history, and intraspecific differences in response. Nutrient concentrations are well known to regulate the rate of nutrient uptake (uptake kinetics), enzyme activities, the rate of growth, but also affect other cellular and metabolic processes such as sexual reproduction, cyst formation and germination (Anderson et al. 1984). While many of these relationships are recognized in a general metabolic context, knowledge of how specific nutrients influence individual processes within individual species are far from well understood.

Nutritional history also affects the affinity of an algal cell for a particular form of nutrient, the immediate fate of that nutrient once taken up and, in the case of some HAB species, the degree of toxicity (e.g., Johansson and Granéli 1999, Skovgaard et al. 2003, Leong and Taguchi 2004). For a nutrient-replete cell, the rate of incorporation of newly acquired nutrient may be slower than the rate of incorporation by a nutrient-deficient cell. Several decades of research on short-term physiological responses by a range of phytoplankton species have demonstrated that nitrogen-limited cells enhance nutrient uptake capabilities by orders of magnitude, relative to their rates of nutrient uptake when nitrogen sufficient (e.g. McCarthy and Goldman 1979, Goldman and Glibert 1982). Thus, a nutrient pulse will be assimilated by species at different rates depending on whether they are nutrient-limited or nutrient-sufficient. Moreover, the same strain, as well as the same species, can show a different response to the same nutrient pulse at different phases of its growth (Conway and Harrison 1977, Burkholder and Glibert 2006, Burkholder et al. 2008). Relationships between eutrophication and HABs extend beyond correlations between total nutrient load and changes in nutrient composition, however, as nutrients can also stimulate or enhance the impact of toxic or harmful species in several more subtle ways.

Nutrient availability or composition may also alter the toxin content of individual species without altering their total abundance, or may impact other members of the food web, such as bacteria and viruses, which may directly or indirectly impact the abundance or toxicity of HABs (e.g. Carlsson et al. 1998, Anderson et al. 2002). Laboratory studies have also revealed that the neurotoxin domoic acid (DA) production by the diatom *Pseudo-nitszchia* spp. can vary as a function of the nitrogen substrate being utilized for growth. For exponentially growing cultures of *P. australis*, nitrate and ammonium-grown cells produce equivalent amounts of dissolved and particulate DA, whereas DA production is enhanced in cultures growing solely on urea (Armstrong-Howard et al. 2007,Cochlan et al. 2008). However, for the smaller-celled species, *P. cuspidata*, the nitrate-grown cells are the most toxic (Auro, 2007).




Dissolved domoic acid concentrations of *Pseudo-nitzchia australis* grown on different nitrogen substrates indicated (redrawn from Armstrong-Howard et al. 2008)

## Indicators of Eutrophication

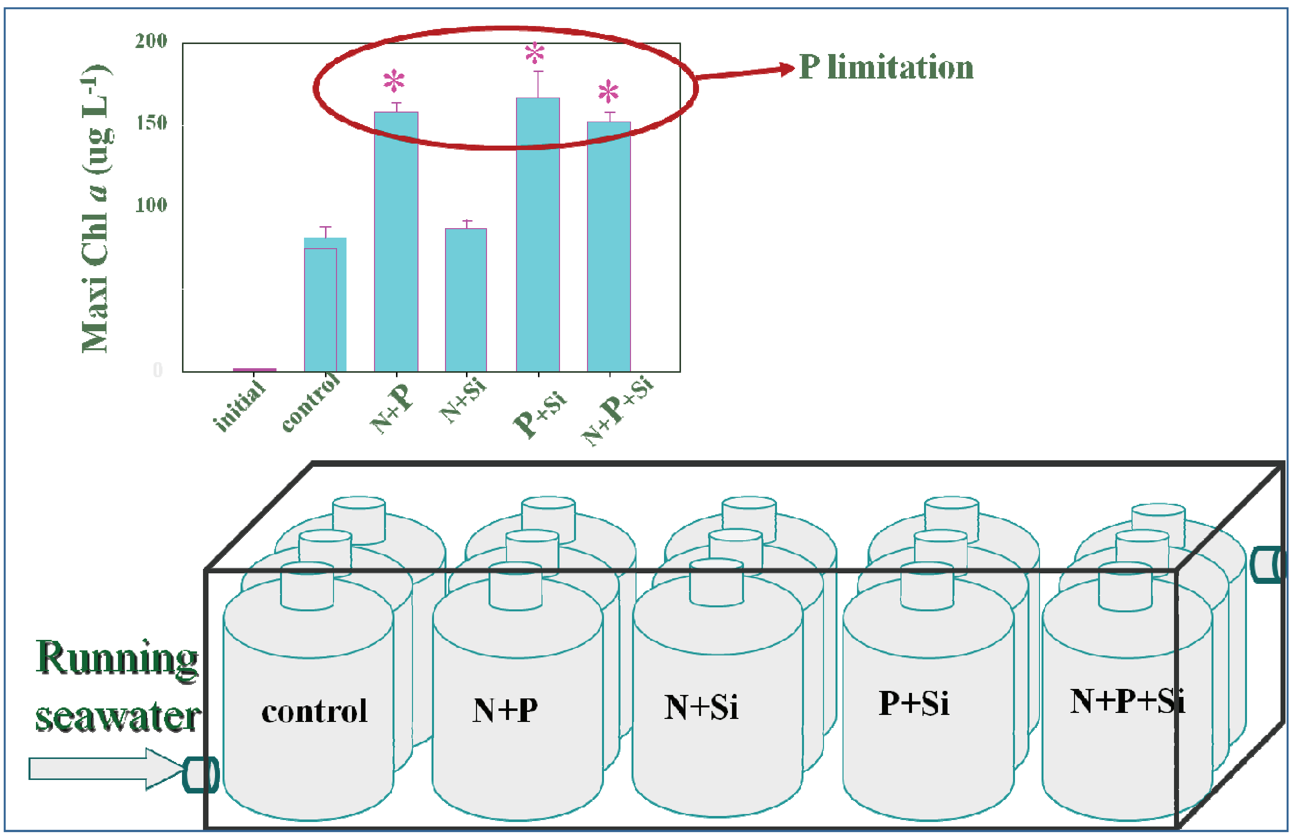
Although there is much to be understood with respect to the responses of individual species to species nutrient concentrations and forms, there are various approaches that have been found useful as indices of nutrient status. The typical indication of eutrophication is the determination of excessive nutrient concentrations in surface waters and the subsequent ecosystem response and the impacts of utilization of these nutrients. Among the many effects of eutrophication are a shift in algal species composition and an increase in the frequency and intensity of nuisance blooms or HABs (Hallegraeff 1993, Anderson et al.

2002, Glibert et al. 2005, Smith et al. 2006, Heisler et al. 2008). There are a number of approaches that have been applied toward characterizing eutrophication status of a water body; several examples of these approaches are described here.

The simplest index of eutrophication is the ambient inorganic nutrient ratio of the water and a comparison with the Redfield ratio of 16N:1P (Redfield 1934) and a Si:N ratio of 1:1 (Brzezinski 1985). If nutrients are not limiting, then this index of N:Si:P estimates the 'potential' limiting nutrient assuming that the remaining nutrients are utilized in the Redfield ratio. For example, in Moreton Bay, Australia, where inorganic nitrogen and phosphorus vary seasonally and spatially, a comparison of the inorganic nitrogen:inorganic phosphorus ratios at all seasons suggests nitrogen limitation (Glibert et al. 2006b). Nitrogen limitation in these assemblages is further underscored when the nitrogen:phosphorus ratio of the biomass is compared to that of the ambient water. Furthermore, knowing the N:chlorophyll or P:chlorophyll ratio, the potential amount of algal biomass that could be produced from the remaining nutrients (i.e. the algal yield) can be estimated. It is useful to know the 'potential' limiting nutrient for management practices such as determining which nutrient should be removed in sewage treatment to control algal blooms.

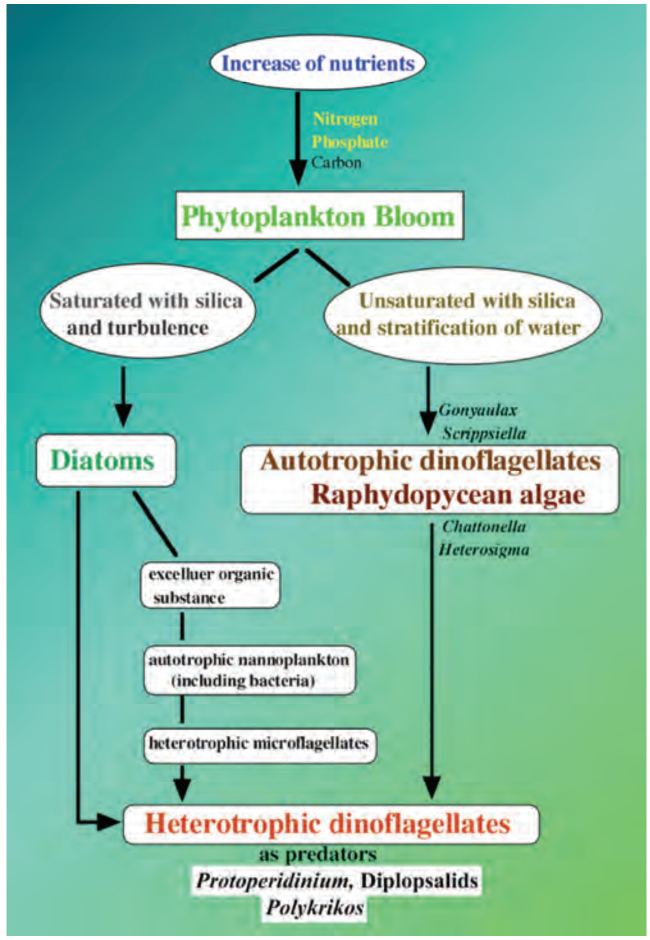
Potential limitation can also be easily estimated by nutrient addition/omission bioassays. Bioassays are short-term (typically 1-5 days) experiments in which the biomass (generally as chlorophyll) is determined upon enrichment to nutrients supplemented singly or in combination. These are useful because they give an indication of the potential algal yield (i.e. the potential eutrophication impact) and the bloom species when physical loss factors are eliminated and grazing reduced (removal of large mesozooplankton). Using such an approach in Hong Kong western waters near the Pearl River estuary, only about 10-20% of the potential eutrophication impact is realized because of the very active physical processes (Xu et al. 2009). An extensive seasonal comparison between ambient nutrient ratios and nutrient enrichment bioassays demonstrated that there was excellent agreement and hence ambient nutrient ratios can provide a rapid and reliable estimate to the 'potential' limiting nutrient and in some cases, co-limitation (Xu et al. 2008).

Multiple, integrated parameters are often better indicators of ecosystem response than single cause-




An illustration of the bioassay approach used in studies of Hong Kong and an example of the response in chlorophyll after several days of incubation. This example shows a significant (*) effect of added phosphorus (P), illustrating phosphorus limitation (modified from Xu et al. 2009).

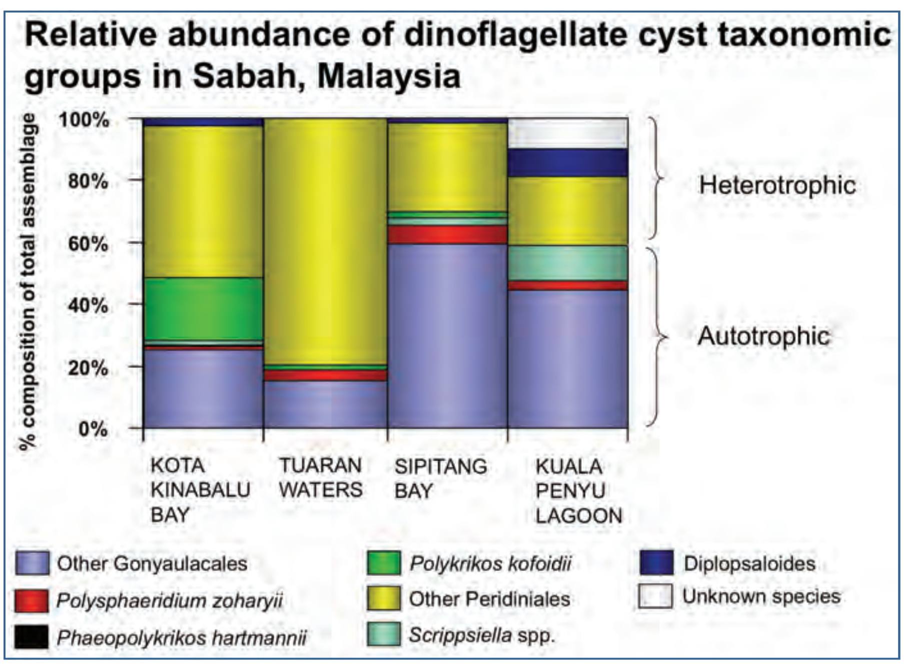
and-effect relationships. Ultimately, integrated parameters should incorporate system state variables (such as nutrients, dissolved oxygen levels), with those of biotic response (such as phytoplankton abundance and species composition) and secondary ecological responses (such as seagrass occurrence or shellfish abundance). Where data are available, rates of processes (such as primary production, nutrient uptake rates, bacterial production, zooplankton grazing) and rates of biogeochemical fluxes (such as regeneration rates of benthic fluxes) add additional information for an integrated assessment. Using such an approach, the U.S. National Oceanic and Atmospheric Administration has developed an assessment of the eutrophication status of the 138 estuaries of the U.S. coastline (Bricker et al. 2007).




In eutrophic coastal waters with high silica concentrations, diatoms bloom first, and after most of the silica is consumed, the autotrophic dinoflagellates are able to bloom. Then, heterotrophic dinoflagellates can predate these autotrophs as food. Thus, an increase in the numbers of cysts of the heterotrophic dinoflagellates in sediment cores is probably a good signal for eutrophication in coastal areas (Matsuoka 1999).

Historical indicators of nutrient loading can be obtained from the cyst record. This approach yields a longer time record of the relationship between nutrient loading and species shifts, and is based on the premise that under eutrophic conditions, there is an increase in cyst density and a proportional increase in cysts of heterotrophic dinoflagellates (Thorsen and Dale 1997, Matsuoka 1999, Dale 2009).

Nutrient enrichment of N, Si and P generally enhances the growth of diatoms and autotrophic dinoflagellates, which are good prey for heterotrophic dinoflagellates. Hence, an increase in both autotrophic and heterotrophic dinoflagellate cysts in the sediment likely reflects an increase in nutrients (Matsuoka 1999). In inner Oslo Fjord, an increase in dinoflagellate cyst abundance was accompanied by an increase in *Lingulodinium machaerophorum* and this was suggested to be a signal of eutrophication (Dale et al. 1999).




Distribution of cysts in sediments are essential for understanding the ecology and bloom dynamics of some toxic dinoflagellates. In Sabah, Malaysia, relative abundance of dinoflagellate cysts is highly variable among locations, reflecting both local dinoflagellate composition, and physical processes during sedimentation of cysts. Even with small numbers, *Polysphaeridium zoharyii* (cyst of *Pyrodinium bahamense*) consistently occurs in this area. (Furio et al. 2006)

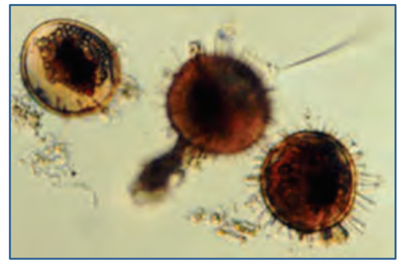
# Adaptive Strategies

Knowledge of the adaptive strategies of HAB species is required in order to understand the biodiversity of potentially harmful species and their biogeography, and to establish the parameters necessary to ultimately construct models which can simulate and/or predict their occurrence. Strategies that are potentially important in the formation, maintenance and perseverance of blooms of Asian HAB species are described below.

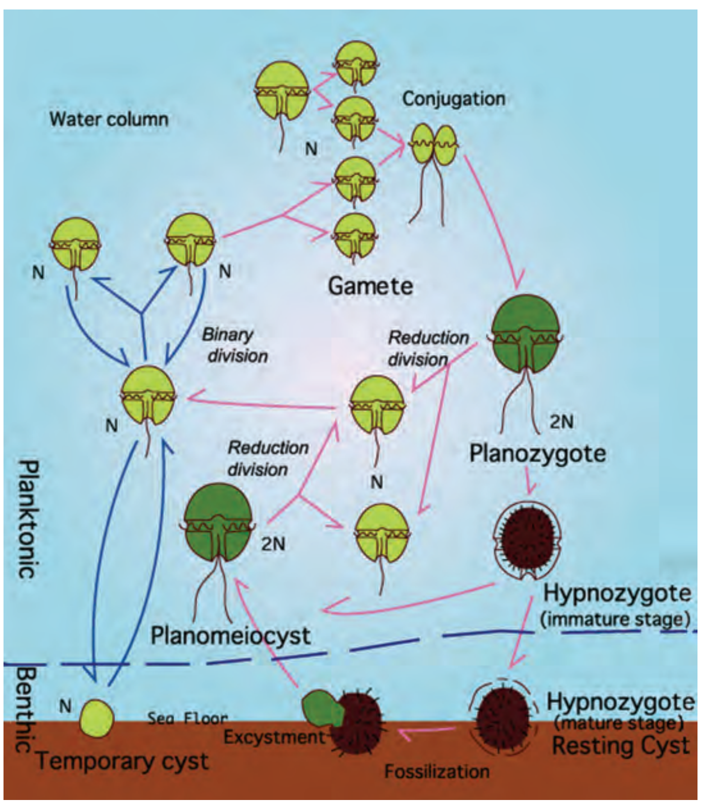
## Life Histories

There are two key aspects pertaining to life histories that are central to understanding blooms of HAB species, the role of the cyst (diploid) stage in the promotion and timing of blooms, and factors which cause bloom termination. In global terms very little is known of these two issues that are of major importance in determining HAB dynamics, and this is particularly true for HAB species in Asia.

The diploid cyst stage has been characterized for many dinoflagellate species, particularly when these occupy an extended (months) dormant stage in the life cycle. Most information is available for *Alexandrium* where information is available on dormancy, cyst maturation and excystment. For some time the cyst stage of HAB species of many genera has been elusive. *Dinophysis* and *Karenia* are two obvious examples. It now appears for *Gymnodinium catenatum*, and also *Dinophysis*, that the cyst stage is very short-lived, so comprehensive cyst beds of these forms are not found in sediments. This stage in the life cycle may be so short that cysts hardly ever reach sediments for certain species (Matsuoka et al. 2006). 'Small cells' of *Karenia mikimotoi* have been identified as a stage in the life cycle of the species, yet diploid cells of this and *K. brevis* have not yet been described, either in the field or in culture. Similarly, the life history of *Cochlodinium* is largely unknown; cyst formation and cyst distribution for this species have not yet been confirmed. Kim et al. (2002) and Kim et al. (2007) described cysts of this species, but no other reports have confirmed this yet and thus cyst formation is still in debate. Although as yet the dynamics of the cyst stage is known for only a very few HAB species, the range of variation known suggests that the cyst stage may contribute to the success of HAB species in many different ways.



Cysts of *Pyrodinium bahamense* v. *compressum* collected from Manila Bay. Photo by Y. Fukuyo.

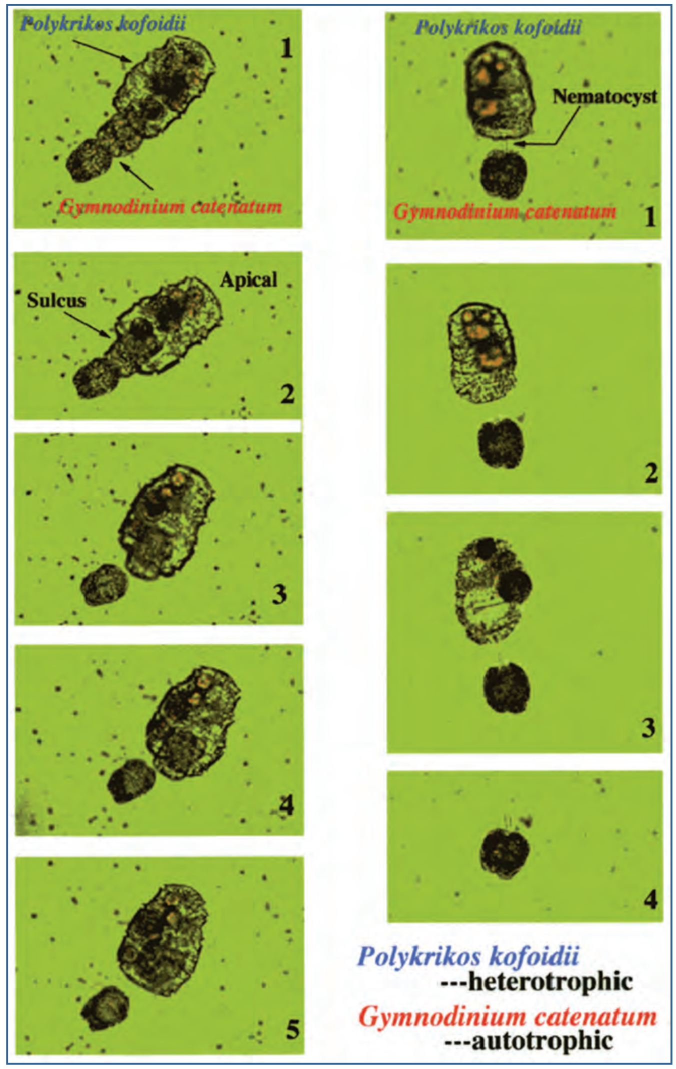



Schematic life history of dinoflagellates. Courtesy of K. Matsuoka.

The termination of blooms of HAB species can occur extremely rapidly. In all the cases of HAB studies in the field, the direct causes of bloom termination are not well known. Bloom termination may occur due to a variety of mechanisms.

There is no doubt that collapses in many diatom blooms, in particular the spring bloom of temperate regions, is caused by the exhaustion of a macronutrient, in particular nitrogen. The subsequent flocculation and sedimentation of diatom cells has been documented on many occasions. The situation is not so straightforward with dinoflagellates, the taxonomic grouping to which many HAB species belong. Harmful blooms of dinoflagellate species can occur in the apparent absence of a macronutrient because many can migrate vertically and take up nitrogen at the nutricline when surface waters become nitrogen-depleted. There is also a range of micronutrients, including trace elements and vitamins, that are also required by phytoplankton. These nutrients are rarely, if ever, measured during field bloom studies and thus the data set on which the nutrient forcing of bloom termination hypothesis can be examined is extremely limited. A major question is the speed with which blooms terminate. Mortality (or other cell export) rates have to be exceptionally high using nutrient-growth models to mimic the disappearance of cells. This has led to other hypotheses on why blooms disappear, which may (or may not) occur in tandem with nutrient control.

Some HAB species, in particular *Alexandrium*, can form temporary (haploid) resting cysts. Their formation can be induced by triggers such as a severe change in temperature, salinity or turbulence. Thus life cycle transformations triggered by environmental stress occur, and it is possible that the promotion of gamete formation can be environmentally forced.



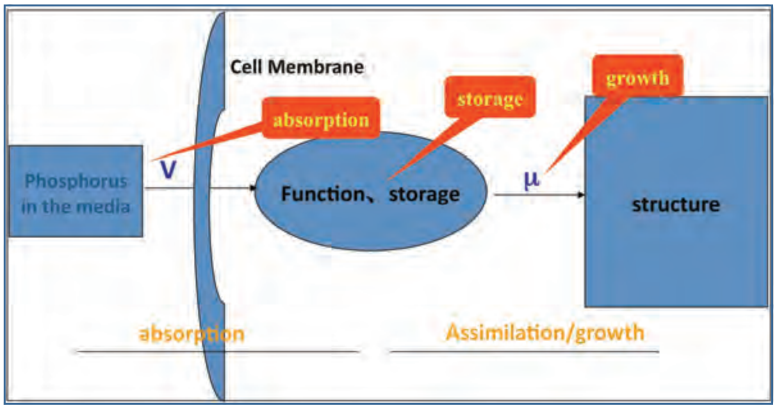

Feeding behavior of an unarmored heterotrophic dinoflagellate *Polykrikos kofoidii* on *Gymnodinium catenatum* in a natural sample (Matsuoka et al. 2000). Left column: *P. kofoidii* is engulfing a four-cell chain (1) of *G. catenatum* through the sulcus (2, 3). The cell shape is changing in engulfing prey cells (4, 5). Right column: *P. kofoidii* uses a nematocyst for catching a prey, *G. catenatum* (1). Unfortunately, *P. kofoidii* fails to engulf the prey (2, 3) probably due to the string of the nematocyst breaking off (4). Photos by K. Matsuoka.

## Pathogenic Infection through Parasites, Bacteria and Viruses

Again, our knowledge is very limited on this subject. It is known that bloom collapse of some phytoplankton species is associated with the presence of bacteria and viruses (e.g., Imai et al. 2001). We also know that some parasites infect specific HAB dinoflagellate species (e.g., Nishitani et al. 1985, Salomon et al. 2003). The attraction of the pathogen-induced bloom termination argument is that from what we generally know of their dynamics, to be successful (i.e. produce an epidemic) a pathogen requires a relatively high population density. Thus blooms where cell densities are high can be considered as open to severe pathogen infection (Yoshinaga et al. 1998, Nagasaki et al. 2004). The problem is that at the bacterial/viral level infestations cannot be observed in plankton samples, and at the parasite level infections are most often unobserved simply because they are rarely the subject of the investigation. For possible use as a microbiological agent against harmful algal blooms, bacteria and virus that exhibit algicidal activity have been isolated from blooming waters of various HAB species to examine their biological properties (Nagasaki and Tarutani 1999).

## Chemical sensing

Infochemicals produced by phytoplankton species (including HABs) may play a critical role in cell-to-cell communication, involving processes such as the induction of sexuality and life-cycle transitions (Wyatt and Jenkinson, 1997). These compounds should be distinguished from low molecular weight inorganic and organic nutrients, and complex but poorly defined DOM that may be utilized as growth substrates by the HAB population. Since known infochemicals are only produced in extremely minute concentration (typically sub-picomolar per cell), and solubility

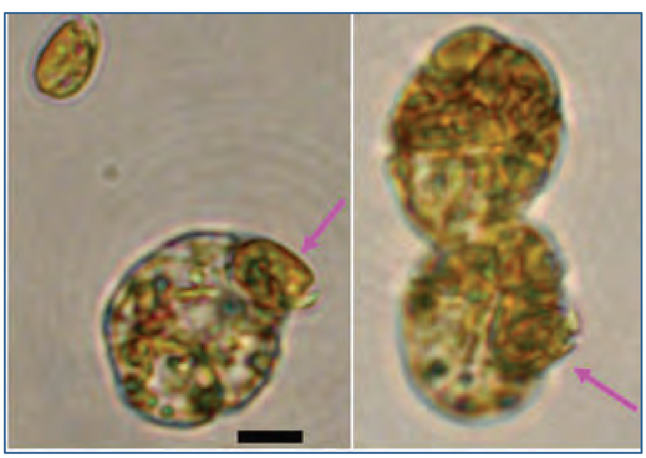



Nutrient uptake and assimilation of nutrients into structural components of the cells is a multi-step process and each step may be controlled by different factors. After S. Lu.

(particularly for lipophilic compounds) may be very limited in the aqueous medium, a HAB population of high-biomass bloom proportion could raise and sustain the concentration of such biologically active metabolites.

## Nutrition

As described previously, there are multiple aspects about nutrition that are important in the survival and success of HAB species. First, there is the way in which species have adapted to macronutrient (N,P, Si) supply in terms of uptake, kinetics, growth, and limitation. Different species display differential preferences for nutrient forms, and they often thrive in different nutrient regimes. These differences are derived from fundamental differences in physiology that can be measured, for example, in terms of uptake kinetics, enzyme activities, and growth rates under different nutrient regimes, Nutritional preferences may also be modified by various physical factors such as light, temperature and pH.



Feeding by *Cochlodinium polykrikoides* on the dinoflagellate *Amphidinium carterae* (arrows). Scale bar = 5 mm. From H.J. Jeong.

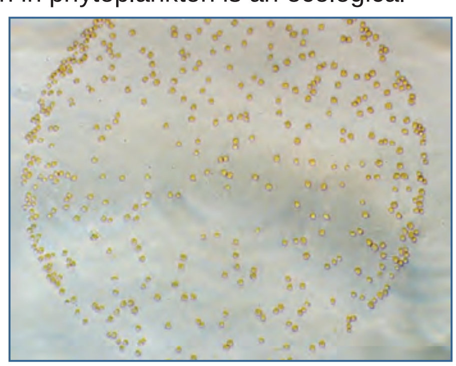
Heterotrophic nutrition of many dinoflagellates and other HAB groups is increasingly recognized. Feeding through trapping hosts with a pallium veil and then feeding through a peduncle, has been described for *Protoperidinium*, and is now likely to be the route whereby species from this genus become toxic. This is not the case for *Dinophysis* which synthesises its own toxins, yet mixotrophic species from this genus are known. *Dinophysis* can be grown on *Myrionecta rubra* (Park et al. 2006), and there is some recent evidence that cells of this genus taken from the field have contained other dinoflagellates. For many species, feeding not only provides an additional source of nutrients, but many species also appear to grow faster when provided prey rather than inorganic nutrients (Jeong et al. 2005, Adolf et al. 2006, Glibert et al. 2009).

## Colony Formation

Many phytoplankton have the ability to form colonies or chains. Diatoms, particularly those living in mixed, turbulent waters, often form chains of cells which are robust, held together by siliceous polymers. The haptophyte *Phaeocystis* also forms relatively solid colonies during its life cycle, which may be linked to turbulence (Seuront et al. 2007). Some harmful dinoflagellates, such as *Gymnodinium catenatum*, form long chains of cells. Chain formation in motile species such as dinoflagellates gives the advantage of being able to swim faster than single cells of similar size and shape, and hence optimise the advantages of vertical migratory patterns (Fraga et al. 1989).

## Motility and Migration

Depth regulation in phytoplankton is an ecological strategy. Diatoms and flagellates can regulate their depth either by changing their buoyancy or by using their flagella. Chain-forming flagellates such as *Gymnodinium catenatum* can

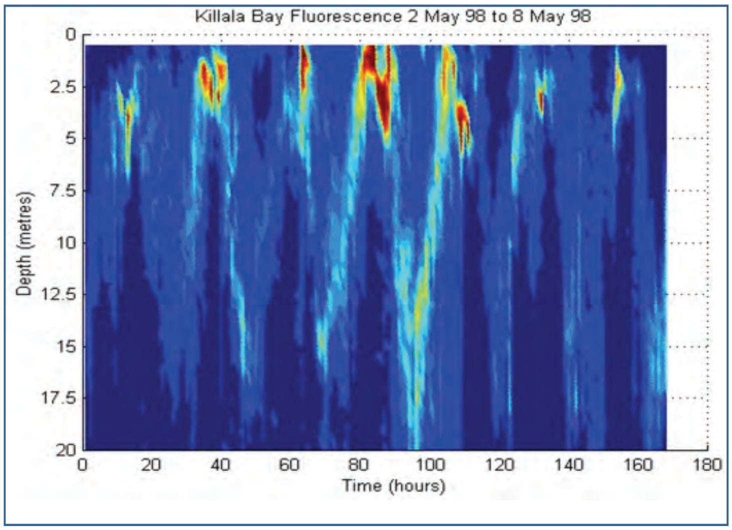


*Phaeocystis globosa*. Colonies, chains and other structures are important adaptive strategies.

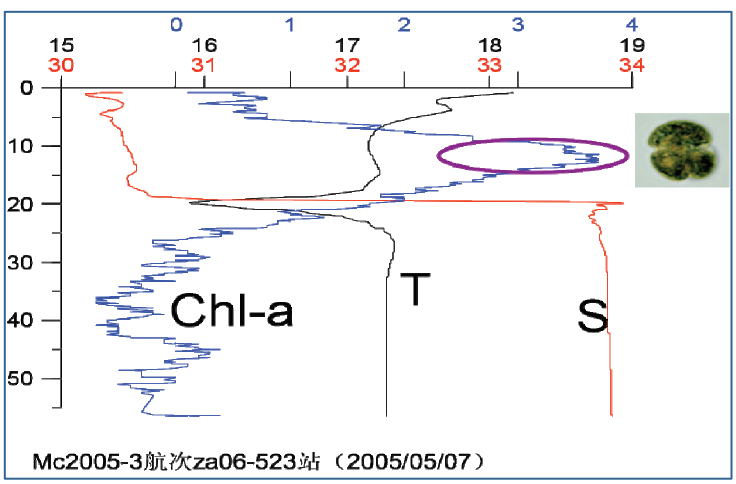
move faster than single cells of species with similar size and shape (Fraga et al., 1988). Some phytoplankton actively seek out an optimal depth and it has been shown that if they do not find such an optimal depth, they will keep moving up and down (Cullen, 1985). In some cases phytoplankton migrate, in other cases they do not. A single species may be able to switch behavioural pattern from migrating to layer forming during different nutritional modes (especially in mixotrophs) and/or stages of the population growth.

## Thin Layer Formation

Many HAB species form sub-surface thin layers of very high cell density. This subject has been reviewed in detail elsewhere (GEOHAB 2008). A notable example is that of *Karenia,* which is found in sub-surface layers, usually at or just below the pycnocline, in which cell densities achieve several million cells per litre (Gentien et al. 2007). The advantages of this strategy are many and include the potential optimization of net growth (even when conditions might be sub-optimal) by minimising dispersive losses, improving the chances of successful sexual reproduction, and the advantageous modification of the chemical environment through the promotion of recycling processes.




Time-depth fluorescence showing diel vertical migration of the toxic dinoflagellate *Gymnodinium catenatum* at Killala Bay in the Huon Estuary, Tasmania. In vivo fluorescence of chlorophyll pigment is used to track the rhythmic movement of cells in the water column. From CSIRO Marine Research.




Subsurface chlorophyll maximum dominated by *Karenia mikimotoi* in the East China Sea as detected by fluorescence signals. From Y.F. Wang.

## Interspecific competition

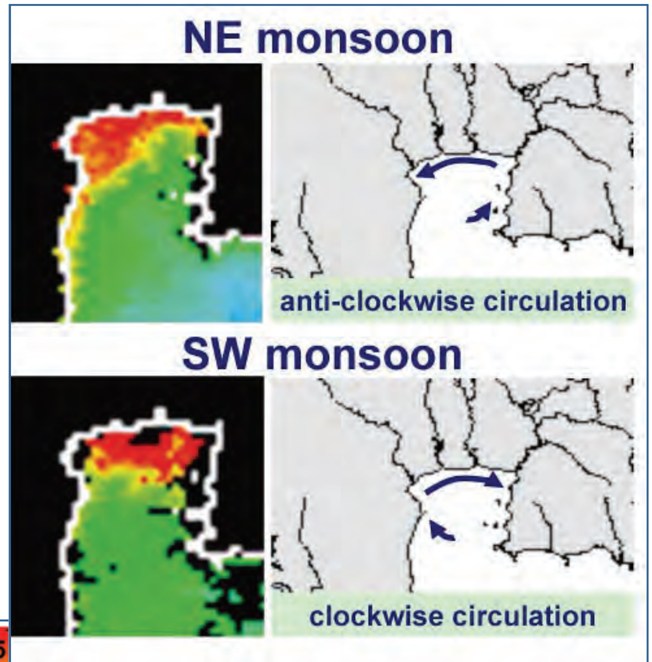
Interspecific competition occurs between HABs and other organims in various ways through trophodynamics (grazing), allelopathy, and microbial interactions with bacteria and viruses. Knowledge on these processes is essential to understand population dynamics of HABs in nature. For example, when *Chattonella marina* and *Chattonella ovata* are cultured with *P. globosa*, growth of *C. marina* and *C. ovata* is significantly inhibited, suggesting that *P. globosa* out-competed *C. marina* and *C. ovata* in population competition (Y. Qi, unpubl.). Both cell-free filtrates and haemolytic extracts from *P. globosa* at the senescence phase show a similar inhibitory effect on coexisting *P. donghaiense*, *C. marina* and *C. ovata,* implying that *P. globosa* have an allelopathic effect on these HAB species, and that haemolytic toxins or allelochemicals of *P. globosa* have important roles in its population competition

## Comparative Ecosystems

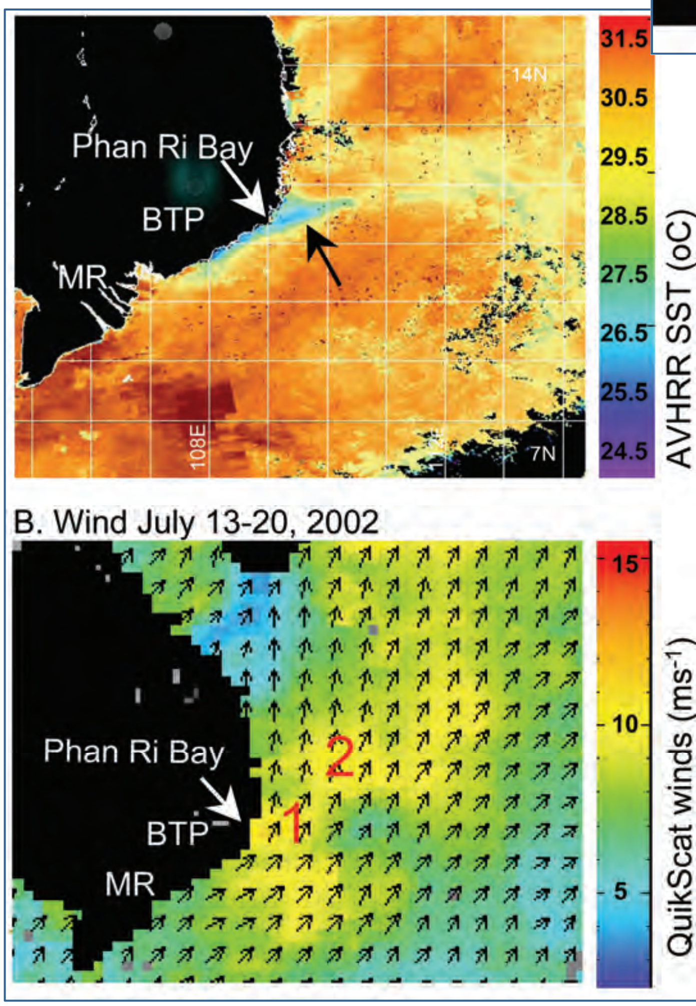
Coastal regions are subjected to a wide range of highly variable physical forcings such as wind speed and direction, rainfall and run-off, tides and currents. Similar ecosystems should respond to perturbations in broadly similar ways, and thus comparative studies carried out either globally or regionally are of potential benefit. A clear link exists between phytoplankton dynamics and physical oceanographic processes, a theme which extends to HABs. Across southeastern Asia there are many, mainly meteorological, physical processes which are common to coastal zones and which impact in varying degrees on the initiation, frequency and intensity of HABs. Stratification also affects the development of HABs.

## Winds

Monsoons, other upwelling favourable winds or on-shore winds can all impact HABs in a variety of ways. There is a seasonal pattern in monsoon winds, which are southwesterly in the wet season from April to September, and northeasterly winds in the dry (November-January) season. Wind-forced upwelling will occur where the coastline is suitably exposed, as in Korea and Vietnam, where *Phaeocystis globosa* blooms can result (Tang et al., 2004). Upwelling may also occur in the region such as along the Sulu Archipelago in the Philippine Islands, a phenomenon associated with topography, and along the coast of China, caused by on-shelf intrusions of the Taiwan Warm Current. Modifications in the nutrient environment caused by the uplift of cool, nutrient-rich deep water to the sea surface are well understood. More specifically, water upwelled along the Changjiang coast is relatively high in phosphorus, and can complement the nitrogen-rich runoff from the Changjiang River, which contributes to the extensive blooms of *P. donghainese* and *K. mikimotoi* that occur along this part of the coastline.



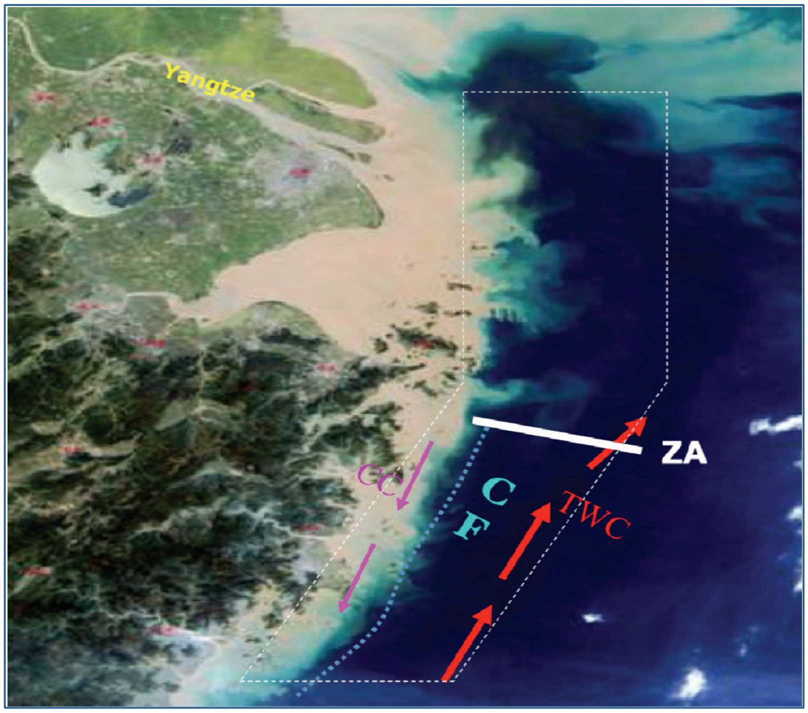

Seasonal monsoon causes an alteration of water circulation in the upper Gulf of Thailand, leading to changes in location of bloom formation of green *Noctiluca* (redrawn from Sriwoon et al. 2008).

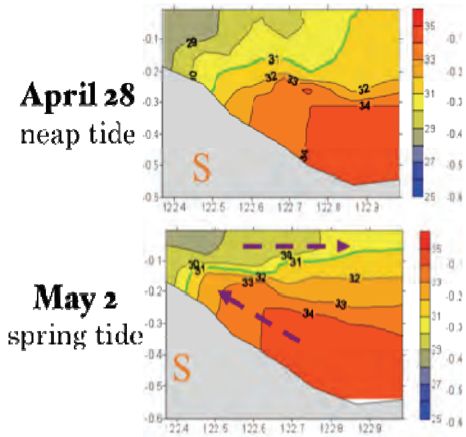



During the southwest monsoon, wind-induced upwelling provides high nutrients along a part of the southern coast of Vietnam, producing dense blooms of *Phaeocystis globosa*. The intensity of upwelling is amplified by narrowing and thus steepening of the shelf around 12.5°N. The intensity of the southwesterly wind is also an important factor. As another prominent feature off Vietnam, the upwelled cold water also affects the interior of the South China Sea, as a result of the offshore advection of wind-driven upwelling coastal jet. From Tang et al. (2004).

In contrast, in the Pearl River estuary and coastal waters of Hong Kong, the summer upwelling dilutes the high nitrate concentrations in the estuarine plume, since the nitrate concentration in the upwelled deep water is up to 5 times lower than in the surface plume. Therefore upwelling may decrease potential eutrophication impacts in Hong Kong waters (Harrison et al. 2008).

Aside from increasing the mixing of the water column, monsoons can, in the context of HABs, also alter circulation patterns, a phenomenon widely observed across the region. This alteration impacts HAB bloom dynamics (Sriwoon et al. 2008). In the upper Gulf of Thailand, blooms of green *Noctiluca scintillans* are formed in the eastern part during the southwest monsoon, while the bloom shifts to the western gulf during the northeast monsoon.



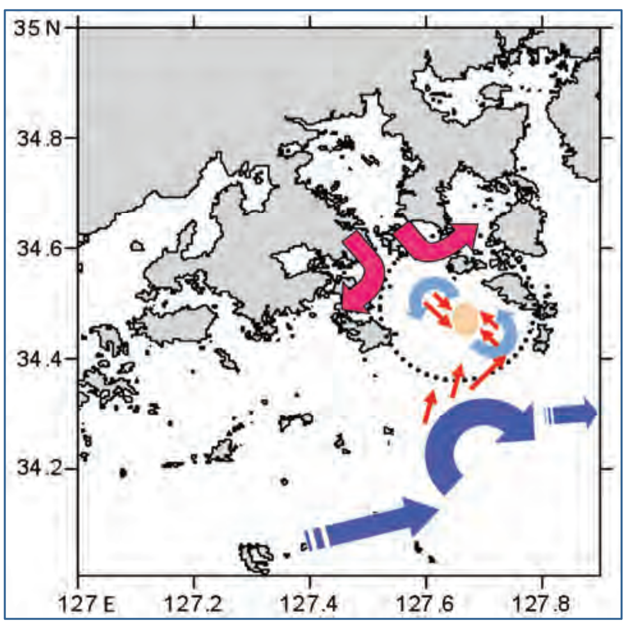



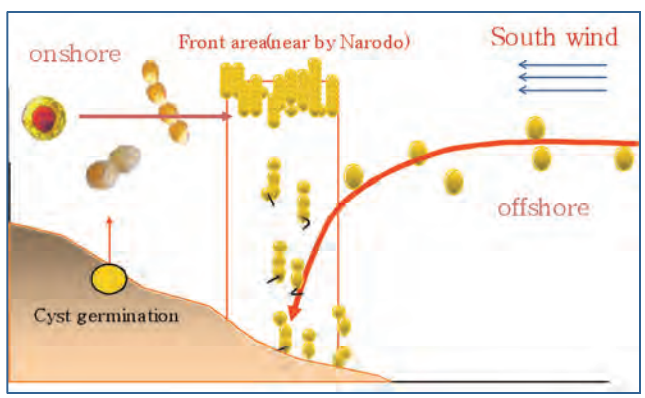

A SW wind induces upwelling intrusion of bottom water, and surface water with high nutrients moves offshore. TWC: Taiwan Warm Current, CC: coastal counter current, CF: coastal front. ZA denotes a designated transect line. Courtesy of D.D. Zhu.

In Manila Bay, Philippines, *Pyrodinium* blooms are formed during the southwest monsoon, generally from June to September, and both vegetative cells and cysts are the highest at this time. In contrast, the abundance of this species is lowest during the northeast monsoon from October to February. Two major seedbeds of this species have been identified, which feed the entire bay following specific climatological and other physico-chemical changes (Azanza et al. 2004). Bloom simulations using physical and biological parameters have shown that blooms tend to occur during spring tide, and are advected almost always along the coastline and following wind direction (Villanoy et al. 2006).

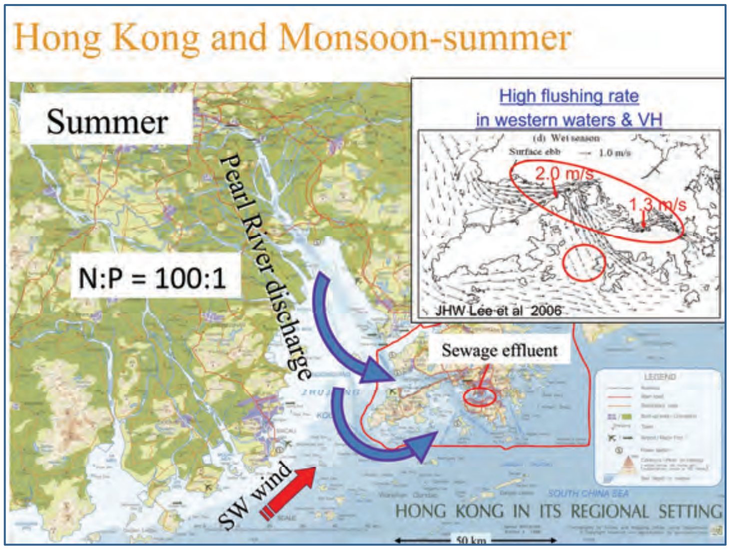
## Stratification

Stratification can be very important in allowing HABs to develop. A common observation is of high-biomass blooms developing a few days after heavy rainfall. The traditional reasoning is that stratification, which develops due to warm sunlit days following heavy rains and high freshwater input provides a suitably stable eutrophic zone for




Ocean currents and/or wind-induced onshore advection play an important role in transport and concentration of HABs on the southern coast of Korea. This transportation of cells towards a coastal retention zone, Narodo region, depicted by a circle with a dotted line, is considered as a source of the seed population of cells which initiate blooming of *C. polykrikoides* in the southern coast of Korea (Park et al. 2005, Lim et al. 2000, Kim et al. 2001, Lee 2008). The initial blooms always occur nearby in the Narodo region. Experiments using drifting buoys showed that *Cochlodinium* blooms are always transported from the southern coast to eastern coast by the easterly Korean coastal current. The strength of the Kuroshio current that influences the advective capacity of the Korean coastal current, and a cold water mass with high nutrients which occurs every summer near by Korean Peninsula, determine the magnitude of blooming (Suh et al. 2001).




Map of the Pearl River Estuary and waters around Hong Kong illustrating that water from the estuary has a very high N:P ratio, 100:1, and is transported into Hong Kong waters by the south-western monsoons in summer. The inset shows the high tidal currents that increase the flushing. Courtesy of P. Harrison.

plankton to bloom. Thus stratification favours HAB development.

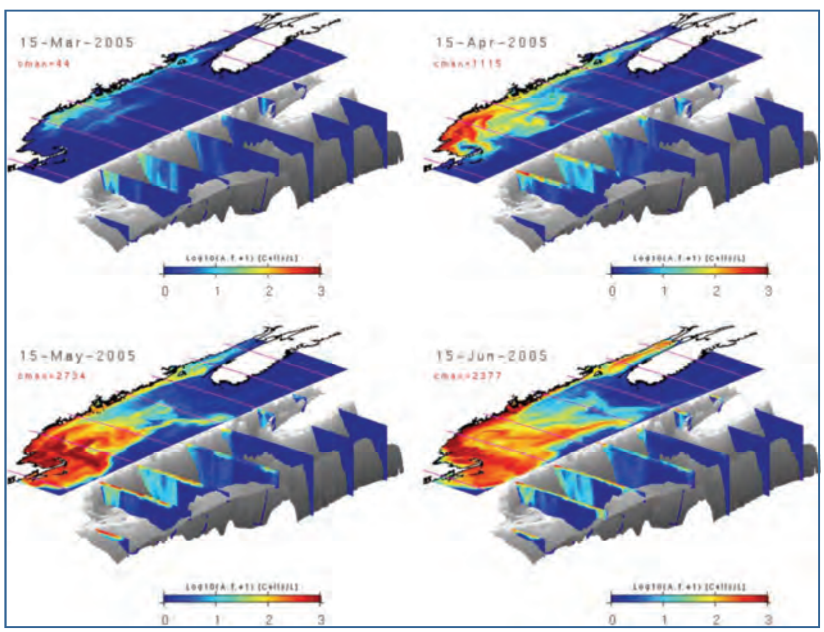
The relationsip between stratification and HABs can be subtle. For example, the nutrient supply from the Pearl River in Hong Kong does not usually promote excessive blooms because their effect in Victoria Harbour is dampened by the high degree of flushing and mixing (Lee et al., 2006). However, bioassays in which physical processes such as mixing and dilution are eliminated, have shown that if stratification can be maintained for only two days, then extensive blooms of chain-forming diatoms can quickly develop here (Xu et al. 2009).

## Observation, Modeling and Prediction

The ultimate goal of HAB research is the prediction of harmful events. Where HABs arise as a consequence of eutrophication, a thorough understanding of the dyna- mics will ultimately provide us the management tools and issues whereby their occurrence, frequency or intensity can be reduced. These goals can be achieved through modelling of HAB events.

In the global context, models currently attempt to predict HABs and cover a wide variety of complexity. At the more sophisticated level 3D physical models coupled with biological models are usually species-specific, and cover life cycles and other biological processes important in blooms. They are usually also site-specific and cover relatively large areas. One example of this approach is the *Alexandrium fundyense* model for the Gulf of Maine (He et al. 2008). Others are available, for example, for *Karenia* blooms of northwestern France (Vanhoutte-Brunier et al. 2008).

At a lower scale of complexity are models which are still biophysical coupled models, but which have a more limited set of parameters. However, they may still require a high degree of background information in order to be utilized. An example is a model which predicts the initiation of *Alexandrium minutum* blooms in an inlet on the Irish coast (Ní Rathaille 2007). In this case, knowledge of the growth rate dependency on light and temperature is coupled with the effect of tidal dilution. Blooms result when growth exceeds dilution by the tide. Note that important environmental parameters such as nutrients are not, in this case, necessary.




Temporal and three-dimensional spatial evolution of simulated *Alexandrium fundyense* bloom conditions along the U.S. northeast coast on 15 March, 15 April, 15 May and 15 June 2005. In each panel a surface cell concentration map is shown on top of seven sections showing vertical cell distribution. Note that for better visualization, both surface and vertical cell concentrations are scaled by Log10 (from He et al. 2008)

The advantages of the less complex models are firstly they can be run successfully using simple spreadsheets or other generic software on small computers. Secondly, they can be highly effective management tools in that for a particular location, the important forcing variables have been identified and thus models are substantially simplified. They do, however, still require a high degree of background information and understanding of the system in order to be formulated.

In terms of using models as management tools, another effective technique is the use of fuzzy logic. These logic models are essentially based on statistical probabilities and have been developed for some HABs (Blauw et al. 2006). Site specific logic models, as opposed to those which are species specific, seem to be most successful. The model for *Dinophysis* (DSP) blooms in the bays of southwestern Ireland is a good example (Raine et al. 2010). Populations are transported along the coast when the wind is blowing from a particular direction, and when the wind direction changes the bloom is transported into aquaculture production sites. If the correct wind direction is forecast and it is the correct time of year, then there is a very high probability of a bloom. The accuracy and range of this approach is limited in this case to that of the local weather forecast, approximately 5-6 days.

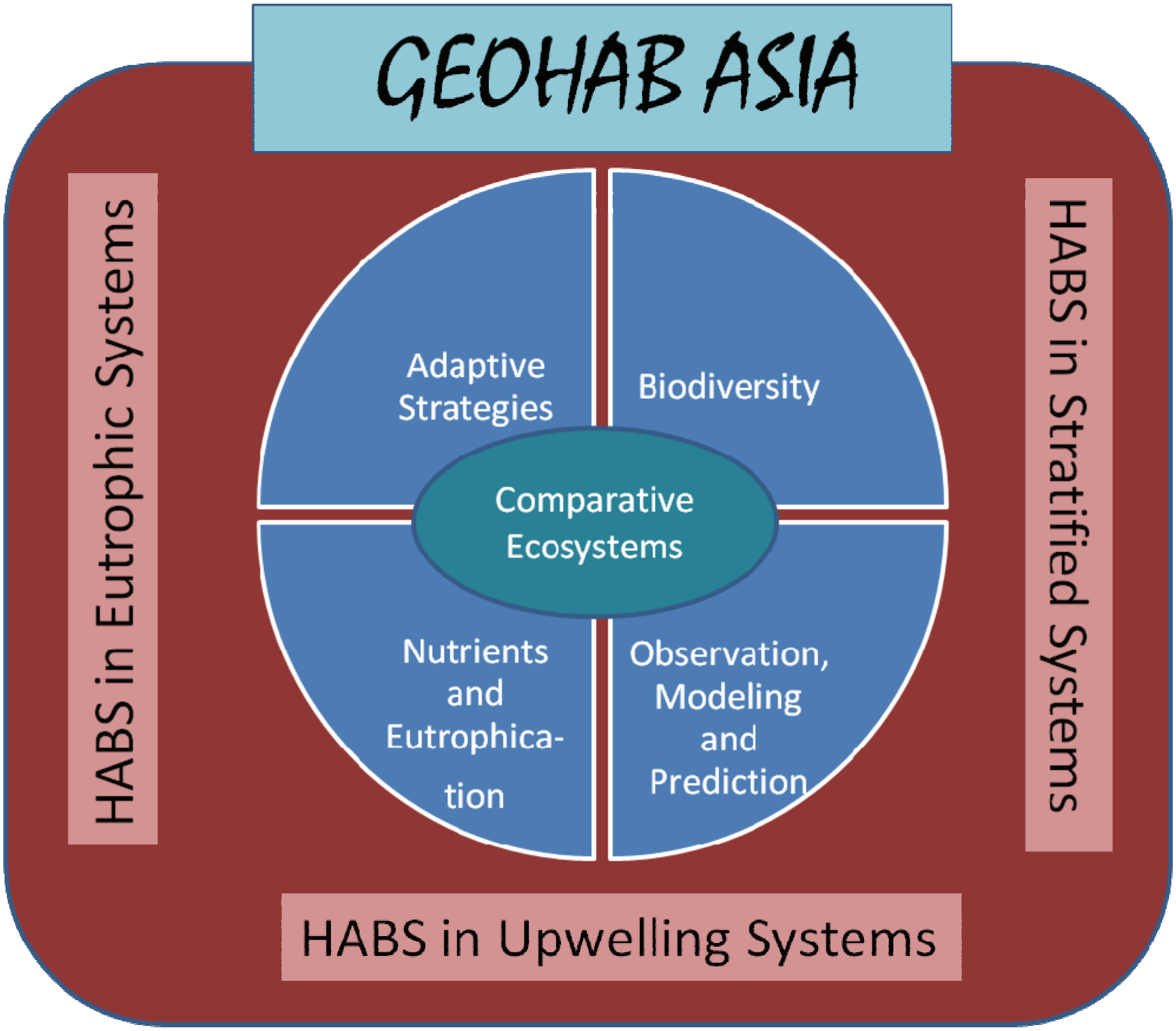
A variety of types of model are available for the range of scales which are appropriate for modeling harmful algal blooms. Referred to above are only a sample of those types available. The scales required range from the intracellular, cellular and up to the community scale for biological models, whereas the scales that can be required from physical models range from centimeters to kilometres and from seconds to weeks. It will be a challenge to see how available modeling approaches can be adapted to the prediction of blooms of *Cochlodinium, Phaeocystis, Noctiluca* and other harmful forms of plankton in Asian waters.

# Implementation of GEOHAB Asia by Programme Element

Contrasting systems in subtropical Asia. Photos by P. Glibert

**Research** on HABs in Asia will benefit from a comparative, international approach. A regional community of scientists is required to better understand the diversity of HABs and their impacts, and the multiple factors that are controlling their population dynamics, in some cases in different ways regionally.

Highlighted in this chapter are the overarching objectives of GEOHAB *Asia*, organized around the 5 Programme Elements as described earlier in this document and in the GEOHAB Science Plan (2001). As a Regional Programme of GEOHAB, the research of GEOHAB *Asia* also intersects and contributes to Core Research of GEOHAB. Highlighted in this chapter are the key objectives and questions that can and should be studied on a regional comparative basis. Examples are provided of detailed research questions. In most cases, suitable sites and studies are numerous; thus, the identified questions and systems are representative and not intended to be a comprehensive list.




Programme elements in GEOHAB Asia and its relationship with Core Research Projects.

## Programme Element 1: Biodiversity and Biogeography

Despite taxonomic descriptions of HAB species there still remain several uncertainties in their systematics. Understanding biodiversity and biogeography of species is essential before relationships can be developed with oceanographic, anthropogenic or climatic factors.

Example specific questions of particular relevance to GEOHAB *Asia* region include:

- *What are the morphological and molecular characteristics of HAB species across the region?*
- *What is the distributional pattern of HAB species in the water column and benthic habitats across the region?*

The GEOHAB Objectives for Biogeography and Biodiversity, adapted for GEOHAB *Asia*, include

1. Assess the genetic variability of HAB species in relation to their toxicity, population dynamics, and biogeography
2. Determine the changes in the biogeographical range of HAB species caused by natural mechanisms or human activities
3. Determine changes in microalgal species composition and diversity in response to environmental change

Examples of HAB species identified for co-operative comparative studies in GEOHAB Asia.

| Taxa | Toxicity/harm | Species |
|---|---|---|
| Diatoms | Domoic acid producer | *Pseudo-nitzschia* spp.<br>*Nitzschia navis-varingica* |
| Prymnesiophytes | Haemolysin & Allelopathy | *Phaeocystis globosa* |
| Dinoflagellates | PSP-causative species | *Pyrodinium bahamense* var. *compressum*<br>*Gymnodinium catenatum*<br>*Alexandrium* spp. |
| | Ichthyotoxic species | *Cochlodinium polykrikoides*<br>*C. fulvescens*<br>*Karenia mikimotoi*<br>*Heterocapsa circularisquama* |
| | Benthic species | *Ostreopsis* spp.<br>*Prorocentrum lima*<br>*Gambierdiscus* spp.<br>*Coolia* spp. |
| | Biomass producer | *Prorocentrum donghaiense*<br>*P. dentatum*<br>*Noctiluca scintillans* |

Potential outputs of studies of biogeography and biodiversity of HABs in Asia include

- New tools for detecting HAB species
- Comprehensive inventories of regionally important HABs
- Quantitative assessments for determining relationships with climate and human activities

## Programme Element 2: Nutrients and Eutrophication

As described earlier in this report, the increasing trend toward regional eutrophication is of great concern, and therefore understanding the relationships between increasing eutrophication and the apparent regional increase in HABs is important.

GEOHAB *Asia* is thus an important regional contributor to the GEOHAB Core Project on HABs in Eutrophic Systems, and shares many of the key questions, such as

- ♦ *Are there clusters or specific types of HABs that are indicative of nutrient increases?*
- ♦ *To what extent do residence time and other physical processes impact the relationship between nutrient loading and HAB proliferation?*
- ♦ *How do feedbacks and interactions between nutrients and the planktonic microbial food web impact HABs and their detrimental effects?*
- ♦ *Do anthropogenic alterations of the food web, including overfishing and aquaculture activities, synergistically interact with nutrients to favour HABs?*
- ♦ *How do anthopogenic changes in land use, agricultural use of fertilizer, and NOx emissions from vehicles and dam construction affect the delivery of nutrients to coastal waters and the resulting incidences of HABs ?*
- ♦ *Do climate change and climate variability have impacts on ecosystems that augment the impacts of eutrophication in the formation of HABs?*

Potential outputs of studies on nutrients and eutrophication include:

- Guidance for development of policies related to eutrophication and HABs
- Improved basis for establishing site selection criteria for aquaculture operations
- Quantitative baseline information for integrated coastal management

Nutrient, phytoplankton, and bacterial sampling in Hong Kong Harbor. Photo by P. Glibert.

The GEOHAB Objectives for Nutrients and Eutrophication, adapted for GEOHAB *Asia*, include

1. Determine the composition and relative importance to HABs of different nutrient inputs associated with human activities and natural processes
2. Determine the physiological responses of HAB and non-HAB species to specific nutrient inputs
3. Determine the effects of varying nutrient inputs on the harmful properties of HABs
4. Determine the role of nutrient cycling processes in HAB development and proliferation

# Programme Element 3: Adaptive Strategies

Adaptive strategies are the physiological bases for explaining why HAB species occur and proliferate. As already stated, these include variations in life histories and nutritional, toxin production and migration strategies. Our current awareness of these strategies vary across the suite of HAB species that occur around southeastern Asia. Increasing our knowledge of them will allow us to define those strategies important in determining when and where HABs occur and produce harmful effects.

The GEOHAB objectives can be achieved through cooperative studies designed either at the species-specific or generic level. Example questions tackling species-specific issues include

## Ocean Fertlization

Telegraph.co.uk

**Proposal to fix Pacific with 'urea' dump**

By Charles Clover, Environment Editor

Last Updated: 6:01pm GMT 05/11/2007

Proposals to dump large quantities of nitrogen-rich chemical in the Pacific as a quick fix for climate change have emerged at a UN treaty meeting in London.

Governments meeting to discuss whether the oceans should be used for experiments aimed at "fixing" carbon from the atmosphere heard that an Australian company is planning to dump 500 tons of industrially-produced urea – a substance that naturally occurs in urine – into the sea between Philippines and Borneo.

Ocean fertilization schemes have been suggested as a means by which phytoplankton blooms could be promoted and which could ultimately result in the sequestration of carbon to the deep ocean when these organisms die. Both iron and urea have been proposed in different parts of the world's oceans in fertilization schemes; these substrates would provide the limiting nutrient (iron, nitrogen) in these regions. All of the schemes for ocean fertilization share common concerns over verification. Quantifying the flux of carbon to the deep sea is complex, as much of it is recycled via the microbial food web, and some may be transported via ocean currents.

Ocean urea fertilization is of particular concern with respect to HAB development because urea is used preferentially as a nitrogen source by some cyanobacteria and dinoflagellates. Some HAB species also increase their toxicity when grown on urea. The most recent proposal for urea fertilization was in the Philippines where toxic dinoflagellates such as *Pyrodinium bahamense* and *Gymnodinium catenatum* are common and where *Cochlodinium* sp. has been known to cause fish kills.

- *Why is the strategy for vertical migration different between* Cochlodinium *and* P. donghaiense *and do these strategies vary with bloom stage? How can these strategies be used effectively when clay spraying is used for bloom control?*

- *Why do non-chain forming HAB species actively migrate equally well compared with the chain formers (*G. catenatum, P. bahamense, A. tamiyavanichii, C. polykrikoides*)?*

- *What causes bloom termination (environmental conditions, pathogens, grazing, chemical sensing, or disperal) and how does it vary with species?*

- *Do toxins act against other phytoplankton species or bacteria?*

- *Are geographic variations in toxicity a result of species composition (e.g.,* Pseudo-nitzschia *and ASP), or are they caused by availability of nutrients?*

- *Why do HAB species such as* P. bahamense *and* Karenia *sp. form thin layers?*

The GEOHAB Objectives for Adaptive Strategies, adapted for GEOHAB *Asia*, include

1. Define the characteristics of HAB species that determine their potential for growth and persistence
2. Define and quantify the effects of life histories on growth and population dynamics of HAB species
3. Define and quantify the effects of colony formation, motility and vertical migration on growth and population dynamics of HAB species
4. Define and quantify the effects of interspecific competition, microbial interactions and info- and allelo-chemicals on growth and population dynamics of HAB species

The studies of adaptive strategies in GEOHAB *Asia* also has relevance to the GEOHAB Core Research Project on HABs in Stratified Systems. The link between stratification and the dominance of flagellates in marine systems is well understood in general terms. Most HAB species belong to this broad group of microalgae. Yet, the precise strategies whereby these algae are adapted to stratified environments have yet to be fully described, but one common feature is their existence in high densities in sub-surface thin layers. Research into this aspect of HAB species is the main topic of the Core Research Project on HABs in Stratified Systems.

## Programme Element 4: Comparative Ecosystems

Marine ecosystems can be classified operationally by their morphology into different categories, such as coastal bays, continental shelves, lagoons and estuaries. Commonalities exist within the oceanography, typology and ecosystem types along the coastline of Asia. As HABs should respond in broadly similar ways in similar ecosystems, a comparison of ecosystems will allow the grouping of HABs from similar habitats and to distinguish the mechanisms controlling their population dynamics. Comparative studies will therefore allow identification of environmental signals that indicate the development of a HAB event. In this region, comparative studies are needed, targeted towards important individual species. First, this is required to explain why an organism has its particular distribution pattern and to establish if there are physical links (e.g. transport) between areas where it blooms regularly. Second, the organism in question may be involved in a shift in the (interannual) dominance in the microalgae, such as has been noted for *Cochlodinium*. *Phaeocystis globosa*, *Cochlodinium polykrikoides*, (green) *Noctiluca scintillans*, *Prorocentrum donghaiense*, *Karenia mikimotoi*, and *Pyrodinium bahamense* var. *compressus*, all lend themselves to these types of studies. Comparative studies usually employ common physical, chemical and biological oceanographic measurements during HAB investigations. Results can be used in a comparative way in order to define forcing variables which control HABs. In general terms HAB events in Asia appear to be closely associated with eutrophication.

Example questions related to comparative systems include

- *Are patterns in the frequency and intensity of specific blooms related to nutrient concentrations, forms, or loads in similar ways in different systems?*

- *Are blooms of a target species across the region linked to commonalities in the local physical oceanographic processes for each location?*

The GEOHAB objectives for Comparative Ecosystems, adapted for GEOHAB *Asia*, include

1. Identify the response of HAB species to environmental factors in natural ecosystems
2. Identify and quantify the effects of physical processes on accumulation and transport of harmful algae
3. Identify and quantify the community interactions influencing dynamics
4. Define functional groups in communities containing HAB species

# Programme Element 5: Observation, Modelling and Prediction

There is a clear need to develop operational models in order to predict HAB events. In many, if not the majority of cases, models are required to predict harmful blooms in bays, as aquaculture production is often developed at a local, as opposed to regional, geographic scale. Circulation models are extremely useful as a first step, whether these are conceptual, or two- or three- dimensional. These models often indicate the locations where sampling can be done most effectively and efficiently. Determination of the forcing variables, whether physical (water clarity, temperature, wind, light, salinity), chemical (e.g. nutrient) or other environmental parameters that promote blooms in the target sites, will allow the development of predictive models.

At a more regional level, transport and bloom models for, for example, *Cochlodinium* and *Karenia* might be developed for the larger scale blooms of these harmful dinoflagellates which develop around China, Japan and Korea.

The HAB monitoring programmes of many countries across Asia now have extensive time-series data (e.g. Seto Inland Sea). These data are highly valuable for both assessing the forcing factors which can promote blooms as well as for testing models.

Example questions related to HAB modeling include:

- *Can models of physiological processes for endemic Asian HAB species be developed?*

- *Can site-specific operational models be generated for locations within the GEOHAB Asia region which provide effective management tools for the occurrences of HAB species?*

- *How can HAB monitoring programmes within the GEOHAB Asia region be improved or enlarged, if necessary to include additional environmental parameters, to facilitate the development of predictive models?*

The GEOHAB Objectives for Observation, Modelling and Prediction, adapted for GEOHAB *Asia*, include

1. Develop capabilities to observe HAB organisms in situ, their properties and the processes that influence them
2. Develop models to describe and quantify the biological, chemical, and physical processes related to HABs
3. Develop and evaluate systems for long-term monitoring of HAB species
4. Develop capabilities for describing and predicting HABs with empirical models.
5. Develop capabilities in real-time observation and prediction of HABs

# Specific Recommendations

This document will form the basis for Regional/ National Research activities in Asian waters relevant to the objectives of the *GEOHAB Science Plan* (2001). As reviewed here, there are a number of critical HABs issues in Asia. Most of them are closely related to CRPs of GEOHAB: *HABs in Upwelling Systems, HABs in Eutrophic Systems, HABs in Stratified Systems,* and *HABs in Fjords and Coastal Embayments*. People are still experiencing fatal PSP incidents, and massive fish kills and deterioration of coastal environments due to high biomass producers are serious. Therefore, key questions raised in the previous chapter for robust understanding and quantification of the factors that regulate the dynamics of HABs needs urgent attention. Therefore, research activities as Regional/National research are effective by working through five programme elements of GEOHAB: Biodiversity and Biogeochemistry; Nutrients and eutrophication; adaptive strategies; comparative ecosystems; and observation, modeling and prediction (GEOHAB 2001). Research needs as identified during the two GEOHAB Asia Meetings, WESTPAC Symposia, EASTHAB Workshops and PICES Symposia will effectively advance our scientific understanding of HAB issues with international cooperation under the framework of GEOHAB.

Regional/National GEOHAB research is co-ordinated at a regional or national level, and national and international teams of scientists are invited to participate in GEOHAB by applying for endorsement of their research. The GEOHAB SSC may endorse already funded projects, project proposals before these are submitted for funding, or even letters of intent. In order to ensure that research is funded and co-ordinated appropriately, the plan needs to be disseminated to the interested research community and to the national agencies that might fund this research. Furthermore, national and international teams of scientists are advised to propose research related to the key questions and affiliate their research to international GEOHAB.

Examples of endorsed Regional/National Research activities in GEOHAB are listed at http://iodeweb6.vliz.be/geohab//index.php?option=com_content&task=view&id=40&Itemid=71.

Such international co-ordination provides benefits to participating scientists by enabling the comparison of different ecosystems of a similar or contrasting type in different parts of the world. The benefits include:

1. Assistance in project development, adoption of protocols, data management and co-ordination of modelling activities, contribution to and participation in appropriate framework activities.
2. Establishment of close working links with GEOHAB CRPs, and other relevant international programmes and projects.
3. Wide dissemination of project information through *GEOHAB Newsletters*, *Harmful Algal News*, GEOHAB web sites, special sessions at scientific meetings, and other communication mechanisms.
4. Improved understanding of processes in local areas through comparisons with other ecosystems and through acquisition and application of data and models obtained with common protocols and methodologies.

Training courses are one of the most important activities to enhance HAB research and monitoring in Asia. This is a view from a course on taxonomy and ecology of HABs in Hue, Vietnam. Photo by T. Omura.

# Programme Advancement and Capacity Building

**In accordance** with the GEOHAB strategy, the approach of GEOHAB *Asia* will be comparative, from the cellular to the ecosystem level. Research that is interdisciplinary — focusing on biological, chemical, and physical processes — will be fostered. Research will be multifacteted, as the problems of HABs in Asia are complex, and interactions and processes occur on a broad range of scales. Research should also integrate with the Core Research Projects of GEOHAB as described earlier in this document and with the breadth of regional activities that are ongoing, as described below.

## Regional Activities

Several international framework activities are ongoing in Asia, which will facilitate the implementation of future HAB research by ensuring an exchange of information and collaboration among researchers and managers, and the implementation of capacity building. These ongoing activities include IOC/WESTPAC-HAB, NOWPAP, PICES-HAB and EAST-HAB. Not only are HAB-related problems closely linked to the environment, fisheries and various ecosystems, but also to national policies on how coastal oceans should be utilized and managed. Therefore, holistic governance of coastal waters associated with water, and material cycling between the land and ocean should be established, as clearly stated in Millennium Ecosystem Assessment (http://www.millenniumassessment.org/en/index.aspx). In this context, extensive and intensive cooperation with relevant fields is needed.

## IOC/WESTPAC-HAB (Harmful Algal Blooms in the western Pacific)

IOC/WESTPAC-HAB, a sub-commission of the Intergovernmental Oceanographic Commission (IOC) for the Western Pacific, was established in 1989 to promote and coordinate programmes that demonstrate and enhance the value of marine scientific research and systematic observations of the ocean to resolve the needs of society as expressed and agreed upon by the 20 member countries. IOC/WESTPAC-HAB hosts a scientific symposium every 3 years, during which HAB-related oral and poster presentations are made.

IOC/WESTPAC-HAB, also established in 1989, has been serving as a platform and providing guidelines for the development of relevant programs for HABs and the establishment of communications among member countries. It functions as the regional mechanism for implementing the IOC Harmful Algal Bloom Programme. The project leader and the steering group, which consists of all member countries of WESTPAC interested in participating, meet the scientific, managerial, implementation, and resource requirements of IOC/WESTPAC-HAB activities. The most important activity of IOC/WESTPAC-HAB is Training Through Research (TTR). The TTR was officially started in 2004 with the view of building capacity of HAB scientists in the region, particularly those in Southeast Asia. Future research cooperation would also train young HAB scientists in planning and undertaking research through active collaboration with more senior HAB scientists. Joint authorship of scientific papers can be realized in this project (http://www.unescobkk.org/special-programmes/westpac/projects/ocean-sciences/harmful-algal-bloom-hab/).

## NOWPAP-HAB

The Northwest Pacific Action Plan (NOWPAP) is a part of the Regional Seas Programme of the United Nations Environment Programme (UNEP) and was adopted in 1994 with the objective of preserving the marine and coastal environment in the Northwest Pacific region through the coordination of regional activities for assessment of the state of the marine and coastal environments. Four countries — People's Republic of China, Japan, Republic of Korea and Russian Federation — are members of NOWPAP.

NOWPAP-HAB has implemented activities to understand the occurrence of HABs in the NOWPAP region, such as disseminating related information and making a booklet of countermeasures against HABs, in order to enhance measures against HABs and mitigate damage by HABs. NOWPAP-HAB made it a priority to summarize information on *Cochlodinium* as it is one of the HAB species of greatest concern in the NOWPAP region. NOWPAP-HAB has developed two websites to distribute information on HABs in the NOWPAP region, the HAB reference database and the *Cochlodinium* homepage (http://cearac.nowpap.org/project/index.html). The NOWPAP information materials on HABs are also available at the same website: http://cearac.nowpap.org/assessment/index.html.

## PICES-HAB (Ecology of Harmful Algal Blooms in the North Pacific)

The section on the ecology of harmful algal blooms in the North Pacific was established in 2003 by the Marine Environmental Committee of the North Pacific Marine Science Organization (PICES), an intergovernmental scientific organization. Present member countries of PICES are Canada, Japan, People's Republic of China, Republic of Korea, the Russian Federation, and the United States of America.

This section aims to develop and implement annual bloom reporting procedures that can be consistent with ICES procedures and therefore incorporated into the Harmful Algal Events Database (HAE-DAT). PICES-HAB organizes a HAB species-specific workshop and general session on HABs during the

Instructors and participants of the PICES HAB International Seafood Safety Project, First Workshop in Manila, Philippines, January 2009. Photo by V. Trainer

PICES annual meetings to exchange information on new toxins, new developments, and new approaches. PICES-HAB launched the "Harmful Algal Bloom International Seafood Safety Project" in 2008, with the goal of building partnerships in research and management of HABs, and to ensure the seafood safety of developing countries. A training program has been implemented in Southeast Asia, with priority given to countries with strong support for the monitoring and management of HABs (http://www.pices.int/members/sections/HAB.aspx).

## EASTHAB (Targeted HAB Species in the East Asia Waters)

As reviewed in the previous chapters, several HAB dinoflagellates, including *Prorocentrum donghaiense*, *Cochlodinium polykrikoides*, *Gymnodinium catenatum* and other species, have caused a large amount of damage to the marine environment of the East China Sea, and to aquaculture in Japan, China and Korea. In order to diminish the damage and restore the environment, communication among researchers in this region is essential. EASTHAB was established in 2004 as a scientific network consisting of Japan, China and Korea. HAB scientists participate in EASTHAB on an individual basis. EASTHAB has organized a 2-day annual meeting regularly since 2004; the meeting will be held every 2 years starting from 2010.

# Capacity Building

IOC/WESTPAC-HAB has been taking the initiative of capacity building on HAB research and management in Asia by conducting training courses. Subjects of training courses have been identified as regional needs through discussion during a series of IOC/WESTPAC-HAB symposia and various workshops held in Asia and other regions. The first training course was held in Bangkok, Thailand in 1985, and a total of 25 training courses have been held under the IOC or IOC/WESTPAC-HAB framework since then. The courses have covered taxonomy and identification of HAB species, monitoring techniques of HAB species, toxins and shellfish toxicity, physiology and ecology of HABs, and HABSEA Portal Drafting and E-learning. Since 2004, TTR projects have been emphasized. Three TTR projects are ongoing: dinoflagellate cyst mapping at the SEA region, characterization of HAB species, and development of ELISA (Abraxis Enzyme-Linked Immunosorbent Assay) detection of PSP. In the dinoflagellate cyst mapping project, cyst sampling and analysis of samples are conducted in a cooperative manner with an emphasis on the training aspect, including the standardization of techniques. To date, cysts/sediments from coastal waters of the Philippines, Malaysia and Indonesia have been described. Results have been presented in international conferences and published with multiple authorship in a scientific journal (Furio et al. 2006), and there is a plan to prepare an atlas of cysts in the area. The project "Characterization of HAB Species" aims to phylogenetically analyze and describe major HAB species in the WESTPAC region using conventional and molecular techniques.

The project "Development of ELISA Detection of PSP" organized an initial training course at Nha Trang Oceanographic Institute in Vietnam. PICES-HAB held its first training class in Manila (Philippines) on HAB species identification and PSP screening methods. The class also provided an introduction to relational and online HAB-related databases.

In spite of these activities, there is increasing demand for training in various aspects on HAB research and management with the increasing magnitude of HAB problems, and expansion of the distribution of HAB species. Thus, under such circumstances international collaboration for capacity building is important for future success.

# Data Management

GEOHAB recognizes that the collective value of data is greater than its dispersed value, and that comparative research requires effective data sharing among scientists working in different regions. The development of an appropriate data management plan is a fundamental and critical activity upon which the ultimate success of all GEOHAB projects depends. GEOHAB is using a decentralized data management and distribution system, and it is expected that as GEOHAB *Asia* develops, a centralized metadata index will become available.

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# ASIAN GEOHAB MEETING
15-16 March 2007
Koshiba Hall, the University of Tokyo

**March 15 (Thursday), 2007**

Chairperson: Ken Furuya

9:20- 9:40 *Robin Raine*, The Global Ecology and Oceanography of Harmful Algal Blooms: The GEOHAB programme
9:40-10:00 *Catherine A. Brown* and *Marcel Babin*, GEOHAB website
10:00-10:20 *Patrick Gentien*, Upwelling, eutrophication coastal embayments, and stratified environments

10:20-10:40 *Break*

Chairperson: Grant Pitcher

10:40-11:00 *Yasuwo Fukuyo* and *Rhodora Azanza*, TTR 'Training through Research', a new trial for the establishment of cooperative researches in WESTPAC
11:00-11:20 *Elsa F. Furio, Val Borja, Rhodora V. Azanza, Yasuwo Fukuyo and Kazumi Matsuoka*, Potential importance of dinoflagellate cyst mapping in depicting HAB expansion in the Southeast Asian region
11:20-11:40 *Dao Viet Ha* and *Shigeru Sato*, WESTPAC cooperative research on application of ELISA as a monitoring tool for paralytic shellfish poisons

11:40-13:00 *Lunch break*

Chairperson: Patricia Glibert

13:00-13:20 *Tian Yan* and *Mingjiang Zhou*, The species succession and harmful effects of HAB in the East China Sea
13:20-13:40 *Douding Lu, Dedi Zhu* and *Yunfeng Wang*, What's kind of role of thin layers in forming massive Blooms in the ECS
13:40-14:00 *Songhui Lu, Douding Lu, Dedi Zhu, Yunfeng Wang* and *Chuansong Zhan*g, Blooming ecology of *Karenia mikimotoi* in the East China Sea

14:00-14:20 *Break*

Chairperson: Patrick Gentien

14:20-14:40 *Kazumi Matsuoka* and *Mitsunori Iwataki*, *Cochlodinium polykrikoides*, one of targeted species in the Japanese, Korean and Chinese joint study for harmful algal blooms in the East China Sea
14:40-15:00 *Hak Gyoon Kim*, Four decadal changes of microalgal response along with nutrient dynamics in Korean coastal waters
15:00-15:20 *Hae Jin Jeong, Jae Seong Kim, Tae Hoon Kim, Jae Yoon Song* and *Yeong Du Yoo*, The roles of mixotrophic dinoflagellates in marine planktonic food webs

15:20-15:40 *Break*

Chairperson: Robin Raine

15:40-16:00 *Paul J. Harrison* and *Kedong Yin*, Eutrophication in Hong Kong waters is reduced by physical and chemical factors

16:00-16:20 *Rhodora A*zanza, Interdisciplinary oceanographic approach to the study of harmful algal blooms in the Philippines

16:20-16:40 Po Teen Lim, C.-P. Leaw, Atsushi Kobiyama, Kazuhiko Koike and *Takehiko Og*ata, Unique ecophysiological adaptation of tropical *Alexandrium* species (Dinophyceae)

18:00-20:00 *Banquet at Sanjo Conference Hall*

**March 16 (Friday), 2007**

Chairperson: Allan Cembella

9:00-9:20 *Ichiro Imai, Shigeru Itakura* and *Yasunori Watanabe*, Activity and evolution of HAB section in the North Pacific Marine Science Organization (PICES)

9:20-9:40 *Mineo Yamaguchi, Haruo Yamaguchi, Setsuko Sakamoto* and *Shigeru Itakura*, Ecophysiology of HAB species with special emphasis on the novel red tide flagellates in Japanese coastal waters

9:40-10:00 *Hiroshi Kawamura*, Remote sensing contributions to the Asian HAB research/ monitoring

10:00-10:30 *Marcel Babin*, New approaches and technologies for observing harmful algal blooms

10:30-10:50 *Break*

10:50-12:10 General discussion

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# 2ND ASIAN GEOHAB MEETING
31 January—1 February 2008
Institute of Oceanography
Nha Trang, Viet Nam

**31 January (Thursday), 2008**

Chairperson: Hakgyoon Kim

9:00– 9:20 *Ken Furuya,* Background and overview of the 1st Asian GEOHAB Meeting, Tokyo March 2007
9:20– 9:50 *Patricia M. Glibert,* Overview of the GEOHAB Core Research Project on HABs in Eutrophic Systems
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northern Vietnam

16:20–16:40 *DanLing Tang, JiuJuan Wang* and *YQ Chen*. Oceanography analysis of annually variation of harmful algal /phytoplankton blooms in the western South China Sea

16:40–17:00 *Robin Raine,* On the prediction of harmful algal events

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9:00–9:20 *Jacob Larsen,* Toxic epiphytic and benthic dinoflagellates

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11:00–12:00 Wrap-up

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| 8 | Article from the *Philippine Daily Inquirer* on May 19, 1995, reporting victims who ate green mussels collected from Manila Bay. | Philippine Daily Inquirer. Reproduced with permission. |
| 10 | The increases in nutrient loading in Asia have been well documented through direct measurements and through global modeling of nutrient fluxes... | Glibert PM, Seitzinger S, Heil CA, Burkholder JM, Parrow MW, Codispoti LA, Kelly V (2005) The role of eutrophication in the global proliferation of harmful algal blooms. Oceanography 18 (2):198-209.Reproduced with permission. |
| 10 | Global models of riverine nitrogen export also predict that Asia will have the largest increase in nitrogen export in the coming decades. | Seitzinger SP, Kroeze C (1998) Global distribution of nitrous oxide production and N inputs in freshwater and coastal marine ecosystems. Global Biogeochemical Cycles 12:93-113. Reproduced with permission. |
| 11 | The recent increase in HAB events off the coast of China is related to the increase in nitrogen-based fertilizer use over the past two decades. | Heisler J, Glibert PM, Burkholder JM, Anderson DM, Cochlan W, Dennison WC, Dortch Q, Gobler CJ, Heil CA, Humphries E, Lewitus A, Magnien R, Marshall HG, Sellner K, Stockwell DA, Stoecker DK, Suddleson M (2008) Eutrophication and harmful algal blooms: A scientific consensus. Harmful Algae 8:3-13. Reproduced with permission. |
| 11 | A long-term variation in nitrate concentrations at the mouth of the Changjiang River... | Zhou MJ, Shena ZL, Yua, RC (2008) Responses of a coastal phytoplankton community to increased nutrient input from the Changjiang (Yangtze) river. Continental Shelf Research 28:1483– 1489. Reproduced with permission. |
| 16 | Distribution of harmful chain-forming *Cochlodinium* species occurred in East and Southeast Asian coastal waters. | Iwataki M, Kawami H, Mizushima K, Mikulski CM, Doucette GJ, Relox. Jr. JR, Anton A, Fukuyo Y, Matsuoka K (2008) Phylogenetic relationships in the harmful dinoflagellate *Cochlodinium polykrikoides* (Gymnodiniales, Dinophyceae) inferred from LSU rDNA sequences. Harmful Algae 7:271-277. Reproduced with permission. |
| 16 | MODIS-aqua chlorophyll images indicate that a plume of high chl *a* extending from the Sabah coast ... | Azanza RV, David LT, Borja RT, Baula IU, Fukuyo Y (2008) An extensive *Cochlodinium* bloom along the western coast of Palawan, Philippines. Harmful Algae 7:324-330. Reproduced with permission. |
| 20 | Green *Noctiluca* is distributed in tropical coastal waters of the western Pacific... | Saito H, Furuya K (2006) Endosymbiosis in microalgae with special attention to *Noctiluca scintillans*. Bulletin of Plankton Society of Japan 53:14-21. Reproduced with permission. |
| 23 | According to the Global NEWS model, $N_2$ fixation constitutes the dominant form of DIN export | Dumont E, Harrison JH, Kroeze C, Bakker EJ, Seitzinger SP (2005) Global distribution and sources of dissolved inorganic nitrogen export to the coastal zone: Results from a spatially explicit, global model. Global Biogeochemical Cycles 19:GB4S02. Reproduced with permission. |
| 24 | Percent dissolved organic nitrogen (DON) from anthropogenic sources discharged into coastal areas... | Glibert PM, Mayorga E, Seitzinger S (2008) *Prorocentrum minimum* tracks anthropogenic nitrogen and phosphorus inputs on a global basis: Application of spatially explicit nutrient export models. Harmful Algae 8:33-38. Reproduced with permission. |
| 25 | Moreton Bay, located on the northeast coast of Australia, is a shallow, well-mixed estuary... | Glibert PM, Harrison J, Heil CA, Seitzinger S (2006a) Escalating worldwide use of urea – a global change contributing to coastal eutrophication. Biogeochemistry 77:441–463. Reproduced with permission. |
| 26 | Dissolved domoic acid concentrations of *Pseudo-nitzschia australis* grown on different nitrogen substrates... | Armstrong-Howard MD, Cochlan WP, Kudela RM, Ladizinsky N, Kudela RM (2007) Nitrogenous preference of toxic *Pseudo-nitzschia australis* (Bacillariophyceae) from field and laboratory experiments. Harmful Algae 6:206-217. Redrawn and reproduced with permission. |

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| 27 | An illustration of the bioassay approach used in studies of Hong Kong... | Xu J, Ho AYT, Yin K, Yuan X, Anderson DM, Lee JHW, Harrison PJ (2009) Temporal and spatial variations in nutrient stoichiometry and regulation of phytoplankton biomass in Hong Kong waters: Influence of the Pearl River outflow and sewage input. Marine Pollution Bulletin 57:335-348. Reproduced with permission. |
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| 33 | During the southwest monsoon, wind-induced upwelling provides high nutrients along a part of the southern coast of Vietnam. | Tang DL, Kawamura H, Doan-Nhu H, Takahashi W (2004) Remote sensing oceanography of a harmful algal bloom off the coast of southeastern Vietnam. Journal of Geophysical Research-Oceans 109:C03014.Reproduced with permission. |
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