FEW Workshop: Food, Energy, and Water Nexus in Sustainable Cities

Water Crisis of Lake Taihu, China

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Contents

1. Cyanobacterial Blooms at Lake Taihu

Where is Lake Taihu?

Catchment of Taihu: floodplain, urbanlization

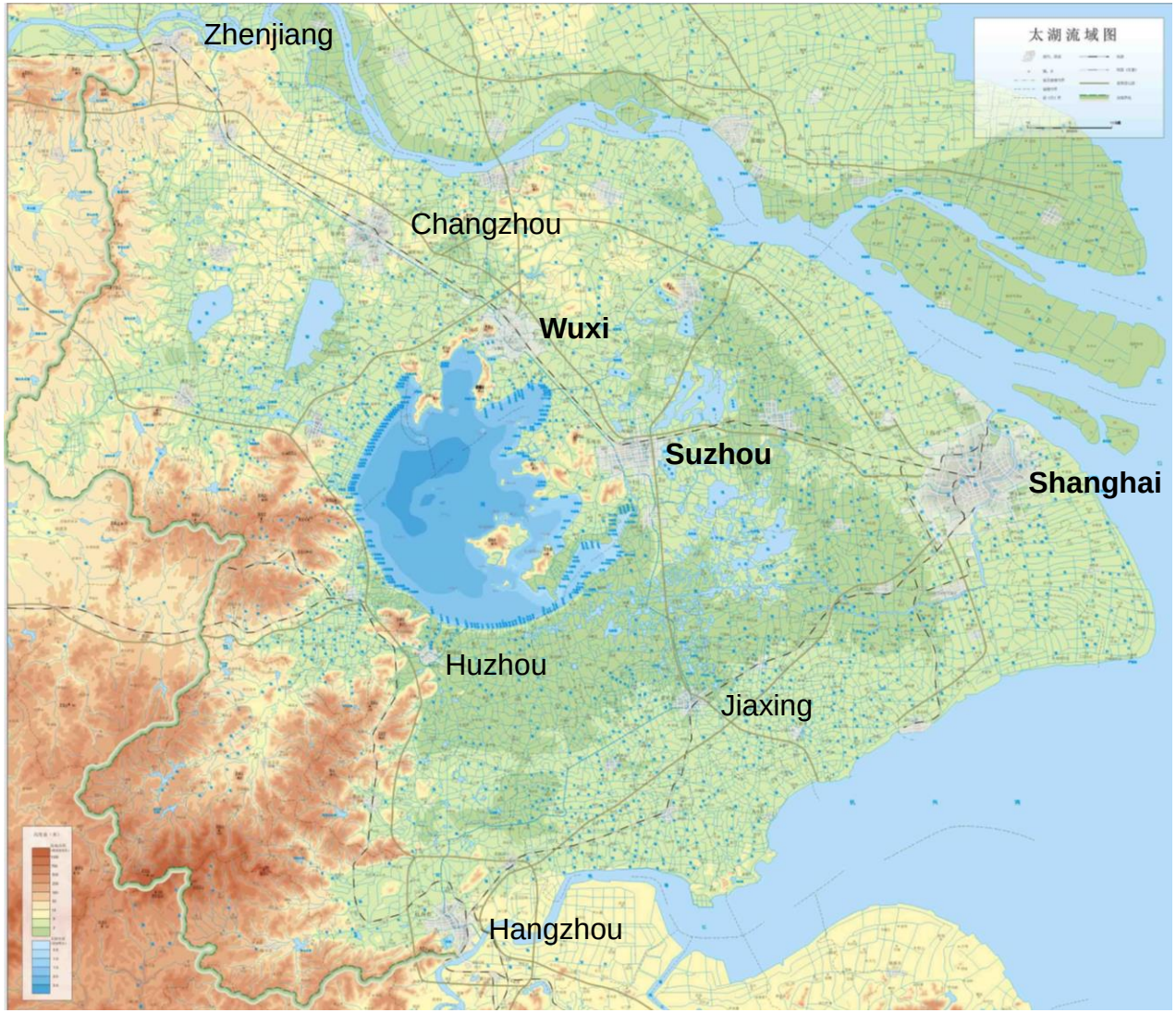
Water surface: 2338 km^2

Average depth: 2 m

Maximal depth: 3 m

Catchment: 36500 km^2

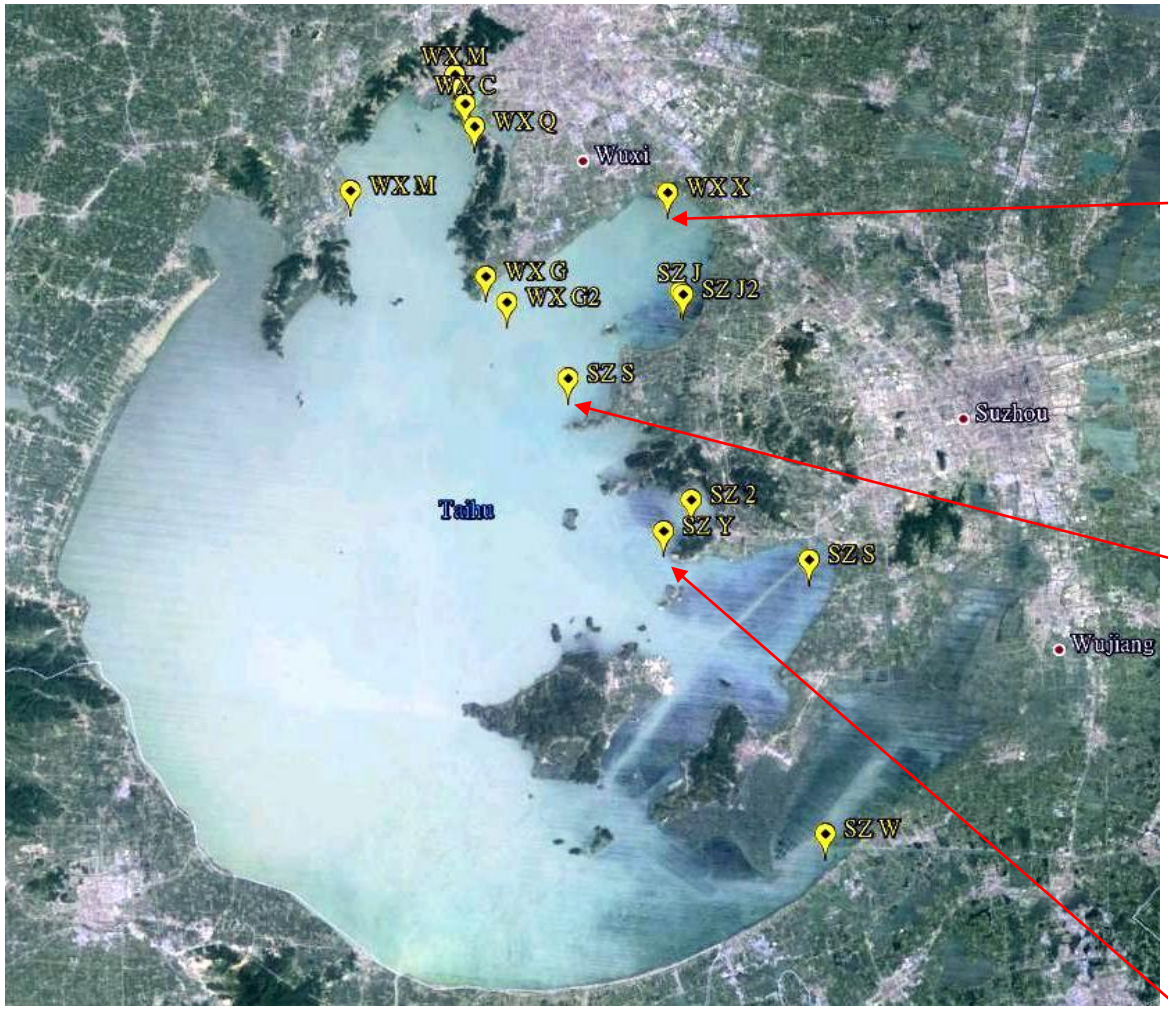
Population density: >1200



Functions of Taihu

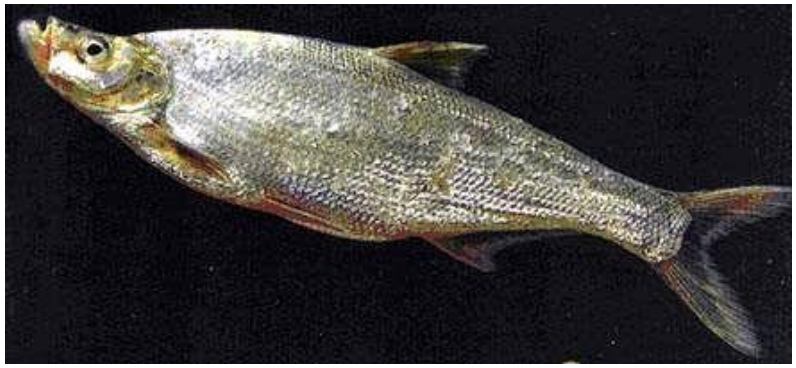
1. City water supply
2. Fishery
3. Recreation
4. Flood buffer
5. Water way

Water intakes in Taihu



Water intakes for water plants in Taihu.

Fishery



Culter alburnus Basilewsky

Hemisalanx prognathus

Exopalaemon modestus

Aristichthys nobilis

Coilia nasus Temminck *et* Schlegel

Hyriopsiscumingii

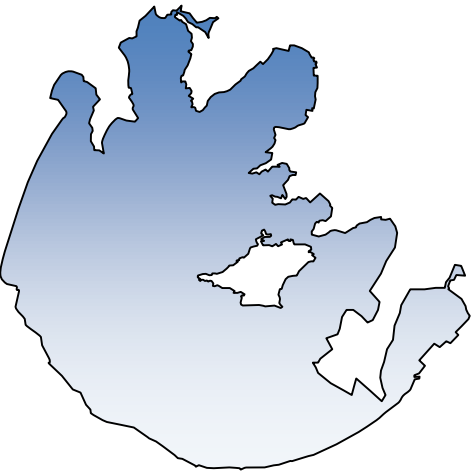
Hypophthalmichthys molitrix

Pelteobagrus fulvidraco

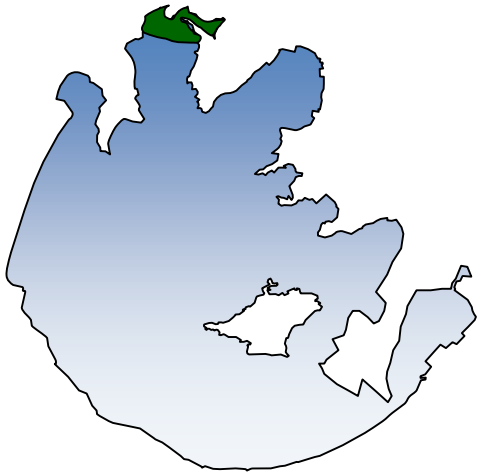
Eriocheir sinensis Milne-Edwards

Cyanobacterial blooms in Taihu

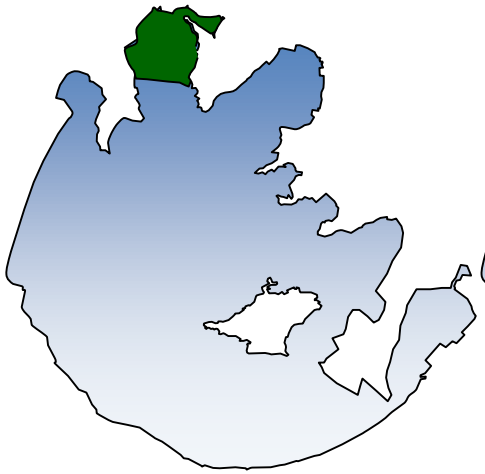
History of blooms in Taihu



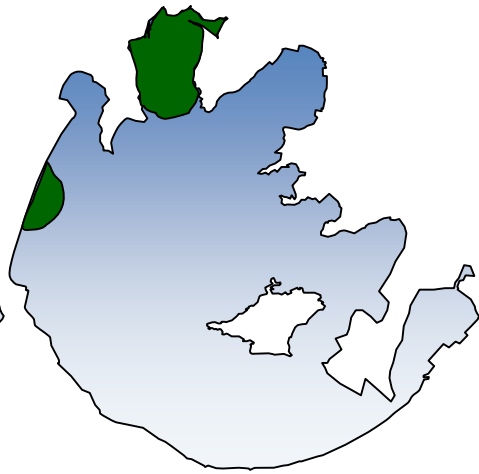
1950's



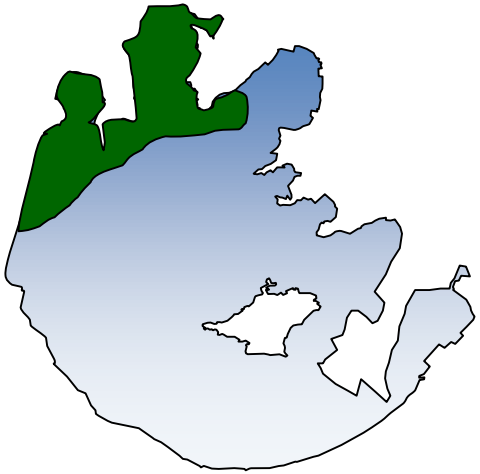
1970's



1980



1987



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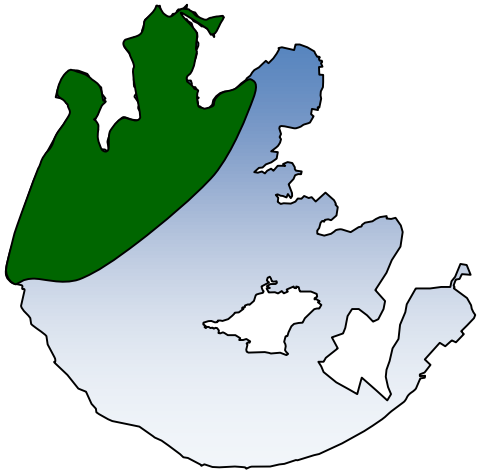
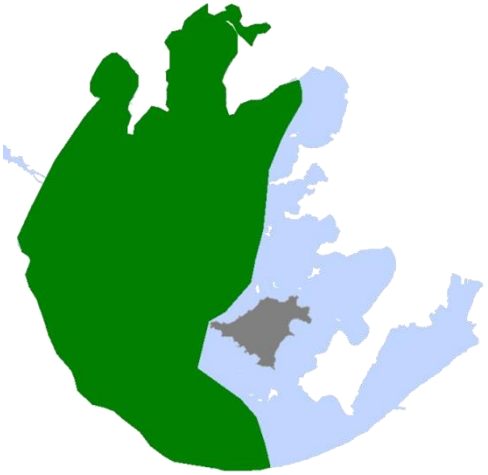
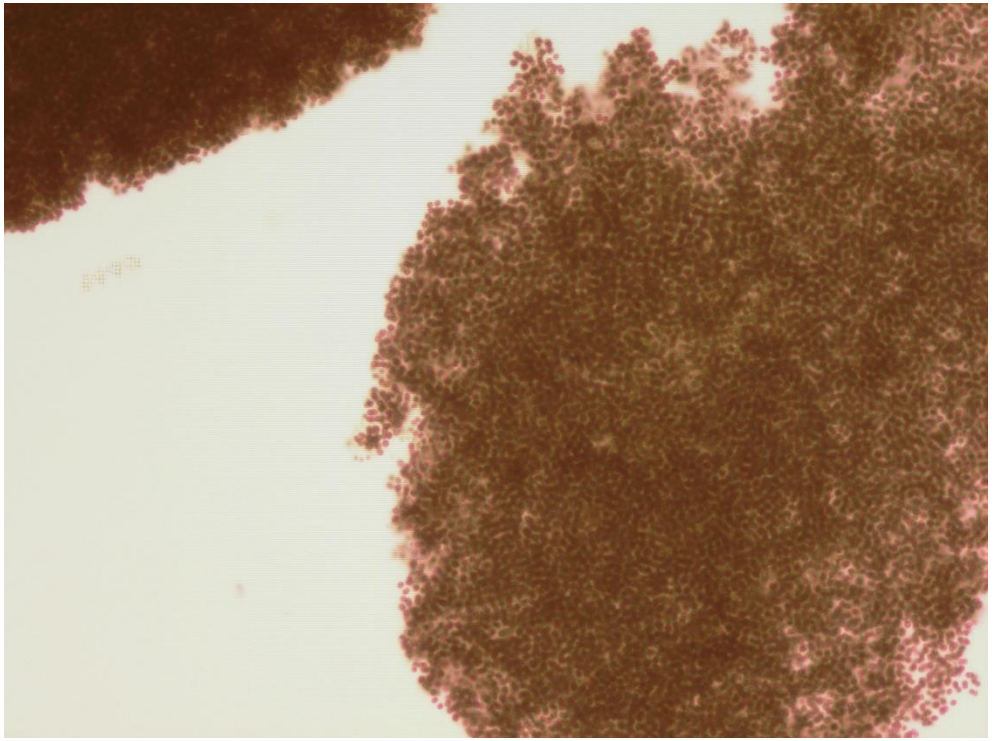


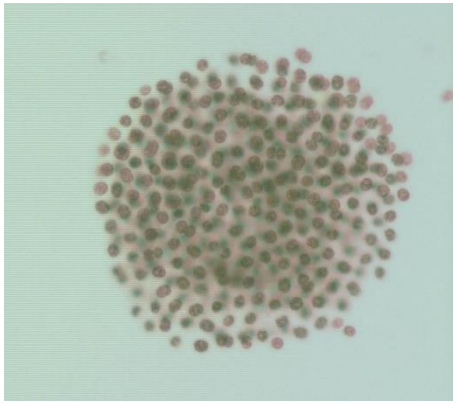
2000



2006

Major player: *Microcystis* spp.



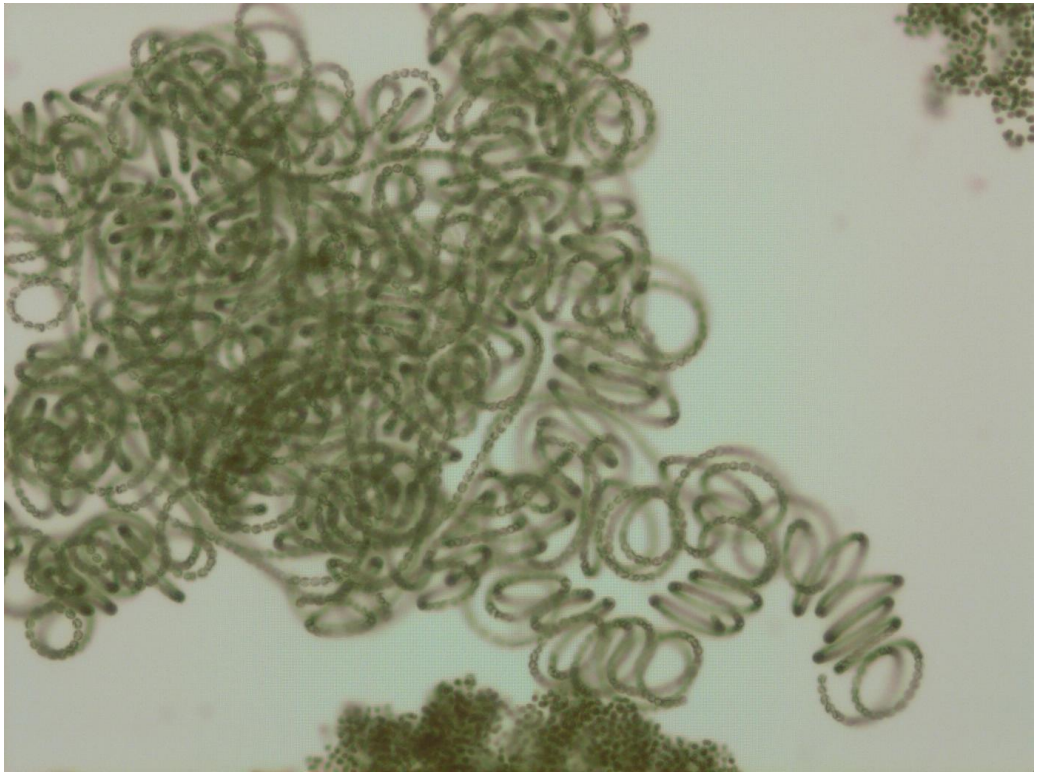


Photos by Gregory Boyer, at May 28 2012

Microcystis spp. in Taihu

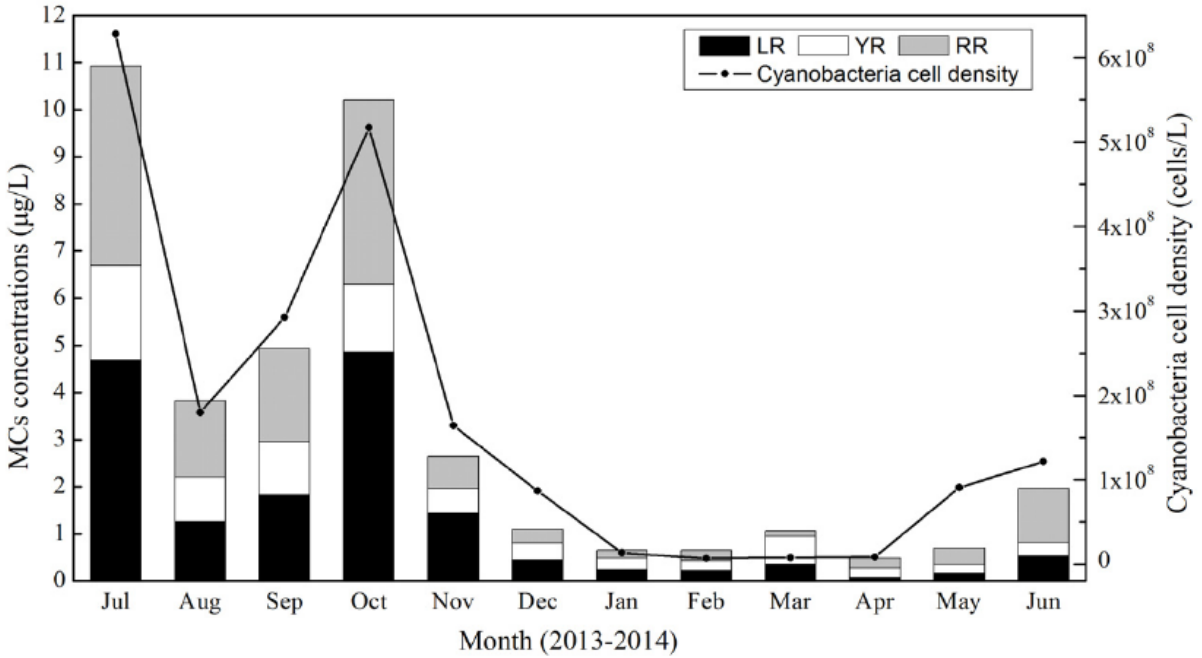
Microcystis aeruginosa *Microcystis wesenbergii* *Microcystis flos-aquae*

Supporting actor: *Anabaena* spp.



Photos by Gregory Boyer, at May 28 2012

Problem caused by blooms: Microcystin



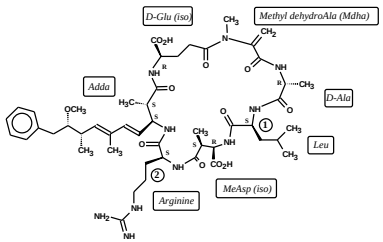


Figure 3. Monthly variability of the concentrations of MCs and cyanobacteria cell density in Lake Taihu.

Su et al., Toxins, 2015

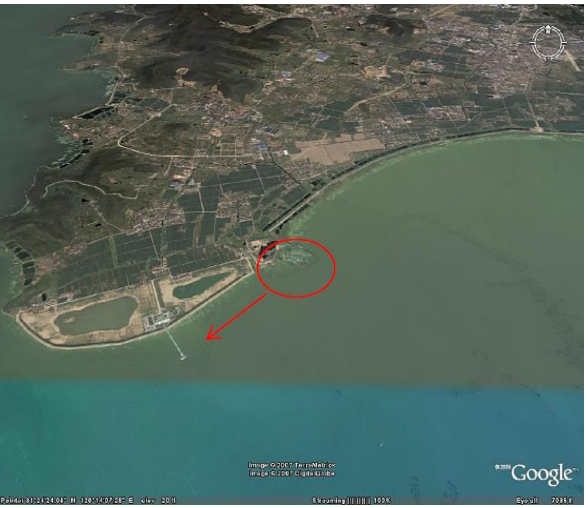
Problem caused by blooms: Black patch

Black patch at northwest bay of Taihu, June 22, 2015

Dimethyl trisulfide (DMTS); Geosmin; 2-MIB;
β-cyclocitral, β-ionone; 2-isobutyl-3-methoxypyrazine (IBMP)

2. Drinking water crisis at May of 2007

Water crisis caused by black patch in Taihu



Water crisis happened at Wuxi during May 29 – 3 Jun 2007,
for the block of intake at Gonghu blocked by black patch.

The major odor compounds

During the crisis

Dimethyl Trisulfide (DMTS):

A kind of volitile compound produced at anaerobic condition with plenty of corruptive organic matters, for example, the died algae.

The Next year, 2008

Table 3
Seasonal changes of total T&O compounds concentrations, percentage of the dissolved and particulate fractions of each analyte, and occurrence of T&O compounds (dissolved, particulate) that exceeded their OTC values at the 15 sampling sites in Gonghu Bay, Lake Taihu during the study period.

	DMS			DMTS			IPMP			MIB			IBMP			β-cyclocitral			GEO			β-ionone		
	TC (ng/l)	D (%)	P (%)	TC (ng/l)	D (%)	P (%)	TC (ng/l)	D (%)	P (%)	TC (ng/l)	D (%)	P (%)	TC (ng/l)	D (%)	P (%)	TC (ng/l)	D (%)	P (%)	TC (ng/l)	D (%)	P (%)	TC (ng/l)	D (%)	P (%)
Jan	0.00	--	--	0.00	--	--	3.68	0.0	100.0	2.12	23.1	76.9	0.00	--	--	0.81	0.0	100.0	3.52	100.0	0.0	0.00	--	--
Feb	0.13	100.0	0.0	0.00	--	--	4.13	0.0	100.0	1.67	28.0	72.0	3.00	20.0	80.0	3.13	0.0	100.0	5.60	92.9	7.1	0.00	--	--
Mar	64.67	27.3	72.7	23.00	26.7	73.3	8.27	17.7	82.3	0.53	0.0	100.0	0.87	100.0	0.0	2.07	32.4	67.6	3.40	52.9	47.1	0.00	--	--
Apr	84.87	50.0	50.0	0.00	--	--	8.33	25.6	74.4	3.07	21.7	78.3	0.00	--	--	1.33	0.0	100.0	0.60	0.0	100.0	0.00	--	--
May	16.11	17.6	82.4	0.00	--	--	5.42	24.6	75.4	1.60	100.0	0.0	3.41	52.8	47.2	25.74	32.6	67.4	4.65	64.5	35.5	12.28	0.0	100.0
Jun	13.80	100.0	0.0	0.00	--	--	4.87	0.0	100.0	0.00	--	--	0.33	0.0	100.0	26.27	55.8	44.2	0.96	0.0	100.0	14.33	45.6	54.4
Jul	0.00	--	--	0.00	--	--	0.42	0.0	100.0	18.69	0.0	100.0	0.05	0.0	100.0	537.61	42.9	57.1	11.29	72.0	28.0	50.44	16.7	83.3
Aug	0.47	100.0	0.0	0.00	--	--	0.16	84.4	15.6	5.64	20.1	79.9	0.00	--	--	538.12	43.4	56.6	0.53	100.0	0.0	45.52	9.9	90.1
Sep	201.18	0.0	100.0	69.55	0.0	100.0	0.42	0.0	100.0	18.14	99.2	0.8	0.00	--	--	124.84	2.1	97.9	0.40	100.0	0.0	40.80	3.7	96.3
Oct	0.00	--	--	0.00	--	--	0.87	100.0	0.0	0.28	0.0	100.0	0.40	100.0	0.0	260.64	0.7	99.3	0.93	100.0	0.0	46.60	0.0	100.0
Nov	3.87	0.0	100.0	0.00	--	--	0.00	--	--	0.00	--	--	0.00	--	--	77.06	15.7	84.3	8.07	0.0	100.0	1.47	0.0	100.0
Dec	0.93	14.3	85.7	0.20	100.0	0.0	1.60	29.2	70.8	2.27	23.5	76.5	0.00	--	--	0.00	--	--	0.00	--	--	0.00	--	--
AMC	32.17	6.46	25.71	7.73	0.53	7.20	3.18	0.53	2.65	4.50	1.91	2.59	0.67	0.31	0.37	133.13	42.06	91.08	3.33	1.96	1.37	17.62	1.75	15.87
OTC	$0.3\text{-}1\times10^3$			10			20			15			2-16			$0.5\text{-}19.3\times10^3$			4			7		

Chen et al, 2010

The cause 1: Extreme serious bloom

Serious bloom start 8 April, a month earlier than normal.

The cause 2: Extreme warmer spring

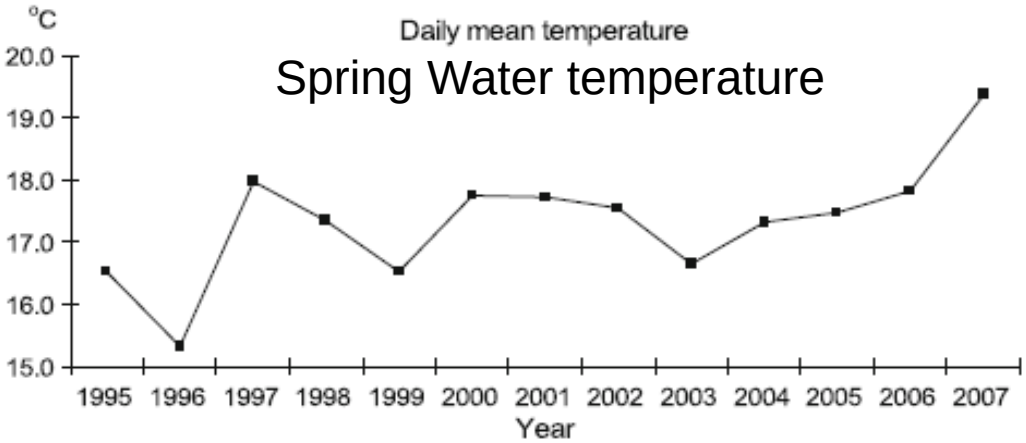
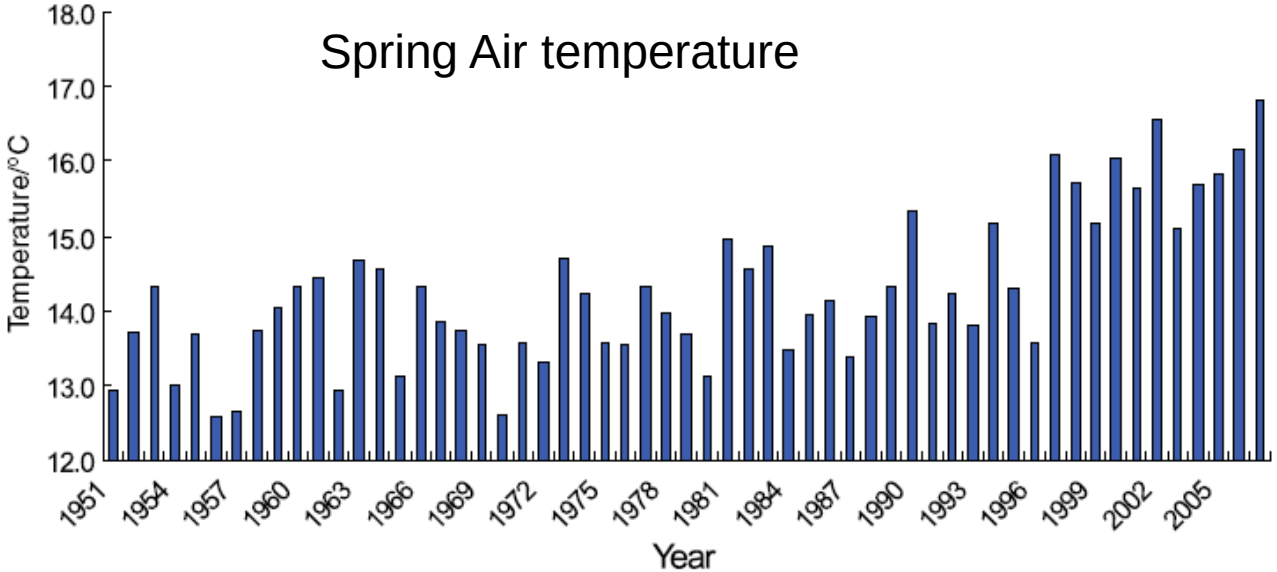


Fig. 3 Changes in daily mean surface water temperature from March 1 to May 31 in Lake Taihu since 1995

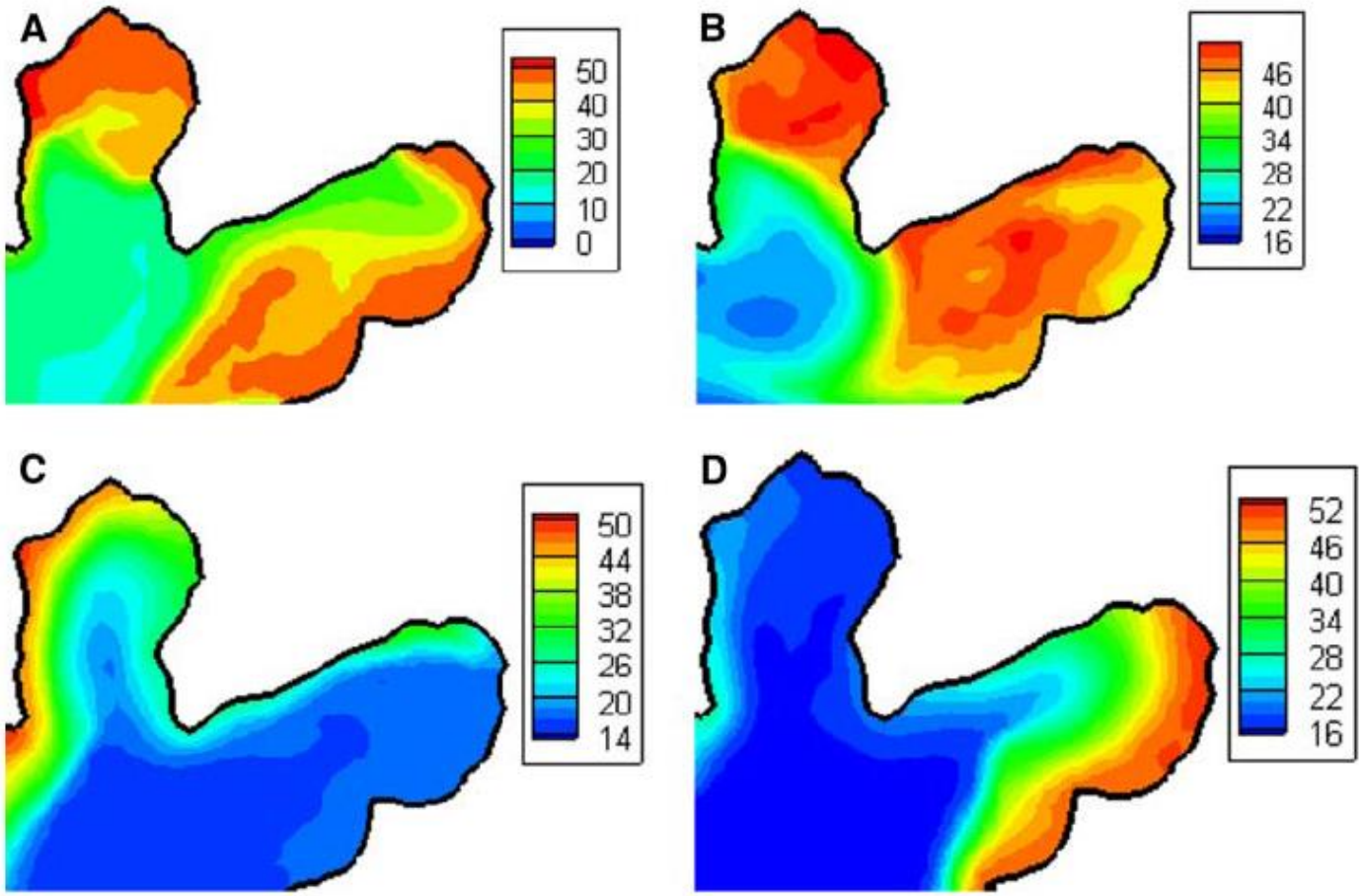
Fig. 4 Changes in spring surface air temperature (March–May) since 1951 at Shanghai Meteorological Station, Meteorological Bureau of China



Qin et al, 2010

The cause 3: Suitable wind direction

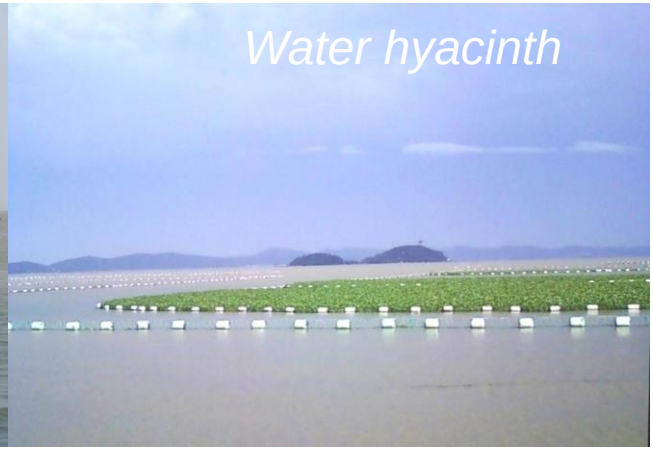
Fig. 5 Simulated spatial distribution of chlorophyll concentration (μg L^{-1}) under the influence of different wind regimes. **a** easterly wind; **b** westerly wind; **c** southerly wind; **d** northerly wind. Bloom intensities are shown as chlorophyll *a* concentrations



3. Actions after water crisis of 2007

The total investigation is over 100 billions RMB

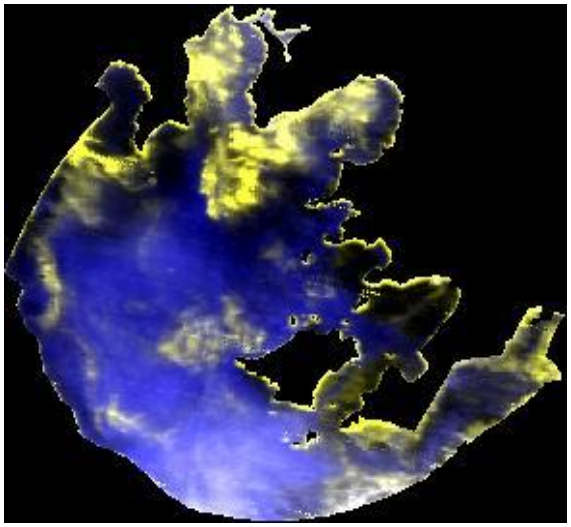
Catchment: ***Fertilization control*** ***Ecological restoration***



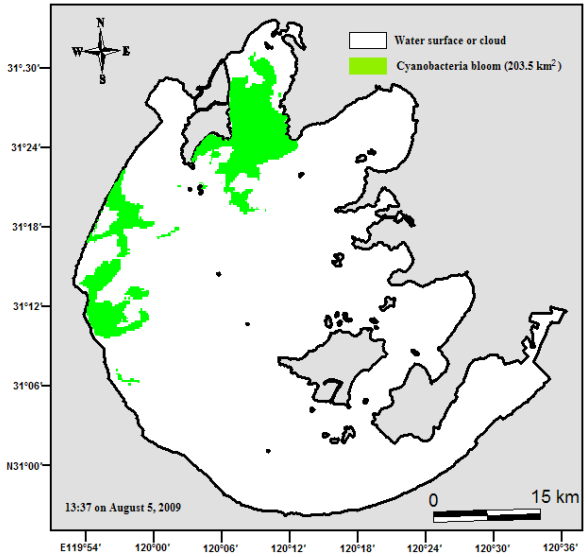
In lake: ***Bloom collection*** ***Sediment dredging*** ***Ecological engineering***

A example: Monitor and forecast of bloom

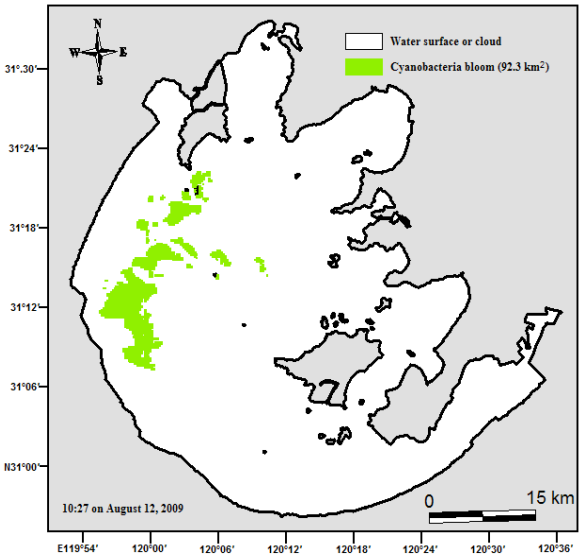
Why we need monitoring and forecast



- Bloom and black patch are very patched in spatial.
- The density of bloom or black patch are depend on weather.
- To remove the toxin or odors from water need time and money.



13:37, Aug 5, 2009



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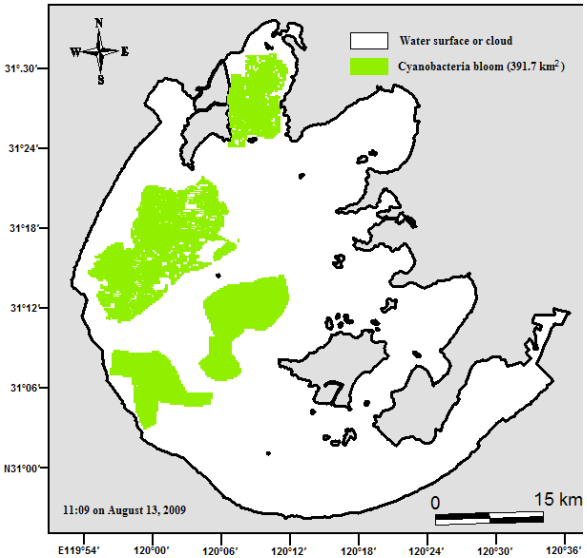
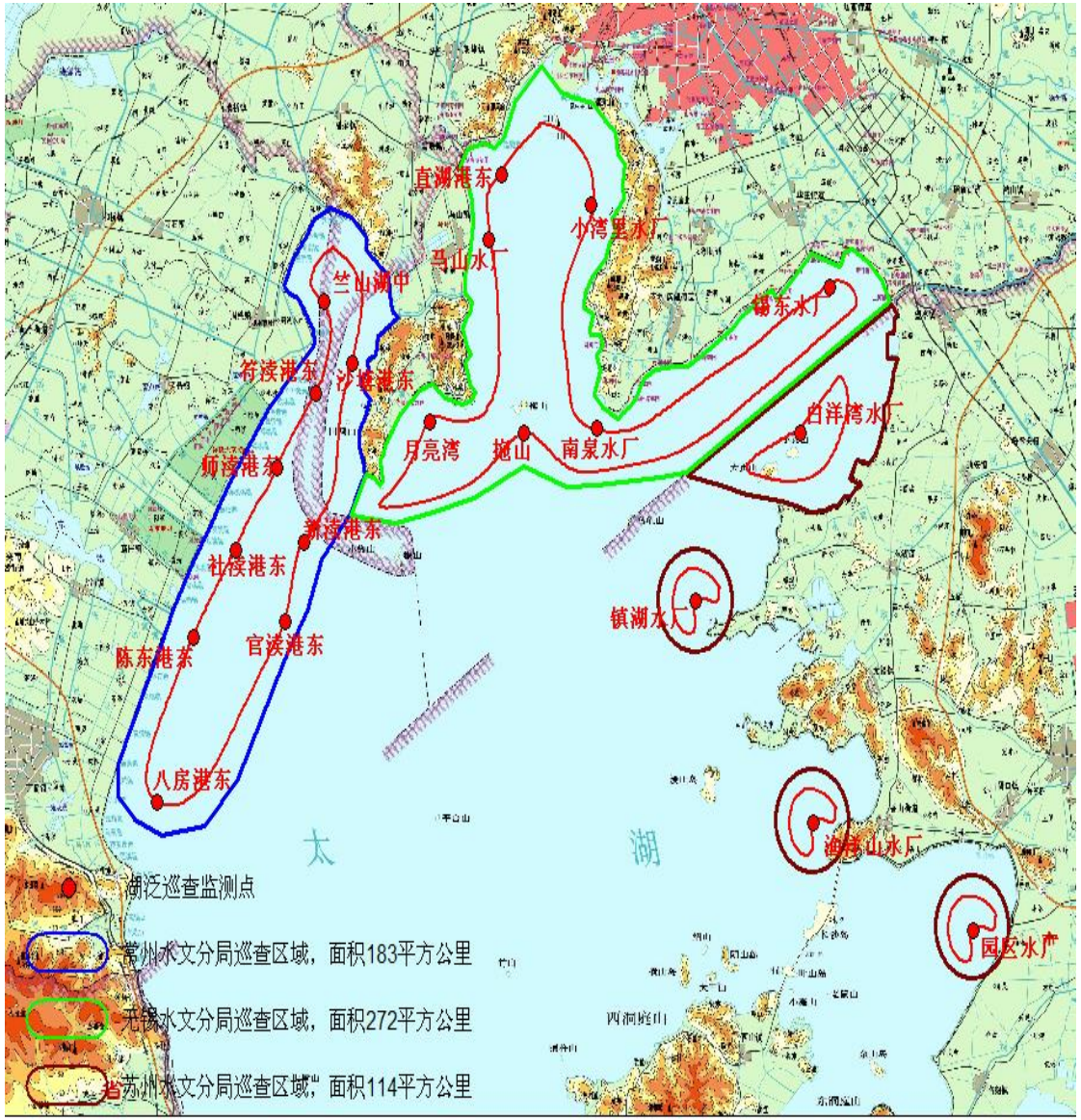


11:09, Aug 13, 2009

Monitor 1: near shoreline check everyday



Checking area: 569 km^2
Route length: 209 km
Stop and measure sites: 24
Dates: 194 days
April 10 to Oct 20

Variables recording:

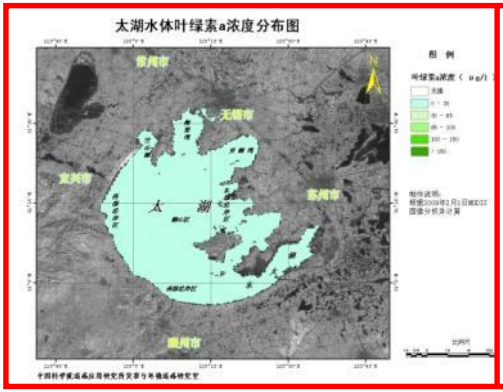
Weather: wind speed;
wind direction
Water temp
Air temp

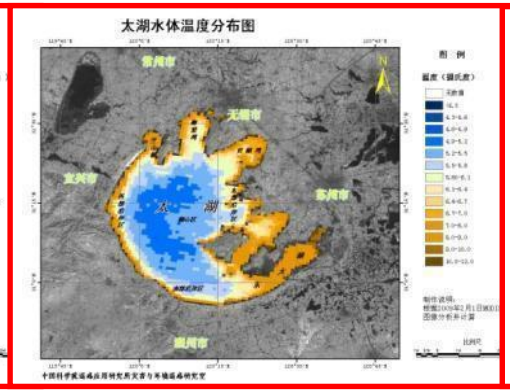
Algal: Cell density
Chlorophyll a

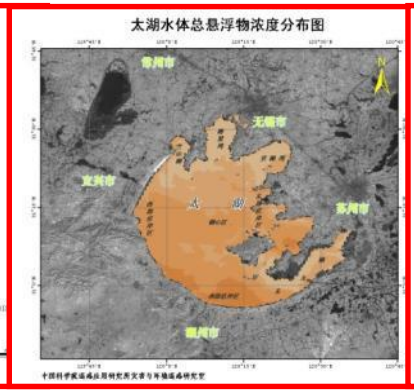
Water: DO; pH; *Eh*
Secchi depth
Odor

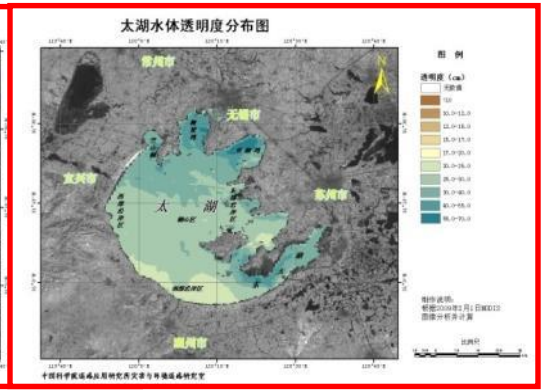
Special designed aeration boat

Monitor 2: Remote sensing image interpret bloom









Chlorophyll *a* **Temperature** **Suspended solid** **Transparency**

Data sources:

HJ – CCD
MODIS
MERIS
GOCI

Interpret model:
APPLE model
or
3 wavelengths model: 660-690 nm; 710-730nm; > 730nm

$$\text{HJ-CCD}: [\text{Chl. a}] \propto R(b_4) - [(R(b_1) - R(b_4)) \cdot R(b_4) + (R(b_3) - R(b_4))] \quad (16)$$

$$\text{MODIS}: [\text{Chl. a}] \propto R(b_2) - [(R(b_3) - R(b_2)) \cdot R(b_2) + (R(b_1) - R(b_2))] \quad (17)$$

$$\text{MERIS}: [\text{Chl. a}] \propto R(b_9) - [(R(b_2) - R(b_9)) \cdot R(b_9) + (R(b_7) - R(b_9))] \quad (18)$$

$$\text{GOCI}: [\text{Chl. a}] \propto R(b_7) - [(R(b_2) - R(b_7)) \cdot R(b_7) + (R(b_6) - R(b_7))] \quad (19)$$

Monitor report of Taihu bloom by remote senser

太湖蓝藻卫星遥感监测报告

总第 458 期

中国科学院南京地理与湖泊研究所　　2012 年 8 月 20 日（第 38 期）

2012 年 8 月 20 日 10 时 28 分的 MODIS 卫星遥感影像显示太湖水面出现蓝藻水华，蓝藻水华集聚面积约 633.2km²。其中高强度水华面积约 174.2km²，低强度约 459.0km²。MODIS 卫星遥感反演结果分别见表 1、图 1-图 3。

表 1 太湖水体卫星遥感反演结果

	叶绿素平均（μg/l）	藻蓝素平均（μg/l）	表层水温平均（℃）	水华面积（km²）
10 时 28 分	异常	异常	25.2	低：459.0 高：174.2

太湖温度分布较为均一，沿岸温度略高于湖中心温度。

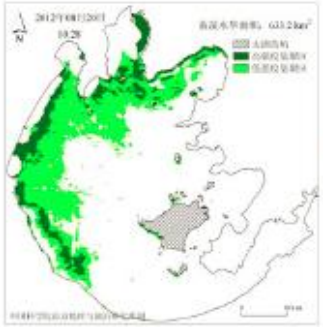


图 1 2012 年 8 月 20 日 10 时 28 分太湖水华分布图

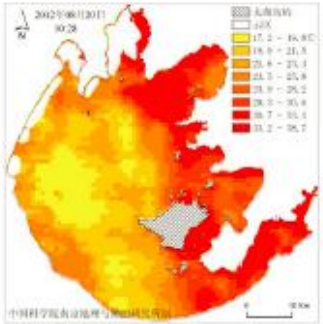


图 2 2012 年 8 月 20 日太湖水面表层温度 MODIS 监测结果

1

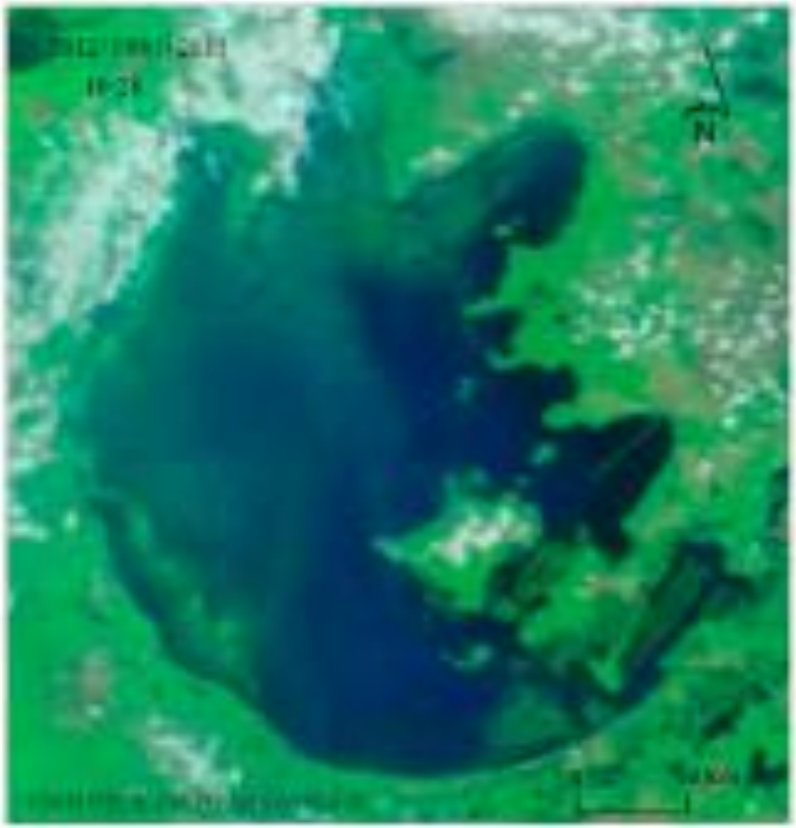


图 3 2012 年 8 月 20 日 10 时 28 分太湖遥感影像

Monitor 3: High-frequency “buoy” monitor

Weather station

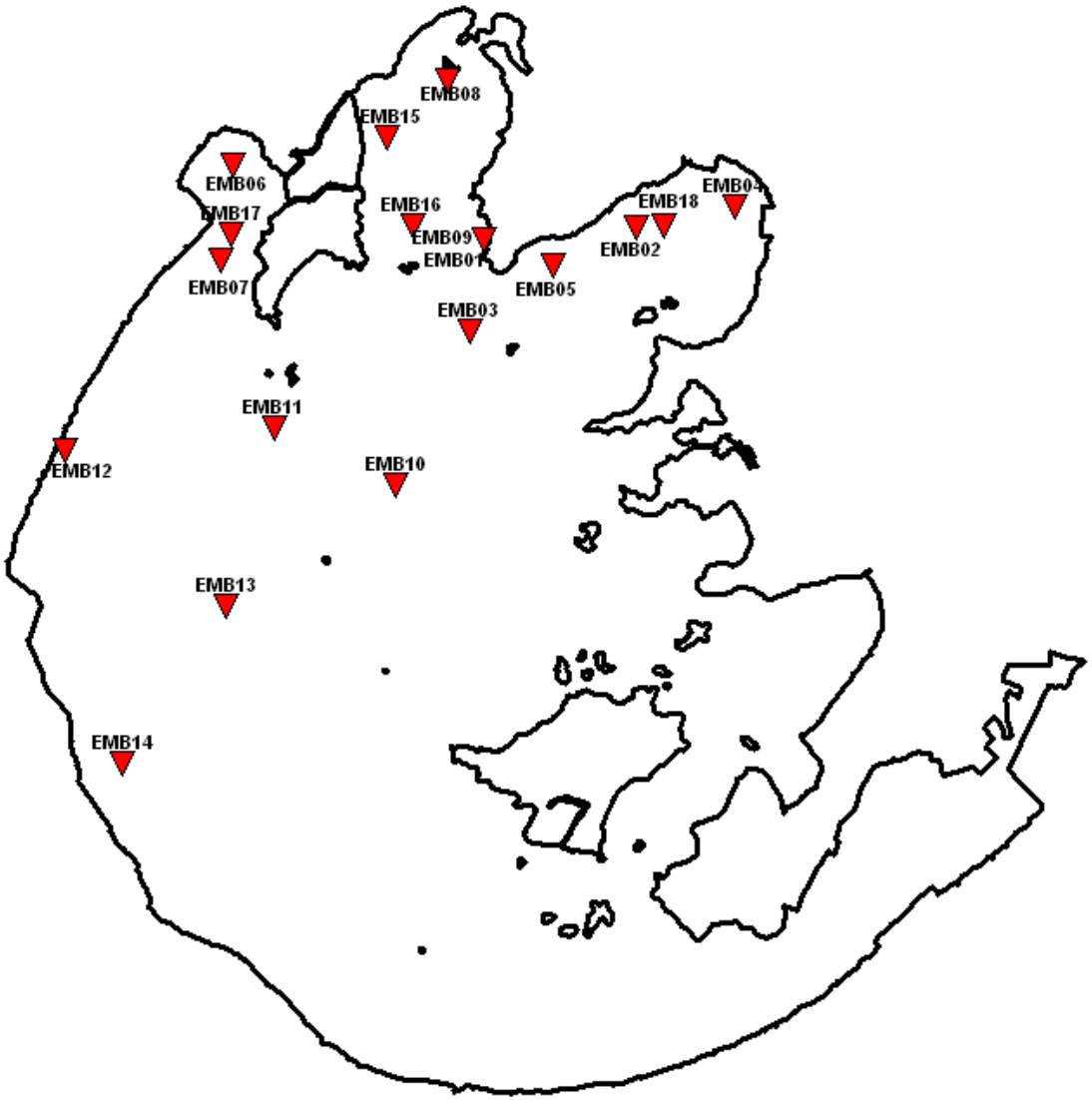
Energy: wind and solar radiation panel

YSI sonde: Chl-a, DO, PC, Turb, pH, Cond, Temperature, et al.

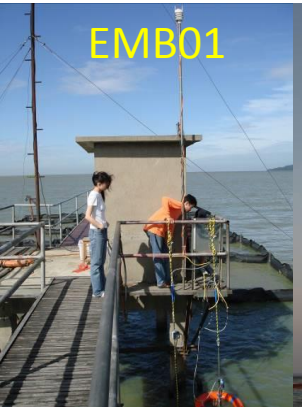
Bottom DO sensor

Wave and current sensors

Buoy distribution

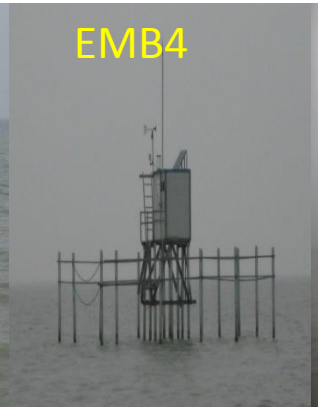


Buoy types


EMB01


EMB02


EMB03

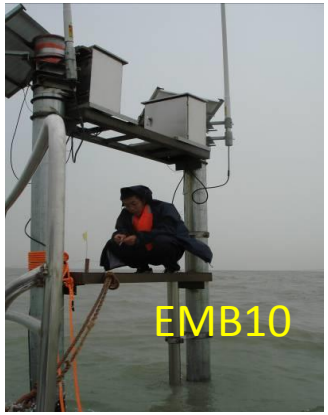

EMB4


EMB5

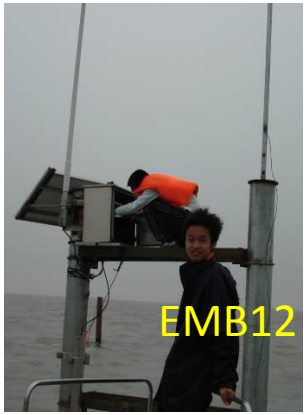

EMB6


EMB7

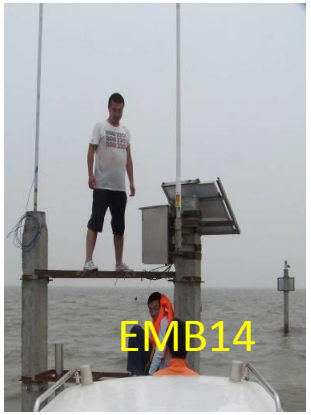

EMB08
2010/07/08


EMB10


EMB11

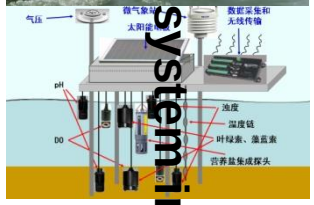

EMB12


EMB13
06/08

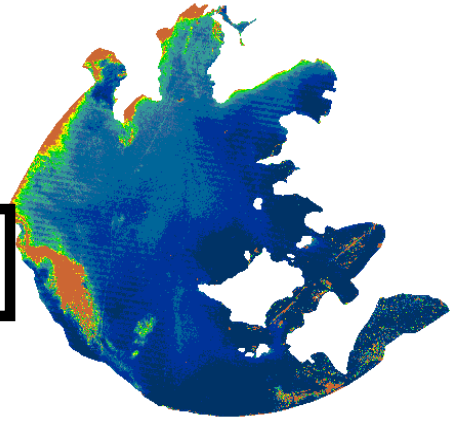

EMB14

Forecast the bloom

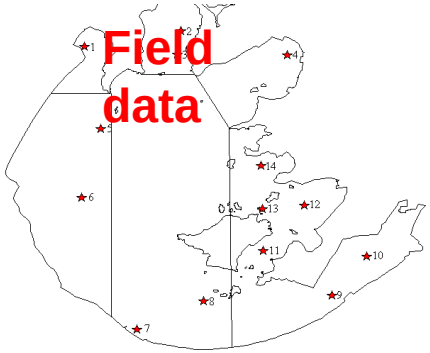
Stereo-monitoring system in Lake Taihu



Model development and calibration



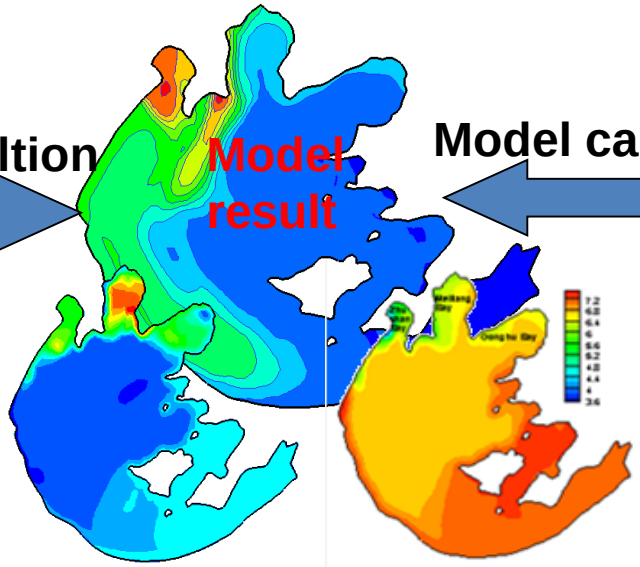
Field data



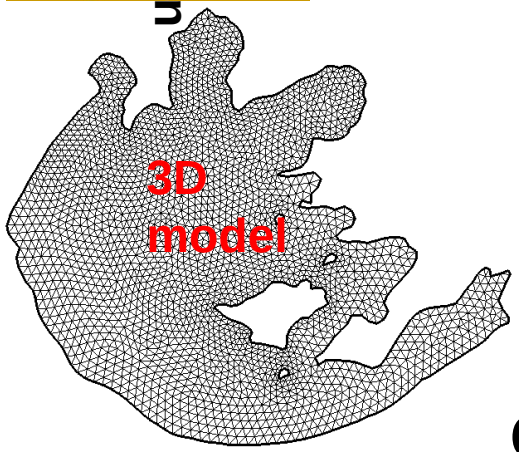
Model calcultion

Model calibration

Model result



Chl-a DO



3D model

Chlorophyll a and DO model

Possibility of bloom and black patch calculation

$$P_{\text{bloom, black patch}} = f_{1,\text{DO}}(O) \times f_{2,\text{Wind}}(V) \times f_{3,\text{ Rain}}(R) \times f_{4,\text{Chl}}(B)$$

DO *mg/L*	f(O)	Wind speed *m/s*	f(V)	Rain	f(R)	Chl-a *μg/L*	F(B)
<2	1	0.3-3.3	1	Sunny	1	>60	1
2--4	0.9	3.4-5.4	0.9	Cloudy	0.9	50-60	0.9
4--6	0.8	5.5-7.9	0.8	Light rain	0.8	30-50	0.5
6--8	0.6	8.0-10.7	0.7	Moderate	0.7	10-30	0.3
>8	0.4	>10.8）	0.5	Heavy rain	0	<10	0.1

3-days forecast report

太湖蓝藻及湖泛监测预警半周报

太湖蓝藻及湖泛监测预警工作小组　　2013-06-27

中国科学院南京地理与湖泊研究所太湖蓝藻及湖泛监测预警半周报

主要预测地点：太湖竺山湾至陈东港　　日期：2013-06-27

	竺山湾至陈东港				三日温度（℃）			三日风向			三日气象		
巡测点	0	1	2	3	28	29	30	28	29	30	28	29	30
Chla(μg/L)	10.5	6.1	5.7	3.3	22-27	23-28	24-29	E	E	E	阴	小雨转大雨	大雨转小雨
DO(mg/L)	7.8	6.0	4.8	3.4									

预测概率

6 月 28 日至 6 月 30 日三天内

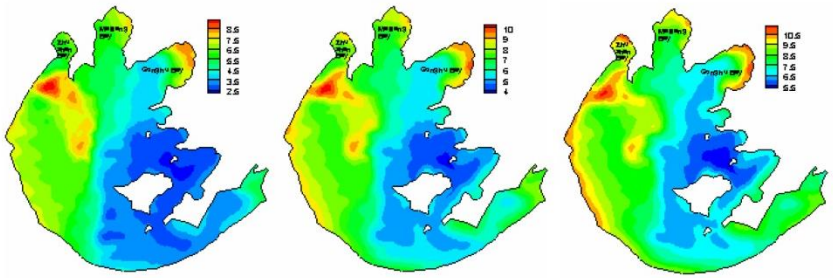
梅梁湾水面灾害性蓝藻水华发生平均概率　70 %
主要区域：各沿岸带
梅梁湾水面湖泛发生平均概率　60%
主要区域：马山水厂至直湖港

贡湖湾水面灾害性蓝藻水华发生平均概率　40 %
主要区域：北部沿岸带及湾顶
贡湖湾水面湖泛发生平均概率　45%
主要区域：黄泥田港至壬子港沿岸带

竺山湾及西部沿岸带水面灾害性蓝藻水华发生平均概率　80 %
主要区域：八房港至竺山湾顶
竺山湾及西部沿岸带水面湖泛发生平均概率　40 %
主要区域：符渎港至竺山湾口

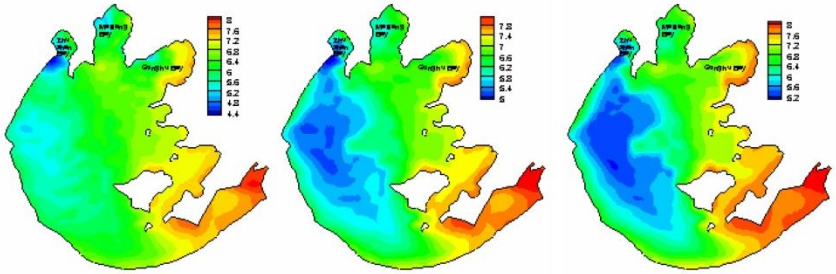
区　域	发生水华概率	出现异味水体概率	异味水体面积
太湖沙塘段	60%	20%	
沙塘符渎段	60%	40%	0.09-0.5 km^2
符渎陈东段	80%	30%	
陈东八房段	80%	20%	
吴塘壬子段	40%	45%	0.09-0.5km^2
蠡河新开段	30%	20%	
梅梁湾	70%	60%	0.04-0.1 km^2

随后三天叶绿素 a 浓度分布



6 月 28 日　　6 月 29 日　　6 月 30 日

随后三天溶解氧浓度分布



6 月 28 日　　6 月 29 日　　6 月 30 日

今日太湖蓝藻水华及溶解氧现状描述：巡测时段整个湖区东南风，风浪中。全湖监测范围内水域均出现颗粒状蓝藻，未现水华，其中湖西新渎港和陈东港水域藻类生物量较高，其余水域藻类生物量不高。

全湖溶解氧浓度最低的水域为梅梁湾直湖港入湖口以北沿岸，浓度低于 2.0mg/L，水色淡黑，气味微臭，面积约 0.09 km^2；贡湖湾北部庙港至杨干港沿岸带，浓度低于 2.0mg/L，水色淡黑，气味微臭，面积约 0.3 km^2；其次为湖西符渎港水域。

未来三天内蓝藻水华及湖泛发展趋势：未来三天以阴雨天气为主，气温不高，气象条件不利于藻类的上浮和聚集。在持续东风的影响下，处于下风口的西太湖沿岸带至竺山湾藻类生物量普遍较高，部分水域在风低雨停时容易出现较多蓝藻水华。梅梁湾各沿岸带，贡湖湾北部沿岸带及湾顶水域在雨停风低时可能出现较多蓝藻颗粒或蓝藻水华。

全湖溶解氧浓度较低的水域出现在湖西符渎港至竺山湾口，梅梁湾马山水厂至直湖港水域及贡湖湾北部沿岸带西段，未来三天的阴雨天气理论上有望缓解异味水体的程度，但应继续关注风向变化和微臭水体在周边水域的动向，加强水源地的保护。

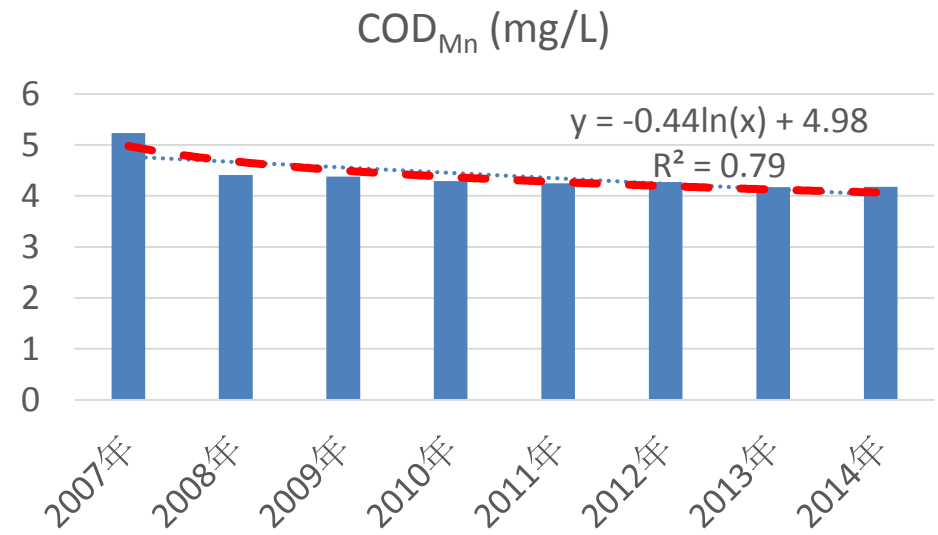
监测人：江苏省水文局　　数据整理人：李未　　预报人：秦伯强、李未、张运林、朱广伟

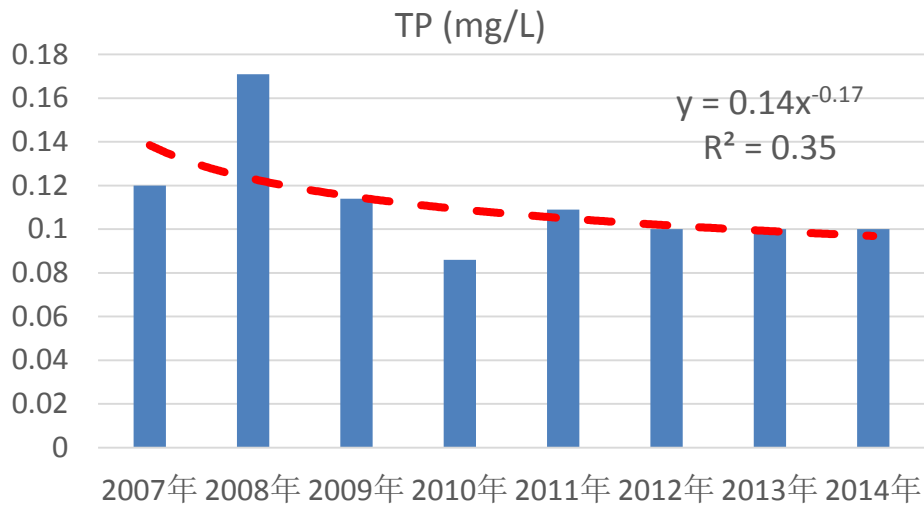
Possible reaction of local managers

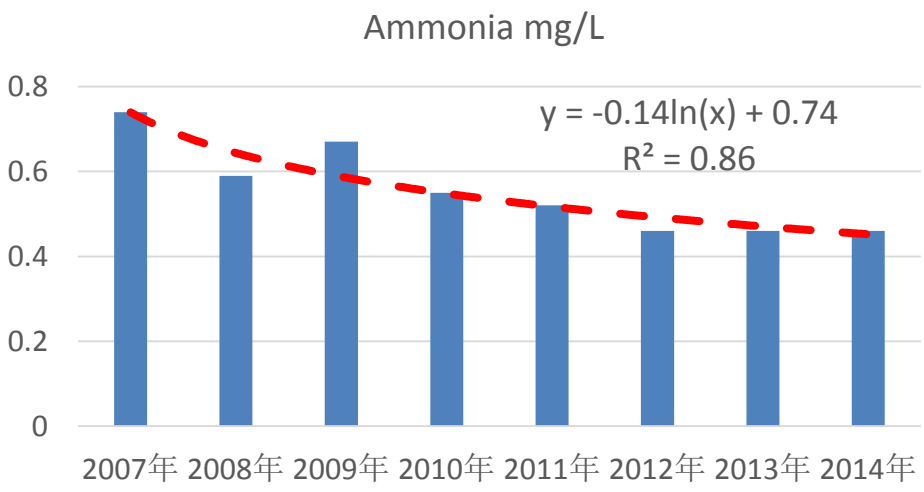
- **Water plants: Change the intake site, or use Yangtze river as source.**
- **Tourism agency: Change the travel lines.**
- **Monitoring agency: Pay more attention to High possible zone.**
- **Bloom emergency team: adjust the collection power.**

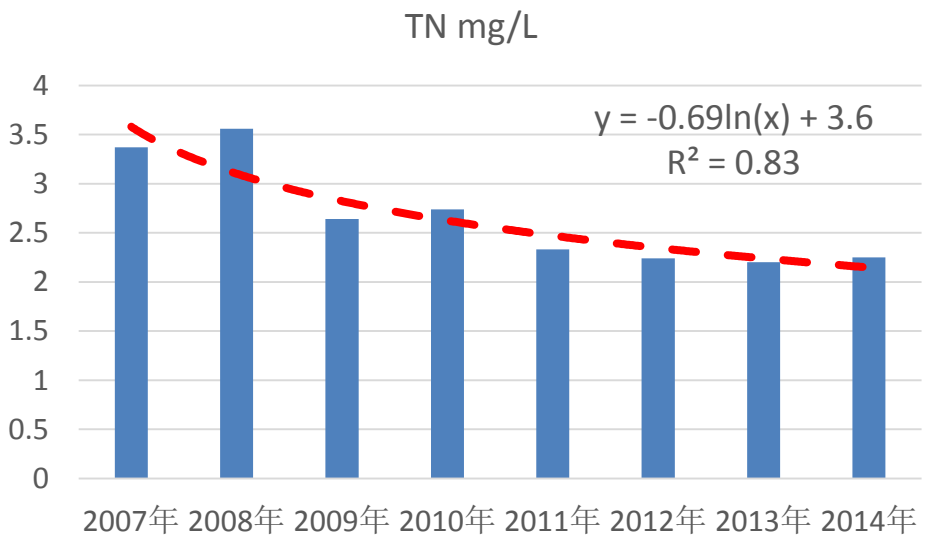
4. Challenge remained

Nutrient reduction still far from bloom control

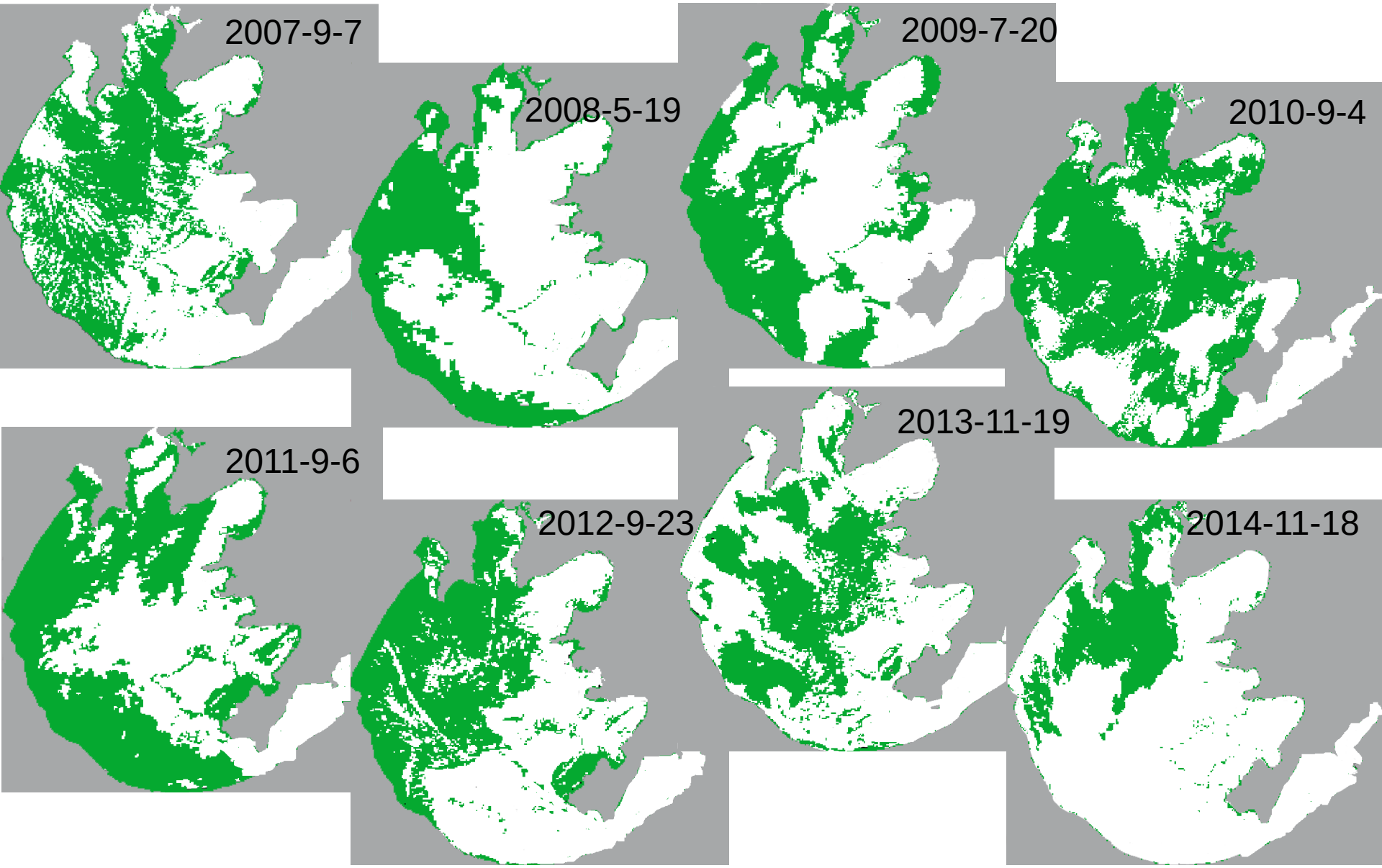








The bloom is still heavy



Conclusion

- **Taihu, similar to Lake Chaohu and Lake Dianchi in China, suffered from cyanobacterial bloom for more than 30 years. The major trouble maker is *Microcystis* spps. In Chaohu and Dianchi, Anabeana spps also are one of the major players.**
- **The biggest challenge in these lakes is the safety of city water supply. Being the spatial drift or movement behaviors of Microcystis bloom, to monitor and forecast the risk of bloom and black patch events for short time in these lakes are very possible.**
- **The ability of technology to solve bloom is limited. The pollution is a social and economic issue, too. To solve the problem, more social and economic solution should be introduced.**

Thank you for your attention!