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人工橡胶林的蜕变
——西双版纳三达山热带雨林生态修复规划

THE REBIRTH OF TROPICAL RAINFOREST — ECOLOGICAL RESTORATION PLANNING FOR SANDA MOUNTAIN OF XISHUANGBANNA, CHINA

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摘要

热带雨林是一种独特的森林生态系统，是地球上生物多样性最高的植被类型之一，当前面临生物多样性迅速消失与生态功能严重退化等问题。在中国西双版纳热带雨林中，三达山是整体生态格局的重要节点，但农业生产与人工橡胶林的大量种植使当地的生态系统日渐破碎，植被生产力也大幅下降。自2017年起，项目团队根据三达山现状生境条件，以30年为修复周期，采用从局部修复、斑块修复、廊道修复到生态完善的动态演替总体思路，借助建群种植物、先锋植物、立体复合型和协助自然再生4种修复方法重建三达山受损的热带雨林生态系统；并利用InVEST模型对修复前后的碳储量变化、生境质量和生态系统服务功能价值展开评估，以动态指导和修正修复计划，逐步实现热带雨林的回归。该项目是复杂而漫长的热带雨林修复实践的一次实验性探索，可为中国乃至全球热带雨林生态修复提供研究与实践基础。

关键词

热带雨林；生态修复规划；修复方式；效益评估；西双版纳

ABSTRACT

Tropical rainforest, a unique forest ecosystem with the richest biodiversity on the earth, is now suffering from rapid biodiversity loss and ecological degradation. Xishuangbanna is such a typical example in China, where the ecosystem of Sanda Mountain is fragmented by agricultural practices and rubber plantation, and the vegetation productivity decreases sharply, threatening its role in the regional ecological security pattern. For an overall ecological improvement of the study area, since 2017, the project team has examined the existing habitat conditions in Sanda Mountain and proposed a thirty-year planning scheme for the ecological restoration by introducing constructive and pioneer plant species, employing a mixed-species planting mode, and facilitating the natural regeneration of vegetation community to recover natural succession through ecological restoration planning at patch-, corridor-, and regional-scales. The team simulated the changes in carbon storage, habitat quality, and ecosystem service value before and after planning via the InVEST model to guide the dynamic adjustment of the tropical rainforest restoration. This exploratory ecological restoration planning for such a large-scale tropical rainforest may provide research and practical references for other studies in China and abroad.

KEYWORDS

Tropical Rainforest; Ecological Restoration Planning; Restoration Methods; Benefit Assessment; Xishuangbanna

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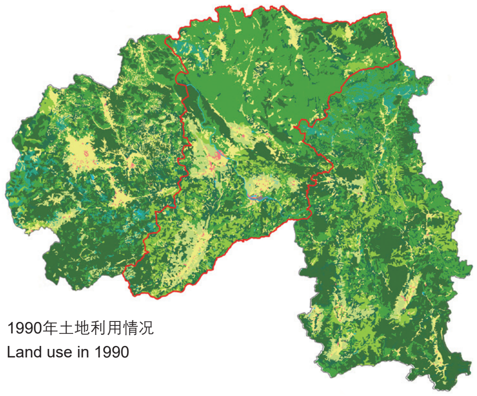
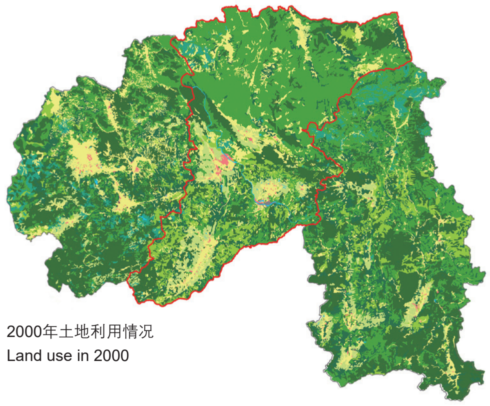
1 项目背景与问题

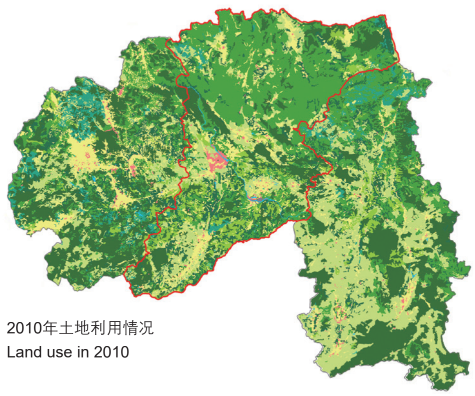
在中国现存的热带雨林中，西双版纳热带雨林是在纬度和海拔都较高的极限条件下形成的一种热带季节雨林[1]。其平均生物量为462.84t/ha，是中国生物多样性最丰富的地区之一[2]。20世纪50年代，西双版纳地区的雨林覆盖率高达55%，但到21世纪初却已不足30%，且目前受保护的热带雨林仅占当地热带雨林总面积的50%，它们零星分布在大面积的退化生境中，呈现为斑块状的“孤岛”[3]。2017年初，作为国家重点生态功能区项目，云南省景洪市政府决定对西双版纳北部三达山区域约80km^{2}的人工橡胶林进行修复，以贯通区域生态走廊，探索人与自然和谐共生之路。



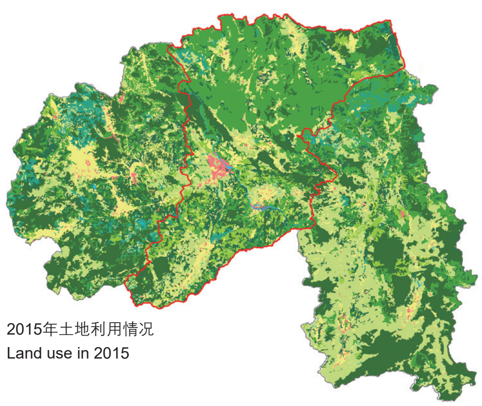
1990年土地利用情况
Land use in 1990



2000年土地利用情况
Land use in 2000



2010年土地利用情况
Land use in 2010



2015年土地利用情况
Land use in 2015

1. 1990年、2000年、2010年和2015年西双版纳土地利用情况。

1. The land use in Xishuangbanna in 1990, 2000, 2010, and 2015.

曾经拥有连绵的原始热带雨林景观的三达山，如今正面临着两大严峻挑战：

1）生态系统破碎化：由卫星遥感影像所得西双版纳地区1990～2015年土地利用①（图1）及景观生态格局的演变可见，区域生态格局正呈现破碎化趋势，具体表现为：耕地面积增加、林地面积减少，生态斑块数量显著增加、生态斑块平均面积减少。其中，农业生产活动和橡胶林种植对原有森林生态系统的侵蚀尤为明显。例如，西双版纳国家级自然保护区内约2 470km^{2}的森林被分割为5个片区，森林的破碎化严重减少了森林乡土物种及热带雨林组成成分，阻碍了物种基因的流动，大大削弱了热带雨林的生态价值。从西双版纳整体生态格局来看，三达山作为联系野象谷自然保护区和西双版纳原始森林公园的重要节点（图2），其范围内的人工造林直接导致区域生态廊道断裂，雨林植被群落结构受损，以致区域生态效益低下。

2）植被生产力下降：通过遥感数据反演景洪市2000～2015年植被净初级生产力（NPP）②可知，植被生产力从2005年起逐年增加，但仍远低于2000年的水平。其原因在于2003年前后景洪市大量砍伐森林以种植人工橡胶，具备高植物生产力的热带雨林系统遭到严重破坏，总体植被生产力急剧下降，同时脆弱物种日渐消失、生物多样性逐年降低[4]（图3）。这种情况在三达山尤甚，该地以橡胶林和果林为主的经济林占比达70%以上（图4）。

2 热带雨林生态修复规划目标与技术框架

热带雨林修复是一个漫长而复杂的动态过程[4]。雨林植被的恢复重建应顺应环境的动态变化，重在恢复生态系统的结构和功能，而非恢复为与过去完全一致的生态系统。在三达山雨林修复中，项目团队汲取国内外先进的修复经验，以现实生境条件为基础，采用多样的动态修复手段，构建"局部修复－斑块修复－廊道修复－生态完善"修复路线，以重建热带雨林植被群落结构与系统，提升物种多样性；为应对复杂多变的雨林生境系统，团队拟在修复过程中对生态修复效益进行动态评估和监测，以便为随时修正热带雨林的修复方法提供数据支撑（图5）。

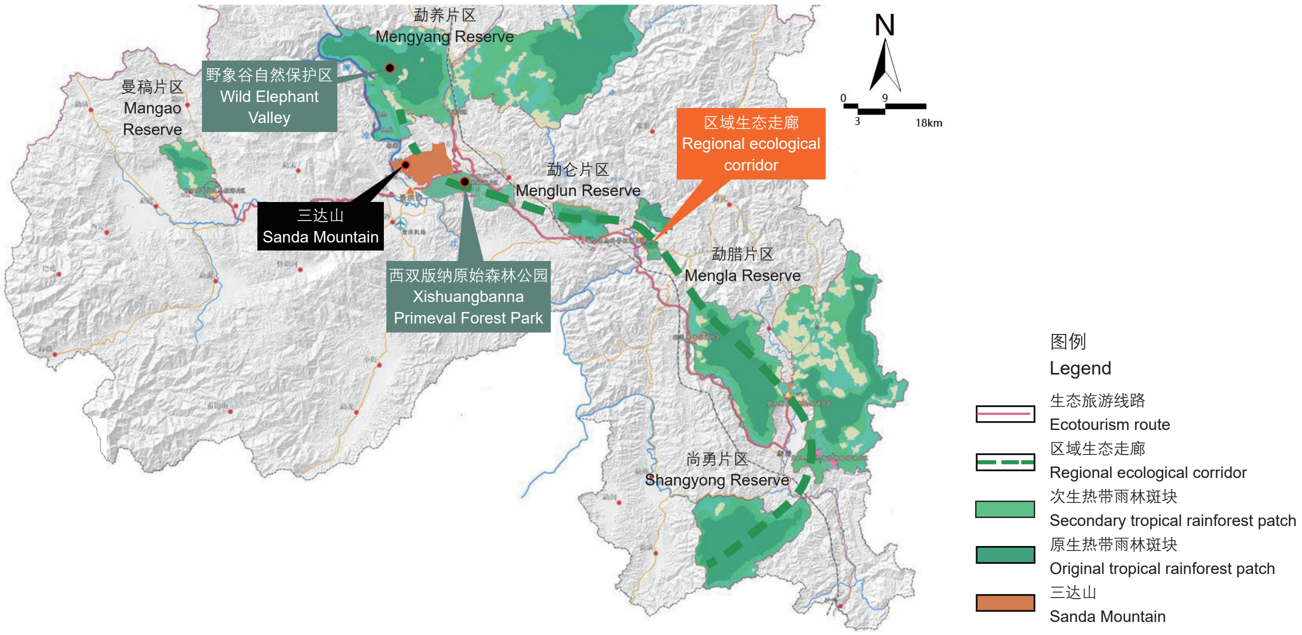
3 生态修复策略

3.1 多元修复方式探索

在热带雨林的恢复过程中，针对不同立地条件与类型，植被恢复方式与重建模式也有所不同。立地条件的划分受到地形、地貌、气候、海拔、土壤、植被、湿度、人为活动等多项综合生态因子的共同作用[5]。因此，项目首先运用权重分析法对场地进行生态多因子综合评价，并将研究区域划定为4个分区，分别因地制宜地利用建群种植物法、先锋植物法、立体复合型修复法和协助自然再生法加以修复（图6）[6]。

① 根据可获取数据，本次规划分别选取1990、2000、2010和2015年的土地利用类型数据进行模拟。

② 净初级生产力是指植物在单位时间、单位面积上由光合作用产生的有机物质总量中扣除自养呼吸后的剩余部分，反映了植物固定和转化光合产物的效率。既是生产者可用于生长、发育和繁殖的能量，也是生态系统中其他生物成员生存和繁衍的物质基础。



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3.1.1 建群种植物修复法

建群种植物修复法即选用对热带雨林群落结构和群落环境形成有明显控制作用的优势植物作为群落建造者，在短时间内建立雨林体系。现状核心沟谷坡度、土壤及湿度等条件适宜各类沟谷雨林植被生长，因此主要采用此方法进行修复。具体而言，由望天树（*Parashorea chinensis*）、绒毛番龙眼（*Pometia tomentosa*）、千果榄仁（*Terminalia myriocarpa*）等热带雨林标志性树种构成森林上层，培育林下植物以形成多层次多物种的森林植被，补植其他地被物种。如此按照热带雨林的层次精细化种植，可在较短时间内形成植物种类丰富、层次复杂、郁闭度高的热带雨林体系，从而逐步实现山谷雨林的修复（图7）。

3.1.2 先锋植物修复法

在山脊、地势陡峭和种植条件恶劣的区域，利用热带先锋树种西南桦（*Betula alnoides*）、马占相思（*Acacia mangium*）、山桂花（*Paramichelia baillonii*）等造林，其可在较短时间内成为山脊优势物种，为后期其他热带雨林植物的生长提供有力的阴地条件。同时，先锋植物的快速生长亦可推动山脊地区结构单一的橡胶林逐步向混交林演替。此区域需控制割胶、砍伐等人为活动，并借助当地优越的气候、土壤条件，补植构成山地雨林的其他乔木、藤本及林下植物，使林分逐步增加，实现山脊雨林的修复（图8）。

3.1.3 立体复合型修复法

在芒果（*Mangifera indica*）林、茶树（*Camellia sinensis*）林等部分产量较高的果林和橡胶林区域采用立体复合型修复法，即保留橡胶林，逐步伐除部分果林，并补植其他珍贵的经济林木，结合生态农业、立体混种等方式构建复合型生态橡胶林。这一途径能显著增加区域生物多样性，提升生态功能，并在较短时间内产生经济效益（图9）。

3.1.4 协助自然再生修复法

协助自然再生是指对仍然具备天然更新能力的森林加以保护，辅以适当的人工干预措施，使之尽快演替为符合培育目标的森林植被。这一方法的关键在于加速自然演替过程，减少杂草等干扰因素与树木的竞争。在水湿条件较好、现存次生林较多的区域，项目团队采取封育保护措施，在林隙种植单株或丛状补植热带雨林树种幼苗，如纤细龙脑香（*Dipterocarpus gracilis*）、云南龙脑香（*Dipterocarpus tonkinesis*）等，以促成其正向演替。尽管协助自然再生修复法耗时较长，却具备成本低和技术简易的优势（图10）。

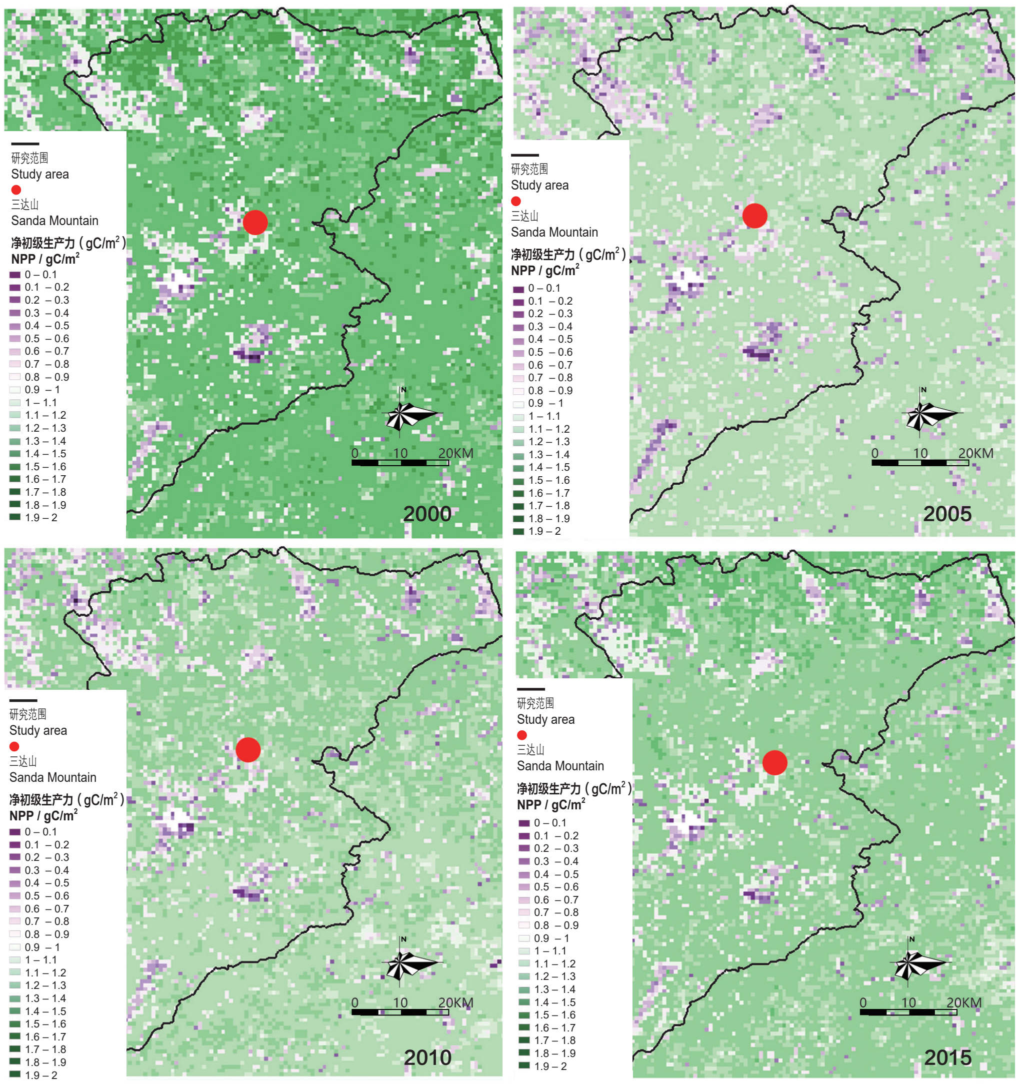
3.2 动态修复与演替

三达山主要呈现为沟壑纵横、地形险峻的沟谷特征。热带雨林修复结合场地特质，总体采用“局部修复－斑块修复－廊道修复－生态完善”的修复策略。首先以现存热带雨林为基础，局部补植雨林树种，改变林分结构；在此基础上，优先恢复立地条件较好的区域，形成分散的热带雨林小斑块，建立简单的热带雨林生态链和植被群落；而后，以沟谷为生态本底与框架连接热带雨林斑块，建立热带雨林生态链和生态廊道，促进生境之间的物种迁徙和交流；节点斑块和沟谷廊道相结合，形成生态网络，动植物沿着生态网络进入基质，逐渐完善结构单一的橡胶林，增加该区域的生物多样性，从而促进其向热带雨林演替，最终实现热带雨林的回归（图11～13）。

③ 原生热带雨林的演替周期通常为5年，而从人工橡胶林等其他林分修复演替到热带雨林所需的时间较长，通常以30年为一个周期。因此，文中近期规划的时间跨度为5年，远期规划的时间跨度为30年。团队通过走访当地热带雨林专家和查阅大量相关资料，拟定了近期、远期的土地利用类型（区别于一般情况下的土地利用类型）。

2. 西双版纳热带雨林生态格局
3. 2000年、2005年、2010年和2015年景洪市植被净初级生产力情况。
4. 三达山植被退化现状

2. The ecological pattern of the tropical rainforest in Xishuangbanna
3. The Net Primary Productivity of Jinghong City in 2000, 2005, 2010, and 2015.
4. Existing degrated rainforest in Sanda Mountain



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4 修复效益评估

考虑到热带雨林生态系统在维持全球碳平衡和区域生物多样性方面的贡献，项目团队对生态修复前后的碳储量变化、生境质量及生态服务价值进行了定量模拟，以评估热带雨林修复的生态效益。[7][8]

4.1 碳储量变化评估

4.1.1 计算方法与过程

团队借助由美国斯坦福大学、世界自然基金会和大自然保护协会联合开发的InVEST（生态系统服务评估与权衡）模型[9]中的碳储量评估模块，估算了热带雨林系统碳储量规划前后的变化情况及空间分布规律，可为实现热带雨林的保护和恢复提供数据参考。主要利用地上碳库、地下碳库、土壤和死亡有机物4个碳库来预测不同土地利用类型地块的碳储量。

InVEST模型碳储量模块的基本运算原理为，由已分类的土地利用面积与其对应的碳密度的乘积得出碳储量，再由不同土地利用类型下的碳储量求和得出总碳储量。本次规划基于景洪市森林资源规划设计调查（简称二类资源调查）报告[10]和访谈、调研与文献检索，最终划定了近期规划（2020–2025）和远期规划（2020–2050）③的7种土地利用类型，并参考燕腾等人估算的云南省森林生态系统植被的碳密度[11]确定了4种碳库的碳密度，再将二者作为初始数据输入InVEST模型中，经过ArcGIS栅格数据处理，评估每个网格单元的碳储量高低，据此对不同土地利用类型进行赋值，最后求和得出总碳储量及其规划前后的变化。

4.1.2 结果分析

经模型测算，现状橡胶林储存的碳储量约为42 259.32MgC，占规划区总碳储量的83.5%。在近期完成斑块修复后，约有$5km^2$的森林重造林产生，届时热带雨林的面积将增加一倍，经济林碳储存贡献率也将大幅下降，总碳储量将从50 609.60MgC降至47 605.64MgC（表1，图14）。在远期规划中，新种植的幼林将发展成为具有复杂生物结构层次的热带雨林，总碳储量将达到69 188.85MgC，比现状增加36.4%（表2，图14）。[12]

4.2 生境质量评估

4.2.1 计算方法和过程

生境质量反映了一定的时间和空间范围内，生态系统对人类生存繁衍、经济发展的适宜程度。本规划借助InVEST生境质量模块，利用现状及远期规划土地利用类型数据，计算两个时期对应的生境质量指数，以揭示规划实施过程中土地利用变化对生境质量的影响[13]。

生境质量模型结合土地利用和威胁因子的信息生成生境质量地图，通过考量威胁因子的影响范围及权重（表3）、生境对于威胁源的敏感系数等因素（表4），评价生境质量。输入生境质量模块的数据共分为6项，分别是现状及规划建成的土地利用覆盖数据，威胁因子（城

市、村庄、道路、矿场和规划道路）的影响范围、权重和生境敏感系数，以及景洪市森林资源规划设计调查报告[10]所提供的以保护等级为依托的准入性底图。

4.2.2 结果分析

通过对5个生态威胁因子及其影响范围进行模拟测算，识别现状高质量生境地区和低质量生境地区的位置。尽管规划道路将对生境质量指数产生较大影响——相较于现状，高质量生境的面积下降到12.02km^2，减少了7.84km^2，中低质量生境的面积由10.32km^2增加至11.55km^2——但规划区东北部及中部远离村镇建设地区的生境质量指数明显提高，且原生生境（即现存的热带雨林生境）面积由现状5.82km^2增加至12.42km^2。因此，从不同质量指数下生境的面积来看，远期规划的生境质量将有所提升（图15）。

4.3 生态系统服务功能价值评估

4.3.1 计算方法和过程

生态系统服务功能价值是指人类直接或间接从生态系统中获得的利益，主要包括向经济社会系统输入有用物质和能量、接受和转化来自经济社会系统的废弃物，以及直接向人类提供的服务。[14]本次修复规划参照余晓新等人提出的中国森林生态系统服务功能价值评估的方法[15]，选取了供给服务、涵养水源、固碳释氧、积累营养物、保育土壤、净化空气和提升生物多样性7项指标，并依据景兆鹏等人提出的云南省西双版纳地区不同用地类型的生态服务价值的动态评估研究确定不同用地的生态服务价值[16]，对修复前后各用地类型的生态服务功能价值进行评估。同时，研究中小尺度区域内生态资产变化与雨林修复进程的关系，可为规划区生态系统管理办法及生态补偿措施的制定提供科学依据。

4.3.2 结果分析

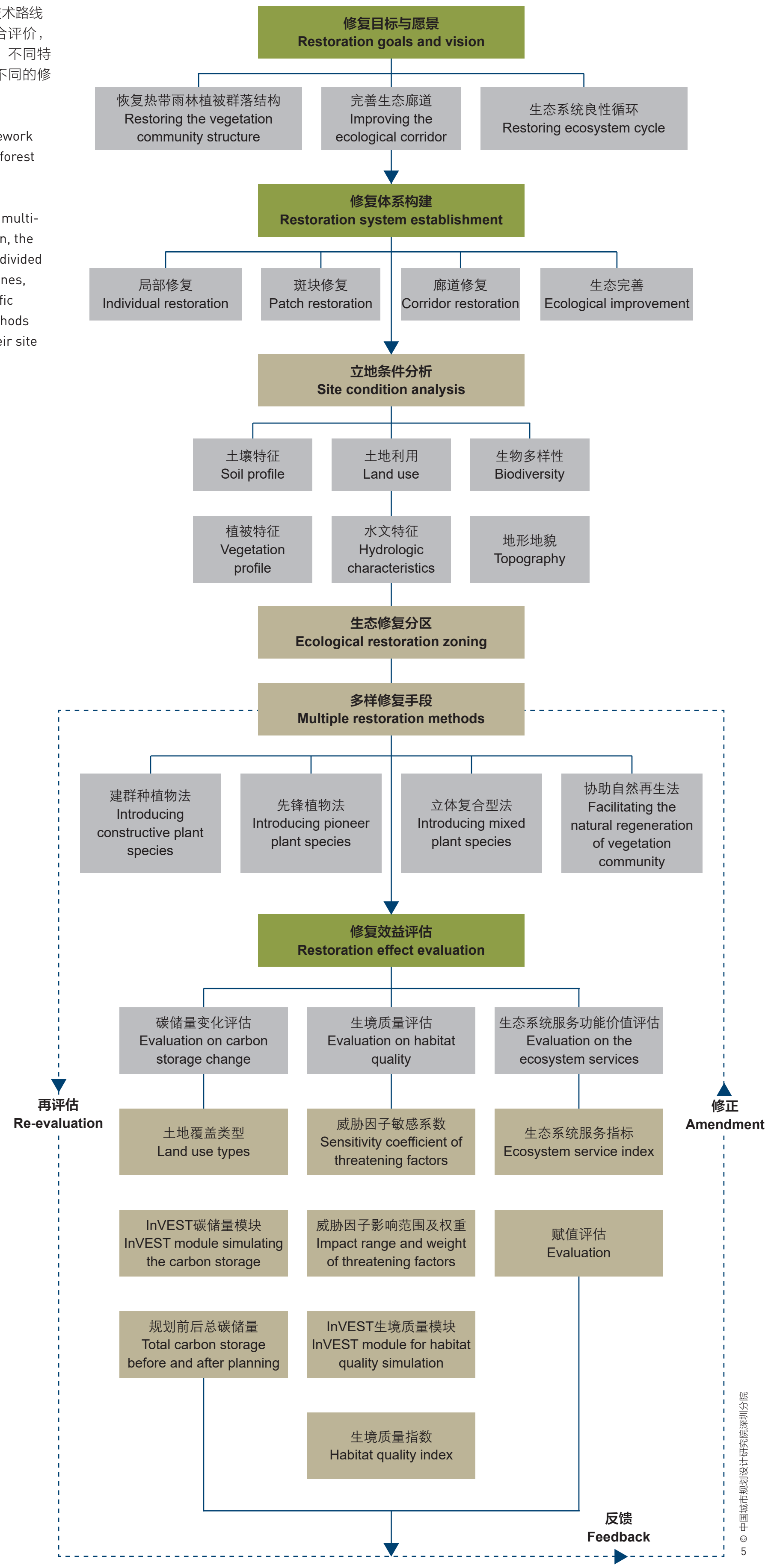
根据生态系统服务功能价值对不同用地类型进行赋值评估（表5），结合规划前后的用地占比，得出规划区域现状总生态系统服务功能价值为20 152万元；到修复后期，随着热带雨林成林增加，水源涵养、固碳释氧、积累营养物等指标明显提升，生态服务价值可提升至24 557万元（表6）[17]。

5 讨论与结论

在制定修复规划的过程中，项目团队深刻认识到生态修复有别于以往以解决单一问题为导向的生态保护、环境治理、改善生态环境，是一个漫长、复杂且不断变化的生态演变过程，应强调持续培育、动态跟踪。当前团队仅初步完成了规划编制工作，尚未展开动态跟踪以对热带雨林修复手段与方法予以反馈，因此，项目中的动态跟踪举措暂且只能停留于技术路线层面。但如此大规模的雨林生态修复无论在

5. 热带雨林修复技术路线
6. 根据多因子综合评价，划定修复分区，不同特点的区域采用不同的修复方式。

5. Technical framework for tropical rainforest restoration
6. Basing on the comprehensive multi-factor evaluation, the study area was divided into different zones, each with specific restoration methods according to their site conditions.



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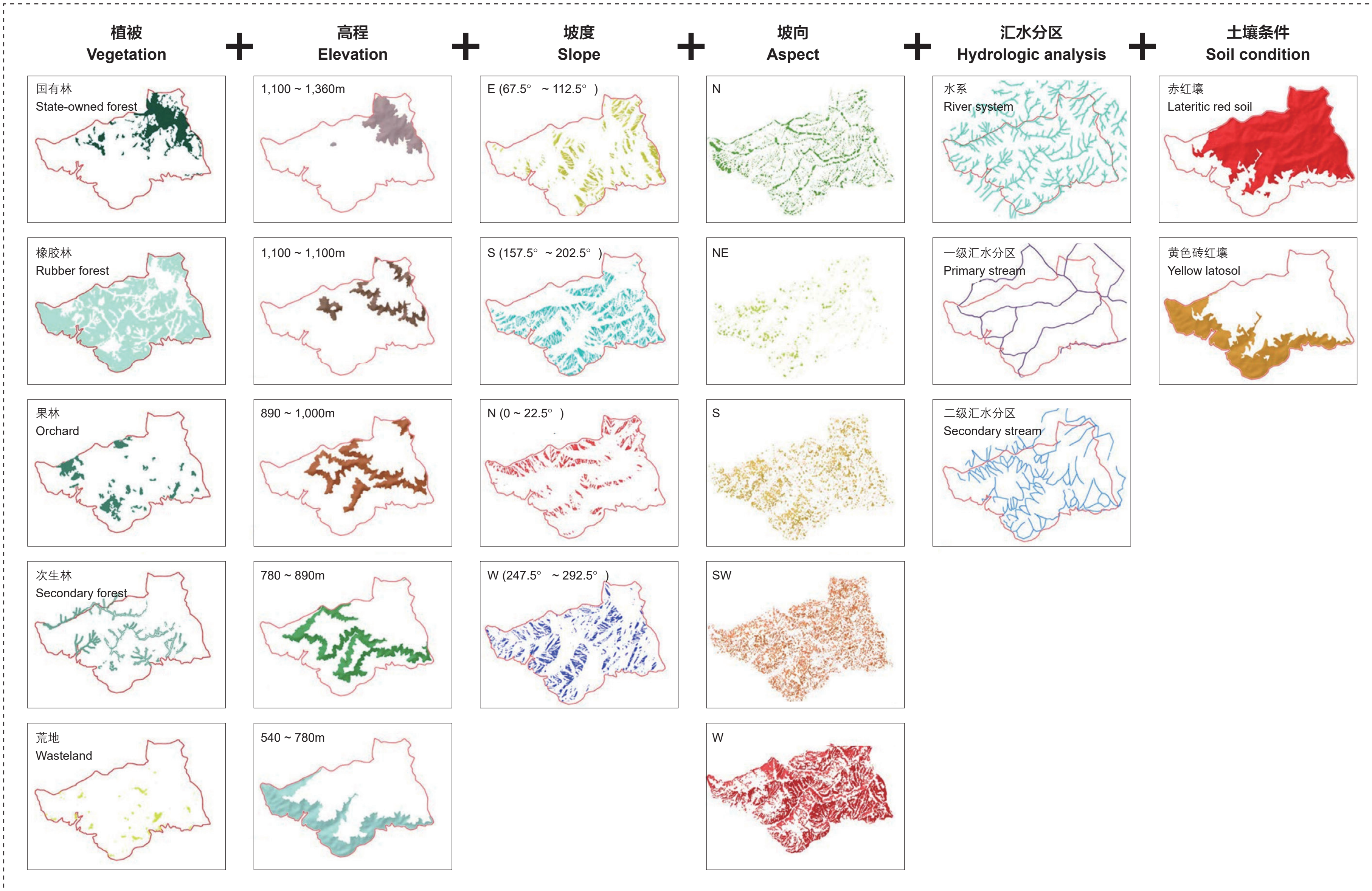


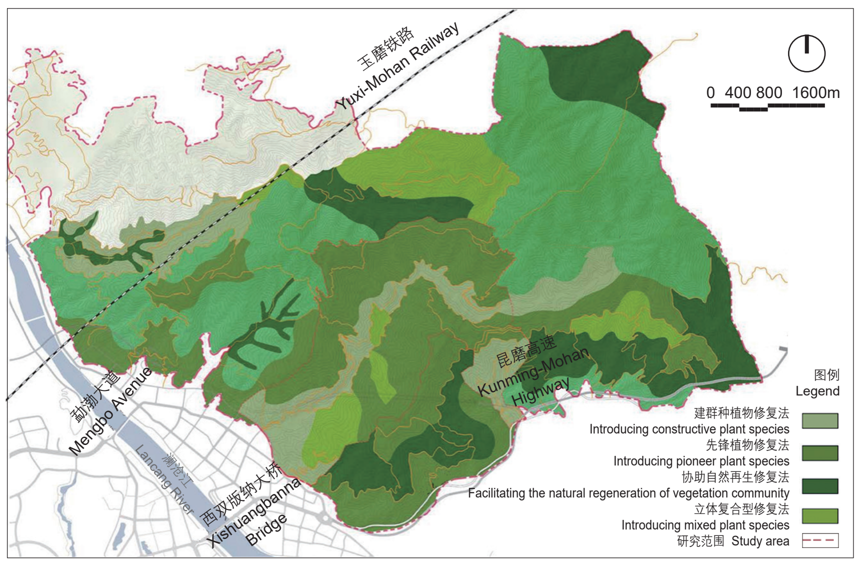
6-1

中国还是全球都是首例，本次规划实践是一次实验性探索，项目所积累的以下三大修复经验将为其他东南亚热带雨林地区的生态修复研究与实践提供宝贵经验。

（1）明确热带雨林生态修复阶段

基于恢复生态学理论，森林修复的过程基本可总结为“林隙阶段–建群阶段–成熟阶段”。而热带雨林生态系统物种组成极为丰富，群落结构也更加复杂，因此生态修复的难度和未知性更大。在本次西双版纳热带雨林生态修复实践中，团队总结出从人工橡胶林到热带雨林，修复周期基本可分为“封山育林–清除非雨林成分–建群–演替–生态完善”5个阶段（图16）。

首先采取人工措施封山育林，停止人类对热带雨林生态系统的干扰，为热带雨林的修复奠定环境基础；其次，结合地形条件，按照一定砍伐比例分批逐步清除部分人工橡胶林或非热带雨林成分，使其预



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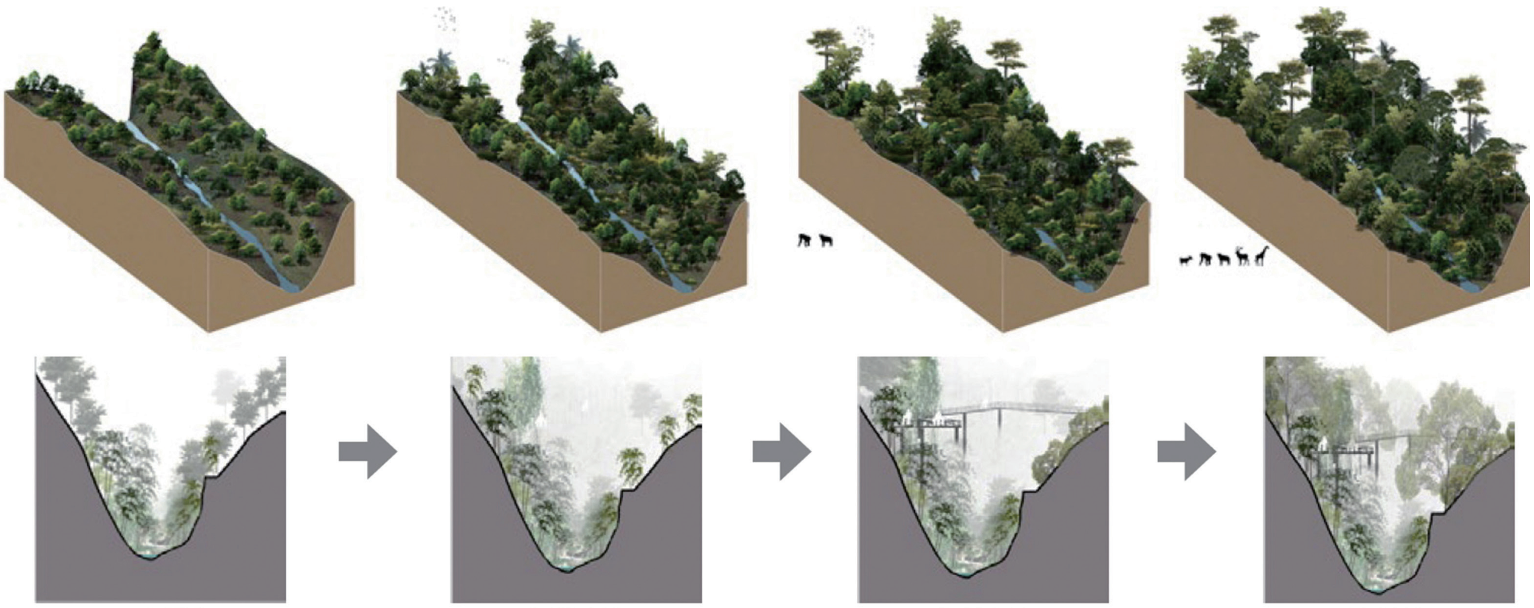
7. 建群种植物修复法
8. 先锋植物修复法

7. The restoration method of introducing constructive plant species
8. The restoration method of introducing pioneer plant species



现状生境
Existing habitats

植物种类较少，群落里物种间生态位重叠较小，土壤养分状况一般，但沟谷湿润的小气候为植被恢复提供了良好基础。

Limited number of plant species with a low niche overlap. Although the soil nutrients stay mediocre, the humid microclimate in the valley would facilitate vegetation restoration.

新建生境
Newly formed habitats

移除70%的橡胶林后，营造建群种群落：采用阳性树种与阴性树种、速生树种与慢生树种、大苗与幼树，以及乔灌草相搭配的多品种混合种植方法，并借助特定工程和生物技术手段，改善土壤养分，加强养护管理，初步奠定热带雨林群落结构。

Once 70 percent of the rubber forest is removed, the dominant plant species community will be established: mixing heliphilous and shade-tolerant species, fast-growing and slow-growing ones, big seedlings and saplings, including arbors, shrubs, and herbs. Specific engineering and biotechnological means may also increase soil nutrients and strengthen forest maintenance so as to form a stable tropical rainforest community structure.

多样生境
Diverse habitats

各层次植物开始生长、演替，恢复中的热带雨林总体具备良好适应性。但因树种配置较多，随着林分发育，竞争关系会逐渐加强，某些树种可能生长受抑制或少量死亡，属于群落内种间关系的正常调适，可通过适当的人工造林措施来应对。

Generally, the tropical rainforest under restoration is adaptive to different growth and succession situations of varied species. However, these wide range of species may be inhibited or die due to species competition, which is a natural adjustment within each vegetation community that could be intervened through appropriate afforestation.

新生境
New habitats

群落达到自然演替的动态平衡状态，林分结构更加优化，密度更加合理，植物平均生态位重叠降低，小气候朝更为阴、凉、湿的环境变化，沟谷雨林植被特色趋于明显。

Once the community reaches a dynamic balance in natural succession, the stand structure will be optimized into a sound vegetation density, less niche overlap on average, a shadier, cooler, and wetter microclimate, and a higher biodiversity in the valley rainforest.

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留空间以为热带雨林成分的发展创造前期生境；在此基础上，根据计划所要恢复的热带雨林群落类型，补植必要的群落建群种或关键种，通过维持适当的种群数来营造热带雨林生境，保持合理的群落结构；经过多样植物群落的更替和发展，形成更为复杂、稳定的热带雨林群落和生境；在后期对雨林进行完善和管理，补植群落中其他层次的乔木种类，以提高热带雨林群落结构的丰富性和合理性。

（2）动态修复，创造新生境

热带雨林的生态系统具有不可逆转性，随着气候变化、关键物种丧失和新物种入侵，意图完全恢复某一历史状态几乎是不可实现的[18]。因此，应当根据动态修复规律，不断调整修复方法，通过恢复其部分结构与功能来创建新的生境，以达到一种新的动态平衡。

（3）建立修复评估和管理机制

热带雨林生态修复需要建立一个健全持续的跟踪评估和管理机制，以在不同修复阶段评价生态系统是否保持稳定且可持续、土壤条件是否得到改善等[19]。例如，哥伦比亚的热带雨林历经190年才恢复到接近原始森林的群落结构。从前期的调查、规划、实施、管理到后期维护和修复评价，均离不开对热带雨林的长期监测与研究[20]。**LAF**

项目信息

项目地址：云南省西双版纳傣族自治州景洪市
项目面积：85km^2
项目委托：景洪市住房和城乡建设局
景观规划：中国城市规划设计研究院深圳分院
首席规划师：朱荣远
设计团队：劳炳丽、卓伟德、任婧、陈侃、王泽坚
合作团队：深圳朗程师地域规划设计有限公司
规划时间：2017年至今

1 Project Background and Problems

The Xishuangbanna tropical rainforest, typical with its seasonal features among China's existing tropical rainforests, grows under extreme conditions of comparatively higher latitude and altitude[1]. It is ranked as one of the richest biodiversity areas in China with an average biomass of 462.84 t/ha[2]. Early in the 21st century, the coverage rate of rainforest in Xishuangbanna has declined by 25% from 55% in the 1950s. Worse, only half of the tropical rainforests scattering as "forest islands" in the large-scale degraded habitats are under protection[3]. At the beginning of 2017, the local government of Jinghong in Xishuangbanna Dai Autonomous Prefecture, Yunnan Province launched the restoration project of an 80-square-kilometer planted rubber forest in northern Sanda Mountain. This demonstrative project of national eco-functional zone explores the symbiosis between human and nature by reconnecting the ecological corridors.

Sanda Moutain, once with a continuous pristine rainforest landscape, is now confronting with two severe challenges:

1) Fragmented ecosystem: According to the satellite remote sensing data indicating the changes in land use (Fig. 1)① and landscape ecological pattern of the Xishuangbanna area from 1990 to 2015, the regional ecological pattern is fragmenting (more eco-patches but smaller in the average size), with an increase of farmlands and a decline of forests. Among these changes, the reclamation of lands for agriculture and rubber plantation has significantly encroached on the original forest ecosystem. For instance, the 2,470-square-kilometer forest in the Xishuangbanna National Nature Reserve is now separated into 5 areas, which heavily weakens the ecological value of rainforests as the diversity of native rainforest species is diminished, impeding gene flows as well. In the larger ecological pattern of Xishuangbanna, Sanda Mountain is a key linkage connecting the Wild Elephant Valley Nature Reserve and Xishuangbanna Primeval Forest Park (Fig. 2) yet suffering from ecological damages in ecological corridor connectivity and vegetation community structure caused

① Considering the accessibility of data, the planning simulated the land use type changes in the year of 1990, 2000, 2010, and 2015, respectively.

② Net primary productivity (NPP) is the remaining amount of organic matters of plants produced by photosynthesis per unit area per unit time after autotrophic respiration, which indicates plants' efficiency of photosynthetic storage and transformation. Such organic matters can facilitate plant growth and spread, while providing energy for other organisms in the ecosystem to survive and reproduce.

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by the intensive rubber plantation, leading to a decrease of regional eco-efficiency.

2) Decreased vegetation productivity: The remote sensing data inversion results of net primary productivity (NPP)② from 2000 to 2015 in Jinghong indicate that the vegetation productivity increased year by year from 2005. However, it was still far below that of 2000 because a large number of forests were replaced with rubber plantation since the year of 2003. With the sharp decrease of ecosystem productivity of the original rainforests and the loss of vulnerable species, the biodiversity has reduced gradually[4] (Fig. 3), especially in Sanda Mountain where economic forests consist mainly of rubber trees and orchards accounting for more than 70% of the total area (Fig. 4).

2 Targets and Technical Framework of Rainforest Ecological Restoration Planning

Tropical rainforest restoration is a time-consuming and complicated process[4], which requires a dynamic adaptation to the changing environment. The core of this process is to restore the structure and services of ecosystems, instead of recovering its appearance. Widely reviewing related practices at home and abroad, the project team proposed a diversified and dynamic restoration roadmap, ranging from individual patch restoration to eco-corridor re-establishment, to realize an overall ecological improvement by reconstructing rainforest vegetation community basing on the existing habitat conditions and increasing species diversity. Considering the complex and changing tropical rainforest habitat conditions, the team proposed to dynamically evaluate and monitor the ecological restoration efficiency along the implementation process, in order to adjust technical methods constantly (Fig. 5).

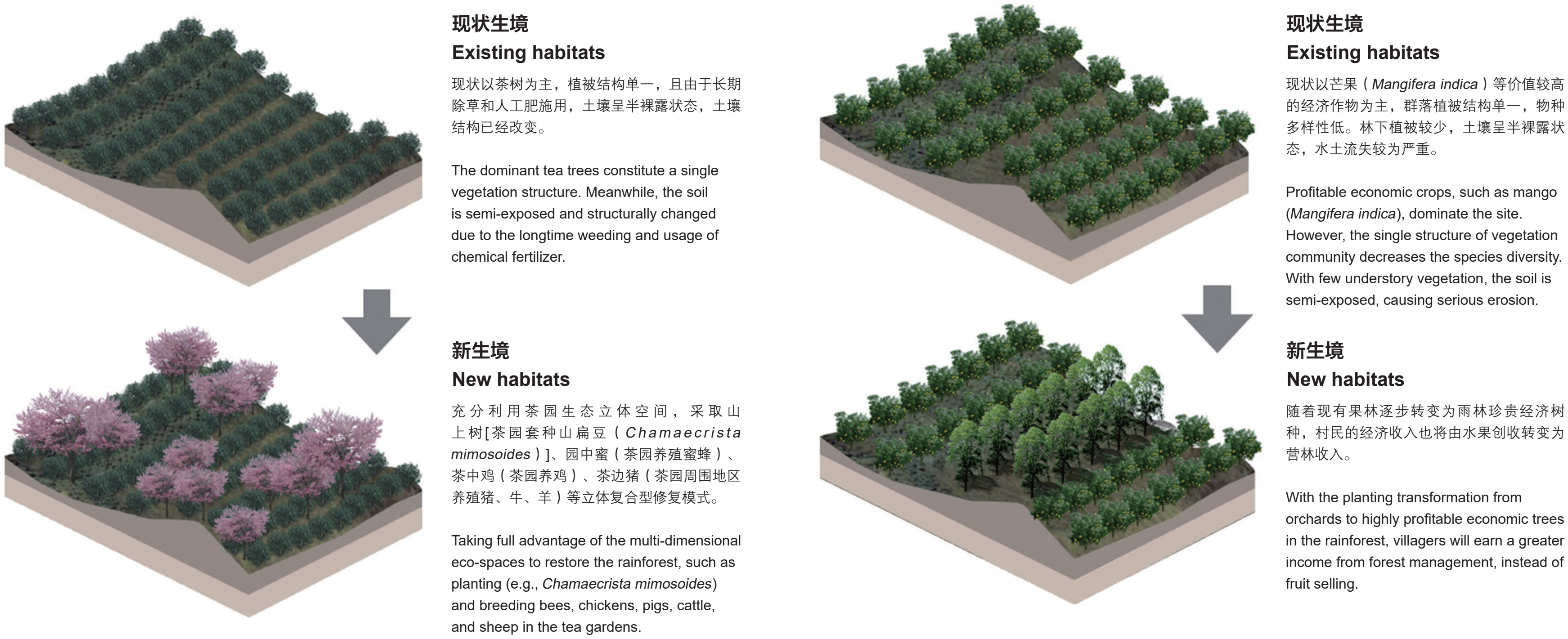
3 Ecological Restoration Strategies

3.1 Exploration of Diverse Restoration Methods

The methods applied in tropical rainforest restoration differ from each other as they have to suit the site locality that is impacted by several ecological factors such as topography, landform, climate, altitude, soil, vegetation, humidity, and human interventions[5]. Therefore, the project team first evaluated the site with weighting analyses on the ecological

9. 立体复合型修复法

9. The restoration method of introducing mixed plant species



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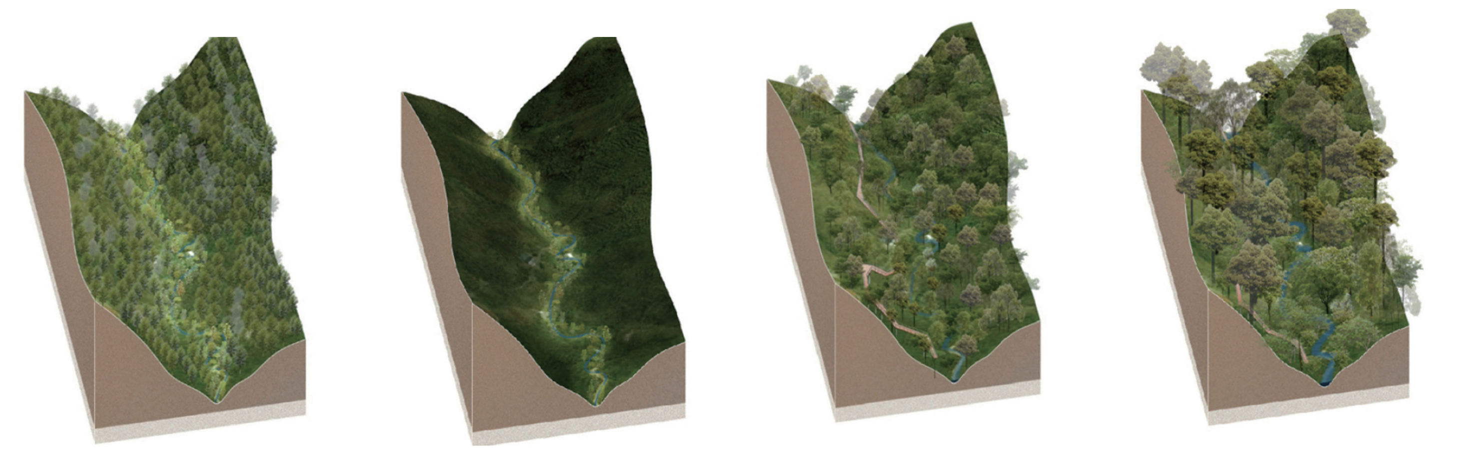
10. 协助自然再生修复法
11. 新热带雨林植被体系构建过程

10. The restoration method of facilitating the natural regeneration of vegetation community
11. The construction process of a new tropical rainforest system



现状生境
Existing habitats

季节性沟谷区域因不适合橡胶种植而残留的次生林正处于不稳定的群落阶段。此区域乔木层植物较少，以灌木和地被植物为主。

The secondary forest, along the seasonal valley which is not suitable for rubber planting, sees unstabilities. It is occupied mainly by shrubs and ground covers, with few arbor vegetation.

新建生境
Newly formed habitats

这一阶段需使用一系列措施以定向抚育和减少干扰来加速演替过程：1）增加植物丰富度，如增植幼苗，使其加快成林；2）关注光照、水和营养等各个方面，减少杂草与乔灌植物的竞争。

A series of measures should be applied to speed up the succession process by targeted breeding and interference reduction: 1) increasing vegetation diversity (e.g., planting more saplings to facilitate mature forest establishment); and 2) reducing the threat from weeds to trees and shrubs by changing conditions of light, water, nutrition, etc.

多样生境
Diverse habitats

各种适于当地环境的植物会逐渐繁茂，根据树种的动态生态位将群落结构划分为主林层、演替层和更新层。此阶段的核心是人为定向引导林分发展方向和质量，根据林分的演替动向确定采伐或抚育对象，并进一步补植珍贵雨林植物品种。

Once the vegetation adaptable to local environment flourish, the community structure will form three layers according to the dynamic niche: the dominant layer, the succession layer, and the new-growth layer. Major tasks here include inteventions on growth direction and quality of varied forest components, mainly by identifying species to remove or nurture in line with the succession trend and supplementing highly profitable rainforest species.

新生境
New habitats

随着自然演替，多样化的季风常绿阔叶林植被体系趋于稳定，在一定条件下出现热带雨林标志性植物。

Through natural succession, a stable diverse monsoon evergreen broad-leaf forest system will come into being, where the symbolic vegetation will appear under certain conditions.

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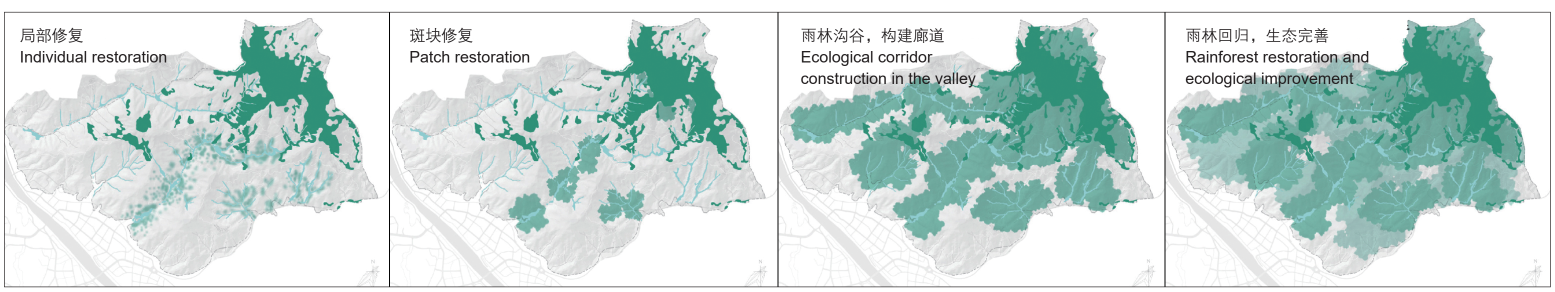
factors, according to which the study area was divided into four zones and treated with different restoration methods, i.e., introducing constructive plant species, introducing pioneer plant species, introducing mixed plant species, and facilitating the natural regeneration of vegetation community (Fig. 6) [6].

3.1.1 Introducing Constructive Plant Species

Constructive plant species can be used to dominate the tropical rainforest community structure and help re-establish a rainforest ecosystem within a short time. This approach was adopted to the valleys where the existing slope, soil, and humidity conditions are suitable to a quick growth of constructive species. Specifically, the upper layer included typical tree species, such as *Parashorea chinensis*, *Pometia tomentosa*, and *Terminalia myriocarpa*, and the lower layer may also constitute a diverse vegetation structure, as well as ground-covering species. Through a precise planning design, the valley rainforest is expected to get gradually restored with rich plant species, multiple layers, and high-density canopy in a relatively short period of time (Fig. 7).



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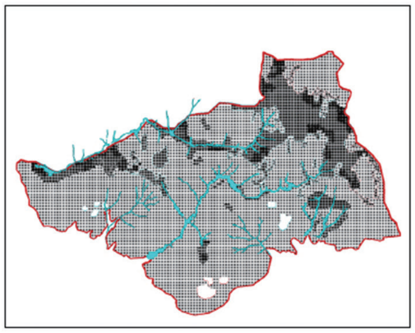
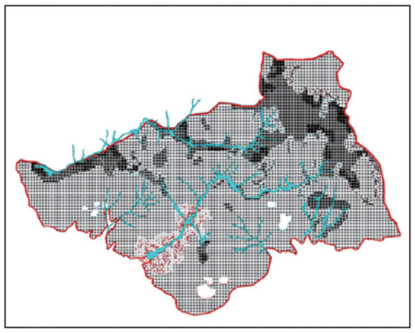


97% 覆被 Vegetation covering
3% 空地 Open area

2017

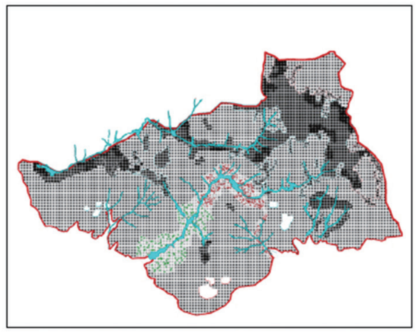
20% 季风常绿阔叶林 Monsoon evergreen broad-leaf forest
8% 热带果园 Tropical orchard
69% 橡胶林 Rubber forest
3% 荒地 Wasteland



89% 覆被 Vegetation covering
8% 修复区域 Area under restoration
3% 空地 Open area

2018

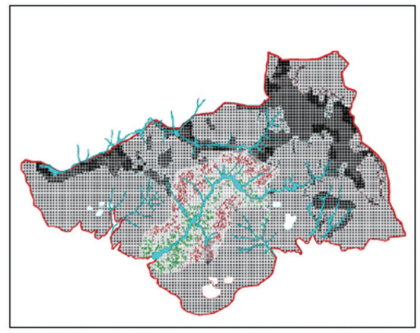
20% 季风常绿阔叶林 Monsoon evergreen broad-leaf forest
7% 热带果园 Tropical orchard
62% 橡胶林 Rubber forest
8% 修复区域 Area under restoration
3% 荒地 Wasteland



81% 覆被 Vegetation covering
8% 新林 New formed forest
8% 修复区域 Area under restoration
3% 空地 Open area

2019

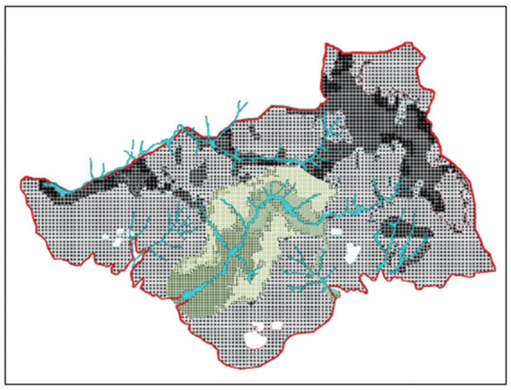
20% 季风常绿阔叶林 Monsoon evergreen broad-leaf forest
7% 热带果园 Tropical orchard
54% 橡胶林 Rubber forest
8% 新生境 New formed habitat
8% 修复区域 Area under restoration
3% 荒地 Wasteland



74% 覆被 Vegetation covering
16% 新林 New formed forest
8% 修复区域 Area under restoration
2% 空地 Open area

2020

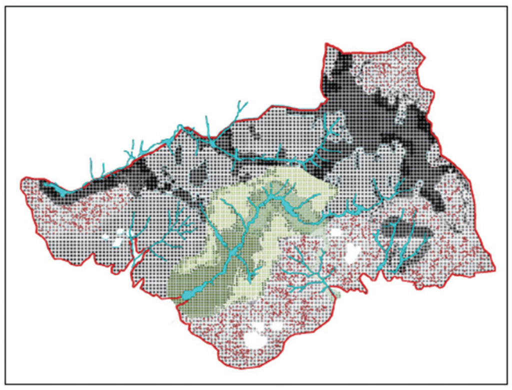
20% 季风常绿阔叶林 Monsoon evergreen broad-leaf forest
6% 热带果园 Tropical orchard
48% 橡胶林 Rubber forest
16% 新生境 New formed habitat
8% 修复区域 Area under restoration
2% 荒地 Wasteland



74% 覆被 Vegetation covering
24% 新林 New formed forest
2% 空地 Open area

2022

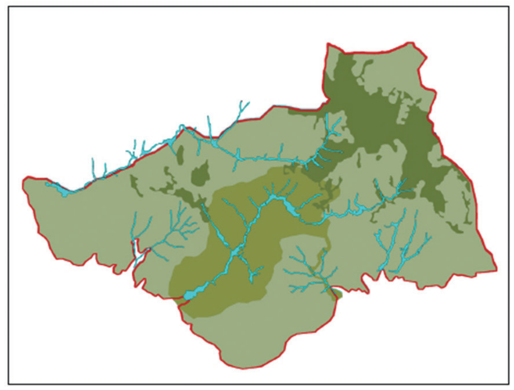
22% 季风常绿阔叶林 Monsoon evergreen broad-leaf forest
5% 热带果园 Tropical orchard
47% 橡胶林 Rubber forest
24% 新生境 New formed habitat
2% 荒地 Wasteland



50% 覆被 Vegetation covering
24% 新林 New formed forest
25% 修复区域 Area under restoration
1% 空地 Open area

2027

24% 季风常绿阔叶林 Monsoon evergreen broad-leaf forest
4% 热带果园 Tropical orchard
22% 橡胶林 Rubber forest
24% 新生境 New formed habitat
25% 修复区域 Area under restoration
1% 荒地 Wasteland



40% 覆被 Vegetation covering
60% 新林 New formed forest

2047

32% 季风常绿阔叶林 Monsoon evergreen broad-leaf forest
3% 热带果园 Tropical orchard
5% 橡胶林 Rubber forest
60% 新生境 New formed Habitat

3.1.2 Introducing Pioneer Plant Species

Pioneer plant species, such as *Betula alnoides*, *Acacia mangium*, and *Paramichelia baillonii*, were selected in the restoration of the ridges, steep terrains, and other areas of poor growing conditions, to shade other tropical rainforest plants later introduced and facilitate the succession from pure rubber forest to a mixed forest on the ridges. In such areas, human interference such as rubber tapping and deforestation should be restricted. Planting other species of trees, vines, and groundcovers when the local climate and soil conditions are suitable may also help increase the forest stands and ultimately restore the mountain ridge rainforests (Fig. 8).

3.1.3 Introducing Mixed Plant Species

The mixed-species planting mode of restoration was employed in the areas with high-yielding orchards (*Mangifera indica*, *Camellia sinensis*, etc.) and rubber forests. Using methods such as eco-agriculture and vertical planting, part existing orchards can be replaced with valuable economic trees while remaining rubber forests to establish compound ecological forest communities. This approach will significantly enhance the local biodiversity, improve ecological services, and increase economic benefits in a short period of time (Fig. 9).

3.1.4 Facilitating the Natural Regeneration of Vegetation Community

The method of facilitating the natural regeneration of vegetation community is to protect forest competent to realize self-recovery and accelerate the succession towards the desired vegetation community with proper human interference. This method may also help alleviate the competition between trees with weeds and avoid disturbance. To the areas of better water and humidity conditions and more secondary forests, the project team took measures of closing hillsides to protect existing forest and planting individual or a cluster of tropical rainforest saplings (e.g., *Dipterocarpus gracilis* and *Dipterocarpus tonkinesis*) in gaps to promote positive succession. Though time-consuming, this method is superior to others for its low cost and low-tech practice (Fig. 10).

3.2 Dynamic Restoration and Succession

An overarching tropical rainforest restoration strategy that covered specific objectives at varied scales aimed to realize an overall ecological improvement, with consideration of the rugged and steep geographic features of Sanda Mountain. The first step was to supplement tropical rainforest tree species in part of the existing tropical rainforest to improve the forest

13

stand structure. Secondly, restoration priority was given to areas with better site conditions so as to restore simple ecological chains and vegetation communities in forms of scattered small tropical rainforest patches. Next, these patches could be connected with valleys to form the ecological spine, establish a holistic ecological chain, and recover eco-corridors in the tropical rainforests, which could promote wildlife migration and exchange between habitats. Finally, an ecological network was created by linkage patches, valleys, and eco-corridors,

12. 热带雨林动态修复路径
13. 规划总平面图

12. The dynamic tropical rainforest restoration processes
13. Site plan of the planning

表1：规划近期碳储量变化（2020~2025年）
Table 1: Short-term carbon storage change planning (2020 ~ 2025)

用地类型 Land use type	地上碳库 Aboveground biomass		地下碳库 Underground biomass		土壤有机碳 Soil organic matter		死亡有机碳 Dead organic matter		总碳储量 Total carbon storage	
	碳储量 Carbon storage / MgC	占比 Proportion / %	碳储量 Carbon storage / MgC	占比 Proportion / %	碳储量 Carbon storage / MgC	占比 Proportion / %	碳储量 Carbon storage / MgC	占比 Proportion / %	碳储量 Carbon storage / MgC	占比 Proportion / %
水系及建筑用地 Water area and building land	0	0	0	0	0	0	0	0	0	0
荒地 Wasteland	0	0	0	0	0	0	0	0	0	0
农业用地 Agricultural land	4.96	0.02	0.31	0.01	6.10	0.03	0.17	0	11.54	0.02
灌木林 Shrub	2808.69	13.40	464.91	18.65	3719.26	17.07	291.67	16.60	7284.53	15.30
经济林 Economic forest	4880.01	22.56	494.16	19.82	5806.39	26.65	418.91	24.50	11599.46	24.37
热带雨林 Tropical rainforest	6738.60	31.20	1148.00	46.05	6084.41	27.93	716.55	38.10	14687.56	30.85
新植幼林 Seedling	7099.95	32.82	385.60	15.47	6169.70	28.32	367.29	20.80	14022.55	29.46
总碳储量 Total carbon storage / MgC	**21532.21**		**2492.98**		**21785.86**		**1794.59**		**47605.64**	

表2：规划远期碳储量变化（2020~2050年）
Table 2: Long-term carbon storage change planning (2020 ~ 2050)

用地类型 Land use type	地上碳库 Aboveground biomass		地下碳库 Underground biomass		土壤有机碳 Soil organic matter		死亡有机碳 Dead organic matter		总碳储量 Total carbon storage	
	碳储量 Carbon storage / MgC	占比 Proportion / %	碳储量 Carbon storage / MgC	占比 Proportion / %	碳储量 Carbon storage / MgC	占比 Proportion / %	碳储量 Carbon storage / MgC	占比 Proportion / %	碳储量 Carbon storage / MgC	占比 Proportion / %
水系及建筑用地 Water area and building land	0	0	0	0	0	0	0	0	0	0
荒地 Wasteland	0	0	0	0	0	0	0	0	0	0
农业用地 Agricultural land	4.95	0.01	0.31	0.01	6.09	0.02	0.31	0.01	11.66	0.02
灌木林 Shrub	2808.65	7.93	464.92	11.52	3719.39	14.40	533.64	13.63	7526.61	10.88
经济林 Economic forest	4879.79	13.78	494.16	12.25	5806.11	22.48	766.41	19.57	11946.81	17.27
热带雨林 Tropical rainforest	27710.54	78.27	3075.92	76.23	16302.02	63.10	2614.94	66.79	49703.77	71.84
总碳储量 Total carbon storage / MgC	**35403.95**		**4035.31**		**25834.27**		**3915.32**		**69188.85**	

providing routes for the flora and fauna to inhabit. With all these strategies, tropical rainforests of a high biodiversity can successfully return from the single-structure rubber forests (Fig. 11 ~ 13).

4 Benefit Assessment after the Restoration

Considering the significant role of tropical rainforest ecosystem played in maintaining global carbon balance and regional biodiversity, the project team quantitatively estimated the changes in carbon storage, habitat quality, and ecosystem service value before and after ecological restoration to evaluate the ecological benefits of restoration.[7][8]

4.1 Assessment of Carbon Storage Changes

4.1.1 Calculation Methods and Processes

Adopting the Carbon Storage and Sequestration Model of InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) jointly developed by Stanford University, World Wide Fund for Nature, and the Nature Conservancy[9], the team estimated the changes and spatial distribution of carbon storage of the study area before and after the planning, to inform the follow-up protection and restoration measures. Four carbon pools, i.e., aboveground biomass, underground biomass, soil, and dead organic matter, were selected to evaluate the carbon storage of different land use types within the study area.

With the Carbon Storage and Sequestration Model, the capacity of carbon storage is calculated by multiplying the area of classified land use and its corresponding carbon density; and the total capacity of carbon storage will be obtained by summing them up. Following this rule, the study determined seven land use types in both the short-term (2020-2025) and long-term (2020-2050)③ planning according to the data of the Planning and Design of Forest Resources Inventory of Jinghong City[10] and interviews, fieldwork, and literature review; the carbon densities of four carbon pools were identified basing on the carbon density of forest ecosystem in Yunnan Province estimated by Yan Teng et al.[11] After inputting these two types of initial data to the InVEST Model and processing the raster data in ArcGIS, the project team obtained an assessment of each grid's carbon storage and weighted each land use type with their corresponding valuation. Finally, the total carbon storage and their changes before and after implementing the short-term or long-term planning were simulated.

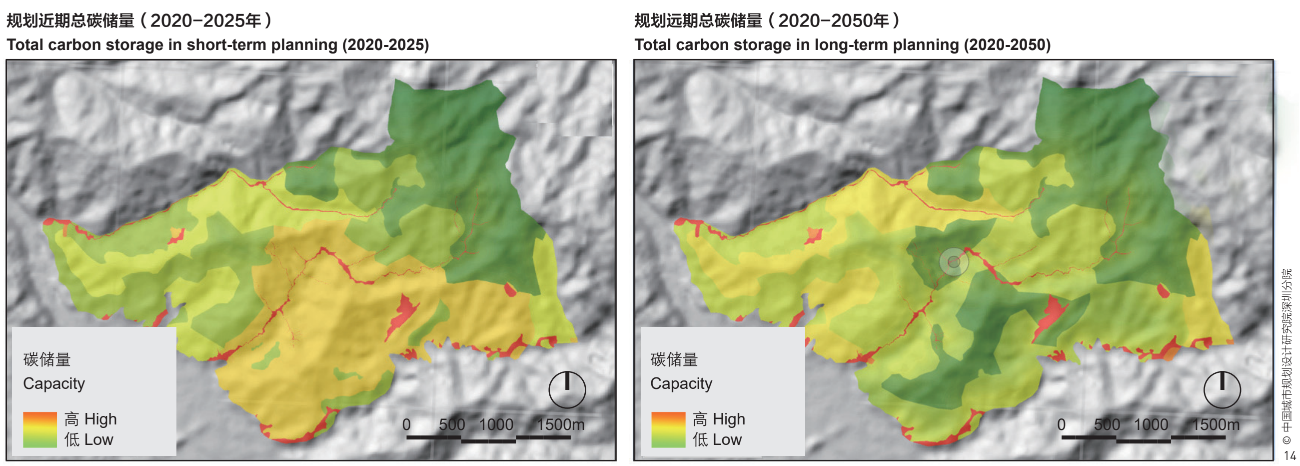
4.1.2 Result Analyses

The simulation results indicated that the carbon storage of current rubber forest is about 42,259.32 MgC, accounting for 83.5% of the total carbon storage in the planning area. Once completing the patch restoration, the area of tropical rainforest will double with about 5 square kilometers of restored rainforest. Meanwhile, the total carbon storage of the economic forests will decrease sharply from 50,609.60 MgC to 47,605.64 MgC (Table 1, Fig. 14). In the long-term planning, when the saplings grow into a mature rainforest with complex biological structure, the total carbon storage will reach 69,188.85 MgC, 36.4% higher than the current level (Table 2, Fig. 14).[12]

4.2 Habitat Quality Assessment

4.2.1 Calculation Methods and Processes

The habitat quality reflects the suitability extent of an



14. 近期规划与远期规划中的碳储量变化

14. The changes of the carbon storage for the short-term and long-term planning

③ Usually, the succession cycle of a tropical rainforest is around 5 years, while the succession from a planted rubber forest and other forest stands would take a much longer time that is usually witnessed around 30 years. Thus, this study prepared a short-term planning and a long-term planning for five and thirty years respectively. Meanwhile, after interviewing with local experts in tropical rainforest and substantial literature review, the team formulated the land use types in the short- and long-term planning, which differed from the land use types in conventional land use planning.

ecosystem for human living and production activities in a certain time period and spatial range. With the land use data in short-term and long-term planning, the project team employed the Habitat Quality Model of InVEST to calculate the habitat quality index of the two time spans, to reveal the impacts of land use changes on the habitat quality[13].

The mapping of habitat quality, according to the data of land use and the threatening factors in the Habitat Quality Model, is conducted to evaluate the habitat quality by examining the threatening factors' scope and weight of impact (Table 3), the sensitivity coefficient of habitat to threatening sources, etc. (Table 4). Six categories of data were used in this model: the current and planned land use coverage, threatening factors (cities, villages, roads, mines, and projected roads) and their impact scope and habitat sensitivity coefficients, and the maps of forest protection level by the Planning and Design of Forest Resources Inventory of Jinghong City[10].

4.2.2 Result Analyses

According to the simulation result which evaluated the five ecological threatening factors and their impact scopes, the high- and low-quality habitats within the study area were identified. Comparatively, the planned roads may largely impact the habitat quality index in that the area of high-quality habitat decreased by 7.84 km² to 12.02 km² and the area of medium- and low-quality habitats increased from 10.32 km² to 11.55 km². However, the habit quality index of the northeast and the central areas of less rural construction was significantly improved, seeing an increase of original rainforest area from 5.82 km² to 12.42 km². As a result, the overall habitat quality may witness an improvement through the long-term restoration (Fig. 15).

4.3 Ecosystem Service Evaluation

4.3.1 Calculation Methods and Processes

The value of ecosystem services refers to the benefits that human beings get directly or indirectly from the ecosystem, mainly including material and energy input to human socio-economic systems, the absorbance and transformation of waste from the systems, and the services directly provided to human societies.[14]

Adopting the evaluation methods from the assessment of the forest ecosystem services evaluation in China by Lu Shaowei et al.[15], seven indicators, including provisioning service, water conservation, carbon sequestration and oxygen release, nutrient accumulation, soil conservation, air

表3：威胁因子影响范围与权重
Table 3: Impact scope and weight of threatening factors

威胁因子 Threatening factors	影响距离（km） Impact distance / km	权重 Weight
城市 City	3	0.8
现状村庄 Existing village	2	0.7
规划村庄 Planned village	0.6	0.6
现状道路 Existing road	1	0.6
矿场 Mine	1	0.5
规划道路 Planned road	0.5	0.5

表4：不同用地类型威胁因子敏感系数表
Table 4: Sensitivity coefficient of threatening factors of different land use types

用地类型 Land use type	威胁因子敏感系数 Sensitivity coefficient of threatening factors				
	城市 City	村庄 Village	现状道路 Existing road	矿场 Mine field	规划道路 Planned road
热带雨林 Rainforest	0.8	0.6	0.7	0.5	0.6
经济林 Economic forest	0.7	0.6	0.7	0.5	0.6
村庄 Village	0	0	0	0	0
矿场 Mine	0	0	0	0	0
其他林地 Other woodland	0.7	0.55	0.6	0.5	0.55
河流 River	0	0	0	0	0
道路 Road	0	0	0	0	0
城市 City	0	0	0	0	0

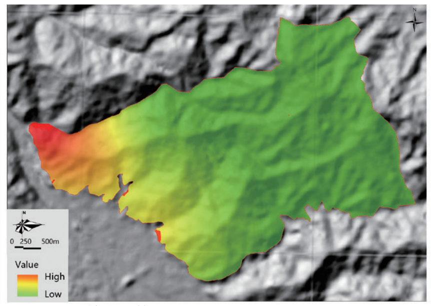
15. 现状与远期规划的生境质量模拟结果对比

15. Simulated result comparison between existing habitat quality and the one under long-term planning

现状生境的质量指数、面积及比例

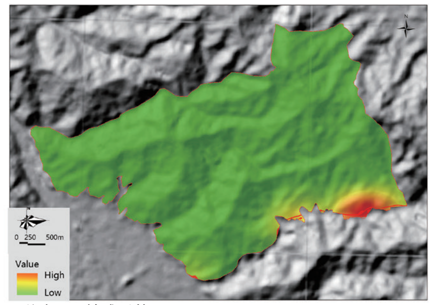
Habitat quality index, area, and proportion of existing habitats

	生境质量指数 Habitat quality index	面积（km²） Area / km²	比例（%） Proportion / %
无生境 No habitat	0	1.08	3.0%
低质量生境 Low-quality habitat	0 ~ 0.48	3.60	10.0%
中质量生境 Medium-quality habitat	0.48 ~ 0.59	5.64	15.7%
高质量生境 High-quality habitat	0.59 ~ 0.79	19.86	55.2%
原生生境 Original habitat	0.79 ~ 1	5.82	16.1%



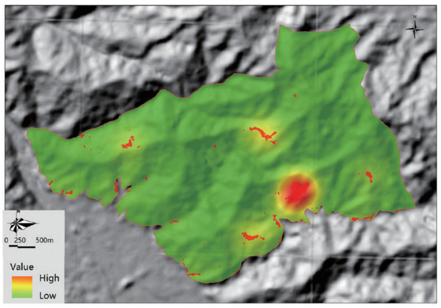
a 城市因子敏感系数

a. Sensitivity coefficient of city factor



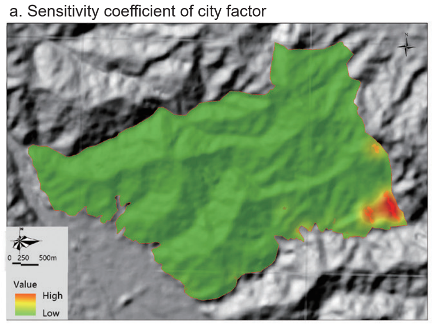
b 道路因子敏感系数

b. Sensitivity coefficient of road factor



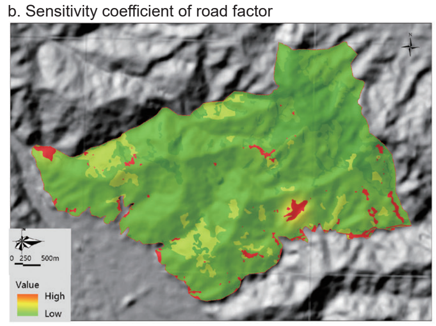
c 村庄因子敏感系数

c. Sensitivity coefficient of village factor



d 采矿因子敏感系数

d. Sensitivity coefficient of mine field factor



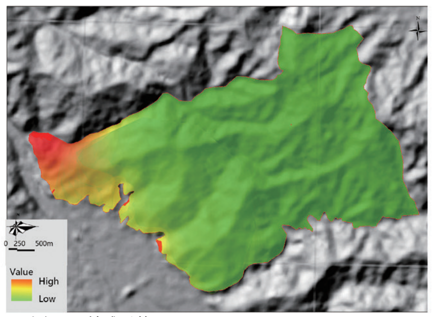
e 现状生境指数

e. Existing habitat index

规划生境的质量指数、面积及比例

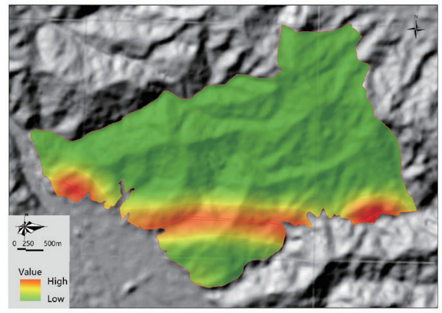
Habitat quality index, area, and proportion of planned habitats

	生境质量指数 Habitat quality index	面积（km²） Area / km²	比例（%） Proportion / %
无生境 No habitat	0	1.79	5.0%
低质量生境 Low-quality habitat	0 ~ 0.48	3.86	10.7%
中质量生境 Medium-quality habitat	0.48 ~ 0.59	5.90	16.4%
高质量生境 High-quality habitat	0.59 ~ 0.79	12.02	33.4%
原生生境 Original habitat	0.79 ~ 1	12.42	34.5%



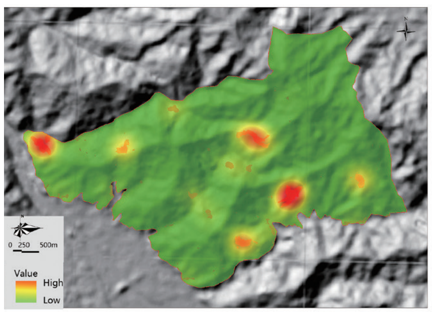
a 城市因子敏感系数

a. Sensitivity coefficient of city factor



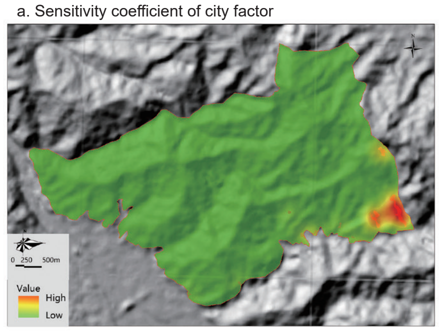
b 道路因子敏感系数

b. Sensitivity coefficient of road factor



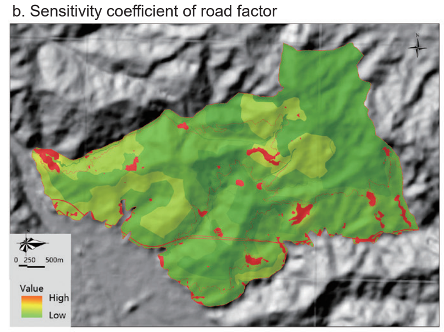
c 村庄因子敏感系数

c. Sensitivity coefficient of village factor



d 采矿因子敏感系数

d. Sensitivity coefficient of mine field factor



e 规划生境指数

e. Planned habitat index

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purification, and biodiversity improvement, were selected to evaluate the ecosystem service value of each land use type before and after restoration, in accordance with the research findings from Dynamic evaluation on ecosystem service values of Xishuangbanna, Yunnan, China by Yu Xiaoxin et al.[16] Moreover, the research on the correlation between ecological asset changes and rainforest restoration processes in medium- and micro-scale areas may provide scientific evidence for the decision-making on ecosystem management and ecological compensation in the study area.

4.3.2 Result Analyses

According to the evaluation of ecosystem services of different land use types (Table 5), as well as the corresponding area proportion, the existing total ecosystem service value of the study area is CNY 201.52 million. In the later stage of restoration, this number might increase to 245.57 million (Table 6) while the indicators of water conservation, carbon sequestration and oxygen release, and nutrient accumulation may increase considerably as the extension of tropical rainforest[17].

5 Discussion and Conclusions

Through this restoration planning practice, the project team corroborate that ecological restoration, compared with single-purpose ecological conservation, environmental management, and ecological improvement, is a time-consuming, complicated, and dynamically evolving process which requires continuous efforts in forest culturation and monitoring. This planning project at present has just finished its preparation of planning schemes; as the ecological restoration implements and monitoring starts, associated data will be collected to inform the adjustment of the technical framework and roadmaps. Still, this project shows an exploratory significance in large-scale rainforest ecological restoration, either in China or globally, and may provide illumination for other explorations of tropical rainforest areas in Southeast Asia.

(1) Stages of Tropical Rainforest Ecological Restoration

Generally, the process of forest restoration includes the Gap Phase, Building Phase, and Maturity Phase according to the theory of Restoration Ecology. However, considering the ecosystem's extremely high biodiversity and complex community structure, the project team proposed a five-stage restoration process — closing the hillsides for afforestation, removing non-rainforest components, re-establishing communities, facilitating succession, and improving the ecosystem — to deal with the unknown challenges in ecological restoration from planted rubber forests (Fig. 16).

First, the strategy of closing the hillsides for afforestation may prevent tropical rainforest ecosystem from human interference in order to minimize disturbance for the restoration. Secondly, through a scheduled removal of planted rubber forests and non-tropic rainforest components with topographical considerations, preliminary rainforest habitats will be created. Thirdly, constructive or key species necessary for vegetation community establishment should be introduced and maintained to form a sound structure

表5：生态系统服务功能价值赋值表
Table 5: Valuation of each ecosystem service value

用地类型 Land use type	各个生态系统服务功能价值 (万元/km^2) Value of each ecosystem service (CNY 10,000 / km²)						
	供给服务 Provisioning service	涵养水源 Water conservation	固碳释氧 Carbon sequestration and oxygen release	积累营养物 Accumulating nutrients	保育土壤 Soil conservation	净化空气 Air purification	生物多样性 Biodiversity
建筑用地 Building land	0	0	0	0	0	0	0
水体 Water	162.44	0	0	0	0	0	0
荒地 Wasteland	0	42.78	187.86	41.39	3.98	0	0
农业用地 Agricultural land	78.55	0	180.44	0	0	0	0
灌木林 Shrub	0	236.25	196.29	49.47	4.72	0.04	0
经济林 Economic forest	145.12	154.17	204.79	36.85	4.45	0.99	0
热带雨林 Tropical rainforest	1.59	235.67	209.21	77.24	6.43	1.31	242.35
新植幼林 Seedling	0.95	141.40	125.53	46.34	3.86	0.79	145.41

表6：生态系统服务功能价值计算结果一览表
Table 6: Calculation results of ecosystem service value

	面积 Area measured / km²	各个生态系统服务功能价值 (万元) Value of each ecosystem service (CNY 10,000)							
		供给服务 Provisioning service	涵养水源 Water conservation	固碳释氧 Carbon sequestration and oxygen release	积累营养物 Accumulating nutrients	保育土壤 Soil conservation	净化空气 Air purification	生物多样性 Bio-diversity	合计 Total
现状 Current situation	36.00	4403.90	5780.15	7230.75	1474.81	164.32	35.16	1063.90	20152.98
规划初期 Early stage of planning	36.00	1312.45	66436.60	7195.34	1841.22	167.85	29.53	3943.46	19926.44
规划后期 Latter stage of planning	36.00	1396.21	7535.95	8207.26	2194.27	197.97	35.73	4989.91	24557.30

16. 从人工橡胶林到热带雨林的不同修复阶段

16. Restoration stages from the planted rubber forest to the rainforest

of tropical rainforest habitats. After years of succession, these vegetation communities will grow into rich-layered and stable tropical rainforests. Finally, actions should be taken to improve and manage the tropical rainforests by introducing more tree species to improve the structure of these rainforest communities.

(2) Creating New Habitats through Dynamic Restoration Methods

Tropical rainforest often undertakes irreversible ecosystem changes. Under the risks of climate change, key species loss, and species invasion, it is impossible to restore the ecosystem to any historical state[18]. Instead, practices should constantly adjust the restoration methods on ecosystem structures and services to create new habitats so as to achieve a new dynamic balance within the ecosystem.

(3) Restoration Evaluation and Management Mechanism

A monitoring system is also essential to evaluate and manage tropical rainforest restoration on each stage, ranging from overall assessments on the ecosystem stability and sustainability to single-factor examination on soil conditions[19]. For instance, it took about 190 years for Colombia to restore its tropical rainforest back to an ecosystem with a primeval-forest-like community structure. Thus, a long-term monitoring and research onto the tropical rainforest should cover the preliminary investigation and planning, the implementation and management of restoration methods, and finally the maintenance and evaluation on the restoration performance.[20] **LAF**

PROJECT INFORMATION

LOCATION: Jinghong City, Dai Autonomous Prefecture of Xishuangbanna, Yunnan Province, China
AREA (SIZE): 85 km^2
CLIENT: Jinghong Municipal Housing and Urban-Rural Development Bureau
LANDSCAPE ARCHITECTURE: China Academy of Urban Planning & Design Shenzhen
CHIEF PLANNER: Zhu Rongyuan
PROJECT TEAM: Lao Bingli, Zhuo Weide, Ren Jing, Chen Kan, Wang Zejian
COLLABORATOR: Shenzhen Long Chase Region Planning & Design Co., Ltd.
PLANNING PERIOD: 2017 to present

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