Eco-compensation for Farming Structure Adjustment Based on N Loss Control

基于氮流失控制的种植结构调整生态补偿

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  研究区域背景介绍
- General Countermeasures
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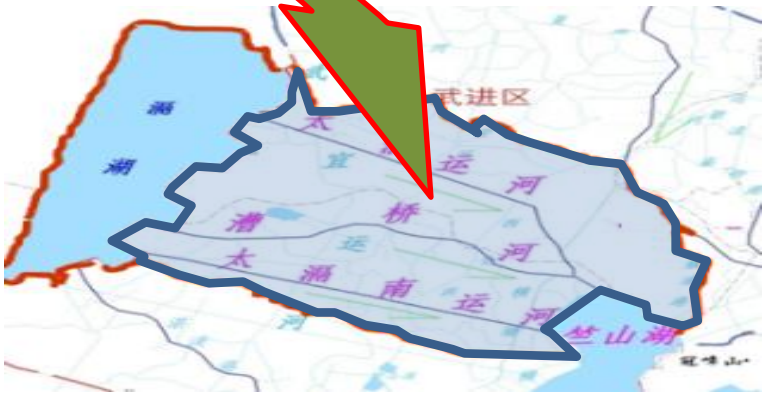
  配套的生态补偿
- Existing Subsidies and Measures in Local Government, Problems and Suggestions
  已有补贴及措施、存在问题与应对策略

Background on Research Region

研究区域背景介绍

周铁镇
万石镇
和桥镇
前黄镇
雪堰镇



竺山湾湖是太湖水域的一部分，属太湖流域水利分区的湖西区，是太湖接纳地表径流的主要区域。区域种植业发达，种植面积大，稻田、菜地以及茶果林比例分别为73%，17%和10%。

- The Zhushan Lake is the part of Tai Lake watershed, located just west of Tai Lake, and is the main area to receive surface runoff.
- With well developed industry of paddy rice, vegetables and fruits growing, account for 73%, 17% and 10%, respectively.

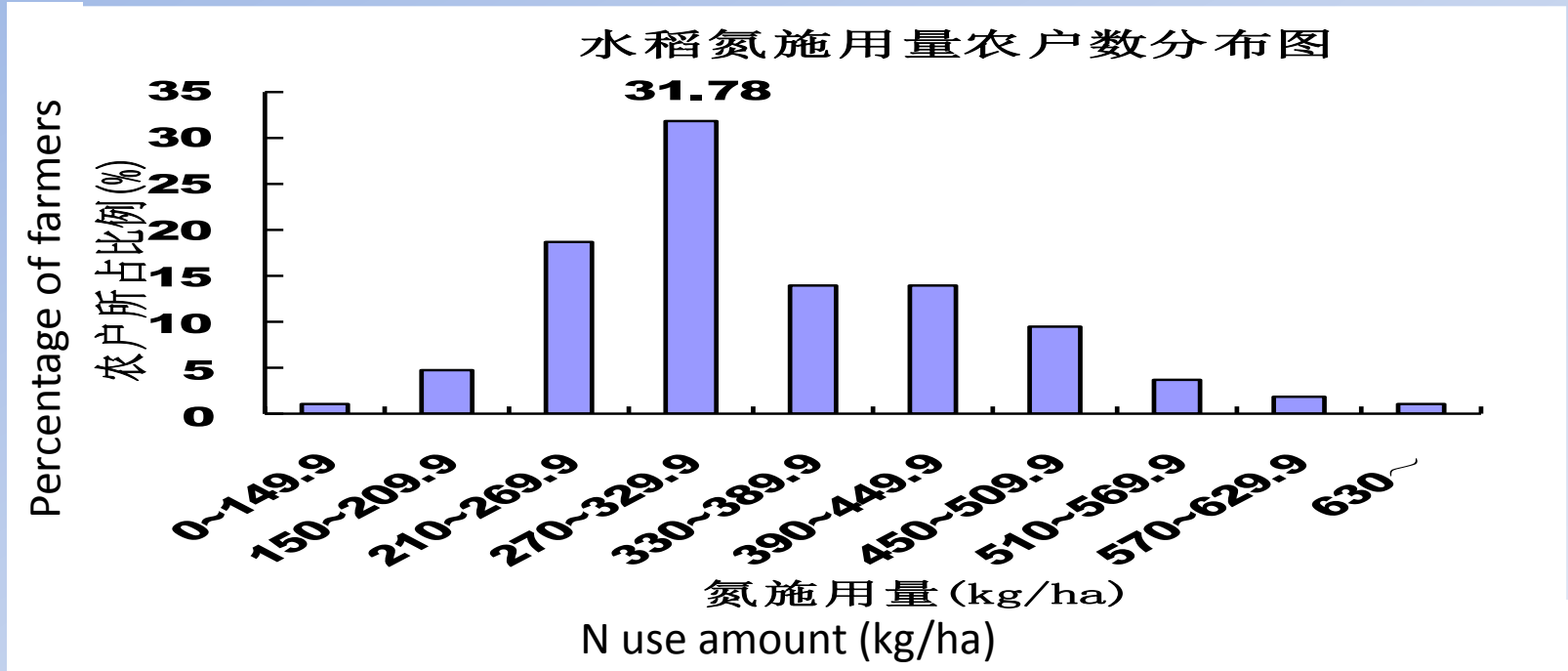
面积 Area km^2	人口(万) Population 10^4	小麦 Wheat 10^4 ha	水稻 Rice 10^4 ha	油菜 Rape 10^4 ha	蔬菜 Vegetables 10^4 ha	果园 Fruits 10^4 ha	林地 Woodland 10^4 ha	总面积 Total 10^4 ha
429	28.87	1.08	1.11	0.04	0.23	0.18	0.46	3.1

资料来源：由常州武进区统计局和无锡宜兴市统计局提供数据整理。Data source : local Statistics Bureau

- **肥料投入量高：为追求产量，种植业化肥投入量远大于作物需求，养分流失严重。**

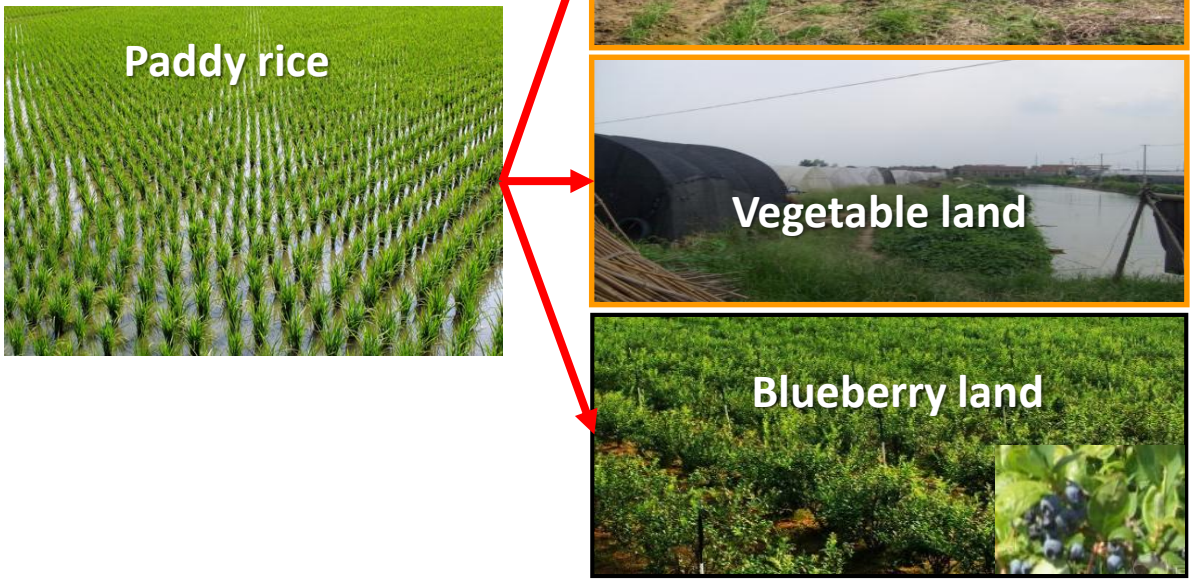
- To pursue high yield, the amount of nutrients input is much higher than crops' demand.

The distribution of the number of **farmers** according to the amount of chemical N usage



- **种植结构不合理：为追求经济利益，稻改菜、稻改果现象突出，加剧了污染排放**

- Farming/planting structure is not reasonable. In order to pursue high economic benefit, the phenomenon like transforming paddy field into vegetable land or fruit orchard is very serious , exacerbating the emission of agricultural nonpoint source pollution.



太湖地区监测结果表明，污染排放量菜地为260～302 kg N ha^{-1} yr^{-1}，稻田仅30～59 kg N ha^{-1} yr^{-1}

- Monitoring results showed that the pollution emission from **vegetables land was about 260-302 N ha^{-1} yr^{-1}, but for rice paddy field, only between 30 and 59 N ha^{-1} yr^{-1}**

- **污染物输移路径短，环境容量小， 入河、入湖速度快**

- The transport path of pollutant is short; the environmental carrying capacity is small; and the speed of entering the river and the lake is fast.

“十一五”太湖流域调查结果，种植业TN占污染总排放量的38%。

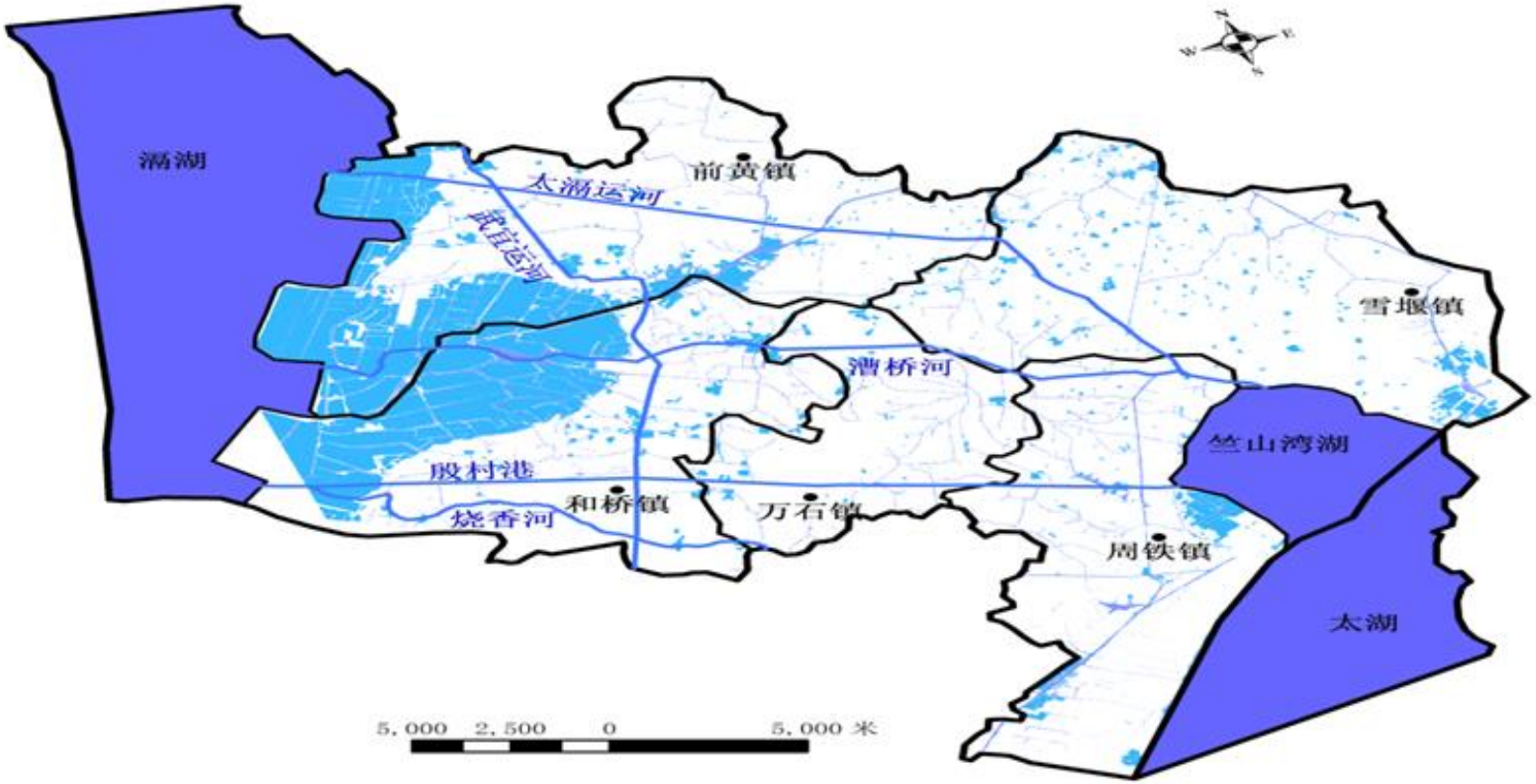
- “Eleventh–five” survey results in Tai Lake watershed showed that the total N emission from crops’ planting accounted for 38% of total pollution emission.

  在以改善水质目标为主导的新形势下，种植业污染减排面临巨大挑战！

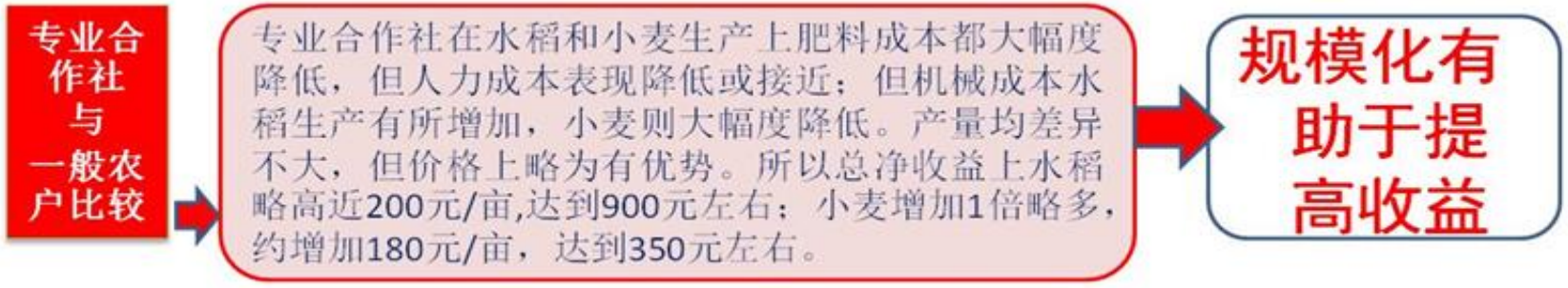
- Under the new situation of aiming at improving water quality, the mitigation of growing source pollution faces great challenge.

种植业结构布局调整成为限制区域种植业污染减排的关键

The adjustment of farming structure has been the key factor in order to realize the pollution reduction.



种植业生产成本分析（一）--水稻和小麦



- Based on our on-site survey, compared to small farmers, the professional cooperative can improve crop growing benefit due to their farmland scale management. Like rice and wheat growing, net benefit per *mu* will be CNY900 and CNY350, about CNY200 higher than that of small farmers.

小麦收益不高，为稻-麦模式扭转稻-绿肥模式提供了可能

- Low benefit from wheat growing for small farmers, this provides the possibility that rice-wheat pattern will be transformed to rice-cover/legume crop pattern.
- For small farmers, they lost income one season, so they need to be subsidized by government because of environmental protection practice.

高温高湿度季节
High temperature & high humidity season

253.5±247.7 | 76.9±90.0

190.6±126.4 | 153.9±133.3

529.3±144.2 | 94.8±118.0

0 | 0

填闲作物
Catch crop

It is a new measure to prevent nitrogen loss by using nitrogen catch-crops in the vegetable rotation system recent years.

压缩蔬菜种植面积，需要对压缩面积的农户给予补偿。

Need to subsidize those small farmers who minimize their planting area of vegetables.

- 肥料N投入总量平均为454 kg N/ha，其中有机肥料N 占52.5%，无机肥料N占47.5%。
- The average total N input from fertilizer is 454 kg/ha; the supplies of inorganic source N and organic source N account for 50% each.

- 果农追肥多数是撒施无机肥于地表
- Generally, inorganic source N as topdressing is applied on the surface by farmers and easily gets lost into water body through run off.

- 推荐应用生草覆盖技术
- Recommend farmer to plant clover or alfalfa between fruit trees to intercept nutrients runoff.

- 对总氮和总磷削减能力均达34%
- The ability of reducing both total N and total P can reach 34%.

This practice needs additional labor input so farmers hope to be subsidized.

General Countermeasures

基于N流失控制的种植结构调整总体思路

种植结构调整思路 • The idea for farming structure adjustment

土水养分响应关系
The responding relationship of nutrients between land use and water body

水功能区划分重要程度
The importance of water function

识别水功能重要区污染高风险的种植土地利用类型
To identify land use type with high pollution risk around important water function division

然后按水功能区划重要性，结合太湖流域保护区分级，重建并优化调整土地利用类型作物种植结构
- Combine the importance of water function division and protection zone classification around Tai Lake
- Rebuild, optimize and adjust crop planting structure

一是优化污染高风险作物面积
Optimize crop area with high pollution risk

二是在优化面积内采用单一或组合环境友好型农业技术实践
Single and group environmental-friendly agricultural practices are applied in optimized crop area

情景分析 scenario analysis

最优结构
Optimal structure

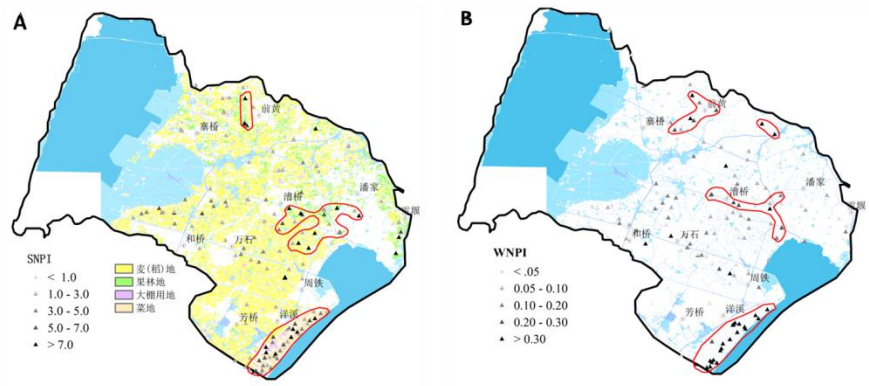
次优结构
Sub-optimal structure

生态补偿建议 Eco-compensation suggestion

$$SNPI = \frac{TN}{TN} \times \frac{AN}{AN} \times \frac{AP}{AP} \quad \cdots\cdots (1)$$

$$WNPI = \frac{TN}{TN} \times \frac{TP}{TP} \quad \cdots\cdots (2)$$

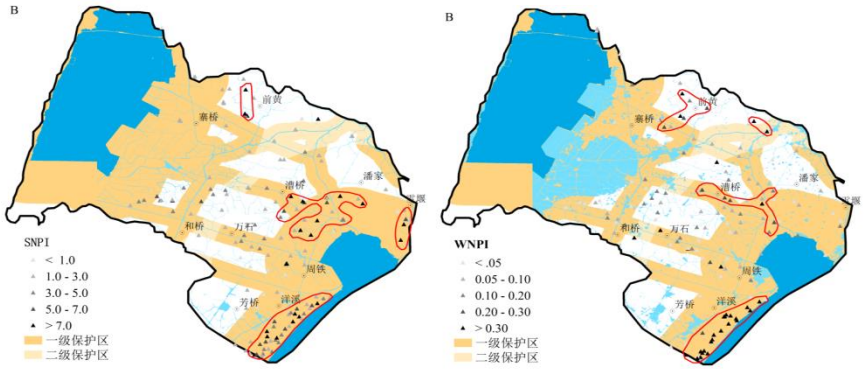
土壤与水体NP指数空间分布格局
Spatial distribution of NP index between soil and water body



土壤氮磷指数和水体氮磷指数空间分布

Spatial distribution of NP index between soil and water body

- 氮磷指数最高的是蔬菜用地，其次是果园等；
- The highest SNPI is vegetables land, followed by fruit orchard.
- 与此对应，环绕水体的氮磷指数也较高，表明较高土壤氮磷含量对太湖水质有较大影响；
- Corresponding to this, the WNPI of the surrounding waterbody is also higher, indicating that the higher soil nitrogen and phosphorus content has a great influence on the water quality of Tai Lake.



土壤氮磷指数和水体氮磷指数反映在太湖流域保护区分级水平下的分布

Spatial distribution of NP index between soil and water body under reserve classification zone around Tai Lake basin

- 氮磷指数高的区域都主要位于太湖流域一级保护区内，表明从结构调整角度属于优先调整优化范围。
- The higher SNPI and WNPI are mainly located in the first level of protection zone around Tai Lake basin, indicating that this area should be a priority to be adjusted and optimized in the view of structural adjustment.

- 太湖流域水环境综合治理总体方案（2013 年修编）;
- 江苏省太湖水污染防治条例 2008;
- 2007无锡市太湖一级保护区保护建设规划;
- 常州市生态文明建设规划（2011-2020）

- 一级保护区：太湖湖体、沿湖岸五公里区域、入湖河道上溯十公里以及沿岸两侧各一公里范围;
- 二级保护区：主要入湖河道上溯十公里至五十公里以及沿岸两侧各一公里范围为;

治理农业面源污染，提高治污标准，一级区实施退耕和还林还草还湿地，建设太湖保护天然屏障.（《江苏省太湖流域水环境综合治理实施方案（农业类）》的规划）

According to the overall scheme of water environment comprehensive management in Tai Lake basin

First level reserve zone include:
Tai Lake area, 5 km along the lakeshore, back 10 km of rivers into the lake, and 1 km on each side along the river

Actions should be implemented in this area, such as returning farmland to forest, grassland, and wetland so as to build natural protective barrier of Tai Lake.

- 基于GIS的空间分析功能，尝试对氮磷含量较高和氮磷迁移能力较强的土地利用种植结构和施肥模式进行调整。
- Based on the spatial analysis function of GIS, we try to make changes to the land use of farms containing high nitrogen content in soils or vulnerable to loss of nutrients, and adjust and optimize fertilization mode.

- 通过实施种植业结构调整措施，实现N投入量减少20%以上，N流失量减少30%以上的污染减排目标，当然还要确保农户收益。
- By implementing structural adjustment, we want to realize farmland nonpoint pollution reduction targets, that is, the amount of both input N and runoff N loss can be reduced over 20% and over 30%, respectively. At the same time, farmers' income can be guaranteed.

调整范围
The range of adjustment

竺山湾区域种植业结构的调整范围应在环湖有机农业生态圈之外的区域开展。通过相应时期的遥感影像，可以计算出稻麦作物、蔬菜、果树在有机农业生态圈内的种植面积占竺山湾区域各自总面积的比例（14.7%、46.6%、15.0%），以此计算出环湖有机农业生态圈以外的稻麦作物、蔬菜、果园的面积（1.012、0.126、0.163万公顷），三者合计为1.301万公顷。

- The scope of adjustment around Zhushan Bay watershed should be done outside the areas of organic agricultural ecosphere along the Lake.
- Through the corresponding period of the remote sensing images, the proportion of rice & wheat crops, vegetables, and fruit trees planting areas in the total organic agriculture ecosphere can be calculated as 14.7%, 46.6%, 15.0%, respectively.
- Then their respective planting areas outside the organic agriculture ecosphere can be calculated as 10,120 ha, 1,260 ha, and 1,630 ha.

竺山湾区域环湖有机农业圈及以外的种植业面积

Planting Areas Outside the Organic Agriculture Ecosphere

种植业面积 Planting area	稻麦作物 Rice and wheat crops		蔬菜 Vegetables		果树 Fruit trees		合计 Total	
	面积 10^4 ha	比例 %	面积 10^4 ha	比例 %	面积 10^4 ha	比例 %	面积 10^4 ha	比例 %
含有机农业圈的竺山湾区域 Aoshan Bay area	1.186	73.3	0.235	14.6	0.196	12.1	1.617	100
环湖有机农业圈 Lakes	0.174	55.5	0.110	35.1	0.029	9.4	0.316	100
不含环湖有机农业圈区域 Excluding Lakes	1.012	77.6	0.126	9.7	0.163	12.8	1.301	100

竺山湾小流域作物种植N投入量、N流失量及经济效益参数

Tab 2 N Input, N Loss and Economic Benefit Parameters of the Crop Production in the Zhushanwan Catchment

种植模式 Production pattern	N投入量 N input (kg hm^{-2})	N流失量 N runoff and leaching (kg hm^{-2})	收获产量 Harvested yield (t hm^{-2})	毛收益[1] Gross revenue (CNY10^4 hm^{-2})	人力成本 Labor cost (CNY10^4 hm^{-2})	机械成本[2] Mechanical cost (CNY10^4 hm^{-2})	N肥成本 N fertilizer cost (CNY10^4 hm^{-2})	相对净收益 Relative net revenue (CNY10^4 hm^{-2})
(C0) 稻/麦常规①	510	45.5	13.9	3.52	0.74	0.7	0.19	1.88
(C1) 稻/绿肥②	150	12.0	7.4	2.08	0.74	0.54	0.06	**0.73**
(C2) 稻/麦减量③	390	33.5	13.5	3.41	0.74	0.7	0.15	**1.82**
(V0) 蔬菜常规④	1480	185	251	36.3	7.6	—	0.6	28.1
(V1) 蔬菜/填闲⑤	1200	128	265	39.4	8.0	—	0.5	**30.9**
(F0) 果树常规⑥	739	40.7	21.3	18.7	3.5	0.1	0.3	14.9
(F1) 果树/三叶草⑦	537	10.3	23.8	21.0	3.5	0.4	0.2	**16.8**

C0: Conventional rice/wheat rotation

C1: Rice/green manure rotation

C2: Reduced fertilization for rice/wheat rotation

V0: Conventional vegetable production

V1: Combination of catch crop and reduced fertilization

F0: Conventional fruits production

F1: Clover/fruit inter-cropping with deep fertilization

构建优化模型 / Building optimization model

利用优化求解Lingo软件来优化种植业结构。设定粮食、蔬菜、水果的自给率为1。
To optimize the planting structure with Lingo software, set the self-sufficiency rate of grains, vegetables and fruits as 1.

目标函数：
Target function with relative maximum net income

$$\text{Max}\, E(X) = \text{Max}\left(\sum_{i=1}^{n} N_{i0}X_{i0} + \sum_{i=1}^{n} N_{i1}X_{i1} + \sum_{i=1}^{n} N_{i2}X_{i2}\right)$$

其中：$E(X)$为净收入，亿元；N_{i0}为i类农作物常规生产模式的相对净收益，10^4·Yuan /ha；X_{i0}为i类农作物常规生产模式下种植面积，10^4·ha； N_{i1}、N_{i2}为i类农作物清洁生产模式1 、2净收入，10^4·Yuan /ha；X_{i1} 、X_{i2} 为i类农作物清洁生产模式1、2下的种植面积，ha。

$$\begin{cases} \sum_{i=1}^{n} TN_{i0}X_{i0} + \sum_{i=1}^{n} TN_{i1}X_{i1} + \sum_{i=1}^{n} TN_{i2}X_{i2} \le B_{TN} \\ \sum_{i=1}^{n} (X_{i0} + X_{i1} + X_{i2}) \le S_t \\ h_{g0}X_{g0} + h_{g1}X_{g1} + h_{g2}X_{g2} \ge Y_g \end{cases}$$

(1) 污染总量控制约束
Total pollution control constraint

(2) 农田耕地面积约束
Arable area constraint

(3) 粮果蔬需求约束
Demand constraint of grains, vegetables & fruits

约束条件
Constraints

其中：(1)式中B_{TN}为N流失总量，t；TN为N排放系数，kg/ha；(2)式中S_t为耕地总面积，10^4·ha；(3)式中Y_g为粮食需求量，t；h_g为产量，t/ha。

-----调整技术支撑及情景
Scenario design of structure-adjustment and matching environment-friendly technologies

Reference to local conventional mode, to set five scenarios with L loss from high level to low level.

In table, (1) stands for local traditional fertilization and planting mode; (2) Scenario I was designed to achieve the highest economic benefit; (3)~(5) Scenarios II, III, IV was to reduce N loss by 20%, 30% and 40%, respectively, as compared with Scenario I while achieving their respective targets of economic benefit; and (6) Scenario V was designed to achieve its target of minimum N loss.

通过Lingo软件模拟，可计算出不同情景下各种植模式的种植面积

表3 常规种植和五种情景下各种植模式的面积及所占比例

Tab. 3 Planting Areas and Proportions of Different Crop Production Patterns in Conventional Cultivation System and Five Scenarios

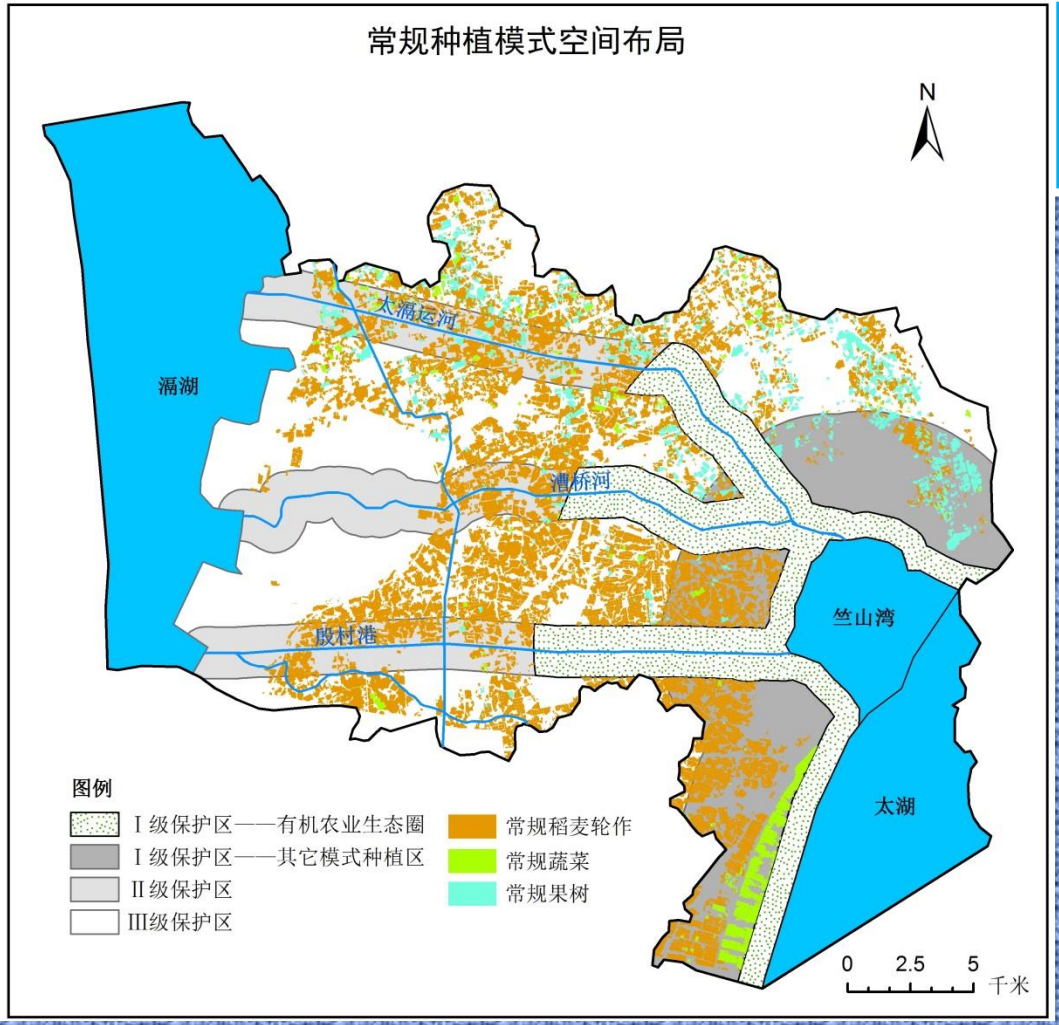
种植模式 Production pattern	常规种植1) Conventional		情景 Ⅰ 2) Scenario I		情景 Ⅱ 3) Scenario II		情景Ⅲ4) Scenario III		情景Ⅳ5) Scenario IV		情景 Ⅴ 6) Scenario V	
	面积 Area (10^4 hm^2)	比例 Ratio (%)	面积 Area (10^4 hm^2)	比例 Ratio (%)	面积 Area (10^4 hm^2)	比例 Ratio (%)	面积 Area (10^4 hm^2)	比例 Ratio (%)	面积 Area (10^4 hm^2)	比例 Ratio (%)	面积 Area (10^4 hm^2)	比例 Ratio (%)
C0	1.012	78	1.012	78	—	—	—	—	—	—	—	—
C1	—	—	—	—	0.028	2	0.296	23	0.396	31	0.527	40
C2	—	—	—	—	0.984	76	0.723	56	0.668	51	0.596	46
V0	0.126	10	—	—	—	—	—	—	—	—	—	—
V1	—	—	0.126	10	0.126	10	0.119	9	0.074	6	0.015	1
F0	0.163	12	—	—	—	—	—	—	—	—	—	—
F1	—	—	0.163	12	0.163	12	0.163	12	0.163	12	0.128	10

-----调整技术支撑及情景
Scenario design of structure-adjustment and matching environment-friendly technologies

表4　常规种植和五种情景下的N投入量、N流失量和经济收益

Tab. 4　N Inputs, N Loss and Economic Profits in Conventional Production Mode and Five Different Scenarios

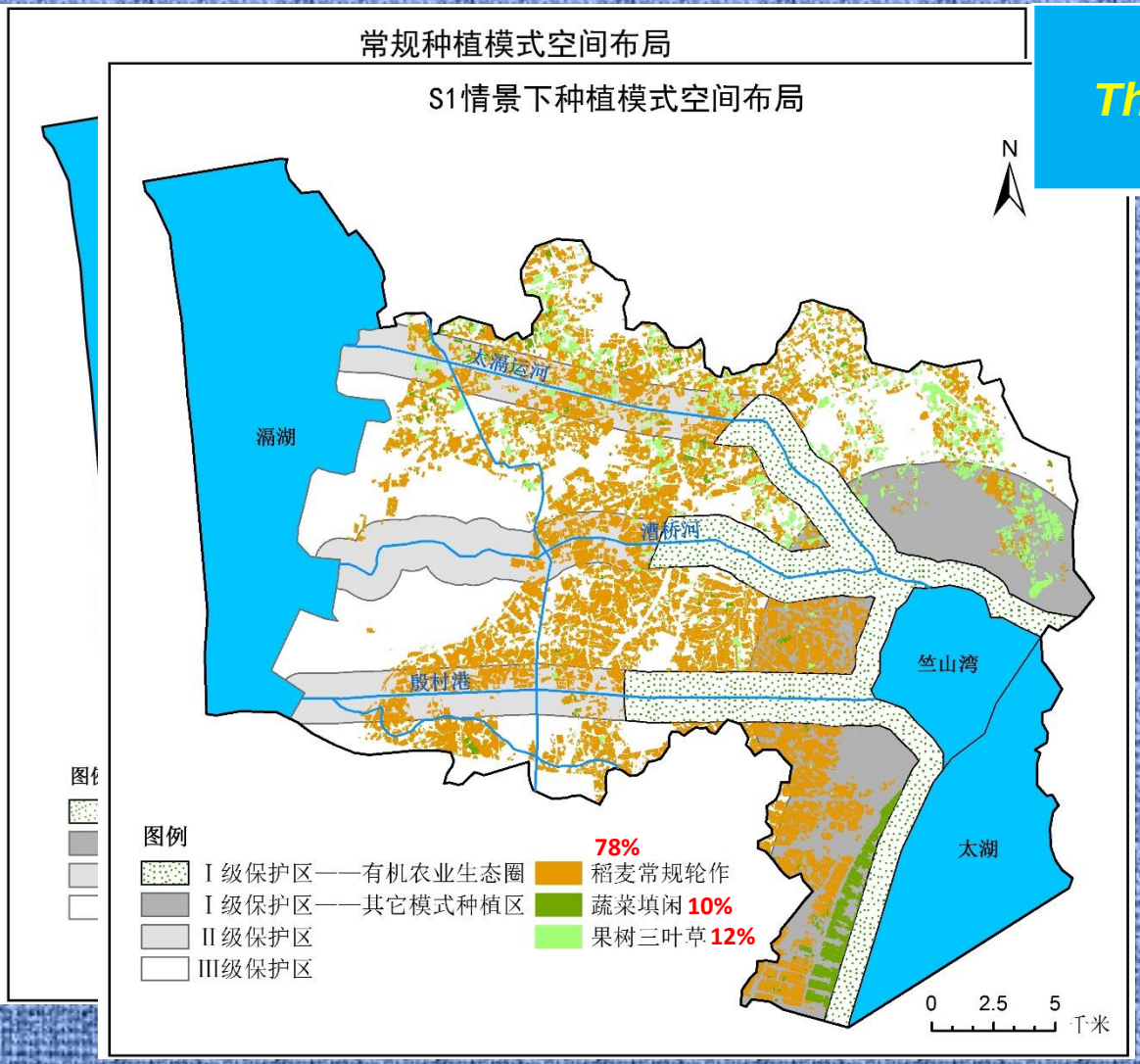
污染和经济指标 Pollution and economic indices	常规种植 Conventional mode	情景 I Scenario I	情景 II Scenario II	情景III Scenario III	情景IV Scenario IV	情景 V Scenario V
N投入量 N input (t a^{-1})	8231	7549	6267	5567	4963	3982
			↓ 23.9%	↓ 32.4%	↓ 39.7%	↓ 51.6%
N流失量 N loss (t a^{-1})	759	638	511	447	383	295
			↓ 32.7%	↓ 41.1%	↓ 49.5%	↓ 61.1%
经济收益 Economic profit (CNY 10^8 a^{-1})	7.87	8.54	8.45	7.96	6.55	4.09



--不同情景种植业结构布局

The spatial layout of structure-adjustment

--不同情景种植业结构布局
The spatial layout of structure-adjustment

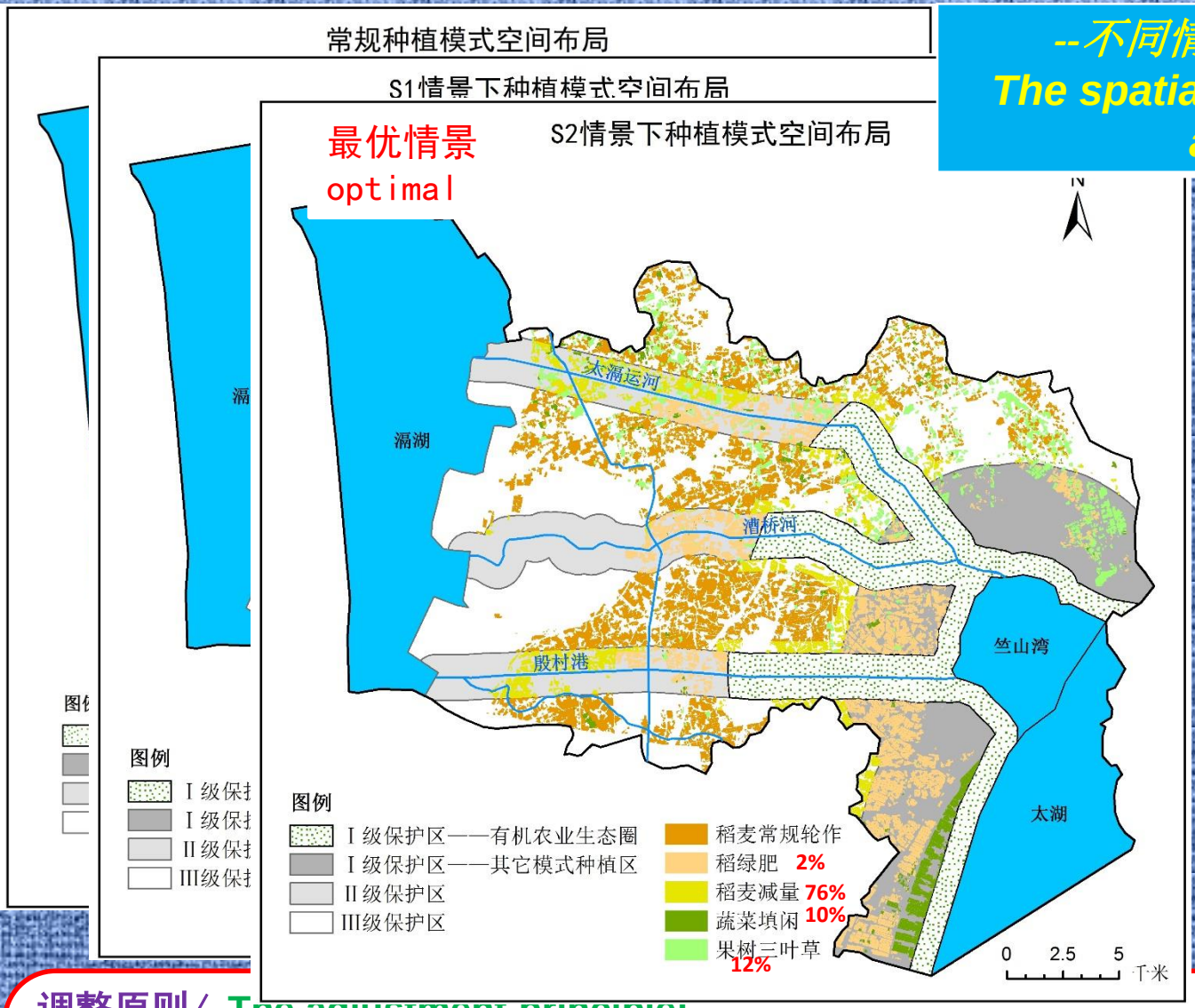


调整原则/ The adjustment principle:

对需要调整为清洁种植模式的面积首先布局于距离一级保护区最近的地点，之后随距一级保护区边界的远近按近到远的顺序扩展，直至调整面积达到优化值为止。

Environment-friendly practices will be preferentially introduced to the nearest area to the first-level protection zone, and then extend from near to far distances from the boundary of the first-level protection zone until the adjustment area reaches the optimization scale.

--不同情景种植业结构布局
The spatial layout of structure-adjustment

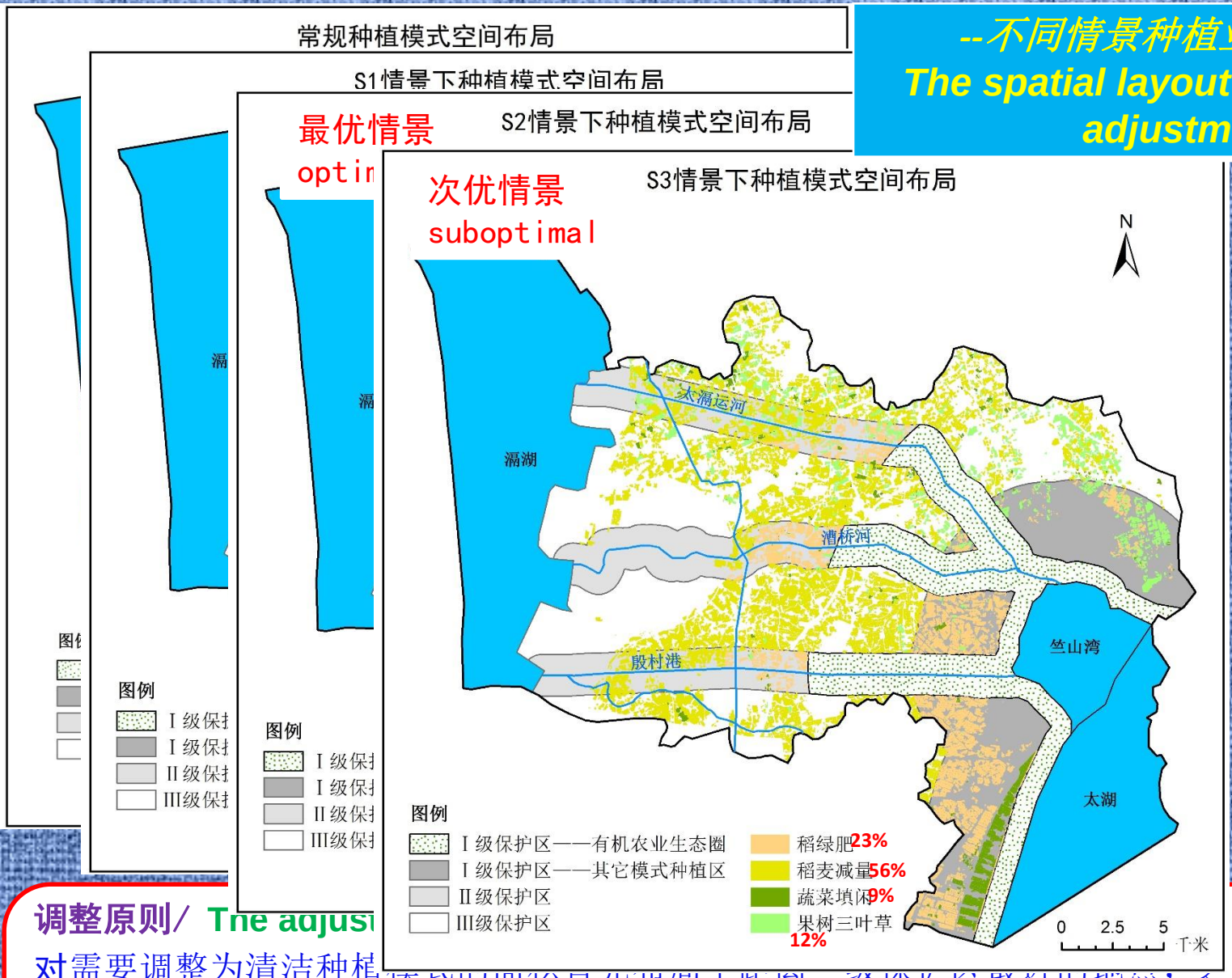


调整原则/ The adjustment principle:

对需要调整为清洁种植模式的面积首先布局于距离一级保护区最近的地点，之后随距一级保护区边界的远近按近到远的顺序扩展，直至调整面积达到优化值为止。

Environment-friendly practices will be preferentially introduced to the nearest area to the first-level protection zone, and then extend from near to far distances from the boundary of the first-level protection zone until the adjustment area reaches the optimization scale.

--不同情景种植业结构布局
The spatial layout of structure-adjustment



调整原则/ The adjust

对需要调整为清洁种植模式的面积首先布局于距离一级保护区最近的地点，之后随距一级保护区边界的远近按近到远的顺序扩展，直至调整面积达到优化值为止。

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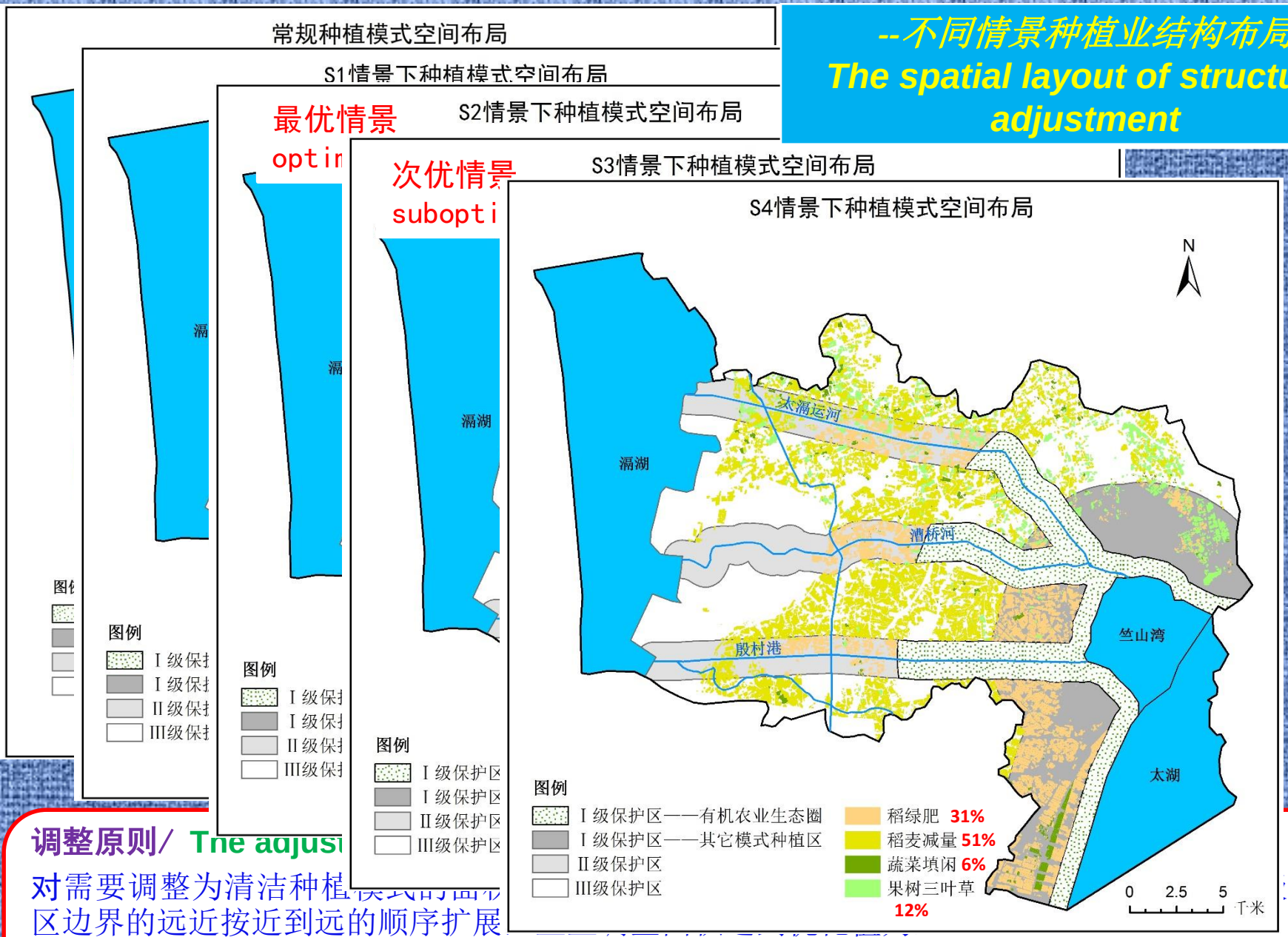
--不同情景种植业结构布局
The spatial layout of structure-adjustment

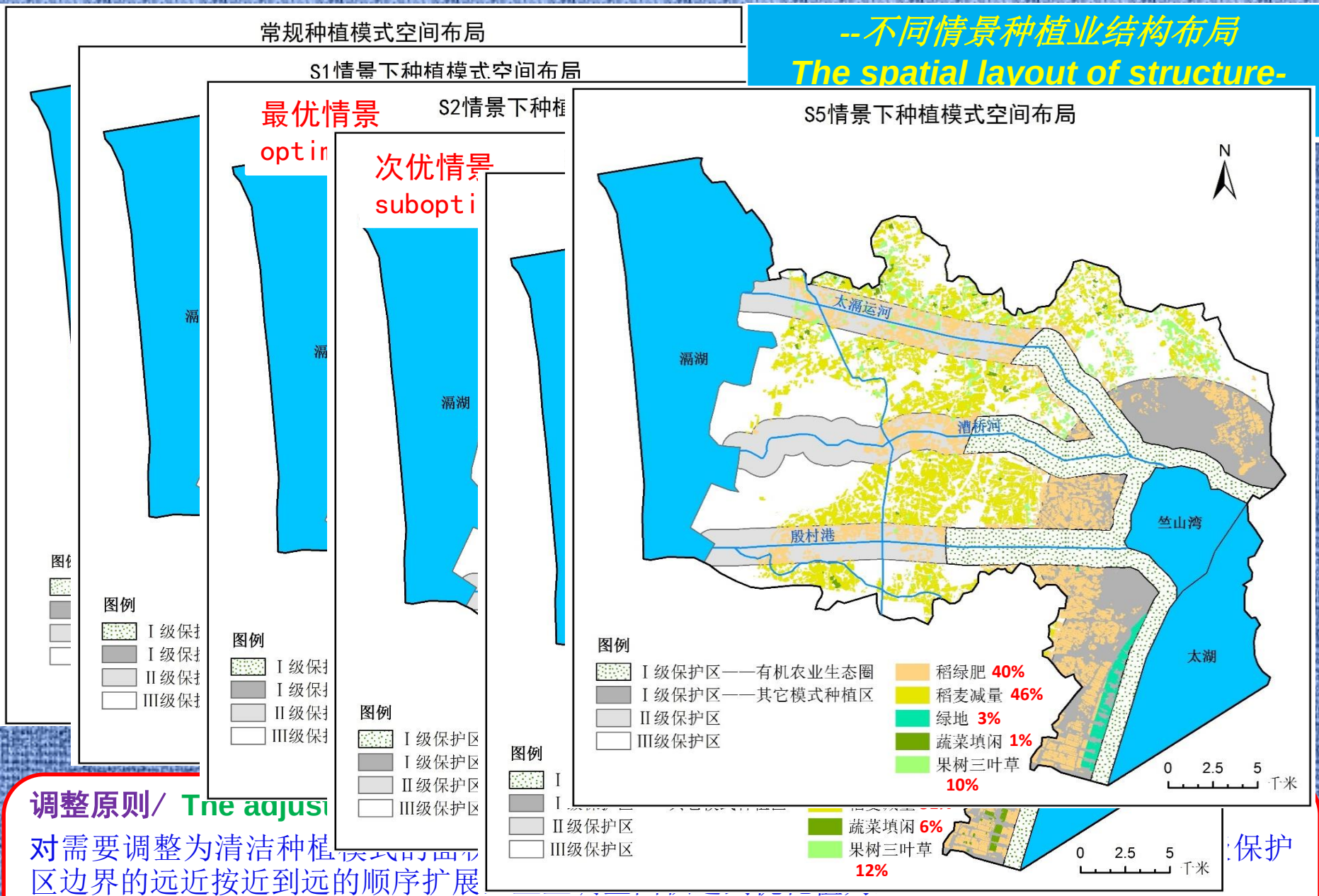


调整原则/ The adjust

对需要调整为清洁种植模式的面积，保护区边界的远近按近到远的顺序扩展

Environment-friendly practices will be preferentially introduced to the nearest area to the first-level protection zone, and then extend from near to far distances from the boundary of the first-level protection zone until the adjustment area reaches the optimization scale.

--不同情景种植业结构布局
The spatial layout of structure-



调整原则/ The adjust

对需要调整为清洁种植模式的面积，保护区边界的远近按近到远的顺序扩展

Environment-friendly practices will be preferentially introduced to the nearest area to the first-level protection zone, and then extend from near to far distances from the boundary of the first-level protection zone until the adjustment area reaches the optimization scale.

Matching Eco-compensation Strategy

配套的生态补偿

竺山湾区域种植结构调整优化情景
——补贴标准

表5 最优情景Ⅱ和次优情景Ⅲ的生态补偿方案

Tab. 5 Eco-compensation Scheme for Optimal Scenario II and the Second Optimal Scenario III

情景 Scenario	种植面积 Planting area (10^4 hm^2)	常规种植净收益① ($CNY10^8$)	清洁种植净收益② ($CNY10^8$)	常规种植N投入量③ (t)	清洁种植N投入量④ (t)	生态补偿总金额 ($CNY10^4$)			平均补贴金额⑧ ($CNY hm^{-2}$)
						机会成本补贴⑤	生态效益奖励⑥	除去15%用于管理的交易成本后合计⑦	
Ⅱ Optimal	1.301	7.87	8.44	8,231	6,267	912	218	961	739 ($112)
Ⅲ Sub-optimal	1.301	7.69	7.95	8,163	5,567	3,838	288	3,507	2,696 ($408)

C1 : Rice/green manure rotation
C2: Reduced fertilization for rice/wheat rotation

Lost income

Extra bonus for reduced N loss

① Net profit of conventional production
② Net profit of the cleaner production mode
③ N input in the conventional production
④ N input in the cleaner production mode
⑤ Opportunity cost-based subsidies
⑥ Ecological benefit rewards-based subsidies
⑦ The funds of eco-compensation include the budget of 15% for overhead expense
⑧ Average subsidies of eco-compensation per unit area

Existing Subsidies and Measures in Local Government, Problems and Suggestions

已有的补贴及措施、存在问题与应对策略

已有的补贴及措施
Existing Subsidies and Measures in Local Government

当地法规文件中涉及到的补贴及治理措施	Existing subsidies & measures in local regulation and program
化肥、农药减施工程	Reduction of fertilizer and pesticide program
环湖有机农业圈工程	Organic agriculture zone program
面源氮磷生态拦截沟渠塘工程	Eco-intercepting ditches/pond program for diffused pollution control
农作物秸秆综合利用项目	Project on comprehensive utilization of crop straw
对配方肥、有机肥和缓释肥的推广和补贴	Popularization and subsidy of formula fertilizer, organic fertilizer, and release fertilizer
生态补偿条例	Regulation of Ecological Compensation
对无公害农产品、绿色食品、有机农产品和地理标志农产品的补助	Subsidies for Pollution-free, green food, organic and geographical indications of agricultural products
太湖流域分三级保护区的保护	Three levels of protection areas for Tai Lake basin

现有补贴行动中存在问题
Solutions to Existing Problems

- 项目或工程结束，补贴支持结束
- As the project to program ends, there is no subsidy.
- 补贴水平起点低，对一般老百姓吸引不够
- The subsidy level is too low to attract farmers.
- 需要调整补贴对象，着重向规模农户倾斜。
- Need to adjust subsidizing objects, especially subsidizing scale farmers.
- 需要生态补偿长效机制，特别是随经济发展水平同步的可调升的补贴机制
- Need an ecological compensation of long-term mechanisms, especially the adjustable subsidy mechanisms that are synchronized with economic development.
- 补偿资金主要来源于土地出让金中提取，还可向生产化肥和农药等农资生产企业适当征收环境税，公开向企业和个人募集生态补偿资金
- Compensation funds can mainly be sourced from land sales, but can also come from environmental taxes from fertilizers and pesticides production enterprises, or appropriately raised ecological compensation funds for businesses and individuals.

CEPRC
中国生态补偿政策研究中心
China Eco-compensation Policy Research Center

50 YEARS

ADB

Thank you for your attention!