面向昆蒙框架的生物多样性快速评估和早期预警

俞乐
清华大学 地球系统科学系
leyu@tsinghua.edu.cn
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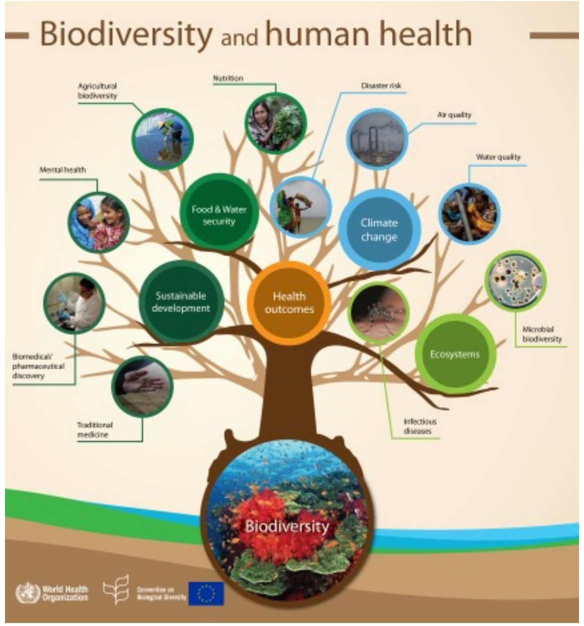
Kunming-Montreal
GLOBAL BIODIVERSITY FRAMEWORK

人类的生存发展需要生物多样性

生物多样性(生态系统、物种、遗传多样性)并非“锦上添花”，而是人类生存的基石

- 粮食安全：全球约75%的粮食作物依赖动物传粉，包括蜜蜂、蝴蝶、鸟类等（IPBES，2016）
- 气候调节：热带森林每年吸收约11.2Gt CO_2，占全球人类排放的30%（Friedlingstein et al., 2023）
- 渔业生计：全球渔业产业为约6,000万人提供就业，每年提供超1.5亿吨水产品（FAO，2022）
- 药用资源：超过**50%**的现代药物源自自然物种，如紫杉醇（抗癌）来自红豆杉，青蒿素（抗疟疾）来自青蒿（WHO, 2015）

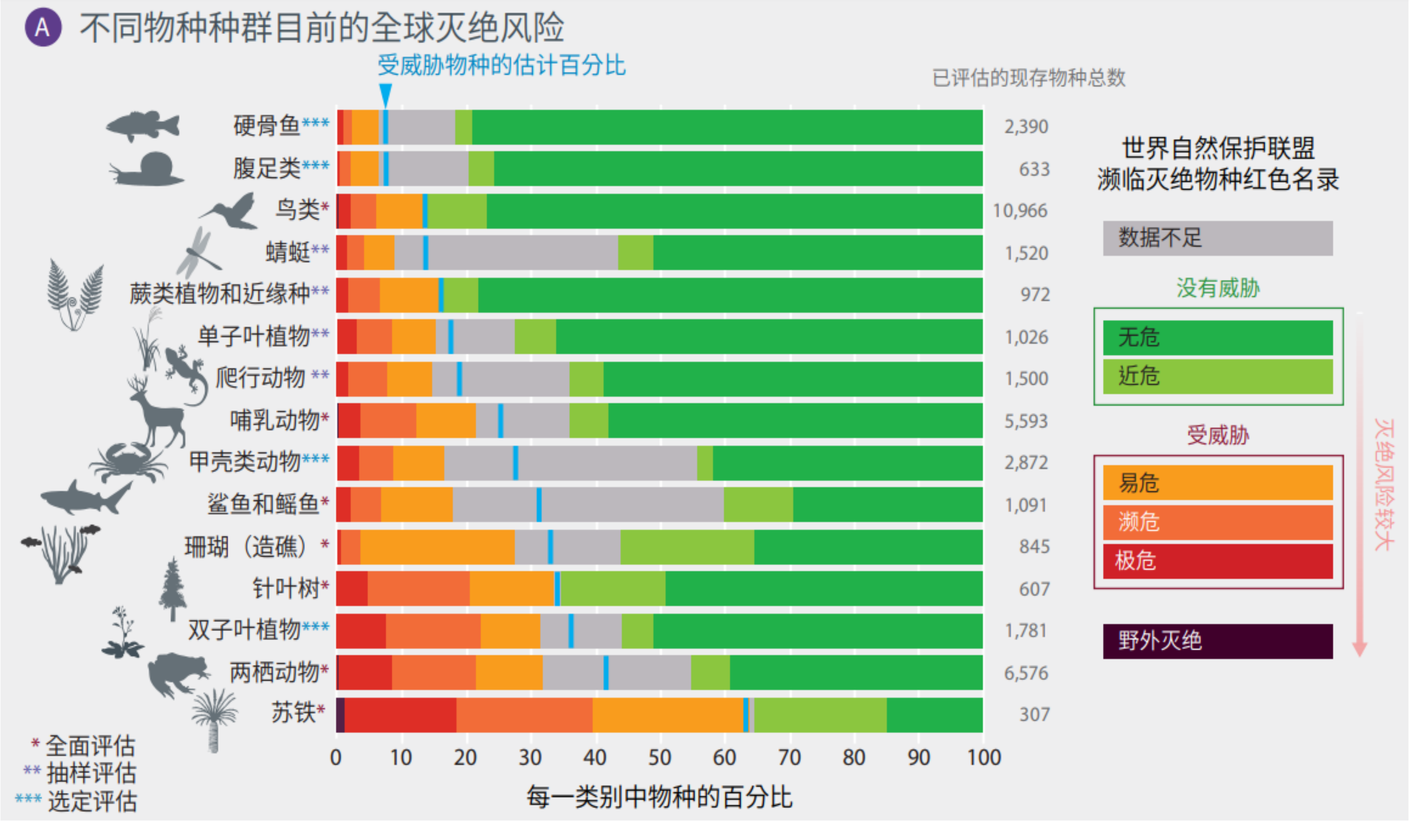


(WHO, CBd, EU, *2015*)

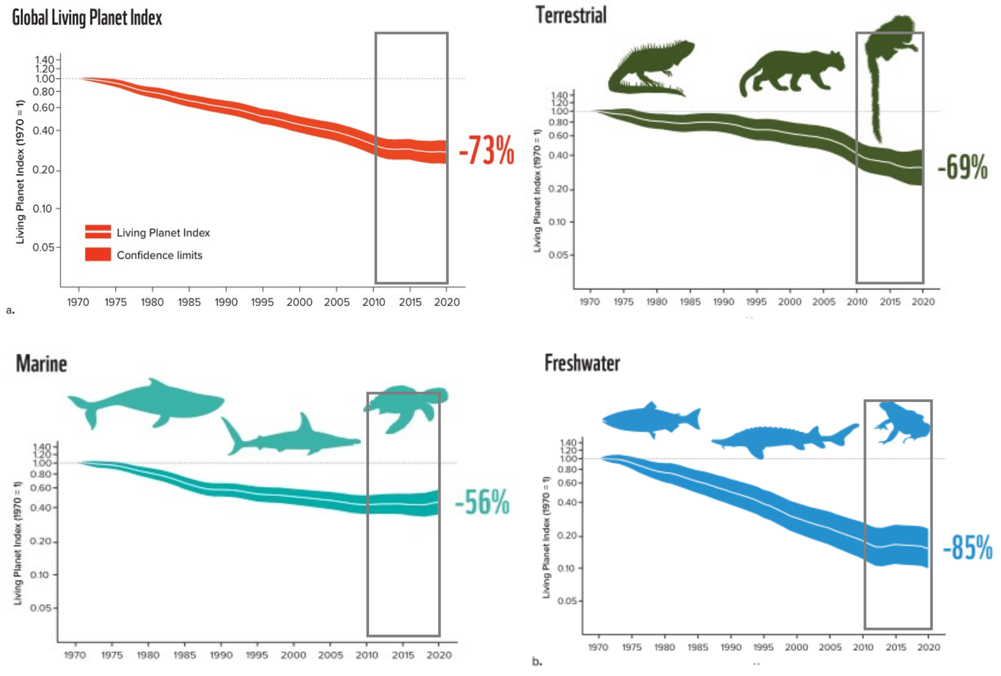
(WWF, *2024*)

全球生物多样性丧失现状

- 人类活动造成的栖息地丧失、气候变化、环境污染等驱动因素正持续威胁地球的生物多样性
- 全球物种绝灭速度比背景灭绝速度(过去一千万年的平均速度)高至少几十倍到几百倍，而且仍在加速
- 目前面临灭绝威胁的物种的平均比例约为25%
- 地球生命力指自1970年以来下降73%

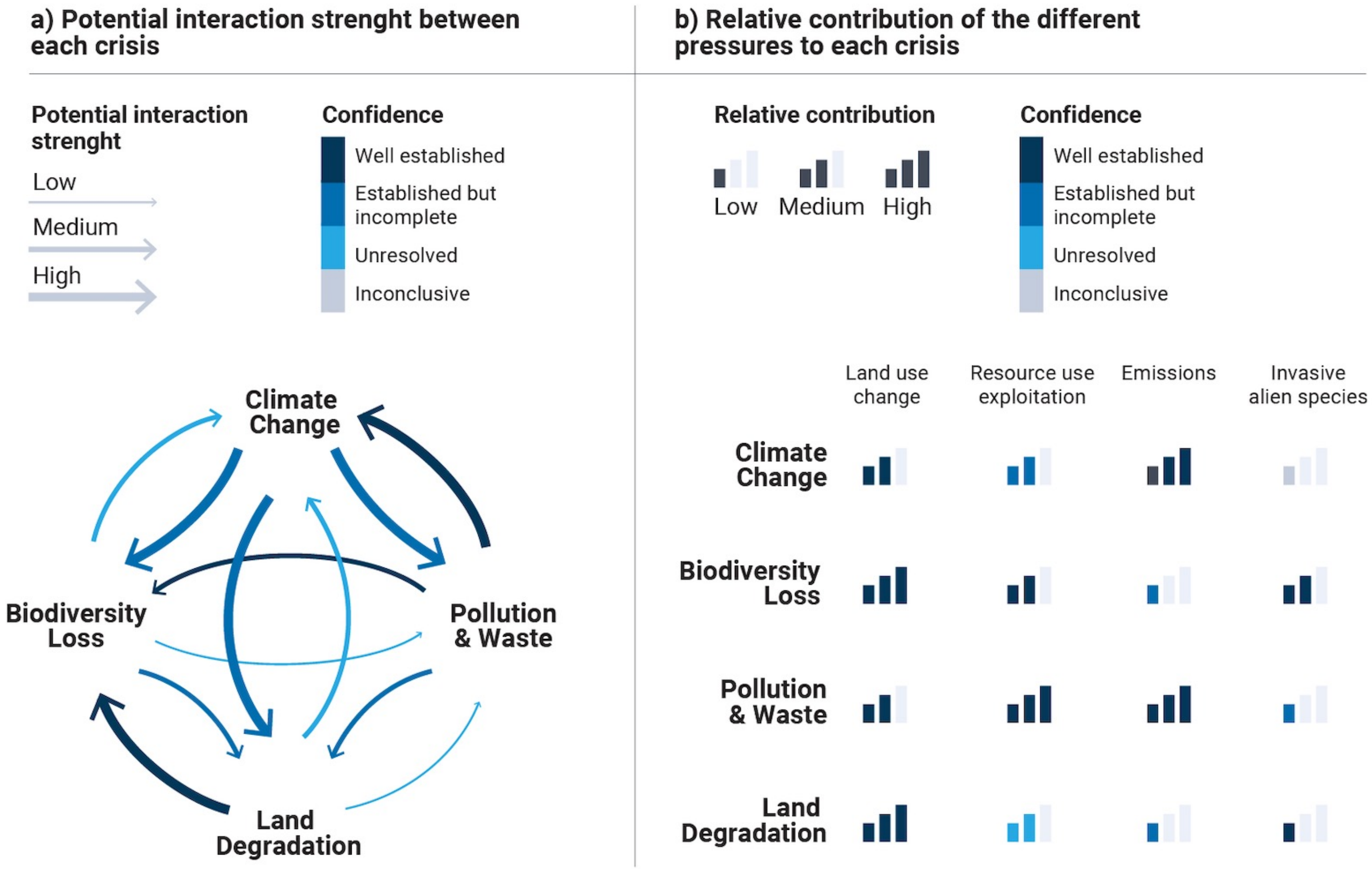


(IPBES, *2019*)



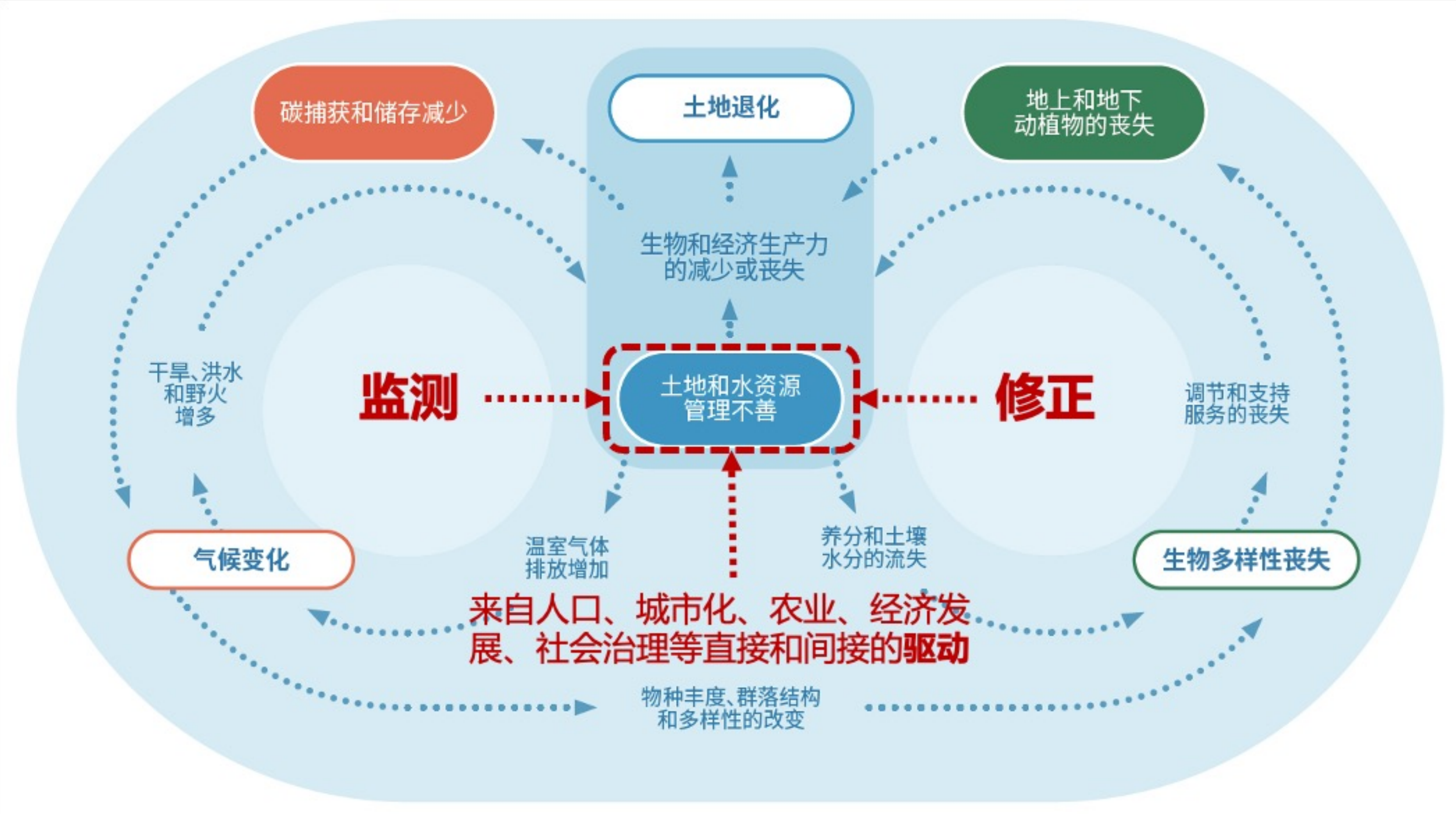
(WWF, *2024*)

全球环境危机互相交织



(UENP, 2025, *Global Environment Outlook 7*)

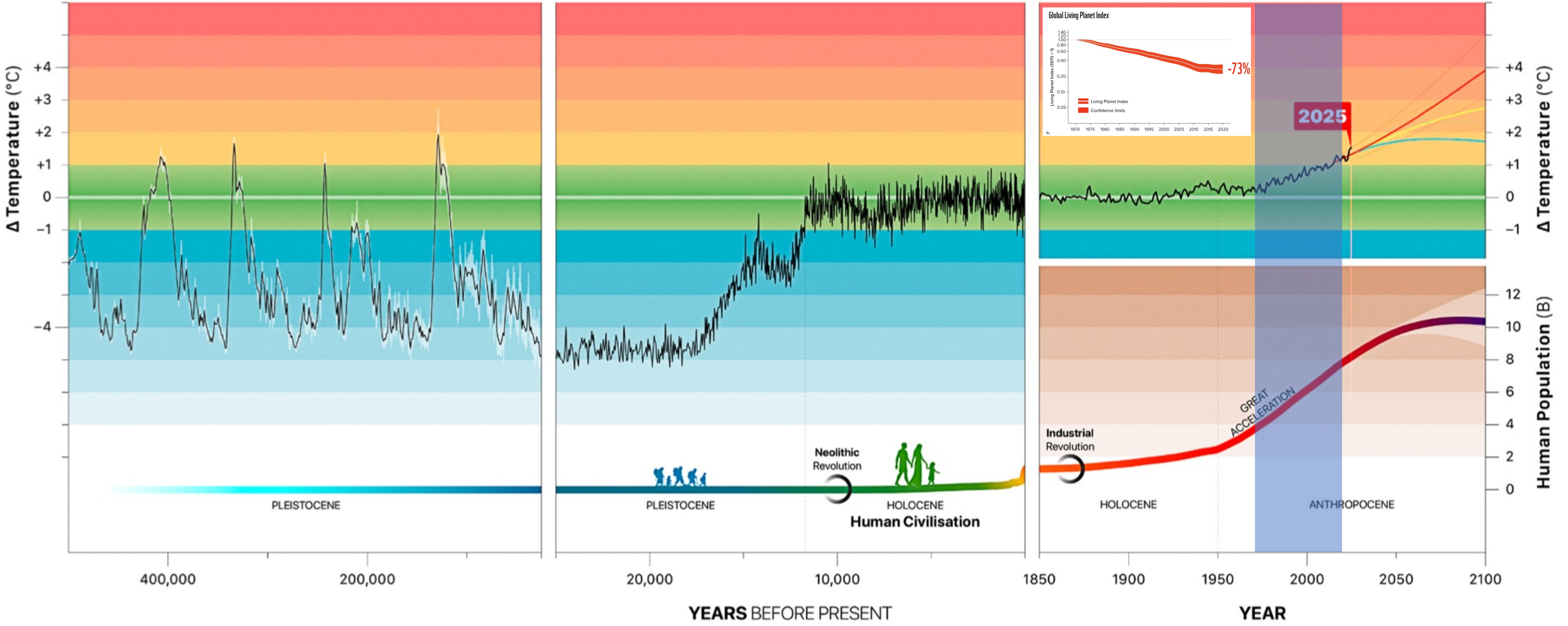
及时监测与评估



资料来源:千年生态系统评估,2005年。

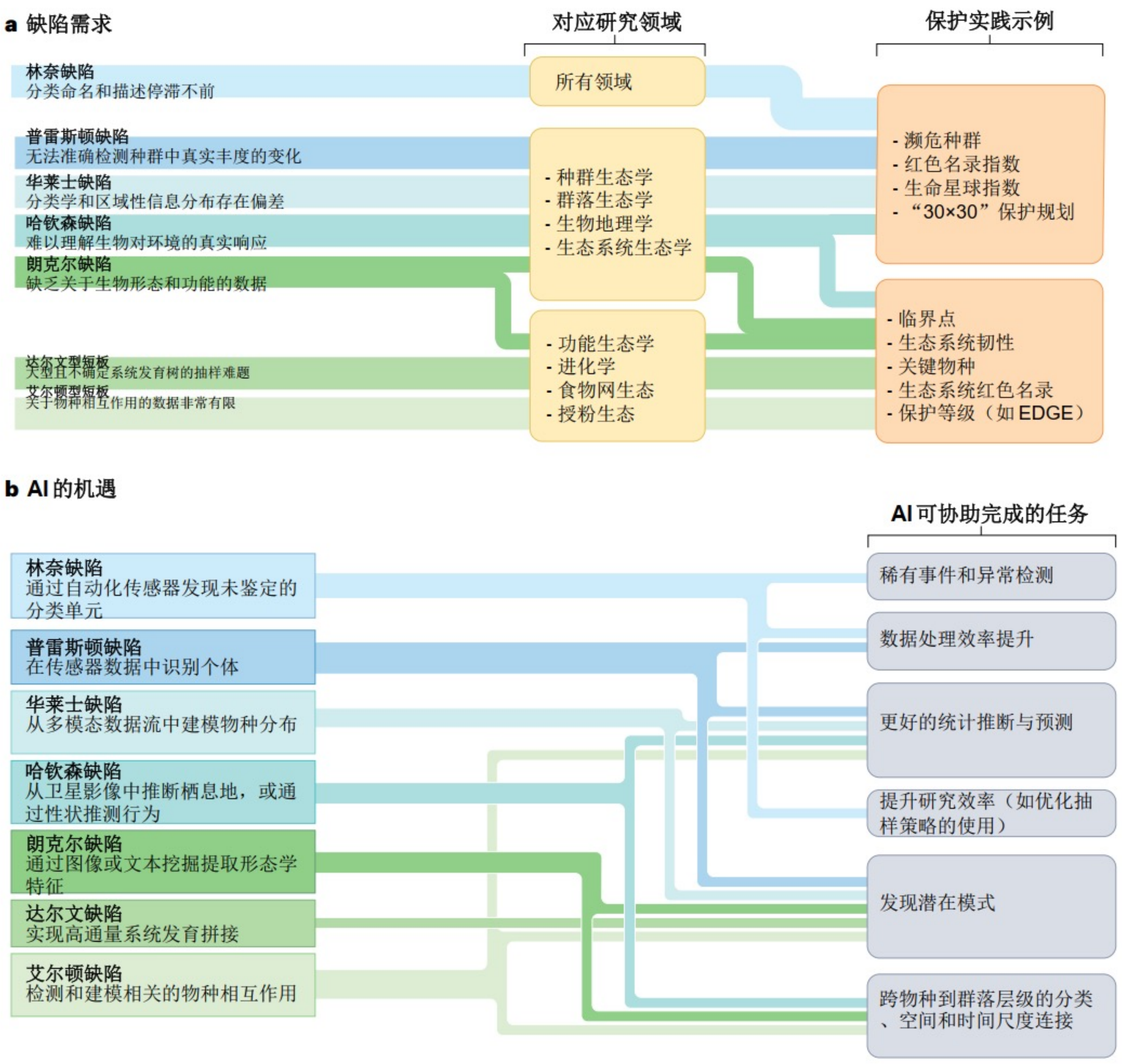
快速评估和早期预警

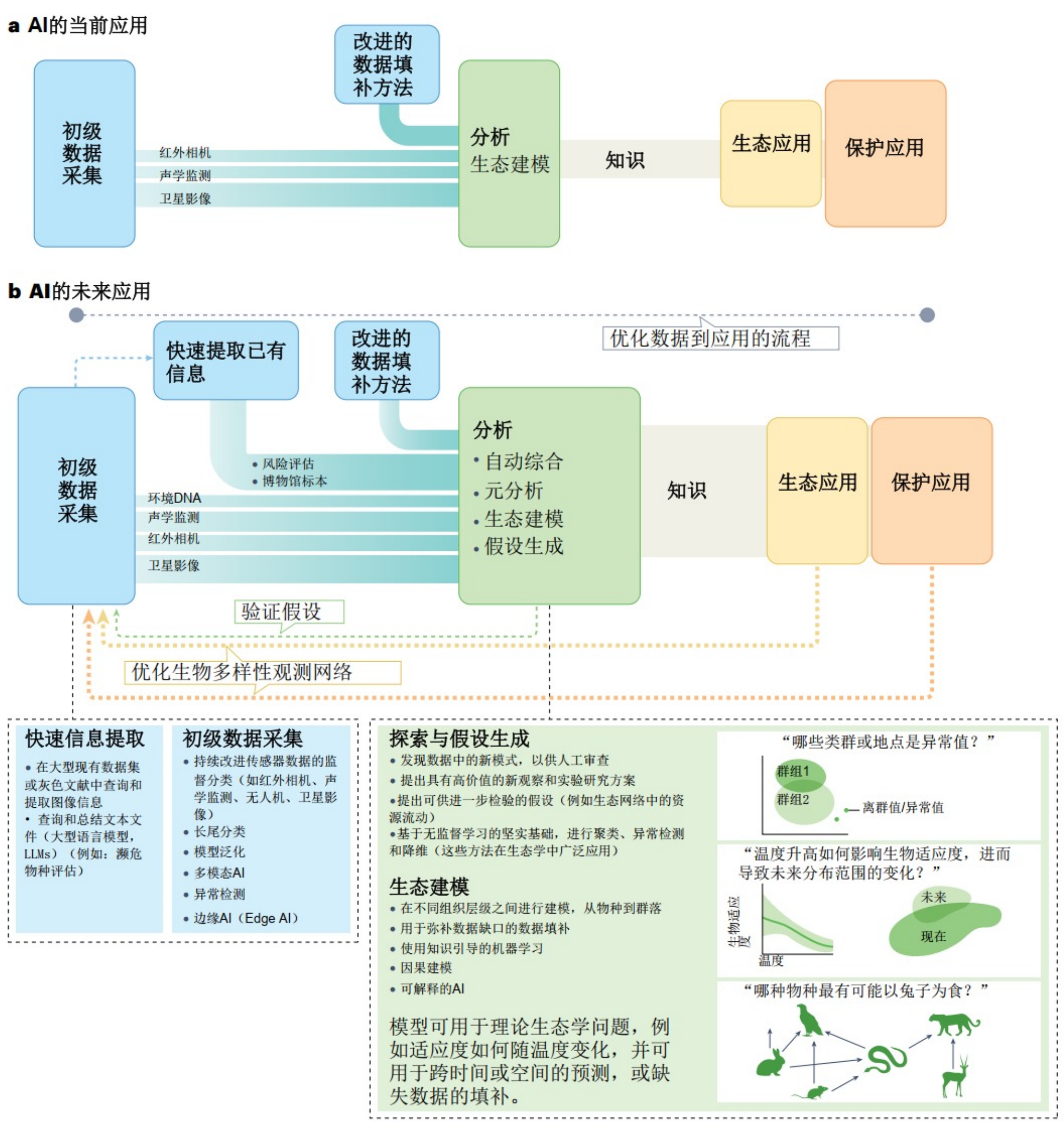
“一万多年来，人类一直生活在**气候极为稳定的时期**（即“绿色走廊”），并在这一时期演化发展，不断调整自身的技术与文化。然而，随着包括气候变化在内的多项行星边界被突破，**这一稳定时期已然终结**，我们正步入一个**全新而危险的阶段**——在这一阶段中，仍在持续增长的全球人口必须全力保障人类福祉。”



(PBScience, 2025. *Planetary Health Check 2025*)

信息技术+AI





(Pollock et al., 2025, *Nature Reviews Biodiversity*)

研究现状

1 长时序生物多样性**遥感监测**

进展：多尺度、全方位的监测能力提升，以及新技术如无人机和激光雷达的应用，使得生物多样性信息的获取更加直接和精确

局限：

- 多源遥感数据的海量性和复杂性，给数据处理、运算能力、存储空间带来挑战
- 空间分辨率的限制导致微观生态特征的捕捉能力欠佳
- 敏感性不足，面临气候变化和极端事件时的快速响应能力亟需增强

传统生物多样性监测

范围较小且耗时耗力，受限于指示物种

(Alberta Biodiversity Monitoring Institute)

生物多样性关键变量
EBVs, Essential Biodiversity Variables

… …

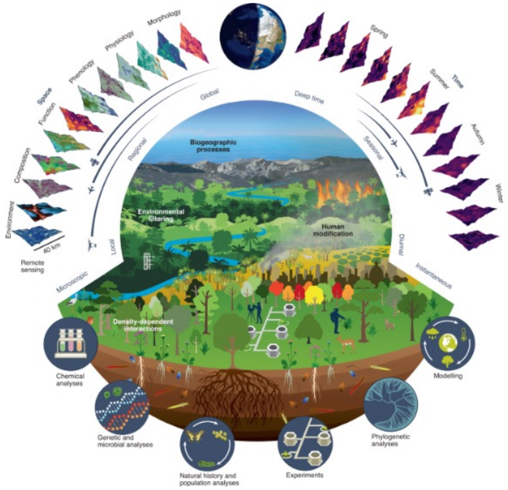
生态系统 — 物种 — 基因

… …

气候变化关键变量
ECVs, Essential Climate Variables

基于遥感的生物多样性监测

大范围长时间序列综合自动观测，直接有效

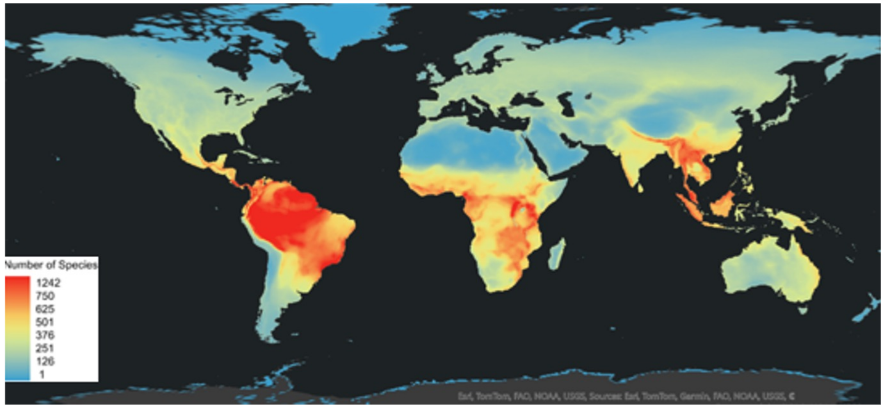


(Cavender-Bares, J., *Nature Ecology & Evolution*, 2022)

研究现状

2 生物多样性**制图**

进展：遥感和GIS技术使全球物种多样性制图取得显著进展，系统发育树和高通量测序技术推动了系统发育和基因多样性研究

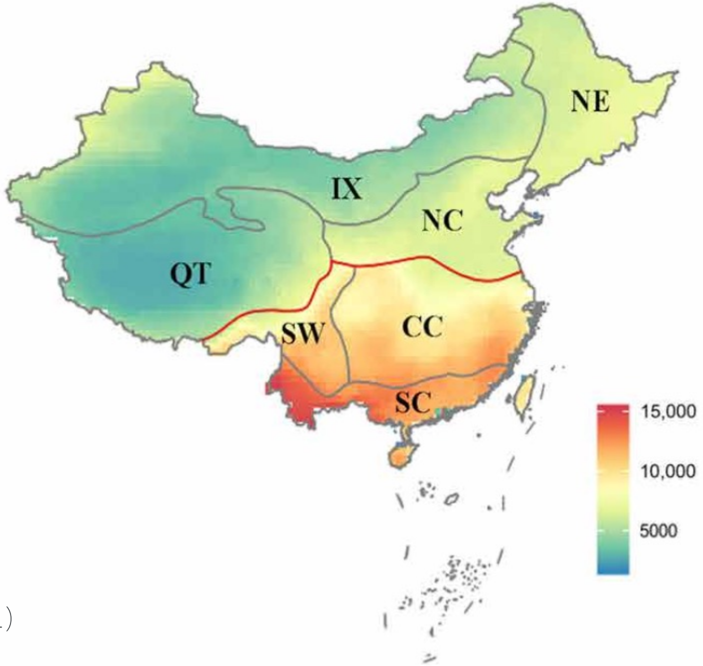


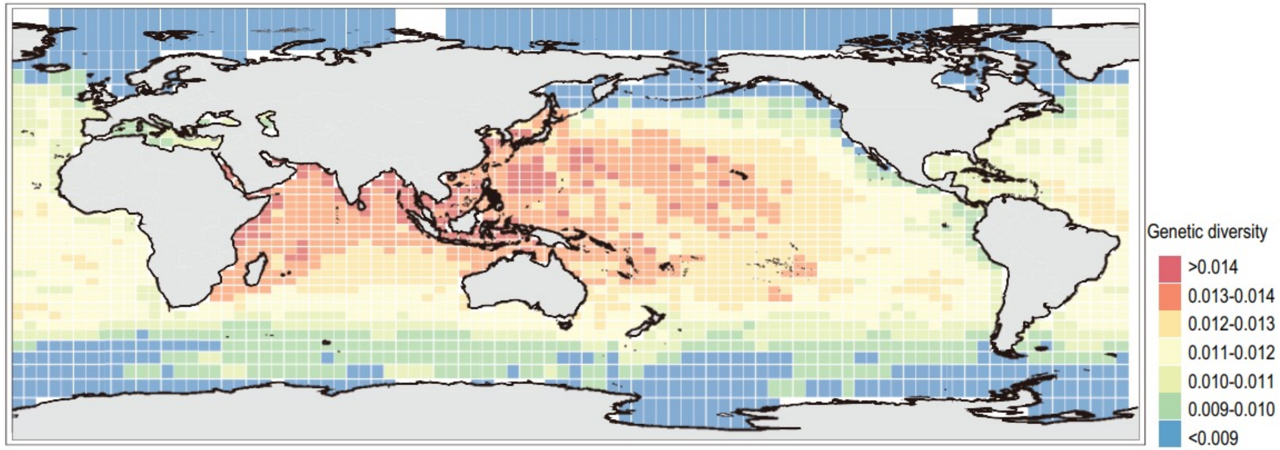
全球陆生脊椎动物物种多样性

IUCN Red List 2024）

中国陆生脊椎动物系统发育多样性

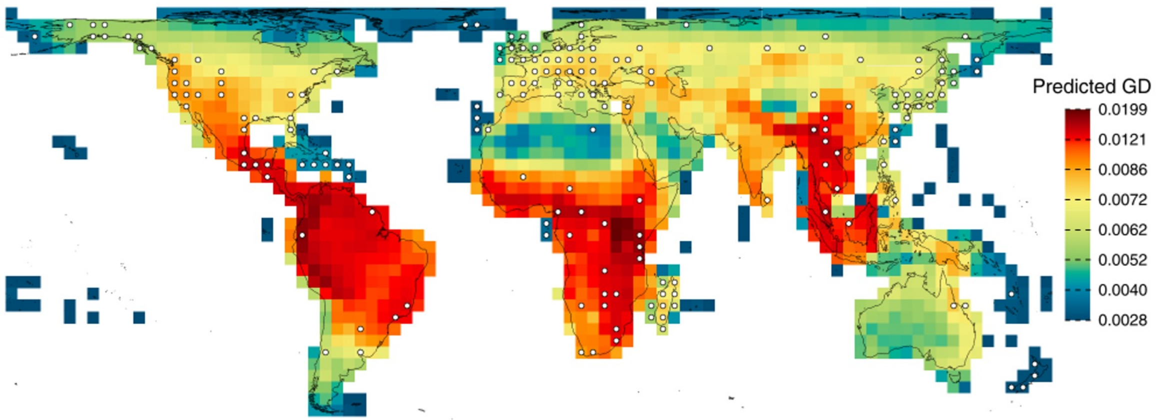
（Hu,et al., *Science Advances*, 2021）





全球海洋物种遗传多样性空间格局

（Fan et al., *National Science Review*, 2023）



cytb线粒体基因标记的全球哺乳动物遗传多样性预测

（Theodoridis et al., *Nature Communications*, 2020）

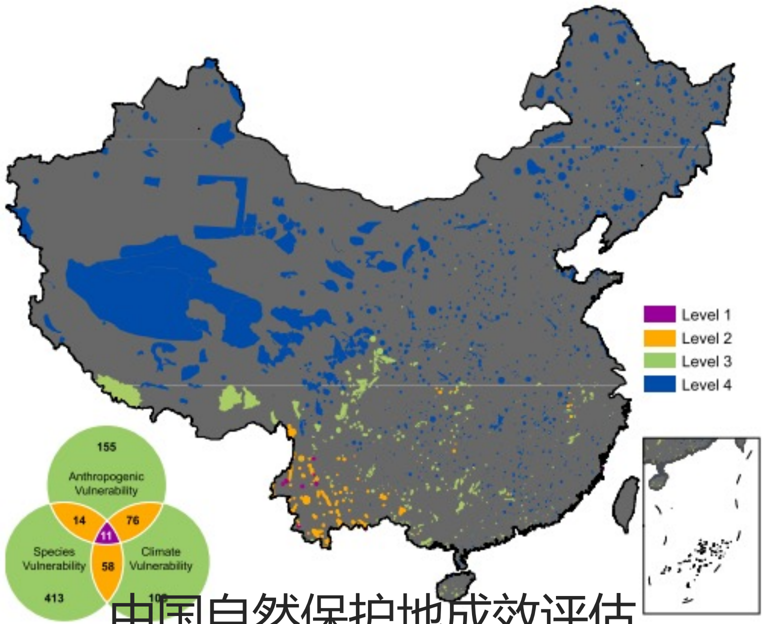
研究现状

3 保护成效评估

进展：揭示了保护区在缓解栖息地丧失方面的有效性和全球不同地区保护成效的显著差异

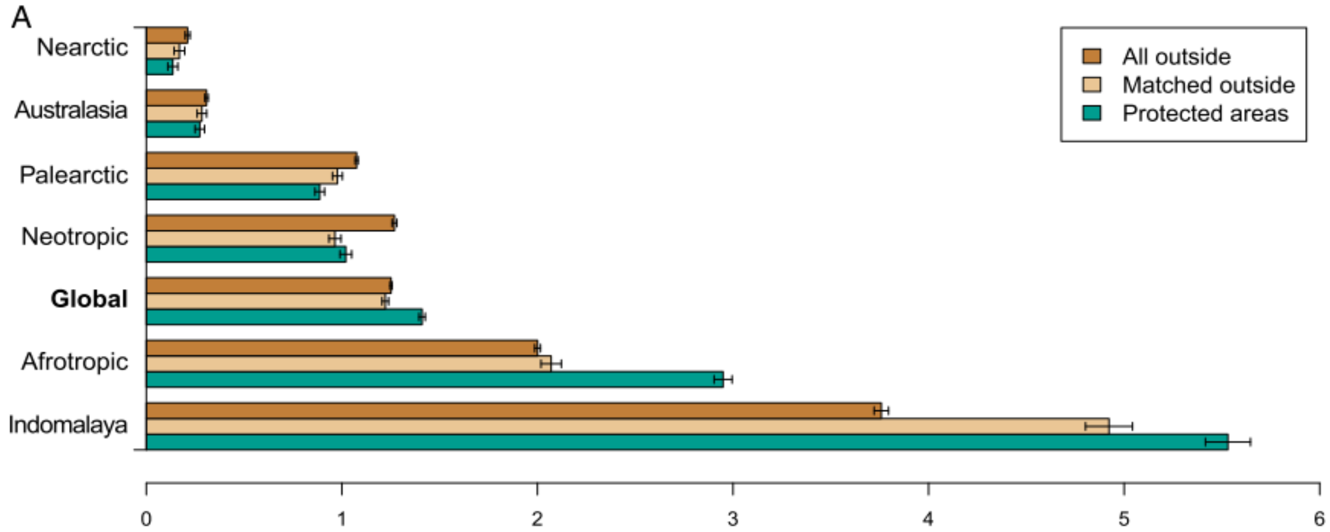
局限：

- 气候变化影响复杂且难以量化，保护成效评估的全面性不足
- 人类活动干扰难以分离，保护成效评估准确性不足
- 生物多样性动态变化难以捕捉，保护成效评估时效性不足



中国自然保护地成效评估

(Shrestha et al., *Nature Communications*, 2021)



与未受到保护的土地相比，自然保护地内的生境丧失情况

(Geldmann et al., *PNAS*, 2019)

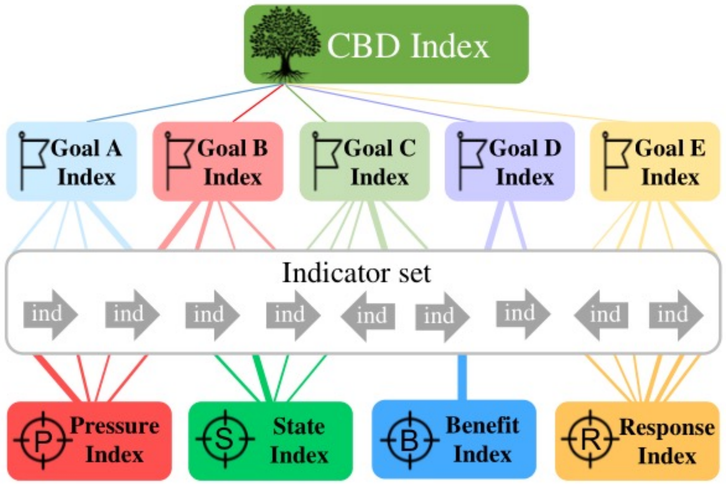
研究现状

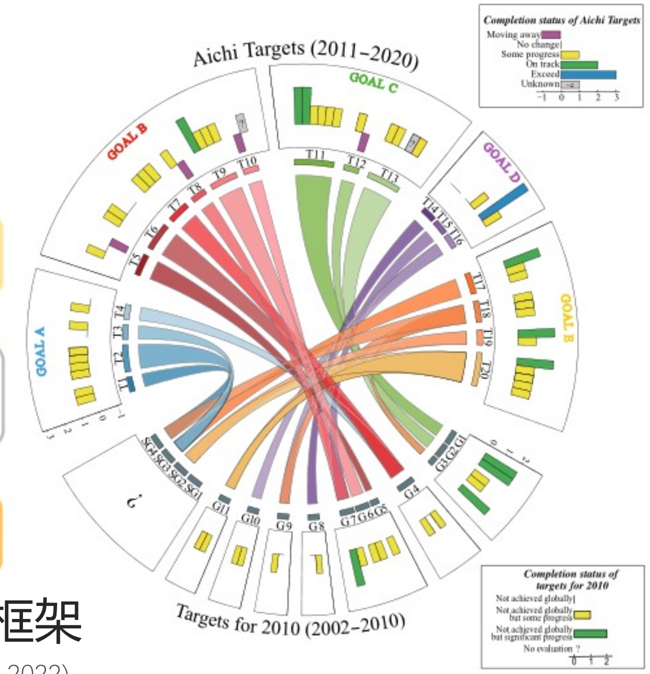
4 全球生物多样性目标进展盘点

进展：建立基于指标的评估框架和适应性统计框架，初步揭示了在各地区和领域的不同达成情况

局限：

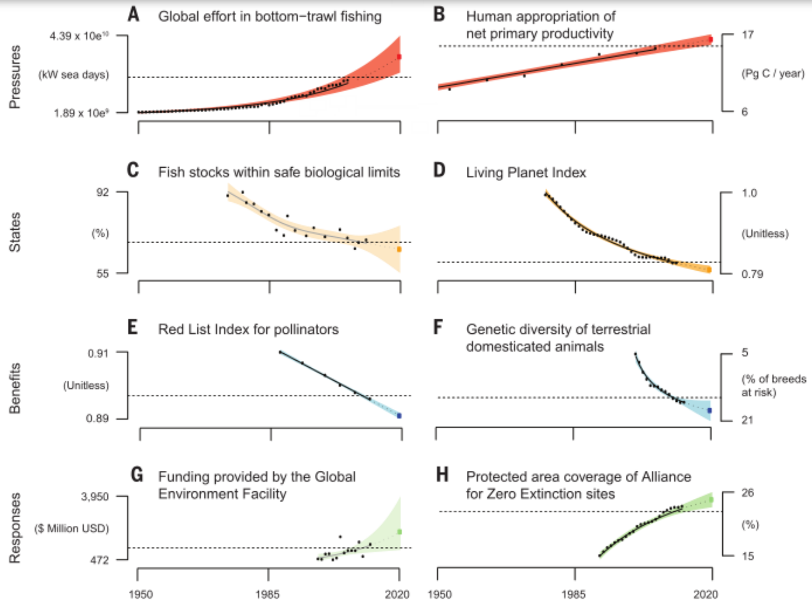
- 未能兼顾全面性和简洁性，指标过于复杂影响可操作性，指标过于简单影响全面性
- 因各层次目标和优先级不同，难以在全球、区域和国家多尺度上实现差异化评估
- 不同地区数据获取能力差异影响跨区域评估准确性





基于指数的评估框架

(Hu et al., *Science Advances*, 2022)



适应性统计框架

(Tittensor et al., *Science Advances*, 2014)

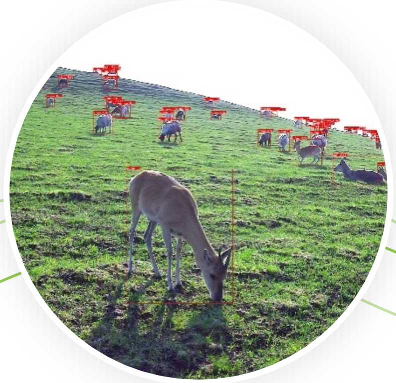
研究现状

5 AI助力生物多样性保护

从物种识别到栖息地监测，从威胁检测到决策支持，人工智能在生物多样性保护中的应用代表了一场范式转变，为解决复杂的生态挑战提供了新的视角和工具。

但面临数据质量不齐、AI偏见与幻觉等问题，未来应学科交叉、整合技术，突破数据壁垒，共建生物多样性基础大模型。

物种识别与分类



(Tomer et al., *IET Computer Vision*, 2024)

栖息地监测与分析

(Chen et al., *Advances in Climate Change Research*, 2022)

威胁预警与防范

(Kwame Nti et al., *Sustainable Futures*, 2022)

种群跟踪与统计

(Liu et al., *Computers and Electronics in Agriculture*, 2024)

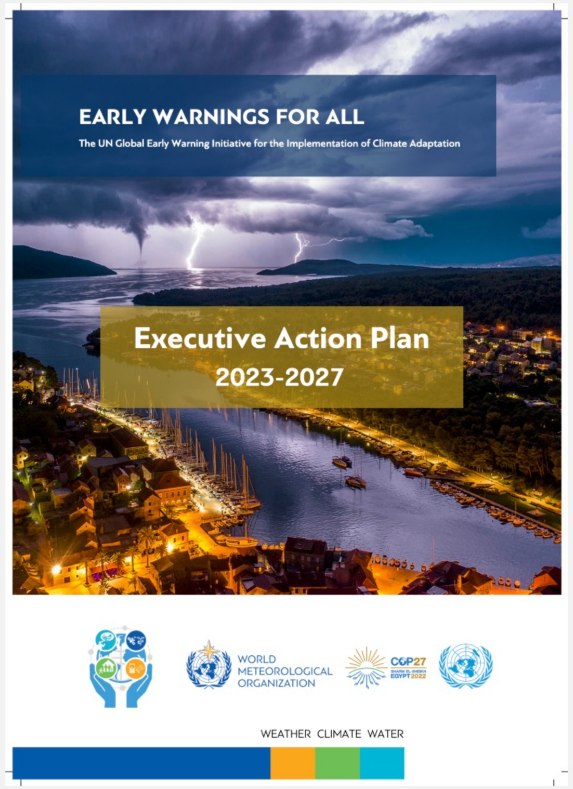
生态预测与决策支持

(Chen et al., *Ecology and Evolution*, 2021)

研究现状

联合国全民早期预警行动计划

Early Warnings for All: Executive Action Plan 2023-2027



"The facts are clear. Early warnings save lives and deliver vast financial benefits. I urge all governments, financial institutions and civil society to support this effort." – UN Secretary-General António Guterres

The Action Plan calls for investments of US$ 3.1 billion over five years – just 50 cents per person per year – to strengthen disaster risk knowledge and management, observation and forecasting, dissemination and communication of warnings, and preparedness and response capabilities.

It leverages existing pooled funding mechanisms, such as the Climate Risk and Early Warning Systems initiative and the Systematic Observations Financing Facility, as well as global multilateral funds including the Green Climate Fund and the development banks.

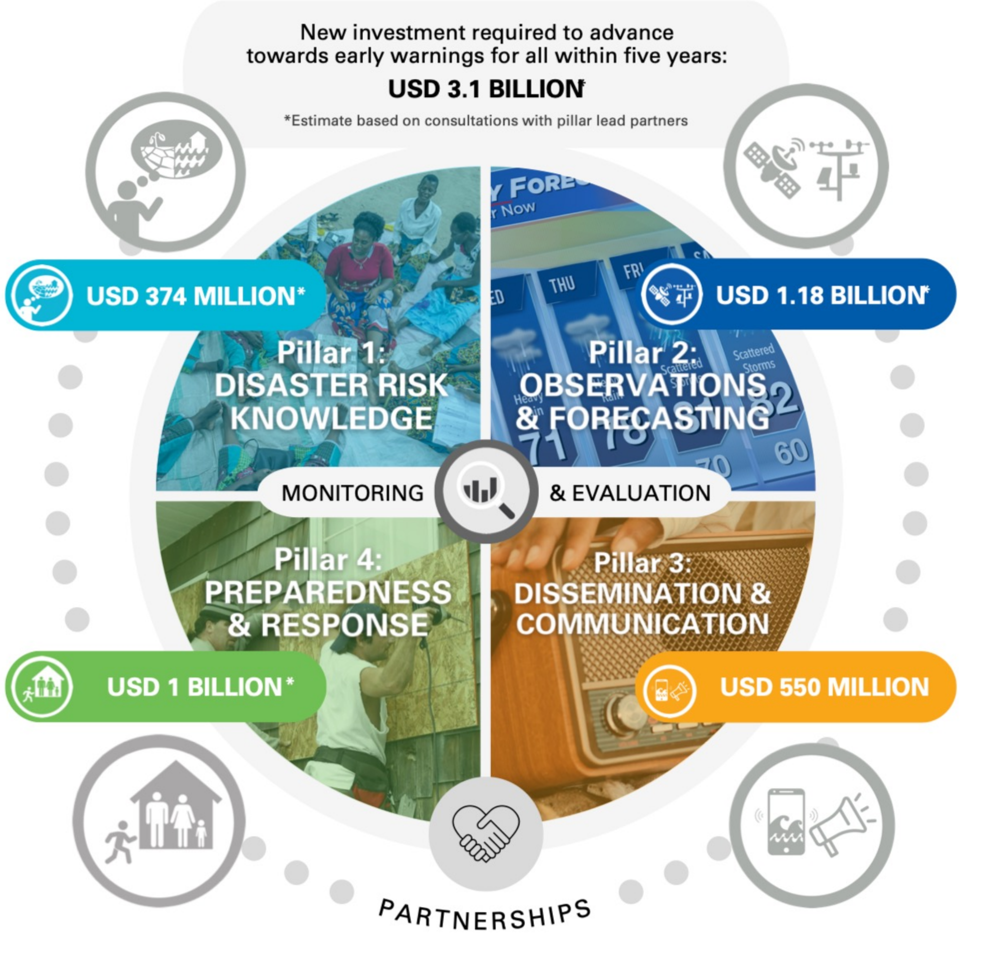


Figure 1: Budget overview for the four Pillars of the Early Warnings for All Initiative

https://earlywarningsforall.org/site/early-warnings-all/dashboards/early-warnings-all-dashboard

研究现状

全球早期预警系统建设核心要素

定义：识别**潜在危机**（饥荒、洪灾、疾病等）、发出警报的信息系统，核心价值为提前识险、快速响应、减轻灾害冲击

- ☐ **风险知识：**系统性数据收集与风险评估
- ☐ **监测预警服务：**技术监测与事件预测
- ☐ **信息传播沟通：**预警信息及时传达
- ☐ **响应能力：**社区 / 公众理解与应对能力

领域	核心系统 / 倡议	关键功能
农业	GIEWS（FAO）、FEWS NET（USDA）、CropWatch（CAS）等	作物监测、产量预估、粮食安全风险预警
城市	MCR2030 倡议、C40 城市气候联盟	城市韧性建设、热浪 / 暴雨等气候风险应对
灾害	GMAS（WMO）、GDACS（UN / 欧盟）	多灾种监测、跨区域协同；108 国已部署（2024）
健康	EWARS（WHO）、GPHIN、GOARN	传染病监测、跨国应急响应、公共卫生安全保障
生物多样性	借鉴多领域经验构建一体化框架	监测 - 评估 - 响应协同，支撑《昆蒙框架》目标

(俞乐等, 2025, *生物多样性*)

研究现状

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https://doi.org/10.5194/esd-15-1117-2024

Earth System Dynamics
Open Access
EGU

Review

Tipping point detection and early warnings in climate, ecological, and human systems

Vasilis Dakos[1], Chris A. Boulton[2], Joshua E. Buxton[2], Jesse F. Abrams[2], Beatriz Arellano-Nava[2], David I. Armstrong McKay[2,3], Sebastian Bathiany[4], Lana Blaschke[4,5], Niklas Boers[2,4,5], Daniel Dylewsky[6], Carlos López-Martínez[7,8], Isobel Parry[2], Paul Ritchie[2], Bregje van der Bolt[9], Larissa van der Laan[10], Els Weinans[11], and Sonia Kéfi[1,12]

[1]ISEM, Univ Montpellier, CNRS, EPHE, IRD, 34095 Montpellier, France
[2]Global Systems Institute, University of Exeter, Exeter, UK
[3]Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden
[4]Earth System Modelling, School of Engineering and Design, Technical University Munich, Munich, Germany
[5]Potsdam Institute for Climate Impact Research, Potsdam, Germany
[6]Department of Applied Mathematics, University of Waterloo, Waterloo, Ontario, Canada
[7]Signal Theory and Communications Dept., Universitat Politècnica de Catalunya UPC, Barcelona, Spain
[8]Institut d'Estudis Espacials de Catalunya IEEC, Barcelona, Spain
[9]Environmental Sciences Group, Water Systems and Global Change, Wageningen University and Research, Wageningen, the Netherlands
[10]Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
[11]Copernicus Institute of Sustainable Development, Environmental Sciences, Faculty of Geoscience, Utrecht University, Utrecht, the Netherlands
[12]Santa Fe Institute, 1399 Hyde Park Road, Santa Fe, NM 87501, USA

Correspondence: Vasilis Dakos (vasilis.dakos@umontpellier.fr) and Chris A. Boulton (c.a.boulton@exeter.ac.uk)

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OPINION

Plants People Planet PPP
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Integrating machine learning, remote sensing and citizen science to create an early warning system for biodiversity

Alexandre Antonelli[1,2,3] | Kiran L. Dhanjal-Adams[1] | Daniele Silvestro[2,4,5]

[1]Science Directorate, Royal Botanic Gardens Kew, Richmond, UK
[2]Gothenburg Global Biodiversity Centre, Department of Biological and Environmental Sciences, University of Gothenburg, Gothenburg, Sweden
[3]Department of Biology, University of Oxford, Oxford, UK
[4]Department of Biology, University of Fribourg, Fribourg, Switzerland
[5]Swiss Institute of Bioinformatics, Fribourg, Switzerland

Correspondence
Alexandre Antonelli, Science Directorate, Royal Botanic Gardens Kew, Richmond, Surrey, TW9 3AE, UK.
Email: a.antonelli@kew.org

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Societal Impact Statement
The development and implementation of conservation actions that address urgent threats to biodiversity across the globe require large amounts of historic and current data. Machine learning approaches offer the tools to process, analyse and interpret large data sets, giving insights into trends and guiding evidence-based allocation of limited resources to maximise positive biodiversity outcomes. Here we describe how data acquired from remote sensing, citizen science and other monitoring approaches could feed in near-real time into an early warning system for biodiversity that integrates automated red-listing of species with the identification of priority areas for conservation.

Summary
Application of machine learning approaches is aiding biodiversity conservation and research at a time of rapid global change. Two emerging topics and their data requirements are presented. First, to identify areas of priority protection for preventing biodiversity loss, reinforcement learning is used by training models that take into account human disturbance and climate change under recurrent monitoring schemes. Second, neural networks are used to approximate classification of species into Red List categories of the International Union for Conservation of Nature, offering the possibility of real-time re-classification after events such as widespread fires and deforestation. We discuss how the identification of areas and species most at risk could be integrated into an 'early warning system' based on climatic monitoring, remotely sensed land-use changes and near-real time biological and threat data from citizen science initiatives. Such system would help guide actions to prevent biodiversity loss at the speed required for effective conservation.

KEYWORDS
artificial intelligence, citizen science, climate change, conservation biology, machine learning, modelling, neural network, warning system

融合多源卫星遥感与近地表相机的物候监测优化

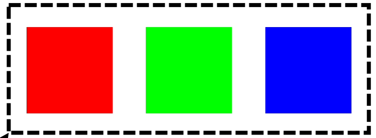
近地面遥感是指利用地基传感器或成像设备来监测并研究局部植被物候和生态系统过程

主要优势

- 高时空分辨率（从小时级到逐日级别的观测结果），捕捉快速的物候变化
- 观测数据可与单个被监测植被构建直接联系
- 可以验证和丰富大尺度卫星监测结果

地表监测应用

- 可与卫星图像相结合，进行高分辨率、高频率的土地覆盖动态制图
- 监测植被和作物状况，验证卫星遥感监测产品，了解多尺度生态系统过程



$$GCC = \frac{2\times Green}{Red + Green}$$

绿色色度坐标

提供验证数据:

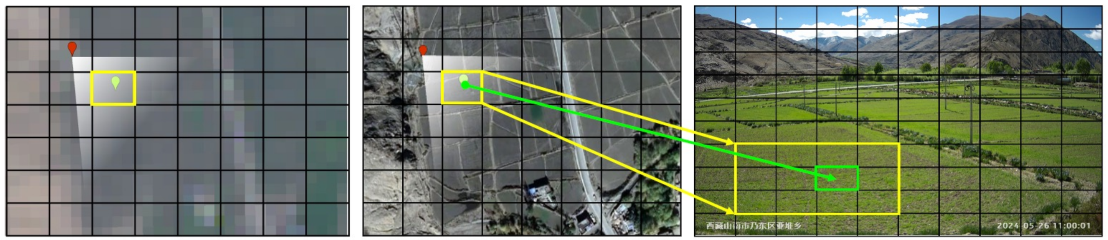
- 植被物候
- 人类活动
- 积雪变化
- 极端天气
- … …

(Yu* et al., 2024, *Climate Smart Agriculture*)

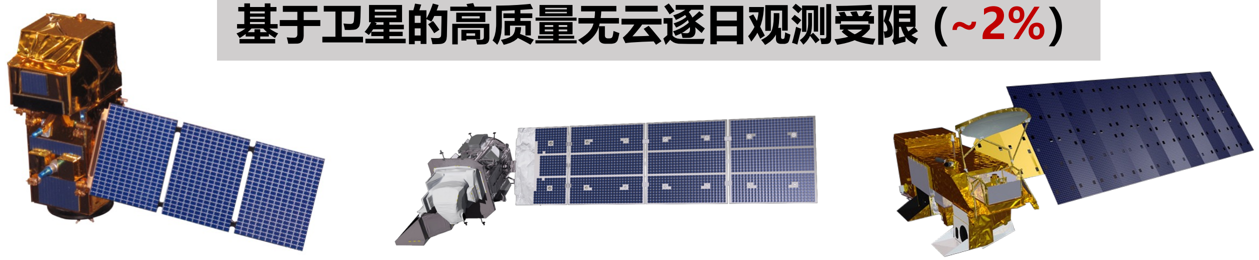
融合多源卫星遥感与近地表相机的物候监测优化

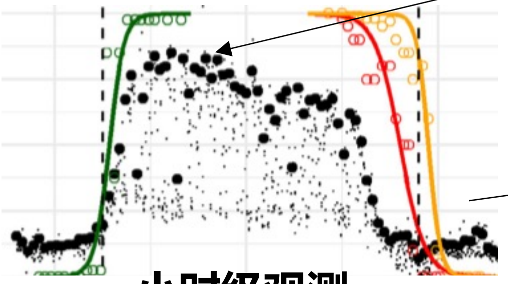
近地表相机与卫星数据的空间匹配及融合

哨兵2号　　谷歌地球影像　　近地表相机

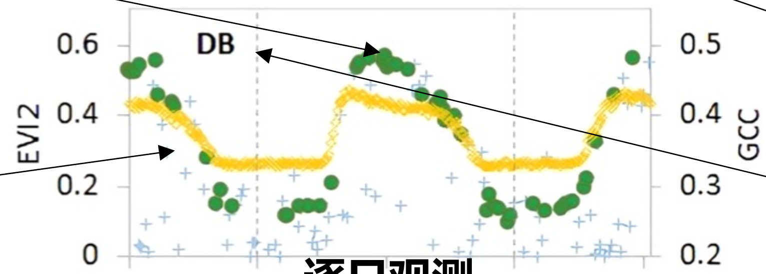


基于卫星的高质量无云逐日观测受限（~2%）

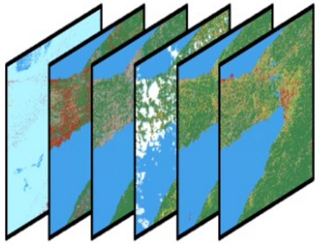




小时级观测



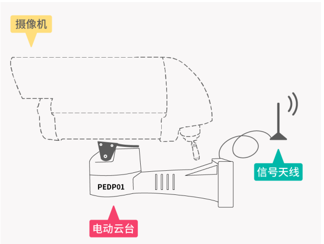
逐日观测



地表动态监测

新型近地表相机设计

- 网络状况
- 天气状况
- 能源效率
- 易于安装
- 图像/视频/音频
- 价格低廉

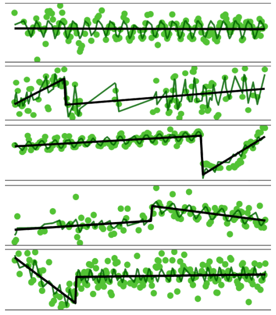


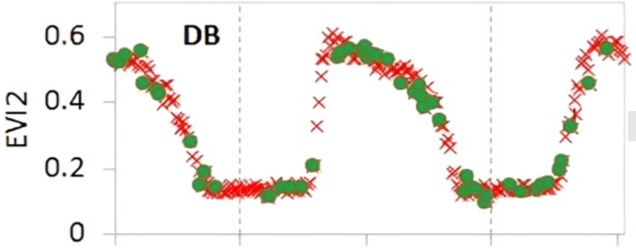
prototype

精准且快速的地表动态变化监测

变化程度
(细微变化，巨变)

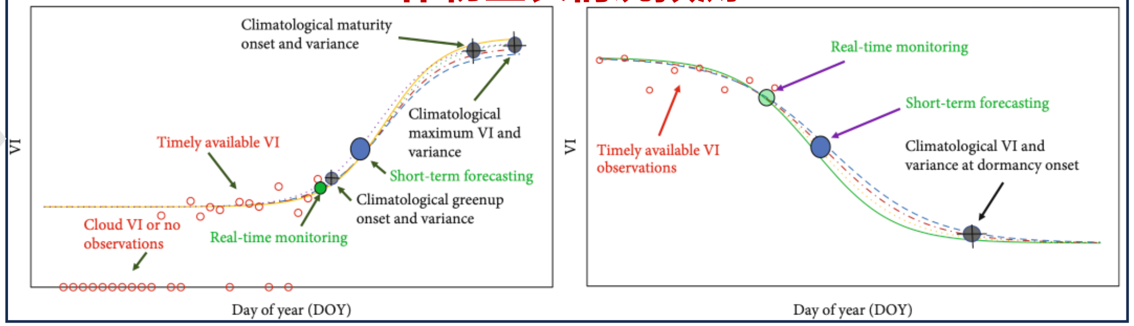
变化持续时段
(突变，缓变)





融合校准后的逐日观测

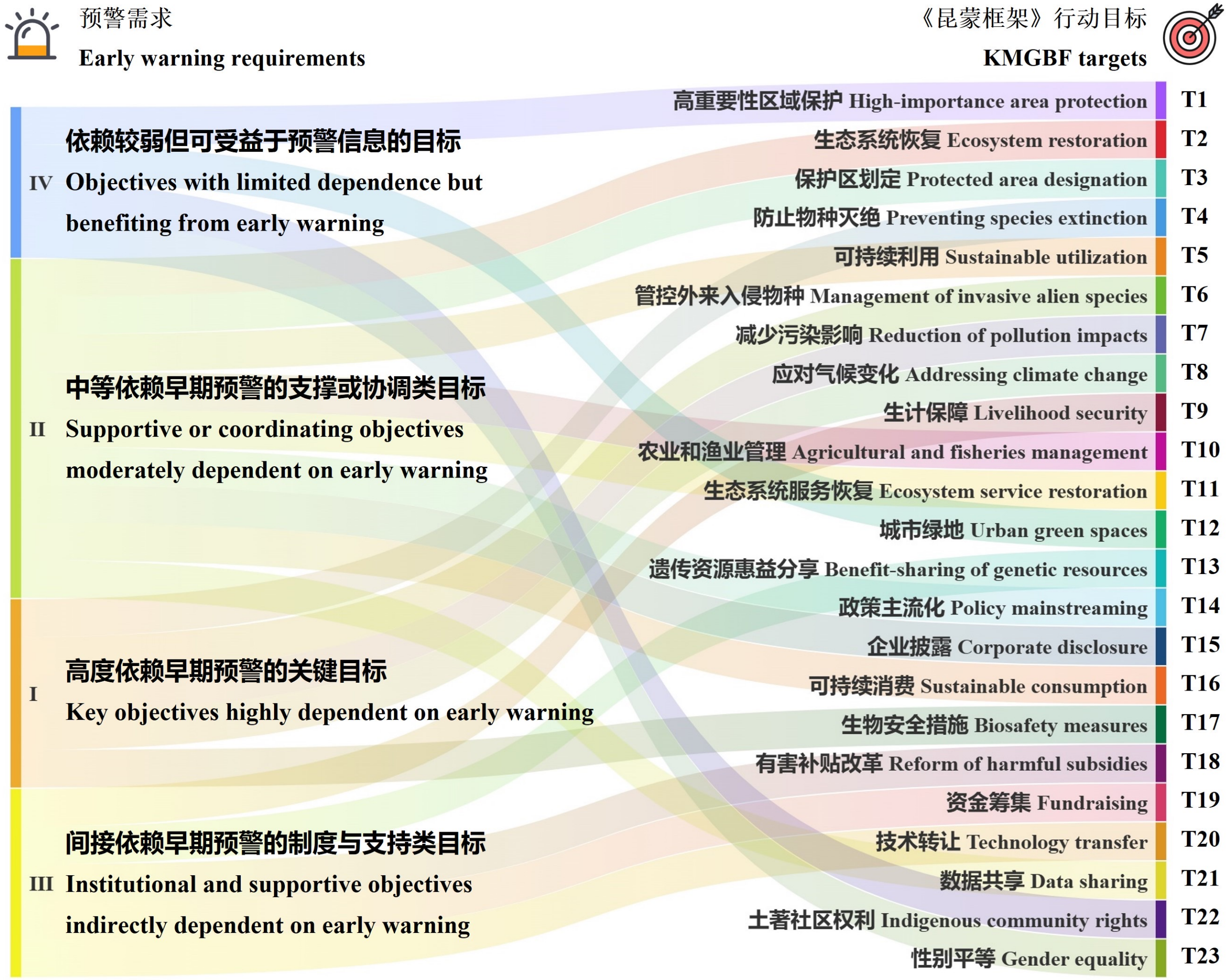
作物生长情况预测



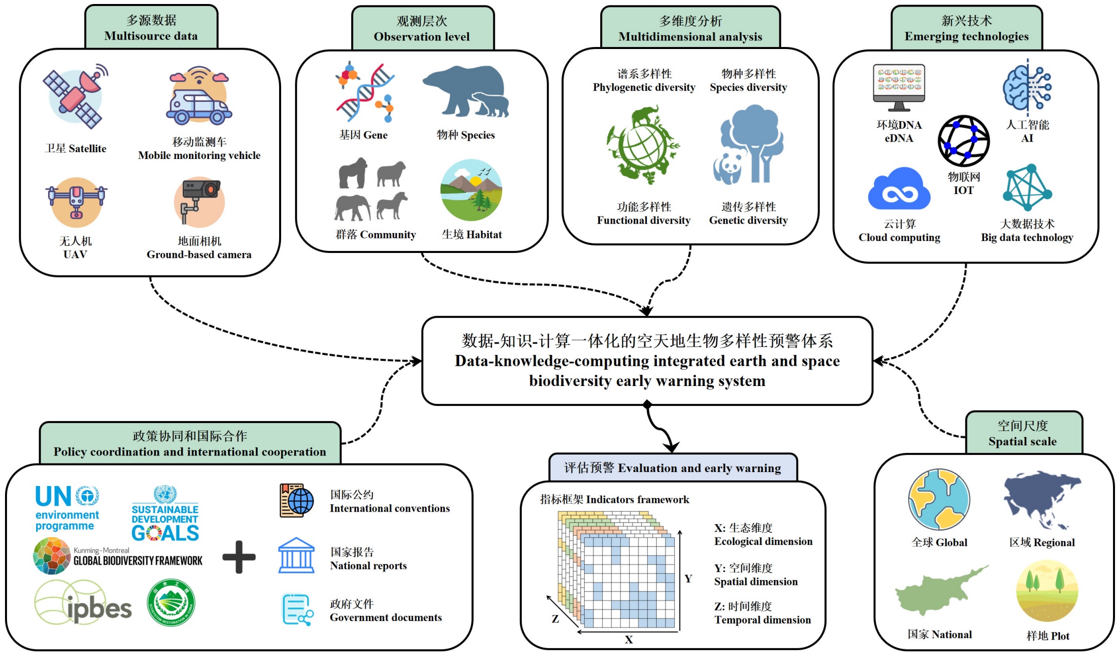
(Yu* et al., 2024, *Climate Smart Agriculture*)

生物多样性变化快速评估与早期预警

面向《昆蒙框架》目标的生物多样性早期预警



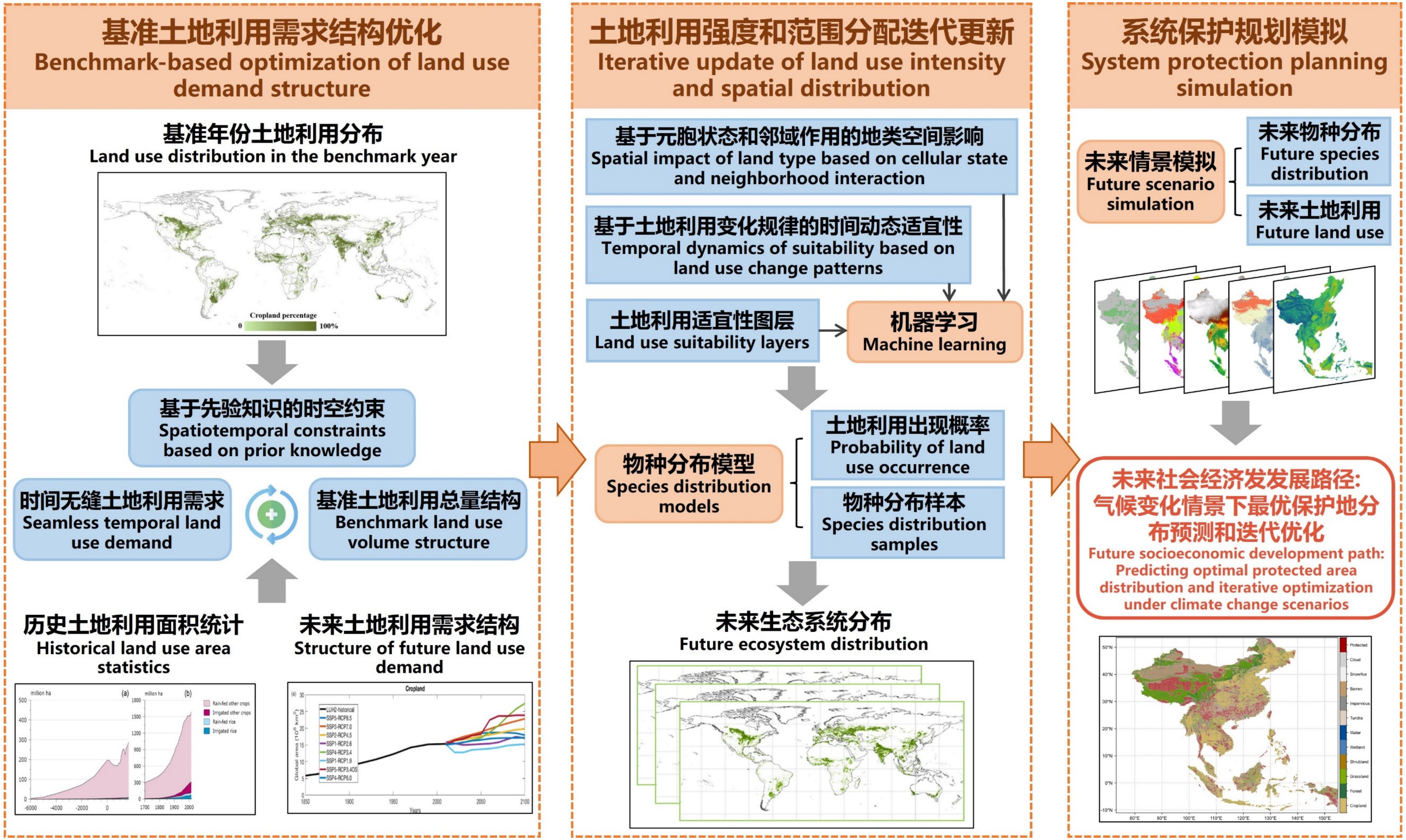
面向《昆明-蒙特利尔全球生物多样性框架》的全球生物多样性预警体系



《昆明-蒙特利尔全球生物多样性框架》与预警体系需求的关联性

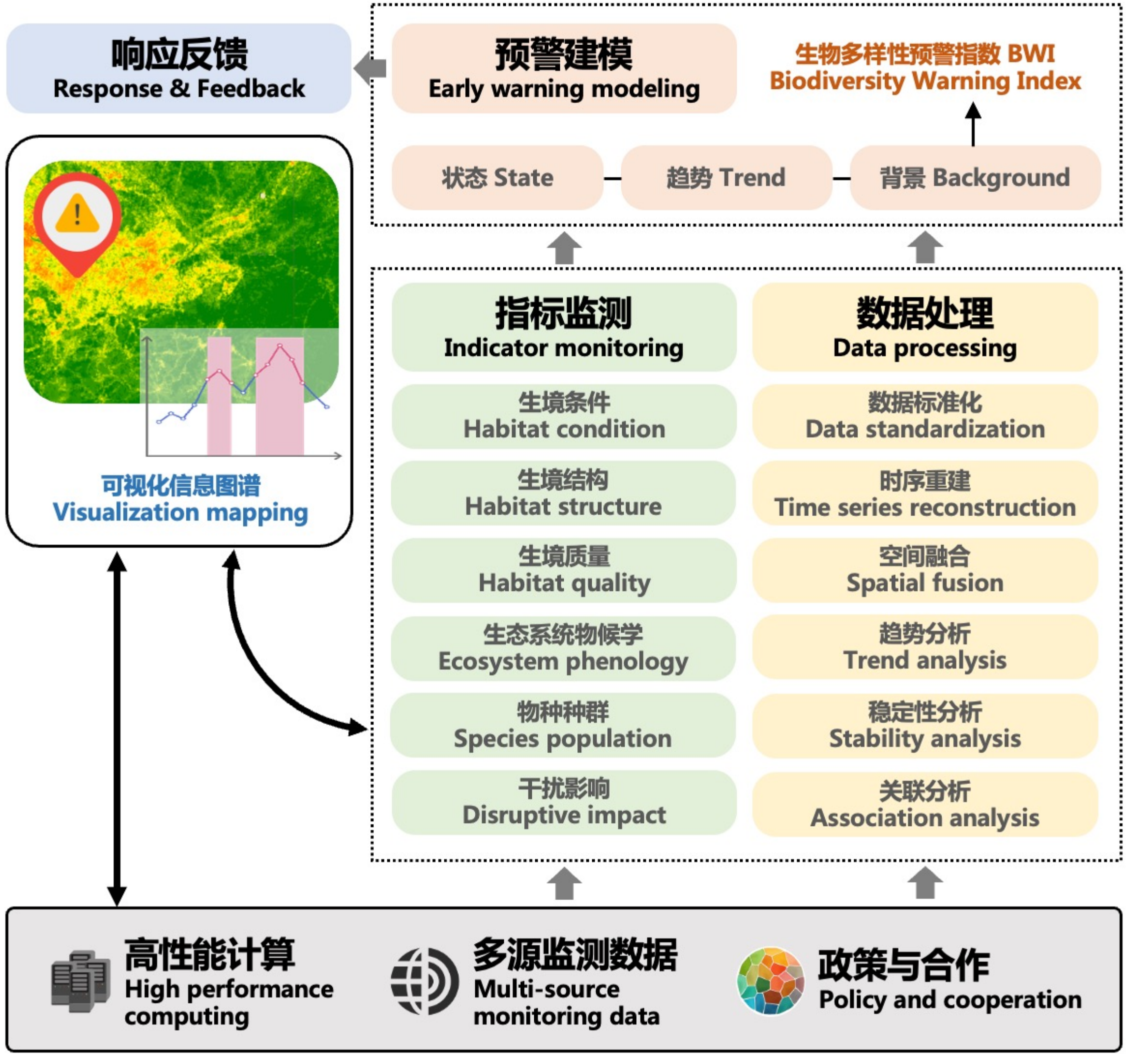
(俞乐等, 2025, *生物多样性*)

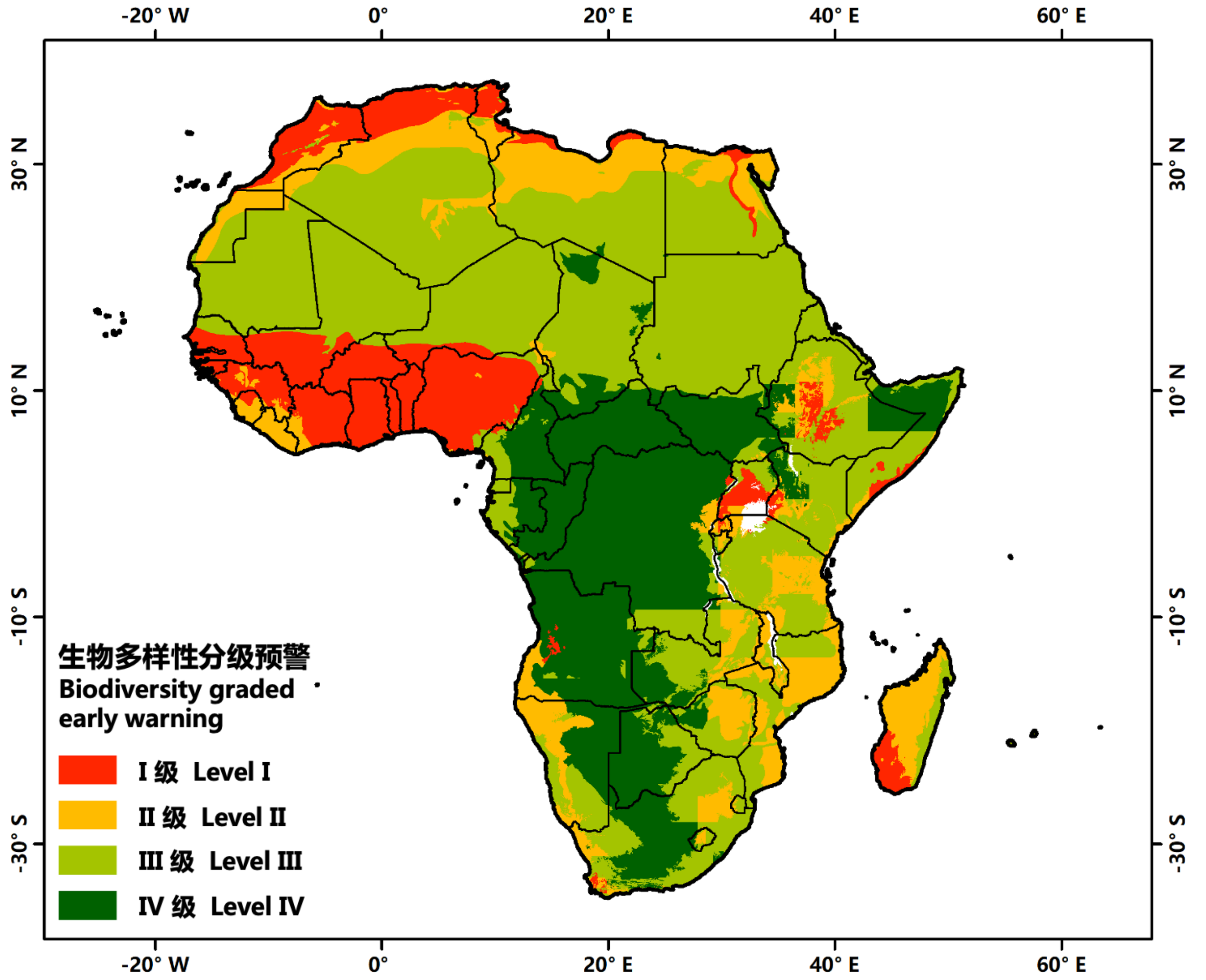
生物多样性变化快速评估与早期预警



(俞乐等, 2025, *生物多样性*)

生物多样性变化快速评估与早期预警





(俞乐等, 2025, *生物多样性*)

致谢：武慧、杜贞容、顾珈同、赵强、李曦煜

感谢各位专家
敬请批评指正

俞乐
清华大学 地球系统科学系
leyu@tsinghua.edu.cn
2025-12-25

Kunming-Montreal
GLOBAL BIODIVERSITY FRAMEWORK