Multi-Stakeholder Dialogue and Capacity-Building Partnership Event
UN Headquarters 2019.01.25

Segment 3: opportunities, best practices and lessons-learned for enhancing the science-policy interface

# Science-Driven Management Decision-Making in Formulating Sewage Treatment Strategy


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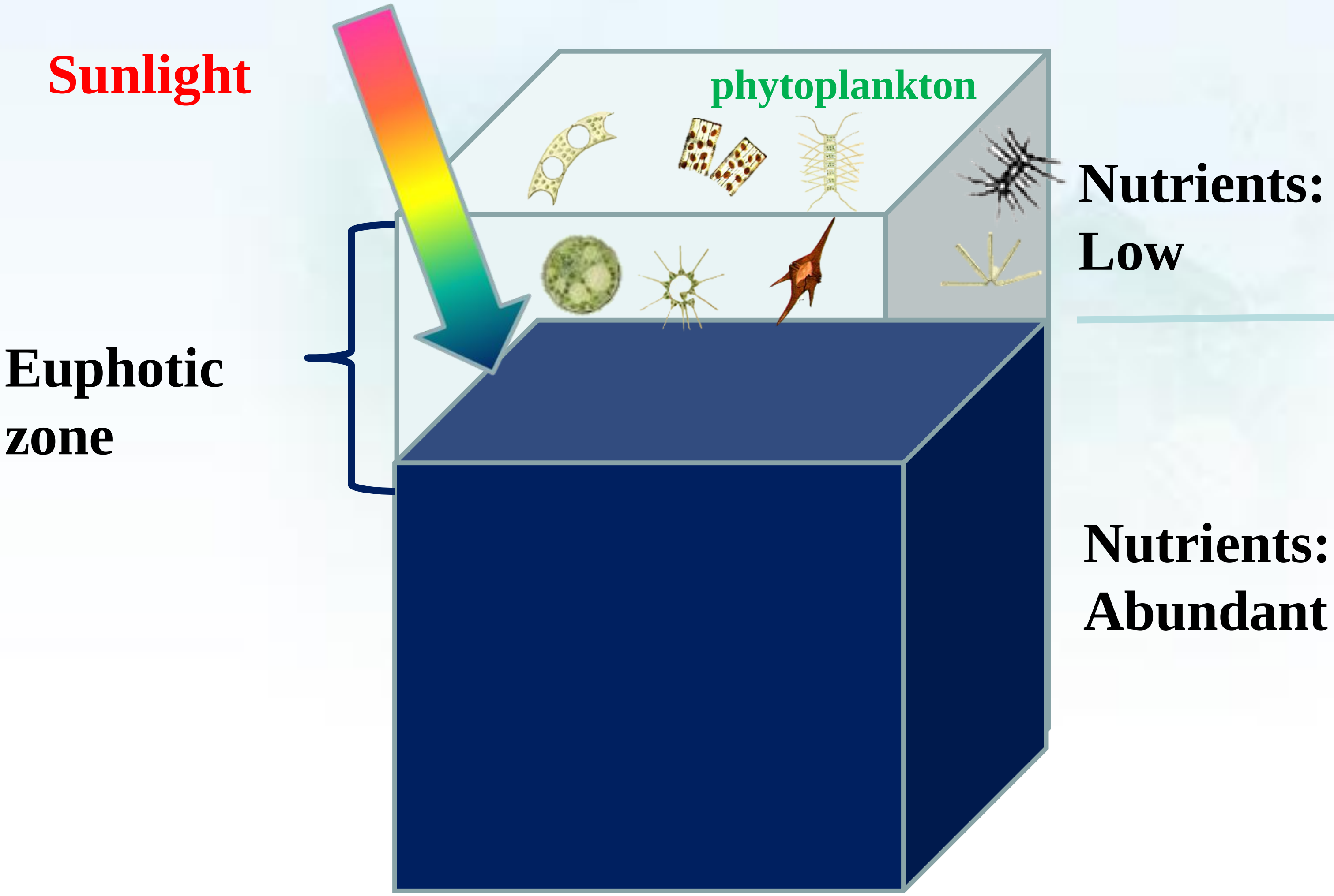
# Coastal Eutrophication in the world

- **Enrichment of Nutrients (e.g. C, N, P, Si) in coastal waters,**

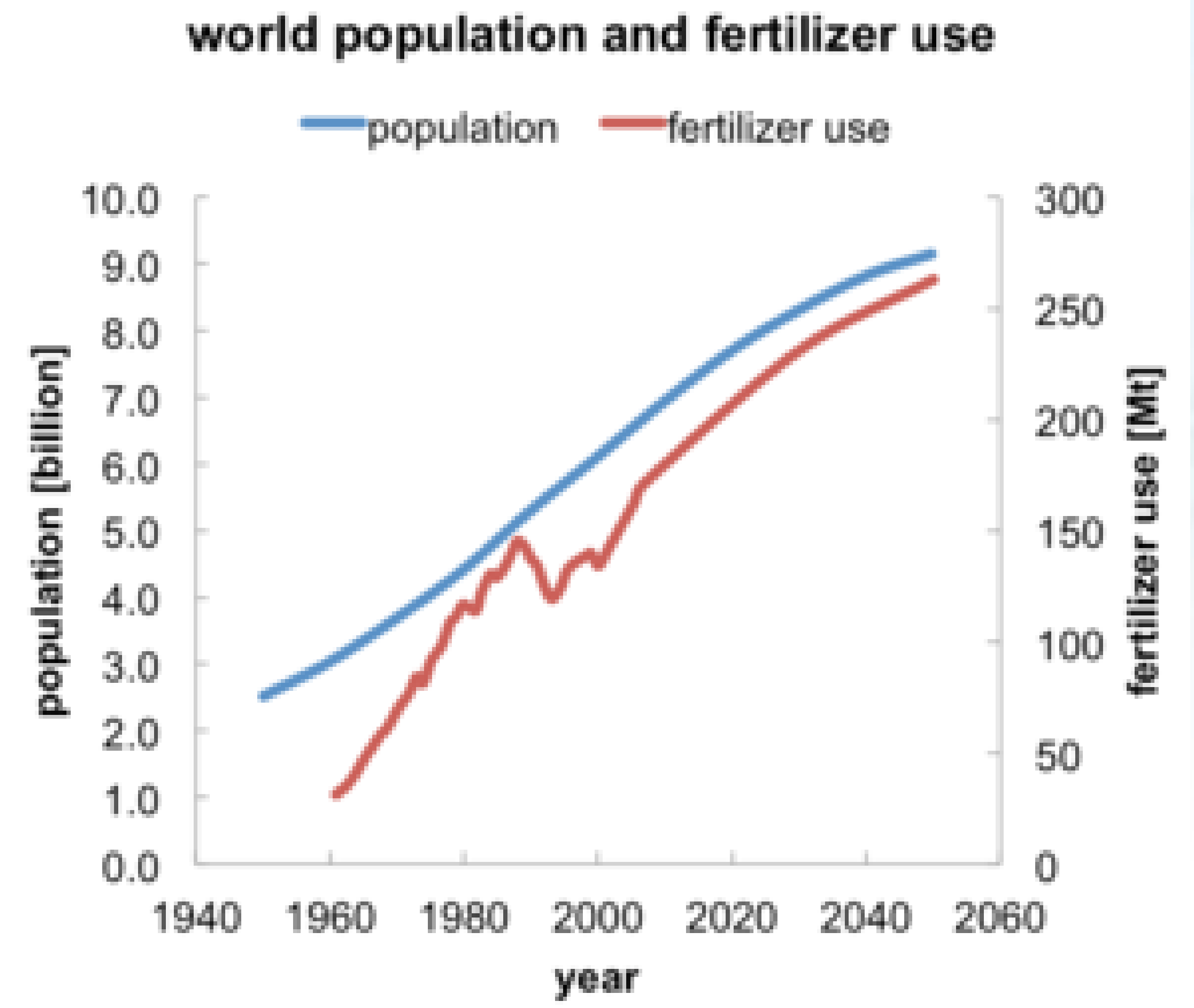
**Eutrophication symptoms or impact:**

- **Harmful algal blooms**
- **Excess algal biomass**
- **Hypoxia/anoxia in the bottom layer**

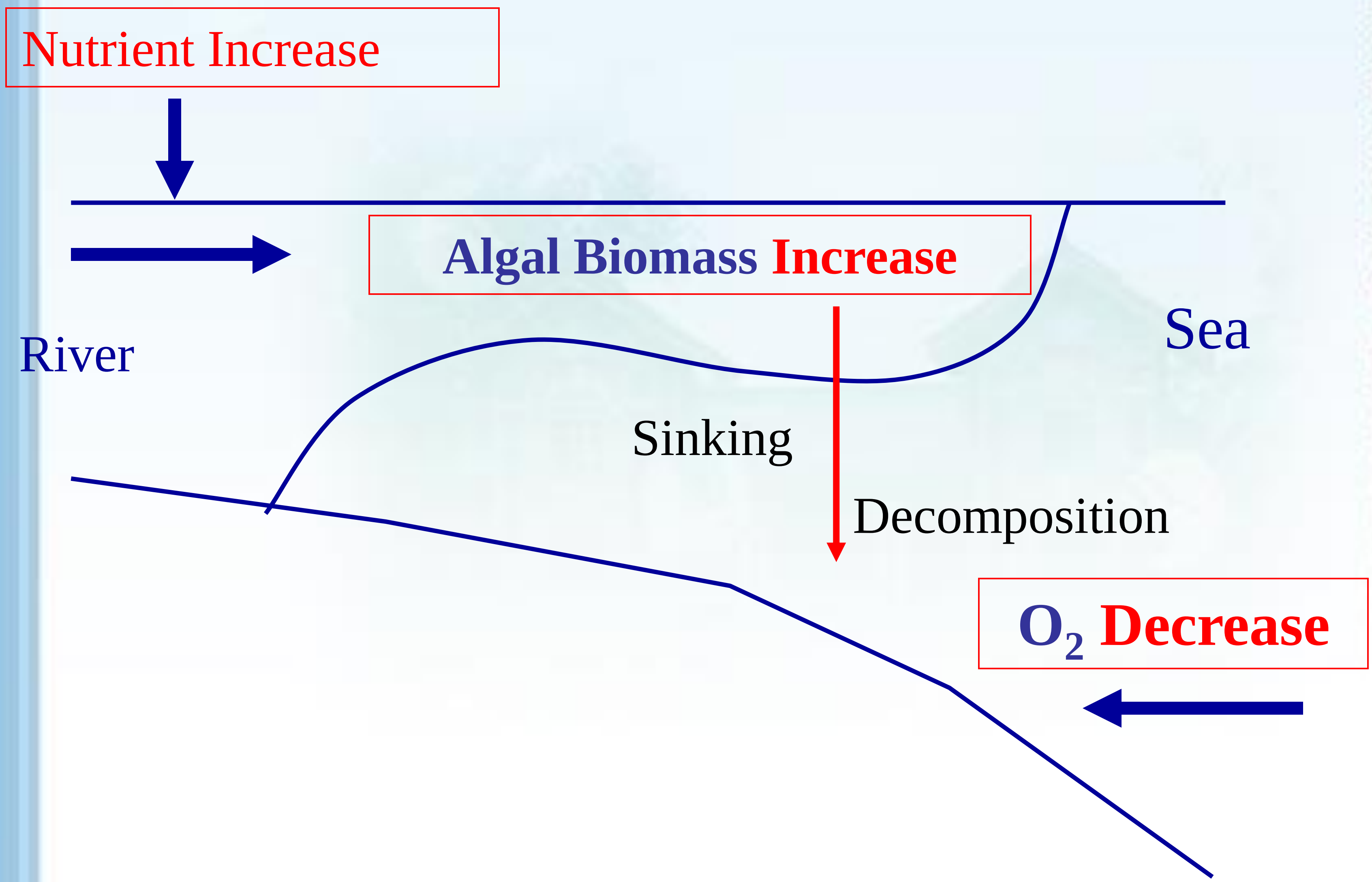
# In coastal oceans nitrogen, phosphorus or silica limits phytoplankton biomass



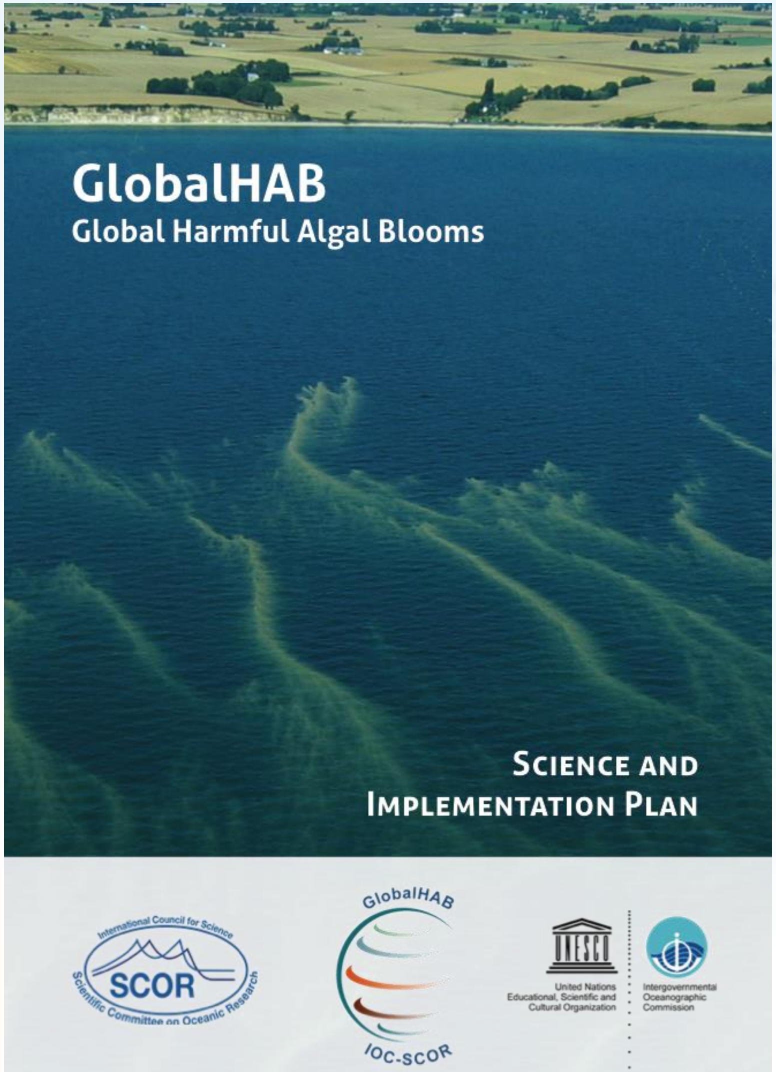
# Sources of Nutrients：
# Global population and fertiliers

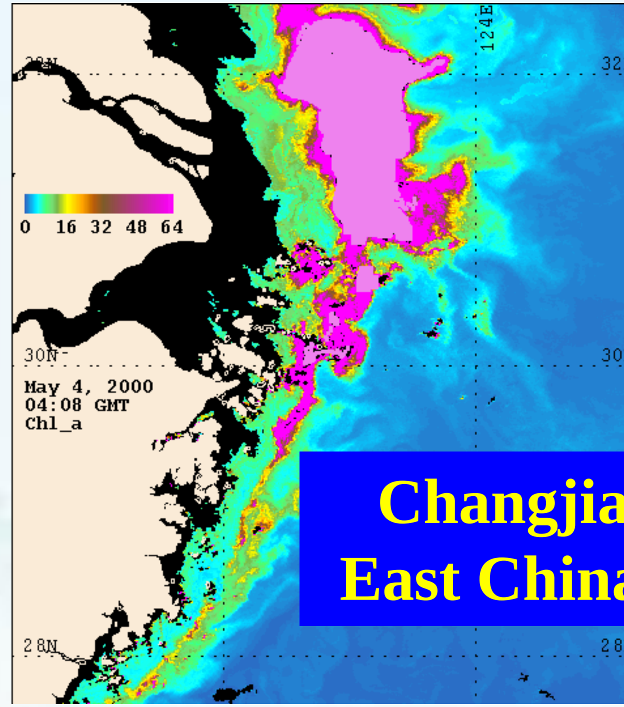


# Environmental Impact from Nutrients

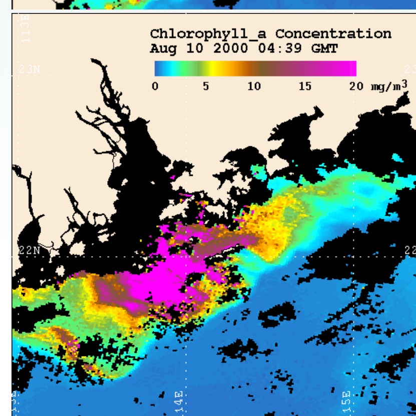


# Widespread occurrences of harmful algal blooms




**Changjiang-East China Sea**




**Zhujiang-South China Sea**

# Anthropogenic influenced "Dead zones" is expanding

Science AAAS

**Spreading Dead Zones and Consequences for Marine Ecosystems**
Robert J. Diaz and Rutger Rosenberg
*Science* **321**, 926 (2008);
DOI: 10.1126/science.1156401

2008

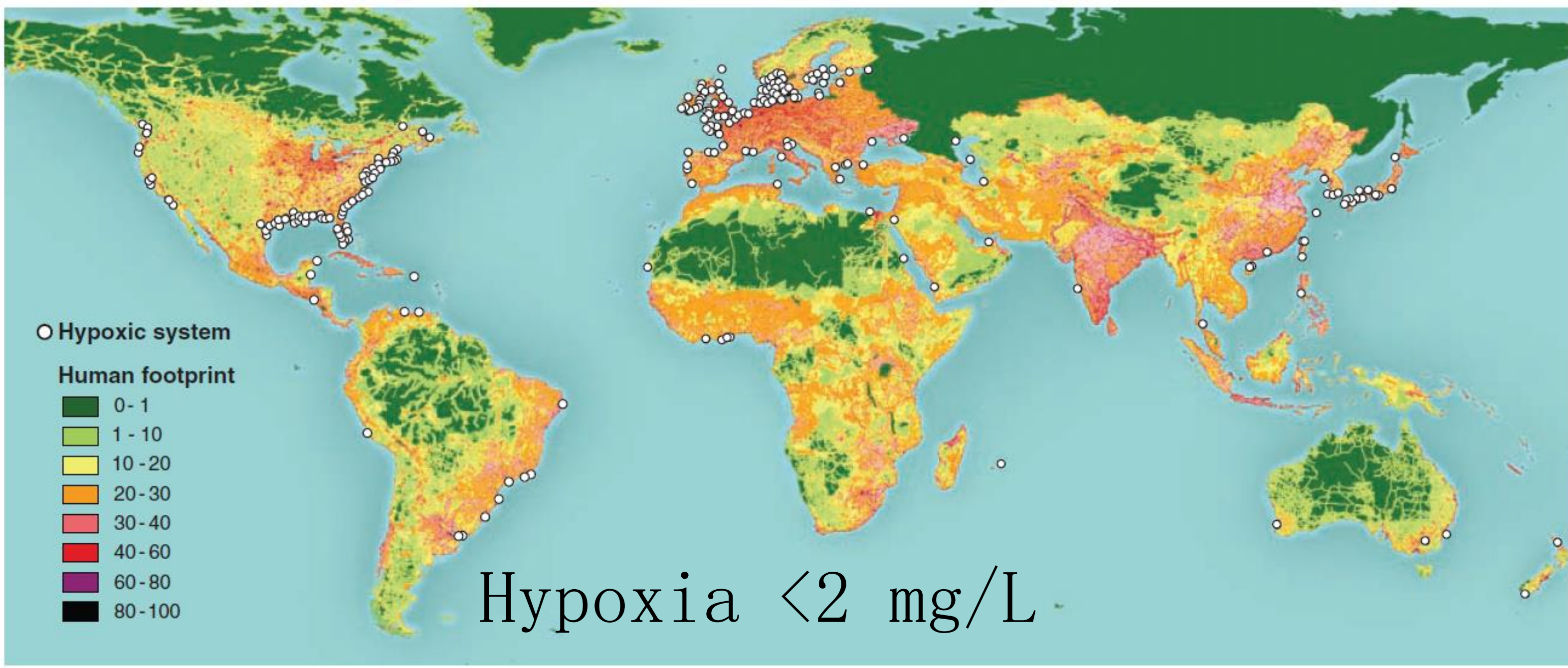



**Fig. 1.** Global distribution of 400-plus systems that have scientifically reported accounts of being eutrophication-associated dead zones. Their distribution matches the global human footprint [the normalized human influence is expressed as a percent (*41*)] in the Northern Hemisphere. For the Southern Hemisphere, the occurrence of dead zones is only recently being reported. Details on each system are in tables S1 and S2.

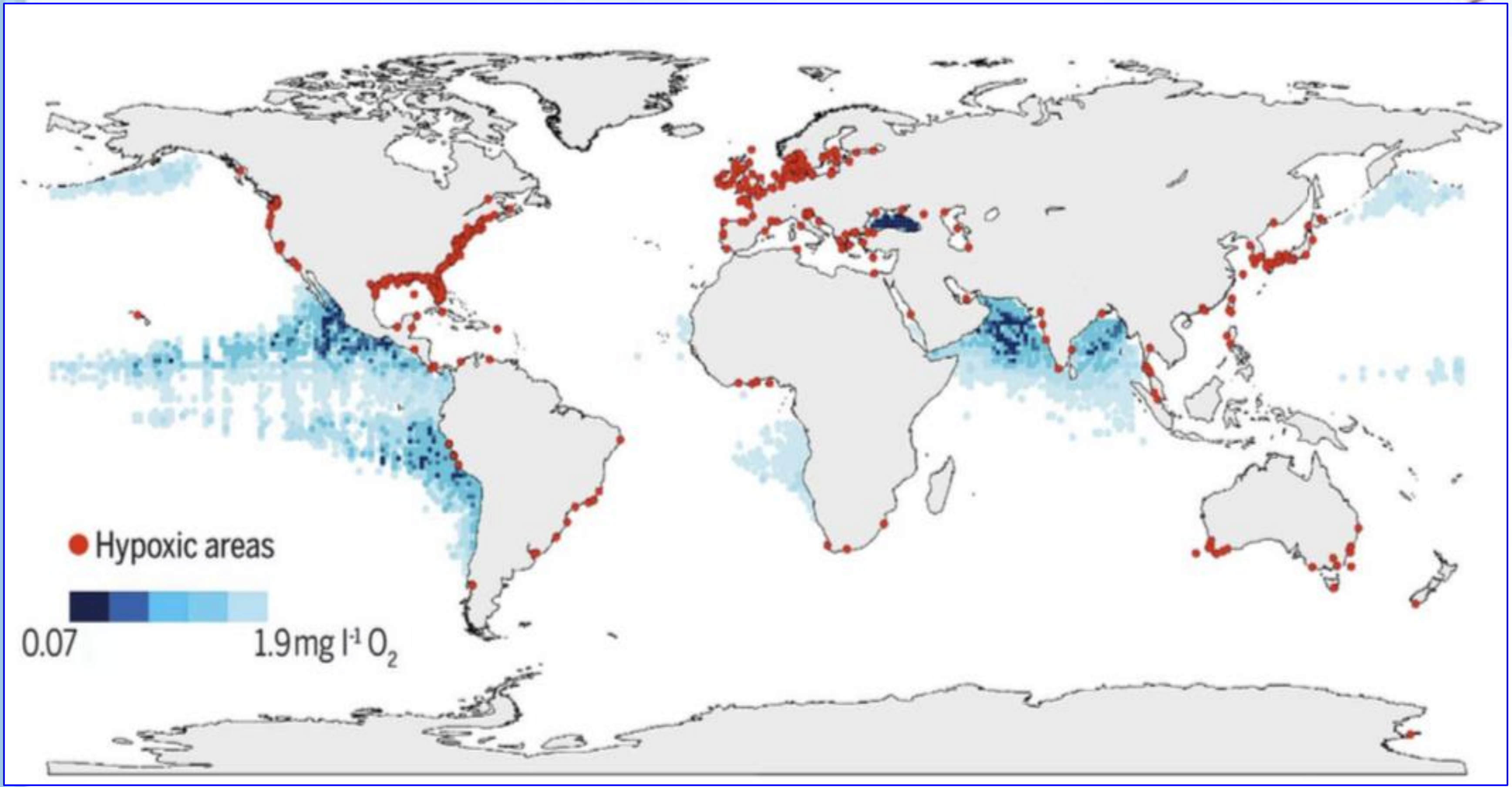
# Global Ocean Is Losing its Breath

**REVIEW**

Science 2018

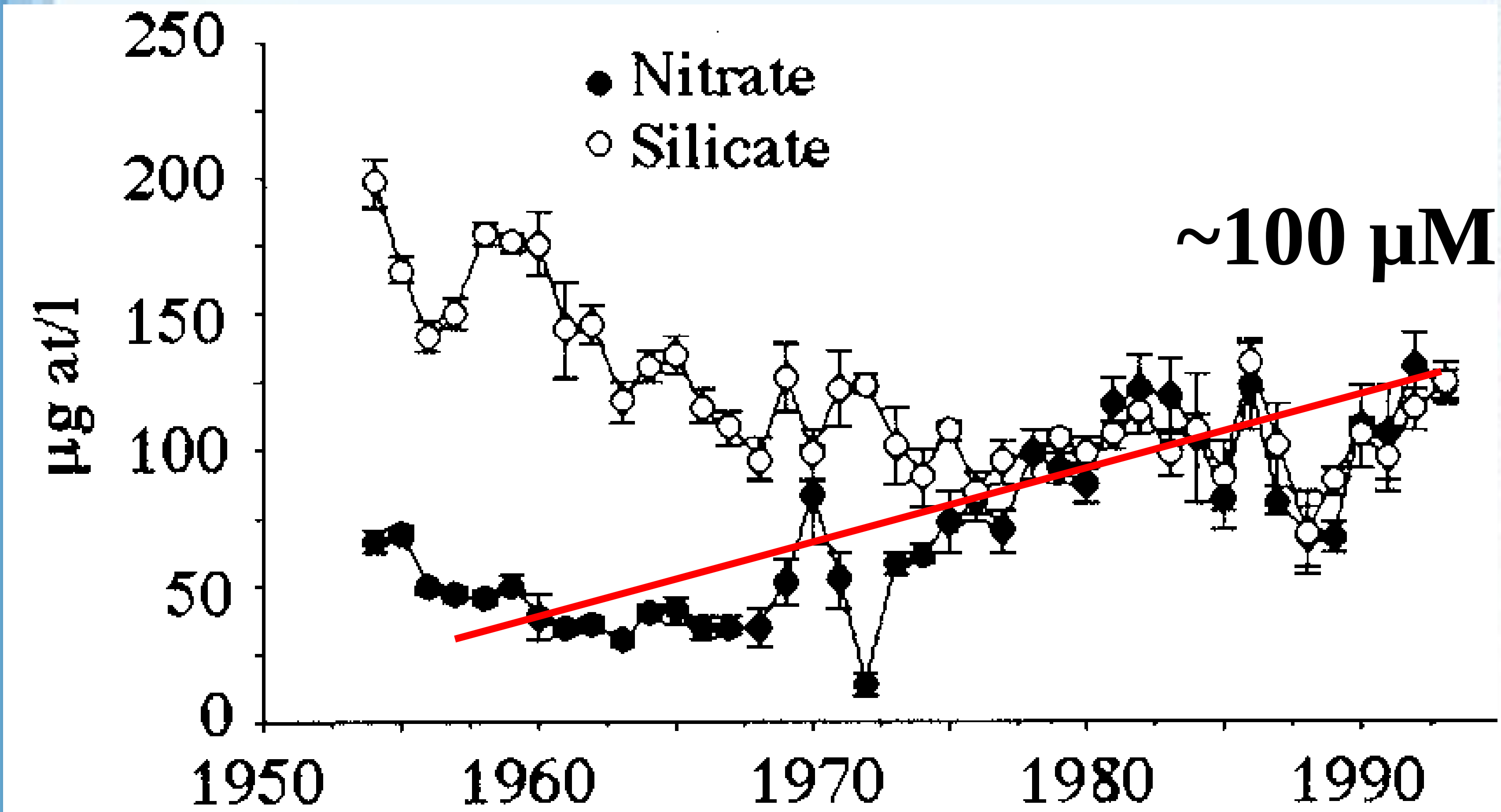
OCEANS

## Declining oxygen in the global ocean and coastal waters



# Mississippi River: Average annual concentrations

Turner et al. 1998. Proc. Natl. Acad. Sci. USA

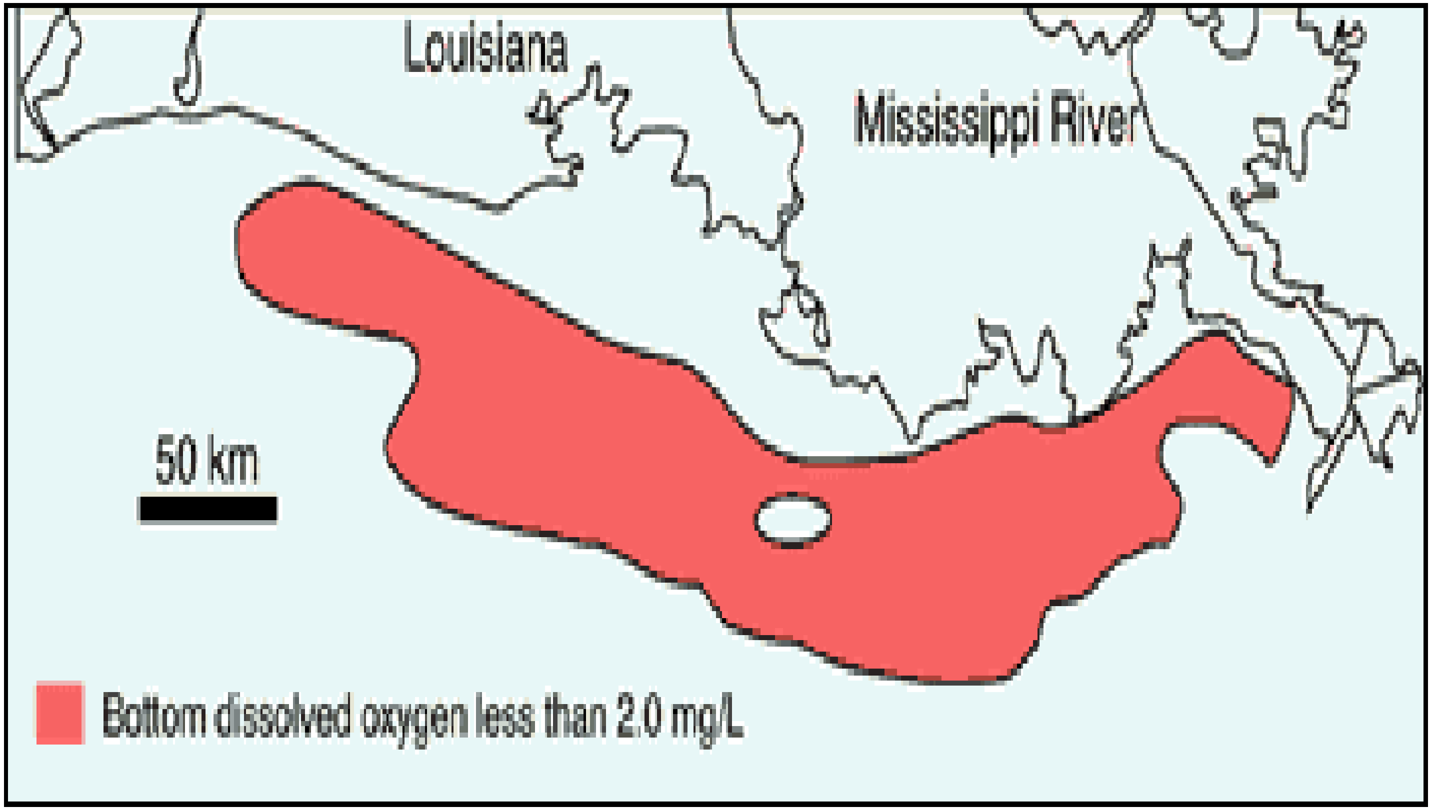



Years

# Northern Gulf of Mexico:

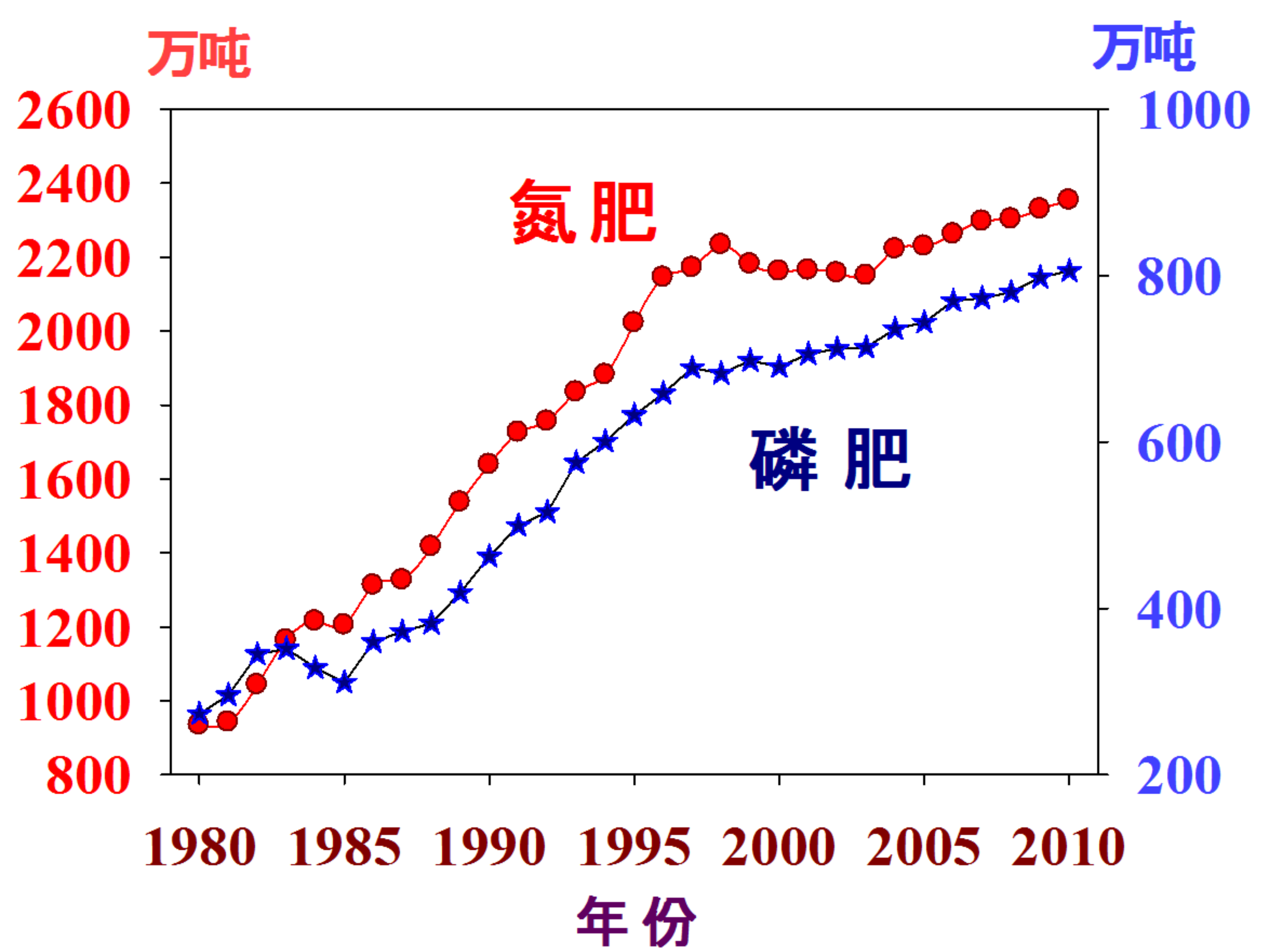
## a large area of hypoxia "dead zone" (20,000 $km^2$)

(<2 $O_2$ mg/L)




Science 281, 1998

# Nitrogen,Phosphorus fertilizers in China



# Persistent Cyanobacterial Blooms in Diachi Lake in Kunming

# Taihu Lake

## Cyanobacterial blooms shut down the city water supply for weeks

Pea soup. Hans Paerl samples cyanobacteria in ailing Taihu Lake.

ECOLOGY

### Doing Battle With the Green Monster of Taihu Lake

In attempting to subdue a vicious algal bloom, scientists aim to restore the health of a major lake in China and hone strategies for heading off toxic soups elsewhere

TAIHU LAKE, CHINA—As the motorboat glides through a carpet of fetid algae, Hans Paerl leans over the side and scoops up some of the tea-green muck with a plastic sampling bottle. In early June, a bloom of cyanobacteria, also called blue-green algae, fanned out across Taihu, China's third-largest lake. The growth was unchecked when a team led by Paerl, a cyanobacteria expert at the University of North Carolina, Chapel Hill, arrived last month to help colleagues at the Nanjing Institute of Geography and Limnology combat the foul bloom.

Much is at stake. Taihu, fed by the Yangtze River, helps irrigate millions of hectares of grains and cotton in a lush agricultural region between Shanghai and Nanjing. When it's healthy, the lake also provides drinking water for more than 2 million people, and it sustains one of China's most important fisheries for crabs, carp, and eels. The bloom that has turned Taihu into a toxic nightmare shows no signs of abating and may last until winter, experts say.

The ecological drama has far-reaching consequences. "It's safe to say that it's a pretty serious problem, and not just in China," says Paerl. At one time a villain largely confined to small lakes, algal blooms have of late gotten serious footholds in larger water bodies. Paerl warns that lakes such as Victoria in Africa and Erie and Okeechobee in the United States could be on the brink of becoming perennial algal soups.

That could pose a grave health risk. Some cyanobacteria, such as *Microcystis aeruginosa*, make toxins that can damage the liver, intestines, and nervous system. "Toxic cyanobacteria in drinking-water supplies pose a direct threat to public health," says Brett Neilan of the University of New South Wales in Sydney, Australia. Microcystis causes symptoms including diarrhea and liver failure. Reining in the algae at Taihu, Neilan says, could help prevent disasters elsewhere.

It wasn't long ago that Taihu enjoyed a cleaner reputation. A popular 1980s song, "Taihu Beauty," boasted of "white sails above the water, green reeds along the water, fish and shrimp below the water." Back then, says Paerl, Taihu rarely suffered blooms. Now they arrive like clockwork every summer, forcing locals to resort to bottled drinking water.

The root cause of Taihu's ills is an accumulation of nutrient-rich sewage and agricultural runoff in the shallow lake. That resulted in severe eutrophication: a surfeit of minerals and organic nutrients that nourishes algal growth. Unusually hot, dry conditions in early summer appear to have been the spark that ignited this year's bloom.

After the bloom reached nightmarish proportions 2 months ago, cleanup crews skimmed more than 6000 tons of algae from the lake and laid a polyvinyl chloride barrier to prevent algae from getting swept into pipes that funnel water to a drinking-water plant. But some organisms still seep through, says Qin Boqiang of the institute in Nanjing, and currents cannot flush away algae in water enclosed by the barrier.

Simply "cleaning out the algae" will not solve the problem, says Qin. He emphasizes the need to reduce nutrients, especially phosphorus and nitrogen, in the agricultural runoff and sewage. Paerl and Qin are conducting experiments to determine how much nutrient concentrations must fall to arrest a bloom. They also hope to unravel the dynamics of bloom formation. "The reason we developed this collaborative effort is that we have similar problems in the United States," says Paerl. "We thought, 'Why not combine our expertise?'"

Other researchers are probing the molecular biology of cyanobacteria toxins. With global temperatures rising, warmer surface water leads to less mixing, which favors the growth of toxic cyanobacteria. Deciphering the toxins' biological role and how the environment influences their production may suggest strategies for making blooms less venomous, Neilan says.

Cyanobacteria have a long history of acquiring remarkable adaptations, such as nitrogen fixation and gas vesicles that keep them afloat and enable them to outcompete diatoms and green algae for light and nutrients. They can lie dormant in extreme conditions—surviving droughts and freezing—then roar to life when conditions improve. Cyanobacteria are "very tough," Paerl says. "They're the cockroaches of lakes."

To control Taihu's little green pests, the government in the nearby city of Wuxi crafted an aggressive recovery strategy. The plan promulgates tough emissions standards for phosphorus and nitrogen for factories near Taihu and requires the installation of facilities that remove nutrients from sewage. Nutrient-rich agricultural runoff would be stemmed by banning chemical fertilizers, pesticides, and detergents that contain phosphorus or nitrogen. The amount of clean water pumped from Taihu is projected to reach 1 million tons per day by the end of 2008, and industries in Wuxi must meet a water-recycling rate of 78% by 2010.

"There's no doubt that Taihu is going to be a challenge," says Paerl. Degradation of the lake's water quality was a slow-motion train wreck that played out over several decades. It may take many more years to banish the blooms and bring back the Taihu Beauty of yore.

–LUCIE GUO

Lucie Guo is a freelance writer based in Boston.

CREDIT: HANS PAERL





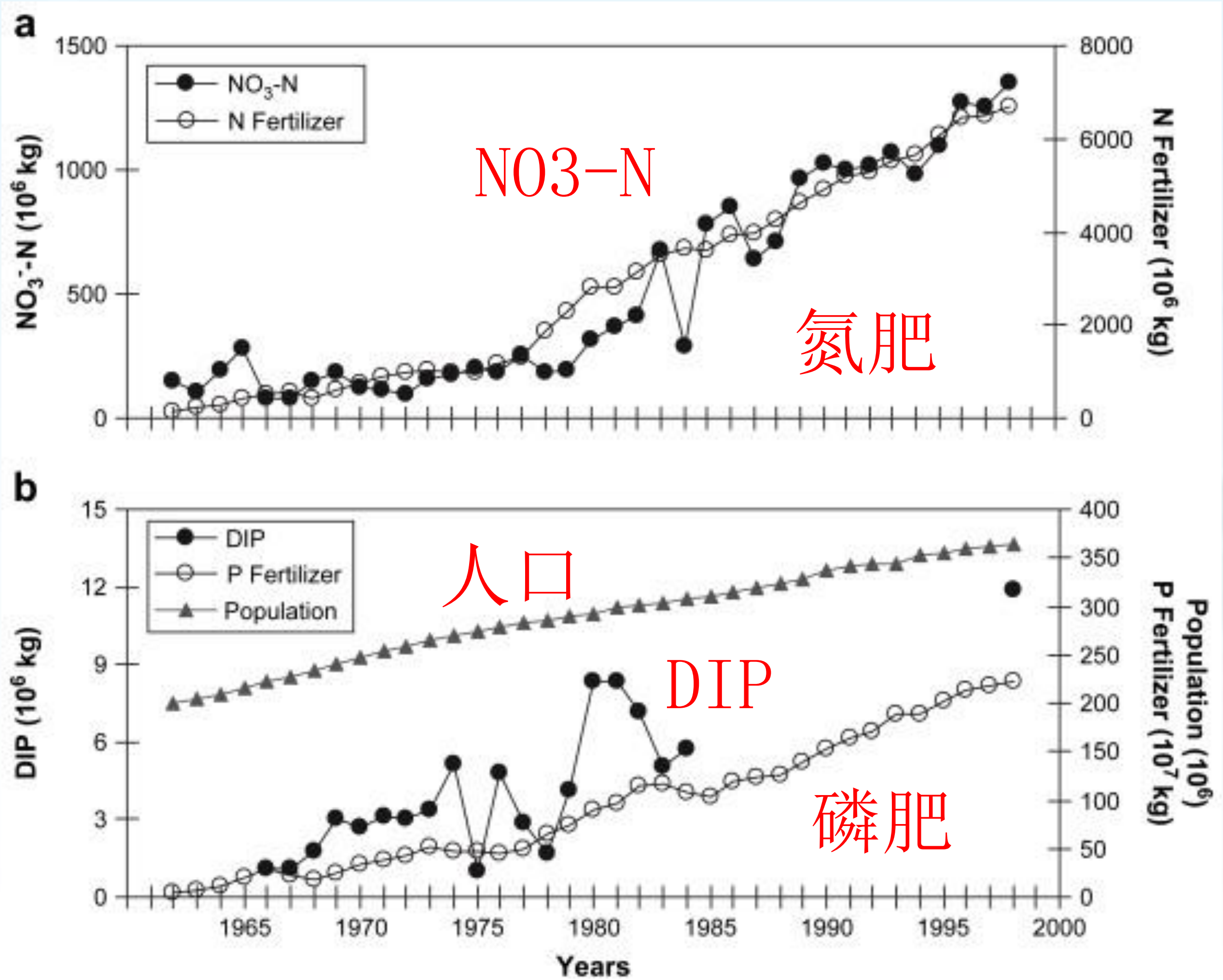
Science 31 Aug 2007

# Green Algal Blooms in Qingdao where Olympic sailing game will take place July 2008

Scores of PLA soldiers remove masses of algae from a beach in Qingdao, where the Olympic sailing events are scheduled to take place from August 9. (Photo: Bloomberg) (from SCMP, 4 July 2008)

A soldier walks through blue-green algae near a beach in Qingdao, Shandong province. (Source: Bloomberg) (from SCMP, 4 July 2008)

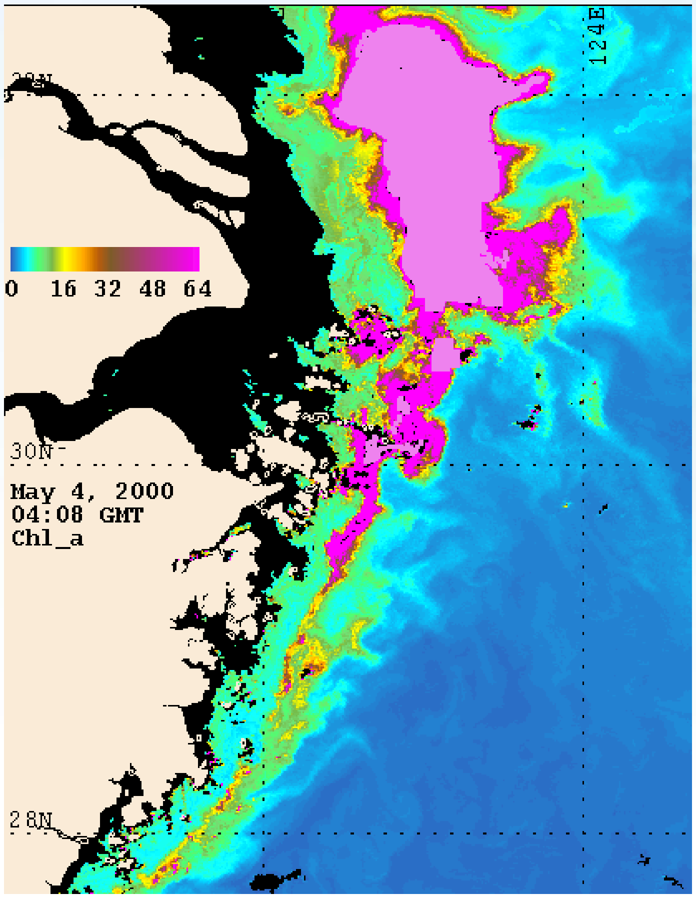
# Flux of Nutrients in Changjiang



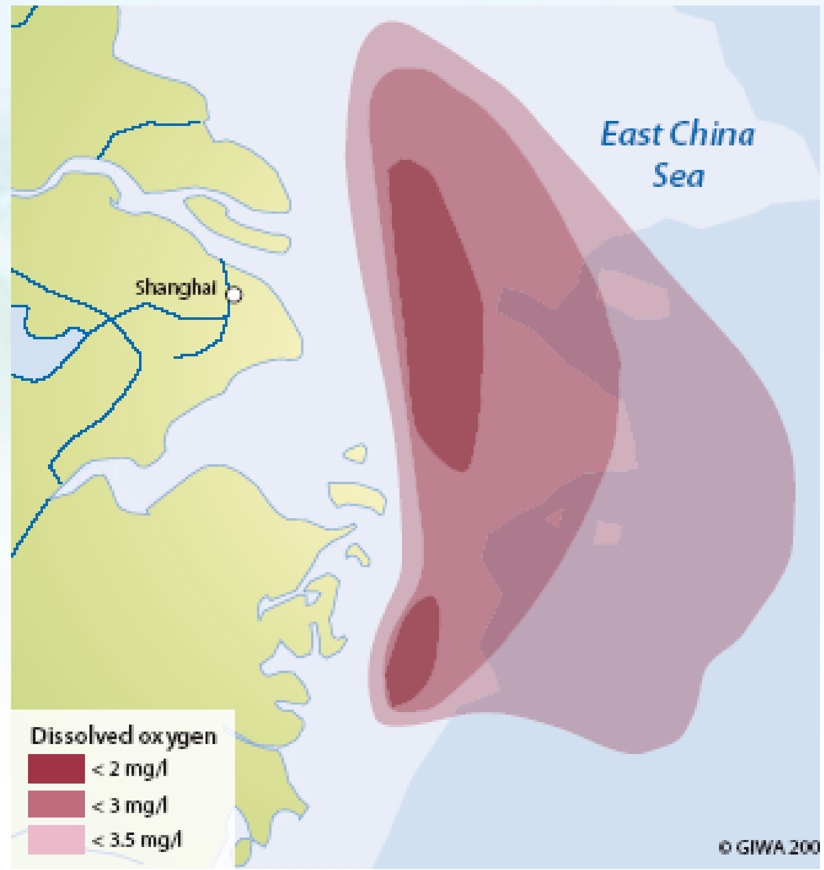

Duan Shuiwang, 4 others . Seasonal changes in nitrogen and phosphorus transport in the lower Changjiang River before the construction of the Three Gorges Dam. Estuarine， Coastal and Shelf Science 2008, 79(2): 239–250.

# Large areas of harmful algal blooms and hypoxia in Changjiang-East China Sea

## Spring

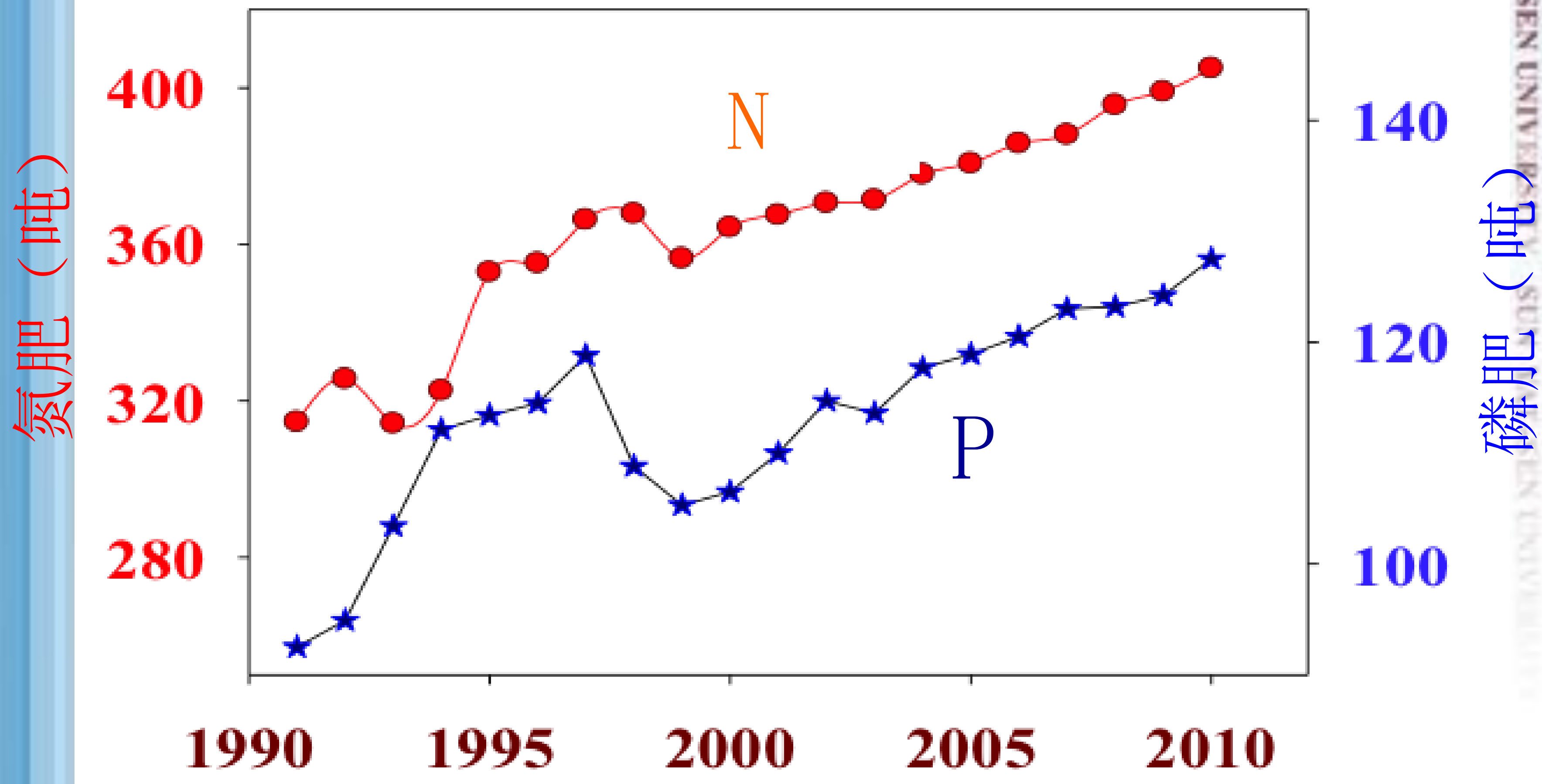



## Summer

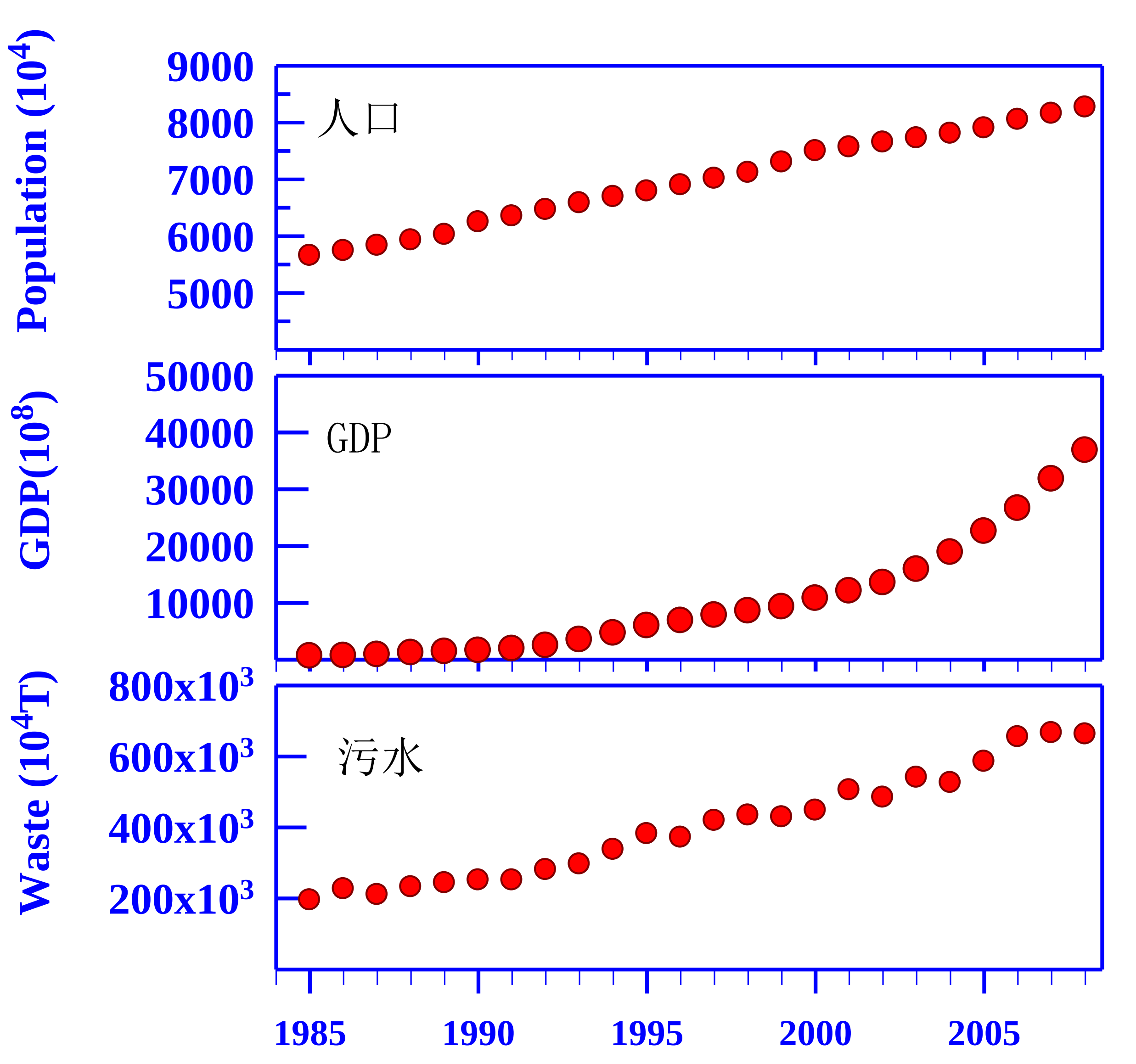



Li et al., 2002

# Pearl River Watershed



# Population, GDP and Wastewater in Guangdong



# Pearl River Estuary

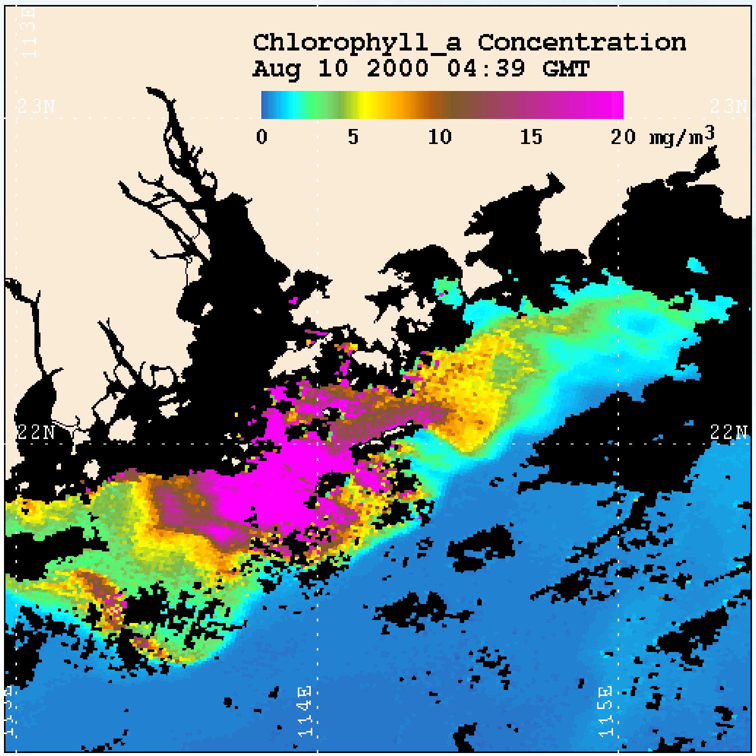

# Pearl River

- **The 2nd largest river in China**
- **The 13th largest river in the world**
- **2,200 km long**
- **454,000 km² drainage basin**
- **100 million people**

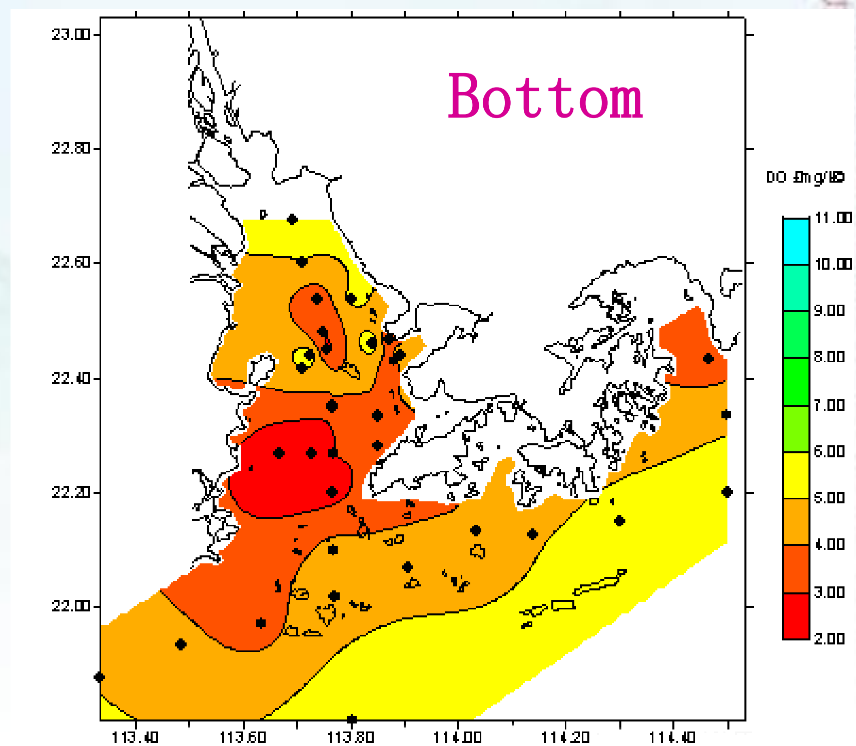
# Zhujiang Estuarine Coastal Waters:

# HAB and Hypoxia events

## Chl-a




## Hypoxia

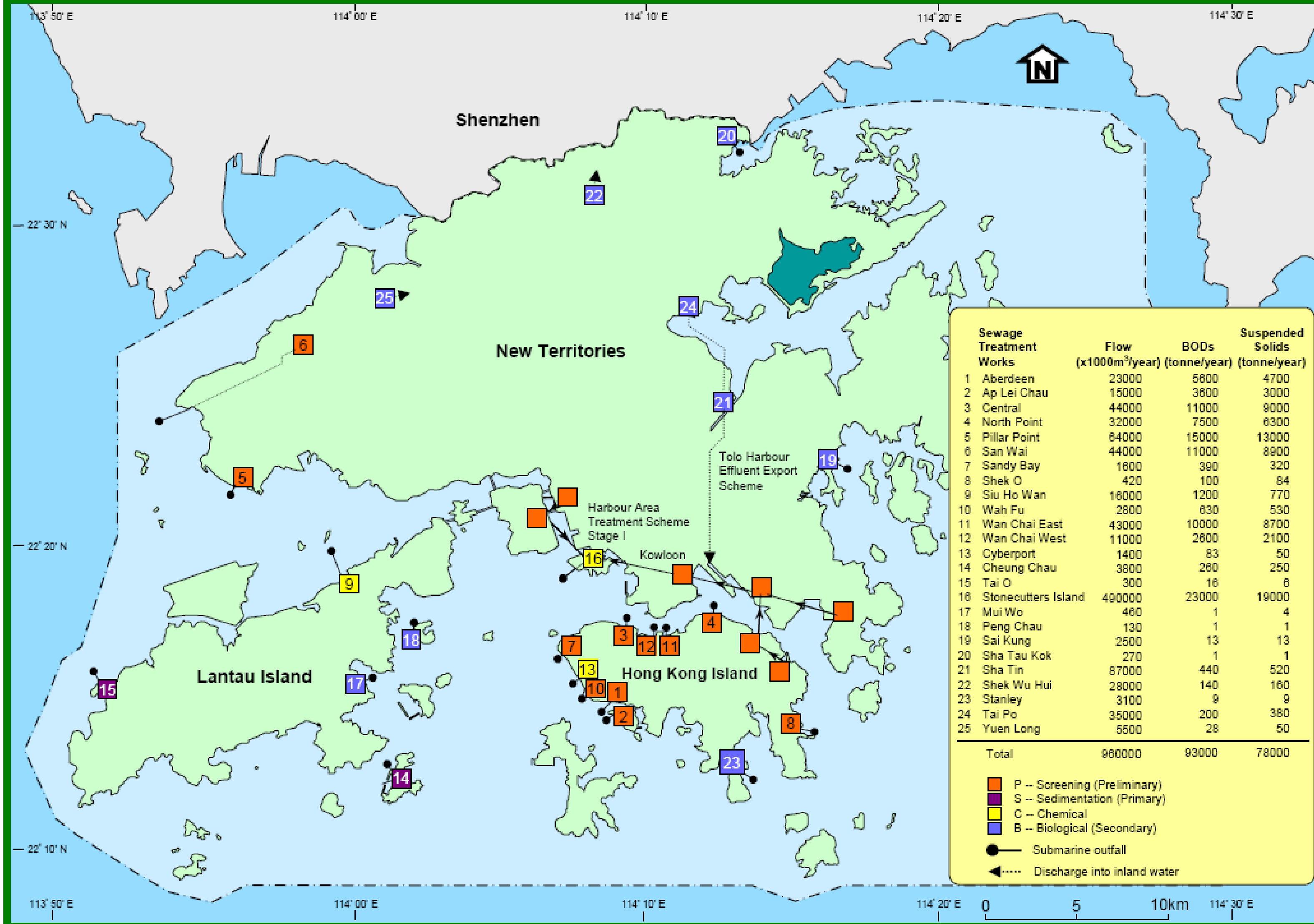


# Harbour Area Treatment Scheme (HATS):

# The Strategy of Sewage Treatment in Hong Kong started in 2001

# Hong Kong Sewage Effluent Outfalls

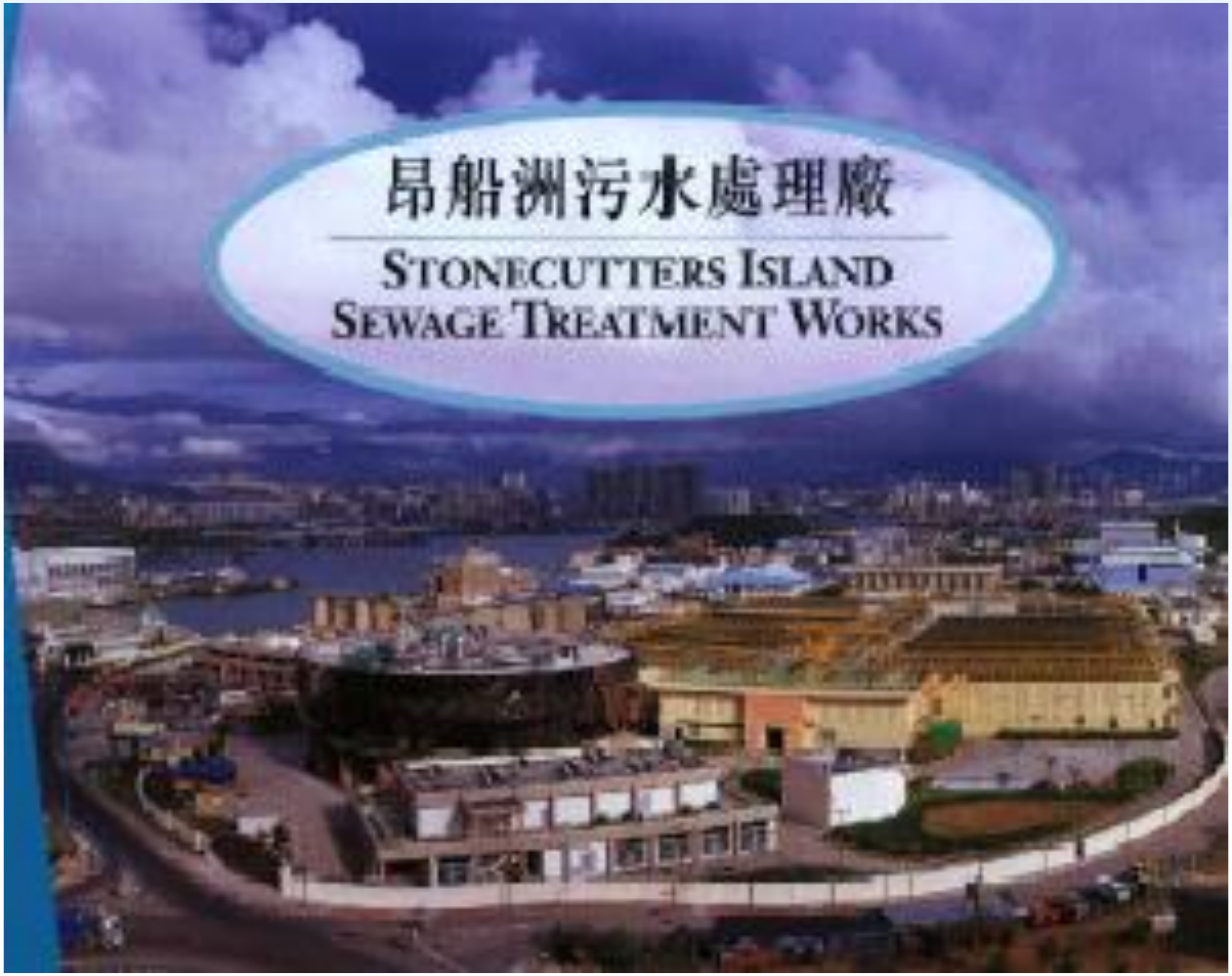
Major public sewage treatment works, outfalls, and pollution load in Hong Kong in 2007
(sources: Drainage Services Department and Environmental Protection Department)




| | Sewage Treatment Works | Flow (x1000m$^3$/year) | BODs (tonne/year) | Suspended Solids (tonne/year) |
|---|---|---|---|---|
| 1 | Aberdeen | 23000 | 5600 | 4700 |
| 2 | Ap Lei Chau | 15000 | 3600 | 3000 |
| 3 | Central | 44000 | 11000 | 9000 |
| 4 | North Point | 32000 | 7500 | 6300 |
| 5 | Pillar Point | 64000 | 15000 | 13000 |
| 6 | San Wai | 44000 | 11000 | 8900 |
| 7 | Sandy Bay | 1600 | 390 | 320 |
| 8 | Shek O | 420 | 100 | 84 |
| 9 | Siu Ho Wan | 16000 | 1200 | 770 |
| 10 | Wah Fu | 2800 | 630 | 530 |
| 11 | Wan Chai East | 43000 | 10000 | 8700 |
| 12 | Wan Chai West | 11000 | 2600 | 2100 |
| 13 | Cyberport | 1400 | 83 | 50 |
| 14 | Cheung Chau | 3800 | 260 | 250 |
| 15 | Tai O | 300 | 16 | 6 |
| 16 | Stonecutters Island | 490000 | 23000 | 19000 |
| 17 | Mui Wo | 460 | 1 | 4 |
| 18 | Peng Chau | 130 | 1 | 1 |
| 19 | Sai Kung | 2500 | 13 | 13 |
| 20 | Sha Tau Kok | 270 | 1 | 1 |
| 21 | Sha Tin | 87000 | 440 | 520 |
| 22 | Shek Wu Hui | 28000 | 140 | 160 |
| 23 | Stanley | 3100 | 9 | 9 |
| 24 | Tai Po | 35000 | 200 | 380 |
| 25 | Yuen Long | 5500 | 28 | 50 |
| | Total | 960000 | 93000 | 78000 |

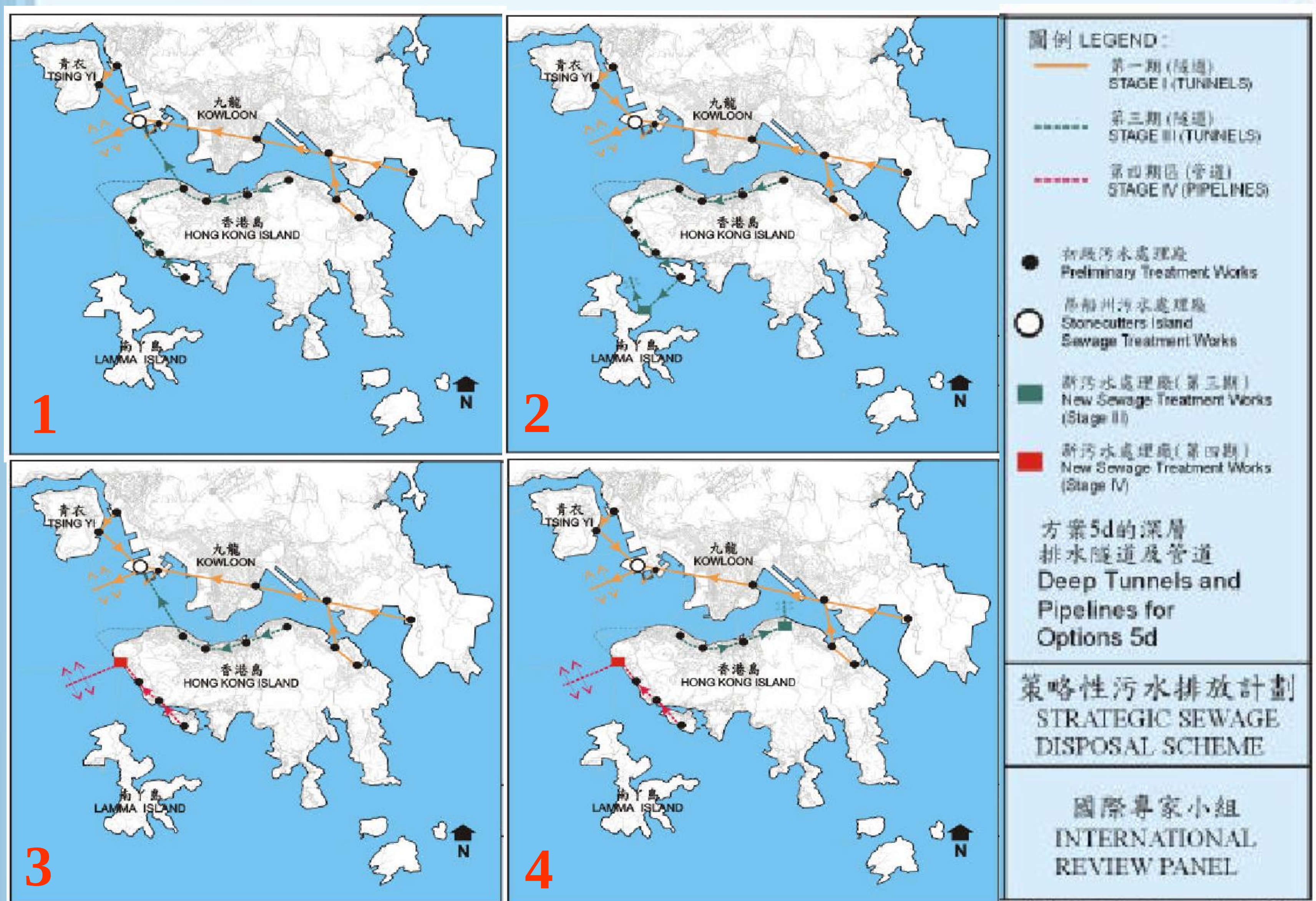
# Strategic Sewage Disposal Scheme (SSDS) before 2001

# Chemically Enhanced Treatment Plant (CEPT)

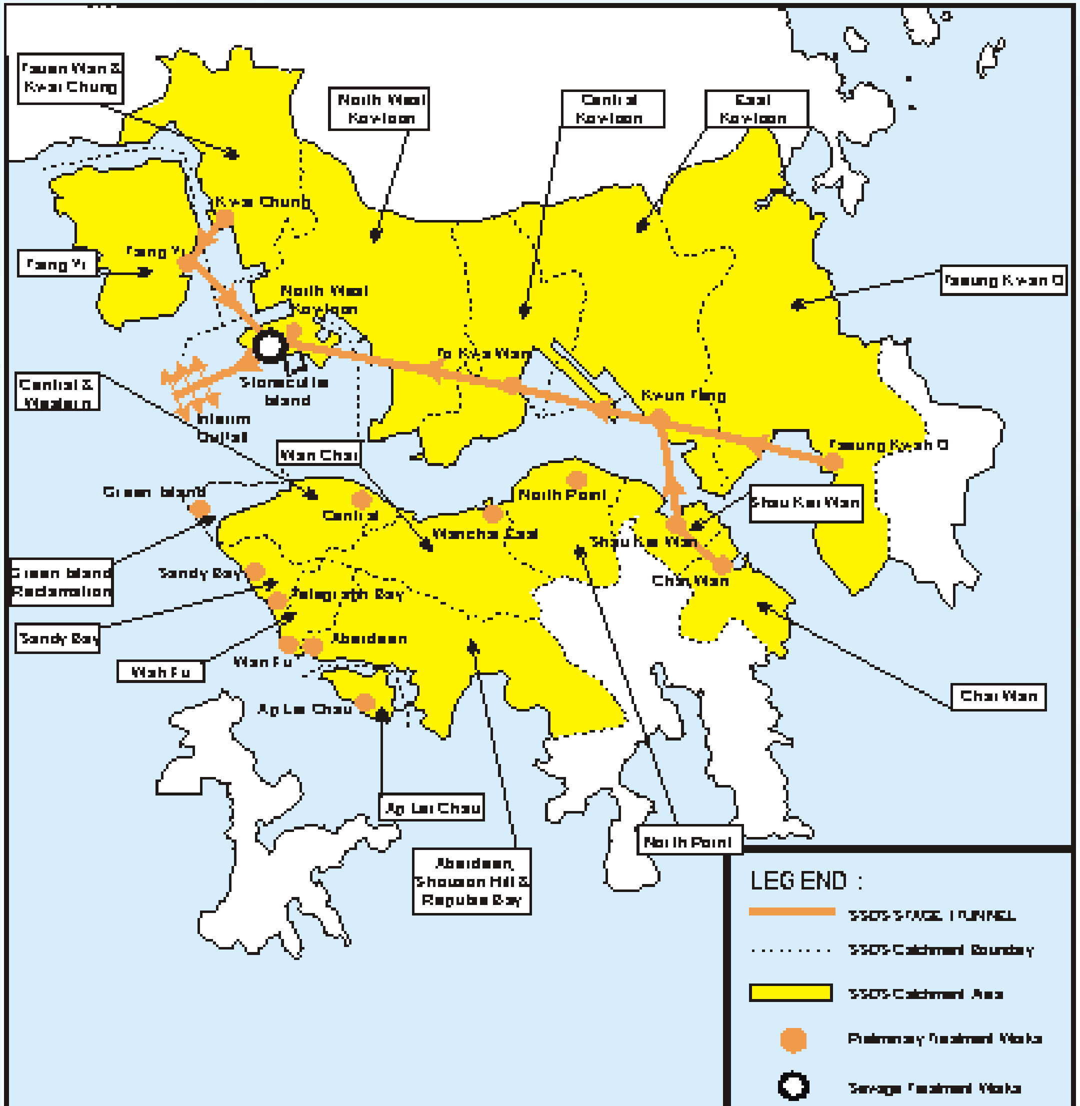


# Sewege Collecting Pipe Tunnel under bedrock

# 4 options by International Review Panel (IRP 2000)



# Harbor Area Treatment Scheme (HATS) started in 2001




**HATS Catchment Area**

**1.85 million $m^3$ sewage effluent of Hong Kong**

# Harbour Area Treatment Scheme (HATS):

## Sewage treatment strategy

## One of the most important coastal infrastructure in Hong Kong

# Harbor Area Treatment Scheme (HATS):

## All 4 options require:

- Short outfalls

- Upgraded treatment facility to tertiary or biological removal of inorganic nutrients, nitrogen or phosphorus

This triggers an important scientific question: which nutrient should not be added to the recipient water?

# HATS: short outfalls with biological treatment (Biological Aerated Filter)

**An important management decision:**

**removal of nitrogen or phosphorus?**

**Science-Policy Making Interface**

**An important scientific question:**

**Which nutrient is the most limiting in the recipient waters**

# Environmental Impact Assessment Ordinance, Hong Kong

## Assessment Philosophy

**Assessment should rely on the concept of assimilative capacity of the receiving water body and water quality objectives**

# Ecosystem Buffering

Anthropogenic input → **Ecosystem Buffering Capacity** → **Impacts:**

- Excessive algae
- Red tides
- Low DO waters
- OA

**Seasonality: Dry and Wet**

**Spatial and Temporal Variability**

**Climatic events**

- Monsoons
- River outflow
- Tidal cycles
- Rainfall

**Circulation**
**Stratification**
**Mixing**

**Light**
**Salinity**
**Temperature**
**Nutrients**
**Nutrient Ratios**

**Algal Growth**
**Nutrient utilization**
**Nutrient Limitation**
**DO consumption**

Drivers ⇒ Processes ⇒ Factors ⇒ Biology

# Ecosystem Buffering Capacity:

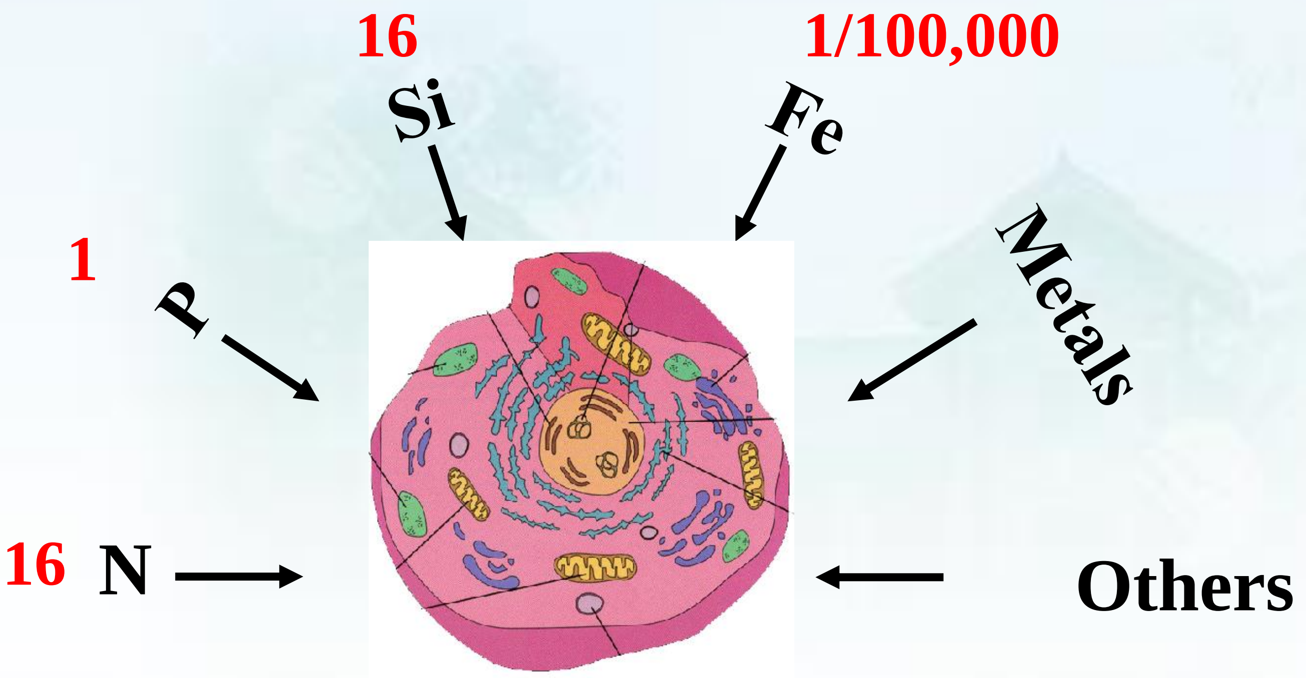
The most limiting nutrient

**determine phytoplankton biomass and $O_2$ consumption**

**(Yin et al. 2000, 2001, 2004, 2008)**

# The Most Limiting Nutrient

**The Minimum Law: the nutrient that is the least by elemental ratio is the first nutrient to limit cellular biomass.**




**Cellular N:P= 16 : 1**

# How does a N/P ratio indicate which nutrient is the most limiting

**N:P < 16:1, N is limiting**

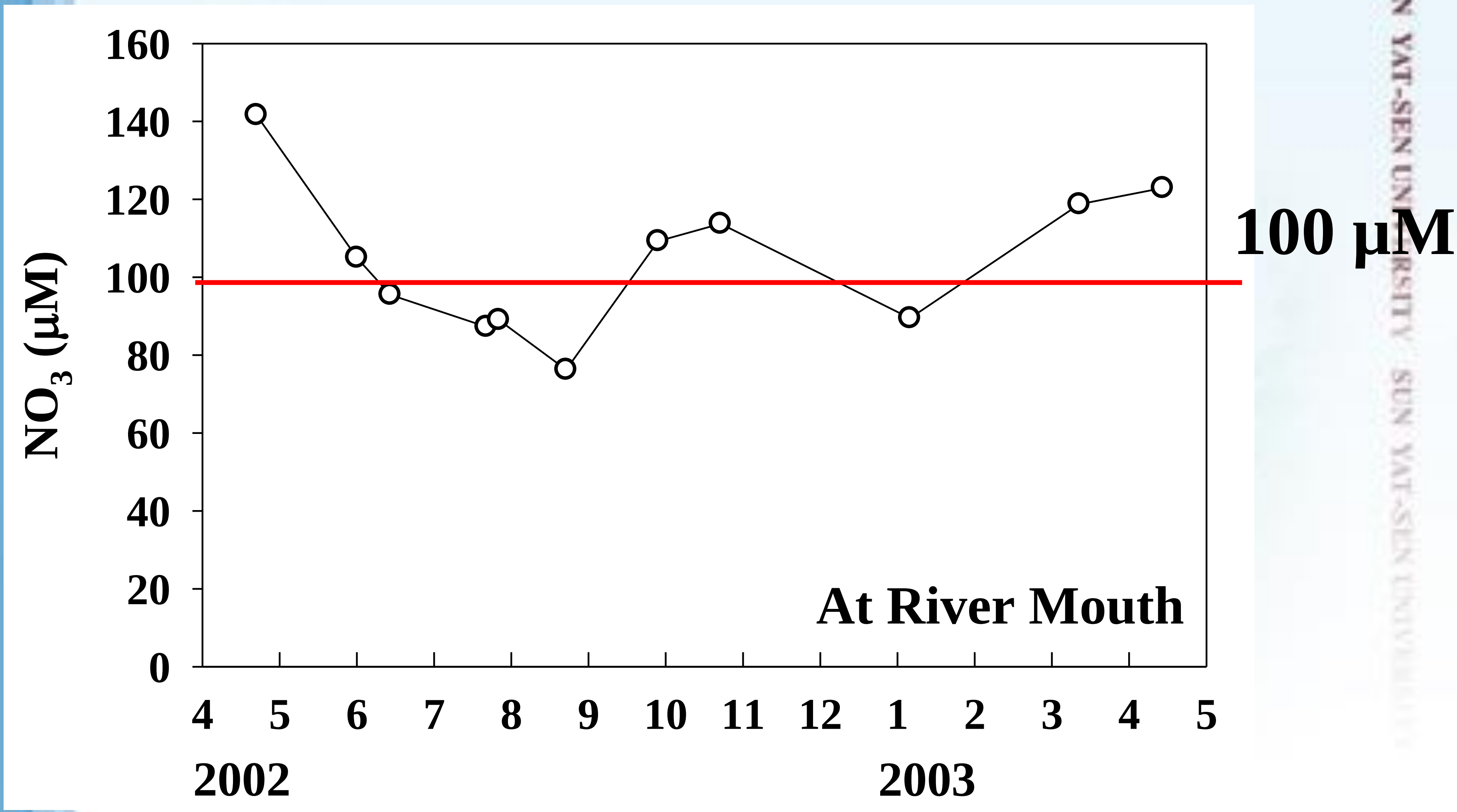
**N:P > 16:1, P is limiting**

# In general,

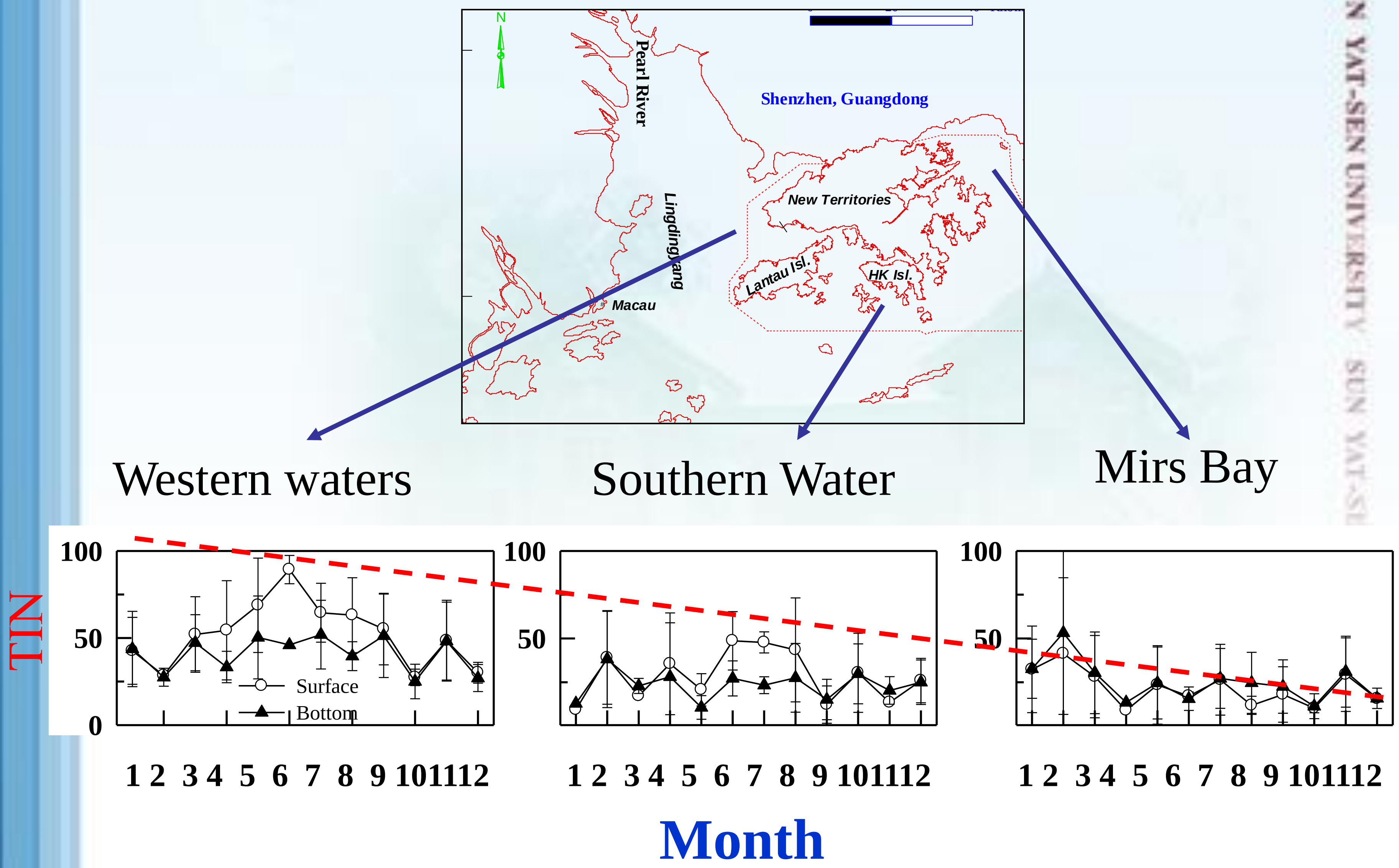
**Nitrogen is considered to be the nutrient enrichment causing eutrophication in the coastal waters**

**What about Hong Kong waters:**

# $NO_3$ at Humen (a river mouth of the Pearl River)



# Monthly Average of total inorganic nitrogen during 1991-2000 (Yin 2002)



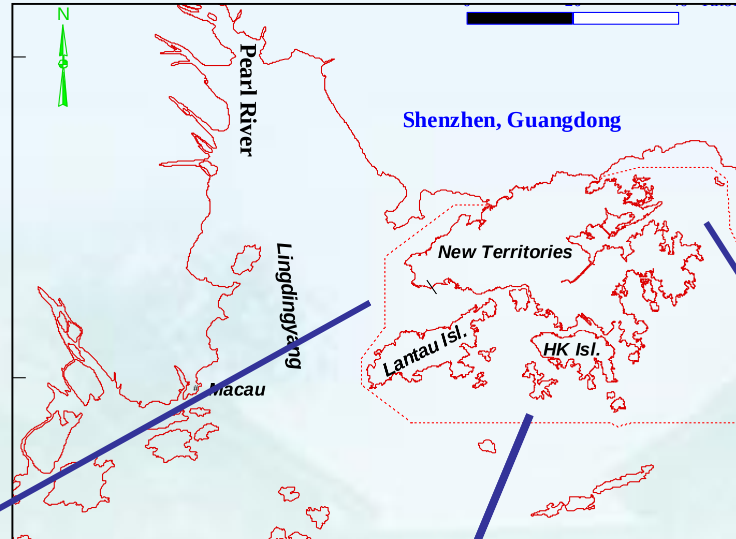
# Yes, there is nitrogen over-enrichment in the Pearl River estuary

- **Nitrogen (N)**
  - **High (100 μM) in the Pearl River vs 30 μM in marine fertile waters**
  - **Excess in HK southern waters in summer**
  - **Low in winter**

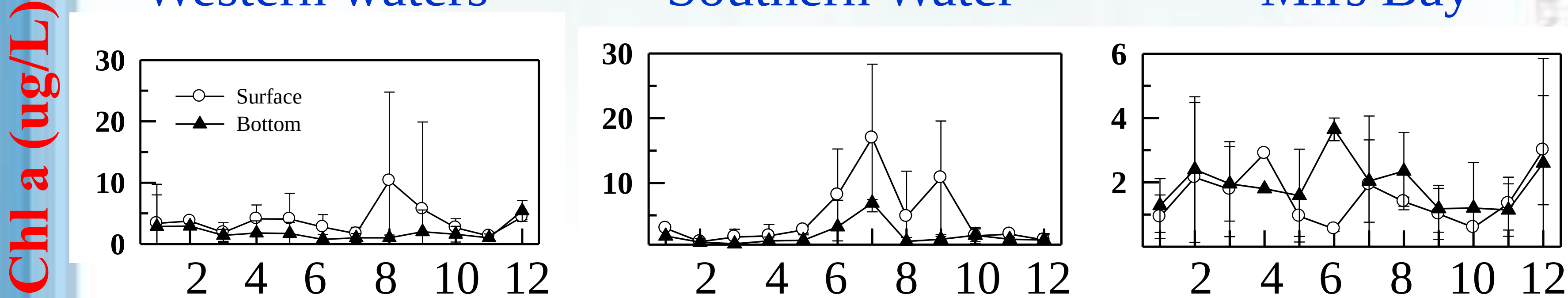
- **In fact, N concentration has increased at least 3 times during the past 3 decades**

# Monthly Average of chl *a* during 1991-2000 (Yin 2002)

**< 20 ug/L**



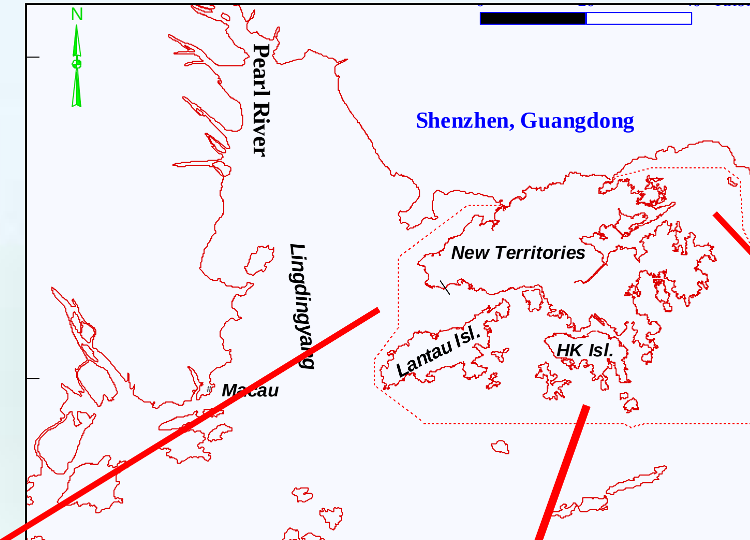

Western waters | Southern Water | Mirs Bay




**Month**

# Monthly Average of Dissolved $O_2$ during 1991-2000

## Dissolved $O_2$ does not drop to hypoxia!

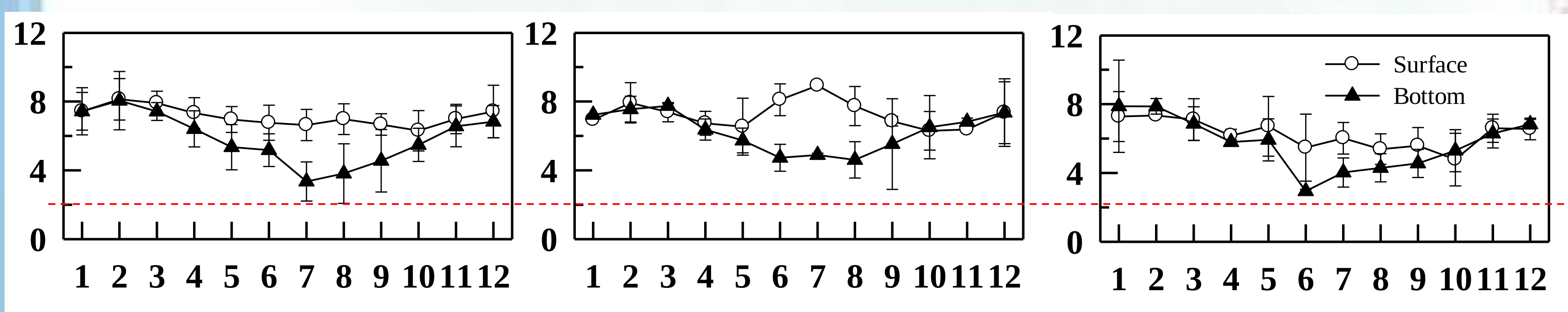



Western waters

Southern Water

Mirs Bay

$O_2$ (mg l-2)

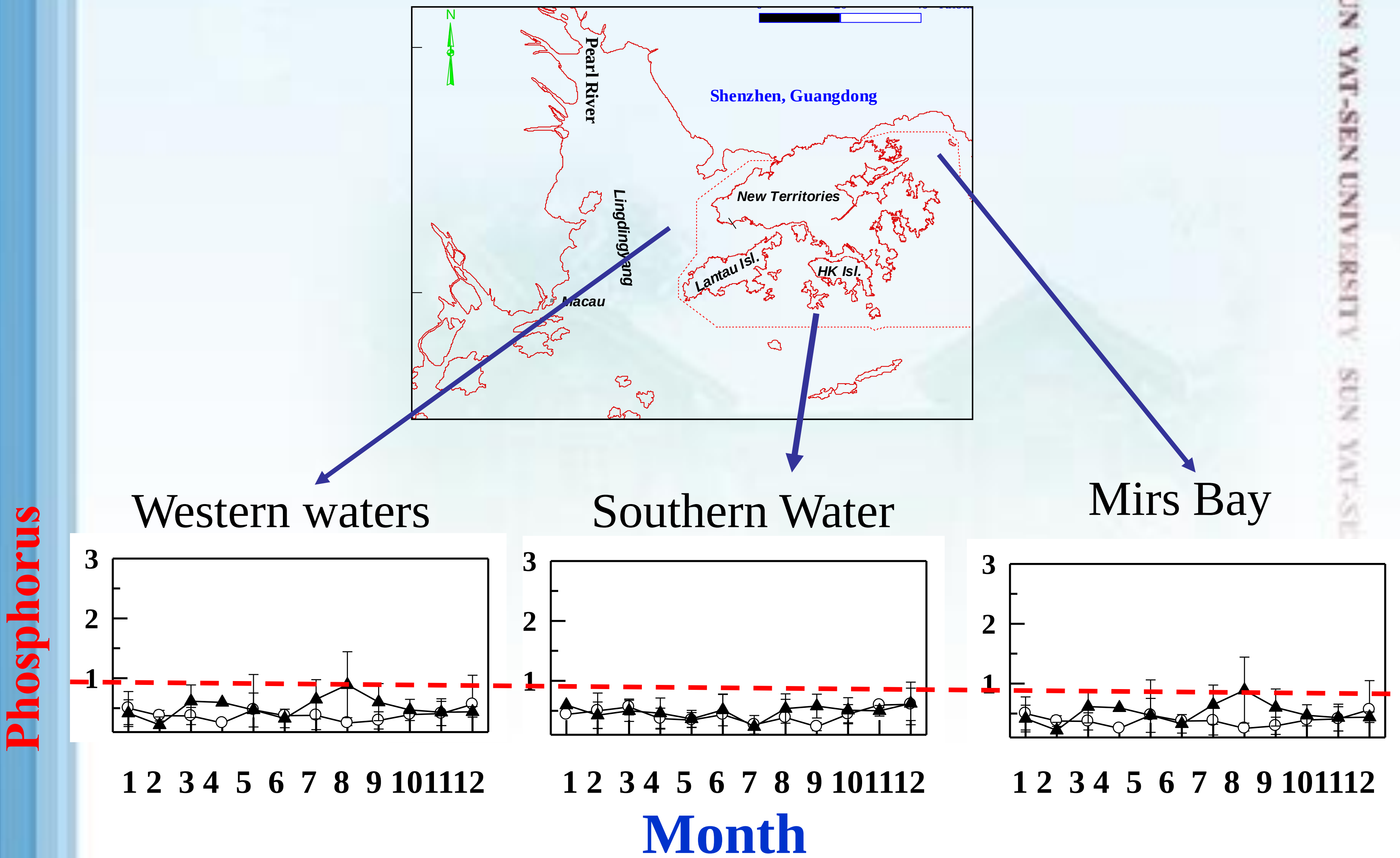



Month

# Findings:

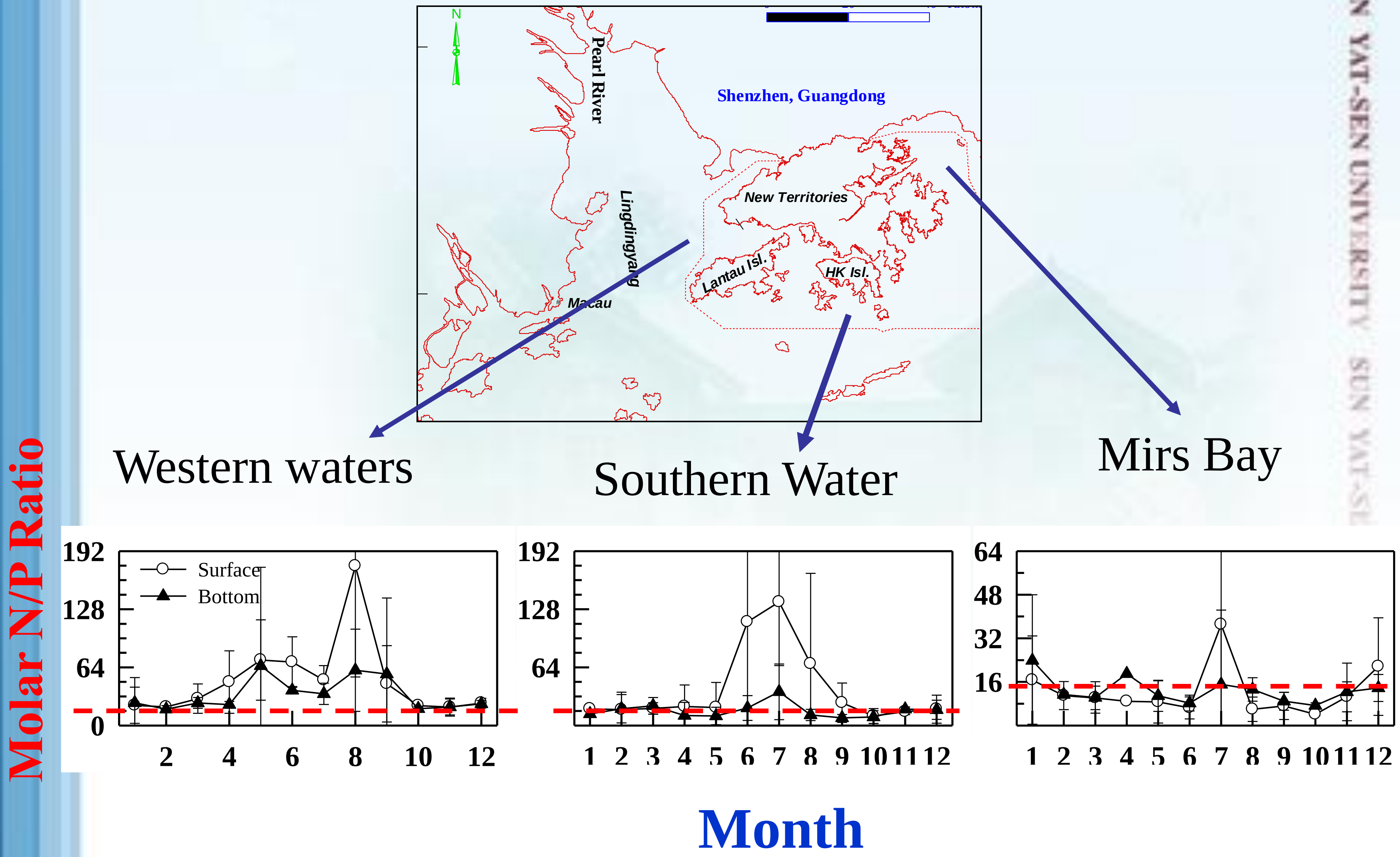
- **Algal biomass is not as high as expected from high nitrogen;**
- **Dissolved $O_2$ remains above 2 mg/L most of the time-no seasonal hypoxia (low oxygen waters) has been found**

# Monthly Average of phosphate during 1991-2000 (Yin 2002)



# Monthly Average of Molar N:P ratio during 1991-2000

**(Yin 2002)**



# Findings

- Nutrients are low in winter
- Phosphorus is potentially the most limiting nutrient in summer
  - for phytoplankton biomass
  - the amount of DO consumption

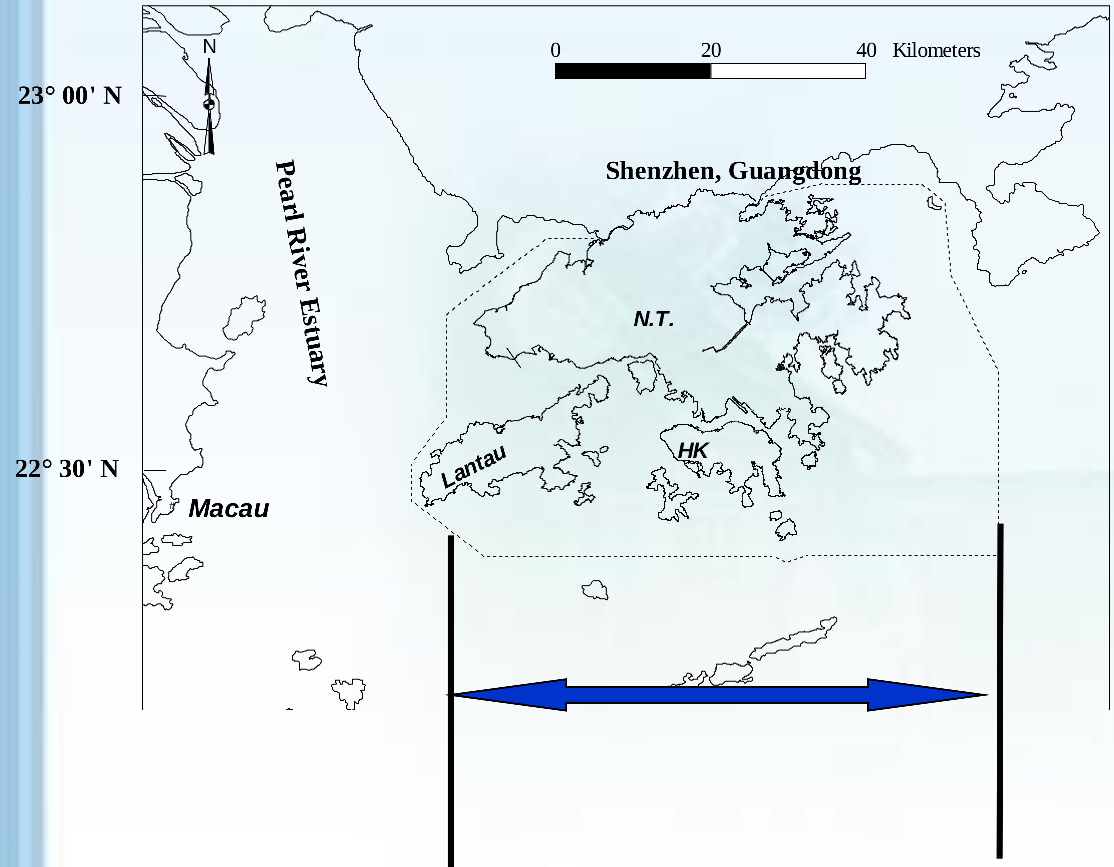
# High N:P ratios (>16:1) imply:

1) Phosphorus appears to be the most limiting nutrient

2) There is excess N, and

therefore, removal of N does not help reduce nutrient-caused impact

# Scenario 1-Dry Season:
# large capacity, less concern



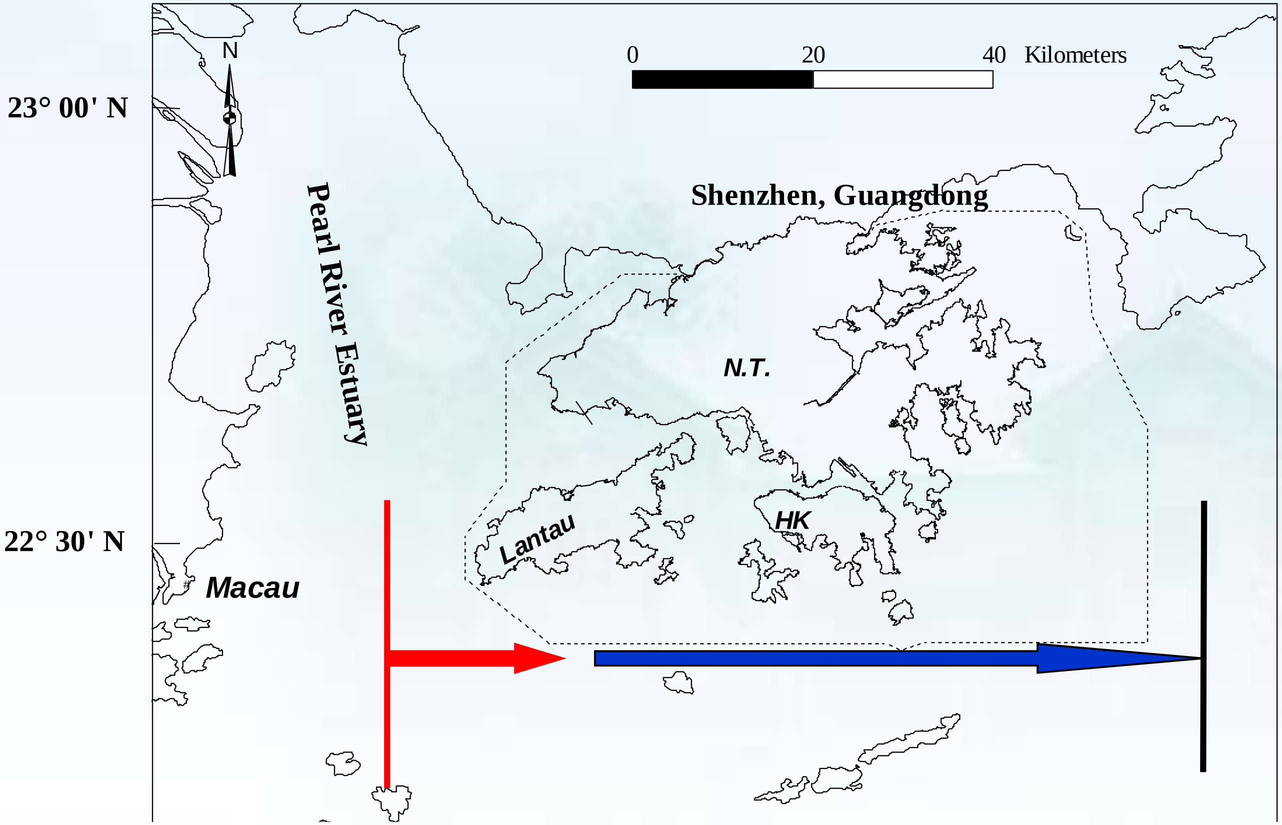

- Potential N limitation
- **but low nutrient levels**
- **Physical dilution dominant over biological processes**

**Low N/P ratios**

**Low in all nutrients**

# Scenario 2-Spring:

# N to P-limitation – P may be a concern



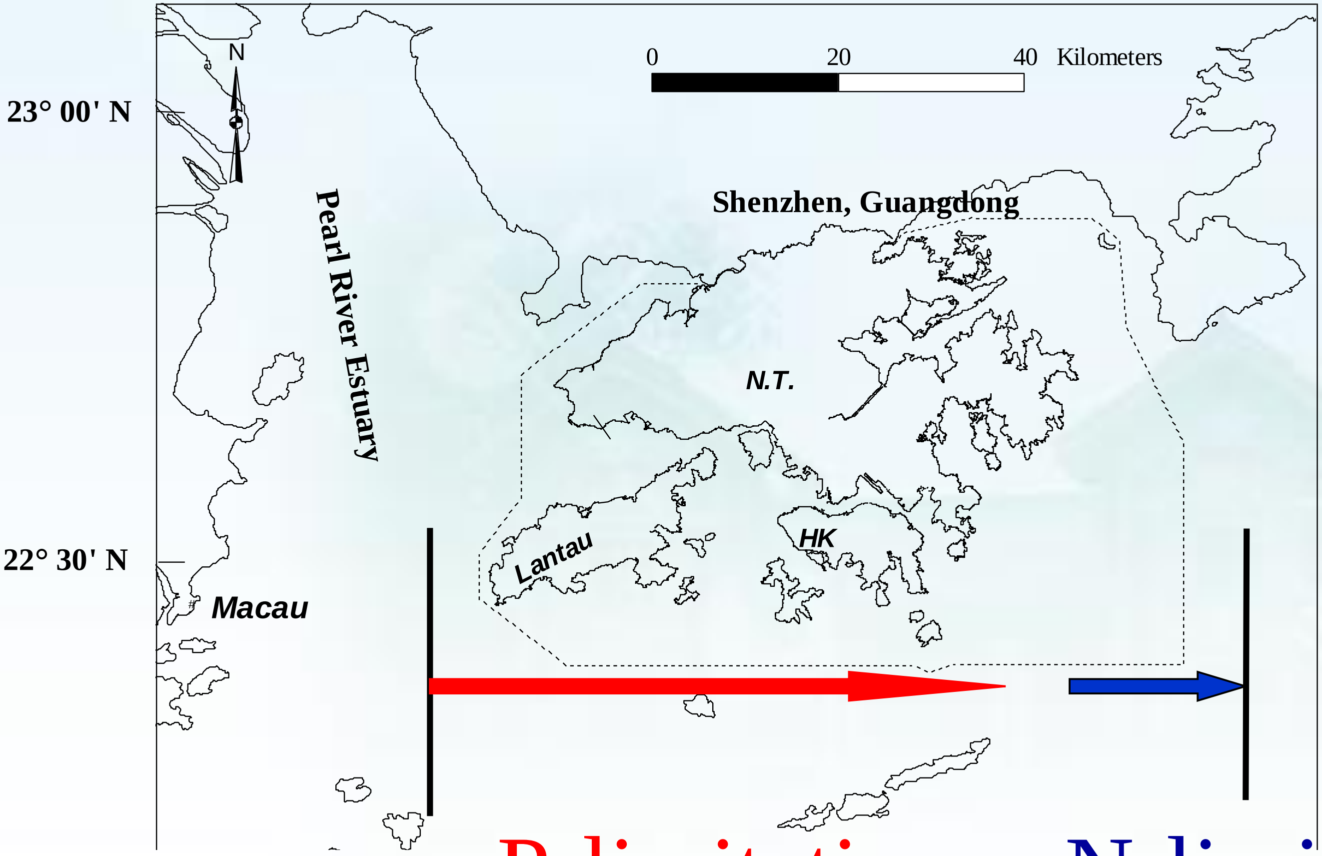

P-limitation

High N, Low P

N-limitation

Low in all nutrients

# Scenario 3-Summer:
# P-limitation - P is a concern




P-limitation — N-limitation

High N, Low P — Low Nutrients

# HATS: short outfalls with biological treatment (Biological Aerated Filter)

**Removal of N – is not cost effective**

**An important management decision:**

**removal of nitrogen or phosphorus?**

**Removal of P is more effective**

**An important scientific question:**

**Which nutrient is potentially the most limiting in the recipient waters**

# HATS: Short outfalls-biological treatment

**An important management decision:**

**removal of nitrogen or phosphorus?**

**120亿 HK$ difference**

**If P is the most limiting nutrient,**
**N removal is not economic environmentally**

# Acknowledgement

**UN DOALOS Invitation**

**Environmental Protection Department (EPD) for their routine water quality monitoring program**

**Agriculture, Fisheries & Conservation Department for their networking of red tide watching program**