

## 响应式生物修复： 规范海南沿海开发的不确定性、 评价及调和

# RESPONSIVE BIOREMEDIATION: REGULATING THE UNCERTAINTY, ASSESSMENT, AND NEGOTIATION FOR COASTAL DEVELOPMENTS IN HAINAN, CHINA

## 1 背景

相关统计显示，21世纪全球填海造地活动愈演愈烈。自2006年以来，中国海南填海造地面积不断扩大，并于2013年达到峰值（1 351.77km<sup>2</sup>）<sup>[1]</sup>。2010年，中央政府宣布将海南定位为“国际旅游岛”<sup>[2]</sup>，开发商随即开始在其沿海区域竞相圈地、填海造地，以期通过这种快速且相对廉价的方式获得绝佳海景。然而，研究发现海南的珊瑚礁覆盖率已从20世纪80年代的70%下降至21世纪10年代的10%左右<sup>[3]</sup>，这与愈演愈烈的填海活动及随之而来的渔业及疏浚工程等人类干扰密切相关。

治理不力是海南珊瑚礁栖息地消失的主要原因。保护体系、流程及相关法律法规未被严格贯彻执行，不完善的环境影响评价（下文简称“环评”）体系，以及科学知识的匮乏又致使疏浚活动对于珊瑚礁保护区的影响被低估。由于海南沿海及海洋环境遭到严重破坏，中央政府对海南进行了数月的环境监察后，于2017年12月叫停了所有填海造地项目<sup>[4]</sup>。

### 郭小曼\*

粤港澳大湾区生态与景观联盟秘书长

#### \*通讯作者

地址：中国香港铜锣湾告士打道262号中粮大厦11楼

邮编：999077

邮箱：mandykwok@gbaela.org

### KWOK Siu Man

Secretary General, Guangdong-Hong Kong-Macau Greater Bay Area Ecology and Landscape Alliance (GBAELA)

## 摘要

填海造地和疏浚活动会损害海洋和沿海生态。本研究理性分析了获批的环境影响评价中存在的冲突点，包括对沿海和海洋生境所受直接及间接影响的忽视，环评流程中的漏洞，以及海洋环境修复方案的缺陷，旨在使利益相关者更好地了解填海造地对海洋和沿海生态系统造成的直接及间接影响，以促使其遵循合理的环评流程，并实施响应式海洋生物修复方案。研究以中国海南海花岛为例，通过在疏浚之前及过程中应用响应式牡蛎-海草-珊瑚滤床系统，使周边海域的水浊度和悬沙浓度保持在珊瑚礁的耐受范围之内。

## 关键词

填海造地；疏浚；环境影响评价；海洋生物修复；响应式原型；牡蛎-海草-珊瑚滤床系统

## ABSTRACT

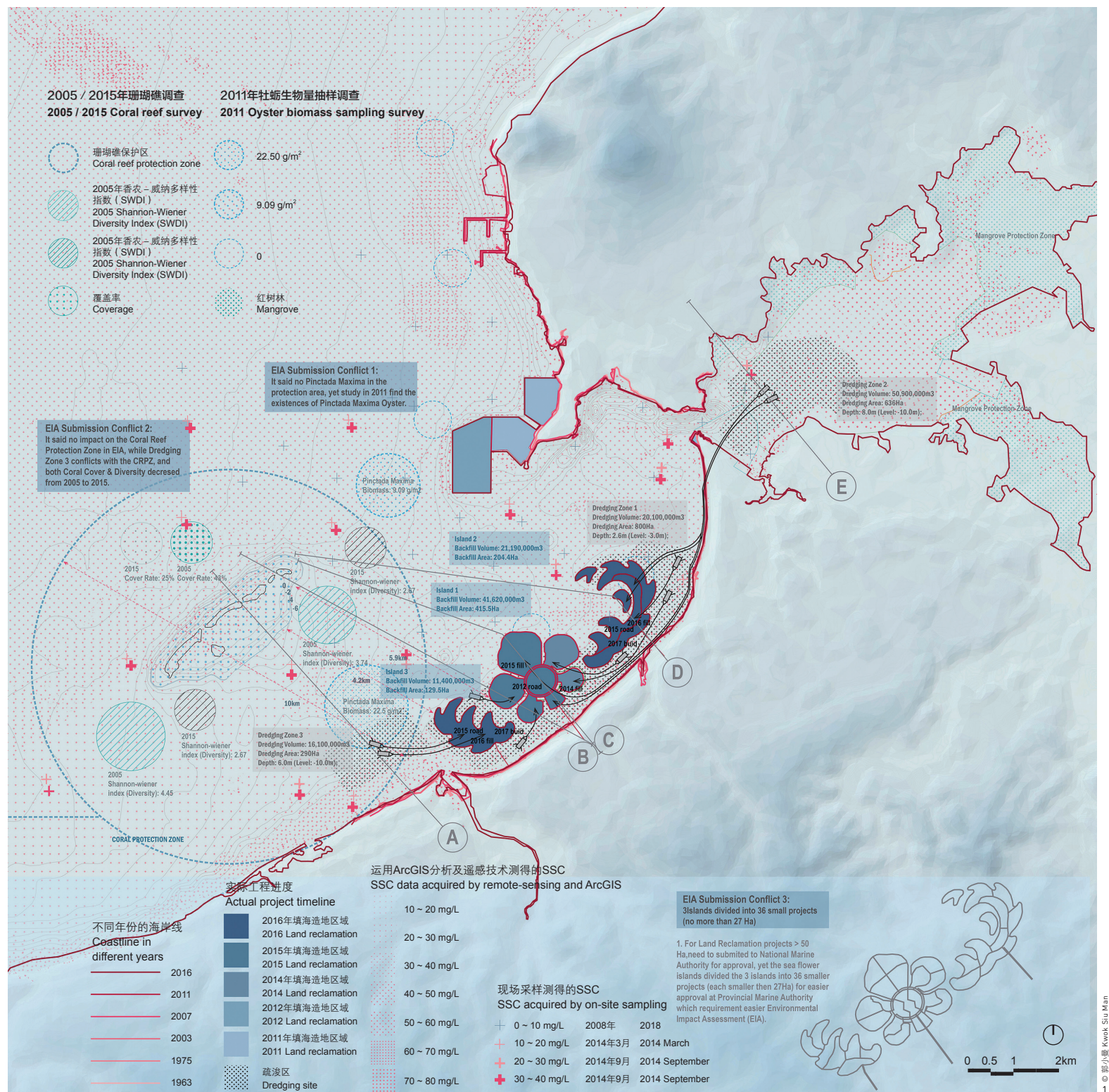
Land reclamation and dredging have a damaging effect on marine and coastal ecology. This study rationally analyzes the conflicts in the approved environmental impact assessment (EIA), including the negligence of the direct and indirect effects on coastal and marine habitats, the short circuit of the EIA procedures among stakeholders, and the insufficient marine environmental restoration schemes. This study also promotes awareness among the stakeholders so they will understand the direct and indirect effects of land reclamation on marine and coastal ecosystems, as well as the indications if they follow the EIA procedures, and implement a responsive marine bioremediation before and during the dredging process. By taking the Ocean Flower Island in Hainan, China as an example, this study applied the responsive oyster-seagrass-coral filtration bed system before and during the dredging process to maintain the water turbidity and suspended sediment concentration below the tolerance limits of the coral reefs in the adjacent areas.

## KEYWORDS

Land Reclamation; Dredging; Environmental Impact Assessment; Marine Bioremediation; Responsive Prototype; Oyster-Seagrass-Coral Filtration Bed System

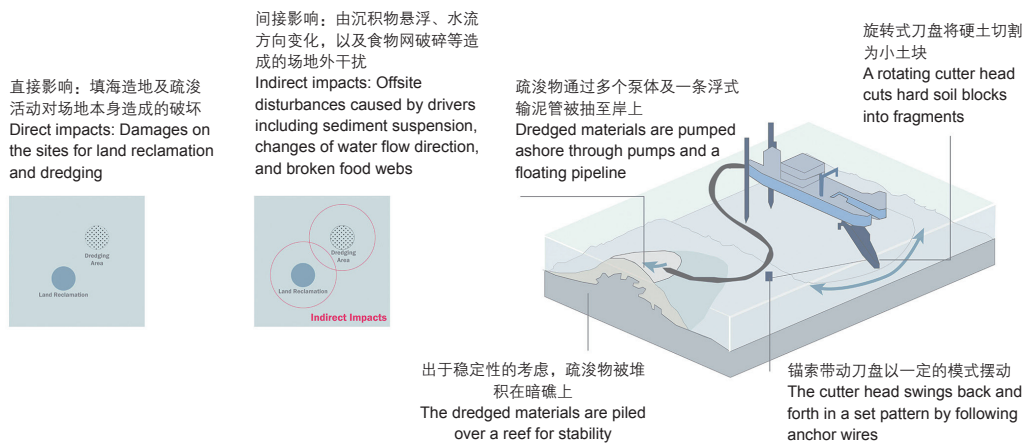
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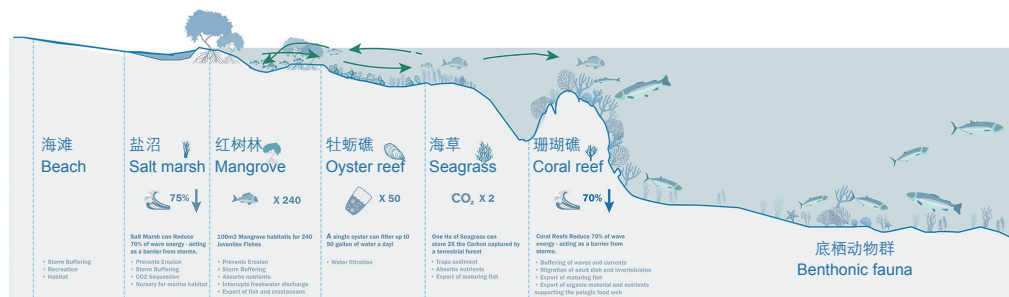


1. 填海造地及疏浚活动给海花岛周边海域造成的影响，以及海花岛环评报告与其他研究结果间存在的矛盾冲突。

1. A map of land reclamation and dredging impacts around Ocean Flower Island with conflicts in EIA report

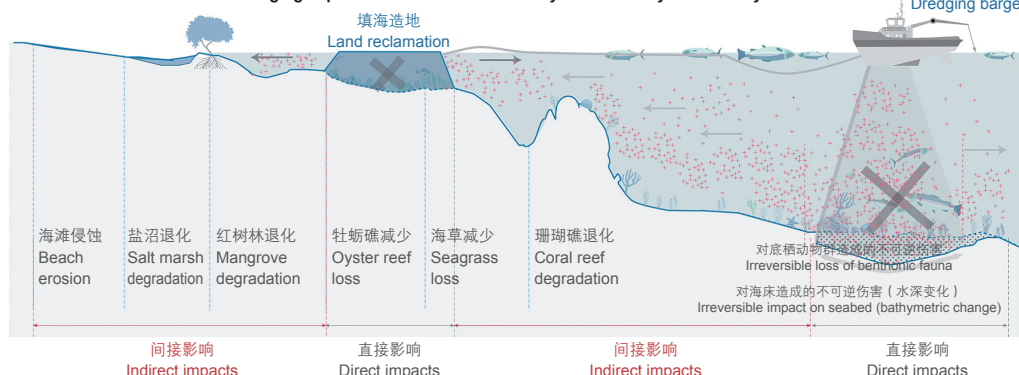


## 沿海及海洋生态系统 Coastal and marine ecosystems



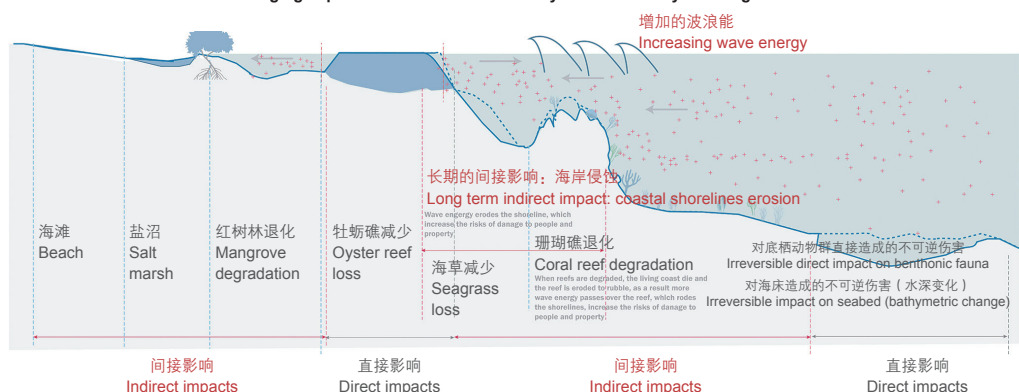
## 填海造地及疏浚活动会对沿海及海洋生态系统造成何种直接及间接影响?

How do land reclamation and dredging impact coastal and marine ecosystems directly or indirectly?



## 填海造地及疏浚活动会对沿海及海洋生态系统造成何种长期的间接影响?

How do land reclamation and dredging impact coastal and marine ecosystems indirectly in a long term?



## 2 提案

一个健康的沿海及海洋生态系统应由不同的海洋生境组成，包括渔场、珊瑚礁、海草、牡蛎场、红树林和盐沼，各生境之间相互提供生态系统服务。疏浚和填海活动会对海洋生态系统造成不可逆转的损失以及生境退化，直接导致底栖动物群死亡及海床变化，并使海水悬浮沙浓度（SSC）增加，间接引起珊瑚退化。由于间接影响的测算需要较长时间，因此中国的许多环评项目都将其略过，或仅以简单笼统的陈述代替量化评价。长此以往，珊瑚礁自身的退化将导致其消浪能力不断下降，无法阻挡波浪能对海岸线的侵蚀，使人类的生命和财产安全面临风险。然而，疏浚过程导致的SSC上升也为滤食性动物牡蛎增加了食物来源。这一生物修复过程可用于缓解填海造地带来的问题。

通过研究多种海洋生存环境以及牡蛎和海草的生物修复作用，并对牡蛎滤床、海草滤床、牡蛎—海草滤床原型进行测试后，本研究提出了牡蛎—海草—珊瑚滤床系统，以保护珊瑚礁，降低波浪对沿海地区的冲刷。在疏浚之前及疏浚过程中，采用本研究设计的滤床系统并严格遵循EIA流程，可使水浊度和SSC维持在低水平（10mg/L），为珊瑚的健康生长提供理想的水环境，进而改善珊瑚生境。

## 3 模拟设计

本课题的研究区域“海花岛”位于海南省儋州市北岸，是一个于2012年9月开工建设的面积约为780hm<sup>2</sup>的人工群岛，包含三个从附近的海床上挖泥填海而成的独立小岛（海花岛1~3号）。研究首先深入分析了已获批的环评报告中的信息与学术论文中发表的海洋生境数据之间存在的冲突。除评价程序本身存在的漏洞以及不当操作之外，研究进一步确定了4项主要冲突点（图1，2）。

冲突点1：环评报告对2011~2012年以及填海造地施工期内的保护区情况进行了评价对比，称在2011年未发现大珠母贝（*Pinctada maxima*），但该物种曾出现在2011年进行的一项研究中<sup>[5]</sup>。

冲突点2：已获批的环评报告称，疏浚活动对珊瑚礁保护区没有影响，但此前有研究指出，疏浚三区对该区域造成了影响，致使珊瑚的覆盖率及多样性在2005~2015年间不断降低<sup>[6]</sup>。

冲突点3：国家规定，对于50hm<sup>2</sup>以上的填海造地项目，其环评报告及所有项目计划书都要上报至国家层面进行审批，审批时间较长且可能会被驳回<sup>[7]</sup>。因此，该项目被划分为36个小项目，以便尽快、顺利通过审批<sup>[8]</sup>。

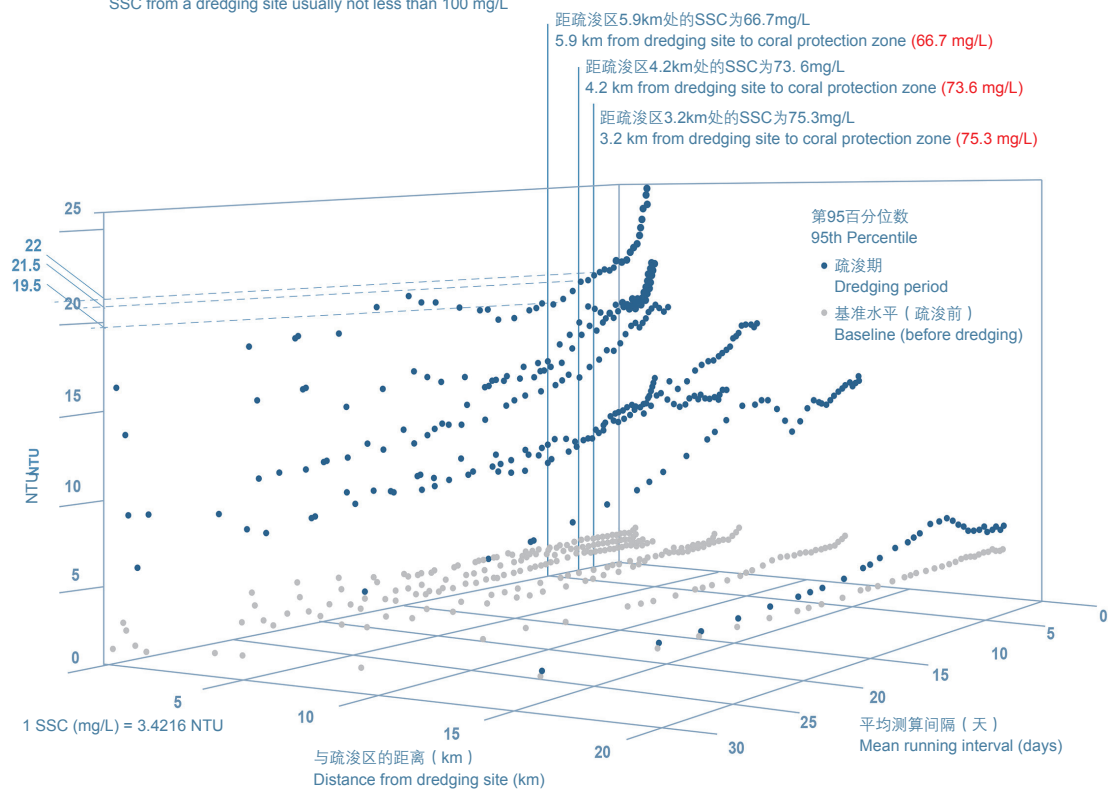
冲突点4：海花岛环评报告显示，2008年其周边海域的SSC小于珊瑚健康生长的理想水浊度阈值10mg/L。在2015年的报告中，两次现场抽样结果显示，海花岛区域在2014年3月和9月的SSC范围分别为10~20mg/L和20~40mg/L。然而，其他众多研究结果表明，疏浚区的SSC普遍不低于100mg/L。

基于由重量分析法确定的总固体悬浮物水平与浊度计读数之

2. 填海造地及疏浚活动对海洋生态系统造成的直接及间接影响
3. 与疏浚区距离不等的采样点的SSC水平
2. Direct and indirect impacts of land reclamation and dredging on marine ecosystem
3. SSC of sample sites at different distances from dredging site

### 海花岛案例 Ocean Flower Island case

疏浚区的SSC通常不低于100mg/L  
SSC from a dredging site usually not less than 100 mg/L



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比，比浊法浊度单位（NTU）数据可以通过换算系数转换为SSC（1 SSC=3.4216 NTU）。本研究将海花岛疏浚区的SSC设为100mg/L，距离疏浚区越远，SSC越低。对位于疏浚区和珊瑚保护区之间的三个地点（分别距疏浚区3.2km、4.2km及5.9km）进行采样，测得其SSC分别为75.3mg/L、73.6mg/L和66.7mg/L，均为经大量研究证实的珊瑚部分致死浓度（图3）。此前的一项研究将珊瑚生长的SSC耐受水平分为三个等级并规定了相应阈值：10mg/L级，珊瑚可存活；20mg/L级，珊瑚部分死亡；以及100mg/L级，珊瑚全部死亡<sup>[9]</sup>。

环评报告除了与其他研究结果存在冲突外，亦忽略了疏浚和填海造地所带来的间接影响。在报告中，此类影响被理所当然地认为难以测量，但多项研究已成功评价出了与疏浚区距离不等的采样点的SSC水平<sup>[10]-[12]</sup>，并证实这些疏浚区所带来的间接影响严重威胁着珊瑚生境。

## 4 设计策略

### 4.1 滤床原型

为了解决上述冲突，本研究通过详细调研生物修复过程、各种海洋生境的维持条件（表1），以及可在疏浚和填海造地之前及施工期

间进行的生产—修复周期与培育过程（图4~6），提出了一项设计策略——利用牡蛎的滤食习性，将其与海草一起制成过滤层来防止珊瑚退化，从而降低波浪能，保护沿海区域。

本研究开发了三种滤床原型（图4~6）。这些滤床的过滤阈值不同，可设置在海花岛填海造地及疏浚区附近的不同水深处（图7，8）。

原型一为牡蛎滤床，可布置在水深为1~3m、SSC为10~100mg/L的位置。一只成年牡蛎每天可过滤0.2m<sup>3</sup>的水，而一个30m×120m的牡蛎滤床单元可容纳36万只牡蛎，其过滤速率可满足被一艘疏浚速率为3 000m<sup>3</sup>/小时（即72 000m<sup>3</sup>/天）的挖泥船所影响的水体的净化需要。

原型二为海草滤床，可布置在水深为1~15m、SSC为10~20mg/L的位置。一个30m×120m的滤床单元可容纳72万株海草。

原型三为牡蛎—海草滤床，可布置在水位为1~15m、SSC为10~100mg/L的位置。一个尺寸为30m×120m的牡蛎—海草滤床单元可容纳36万只牡蛎和72万株海草。

### 4.2 响应式生物修复设计

对于初始SSC水平为100mg/L的疏浚区，使用响应式牡蛎滤床可将SSC降至30mg/L；继续使用响应式牡蛎—海草滤床后，SSC将进一步

表1: 牡蛎—海草—珊瑚栖息地生存条件  
Table 1: Living conditions of oyster-seagrass-coral habitat

过滤目标 Filtration target	水深 Water depth	生命周期 Life cycle	生长条件 Growing conditions	数量 Quantity	成功案例 Successful cases
一只牡蛎一天可过滤0.19m <sup>3</sup> 的水体。牡蛎直径为100~115mm An Oyster can daily filter 0.19 m <sup>3</sup> water. Oyster size: 100 ~ 115 mm	潮间带与潮下带，水深约为1~3m Intertidal and sub-tidal zones with water depth of around 1 ~ 3 m	2~6周培育，2~3年成熟，3年后进入繁殖期 2 ~ 6 weeks for nursery; 2 ~ 3 years to be mature; reproductive prime at 3 years of age	温度0~4℃，微咸水环境 Temperature between 0 ~ 4 °C; Brackish water	0.4hm <sup>2</sup> 可培育出750 000只牡蛎 One acre can produce 750,000 Oysters	大湾区河口：360hm <sup>2</sup> 的生物滤床每4天可将整个河口的水体过滤一次 Great Bay estuary: 360-hectare filtration bed can filter the entire estuary every 4 days
海草可过滤浅水 Seagrass can filter shallow water	多数海草生长在水深1~15m的水域，最深可生长于58m处。 Many seagrass species live in depths of 1 ~ 15 m, but the deepest-growing one has been found at a depth of 58 m.	大约6年 Approximately 6 years	温度10~16℃，清澈、富含营养的低波浪能浅水域 Temperature between 10 ~ 16 °C; Clear, shallow, nutrient-rich, and low-energy water	0.4hm <sup>2</sup> 可培育出近30 000株海草 One acre can produce nearly 30,000 seagrass trace sediments	海草滤床能截留沉积物以降低SSC Seagrass filtration bed can reduce SSC by trapping sediments
珊瑚能够降低波浪能，进而避免海岸线侵蚀 Coral reef can reduce wave energy to protect coastline from erosion	水深为2~6m Water depth of 2 ~ 6 m	8~14个月培育（从1~2cm的断枝培育成直径6~9cm的幼年珊瑚） 8 ~ 14 months for nursery (from 1 ~ 2 cm fragments to 6 ~ 9 cm in diameter)	温度23~29℃ Temperature between 23 ~ 29 °C	珊瑚礁能够降低70%的波浪能 Coral reef can reduce wave energy by 70%	菲律宾、日本富士市、马尔代夫 The Philippines, Fuji, Japan, and Maldives

下降至10mg/L，达到适宜珊瑚生存的水平。不过，一些意外事件或过度疏浚可能会导致过滤系统崩溃，本研究为此进一步设计了具有多重阈值的牡蛎—海草—珊瑚系统，以响应不同的水质条件：当SSC超过10mg/L时，珊瑚首先停止正常生长；当SSC超过30mg/L时，海草停止正常生长；SSC超过100mg/L，牡蛎则会停止滤食，闭合外壳。

牡蛎—海草—珊瑚响应系统可通过远程闭路电视（CCTV）进行监控。如果牡蛎壳张开，则该牡蛎正在进行滤食；如果牡蛎壳闭合，则说明SSC超过了100mg/L。在后一种情况下，海洋管理部门可责令疏浚方停止作业并接受检查。同样，如果海草生长状况不佳，则说明SSC可能超过了30mg/L（图9）。

另一种响应式设计是在珊瑚礁附近培育珊瑚，通过观察珊瑚的生长情况评价水质是否达到了珊瑚的健康生存标准。珊瑚养殖户收割珊瑚后，放在养殖盘或珊瑚树上培育幼珊瑚，并通过远程水下CCTV进行监控，如果珊瑚在数月内生长良好，则说明水质达标，珊瑚将会被转移至原来的生境，以增加原生境的珊瑚覆盖率；若珊瑚死亡，疏浚作业则会被叫停并接受检查（图10）。

综上，通过对填海造地的环评程序进行微调并融合生物修复方案，本研究提出了一个新的海花岛施工时间表（图11），其表明如果在疏浚前和疏浚期间妥善使用响应式牡蛎—海草—珊瑚滤床进行生物修复并严格遵循环评流程，海花岛1号填海造地和地面建设的开工时间将分别至少推迟5年和8年。

## 5 结论

在疏浚过程中采用响应式牡蛎—海草—珊瑚滤床系统作为生物修

复手段并遵循合理的环评流程可以有效保护并改善海洋生境，但在实施环评流程以及在不同利益相关方之间进行协调的时间成本也将显著增加。本研究提出的修复设计方案均基于理想状态，实际施工中的突发事件或各种延迟都会影响项目进度。在这种情况下，鉴于开发时间成本高、生物修复投入大，利益相关者在决定填海造地前必定会进行谨慎权衡，因为这与他们快速获取廉价土地的初衷相矛盾。然而，无论时间成本如何，响应式生物修复设计对生态系统而言都是具有价值的——这些生物修复原型可用于净化任何高SSC水体，从而改善海洋生态。

人类活动影响着生态系统和生态环境，而生态系统的崩溃将会威胁到人类的生命和财产安全。生态系统所包含的种类丰富的生境为其赋予了生命力，使其成为城市建设中活跃而复杂的主体，在物理和生物层面与各种先进生物技术、治理活动、公共政策和土地动态变化发生关联。本研究探讨了牡蛎—海草—珊瑚生境体系所提供的生态系统服务及其作用机制。该系统所展现出的水体净化能力表明其在海洋和沿海保护方面均具备响应性、适应性及有效性，是一种全新的创造性生物修复途径，证明了“解决自然问题最终需借助自然之力”。LAF

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## 1 Background

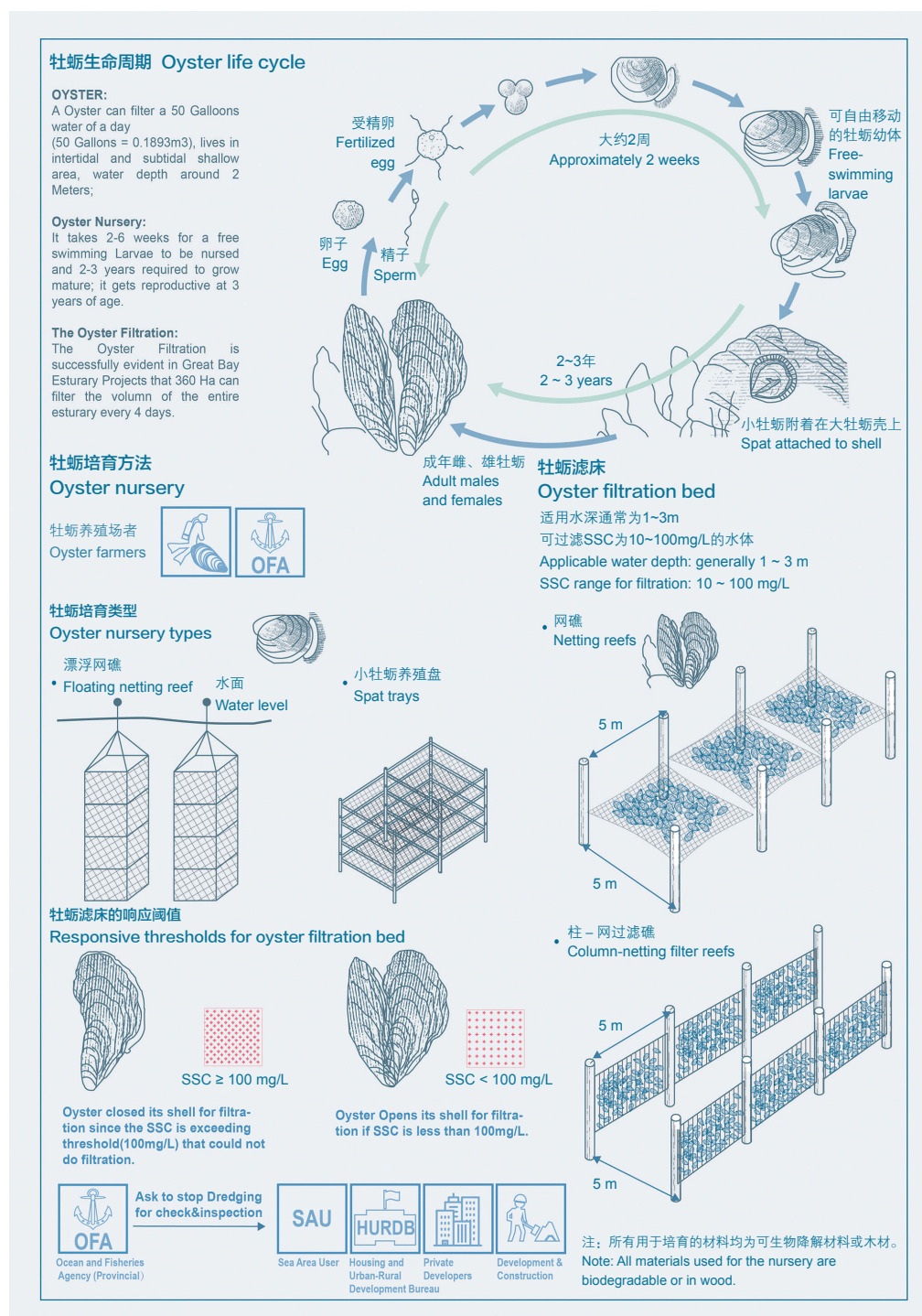
Statistics shows that land reclamation activities are increasing worldwide in the 21st century. The land reclamation areas in Hainan, China are rising since 2006 and eventually reached the peak at 1,351.77 km<sup>2</sup> in 2013<sup>[1]</sup>. After the central government declared Hainan as an International Tourism Island in 2010<sup>[2]</sup>, developers rushed to occupy the coastal area because land reclamation is a fast and cheap way to obtain excellent sea view lands. However, research findings showed that the percentage of local coral reef cover decreased from 70% in the 1980s to nearly 10% in the 2010s<sup>[3]</sup>. Such dramatic shrinking is closely related to the increasing land reclamation, as well as the following human activities like fisheries and dredging.

The loss of coral reef habitats in Hainan is caused by governance failure. Conservation structures, processes, regulations, and laws are bypassed by stakeholders. The effect of dredging on coral reef protection zone is underestimated due to the insufficient environment impact assessment (EIA) and lack of scientific knowledge. In December 2017, all land reclamation projects were paused after months of environmental inspection by the central government in Hainan due to the serious coastal and marine environmental damages<sup>[4]</sup>.

## 2 Proposition

A healthy coastal and marine ecosystem consists of different marine habitats, including fisheries, coral reefs, seagrasses, oyster beds, mangroves, and salt marshes, which provide ecosystem services to each other. Dredging and land reclamation activities cause irreversible loss and habitat degradation to marine ecosystems. The direct effects include the irreversible loss of benthonic fauna and changes in the seabed, and the indirect one, which can be attributed to the increasing suspended sediment concentration (SSC), causes coral degradation. Given that it takes long to measure the latter, many EIAs in China exclude this part or just provide a simple and general statement without quantification assessments. In the long term, the wave reduction ability of degraded coral reefs will decline. As a result, increased wave energy passes over the reef, which causes shoreline erosion and increases the risks of damage to people's lives and properties. On the other hand, the increasing SSC caused by the dredging process can serve as a positive source for oysters as filter feeders, which is an ecological solution to land reclamation through the bioremediation process.

By examining the different marine living conditions and



- 牡蛎的生命周期、培育方法及滤床设计
- Life cycle, nursery, and filtration bed design of oysters

bioremediation that oysters and seagrass provide, and testing the prototypes of oyster filtration bed, seagrass filtration bed, and oyster-seagrass filtration bed, the oyster-seagrass-coral filtration bed system is proposed in this study to protect the coral reef and consequently reduce wave energy and protect the coastal area. Adopting the designed filtration bed system before and during the dredging process and strictly following the EIA procedures can maintain the water turbidity and the SSC at a low level (10 mg/L), thereby providing an ideal living water condition for the healthy growth of corals and enhancing their habitats.

### 3 Speculation

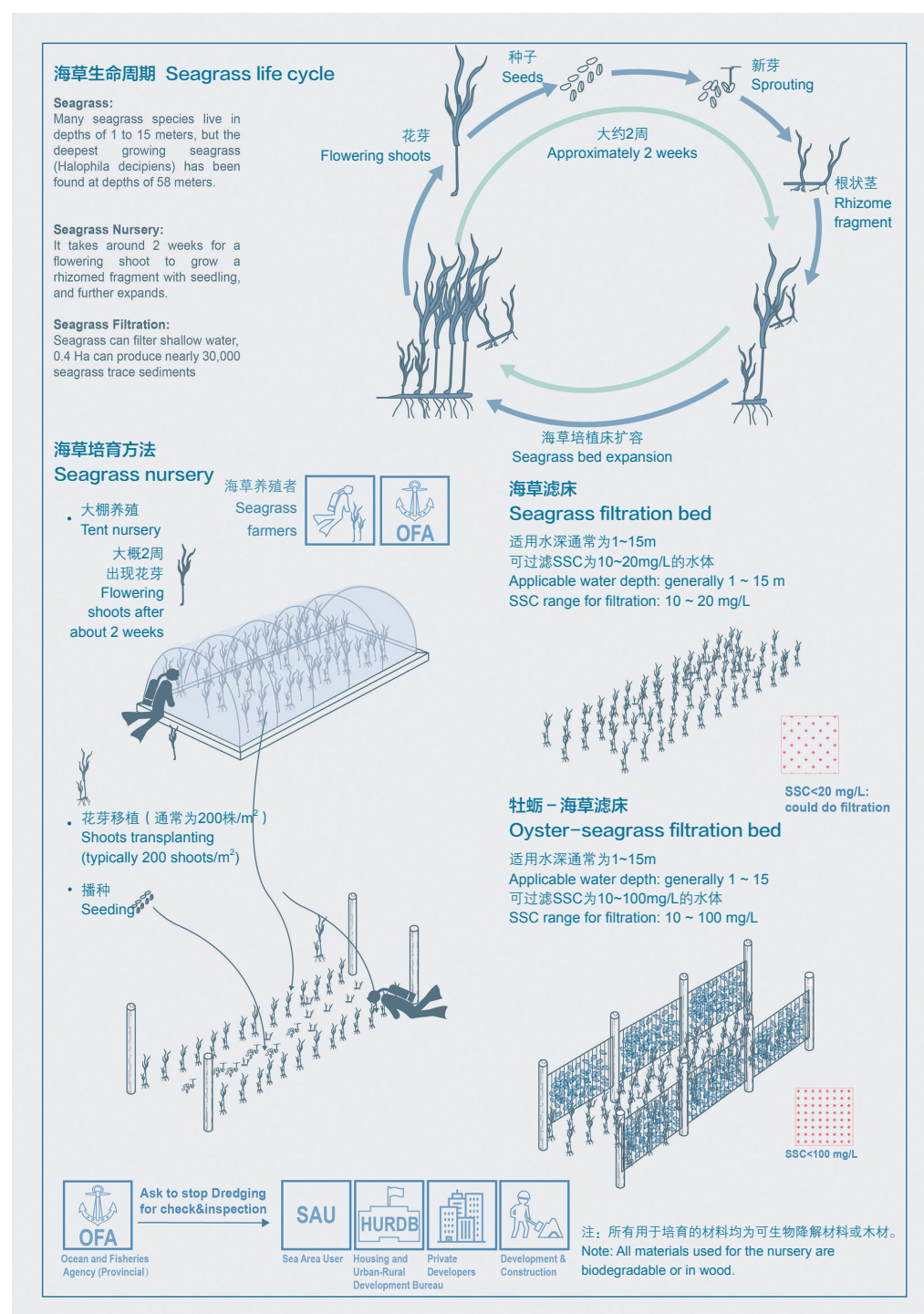
The study area is the Ocean Flower Island, a 780-hectare artificial archipelago located at the north coast of Danzhou in Hainan. The island consists of three independent islets (Ocean Flower Islet 1 ~ 3), which were reclaimed by dredging from the nearby seabed since September, 2012. The study started with a thorough analysis of the conflicts between the information declared in the approved EIA and the marine habitat data published in research papers. In addition to the short circuit and misconduct of EIA procedures, four other major conflicts were identified (Fig. 1, 2).

Conflict 1: No *Pinctada maxima* was reported in 2011 in the protection area in EIA which evaluated and compared the coastal ecology in 2011 ~ 2012 and during the land reclamation and dredging, but a study conducted in 2011 found this oyster species in the region<sup>[5]</sup>.

Conflict 2: The approved EIA claimed that the dredging activities have no effect on the coral reef protection zone, but a previous study stated that Dredging Zone 3 affected this zone and the coral coverage and diversity decreased from 2005 to 2015<sup>[6]</sup>.

Conflict 3: As the central government requires, the EIA and all project proposals of land reclamation projects covering more than 50 hectares should be approved at the national level, which may take a long time and be rejected<sup>[7]</sup>. Therefore, the project was divided into 36 small projects to obtain approval quickly and easily<sup>[8]</sup>.

Conflict 4: The Ocean Flower Island EIA report showed that the SSC around the island in 2008 was less than 10 mg/L (the threshold of an ideal water turbidity for the healthy growth of corals). In the EIA conducted in 2015, a two site-sample survey showed that the SSC range in March and September 2014 was 10 ~ 20 mg/L and 20 ~ 40 mg/L, respectively. However, the results were inconsistent with the findings of numerous studies,



5. 海草的生命周期、培育方法及滤床设计
5. Life cycle, nursery, and filtration bed design of seagrasses

which argued that the SSC of a dredging site is generally not less than 100 mg/L.

The nephelometric turbidity unit (NTU) data can be converted into SSCs (mg/L) by applying site-specific algorithms (conversion factors) based on gravimetrically determined total suspended solid levels versus nephelometer readings (1 SSC = 3.4216 NTU). The SSC of the dredging site in the Ocean Flower Island was set as 100 mg/L, which negatively correlates with the distance to the island. Three locations with distances of 3.2 km, 4.2 km, and 5.9 km, respectively from the dredging site to the coral protection zone were sampled, and their SSC levels were 75.3, 73.6, and 66.7 mg/L, all of which can cause partial coral mortality according to many studies (Fig. 3). A previous research categorized the SSC tolerance levels and critical thresholds for coral growth into three: 1) level where corals survive (10 mg/L), 2) level where corals face partial mortality (20 mg/L); and 3) level where corals die (100 mg/L)<sup>[9]</sup>.

Aside from the conflicts with other research findings, the indirect effects of dredging and land reclamation sites were also disregarded in the EIA report. Such effects are assumed to be immeasurable in EIA, but several studies were able to evaluate the SSC levels at different distances from the dredging site<sup>[10]-[12]</sup>. The findings revealed that the indirect effects of these sites pose serious threats to coral habitats.

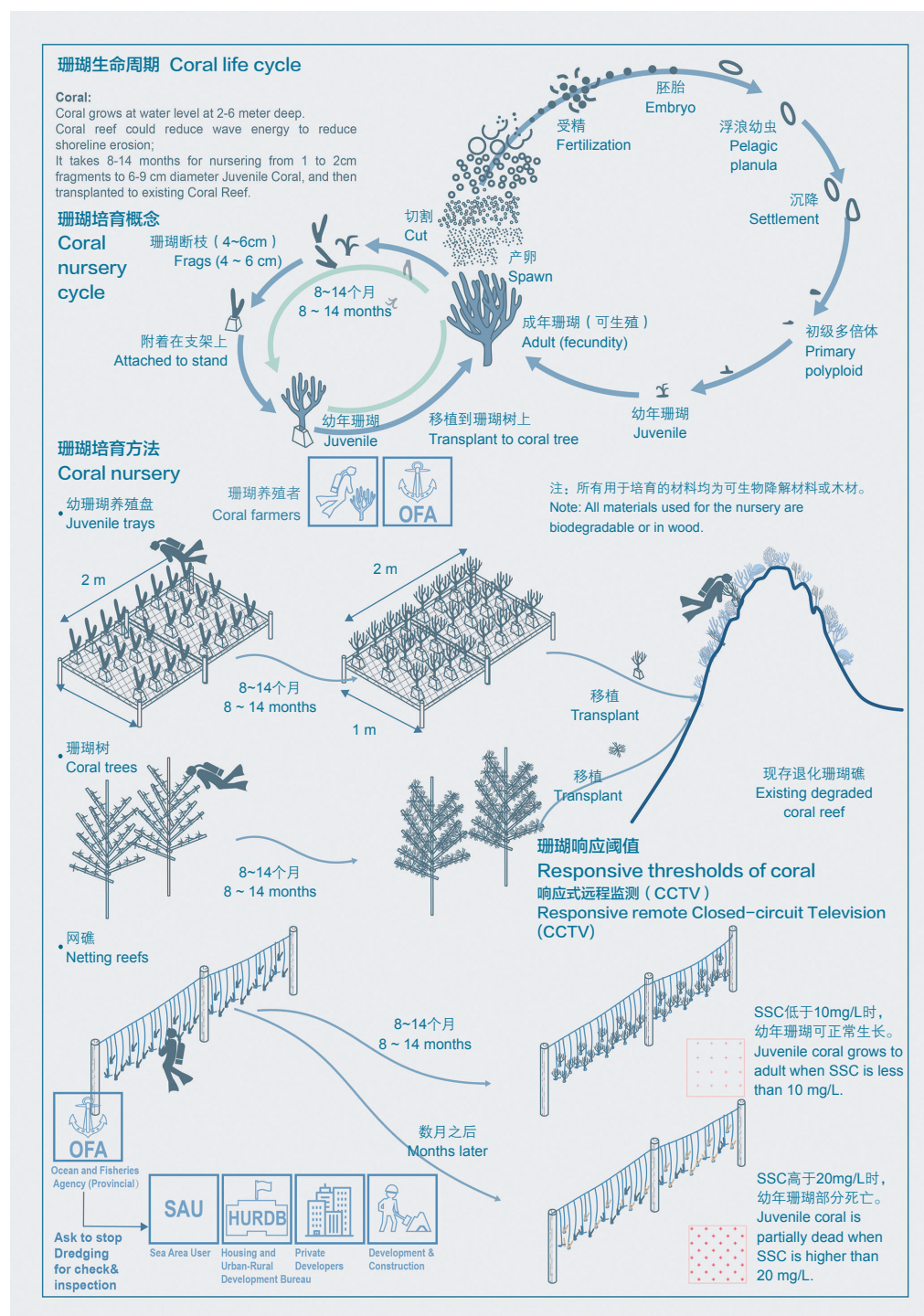
## 4 Design Strategy

### 4.1 Filtration Bed Prototypes

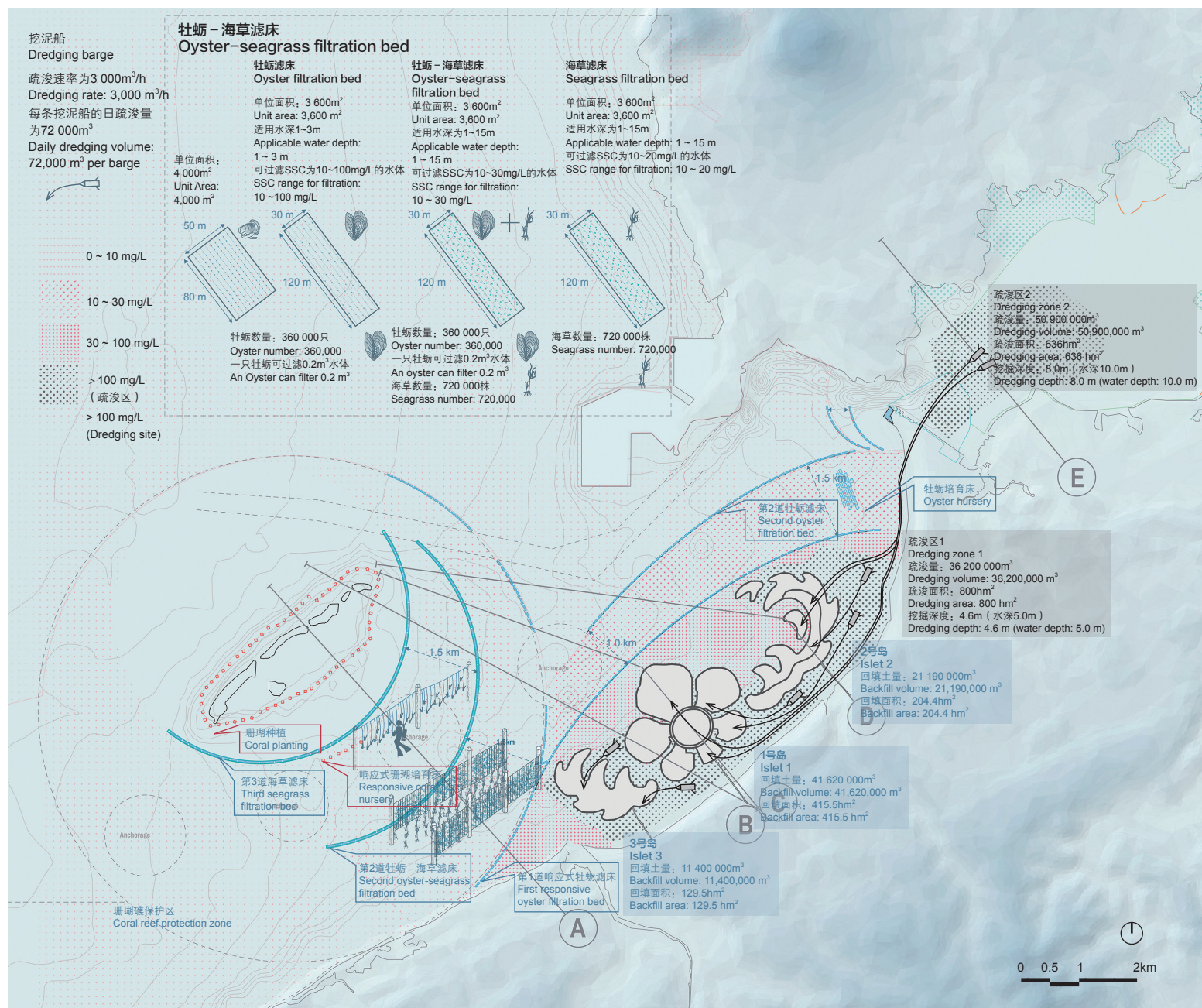
The design strategy, which aims to address the abovementioned conflicts, is based on the detailed investigation of the bioremediation process, living conditions of various marine habitats (Table 1), and life cycle and nursery processes for production and remediation, which are conducted before and during the dredging and land reclamation operations (Fig. 4 ~ 6). This strategy intends to utilize the filtration function of oysters by combining their filtration layers with seagrasses to protect corals from degradation and consequently reduce wave energy and safeguard the coastal areas.

Three filtration bed prototypes are developed (Fig. 4 ~ 6). These beds can be set adjacent to land reclamation and dredging sites in Ocean Flower Island at different locations with distinctive water depths and filtration thresholds (Fig. 7, 8).

Prototype 1 is an oyster filtration bed, which can be deployed at locations with water depth of 1 ~ 3 m and SSC of 10 ~ 100 mg/L. An adult oyster can filter 0.2 m<sup>3</sup> water per day, and an oyster filtration bed unit with a size of 30 m by 120 m can contain 360,000 oysters and therefore facilitate full



- 珊瑚的生命周期、培育方式及响应机制
- Life cycle, nursery, and response mechanism of corals



7. 海花岛生物修复措施应用布局

7. The layout of bioremediation layers for Ocean Flower Island project

filtration at a dredging rate at 3,000 m<sup>3</sup> per hour (i.e. 72,000 m<sup>3</sup> per barge per day).

Prototype 2 is a seagrass filtration bed, which can be deployed at locations with water depth of 1 ~ 15 m and SSC of 10 ~ 20 mg/L. The size of the seagrass filtration bed unit, which contains 720,000 seagrasses, is 30 m by 120 m.

Prototype 3 is an oyster-seagrass filtration bed, which can be deployed at locations with water level and SSC of 1 ~ 15 m and 10 ~ 100 mg/L, respectively. An oyster-seagrass

filtration bed unit contains 360,000 oysters and 720,000 seagrasses with a size of 30 m by 120 m.

#### 4.2 Responsive Bioremediation Design

For a dredging site with an initial SSC level of 100 mg/L, the application of the first responsive oyster filtration bed can reduce the SSC to 30 mg/L. After the second responsive oyster-seagrass filtration bed is used, the SSC level will further decline to 10 mg/L. However, contingencies or over-dredging events can cause the system to break

8. 生物修复措施布局横剖面透视图
8. A sectional perspective of bioremediation layers

down. To address such drawbacks, the oyster-seagrass-coral system is designed to respond to their corresponding physical conditions. Oysters will stop the filtration and close their shells if the SSC exceeds 100 mg/L, and seagrasses and corals will not mature if the water quality is below the normal thresholds (30 mg/L for seagrasses and 10 mg/L for corals).

The responsive oyster-seagrass-coral system can be monitored using Remote Closed-circuit Television (CCTV). If an oyster shell is opened, the oyster is performing filtration; otherwise, the SSC is higher than 100 mg/L. In the latter case, the dredging party might be instructed by the marine authority to stop for inspection. Similarly, if the seagrasses are not growing well, the SSC may be higher than 30 mg/L (Fig. 9).

The coral nursery is another responsive design that is implemented near the coral reef to assess if the water quality exceeds the healthy living threshold. Coral farmers cut the corals and nurse the juvenile on a tray or a coral tree. If the coral exhibits excellent growth during the months monitored by the remote underwater CCTV, the water quality is considered good and the coral will be transferred to the original coral habitat to increase the coral coverage. If the coral dies, the dredging activities will be stopped for inspection (Fig. 10).

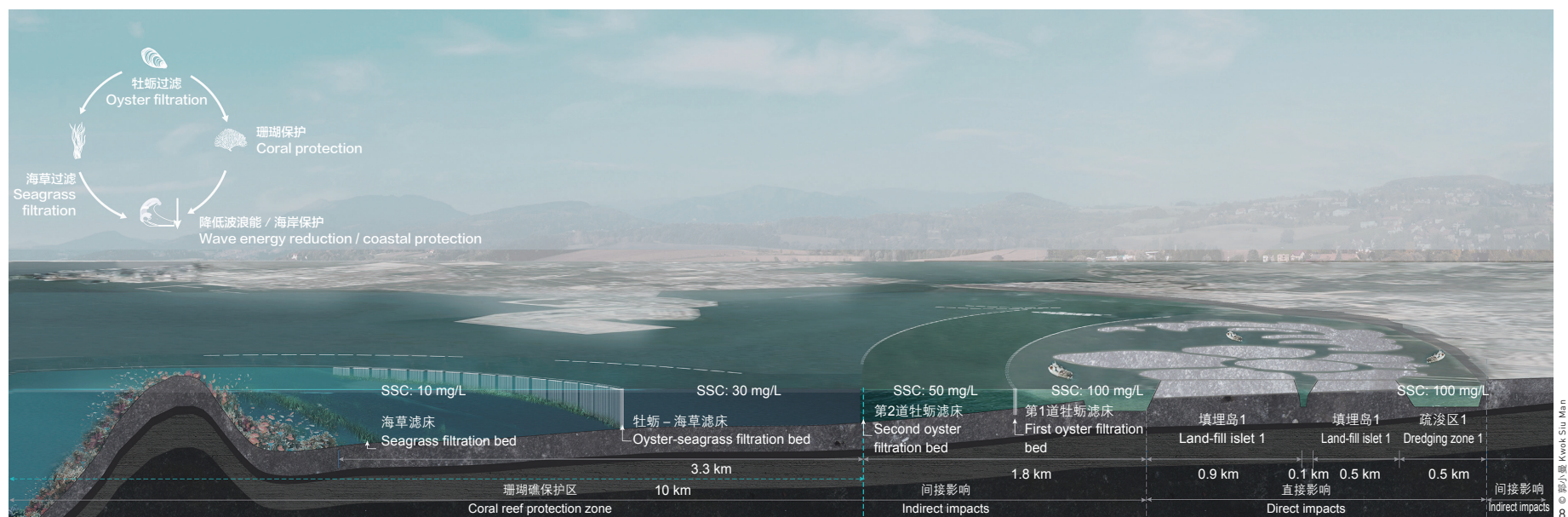
Finally, a new project timeline for Ocean Flower Island is proposed, which incorporates a slightly revised land reclamation EIA procedure and adopts bioremediation programs (Fig. 11). The timeline indicates that the start of

the land reclamation and ground-level construction of Ocean Flower Islet 1 will be delayed for at least 5 and 8 years, respectively, if the bioremediation process for the responsive oyster-seagrass-coral filtration bed runs smoothly before and during the dredging process and the EIA procedure is followed properly.

## 5 Conclusion

Adopting the responsive oyster-seagrass-coral filtration bed system as a bioremediation design and following the EIA procedures for the dredging process to maintain or enhance marine habitats, it takes years of longer time in the process for the assessment and negotiation among different stakeholders in the land reclamation and dredging process. The time cost is extremely high, and everything is counted in an ideal situation. The contingencies or delays in the project will prolong the project timeline. Under such situations, the stakeholders must carefully think before making decisions regarding land reclamation, because high time costs and bioremediation inputs contradict their original intention to obtain land in a fast and cheap way. Regardless of the time cost, the responsive bioremediation design is valuable to the ecosystem. The bioremediation prototypes can be used in any water body with high SSC levels to perform filtration and enhance the marine ecology.

Human activities affect the ecosystem and the ecology.



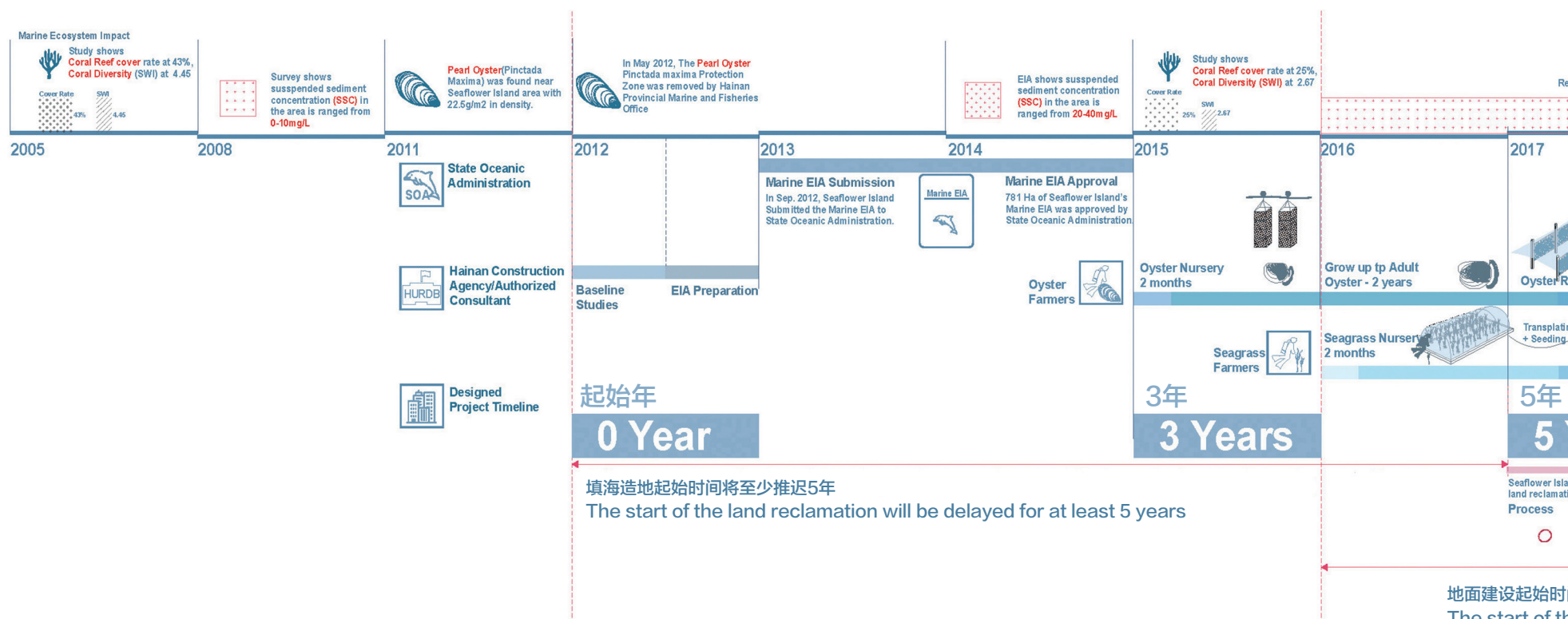
The collapse of the ecosystem poses risks to human lives and properties. The ecosystem is interrelated with different habitats to be a generating force, an active though complicated agent in the structuring of the city, and an agent that physically, biologically, and constructively engages in the various advanced biotechnologies, governances, public policies, and land dynamics. This study discusses the functions of the oyster-seagrass-coral habitat in their ecosystems, including their services and mechanisms. The filtration capacity of this system manifests a new and creative form of bioremediation practices, which are responsive, adaptive, and effective for marine and coastal protection, implying the concept that “design with nature, solve nature with nature.” **LAF**

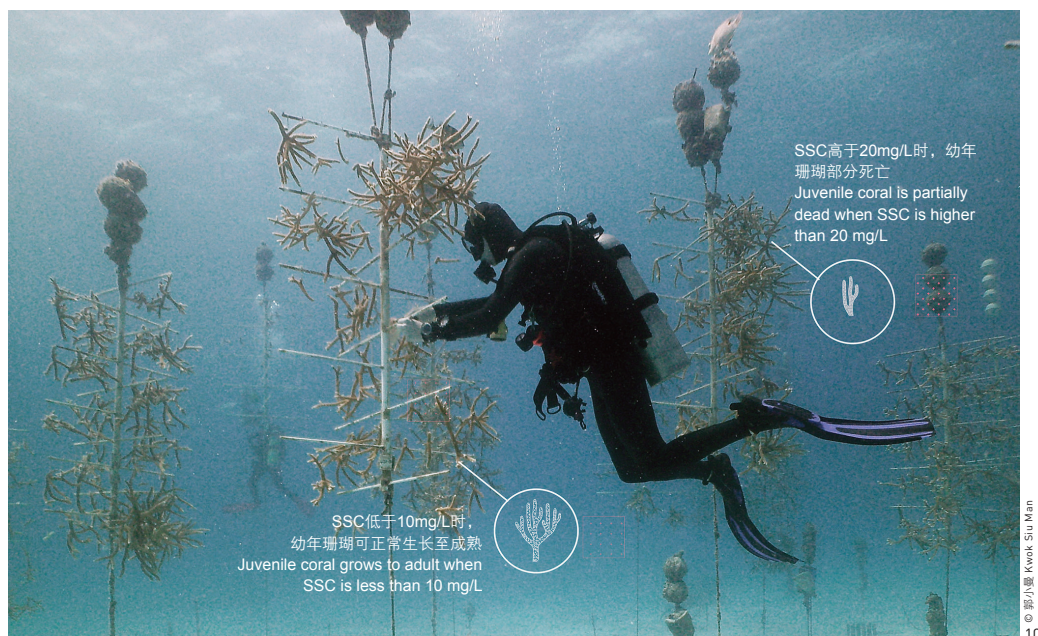
#### ACKNOWLEDGMENTS

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9. 响应式牡蛎—海草—珊瑚滤床
9. Responsive oyster-seagrass-coral filtration bed

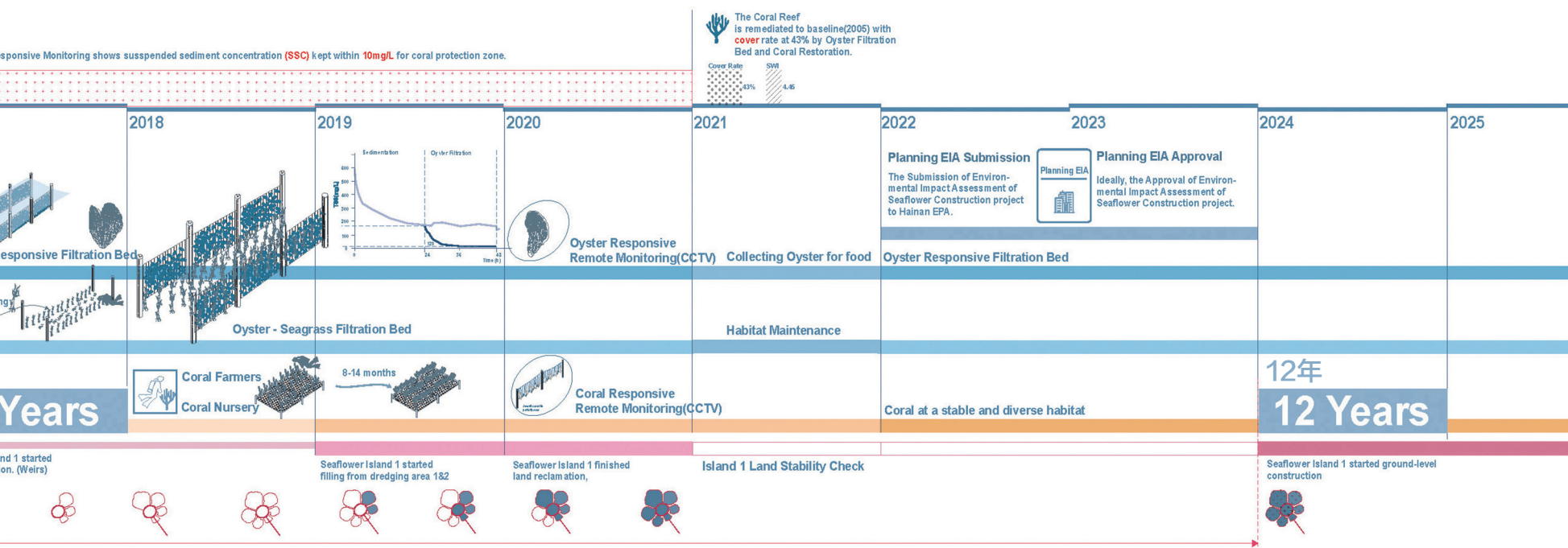




10. 响应式珊瑚培育
  11. 新提出的海花岛工程进度表
10. Responsive coral nursery
  11. The proposed timeline for Ocean Flower Island project

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