以基于自然的解决方案修复圩田生境
——鉴洋湖湿地公园首启区景观实践
Restoration of Polders Through Nature-Based Solutions
—Landscape Practice in the Start-up Area of Jianyang Lake Wetland Park

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摘要

曾经的渔业养殖历史与周边地块的持续开发，对鉴洋湖的生态资源造成了强烈冲击，使场地面临着自然肌理受损、水质污染、水生环境恶化、鹭鸟栖息地流失等问题。为使鉴洋湖的水质重归清澈，再现鹭飞鸟鸣的繁闹景象，项目团队借助基于自然的解决方案对废弃圩田湿地进行改造，打造了占地16hm^{2}的鉴洋湖湿地公园首启区。项目以“保留－打破－整合”为设计理念，建立起包含林－塘－田－湖－岛的复合生态系统，在有限的场地内引入了一套与区域风貌融合、紧凑高效且低维护的湿地净化系统，提升了鹭科鸟类的栖息地环境。同时，通过后期的监测和维护保障湿地净化系统的有效运行，引导场地植物群落的自发性演替。首启区的建设思路和运营绩效，为鉴洋湖湿地公园其他区域后续的修复工作提供了借鉴与经验。

关键词

鉴洋湖；圩田；基于自然的解决方案；生态修复；湿地净化；鹭鸟栖息地

ABSTRACT

The historical fisheries and the speedy urban development have dramatically threatened the ecological resources of Jianyang Lake in Zhejiang Province—the original texture of the site was largely damaged, the lake was severely polluted, and the Ardeidae habitats were badly degraded. To improve the water quality and restore the habitats of Jianyang Lake, as well as represent the scenery of groups of Ardeidae inhabiting there, the design team restored existing polder wetlands through Nature-Based Solutions and set up a 16 hm^2 Start-up Area of the Jianyang Lake Wetland Park. Applying the proposed design concept of "Retaining-Breaking-Integrating," an integrated ecosystem composed of forest, pond, farmland, lake, and island was formed. The design team also introduced a high-efficiency wetland purification system which is harmoniously embedded with the local image and resilient to climate changes with low maintenance, facilitating the optimization of the Ardeidae habitats. The long-term monitoring and maintenance would ensure the efficiency of the wetland purification system and spontaneous succession of the plant communities. The design concept, construction process, and performance of the Start-up Area can further offer references to restoration of the other parts of the park.

KEYWORDS

Jianyang Lake; Polder; Nature-Based Solutions; Ecological Restoration; Wetland Purification; Ardeidae Habitats

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1 项目背景

鉴洋湖位于浙江省台州市黄岩区，地处水网平原区内，同时也是温黄平原的一部分，周边土地类型以湿地和农田为主。是台州市西南部五峰山–鉴洋湖生态绿脉上的核心节点。据清《黄岩县志·光绪》记："鉴洋湖，在三十九都鸡笼山下，修广二千亩许，纵一里、横五里，为东南巨浸。中有沙洲芦荻，鸡鹄鸂鶒翔舞其际"[1]，展现了鉴洋湖百余年前山依水、水照山的原始景致。自清光绪三十一年起，这里就已经有围湖筑堤、种桑养蚕的历史，建国以后更是一度作为劳改农场和鱼种场——这些历史痕迹共同塑造了鉴洋湖以生产性湿地为主的渔耕文化景观。虽然，鉴洋湖湖体以及周边的林地和农田已然成为以鹭鸟为主的各种动物的栖息家园和食物来源，但多年淤积导致的湖面萎缩以及周边地块的接连开发已使今天的鉴洋湖面临着生境退化、水质污染等严峻问题。为了保护鉴洋湖的生态资源，改善湖区及周边生态环境，2009年，《台州黄岩鉴洋湖城市湿地公园总体规划》制定实施；同年，该湿地公园获批列入"国家城市湿地公园"。2018年，为了完善湿地公园的服务配套设施，台州市政府和宁波开投蓝城投资开发集团有限公司在鉴洋湖下湖区合作投资，建设了占地16hm^{2}的公园首启区（图1），以期为公园其他区域后续的修复工作提供经验与参照。

2 场地现状分析

2.1 多样的用地类型

在多年以前，约半数的首启区土地曾围堤挖塘，用于培育淡水鱼苗，形成了现如今以圩田堤岸围合而成的三角形区域。场地虽已退渔还湖，但依旧保留了大部分的鱼塘，与周围环境共同构成了由山林、湖体、湿地、农田组成的圩田景观（图2，3）。

渔业养殖的历史背景遗留了如下问题：1）混乱的场地肌理。鱼塘横平竖直的塘埂展现了严重的人工干预痕迹，而新建造的配套服务中心、步道以及其他服务设施也未能与原有的圩田肌理和谐相融；2）严重的水体污染。圩田富营养化较严重，底泥中有大量有机质与氮、磷营养物质的富集，溶解氧浓度较低，导致湿地内水质大多为V类或劣V类地表水，水生栖息地遭到严重破坏；3）单一的景观空间。铺设有混凝土预制板的边坡不利于植物生长与动物停留。

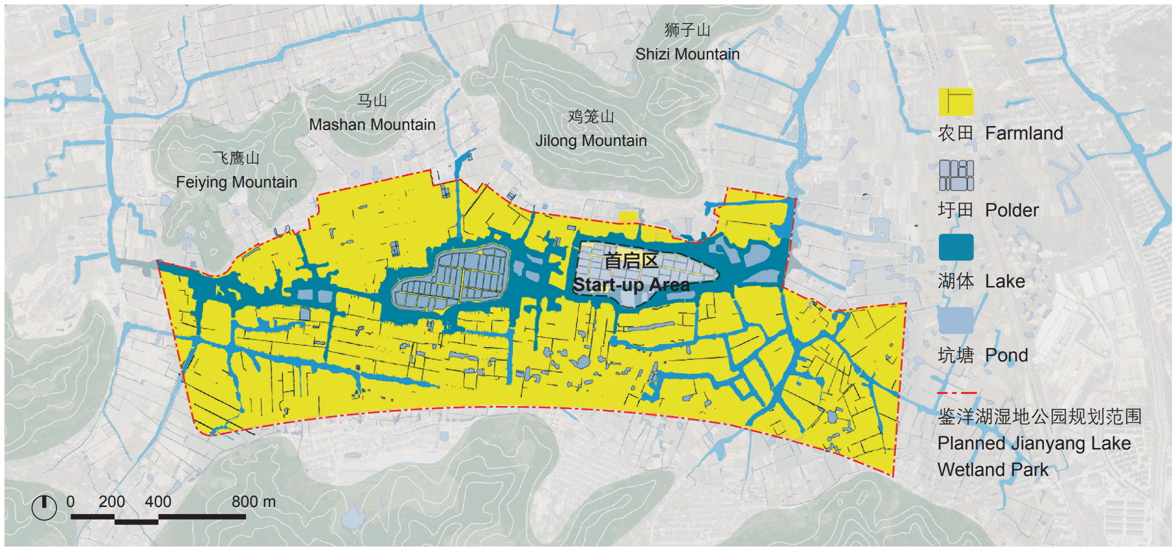
尽管如此，场地外南北两侧的山体植被郁郁葱葱，内部西侧的荷塘和稻田组成的大面积生产性湿地具有较高产量，绿荫环绕的圩田堤岸上的现状乔木长势良好。

2.2 鹭鸟生物多样性现状

根据《台州鉴洋湖湿地生物多样性调查报告》和团队现场调研，鉴洋湖地区动物种群包括鸟类、兽类、两栖爬行类和昆虫类等共计114种，其中鸟类有42种，为浙东南地区鸟种类总数的10.12%[2]。场地内的鸟类资源尤其突出，特别是鹭鸟——中国共有包括鹭属（*Ardea* spp.）和鳽属（*Gorsachius* spp.）等在内的20种鹭科（Ardeidae）鸟类[3]，而鉴洋湖所在的东洋界华中区的鹭科鸟类高达18种。

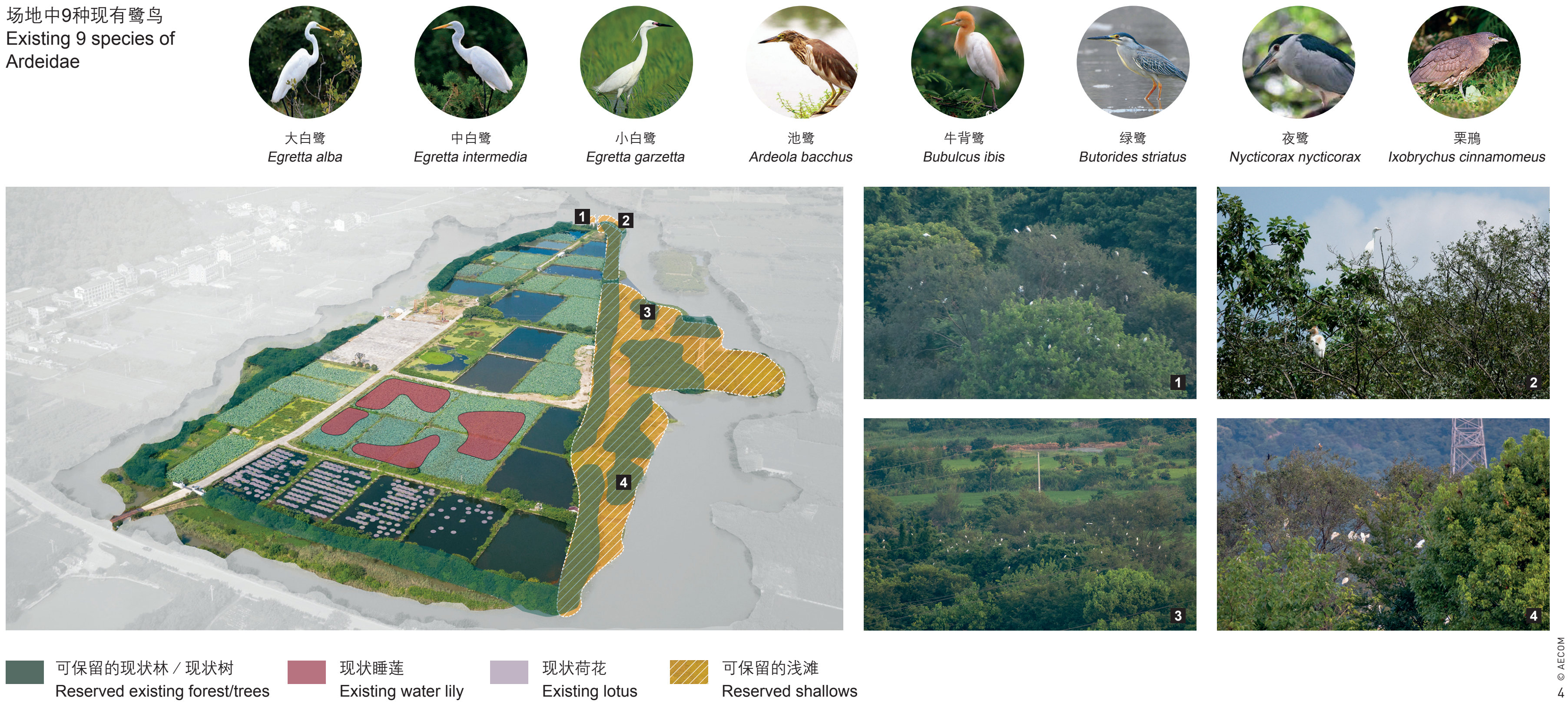
首启区内的塘埂林地、竹林与湿地栖息地现状均保持良好，且已有多种水鸟、林鸟栖息其中。圩田堤岸上的朴树（*Celtis sinensis*）、香樟（*Cinnamomum camphora*）、构树（*Broussonetia papyrifera*）与野桐（*Mallotus japonicus*），以及湖体边缘和湿地中密集的芦苇（*Phragmites australis*）、香蒲（*Typha orientalis*）等挺水植被，为鹭鸟提供了觅食、筑巢繁殖和寻找庇护的理想栖息地[4]（图4），且这些植被均是值得重点保育的优质生态资源。

然而圩田较陡的硬质驳岸和缺失的浅滩水面导致鹭鸟难以在此停歇觅食，仅有少量黑水鸡（*Gallinula chloropus*）、小䴙䴘（*Tachybaptus ruficollis*）等水鸟分布在深水区。同时，在主要道路与配套服务建筑施工时产生的噪声也会给鹭鸟栖息地的保育造成一定影响——尤其是在4～7月的鹭鸟繁殖期期间[3]。



1. 首启区区位图
2. 首启区圩田现状。水体主要超标污染物为氨氮与总磷，溶解氧浓度较低。
3. 现状垂直驳岸

1. The location of the Start-up Area
2. Existing polders in the Start-up Area with low-dissolved oxygen and overloaded ammonia nitrogen and total phosphorus
3. Existing vertical ridges



4. 场地植被以及鹭鸟分布现状
4. Existing distribution of the vegetation and Ardeidae

3 设计方案

3.1 设计理念

基于场地现状分析，遵循国家部委针对湿地公园建设提出的“保护优先、科学修复、适度开发、合理利用”原则[5]，项目引入基于自然的解决方案（Nature-Based Solutions，简称NBS）作为设计理念，即“依靠生态系统的自我调节能力与自我组织能力使其向有序的方向演化，或者在利用生态系统的自我修复能力的基础上，辅以人工措施，使遭到破坏的生态系统逐步修复或使生态系统向良性循环方向发展”[6]。继而提出了“保留－打破－整合”的设计概念，希望能通过最小干预来最大程度地提升场地的生态功能（图5）。其中，“保留”是指保留外围有防涝要求且植被较丰富的堤埂，以及作为隔断的部分塘埂；“打破”是为了增加不同水塘之间水体流动，断开塘埂以扩展水体在湿地中的流动线路；“整合”则是指将打破后相互连通的水塘相互整合，在场地中心塑造一处广阔的湖面空间。此项目没有选择通过大量填方重新塑造新的“自然肌理”，覆盖鱼塘经多年生产留下的历史痕迹，而是期望维护和利用圩田湿地的生态本底与智慧，将湿地净化系统嵌入原有肌理之中，通过建立根孔湿地系统来修复浅滩栖息地。

在项目实施过程中种植的水生植物也会顺应圩田湿地的肌理生长演替，让圩田在四季更迭间焕发新的生命力，以实现可持续发展（图6）。

3.2 设计策略

3.2.1 净化湿地及湖体水质

为了改善现状水质状况，满足未来首启区的景观要求，设计团队以场地西侧进水方向为起点，利用现有鱼塘布局人工湿地净化带主轴，依次通过沉淀池－气浮一体化设备－生态塘－高效脱氮除磷生态滤池－表流湿地－水平潜流湿地－中心湖－生态溪流－清水池的流程，循环净化鉴洋湖水质[7]-[9]，预期达到人工湿地出水水质为地表水Ⅲ~Ⅳ类，中心湖透明度大于1m的水质净化目标。随后，通过涵管和局部破埂的方式，构建了三条换水支线，以保障全岛水系的水质健康与水位稳定，清水池内还布局有湿地内循环和排涝泵等设施，以保障排涝安全（图7）。

具体而言，首先利用沉淀池去除水中悬浮颗粒；初沉后，利用气浮一体化设备中投放的絮凝剂，吸附沉淀池中无法去除的胶体悬浮物；然后，流经生态塘、高效脱氮除磷生态滤池，在微生物、高效脱氮介质和少量PAM混凝剂除磷的作用下去除大部分COD和NH_3-N（图8）——由于当前鉴洋湖水总磷浓度与胶体物质浓度均居高不下，为保障前端中心湖体的水质效果，可根据水质特点精准少量投加PAM混凝剂，以减少对后端湿地处理环节的冲击。

经上述处理单元，水体内大部分主要污染物得以去除，而后再通过表流湿地、水平潜流湿地进行生态处理与净化。此时水质可达到地表水Ⅲ~Ⅳ类标准，作为景观用水进入中心湖，而后形成带状溪流，自出水口流出。出水口处的循环泵可以使水体从回输管道的多个出口处进入前端任意一个处理单元进行二次净化，从而减少净化步骤，节约运行成本。

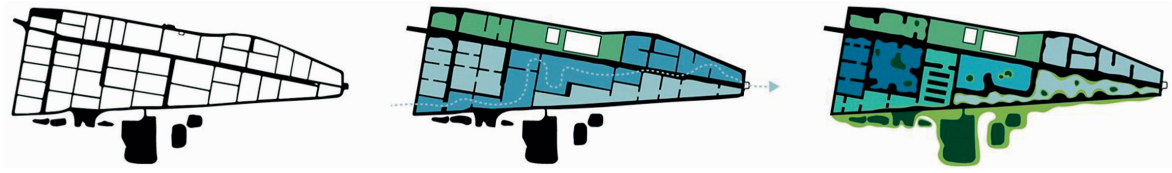
此外，项目团队还探索了一种兼具观赏性和生态功能、可灵活装配的实验性装置，并将其设置在生态塘内用于吸附悬浮颗粒物。此装置利用当地自

然石材和吸附材料（如氧化石墨烯、活性炭和火山石等碳质、生物质和天然矿物材料）[10]，制作成大小不一的吸附圆盘；再根据各类水体实际情况，选取吸附不同粒径的悬浮颗粒物所适宜的圆盘，形成多层的预制结构，创造出一种类似于荷花与荷叶造型的“水中花”装置（图9）。随着鉴洋湖湖水整体水质的持续优化，以及“水中花”悬浮颗粒物吸附装置的运行，可在后期逐步停止投加PAM混凝剂等化学药剂，达到动态优化湿地处理工艺流程的目的。

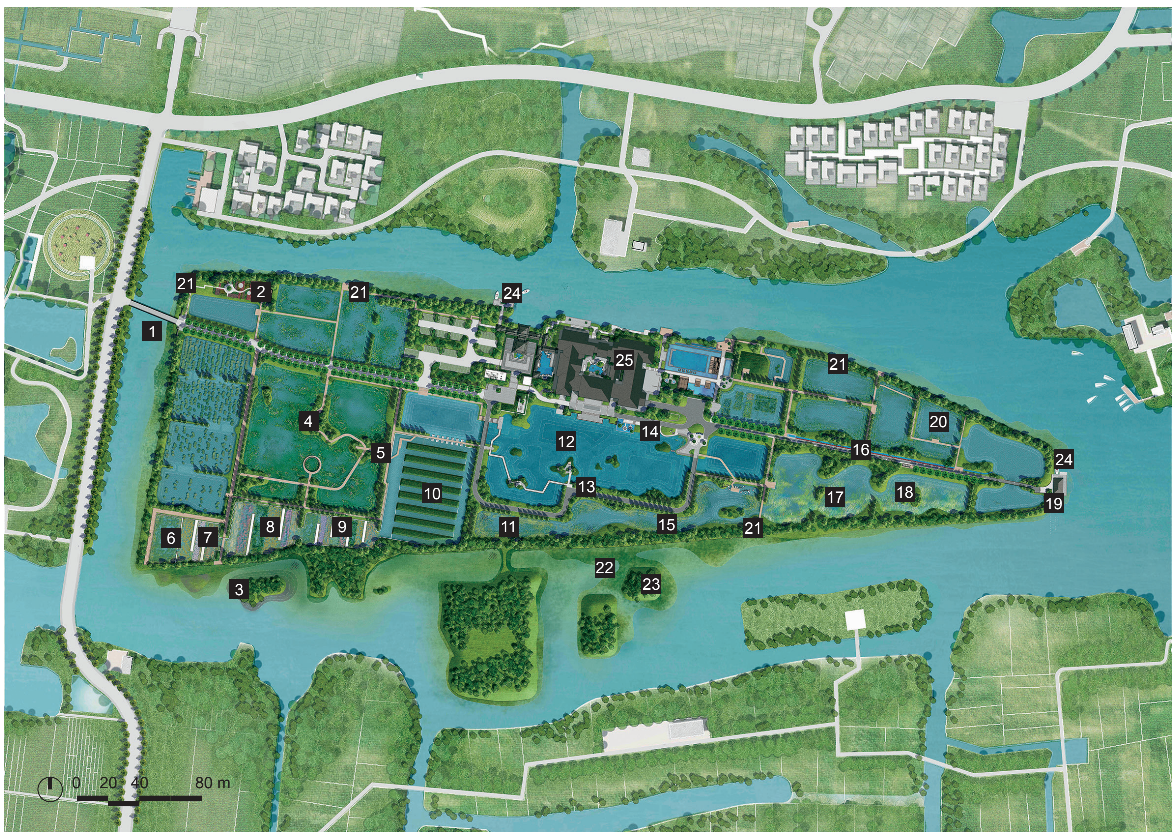
起初，项目团队试图利用场地内已有的水稻秸秆等可再生资源作为湖底填料/介质，建立已在江浙地区广泛用于水质净化的根孔湿地（图10）。具体工艺是在湿地土壤亚表层内埋植水稻秸秆，待其腐烂后，在湿地中形成人造根孔。这些人造根孔可为微生物提供良好的生长界面与条件，进而形成微生物膜，促进针对营养盐、有机污染物和重金属的植物吸收、微生物降解、物理吸附、化学分解和生物抑制等过程的进行。但是，由于施工工期和材料供应发生冲突，在后期实施阶段中，设计团队调整了工艺流程，在根孔湿地已有的空间形态的基础上，选用了已较成熟的湿地净化工艺——水平潜流湿地。水平潜流湿地由湿地植物种植床（选用场地既有的芦苇、香蒲等）和滤料基质层（取材自本地）组成，水流在滤料基质层表面下流动，沿水平方向渗滤经过湿地，从另一端的排水沟流出，进入中心湖。湿地植物根系和滤料基质的存在为湿地中的多种微生物提供了可附着的载体，在植物根系吸收、滤料基质吸附和微生物的生化反应的共同作用下，保障整体湿地处理流程的完善和稳定（图11）。

3.2.2 因地制宜构建多样生境

首启区采取保育为主、修复为辅的生态保护策略，构建了净化湿地缓冲区以及堤北圩田修复区、堤南浅滩修复区、堤顶林带保育区、农田修复区、荷塘修复区五大区域。考虑到人类活动产生的噪音对鹭鸟栖息造成的影响，依据对鹭鸟惊飞距离的文献研究[11][12]与现场测试，首启区内部主要人类活动场地和道路与堤南浅滩修复区中鹭鸟栖息地核心区之间的平均距离控制在50m以上，还设置了人工湿地净化带，作为鹭鸟栖息地的人为影响缓冲区；而首启区外侧的鉴洋湖水域则有效缓冲了城市建成区的交通噪声、建设活动等对场地的影响（图12）。

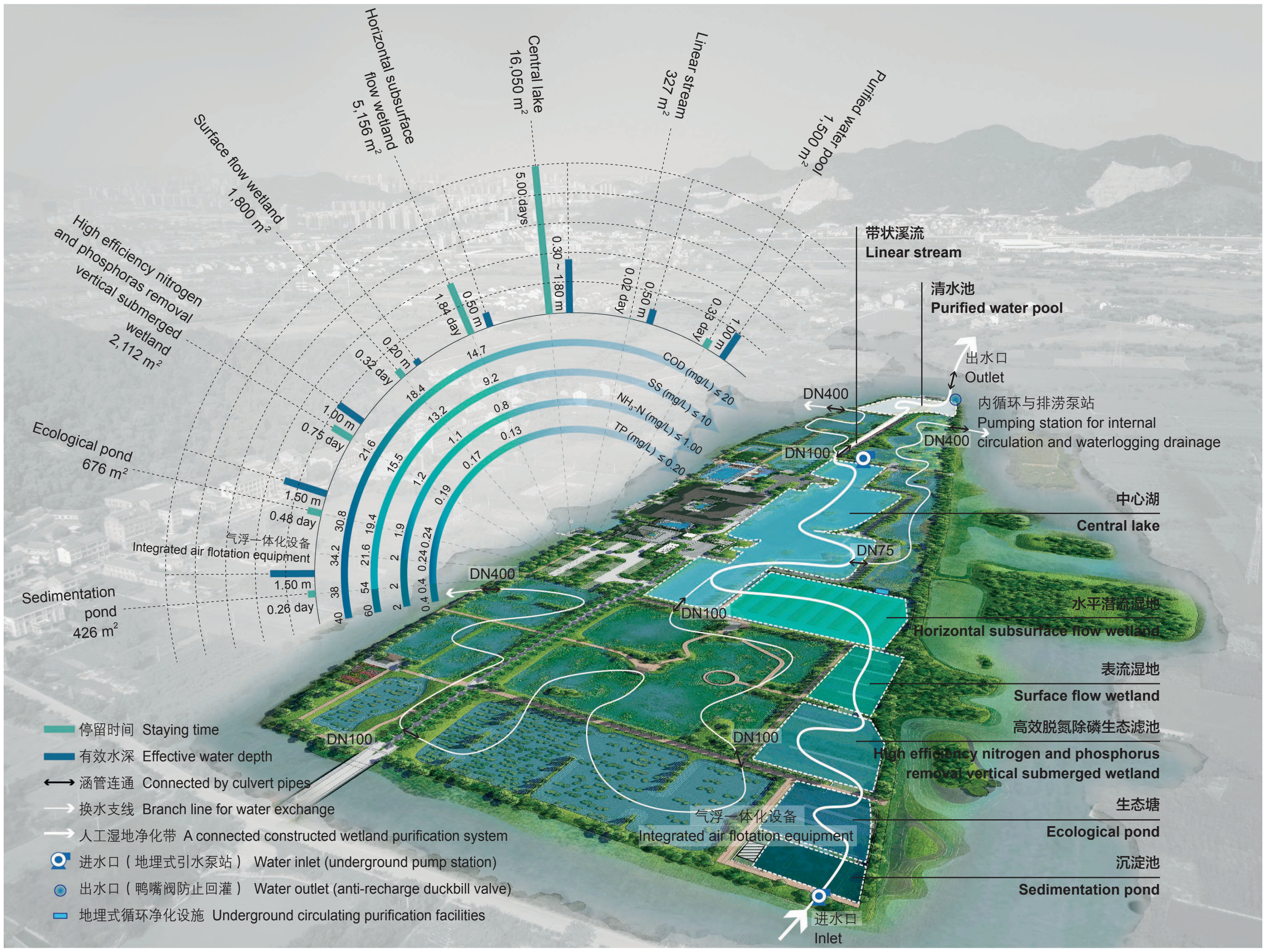


5. 圩田“保留-打破-整合”的设计概念
5. The design concept of "Retaining-Breaking-Integrating"



6. 总平面图
6. Site plan

1 入口景观桥 Landscape bridge (entrance)
2 香草园 Herb garden
3 门户鹭鸟石滩 Ardeidae shallow landmark
4 暖香观荷区 Lotus ponds
5 登高观景塔 Overlook tower
6 沉淀池 Sedimentation pond
7 生态塘 Ecological pond
8 高效脱氮除磷生态滤池 High efficiency nitrogen and phosphorus removal vertical submerged wetland
9 表流湿地 Surface flow wetland
10 水平潜流湿地 Horizontal subsurface flow wetland
11 鹭鸟觅食塘 Ardeidae foraging pond
12 中心湖（水下森林） Central lake (underwater forest)
13 湖心岛 Central island
14 滨水小广场 Waterfront square
15 砾石浅滩 Gravel shallows
16 生态溪流 Ecological stream
17 野趣芦苇荡 Reed marshes
18 湿地鸟岛 Bird island in wetlands
19 观湖平台 Viewing platform
20 清水池 Purified water pool
21 梗上观湖台 Observation platform
22 鹭鸟觅食区 Ardeidae foraging area
23 鹭鸟筑巢区 Ardeidae nesting area
24 水上码头 Dock
25 配套服务中心 Supporting service center



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7. 水处理设计示意图。鉴洋湖水从西侧进水口流入首启区，经过处理后进入中心湖，再从首启区东侧出水口回到鉴洋湖。

7. Water treatment circulation. The water of Jianyang Lake flows into the Start-up Area from the west inlet, enters the central lake after purifying treatment, and then returns to Jianyang Lake from the east outlet.

项目针对堤北圩田修复区和堤南浅滩修复区实施了不同强度的栖息地修复策略。

堤北圩田修复区全面实施缓坡岸线营造、水下地形改造和水生植被群落优化提升等措施。同时，将相互独立的现状圩田进行破埂连通，通过平衡湖底土方量，将约1.50m深的单一水深环境改造为0.10～2.00m不等的深浅交替的湿地水环境。设计用砾石堆出大面积水深低于0.30m的浅滩，在其中稀疏种植湿生草本植物并将其覆盖率控制在25%以内，在保证湿地自然风貌的同时，又保障了足够的鹭鸟停栖与觅食的滩地空间。针对鸦类鹭鸟偏好在成片的芦苇荡内躲避天敌及在乔木上筑巢的习性[3]，选择两处圩田空间种植芦苇，并在芦苇荡中建造乔木树岛，以吸引其在此栖居。（图13，14）

堤南浅滩修复区现状条件较好，包括阔叶林地、竹林和挺水植物带，因此以保育为主，同时在西部未种植植被区域通过局部改造水下地形形成浅滩和鸟岛（图15，16）。为应对鉴洋湖水位变化特征，项目团队营造了三种顶部标高各异的小岛，分别为砾石浅滩岛（顶部标高为1.80m，高于1.70m的鉴洋湖常水位0.10m）、草本植被岛（顶部标高为2.00m，高于常水位0.30m）和乔木树岛（顶部标高为2.50m，高于常水位0.80m）。各岛屿之间由深槽相连，这些深槽可作为冬季低水位时鱼类的逃生通道。

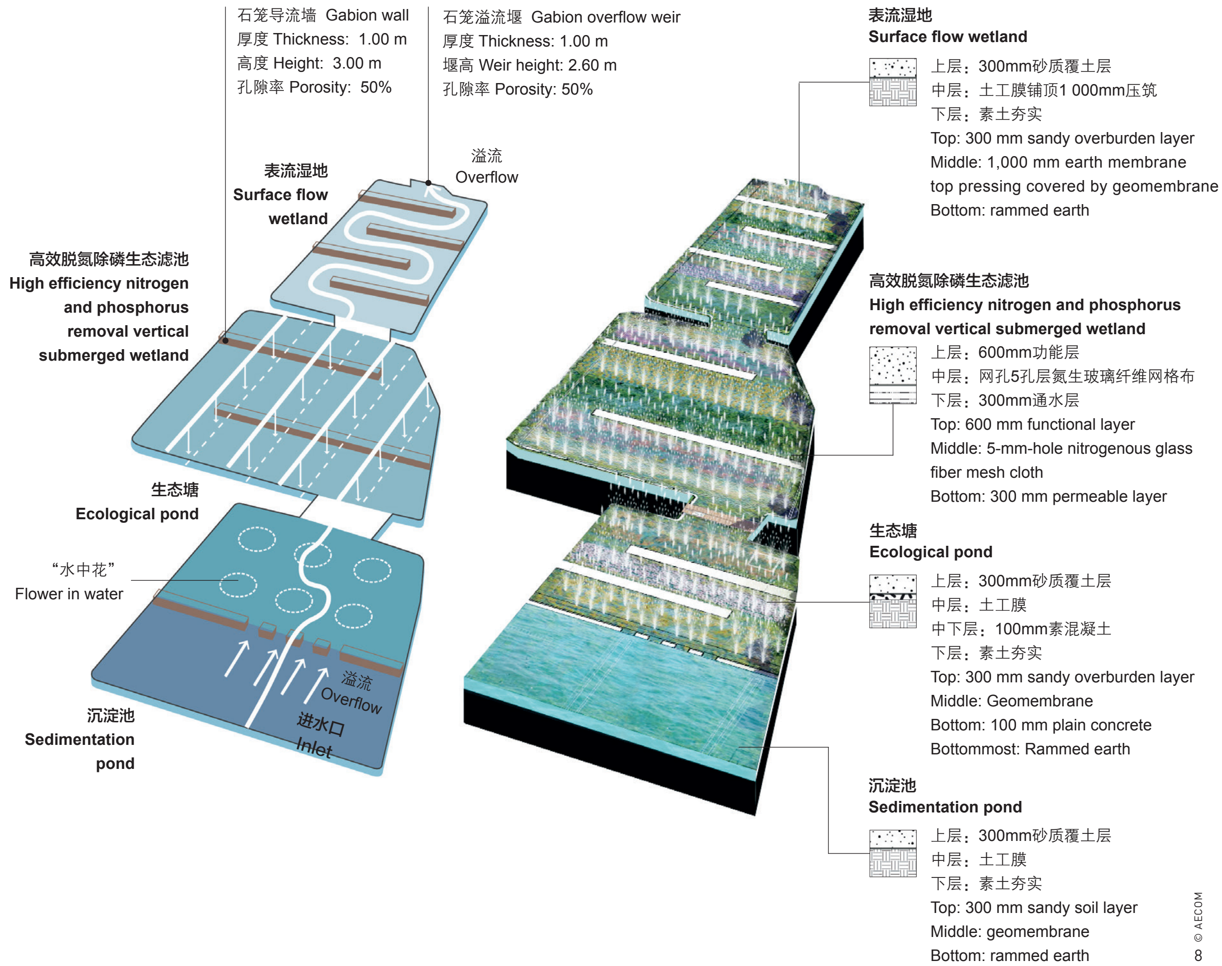
针对堤顶林带保育区，主要实施现状林地的保育。在农田修复区与荷塘修复区内，合理配植香樟、柑橘（*Citrus reticulata*）、栾树（*Koelreuteria paniculata*）等蝴蝶幼虫的寄主植物，海桐（*Pittosporum tobira*）、大花溲疏（*Deutzia grandiflora*）、野胡萝卜（*Daucus carota*）、胡颓子（*Elaeagnus pungens*）等蜜源植物，以及女贞（*Ligustrum lucidum*）、构树（*Broussonetia papyrifera*）、枸骨（*lex cornuta*）等鸟嗜植物。针对荷塘修复区的生态岸线，采取营造缓坡岸线、沿岸铺设大石块等生态修复措施，服务于游禽、林鸟、蝴蝶、两栖类等多种动物，以期恢复“中有沙洲芦荻，鸡鹳鸂鶒翔舞其际”的景象。

3.2.3 适应性措施应对气候变化

台州地区平均每年会受到2～3个台风的正面侵袭，随之而来的强降雨会增加当地的内涝灾害风险。鉴洋湖20年一遇与50年一遇暴雨的水位分别为3.70m和3.86m，现状场地外围堤岸标高基本达到4.10m，可达到50年一遇暴雨防护标准，使得场地内部形成一处相对独立的雨洪调蓄空间①。水文计算和基于ArcGIS软件的淹没区分析显示，在不设置排涝设施的情况下，场地在面临20年一遇、50年一遇和100年一遇的暴雨时，水位可分别达到3.05m、3.23m

和3.37m。然而，场地内大部分区域标高均在3m以下，连20年一遇的暴雨都难以抵御。于是，设计团队在湿地中引入排涝泵站，当实际水位超过设计水位2.20m（在常水位的基础上附加圩田本身提供的0.50m的雨洪调蓄空间）时，即启动强排泵站开始排涝，可将该区域内20年一遇、50年一遇和100年一遇暴雨时的最高水位分别降至2.73m、2.89m和3.02m，足以保障场地安全。其次，水岸带植物配植也充分考虑了耐淹特性。同时，场地内的配套建筑、景观服务设施与主要车行道路的标高均在3.90m以上，高于鉴洋湖50年一遇暴雨的水位标准。这些基础设施均充分考虑了不同降雨工况下的水位，并用ArcGIS进行了淹没范围分析核验——达到了即使是100年一遇的暴雨，亦可保证人员生命财产安全（图17）。

在极端干旱气候发生时，可通过连通管涵从鉴洋湖湖体取水进行生态补水，以避免由于首启区内部水塘水位下降而导致湿地植物，特别是沉水植物无法健康生长，以此来保障生态湿地系统的健康运转。



4 总结与反思

圩田湿地记录着早期生产的痕迹和智慧，也为鸟类提供了半人造半自然的生存环境。首启区采用大面积保留、局部区域打破、多层次整合的概念，来维护场地内既有地方特色又有文化特征的堤埂、植被以及荷塘。将作为人工湿地隔断的内部塘埂有组织地断开，这些剩余堤埂可用于场地内的人行步道，而多余的土方则堆积为多个中心湖内的绿岛。基于"保留－打破－整合"的设计理念建立起了湿地净化系统，并利用圩田和堤岸的高差打造鹭鸟栖息地，使其形态和鱼塘的肌理能够融为一体。2021年5月项目竣工后，已然创造出独具特色的"林－塘－田－湖－岛"复合的圩田湿地景观肌理。远处山峦与湿地交相辉映，结合场地内的湖、塘、堤，创造出丰富的景观层次以及独具魅力的湿地游览体验（图18）。随着首启区项目的逐步建设，这座城市湿地公园也逐渐完善了休闲娱乐、科普教育等功能，成为当地市民旅游观光的好去处。

此项目基于NBS理念，实施了低影响的修复策略。初期，项目团队试图通过布局人工湿地净化带主轴、构建根孔湿地、引入"水中花"物理吸附装置等方式，建立一套湿地自净机制，并逐步减少混凝剂的人工投放。此外，设计团队还在空间设计上进行了一定留白，使栖息地环境能够随着时间的推移逐渐演替、完善，回归自然的本真面貌。

虽然由于项目施工季节原因，根孔湿地因原料不足最终未能落实而替换为了水平潜流湿地，但已有部分监测或观察结果显示出场地修复后的生态效益。2021年5~7月的水质监测平均数据表明，场地出水水质已从原来的劣V类提升至优于Ⅲ类标准的状态（图19～21）。其中，COD从西侧进水口水体的40mg/L降至20mg/L，NH_3-H在潜流湿地处检测值为0.05mg/L，远低于Ⅲ类地表水标准。到7月底现场回访时还发现，在首启区塘埂处以及首启区堤埂两侧的鉴洋湖滩地上已观测到白鹭（*Egretta garzetta*）、大白鹭、池鹭、黑水鸡等物种的身影，它们在施工结束后的第一时间便回归了场地。设计团队后续还将通过持续监测场地情况来不断调整鸟类栖息地的布局，以适应鸟类在不同季节的栖息习性以及未来不确定的气候变化因素。现阶段的研究表明，这种以NBS为基础的新理念和方法在生态实践中可以有效应对全球环境和气候变化的挑战，保护生物多样性，推动实现低碳发展的目标。**LAF**

项目信息

项目地址：中国浙江省台州市
项目面积：16hm^2
项目委托：宁波开投蓝城投资开发集团有限公司
景观设计：艾奕康上海景观团队
生态设计：艾奕康上海生态与水务团队
建筑顾问：Thomas Young
设计团队：陶练、熊斯顿、严伟、周绩、董颖、刘晓丹、唐海玉、许君君、陈宜宁、余婷婷、Orlando Kalinisan、石逸航、荆贝贝、徐建、李熠飞、叶紫葳、贝诗彧、程翊欣、刘迪暄、薛舒文
合作团队：诚邦设计集团有限公司、杭州绿风生态旅游规划设计研究院有限公司
设计时间：2019~2020年
建成时间：2021年

① 相关数据由黄岩区水利局提供

8. 湿地净化部分流程示意图：沉淀池-生态塘-高效脱氮除磷生态滤池-表流湿地。

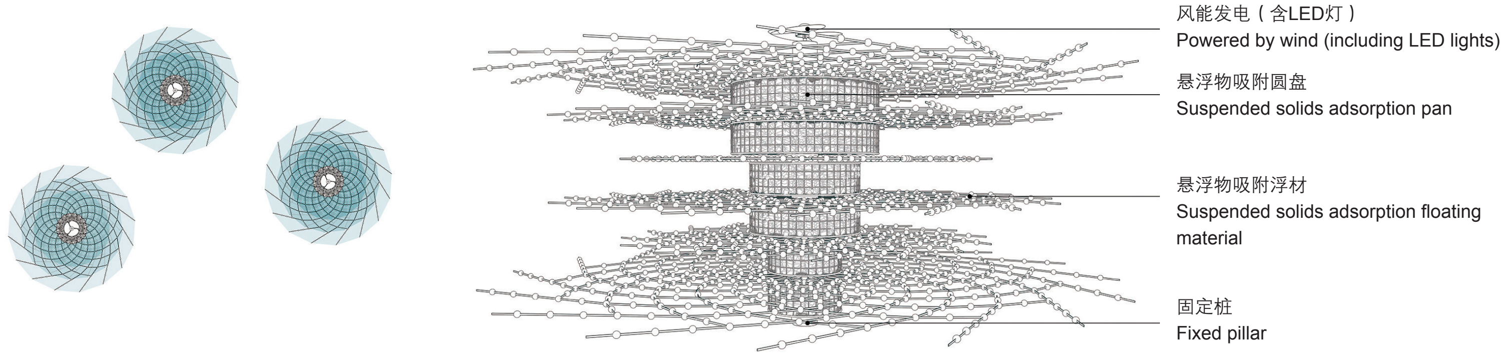
8. Part of the wetland purification process includes sedimentation pond, ecological pond, high efficiency nitrogen and phosphorus removal vertical submerged wetland, and surface flow wetland.

1 Background

Jianyang Lake, located in Huangyan District, Taizhou City, Zhejiang Province, China, is a core node on one of the city's main green corridors. As a part of the Wenling-Huangyan Plain with reticular river network, the lake is surrounded by wetlands and farmlands. *The Huangyan County Annals* has recorded the picturesque scenery of Jianyang Lake in the Qing Dynasty (1636-1912): "Enjoying an total area of 1.32 km^2, 2.5 km in length and 0.5 km in width, Jianyang Lake under the Jilong Mountain is known as one of the biggest lakes in southeast China of Guangxu Reign; The sandbank there covered by reeds is a paradise for waterbirds."[1] Since 1905, part of the lake has been reclaimed to mulberry-fish ponds; After 1949, the site was further transformed into labor farms and fish nurseries. These histories shaped the fishing and agricultural landscape formed by a series of productive wetlands. Nowadays, Jianyang Lake and the surrounding woodlands and farmlands provid habitats and sufficient food for Ardeidae and other species. However, the lake is facing with challenges from the reduced water surface, habitat degradation and water pollution caused by years of siltation and urban sprawl. In 2009, the local government issued the Master Plan of Jianyang Lake Urban Wetland Park in Taizhou, Huangyan and strictly developed the site according to the Plan to enhance the ecological resources and environment, facilitating the park's approval as a National Urban Wetland Park. To promote supporting service facilities of the wetland park and set an examplar for the long-term development, a 16 hm^2 Start-up Area was launched in 2018, supported by Taizhou Municipal Government and Ningbo Kaitou

9. 这种去水体悬浮物生态艺术装置被设计为“水中花”的形式，兼具观赏性与生态功能。
10. 根孔湿地处理基础工艺
11. 调整后的水平潜流湿地

9. The ecological art installations "flower in water" have both ecological function of adsorbing suspended solids and the aesthetic performance.
10. Prototype of the root-hole wetland treatment system
11. Updated horizontal subsurface flow wetlands



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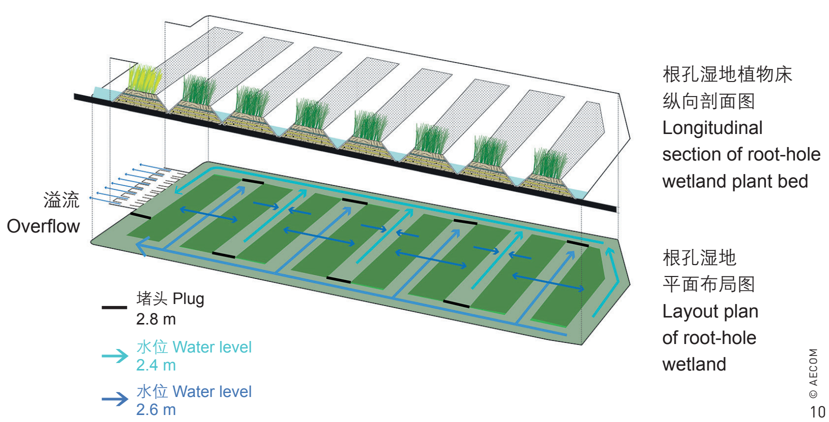

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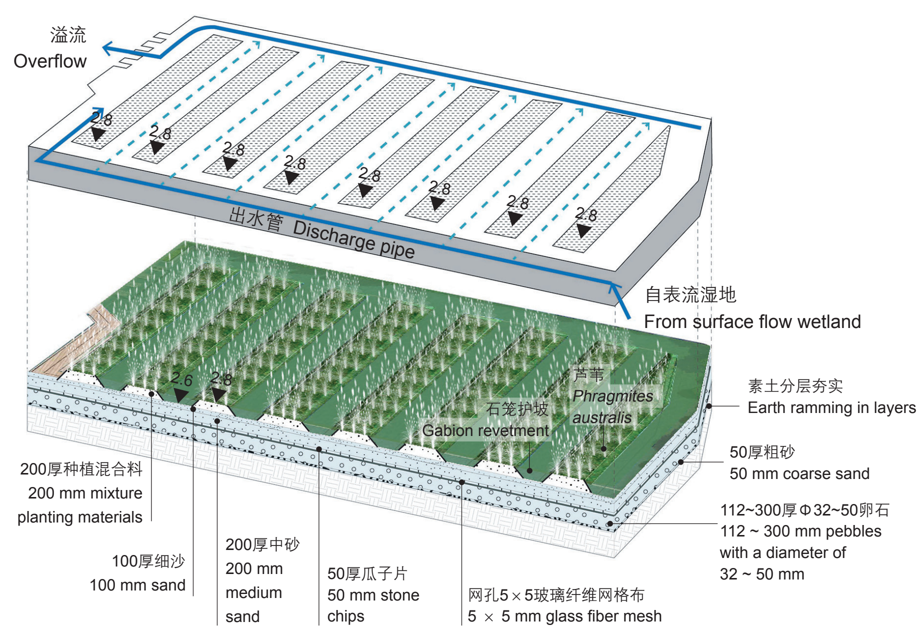

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Bluetown Investment and Development Group Co., Ltd. (Fig. 1).

2 Site Analysis

2.1 Diverse Land Use

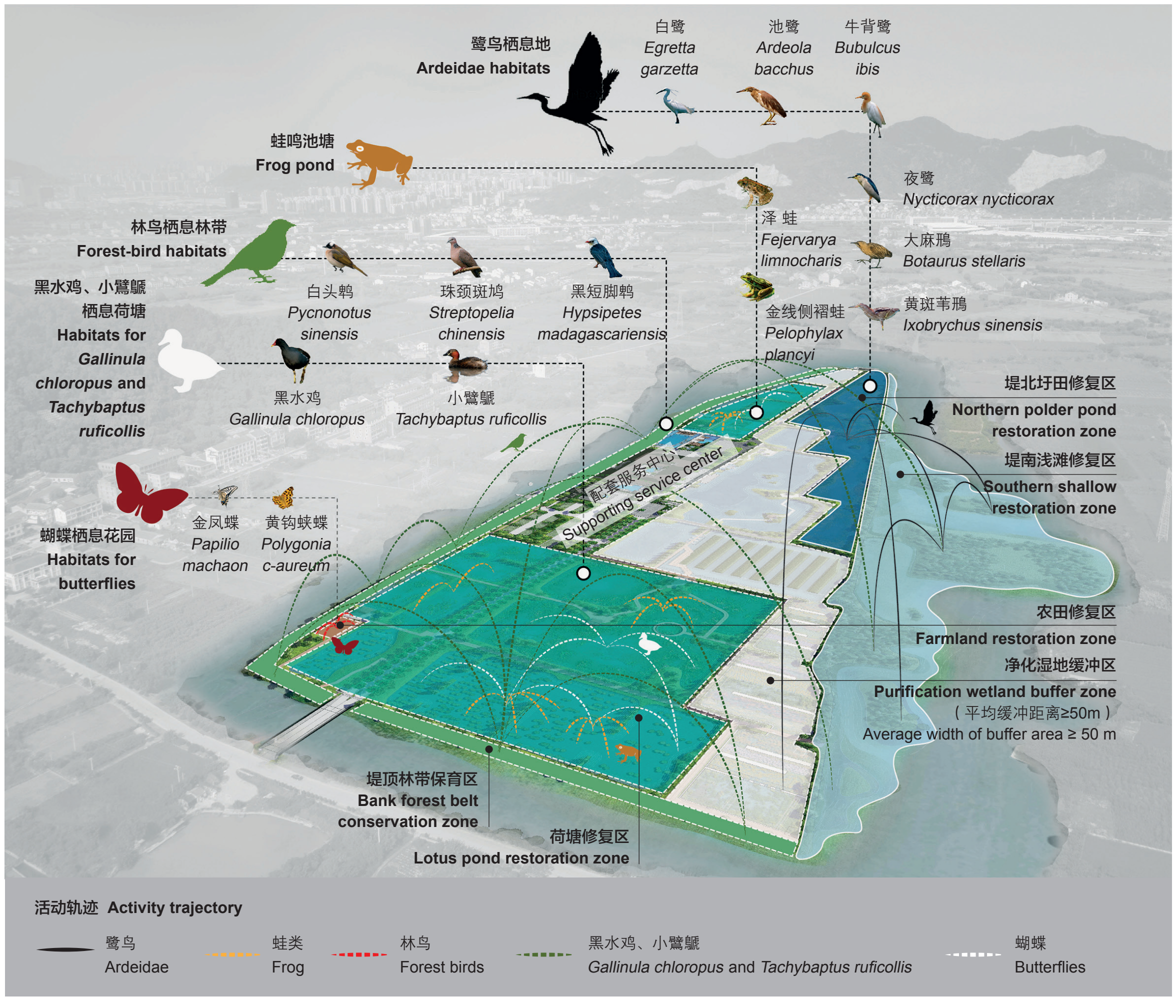
Years ago, about half of the land in the Start-up Area was ponded to cultivate fish fry, forming the existing triangular polder area. Although the aquiculture industry there has been called off, most of the ponds were remained, creating a typical polder landscape together with the surrounding woodlands, lakes, wetlands, and farmlands (Fig. 2, 3).

The previous fisheries left some historical problems: 1) Fuzzy site texture, formed by artificial pond network dotted with disorganized buildings, trails, and other service facilities; 2) Severe water pollution and aquatic habitats destruction, caused by the eutrophic pond with overloaded organic matter, nitrogen and phosphorus nutrients in the bottom mud, as well as deficient dissolved oxygen in the water, resulting the water in serious pollution as the surface water Class V or inferior Class V according to the China Environmental Quality Standard for Surface Water; 3) Non-interacting landscapes, composed of the prefabricated-concrete-slabs-covered riverbank which were difficult for plants to grow and animals to stay.

Nevertheless, there were still apparent advantages, including lush vegetation on the north and south mountains, high-yield lotus ponds and productive wetlands with rice planting area on the west, and well-grown trees surrounding the polders.

2.2 Biodiversity of Ardeidae

The Investigation Report on the Biodiversity of Jianyang Lake Wetland in Taizhou and the additional on-site study revealed that there were 114 species of animals in the lake area, including 42 species of birds (account for 10.12% of the total bird species in southeastern



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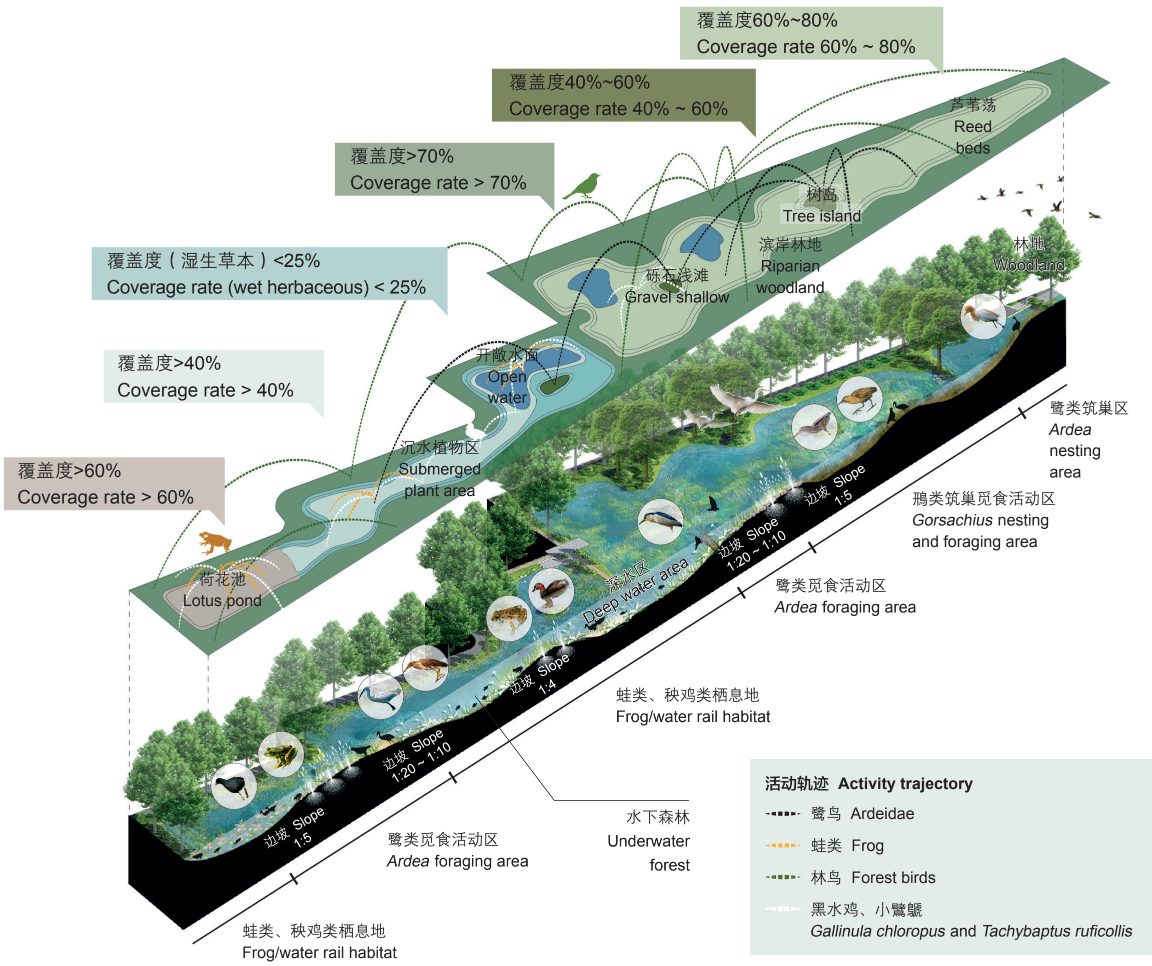
12. 场地被划分为5个生境修复区和一个净化湿地缓冲区

12. The site was composed of five restoration zones and a purification wetland buffer zone

Zhejiang), and many mammals, amphibians and reptiles, and insects[2]. The biodiversity of Ardeidae is one of the characteristics of the site—there were 18 species of Ardeidae e.g. *Ardea* and *Gorsachius* in the Central China of the Oriental Realm where Jianyang Lake located, nearly reaching the total number of 20 across China[3].

In the Start-up Area, the existing ridge woodlands, bamboo forests, and wetland habitats were well conserved, with a variety of water birds and forest birds inhabiting in. Trees (e.g. *Celtis sinensis*, *Cinnamomum camphora*, *Broussonetia papyrifera*, and *Mallotus japonicus*) on the polder ridges, as well as the lush emergent vegetation e.g. *Phragmites australis* and *Typha orientalis* in the riparian area and the wetlands, were all high-quality ecological resources to be conserved, which provided Ardeidae with habitats to forage, nest, breed, and shelter[4] (Fig. 4).

However, the steep hardened bank and the lack of shallow water limited the Ardeidae's resting and foraging activity. Only a few water birds e.g. *Gallinula chloropus* and *Tachybaptus ruficollis* were found in the deep water area. Meanwhile, noise from the construction of main roads and supporting service buildings also undermined the habitat conservation, especially during the Ardeidae's breeding period from April to July[3].



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13. 针对堤北圩田修复区实施缓坡岸线营造、水下地形改造和水生植被群落优化提升。

13. In the northern polder pond restoration zone, strategies of sloping the shoreline, reshaping the underwater topography, and optimizing the aquatic vegetation communities were proposed.

3 Design Proposal

3.1 Design Concept

Based on the site analysis, designers proposed the concept of “Retaining–Breaking–Integrating” to maximize the ecological benefits through minimal interventions (Fig. 5), following the principles of wetland construction raised by the responsible national ministries of China: “giving priority to conservation while highlighting scientific restoration, moderate development, and rational utilization.”[5] The concept also introduced the initiative of Nature-Based Solutions (NBS) which “rely on the ability of the ecosystem to self-regulate and self-organize, to evolve in an orderly direction; or employ the self-repairing ability of the ecosystem, supplemented by artificial measures, to gradually restore the damaged ecosystem or sustainably develop the ecological system.”[6] To be specific, retain the lush peripheral banks of the whole polder area which prevented the site from storm and some internal pond ridges; then, break other ridges to lengthen the flowing route through the wetlands and promote the water fluidity; at last, integrate the interconnected ponds into a vast central lake. In this project, rather than reshaping the historical productive wetland into a new “natural texture” through artificial high-fill embankment, the design team took advantages of the ecological foundation and wisdom of the polder wetland, and embed the wetland purification system into the existing texture, to restore the shallow habitat by the establishment of the root-hole wetland system.

As time goes on, the newly-planted aquatic plants will grow along the wetland texture, inspiriting the polder wetland with new vitality and achieving the sustainable development (Fig. 6).

3.2 Design Strategies

3.2.1 Wetlands and Lake Water Purification

In order to improve the water quality and landscapes in the Start-up Area, the design team introduced a purification system based on existing ponds. The lake water flow into the site from the west inlet, and then was purified by sedimentation pond, integrated air flotation equipment, ecological pond, high efficiency nitrogen and phosphorus removal vertical submerged wetland, surface flow wetland, and horizontal subsurface flow wetland successively, and subsequertly supplied water for the landscape lake, ecological stream, and purified water pool[7]~[9]. The water quality at the outlet of the subsurface flow wetland was expected to be surface water Class III ~ IV and the water transparency of the landscape lake to be more than 1 m. Besides, by laying culvert pipes and breaking certain ridges, three branch lines for water exchange were constructed to ensure water quality and the stability of water level. The waterlogging was avoided by the pumping station of internal circulation and waterlogging drainage equipped in the purified water pool (Fig. 7).

The specific steps are explained as follow. First, suspended solids were deposited in the sedimentation pond while the colloidal suspended was adsorbed by the flocculant put in the integrated air flotation equipment.

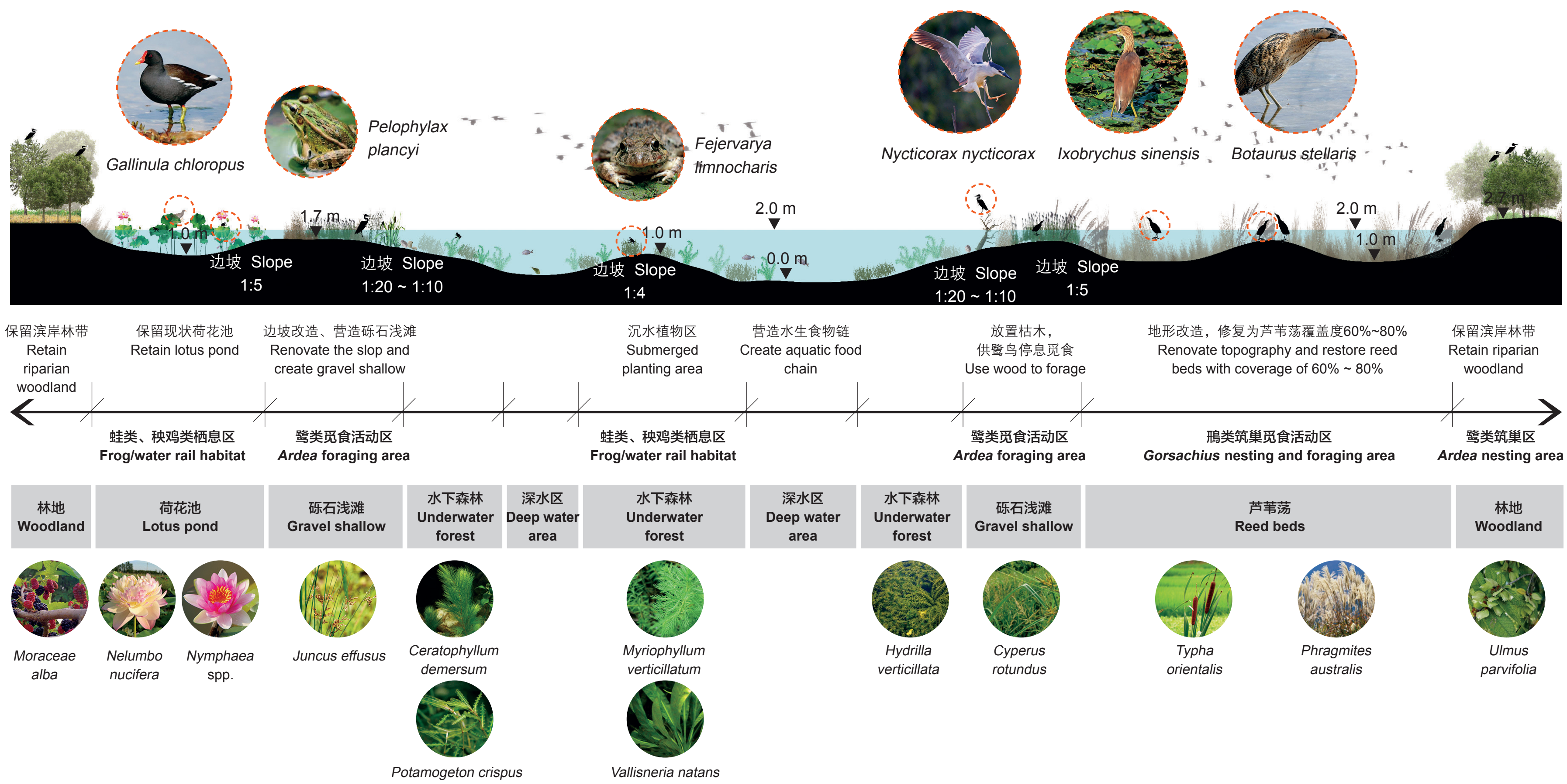
Then, most of COD and NH_3-N can be removed by microorganisms, high-efficiency denitrification media, and a small amount of PAM coagulant (for phosphorus removal) in the ecological pond and the high-efficiency nitrogen and phosphorus removal vertical submerged wetland (Fig. 8). Considering the high concentration of the total phosphorus and colloidal substance in Jianyang Lake, PAM coagulant should be added moderately, to relieve the load of following wetland treatment processes and keep the high water quality of the central lake.

Most of the water pollutants could be removed through above treatment processes. After a further ecological treatment and purification in the surface flow wetland and horizontal subsurface flow wetland, the water entered the central lake with a surface water standard of Class III ~ IV, and then formed a ribbon stream discharging into the Jianyang Lake through the outlet. The circulating pumps installed in the outlet enabled the water to flow back to a certain treatment unit through the corresponding circulating pipeline and engage to a retreatment. The simplified purification steps could save the running cost.

Furthermore, the team introduced a series of experimental installations with both ecological function of adsorbing suspended solids and aesthetic performance in the ecological pond. The installation was formed by layers of adsorption pans in different sizes made of carbonaceous, biomass, and natural mineral materials (e.g. graphene oxide, activated carbon, and pelelith), and other local natural stones and adsorption materials[10]. The vertical distribution of each pan on the axial pillar could be dynamically adjusted according to the location and sizes of the suspended solids. The name "flower in water" was raised from its appearance as blooming lotus with stretching leaves (Fig. 9). With the continuous improvement of the lake water quality and the introduction of the "flower in water" installations, less chemical agents such as PAM coagulant are going to be used at the later stage, gradually optimizing the wetland treatment processes.

Initially, the design team expected to establish the root-hole wetlands which have been widely applied for water purification in Jiangsu and Zhejiang regions by using renewable materials found on the site e.g. rice straws as

14. 破埂连通后的堤北圩田修复区剖面图
14. Section of the northern polder restoration zone after ridge break



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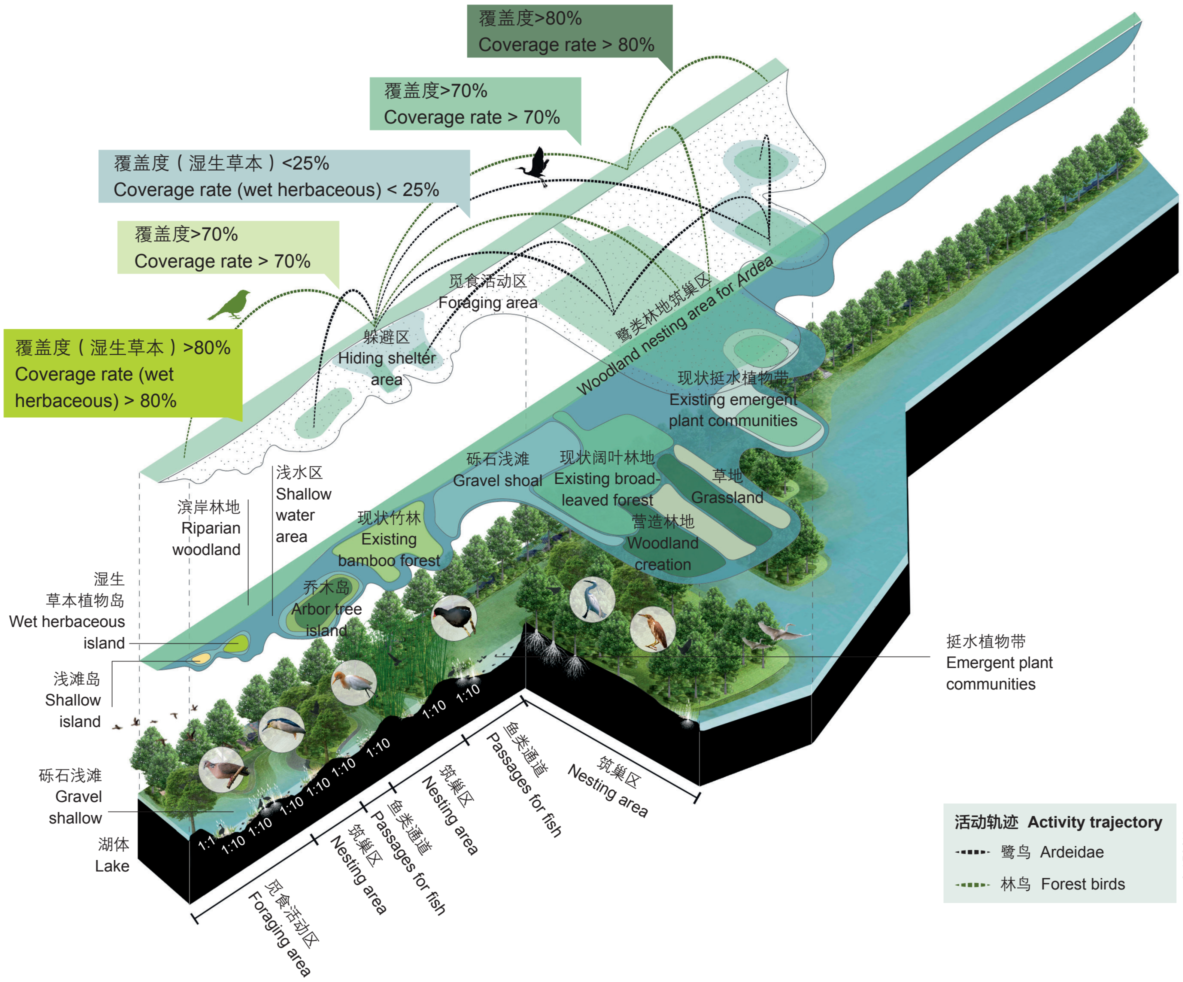

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the bottom filler/media (Fig. 10). The rice straws could bury in the subsurface soil of the wetlands would leave artificial root holes after decay, optimizing the habitats of microorganisms and formation of biofilms, and further promoting plant absorption, microbial degradation, physical adsorption, chemical decomposition, and biological inhibition of nutrients, organic pollutants, and heavy metals. Due to a lack of materials during the construction period, the wetland adjusted into the horizontal subsurface flow wetland, a mature technology, copied the space form of root-hole wetland. Such wetland consists of wetland vegetation planting bed (selected the on-site plants such as *Phragmites australis* and *Typha orientalis*) and filter substrate layer (sourced locally) with water flow underneath—which horizontally passes the vegetation into the central lake. As the carriers of microorganisms in the wetland, the plant roots and the filter substrate could absorb and filter the pollutants, as well as produce the biochemistry reaction of the microbe, to ensure the improvement and stability of the overall purification process (Fig. 11).

3.2.2 Diverse Adaptive Habitats Construction

The Start-up Area was mainly composed of purification wetland buffer zone and five restoration zones (northern polder pond restoration zone, southern shallow restoration zone, bank forest belt conservation zone, farmland restoration zone, and a lotus pond restoration zone) echoing the proposed ecological protection strategies of giving priority to conservation while supporting by restoration. Based on the literature study[11][12] and on-site testing on flight initiation distance of Ardeidae, the core Ardeidae habitats in the shallow area of the south bank was kept 50 m away in average from the main activity spaces and roads. The lake water surrounding the site served as a natural buffer to mitigate the intervention of traffic noise human access and construction works from the urban build-up area (Fig. 12).

Strategies with varied restoration intensities were adopted to the habitats of the northern polder pond restoration zone and the southern shallow restoration zone.

The northern polder pond restoration zone fully implemented various strategies, e.g., constructing gently sloping shorelines, reshaping the underwater topography, and optimizing the aquatic vegetation communities. Meanwhile, by breaking the ridges between the ponds and balancing the earthwork, the design team integrated those once independent ponds, 1.50 m deep, into a whole water body with varied water depths from 0.10 m to 2.00 m. Furthermore, gravels were used to pile up a large area of shallows with a water depth of less than 0.30 m. No more than 25% of the shallows was covered by herbaceous hygrophytes, to balance the natural landscapes of the wetland and habitats for Ardeidae in the shallows to rest and forage. Considering the behaviors of *Gorsachius* spp. that hide from their natural enemies in the reeds and nest on arbor trees, the design team constructed reed marshes in two selected ponds and created an arbor tree island inside (Fig. 13, 14).

In the southern shallow restoration zone with rich natural resource such as broad-leaved forests, bamboo forests, and emergent

15. 堤南滩地修复区以生态保育为主，同时通过局部改造水下地形营造了浅滩和鸟岛。

15. In the southern shallow restoration zone, the priority of conservation was highlighted through limitedly reshaping of the underwater topography and creating of the shallows and bird islands.

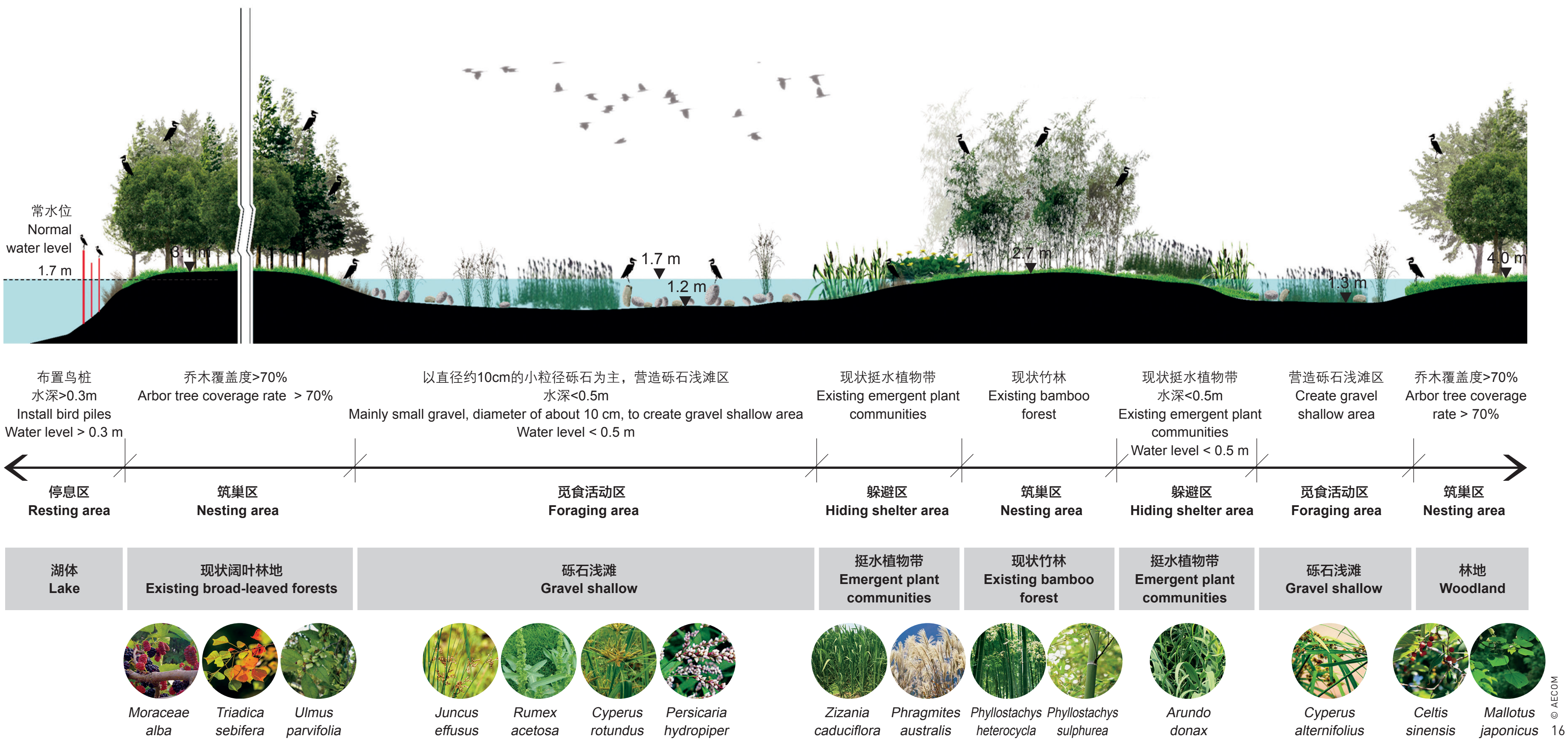
plant communities, the priority of conservation was highlighted. The design team limited the reshaping of the underwater topography to the western bare lands, creating a series of shallows and bird islands (Fig. 15, 16). Considering the water level fluctuation of the Jianyang Lake, three types of islands, the gravel shallow island, the herbaceous vegetation island, and the arbor tree island, were proposed, with elevations of 1.80 m, 2.00 m, and 2.50 m respectively, higher than the normal water level of Jianyang Lake (1.70 m). Deep trenches connecting each two islands could serve as the escape passages for fish during the low water level periods in winters.

Existing forest in the bank forest belt conservation zone was conserved, while host plants for butterfly larvae (e.g. *Cinnamomum camphora*, *Citrus reticulata*, and *Koelreuteria paniculata*), nectariferous plants (e.g. *Pittosporum tobira*, *Deutzia grandiflora*, *Daucus carota*, and *Elaeagnus pungens*), and ornithophilous plants (e.g. *Ligustrum lucidum*, *Broussonetia papyrifera*, and *lex cornuta*) were introduced into the farmland and the lotus pond restoration zones. Additional ecological strategies like constructing gently sloping shorelines and laying large slabs along the shore were applied to the lotus pond zone, which serve a variety of animals e.g. birds, butterflies, and amphibians to represent the scenario described in the *Huangyan County Annals* over a century ago.

3.2.3 Adaptive to Climate Change

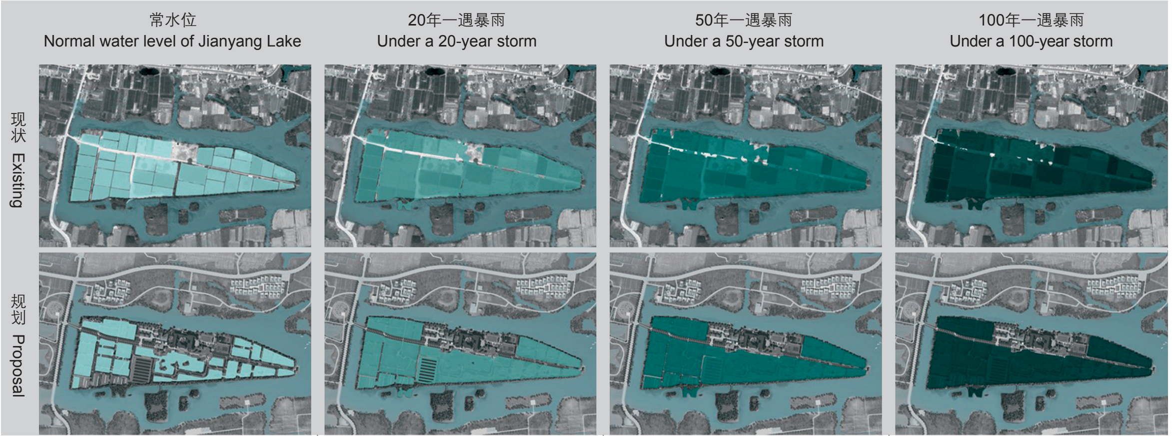
On average, Taizhou is affected by two to three typhoons every year which, together with the subsequent heavy rainfall, increases the risk of waterlogging. The peripheral banks of the site with an elevation of 4.10 m can prevent the Start-up Area from the 20-year storm and the 50-year storm with a water level of 3.70 m and 3.86 m respectively and create a relatively independent stormwater regulation and storage system①. Hydrological calculations and hydrologic analysis on ArcGIS revealed that without drainage facilities, the storm water levels can rise to 3.05 m, 3.23 m, and 3.37 m, when the site suffers from a 20-year, 50-year, and 100-year storm respectively. That is to say, almost all of the Start-up Area would be inundated by then as most elevations on the site were below 3 m. To relieve the waterlogging, the design team introduced drainage pumps into the wetlands. When raising over the design water level of 2.20 m (the additional 0.50 m over the normal water level is offered by existing stormwater regulation

① The data are provided by Huangyan District Water Resources Bureau



16. 堤南滩地修复区剖面图

16. The sectional view of the southern shallow restoration zone



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17. 设计前后的淹没范围
18. 即将竣工的首启区中保留的荷塘林地、人工湿地、鹭鸟栖息地和服务设施与周边景观融为一体。

17. Inundation range before and after design
18. The Start-up Area with reserved lotus ponds, woodlands, constructed wetlands with Ardeidae habitats, and service facilities, was in harmony with the surroundings.

and storage system), the pumps start working to lower the water level to 2.73 m (a 20-year storm), 2.89 m (a 50-year storm), and 3.02 m (a 100-year storm). The waterlogging resistance was highlighted in the waterfront vegetation. The elevations of the buildings, serrice facilities, and main roads are all above 3.90 m, much higher than the water level of a 50-year storm. Based on the ArcGIS analysis of inundated areas under different rain conditions, it was verified that even facing with a 100-year storm, the proposed elevation of the infrastructures could ensure the safety of human life and property (Fig. 17).

When suffering from an extreme drought, water could be supplied from Jianyang Lake to the site through pipe culverts, to ensure the survival of the wetland plants, especially submerged plants, and the well-function of the ecological wetland system.


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4 Summary and Performance

The polder wetlands recording the industry history of the site and human wisdom provided a semi-natural habitat for birds. The concept of largely retaining existing condition, partly breaking the ridges, and integrating the ponds from multi-levels, adopted in the Start-up Area, was to maintain the banks, vegetation, and lotus ponds with both local and cultural features. Some of the ridges were broken to interconnect the wetlands, leaving enough earthwork to construct vegetated islands in the central lake; the remaining unbroken ridges could be used as pedestrian pathways. Based on the design concept of “Retaining–Breaking–Integrating,” a wetland purification system was established. Taking advantages of the height difference between the polders and the banks, habitats for Ardeidae which successfully blend into existing texture were further created. When the project was completed in May 2021, a new texture of the wetland landscape composed of forest, pond, farmland, lake, and island was formed, which echoes each other and attracts visitors (Fig. 18). With the construction of the Start-up Area, multi-functional wetland park gradually develops into a recreation and scientific education center for local residents to travel.

The concept of NBS was highlighted in the low-impact restoration project. At the initial stage, the design team set up a constructed wetland purification system, established the root-hole wetlands, and introduced the "flower in water" adsorption installation, to create the wetland self-purification mechanisms. As time goes on, there would be less and less human intervention (like delivering PAM) to the site, leaving the animals and plantings in the habitats to evolve spontaneously, cover the reserved no-design areas, and represent its original natural state.

Unfortunately, the root-hole wetlands have not been constructed and were substituted by the horizontal sub-surface flow wetlands, due to the shortage of the raw materials in a wrong season. But the performance of the wetland purification system has been demonstrated by on-site monitoring and observation. For example, the effluent water quality of the Start-up Area was found achieved surface water Class III standard according to the average data monitoring from May to July, 2021 (Fig. 19 ~ 21). Specifically, COD in the influent water Start-up Area decreased to 20 mg/L from 40 mg/L, and NH_3-H in the subsurface flow wetland is 0.05 mg/L, perfectly meeting the Class III standard. Furthermore, an on-site observation at the end of July has found *Egretta garzetta*, *Egretta alba*, *Ardeola bacchus*, *Gallinula chloropus* on the bank forest belt conservation zone, northern polder pond restoration zone and southern shallow restoration zone—they have returned to the site soon after the project's completion. In the future, the layout of bird habitats will be adjusted to adapt to the seasonal habits of birds and uncertain climate changes through continuous monitoring. Current studies have indicated that the newly-developed concept and strategies of NBS, can effectively respond to the challenges of global environment and climate change, protect biodiversity in ecological practice, and achieve the low-carbon development visions. **LAF**

PROJECT INFORMATION

LOCATION: Taizhou City, Zhejiang Province, China
AREA (SIZE): 16 hm^2
CLIENT: Ningbo Kaitou Bluetown Investment and Development Group Co., Ltd
LANDSCAPE DESIGN: Landscape Team of AECOM Shanghai
ECOLOGICAL DESIGN: Ecological and Water Team of AECOM Shanghai
ARCHITECTURE CONSULTANT: Thomas Young
PROJECT TEAM: Tao Lian, Xiong Sidun, Yan Wei, Zhou Ji, Dong Ying, Liu Xiaodan, Tang Haiyu, Xu Junjun, Chen Yining, Yu Tingting, Orlando Kalinisan, Shi Yihang, Jing Beibei, Xu Jian, Li Yifei, Ye Ziwei, Bei Shiyu, Cheng Yixin, Liu Dixuan, Xue Shuwen
COLLABORATORS: ChengBang Design Group Co., Ltd; Hangzhou Greenwind Ecotourism Planning and Design Institute Co., Ltd
DESIGN PREIOD: 2019 ~ 2020
COMPLETED TIME: 2021

REFERENCES

[1] Li, C. (n.d.). *Huangyan County Annals*. Retrieved from https://bookinlife.net/book-207405-viewpic.html#page=1
[2] Jianyang Lake Administration Committee. (2008). *Survey of wetland biodiversity in Jianyang Lake, Taizhou*.
[3] Zhu, X., & Zou, X. (2001). *The Herons of China*. Beijing, China: Chinese Forestry Publishing House.
[4] Yan, S., Zhu, X., Yu, Y., & Shen, Y. (2007). The Practical Research on Designing of Urban Green Space for Attracting Birds—A Case Study on Designing of Longshan City-style Heron Habitat in Changxing County. *Planners*, 2(32), 46-49. doi:10.3969/j.issn.1006-0022.2007.02.013
[5] National Forestry and Grassland Administration. (2008). *Construction Regulation of National Wetland Park*. Beijing, China: Standards Press of China.
[6] The Nature Conservancy. (2021). *Nature-based Solutions Research and Practice*. Beijing, China: China Environment Press.
[7] Sun, J., Li, Y., Zhang, Y., Zhang, P., & Cai, Y. (2021). A Review of Ecological Restoration Effects on Water Pollution by Cascade Constructed Wetlands. *Environmental Protection Science*, 47(4), 24-29. doi:10.16803/j.cnki.issn.1004-6216.2021.04.004
[8] Ministry of Ecology and Environment of the People's Republic of China. (2021). *Technical Guide for Constructed Wetland for Water Deep Purification*. Retrieved from http://www.szguanjia.cn/article/1661
[9] Liu, L., Lim J., Ke, F., Li, W., & Hou, C. (2018). The Application of Lakeshore Raised Constructed Wetlands in Agricultural Non-point Source Polluted River Water. *Journal of Anhui Agricultural Science*, 46(19), 83-87. doi:10.13989/j.cnki.0517-6611.2018.19.025
[10] Jiang, H., Xie, S., Liu, Y., Yu, Z., & Xia, Q. (2018). Spatial Distribution of Particle Size of Suspended Particulate Matters in Poyang Lake During Wet Season. *Journal of Nanchang Institute of Technology*, 37(6), 43-47.
[11] Zhang, L., & Zhang, J. (2020). Wetland Park Design for Habitat Restoration—Case Study on the Qinghua Wetland in Baoshan, Yunnan Province. *Landscape Architecture Frontiers*, 8(3), 90-101. https://doi.org/10.15302/J-LAF-1-030016
[12] Zhang, M., Deng, Y., & Zou, F. (2019). Distributional Pattern and Flight Initiation Distance of Birds during Breeding Season in Haizhu Wetland. *Guangdong Landscape Architecture*, 41(3), 33-39.

19. 水质提升后的中心湖及水中植被
20. 由圩田改造的水平潜流湿地
21. 和汀步结合的湿地溢流设施

19. The developed central lake and lotus in the water
20. Horizontal subsurface flow wetlands transformed from polders
21. Wetland overflow facilities combined with pathways


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