

## Assessment and Regulation of Ocean Health Based on Ecosystem Services: Case Study in the Laizhou Bay, China



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2. METHODS
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# 1. INTRODUCTION

## Global Status of Marine Ecosystem

REPORTS

### Depletion, Degradation, and Recovery Potential of Estuaries and Coastal Seas

Heike K. Lotze,<sup>3\*</sup> H. Richard G. Cooke,<sup>5</sup> Charles H. Peterson

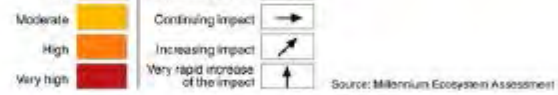
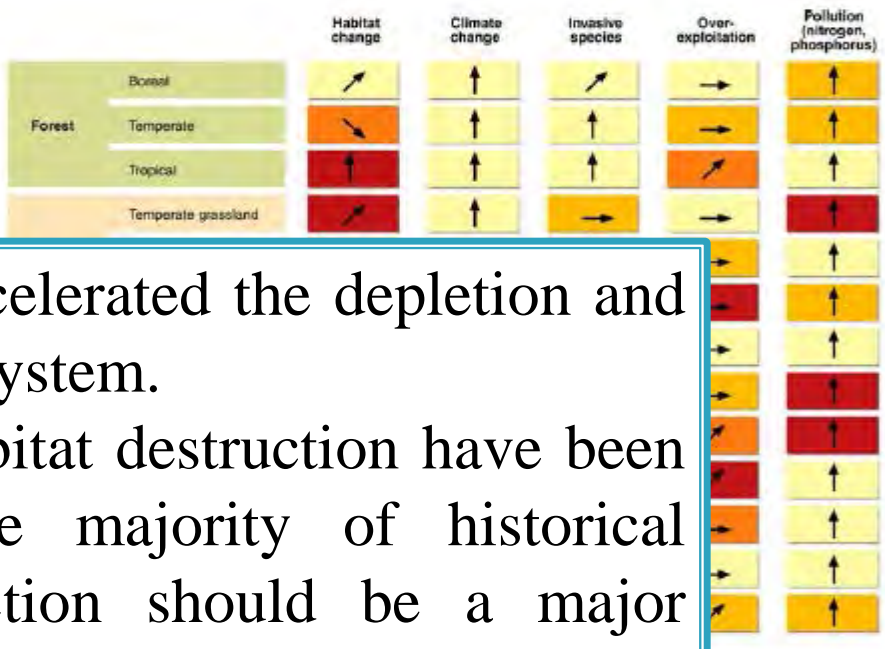
Estuarine and coastal ecosystems over the past 150 to 300 years have become increasingly degraded. Human impacts have depleted wetland habitat, degraded fisheries, and reduced conservation efforts to restore former ecosystems and quantitative targets.

Estuaries and coastal zones are hotspots of human resource use that are vulnerable to overexploitation, pollution, and climate change. Estuarine degradation has undermined their ability to provide ecosystem services. This poses potential risks to human health and well-being in numerous fisheries collapses (1–3) and the recent impacts of the 2004 Asian tsunami and 2005 Hurricane Katrina that were exacerbated by historical losses of mangroves and wetlands (5–7). With recognition of their essential role for human and marine life, estuaries and coastal zones have become the focus of efforts to develop ecosystem-based management and large-scale restoration

➤ Human impacts have accelerated the depletion and degradation of coastal ecosystem.

➤ Overexploitation and habitat destruction have been responsible for the large majority of historical changes, and their reduction should be a major management priority.

parameters and species invasions (10). Species were selected for their economic, structural, or functional significance throughout history. We estimated relative abundance of each species over real time and across seven cultural periods reflecting the stage of cultural and market development rather than calendar dates (tables S2 and S3). Relative abundance was quantified as pristine

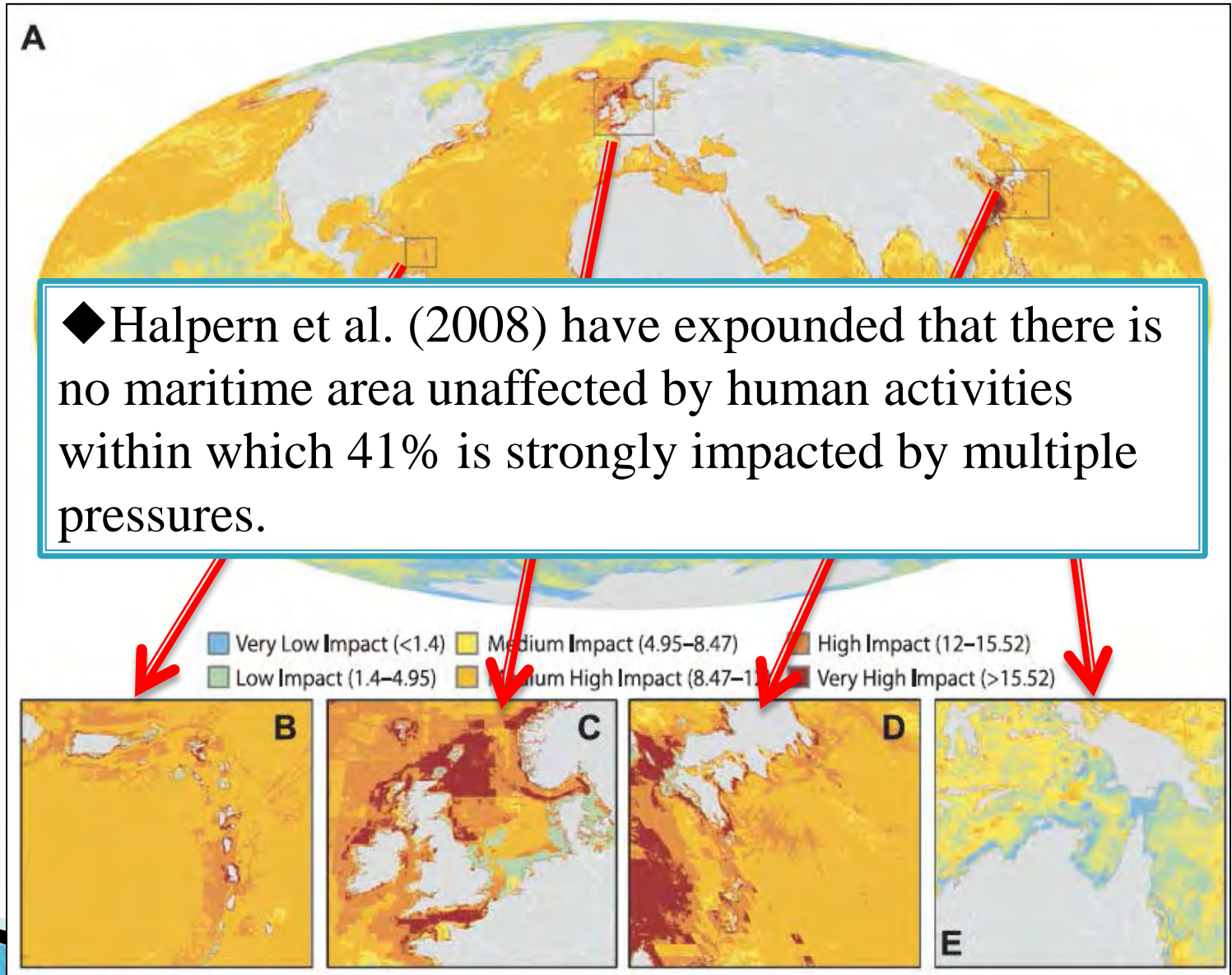


# Global Status of Marine Ecosystem

## A Global Map of Human Impact on Marine Ecosystems

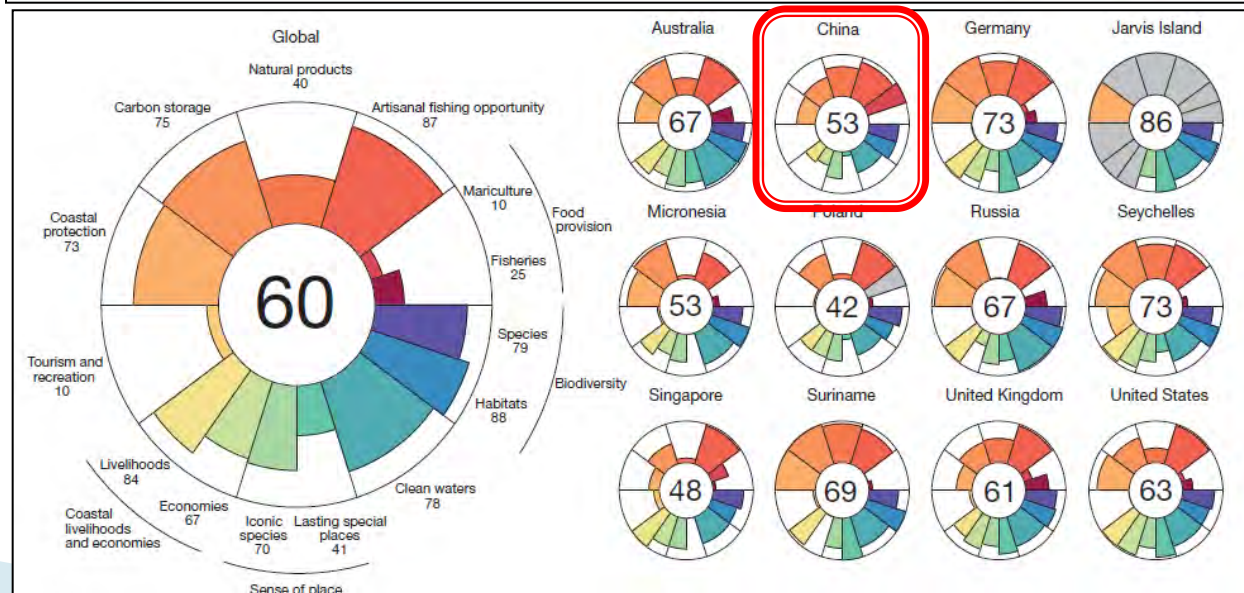
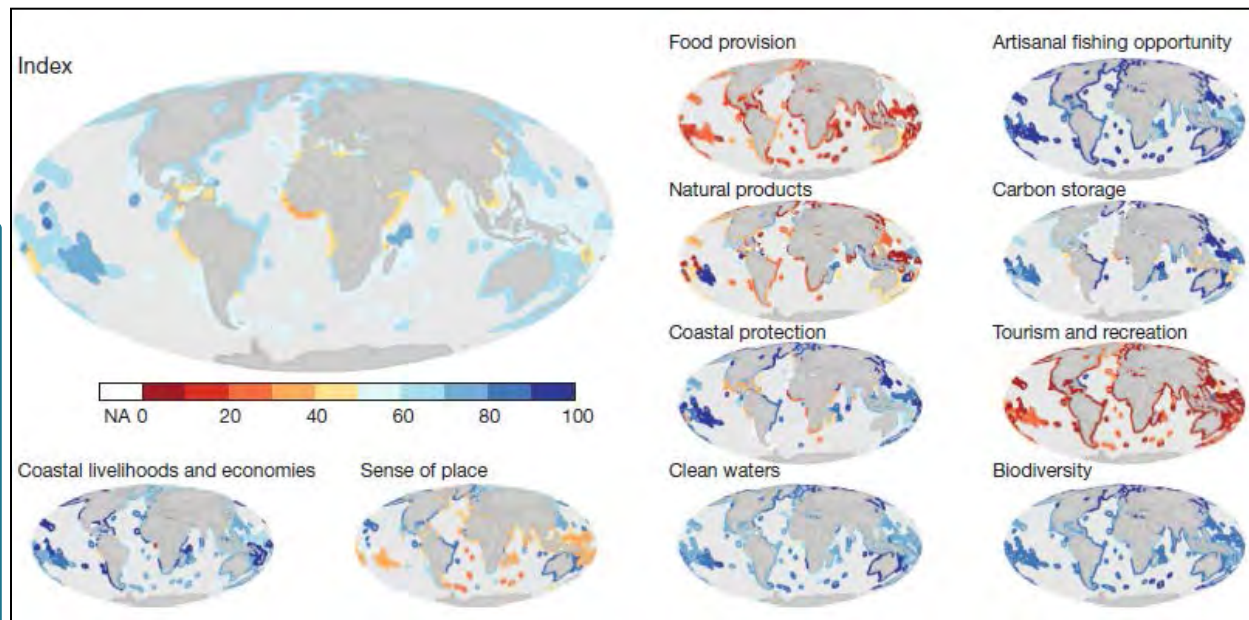
Benjamin S. Halpern, *et al.*

*Science* **319**, 948 (2008);  
DOI: 10.1126/science.1149345

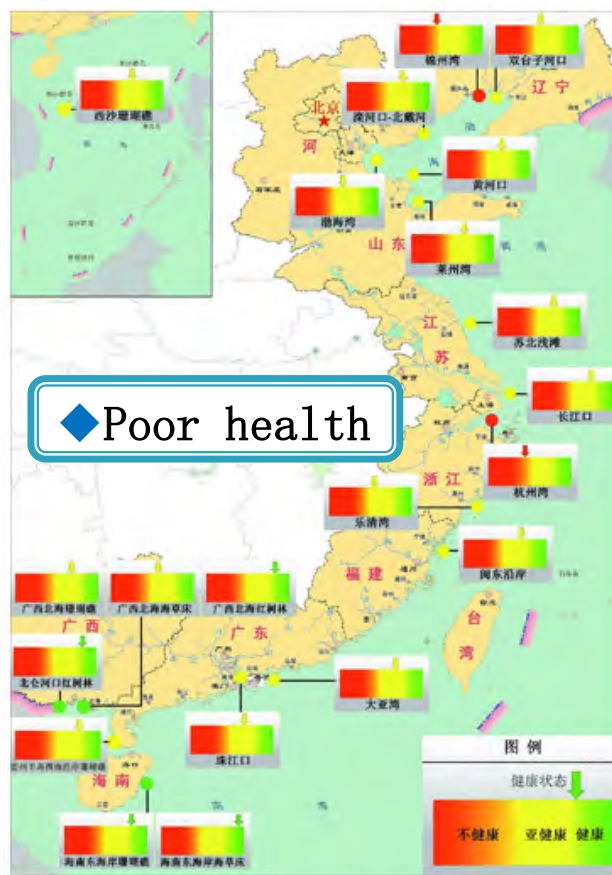
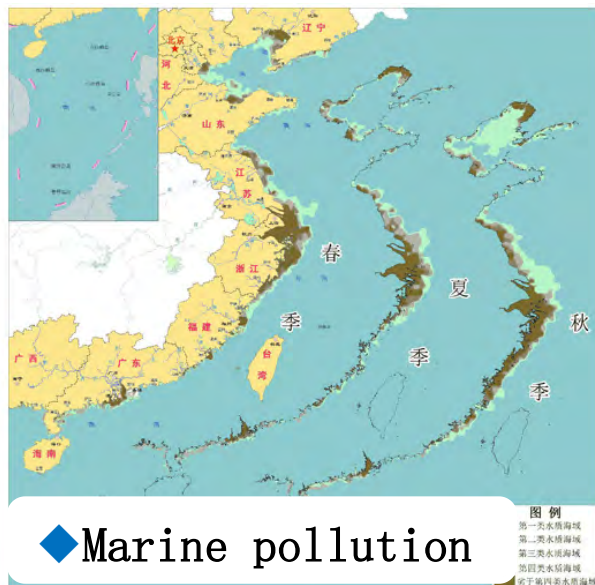


# Global Status of Marine Ecosystem

➤ Halpern et al. (2012) showed that the overall index to assess the health and benefits of ocean is globally 60 out of 100 (concerning the exclusive economic zone).



# Costal Ecological Status of China



2014年典型海洋生态系统健康状况\*



◆ Sourced from Bulletin of Marine Environmental Quality of China in 2014

# Multiple Human Pressures on Ocean

Socioeconomic activities

Watershed area  
(e.g. agriculture, living)

Intertidal zone  
(e.g. reclamation)

Nearshore waters  
(e.g. marine fishery)

Produce

Feedback

Anthropogenic pressures

Add pollutants

Remove, alter, or destroy habitat

Change species composition



# Research on Ocean Health

- ◆ **Ocean health** is generally described as the well-being of coupled human-ocean systems and regarded as the desired state of coastal and marine management.
- ◆ **Assessment of ocean health** gradually focuses on systemic and synthetic measures of ecosystem function and services.
- ◆ Moreover, **human impacts on marine ecosystem** are incorporated to highlight the interactions between human activities and natural systems.





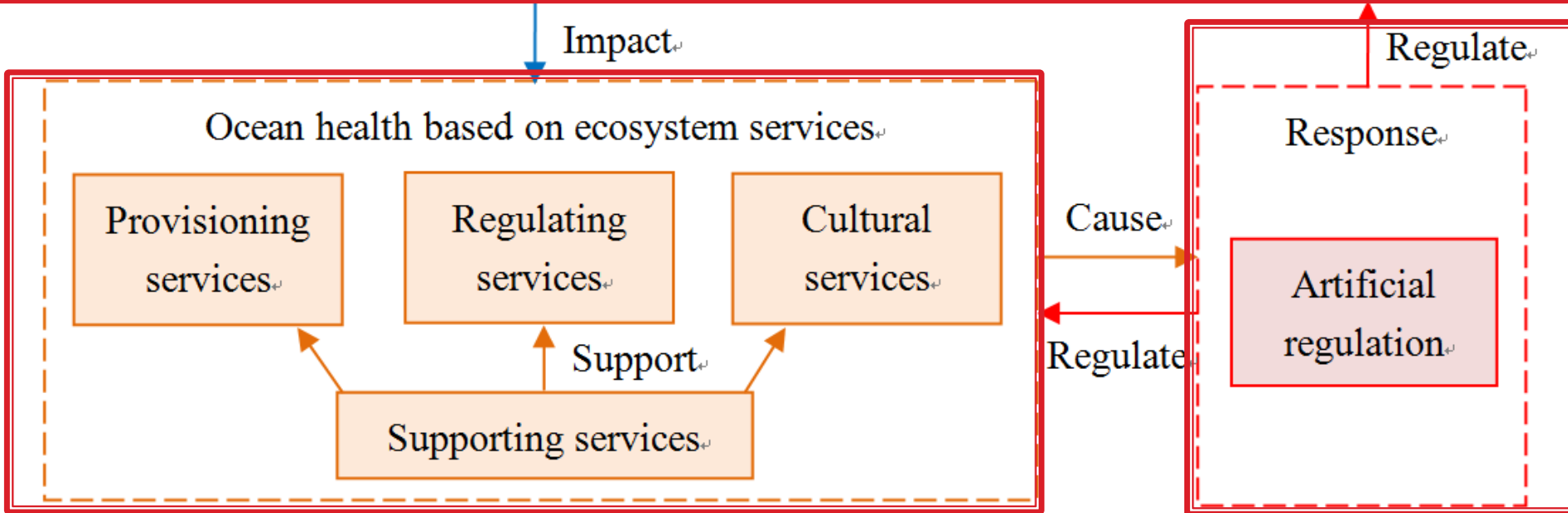
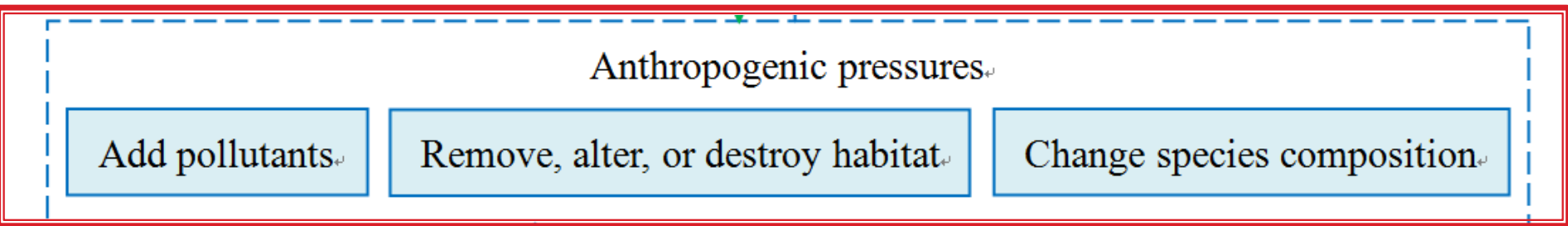
# Research Purpose

- ◆ To assess ocean health based on ecosystem function and services;
- ◆ To guide how to improve it by setting rules and regulations to address ecological pressures;
- ◆ To assist ecosystem-based management in the coastal zone.



## 2. METHODS >> Conceptual Framework based on PSR

### PRESSURE



### STATE

### RESPONSE

## 2. METHODS >> Specific Content

◆ **CURRENT STATUS:** To assess ocean health under current pressures;

◆ **LIKELY FUTURE:** To quantify the range of ocean health in the near-term future after regulations of negative pressures

Current  
status

+

Likely  
future

## 2. METHODS >> Indicator System of Ocean Health

➤ Tab.1 Indicator system of ocean health based on ecosystem services in LZB

1 <sup>st</sup> grade indicators	2 <sup>nd</sup> grade indicators	3 <sup>rd</sup> grade indicators
1. Supporting services	1. Habitat quality	1. Seawater quality including inorganic nitrogen (IN), oil pollutant
		2. Sediment quality including organic matter, sulfide
	2. Vigor	3. Marine primary productivity
		4. Phytoplankton
	3. Community structure	5. Zooplankton
		6. Benthos
2. Provisioning services	4. Food provision	7. Mariculture yield
		8. Fish bycatch
3. Regulating services	5. Regulation of gas and climate	9. O <sub>2</sub> production and CO <sub>2</sub> fixation
	6. Water purification	10. Rate of maritime area reaching the standard of IN
4. Cultural services	7. Coastal tourism	11. Tourist population
	8. Quality improvement of resident environment	12. Local population
	9. Scientific research	13. Number of published papers

## 2. METHODS >> Assessment methodologies of ocean health

### (1) The current score of the 3<sup>rd</sup> grade indicators (normalization methods) ( $S_{P,i}$ )

The sub-indicators of seawater quality and sediment quality

- $S_{P,i} = \min(1, x_0/x)$
- where  $S_{P,i}$  is the present score of sub-indicator  $i$ ;  $x$  and  $x_0$  are the present value and reference value, respectively.
- the reference value required by development to national standard of GB 3097-1997 and in China, respectively

The sub-indicators of community structure

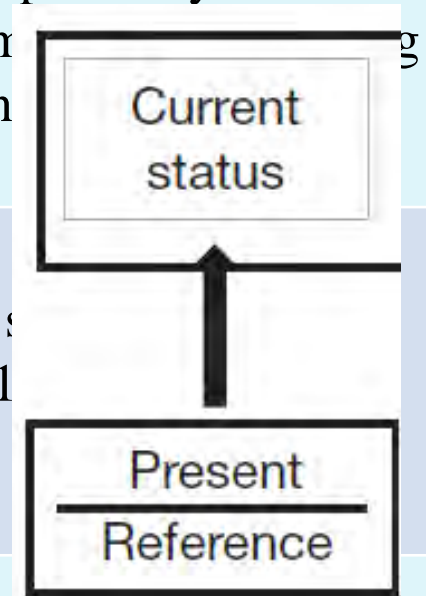
- $S_{P,i} = 2x_{\text{common}}/(x+x_0)$
- where  $x_{\text{common}}$  is the number of common species in the present year and reference year which were 2011 and 2000, respectively
- The similarity index of community structure

The sub-indicator of water purification

- scored by the rate of maritime area reaching the national standard of inorganic nitrogen (IN)

The other sub-indicators

- $S_{P,i} = \min(1, x/x_0)$
- the reference values are determined by temporal comparison



## 2. METHODS >> Assessment methodologies of ocean health

### (2) Aggregation methods of composite indicators

#### The index of ocean health

- $OHI = [SSI (\alpha_1 PSI + \alpha_2 RSI + \alpha_3 CSI)]^{1/2}$
- *OHI* is the score of composite index of ocean health;
- *SSI*, *PSI*, *RSI* and *CSI* are the composite index of supporting services, provisioning services, regulating services and cultural services, respectively;
- $\alpha_i$  is the corresponding weight of which the sum is 1.0 and each value was set as 1/3 herein.

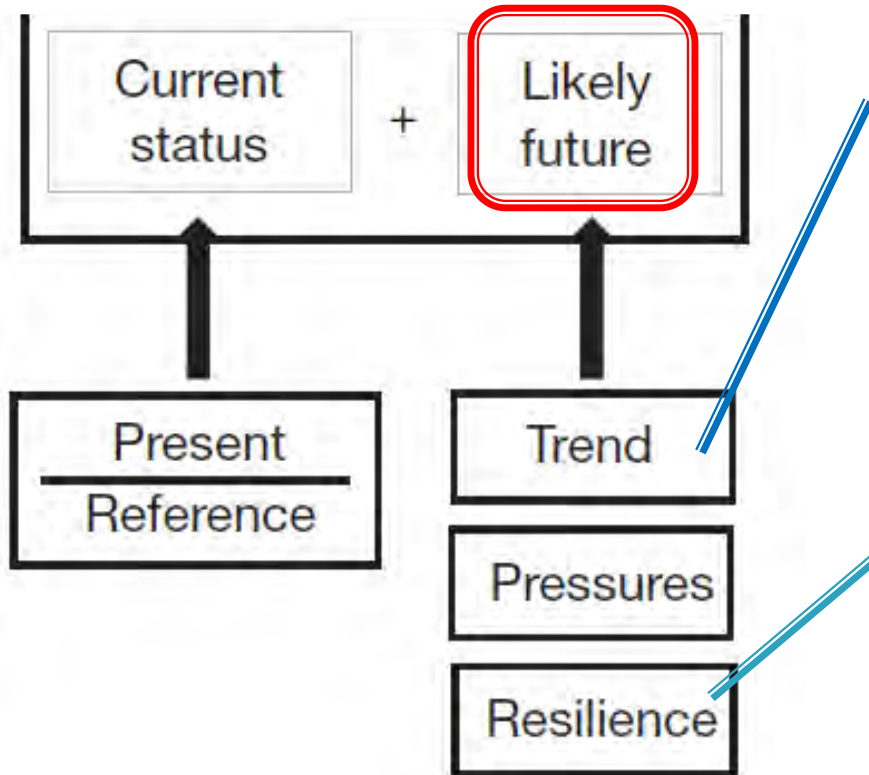
#### The other composite indicators

- Scored as the **weighted average** of corresponding sub-indicators with equal weights.

Scores	0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0
Categories	Very low	Low	Moderate	High	Very high

## 2. METHODS >> Quantitative methodologies of regulation

- By **revising** the approaches proposed by Halpern et al. (2012)



- Means the slope of historical change
- **R2**: Quantify the influences of the regulations on trend
- **R1**: Focus on the goal-specific regulations aiming at addressing negative pressures, which was regarded as one type of measures on resilience of ocean health by Halpern et al. (2012).

◆ (Halpern et al., 2012)

## 2. METHODS >> Quantitative methodologies of regulation

### (1) The likely future scores of sub-indicators in the 3rd grade ( $S_{F,i}$ )

$$S_{F,i} = [1 + \gamma T_{F,i} - (1 - \gamma) P_{R,i}] S_{P,i}$$

- where  $S_{F,i}$  is the likely future score of sub-indicator  $i$  which should be scaled within 0 to 1.0 ;
- $T_{F,i}$  is the likely future trend of sub-indicator  $i$  which should be scaled within -1.0 to 1.0 herein;
- $\gamma$  is the corresponding weight which was valued as 2/3 herein according to Halpern et al. (2012);
- $P_{R,i}$  is the regulated pressure suffered by sub-indicator  $i$  which should be scaled within -1.0 to 1.0 herein.

- The value of pressure in this paper represented the integrated outcome of both human pressures and regulations.

Existing calculation method:

$$\hat{x}_{i,F} = (1 + \delta)^{-1} [1 + \beta T_i + (1 - \beta) (r_i - p_i)] x_i$$



## 2. METHODS >> Quantitative methodologies of regulation

### (2) The likely future trend of sub-indicator in the 3rd grade ( $T_{F,i}$ )

$$T_{F,i} = \begin{cases} \left[ 1 + \left| (P_{R,i} - P_{P,i}) / P_{P,i} \right| \right] T_{P,i} & , T_{P,i} (P_{R,i} - P_{P,i}) < 0 \\ \left[ 1 - \left| (P_{R,i} - P_{P,i}) / P_{P,i} \right| \right] T_{P,i} & , T_{P,i} (P_{R,i} - P_{P,i}) > 0 \end{cases}$$

➤ Quantify the influences of the regulations on trend

- where  $P_{P,i}$  is the present pressure of sub-indicator  $i$ ;
- $T_{P,i}$  is the present trend.

### (3) The present trend of sub-indicator in the 3rd grade ( $T_{P,i}$ )

- Valued as the slope of fitted function divided by its fitted value in the reference year.
- The fitted function refers to the first order linear regression between values of indicator  $i$  from reference year to present year (2006 to 2011) and corresponding years.
- The indicator of community structure used to calculate trend was valued as the Shannon-Wiener index instead of the similarity index of community.

➤ It should be noted that because each trend was calculated according to the variation of indicator values in the past six years, the likely future herein meant the near-term future within about six years rather than any given time in the future.

## 2. METHODS >> Indicator System of Human Pressures

➤ Tab.2 Indicator system of human pressures in LZB

1 <sup>st</sup> grade indicators	2 <sup>nd</sup> grade indicators
1. Habitat destruction	1. Reclamation by infilling, e.g. land construction for port or urbanization
	2. Reclamation by enclosing, e.g. enclosing maritime area for mariculture or salt pan
2. Pollution	3. Land-based nutrient pollutant, e.g. runoffs of pollutant into the sea from its surrounding watersheds
	4. Ocean-based nutrient pollutant, e.g. pollutant sourcing from mariculture
	5. Ocean-based organic pollutant, e.g. oil spilling
3. Change of species composition	6. Marine fishing
	7. Mariculture

## 2. METHODS >> Quantitative methodologies of regulation

### (4) The regulated pressure suffered by sub-indicator in the 3rd grade ( $P_{R,i}$ )

$$P_{R,i} = \sum_{j=1}^M \max_{k=1}^{K_j} (w_{ijk}) p_{R,ij} / \sum_{j=1}^M \max_{k=1}^{K_j} (w_{ijk})$$

➤ Regulated pressure suffered by each health indicator

- where  $M$  is the total number of pressure indicators in the 1<sup>st</sup> grade (Tab.2);
- $K_j$  is the total number of sub-indicators of pressure indicator  $j$  in the 1<sup>st</sup> grade;
- $p_{R,ij}$  is the regulated pressure of indicator  $j$  in the 1<sup>st</sup> grade (Tab.2), suffered by ocean health sub-indicator  $i$  in the 3<sup>rd</sup> grade (Tab.1);
- $w_{ijk}$  is the degree of negative impact of the sub-indicator  $k$  of pressure indicator  $j$  on ocean health sub-indicator  $i$ ;

Calculated as the average acquired by questionnaire survey where it was valued as 1, 2 or 3 representing the low, moderate or high impact

## 2. METHODS >> Quantitative methodologies of regulation

### (4) The regulated pressure suffered by sub-indicator in the 3rd grade ( $P_{R,i}$ )

$p_{R,ij}$  is the regulated pressure of indicator  $j$  in the 1<sup>st</sup> grade (Tab.2), suffered by ocean health sub-indicator  $i$  in the 3<sup>rd</sup> grade (Tab.1);

$$p_{R,ij} = \sum_{k=1}^{K_j} \frac{w_{ijk}}{3} p_{P,ijk} (1 - R_{ijk})$$

➤ Regulated pressure of each pressure indicator

➤  $p_{P,ijk}$  is the present score of the sub-indicator  $k$  of pressure indicator  $j$  in the 1<sup>st</sup> grade which refers to the intensity of negative pressure suffered by ocean health sub-indicator  $i$ ;

Given as 1.0 due to the continuous increase of each pressure in study area recently.

➤  $R_{ijk}$  is the rate of regulation of corresponding pressure.

- Valued artificially to simulate the regulation of pressure.

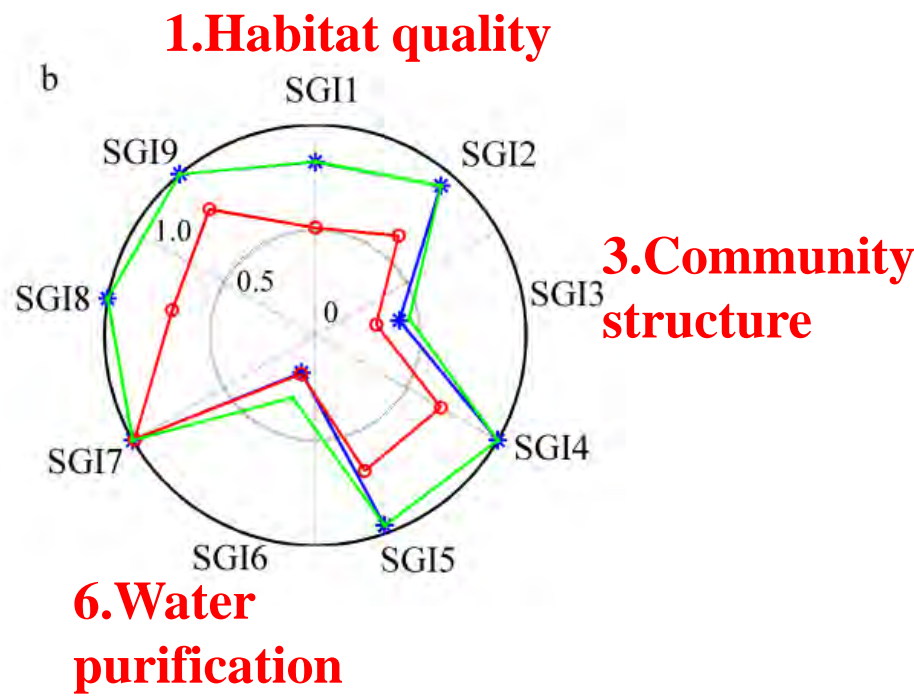
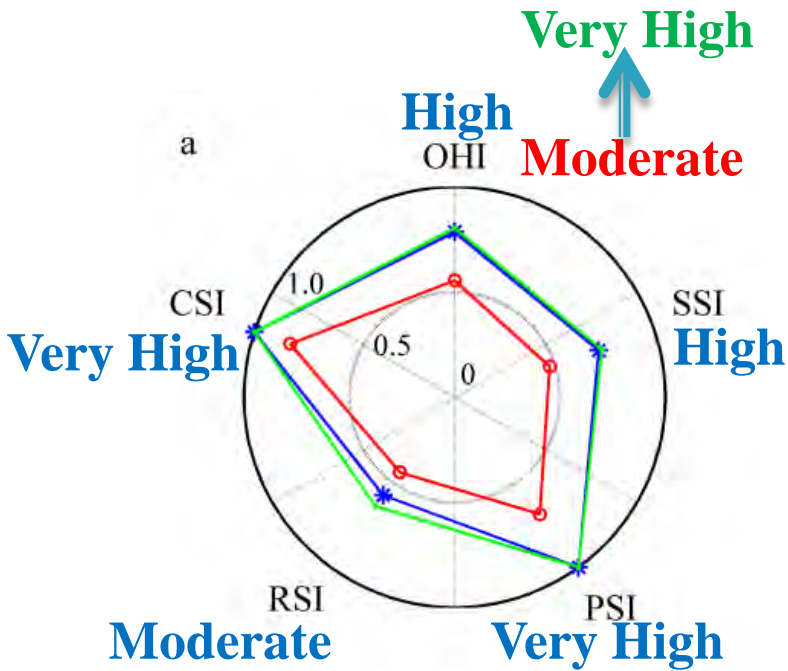
➤ When each parameter of  $R_{ijk}$  was set as a same value, the regulated pressures represented the comprehensive effect of artificial regulation.

➤ = 0,  $P_{R,i} = P_{P,i}$  (regulated pressure = present pressure), the lower bound of near-term score, means no regulation was implemented

➤ = 100%, the upper bound of near-term score, means negative pressure was controlled fully

➤ > 100%, the negative pressures were regulated to be positive drivers on the whole

# 3. RESULTS



\* Present score      ○ Lower bound of near-term score      \* Upper bound of near-term score

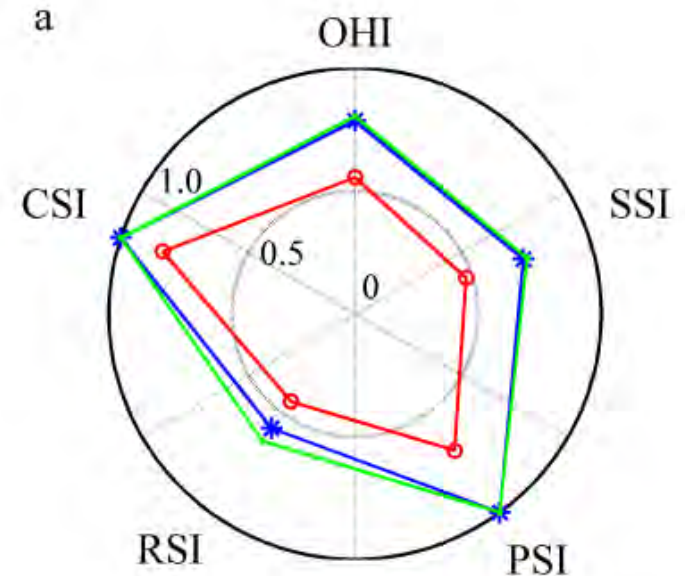
- ◆ The **LB** of near-term score was **much less** than the current score;
- ◆ the **UB** of near-term score was **slightly more** than the current score.

## 4. DISCUSSION >> Characteristics of ocean health based on ecosystem services

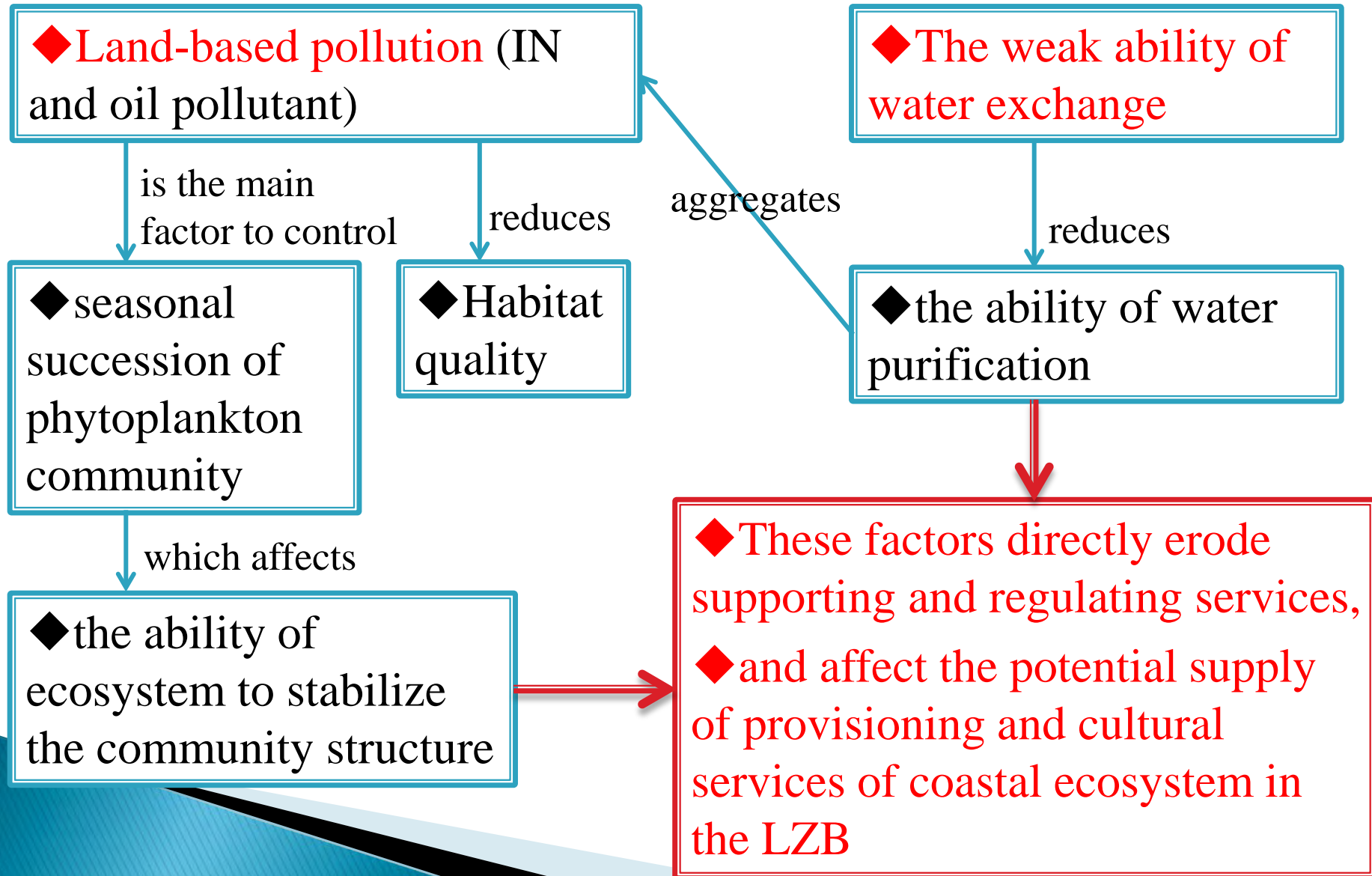
### ◆ Different performance of services:

- ◆ Cultural and provisioning services (CSI, PSI) performed essentially perfectly;
- ◆ Supporting and regulating services (SSI, RSI) functioned less well.

- ◆ It was considered that **cultural and provisioning services** make direct and significant contribution to human welfare and thus receive a large input of human capital,
- ◆ but **supporting and regulating services** are both indirect and potential.



## 4. DISCUSSION >> Characteristics of ocean health based on ecosystem services



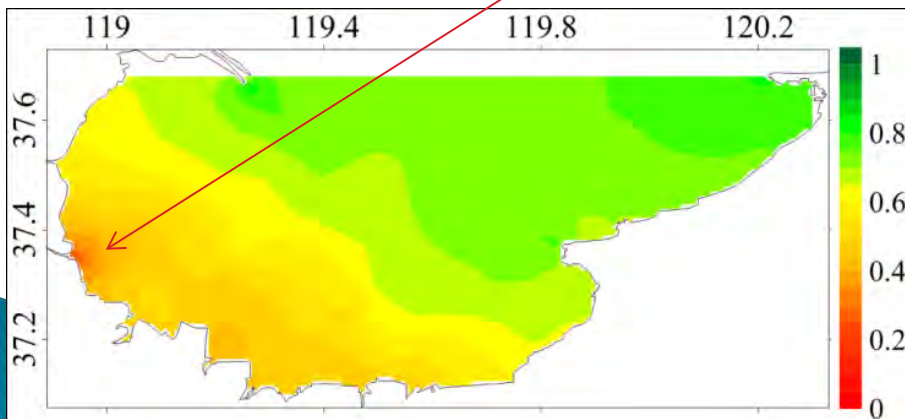
## 4. DISCUSSION >> Characteristics of ocean health based on ecosystem services

◆ **The range of near-term score:** The lower bound of near-term score was much less than the current score; the upper bound of near-term score was slightly more than the current score.



◆ It implied that the present ecosystem of LZB was affected by human pressures **easily and largely**, and was **hard to recover once disturbed**.

◆ Human activities have greatly affected the ecosystem of LZB especially in the **southwestern waters**.



➤ Previous study: Assessment of ecosystem health of the LZB in summer



## 4. DISCUSSION >> Characteristics of ocean health based on ecosystem services

◆ The results of **questionnaire survey on the degree of negative human impact and certainty of recognition**:

◆ The average degrees of negative impact of human pressures on cultural and regulating services were both less than that on provisioning and supporting services; the certainties of recognition on cultural and regulating services were both less than that on provisioning and supporting services.



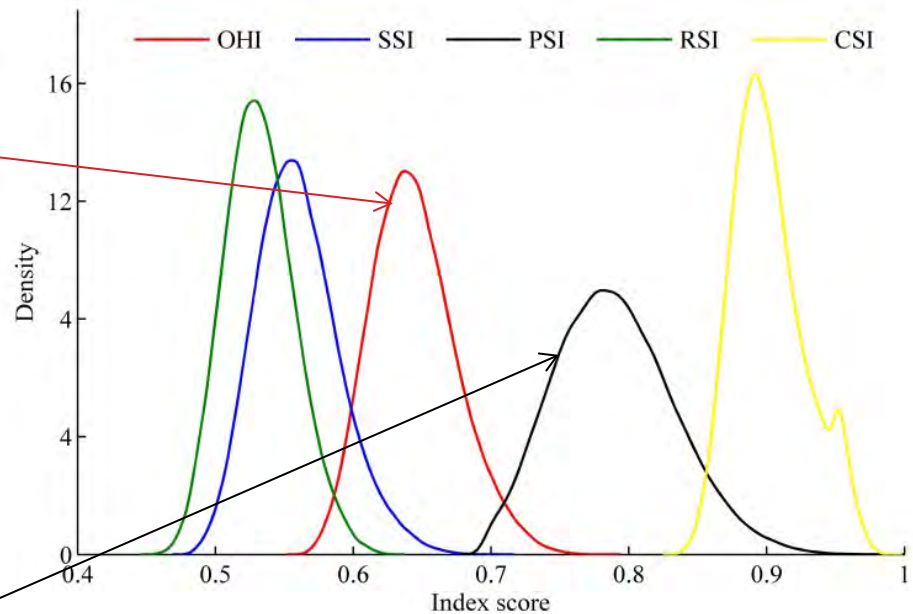
◆ Understanding on **provisioning and supporting services** (which directly serve human beings with their physical conditions and living environment) **was clearer than** that on cultural and regulating services.

◆ Thus, the related **publicity and education** should be further stressed.

## 4. DISCUSSION >> Regulation of human pressures

◆ The standard deviation of OHI was 0.0313; **the index score of ocean health (OHI) ranged from 0.6 to 0.7** with a confidence of 0.95 under various designs of regulation.

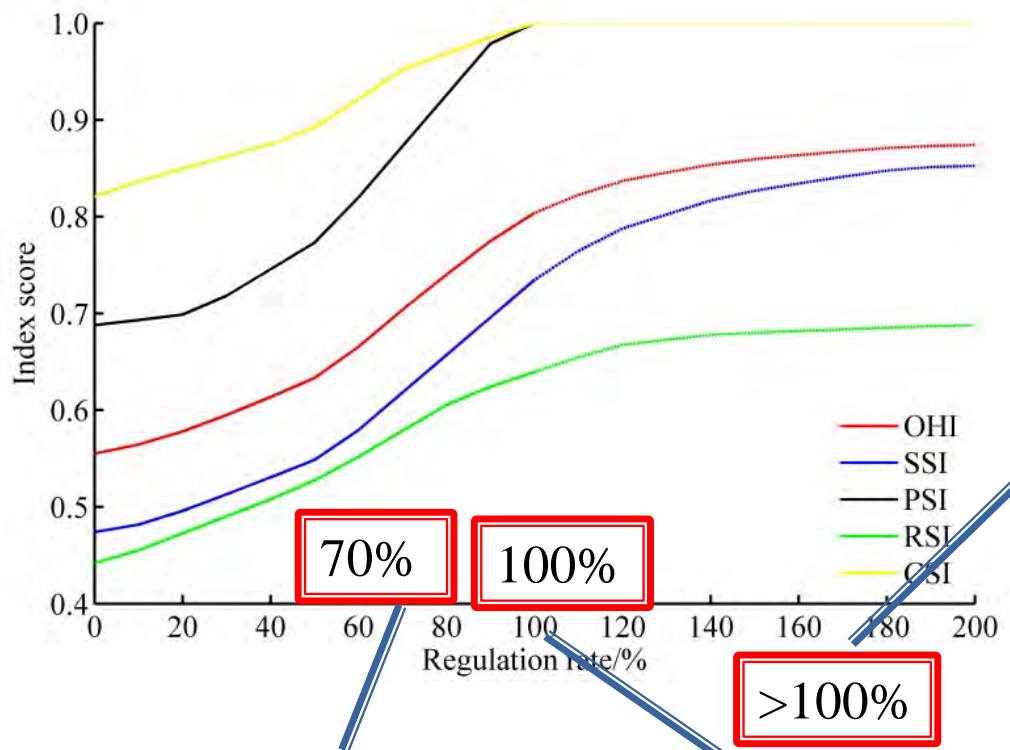
◆ The standard deviation of PSI was 0.0440; **the provisioning services (PSI) hold a relatively wide range under regulation.**



◆ Histogram density plots of **Monte Carlo simulations of regulation rate ( $R_{jk}$ )** with 10 000 trials.

# 4. DISCUSSION >> Regulation of human pressures

◆ Near-term scores of composite indicators under different scenarios of regulation rates



◆ Each index roughly showed the **Logistic correlation** between regulation rate and index score.

- ◆ Means the negative pressures are regulated to be positive drivers on the whole.
- ◆ The minimum score of each index in the near-term future

➤ The growth rate of each index score reached a maximum value .

◆ Each index score can be regarded as its maximum value when negative pressures are regulated to 0 on the whole.

## 5. CONCLUSIONS

◆Content: Quantitative approaches, which were based on the performance of ecosystem services, were developed in this paper to assess ocean health both at present and in the near-term future after regulations of negative pressures in the LZB of China.

◆(1) Actions should be taken to regulate and control the human pressures to avoid the further deterioration of ocean health especially of supporting and regulating services;

◆(2) Publicity and education on ecosystem services especially of cultural and regulating services should be further stressed.

◆It should be noted that the approaches in this paper are aimed to indicate current and near-term ocean health rather than to predict it at any given time in the future.



Thank You!  
Criticism, Please!

