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•保护论坛•

生物多样性和生态系统服务：实现东亚热带和亚热带的生态安全

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摘要：东亚热带和亚热带地区拥有全球陆地生物多样性的15–25%，然而该区域大部分地区的生物多样性因经济的快速发展而面临威胁。实现与生物多样性保护相适应的经济发展需要对自然为人类、社会以及经济提供的惠益进行正确的理解和评价。这些惠益也被称为生态系统服务，且可以多种方式进行分类。大多数生态系统服务的产生依赖于野生物种和生态系统，尽管其质量和数量与野生物种的多样性之间往往没有简单的关联。许多全国范围内的生态系统服务评估已经进行，但这些评估往往过于简单，通常只针对少数几个易于量化的生态系统服务，并没有包括一些对当地居民来说最重要的生态系统服务，因此，依照该评估制定的政策往往是不恰当的。生态系统服务来源于自然资本，即自然资源总量，如果这个资本耗尽，它所能提供的生态系统服务就会减少。生态安全是通过保护或恢复地区重要生态系统服务所需的关键自然资本来实现的。尽管中国的一些生态系统服务有所改善，但东亚热带和亚热带地区大部分生态系统服务总体趋于恶化。要在以人类为主导的世界实现区域生态安全，需要在全球、区域、国家和地方各层面上采取行动。

关键词：生物多样性；生态系统服务；自然资本；生态安全；生态文明

Biodiversity and ecosystem services: Towards ecological security in tropical and subtropical East Asia

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Abstract: Tropical and subtropical East Asia supports around 15–25% of global terrestrial biodiversity. This is now threatened in many areas by rapid economic development. Achieving development that is compatible with biodiversity conservation requires that the benefits of nature to people, to society, and to the economy are understood and correctly valued. These benefits are known as ecosystem services and have been classified in various ways. Most ecosystem services depend on wild species and ecosystems for their production, although there is often no simple relationship between their quality and quantity and the diversity of wild species. There have been many assessments of ecosystem services at the national scale, but these are necessarily very simplified, usually focusing on a few, easily quantified, services. As a result, they often fail to include the services which are of most importance to local people and can therefore lead to incorrect policy decisions. Ecosystem services are derived from natural capital, which is the total stock of natural resources, so if this capital is depleted the services it can produce decline. Ecological security is achieved by preserving or restoring the critical natural capital needed to maintain vital ecosystem services in the region. Although there have been recent improvements in some ecosystem services in China, the overall trends in most services in tropical and subtropical East Asia are negative. Achieving regional ecological security in a human-dominated world will require action at the global, regional, national, and local levels.

Key words: biodiversity; ecosystem services; natural capital; ecological security; ecological civilization

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东亚是全球生物多样性的热点地区。该地区内的大多数物种都分布在热带和亚热带区域，即30°–35° N的中国南部地区和整个东南亚地区，包括缅甸、老挝、越南、泰国、柬埔寨、马来西亚、文莱、新加坡和印度尼西亚。东亚热带和亚热带地区的面积占全球陆地总面积不足4%，但估计孕育了全球陆地植物和动物物种总数的15–25% (Corlett, 2014)。虽然物种总数尚不明确，但已有一些类群被研究得较为清楚，包括约800种哺乳动物、2,300种鸟类、930种蛙类、3,500种蝴蝶以及至少8万种陆生植物。该地区淡水物种多样性所占全球的比例大致相同(Collen et al, 2014)，而海洋物种多样性的比例甚至更高(Tittensor et al, 2010)。该地区还拥有从低地热带雨林到半荒漠和高山冻原以及从珊瑚礁到高海拔湖泊的极其多样的自然生态系统。

东亚热带和亚热带地区聚集着十多亿人口。约7万年前，该地区第一批现代人完全依靠自然资源来维持生存。然而，过去的4,000–5,000年的农业扩张以及近300年来城市的发展削弱了人类福祉与自然资源之间的联系。如今，人类的大部分食物来源于农业生产，服用的大部分药物来源于试验配制，服装多数来源于工厂制造，饮用的水大部分源自供水系统，大部分能源则来自化石燃料。尽管人类仍旧从自然界获得多方面的惠益，统称为“生态系统服务”，但这些往往没有得到充分认识，因此自然界对人类的贡献通常会被低估。

现今经济的迅速发展威胁着整个东亚地区的生物多样性和生态系统服务(Hughes, 2017)，许多物种受到威胁，主要的自然生态系统已经变成小面积的、受干扰的残存区域；因此，生物多样性保护是东亚热带和亚热带地区的一项紧迫任务。但是有超过十亿人生活在这一地区，保护必然与经济发展竞争土地和资源。因此，理解和正确评估自然对人类、对社会和经济的贡献至关重要，这也是本文的重点内容。

1　人类从野生物种和生态系统获得的惠益

人类从大自然获得的惠益被称为生态系统服务。生态系统服务有多种定义和分类方法，但最常见的为以下4类: (1)供给型服务，包括提供食品、药品、材料(木材、纤维、树脂等)、能源和遗传资源; (2)调节型服务，包括调节供水和水质量、清除废弃物、防止土壤侵蚀、防止沙尘暴、降低洪水风险、调节当地和全球气候、减轻空气污染、防治病虫害，以及保持授粉者的种群等服务; (3)文化型服务，包括娱乐、审美和精神价值等非物质惠益; (4)支持型服务。前三类生态系统服务反过来依赖于支持型服务，即构成生态系统的众多生物个体、物种和过程提供的初级生产力和养分循环。

生态系统服务概念的提出有益于人们关注从自然中可以获得的诸多好处，但在实际应用中却存在许多问题。这些问题大部分是由于这个概念融汇了许多不同的内容和方面，其中有些易转换成货币价值(如食物、能源)，有些则难以量化(如遗传资源、气候调节、传粉者的保持)，也有一些只能间接进行量化(如美学、精神价值)(Gunton et al, 2017; Pascual et al, 2017)。不同的生态系统服务对于人类的重要性在不同空间尺度上都有所体现，温室气体在全球范围内扩散，因此巴西森林所提供的固碳服务与云南森林提供的并没有多少差别; 从城市居民的角度来看，食品和原料供应在全国范围内是相互融合的，所以区域供应的变化并不重要; 相反，供水和防洪则集中在一个小的流域尺度上，只有居住在流域内的人才会面临生态系统服务的问题。最后，野生食品和药品的提供，对当地气候、害虫和传粉媒介的调节以及大多数生态系统文化服务的范围都局限于单个村庄及其周边地区。

并非人类和生态系统之间所有的相互作用都是正面的，生态系统对人类也会具有危害性，其中人类与野生动物之间的冲突是最重要的方面。食肉动物可能会攻击人类且常常杀死人类圈养的牲畜，而灵长类动物和大型食草动物可能会摧毁农作物。在局域尺度内，自然界给人类带来的这些危害有时会超过自然界带来的好处，特别是生活在有食肉动物、灵长类动物或大型食草动物的保护区附近的居民，往往遭受重大的经济损失和伤害(Seoraj-Pillai & Pillay, 2017; Karanth & Kudalkar, 2017)。

1.1　供给型服务

在东亚热带和亚热带地区，大部分可持续的供给型生态系统服务来自野生植物。此外，野生动物的肉类一直是许多乡村人们蛋白质和微量营养元素的重要来源，直到今天，在一些人口稀少的地区仍是如此。但是，大部分地区人口的增长降低了大型动物种群数量，且将可能使其种群数量低于可持

续捕猎的水平(Corlett, 2007)。在老挝北部的偏远村庄，啮齿类动物是猎人的主要猎物，其中农田的鼠类占着很重要的比例，其次是森林中的松鼠(Broegaard et al, 2017)。这种对啮齿类动物的捕获量可能是可持续获得的，但同时也对较大型动物造成了捕猎压力。目前大部分地区都禁止狩猎，然而非法狩猎仍然十分普遍，且以娱乐为主要目的(Chang et al, 2017)。野生动物尤其是鸟类以及一些哺乳动物被大量捕获用作宠物，并在整个东亚热带和亚热带地区进行合法或非法的交易(Dai & Hu, 2017; Harris et al, 2017)。常被人们当宠物饲养的动物与供食用的动物大不相同，因此狩猎和活捕对这些动物的影响是叠加的。包括多种食用昆虫(蚱蜢、蜜蜂、黄蜂、蚂蚁、水臭虫和竹毛虫)的无脊椎动物仍可实行可持续的采收，且这些是许多农村地区餐食中重要和颇受欢迎的菜肴(Halloran et al, 2015)。野生蜜蜂的蜂蜜也被广泛采集，但在一些地区，过度采集已经严重影响野生蜜蜂的种群数量(Oldroyd & Nanork, 2009; Corlett, 2011a)。

在东亚热带和亚热带地区，人们利用的植物物种大部分来自于森林，也有部分来自于田野边缘和荒地。传统的水稻耕作系统为整个区域提供了大量的野生植物，以及鱼、螃蟹、蜗牛和昆虫等动物资源(Cruz-Garcia et al, 2016)。开阔的生境则提供了家畜的重要食物来源。林木采伐及其伴随的狩猎活动对该地区森林的影响最为广泛。理论上，在天然林中进行可持续木材采伐是可行的，但在东亚热带地区却难以做到，因此采伐是造成该地区森林退化的主要原因(Corlett, 2014)。包括中国和泰国在内的许多地区使用部分或全面的森林禁伐令作为政策工具。虽然廉价的天然气或电力供应可以使木材的消费迅速下降，但薪柴仍是整个地区农村家庭的主要燃料(Chen et al, 2016)。不加选择地将野生植物资源作为薪柴使用将导致大面积的森林退化，因为该地区人口在不断增长而可以依赖的天然林面积却在不断缩减(Top et al, 2006; Specht et al, 2015)。虽然大部分采集的薪柴是供家庭使用，但也有一些地区将其用于商业贸易供应村办工厂和城市家庭。木炭是一种比薪柴更好的燃料，也是一些农村地区收入的重要来源，但是制作木炭比采集薪柴的负面影响更大，因为木炭的生产需要更多木材且商业生产规模更大。

热带地区的竹子和藤本植物可以从野外广泛采集并制作成各类产品(Yang et al, 2004)。在中国历史上，竹子一直是重要的自然资源，长期作为食品并作为建筑、家具、造纸等的原材料。该地区使用的竹子大多数来自少数几个竹子种类的单一种植园，同时许多野生竹子种类被作为竹笋食用(其中云南省有超过100种野生竹子被食用)，以及用于建造小型建筑、器具和各种工艺品(Yang et al, 2004)。有些竹子具有药用价值，也有些被作为观赏植物或在宗教场所种植。在热带森林地区，棕榈藤的用途与竹子相似，其中最珍贵的棕榈藤本被用于制作家具，已经导致它们在整个地区内被过度开发。其他非木材森林产品(non-timber forest products, NTFP)也包含了数量巨大的植物种类。野外采集的植物通常作为该地区农村居民的食物，其中一些物种也被移植到家庭庭园中。有些野生植物以商业规模进行采集，但大多数种类仅在当地市场销售，或由采集者家庭消费。野生植物通常只占膳食的一小部分，但可能通过提供维生素、矿物质和其他农业主食缺乏的营养物质对人类健康做出重大贡献(Rowland et al, 2017)。事实上，餐食的种类数量是其微量营养素充足性的良好测量指标(Lachat et al, 2018)。从商业角度来看，蘑菇和竹笋往往是最有价值的野生采集的食物，多数在本地消费并且其中的少数品种被广泛交易。野生植物对农民收入的贡献是不同的，但是它们对于没有稳定收入来源的贫困家庭来说是重要的“安全网”。

在中国，至少有1万种本土物种被各民族作为传统药物来使用，且占了全部植物总数的1/3 (Jaiswal et al, 2016)。同样，在泰国至少有2,187种植物(占整个植物区系的22%)被多个少数民族作为药物使用(Phumthum et al, 2018)。东南亚没有可与之比较的评估数据，但传统的植物药物在整个东亚的农村地区以及有农村移民的城市仍然被广泛使用。在该区域内的一些国家(包括中国和泰国)，某些形式的传统医学得到了政府的合法认可和支持。对于药用植物来说，以商业销售为目的的过度采集是主要的风险，尤其在收获地下块茎、根茎或根部后，整株植物将会死亡。

从该地区野生植物中获得的其他大量产品还有胶乳、树脂、树胶、蜡、纤维、染料、熏香和毒鱼素在到达自然森林方便的农村地区，被采集的物

种总体多样性可能很高。例如, 在云南西南部西双版纳纳板河流域国家级自然保护区内, 有480种植物物种被用于药物或食物, 达到了所有记录物种的25% (Ghorbani et al, 2012)。不同的地区被采集的物种有所区别, 对于整个东亚地区, 至少在一个地区被采集的植物占总体植物区系的比例可能更高。传统知识中关于野生植物资源在食品、药物以及其他方面的利用反映了多代人经验积累的结果。该地区的迅速现代化意味着这些知识大部分不能再一代代口头传递, 如果要将这些知识保留下来, 必须将它们永久地记录在书籍、论文和数据库中。

最后, 生物技术、基因组学和合成生物学方面的最新进展为农业和工业中野生植物资源的利用开辟了新的可能性, 包括精准农作物育种、新作物、药物挖掘的改良方法以及新型植物产品的商业生产(Wurtzel & Kutchan, 2016)。

1.2　调节型服务

在东亚热带和亚热带地区, 尽管一些地区草地和灌木林也同样具有调节服务作用, 但大部分的可持续调节服务主要由森林提供。考虑到受惠人口数量, 防止土壤侵蚀、沙尘暴、降低洪水风险、调节当地和全球气候是最有价值的生态系统服务, 且相对容易量化(Ouyang et al, 2016)。森林和其他生态系统也可以帮助减少对人体健康有害的污染物浓度。为了抵消化石燃料燃烧和土地利用变化所排放的部分二氧化碳量而进行的碳固定和碳存贮最近才受到关注, 但是2015年12月与气候变化相关的《巴黎协定》的通过, 成为整个地区森林保护和恢复的一个日益重要的动力。植被也可以通过生物物理效应包括光反射率、表面粗糙度和蒸腾作用影响当地和区域气候。

许多动物也会提供重要的生态系统服务, 如控制病虫害的捕食者以及农作物的授粉者等。很少有人估计亚洲脊椎动物对植食性害虫的捕食价值, 但其贡献无疑是巨大的。泰国的一项研究估计, 每年犬吻蝠(*Tadarida plicata*)对白背飞虱(*Sogatella furcifera*)的捕食可以减少2,900 t稻米的损失(Wanger et al, 2014)。该地区以外的一些研究表明, 食虫蝙蝠和鸟类(Whelan et al, 2015)可以显著减少食草昆虫的多度, 促进植物生长。在亚洲亚热带地区, 除了当地物种之外, 数以亿计的食虫鸟类在春季向北迁移、秋季南返, 在迁徙路线上寻找食草昆虫。啮齿动物尤其鼠类是农业中最重要的有害脊椎动物, 通常被肉食性哺乳动物如鸟类和蛇类等捕食(Corlett, 2011b), 其中许多捕食事件发生在农田中。该地区尚未评估这些食肉动物对鼠类的捕食价值, 然而, 许多食肉动物被捕食或因它们可能会攻击家畜而被杀。昆虫是最重要的作物授粉者, 特别是蜜蜂, 但东南亚对传粉服务价值的估计只有一个研究案例: 针对泰国大长舌果蝠(*Eonycteris spelaea*)对榴莲(*Durio zibethinus*)和球花豆属植物*Parkia species*授粉的研究表明, 其年度经济价值估计超过1.37亿美元(Bumrungsri et al, 2013)。

1.3　文化型服务

文化型服务是最难以定义和评估的生态系统服务, 对于人类来说也是重要的生态系统服务之一。包括旅游在内的娱乐服务最容易评估, 因为人们愿意为娱乐项目支付费用, 包括入场费以及往返娱乐场所产生的费用。随着整个东亚地区生活水平的不断提高, 在自然景区中开展的户外休闲活动越来越受欢迎, 尤其更受具有良好教育背景的城市中产阶级青睐(Buckley et al, 2017)。最近的一项研究将旅行成本作为人们对景观价值的评估, 估计2012年中国自然景观总经济价值至少为975亿美元, 其中以广东、四川和云南的经济价值最高(Xiao et al, 2016)。鸟类和其他观赏动物如蝴蝶, 对休闲观光者、业余观鸟者及业余蝴蝶观察家也具有娱乐价值。在非洲草原和稀树草原中, 大型哺乳动物多样性是游客的主要吸引力(Arbieu et al, 2018), 然而东亚热带和亚热带的自然生态系统多为森林, 大型哺乳动物通常很难被观察到。

其他文化价值更难定义和衡量。自然生态系统为教育和培训以及科学知识的培养提供了机会(Smit et al, 2017)。几千年来, 景观和野生物种的自然美一直是艺术家的主要灵感来源。人类的文化认同感也来源于其所拥有的景观。传统的农业景观, 如与水稻生产有关的农业景观, 往往比自然景观更珍贵(Tekken et al, 2017)。景观可能对于维系社会关系也很重要, 比如提供与家人和朋友见面的场所。

精神价值不容易被纳入生态系统服务框架, 因其通常被认为是人类对自然界的一种认知, 而不是从自然界获得的益处。然而这些价值对人和生态系统都有很大的影响。自然圣境是因宗教信仰或文化习俗而得到保护的自然地区, 且通常以森林斑块形

式存在(Hu et al, 2011; Allendorf et al, 2014; Zeng & Reuse, 2016)。它们构成了很多少数民族文化的一部分，如中国西南部西双版纳傣族的“龙山” (Zeng & Reuse, 2016)、滇西北藏族村寨的“神林” (Allendorf et al, 2014)以及中国南部的“风水林”(Hu et al, 2011)。虽然当地人可能获益于这些自然圣境提供的其他生态系统服务如药用植物，但这并非主要的保护目的，并且在大多数情况下，人们对这些自然圣地的直接开发受到了一定程度的限制；因此，通常这些自然圣境内的生物多样性能够得到保留，尤其是植物多样性以及某些自然圣境中的动物多样性，特别是其所处的景观是人类活动区域内仅存的森林景观，而周围景观内的这些生物则遭受威胁或消失(Hu et al, 2011)。近几十年来，许多“龙山”、“神林”已经消失或严重退化(Zeng & Reuse, 2016)，但仍然有些得到尊重和保护，并将在未来继续发挥作用。

1.4 支持型服务

支持型服务是产生其他所有生态系统服务所需的服务，包括植物初级生产、营造生物栖息地以及维护多样化的动植物群落。从技术角度讲，这些被视为生态过程而不是对人类的服务。但这个概念具有重要意义，因为如果一个生态系统只存在那些直接提供产品、调节或文化服务的物种，那么这个生态系统将不能存在和运行。土壤是最明显的例子：土壤不仅仅是植物的生长介质，而且还支持着许多不同种类的动物以及在死亡植物分解以及营养物质的释放和循环中具有关键作用的微生物。

目前价值未知的物种也具有其重要性，因为它们对人类的未来惠益提供开放的选项；这些可能包括新作物、药物或工业原材料，基因组学和生物技术上的新资源，以及新病虫害的控制。还有证据表明，目前稀有物种具有最独特的特征，可对未来群落功能发挥重要的作用(Mouillot et al, 2013; Leitão et al, 2016)。因此，稀有物种可能会提供一个保险策略来抵御未来气候变化等不可预测的威胁。

2 生物多样性和生态系统服务

传统的保护重点是保护野生动植物物种及其栖息地，即生物多样性保护。尽管大多数生态系统服务依赖于野生物种和生态系统进行生产，但生态系统服务的质量和数量与野生物种的多样性之间通常没有简单的关联性。供给型服务可能随着生物多样性的增加而增加，因为物种更丰富的森林可能会支持更多有价值的物种。也有证据表明授粉和病虫害防治服务随着生物多样性的增加而增加，尤其在区域尺度上更为明显(Liere et al, 2017; Winfree et al, 2018)，但其他大多数调节型服务依赖于一些可以保持土壤和储存大量碳的优势种。

文化型服务与生物多样性之间的关系也没有明显的规律。业余鸟类观察者会被稀有物种的高度多样性和高的可观察率所吸引，而参观美国公园的休闲游客则喜欢欣赏大面积的花海景观而非花卉本身的多样性(Graves et al, 2017)。但是，所有这些生态系统服务都是由维持生态系统的支持型服务支撑，且有充分证据表明生物多样性对支持型服务的重要性(Oliver et al, 2015; Oliver, 2016; Duffy et al, 2017)。生态学理论、室内实验和野外研究均表明，不同的物种之间具有互补作用，生物多样性提高了生态系统的生产力和碳储量(Duffy et al, 2017)以及其他生态功能。此外，生物多样性增加了生态系统在气候变化和其他因素长期影响下的适应能力(Oliver et al, 2015)。因此，生物多样性直接有利于维护生态系统的长期安全。

我们需要多少物种来维持这些生态系统服务？当地生态系统中10%的物种消失被认为是一个安全的阈值，高于这个阈值，生态系统服务将受到威胁(Oliver, 2016)，尽管目前为止证据仍很不充分。在一项全球评估中，58%的地球陆地表面的物种消失已经高于这个阈值(Newbold et al, 2016)。事实上，不同生态系统的安全阈值可能会有所不同，且部分取决于消失的物种。在物种丰富的生态系统中，变化可能是渐进的，没有突然的临界点，并且在以长寿的树木为优势的生态系统中，其变化可能会延迟数十年甚至数百年。

3 自然资本

自然资本是包括矿物质、土壤、空气、水、物种和生态系统以及物理、生物和化学过程在内的自然资源总量(Mace et al, 2015)。植被和土壤往往是最重要的组成部分。自然资本可以看作是金融资本的自然等价物。上述生态系统服务是从这个自然资本中获得的，所以如果这个资本被耗尽，那么它所能生产的生态系统服务就会减少。森林砍伐、土壤侵蚀、野生物种的过度开发以及空气和水污染等人类

活动消耗自然资本, 减少了其所能提供的生态系统服务。供给型服务特别容易受到过度开发的影响, 即使是娱乐等文化服务也会由于过度使用而减少。在一定程度上, 人类技术可以弥补自然资本的消耗: 农业作物可以代替野生食物, 合成药物可以代替传统药物, 农药可以代替自然害虫防治, 受污染的水可以通过技术处理后饮用。但是, 这种可替代性是有限的, 且一些生态系统服务只能以高成本进行替代, 甚至不能被替代。

4　生态安全

满足人类基本需求所需的自然资本被称为关键自然资本。“生态安全”这个术语有多种定义方式, 这里指的是维护或恢复地区内重要生态系统服务所需的关键自然资本。目前还未对东亚热带亚热带地区的生态系统服务总体状况和趋势进行综合评估, 但是东南亚天然林面积的持续萎缩(FAO, 2015)必然已经减少了一些供给型服务、调节型服务和文化型服务。中国和该地区其他几个国家的森林总面积正在增加, 但是增加的森林大部分是单一种植的人工林, 并不能提供类似于天然林的全方位服务(Hua et al, 2016)。东亚热带和亚热带地区的大多数国家为此制定了相关政策, 即通过投资制造业和服务业补偿自然资本的损失(Carrasco et al, 2017)。目前来看, 采取这一策略的一些国家如中国和泰国取得了很大成效, 但其他一些国家的自然资本损失并没有被其他形式的资本收益所抵消。从长远来看, 野生物种和生态系统的持续退化将会威胁到多种生态系统服务, 而且经济收益有可能被环境损失所抵消, 导致某些地区的人类幸福水平总体下降。例如, 在老挝的一些地区, 土地利用变化和农业集约化减少了野生食物的供应, 导致摄入膳食的低营养化(Broegaard et al, 2017)。远离道路和市场限制了替代食物的获取, 因此, 来自经济作物的收入增加并不能抵消野生食物的损失。

近期中国有些生态系统服务的改善在很大程度上来自于自然资本投资, 用以应对20世纪末的环境危机, 这其中包括1998年造成数千人死亡的长江洪水(Ouyang et al, 2016)。这个例子说明了两点: 经济的快速发展可能导致生态安全的灾难性损失, 而政府的政策可以帮助防止和扭转这种损失。中国近期的快速变化也支持了第三个重要观点, 即保护生物多样性和生态系统服务并不一定和经济发展相冲突。在中国, 与自然相适应的发展需要已被囊括在“生态文明”的概念之中, 这个概念包含了环境和社会两个方面的可持续性, 而不再仅仅局限于生态安全。换言之, 生态文明可以看作是一种广义的人类健康形式, 不仅包括个人和社会健康, 还包括这两者所依赖的环境健康(Zhang et al, 2017b)。

5　讨论

在区域或国家范围内的生态系统服务评估通常非常简化, 仅仅关注少数易于量化的服务项目(Carrasco et al, 2017; Han & Dong, 2017; Zhang et al, 2017a)。一种常用的方法是利用易于测量的代表性参数来评估生态系统服务。例如, Zhang等(2017a)将净初级生产力(根据遥感与气候数据估算)和气候、地形和土壤变量结合起来, 绘制整个中国碳固定、土壤保持、供水以及栖息地变化的趋势图。然而这些评估往往不包括对当地人来说最重要的生态系统服务, 由此会产生误导且可能作出错误决策。评估一个地区或生态系统提供的生态系统服务的总货币价值也会产生类似的问题, 因为这些评估通常忽略了对人类惠益有很大贡献但又难以衡量的生态系统服务, 如精神价值和艺术灵感。因此, 需要在国家级的生态系统服务评估中增加一些服务项目, 并进行地方评估, 以便将这些生态系统服务直接与人类健康、生计和幸福联系起来(Ouyang et al, 2016)。

对于很多人来说, 自然界也有其他的价值, 包括与人类利用无关的内在价值。虽然可以将生态系统服务的定义延伸, 把这些内在价值纳入文化型生态系统服务的范围, 但这并不是一个令人满意的解决方案。生物多样性和生态系统服务政府间科学–政策平台(the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Service, IPBES)通过认识人类文化在自然评估中的核心作用并试图将人类文化的多种价值纳入其评估中(Díaz et al, 2018)。这要通过尽可能地结合本土和地方性知识并考虑关于“自然对人类的贡献”的各种不同观点来实现。与生态系统服务中占主导地位的过于简化的评估相比, 这种灵活性具有其优势。然而, 在实践中, 可用金融术语来衡量的生态系统服务趋向于成为评估的主要内容, 因为其易与经济发展的

益处进行对比。

6 结论

在以人类为主导的世界维护生态安全，需要全球、区域、国家和地方层面上付诸行动。全球行动对于气候变化来说最为紧迫，其中2015年的《巴黎协定》是朝着正确方向迈出的一大步。同时，开展区域合作是解决许多问题的必要条件，包括控制污染和入侵物种，禁止植物和野生动植物的非法贸易，关键物种和生态系统的跨界保护以及生物多样性信息的共享等。此外，各国政府需要制定政策，立法并依法严惩违法行为。中国提出的“生态红线政策”即是旨在保护生态安全而采取国家行动的一个例子(Bai et al, 2016)。然而，在许多情况下，地方性的行动是最有效的，如在单个流域、单个保护区、单一村庄或城市地区水平上的保护行动。如果没有地方性的实际行动，全球协议、区域协作和国家政策就无法有效地开展。对于地方性的保护行动来说，对生态系统服务的威胁这一论据可能比对生物多样性的威胁更有说服力；且在地方性水平上，评估生态系统服务的全面多样性也显得尤为重要。

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Biodiversity and ecosystem services: Towards ecological security in tropical and subtropical East Asia

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Abstract: Tropical and subtropical East Asia supports around 15–25% of global terrestrial biodiversity. This is now threatened in many areas by rapid economic development. Achieving development that is compatible with biodiversity conservation requires that the benefits of nature to people, to society, and to the economy are understood and correctly valued. These benefits are known as ecosystem services and have been classified in various ways. Most ecosystem services depend on wild species and ecosystems for their production, although there is often no simple relationship between their quality and quantity and the diversity of wild species. There have been many assessments of ecosystem services at the national scale, but these are necessarily very simplified, usually focusing on a few, easily quantified services. As a result, they often fail to include the services which are of most importance to local people and may therefore lead to incorrect policy decisions. Ecosystem services are derived from natural capital, which is the total stock of natural resources, so if this capital is depleted, the services it can produce will decline. Ecological security is achieved by preserving or restoring the critical natural capital needed to maintain vital ecosystem services in the region. Although there have been recent improvements in some ecosystem services in China, the overall trends in most services in tropical and subtropical East Asia are negative. Achieving regional ecological security in a human-dominated world will require action at the global, regional, national, and local levels.

Key words: biodiversity; ecosystem services; natural capital; ecological security; ecological civilization

East Asia is a global biodiversity hotspot. Within this region, most species are found in the tropics and subtropics, i.e., China south of 30–35°N and the whole of Southeast Asia, including Myanmar, Laos, Vietnam, Thailand, Cambodia, Malaysia, Brunei, Singapore, and Indonesia. Tropical and subtropical East Asia has less than 4% of the Earth's total land area, but is estimated to support 15–25% of all terrestrial plant and animal species (Corlett, 2014). The total number of species is unknown, but estimates for well-studied groups include around 800 mammal species, 2,300 birds, 930 frogs, 3,500 butterflies, and at least 80,000 land plants. The proportion of global freshwater diversity in the region is probably similar (Collen et al, 2014), while the proportion of marine diversity is even higher (Tittensor et al, 2010). The region also supports an extremely high diversity of natural ecosystems, from lowland tropical rainforests to semi-deserts and alpine tundra, and from coral reefs to high-altitude lakes.

Tropical and subtropical East Asia is also home to more than a billion people. The first modern humans in the region, perhaps 70,000 years ago, depended entirely on natural resources for survival. However, the expansion of agriculture in the last 4,000–5,000 years and the growth of urban areas in the last 300 years have weakened and obscured the links between human welfare and natural resources. Most food comes from agriculture, most medicines from laboratories, most clothing from factories, most water out of taps, and most energy from fossil fuels. Humans still derive a vast range of benefits from nature, known collectively as 'ecosystem services', but these are often not recognized and are therefore usually undervalued.

Rapid economic development now threatens both biodiversity and ecosystem services throughout the region (Hughes, 2017). Numerous species are threatened and major natural ecosystems have been reduced to small and disturbed remnants. Biodiversity conservation is therefore an urgent task in tropical and subtropical East Asia, but more than a billion people live in this region and conservation must compete with economic development for land and resources. It has therefore become essential that the benefits of nature to people, to society, and to the economy are understood and correctly valued. This is the focus of this article.

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1 Human Benefits from Wild Species and Ecosystems

The benefits which humans obtain from nature are known as **ecosystem services**. These have been defined and classified in many different ways, but it is most common to distinguish four main categories of ecosystem services: **provisioning services**, which include the supply of foods, medicines, materials (wood, fibers, resins, etc.), energy, and genetic resources from nature; **regulating services**, which include services such as regulating water supply and quality, removing wastes, preventing erosion, protecting against sand storms, reducing flood risk, regulating local and global climate, alleviating air pollution, controlling pests and diseases, and maintaining populations of pollinators; and **cultural services**, which include non-material benefits, such as recreation, as well as aesthetic and spiritual values. These three categories of ecosystem services, in turn, depend on the **supporting services**, such as primary productivity and nutrient cycling, provided by the numerous individual organisms, species, and processes that make up an ecosystem.

Although the concept of ecosystem services has been very useful in drawing attention to the numerous benefits that people derive from nature, there are many problems in its application in practice. Most of these problems arise from the fact that the concept brings together many very different things, some of which are easily converted to monetary values (food, energy), some of which are more difficult to quantify (genetic resources, climate regulation, and pollinator maintenance), and some of which can only be measured indirectly (beauty and spiritual value) (Gunton et al, 2017; Pascual et al, 2017). Moreover, different services are important to people on different spatial scales. Greenhouse gases are mixed globally, so it makes no difference if carbon storage services are provided by forests in Brazil or Yunnan. From the perspective of city dwellers, food and material supply are integrated at a national scale, so local variations in supply are unimportant. Water supply and flood control, in contrast, are integrated at a watershed scale, so problems are experienced only by people within the watershed. Finally, the provision of wild foods and medicines, the regulation of local climate, pests, and pollinators, and most cultural services are localized to the scale of a single village and its surroundings.

Not all interactions between humans and ecosystems are positive. There are also ecosystem disservices, of which human-wildlife conflicts are the most important. Carnivores may kill people and—more commonly—their livestock, while primates and large herbivores can destroy crops. On a local scale, these disservices can sometimes outweigh the benefits derived from nature. In particular, people living next to protected areas that support carnivores, primates, or large herbivores often suffer from significant economic losses and injuries (Seoraj-Pillai & Pillay, 2017; Karanth & Kudalkar, 2017).

1.1 Provisioning services

In tropical and subtropical East Asia, most sustainable provisioning services come from wild plants. Meat from wild animals has been an important source of protein and micronutrients in the diets of many rural people until recently, and still is in some sparsely populated areas, but in most of the region, increasing human populations have depleted most large animal populations below the level at which sustainable harvest is possible (Corlett, 2007). In remote villages in northern Laos, rodents are now the major prey of hunters, with rats of agricultural areas most important, followed by forest squirrels (Broegaard et al, 2017). This rodent harvest may be sustainable, but it also helps to maintain hunting pressure on larger animals. Hunting is now prohibited in most of the region; illegal hunting is still widespread, however, with recreation now the primary motivation (Chang et al, 2017). Wild animals—particularly birds but also some species of mammals—are also trapped and traded in huge quantities throughout the region to keep as pets, both legally and illegally (Dai & Hu, 2017; Harris et al, 2017). The species favored as pets are mostly different from those consumed as meat, so the impacts of hunting and live trapping are additive. Invertebrates, including a diversity of edible insects (grasshoppers, bees, wasps, ants, water bugs, and bamboo caterpillars), can still be harvested sustainably, and are a significant and highly appreciated component of rural diets in many areas (Halloran et al, 2015). Honey from wild bees is also widely harvested, but in some areas overharvesting has severely depleted wild bee populations (Oldroyd & Nanork, 2009; Corlett, 2011a).

Most species of plants that are used by people in the region come from forests, but wild plants are also harvested from field margins and wasteland. Traditional rice systems supply a great variety of wild plants, as well as fish, crabs, snails, and insects, throughout the region (Cruz-Garcia et al, 2016). Open habitats are most important as sources of food for domesticated livestock. Timber harvesting—logging—is, with hunting, the most widespread impact on forests in the region. While it is theoretical possible to harvest timber sustainably from natural forests, this is rarely done in tropical East Asia, so logging is major cause of forest degradation. The difficulties of enforcing sustainable management practices have led to the use

of partial or complete logging bans as a policy tool in many parts of the region, including China and Thailand. Firewood is still a major rural household fuel throughout the region where forest is still accessible, although consumption declines rapidly when cheap gas or electricity are available (Chen et al, 2016). Collecting firewood is a relatively unselective use of wild plant resources and can cause substantial forest degradation where a growing population depends on a shrinking area of natural forest (Top et al, 2006; Specht et al, 2015). Most is collected for domestic use, but there is also a commercial trade in some parts of the region to supply rural factories and urban households. Charcoal is a better fuel than firewood and is an important source of rural income in some areas, but making charcoal has a greater negative impact than firewood collection because it needs more wood and is produced on a commercial scale.

Bamboos and, in the tropics, rattans, are widely harvested from the wild and used in a broad range of different products, both locally and in urban areas (Yang et al, 2004). Bamboos have been an important natural resource throughout China's history for both food and a variety of raw materials, for construction, furniture, paper, etc. Most bamboo used in the region comes from monoculture plantations of a few species, but many wild species are harvested locally for bamboo shoots (>100 species in Yunnan), minor construction, making utensils, and for use in variety of local crafts (Yang et al, 2004). Some bamboo species have medicinal uses and others are planted as ornamentals or for religious regions. Rattans have a similar range of uses to bamboos in tropical forest areas, but the most valuable species are used for making furniture and have now been overexploited throughout the region. Other non-timber forest products (NTFPs) include a huge range of plants. Wild-harvested plants are widely used as food in rural areas in the region, and some of these species are also transplanted into home gardens. Some are collected on a commercial scale, but many others are sold only in local markets or consumed at home by the collectors. Wild plants typically form a small proportion of the total diet, but may make a major contribution to health by supplying vitamins, minerals, and other nutrients that are deficient in agricultural staples (Rowland et al, 2017). Indeed, the number of species in a diet is a good predictor of its micronutrient adequacy (Lachat et al, 2018). From a commercial point of view, mushrooms and bamboo shoots are often the most valuable wild-collected foods, with a few species traded widely and many more consumed locally. The contribution of wild plants to rural incomes is very varied, but their most important role may be as 'safety nets' for poor households without consistent sources of income.

At least 10,000 native species—a third of the total flora—are used in traditional medicines by various ethnic groups in China (Jaiswal et al, 2016). Similarly, in Thailand, at least 2,187 species (22% of the total flora) are used medicinally by at least one ethnic group (Phumthum et al, 2018). There are no comparable estimates for Southeast Asia, but traditional, plant-based medicine is still widely used in rural areas throughout the region, as well as by recent rural migrants to urban areas. In some countries in the region, including China and Thailand, some forms of traditional medicine is legally recognized and supported by the government. Overcollection is a major risk for medicinal plants that are sold commercially, particularly when underground tubers, rhizomes, or roots are harvested, so the whole plant is killed.

Among the great variety of other products obtained from wild plants in the region are latexes, resins, gums, waxes, fibers, dyes, incense, and fish poisons. In rural areas with access to natural vegetation, the overall diversity of species collected can be very high: for example, 480 plant species—25% of all species recorded—were used for medicine or food in the Naban River Watershed National Nature Reserve in Xishuangbanna, SW Yunnan (Ghorbani et al, 2012). Different species are harvested in different areas, and it is likely the proportion of the total regional flora used in at least one area is even higher than this. The traditional knowledge that sustains this use of wild plant resources as foods and medicines, and for other purposes, reflects experience accumulated over many generations. The rapid modernization of the region means that much of this knowledge is no longer passed on orally from generation to generation and must be permanently recorded in books, papers, and databases if it is to survive.

Finally, recent advances in biotechnology, genomics, and synthetic biology have opened up new possibilities for the utilization of wild plant resources in agriculture and industry, including precision crop breeding, new crops, improved methods of drug discovery, and the commercial production of novel plant products (Wurtzel & Kutchan, 2016).

1.2 Regulating services

In tropical and subtropical East Asia, most sustainable regulating services are provided by forests and trees, although grasslands and shrublands are important in some areas. Preventing erosion, protecting against dust and sand storms, reducing flood risk, and regulating local and global climate are the most valuable services, when the number of people affected is taken into consideration, and are relatively easy to quantify (Ouyang et al, 2016). Forests and other ecosystems can also help reduce concentrations of pollutants that

are harmful to human health. Fixing and storing carbon in order to offset some of the carbon dioxide emissions from burning fossil fuels and land-use change is a relatively new concern, but, following the Paris Agreement on climate change adopted in December 2015, it is becoming an increasingly important motivation for preserving and restoring forests throughout the region. Vegetation also influences local and regional climate through biophysical effects, including albedo, surface roughness, and transpiration.

Many animals also provide important services, as predators controlling pests and diseases, and as pollinators of agricultural crops. The value of predation by vertebrates on herbivorous pests has rarely been estimated in Asia, but is certainly large. One study, in Thailand, estimated that consumption of a single pest species, the white-backed planthopper (*Sogatella furcifera*), by a single bat species, the wrinkle-lipped bat (*Tadarida plicata*), reduced rice losses by 2,900 tons a year (Wanger et al, 2014). Several studies outside the region have shown that both insectivorous bats and birds (Whelan et al, 2015) can significantly decrease the abundance of herbivorous insects and increase the growth of plants. In subtropical Asia, in addition to resident species, hundreds of millions of insectivorous birds migrate north in spring and south in autumn, tracking the availability of herbivorous insects. Rodents, particularly rats, are the most important vertebrate pests in agriculture and are consumed by a great variety of carnivorous mammals, birds, and snakes (Corlett, 2011b), many of which occur in farmland. The value of rat predation by these carnivores has not been assessed in this region, however, and many carnivores are killed for food or because they may attack domestic animals. The most important crop pollinators are insects, particularly bees, but the only estimate of the value of pollination services in Southeast Asia is again from a bat in Thailand, where the annual economic value of pollination of durian (*Durio zibethinus*) and petai (*Parkia* species) crops by the dawn bat (*Eonycteris spelaea*) was estimated as more than US$137 million (Bumrungsri et al, 2013).

1.3 Cultural services

Cultural services are the most difficult ecosystem services to define and evaluate, but are also among the most important services for many people. Recreational use, including tourism, is the most easily evaluated component, since people are willing to pay for recreation: not only an entry fee, if there is one, but also the costs of travelling to and from a recreational site. With rising living standards throughout the region, outdoor recreation in natural landscapes has become increasing popular, particularly for the well-educated urban middle class (Buckley et al, 2017). A recent study, using travel costs as an estimate of the value people put on a landscape, estimated that the total economic value of China's natural landscapes was at least US$975 billion in 2012, with Guangdong, Sichuan, and Yunnan having the largest economic values (Xiao et al, 2016). Birds and other easily viewed animals, such as butterflies, also have recreational value, both to casual observers and to amateur bird- and butterfly-watchers. In African grasslands and savannas, large mammal diversity is the major attraction for tourists (Arbieu et al, 2018), but the natural ecosystems of tropical and subtropical East Asia are mostly forests, in which large mammals are usually very difficult to observe.

Other cultural values are more difficult to define and measure. Natural ecosystems provide opportunities for education and training, and for building scientific knowledge (Smit et al, 2017). The natural beauty of landscapes and wild species has been a major source of inspiration for artists for thousands of years. Landscapes are also a source of cultural identity for the people who occupy them, with traditional agricultural landscapes, such as those associated with rice production, often valued more than wild nature (Tekken et al, 2017). Landscapes may also be important for social relationships: as a place to meet with family and friends.

Spiritual values do not fit easily into the ecosystem services framework, since they are often perceived as the duty of humans *to* nature, rather than benefits received *from* nature. Yet these values can have a strong influence on both people and ecosystems. Sacred natural sites are natural areas—often forest patches—that receive protection because of religious beliefs or cultural practices (Hu et al, 2011; Allendorf et al, 2014; Zeng & Reuse, 2016). They form part of the culture of numerous different ethnic groups. Well-documented examples include the Dai holy hills of Xishuangbanna in southwest China (Zeng and Reuse, 2016), the Tibetan village sacred forests in northwest Yunnan (Allendorf et al, 2014), and the fengshui woods of southern China (Hu et al, 2011). Although local people may benefit from other ecosystem services that these sites provide, such as the availability of medicinal plants, this is not the main motivation for their protection and, in most cases, direct exploitation is restricted to a greater or lesser extent. As a result, sacred sites often preserve biodiversity—particularly plants, but also animals in some cases—that is threatened in, or has disappeared from, the surrounding landscape, particularly when they are the only forest left in a human-dominated landscape (Hu et al, 2011). Many sacred forests have been lost or badly degraded in recent decades (Zeng & Reuse, 2016), but others are still respected and protected, suggesting that they

will continue to have a role in the future.

1.4 Supporting services

Supporting services are those required for the production of all the other ecosystem services, and include primary production by plants, the creation of habitats for organisms, and the maintenance of a diverse plant and animal community. Technically, these are ecological processes rather than services to people, but the concept is useful because an ecosystem that includes only the species that directly provide provisioning, regulating, or cultural services could not survive and function. The clearest example is the soil, which is not simply a growth medium for plants, but also supports numerous different species of animals and microbes with critical roles in the decomposition of dead plant materials, and the release and recycling of nutrients.

Species without a currently known value are also important because of their role in keeping options open for future benefits to humans. These may include new crops, medicines, or industrial materials, new applications in genomics and biotechnology, and the control of new pests and diseases. There is also evidence that currently rare species have the most distinctive traits and make a disproportionate contribution to the potential range of functions in a community (Mouillot et al, 2013; Leitão et al, 2016). Rare species may therefore provide an insurance policy against unpredictable threats, such as future climate change.

2 Biodiversity and Ecosystem Services

The traditional focus of conservation has been on protecting wild plant and animal species, and their habitats: biodiversity. Although most ecosystem services depend on wild species and ecosystem for their production, there is often no simple relationship between the quality and quantity of ecosystem services and the diversity of wild species. Provisioning services are likely to increase with increasing biodiversity, since more species-rich forests are likely to support more useful species. There is also evidence that pollination and pest-control services increase with biodiversity, particularly at regional scales (Liere et al, 2017; Winfree et al, 2018), but most other regulating services depend on a few dominant species which protect the soil and store most carbon. Cultural services also show varied relationships with biodiversity. Amateur bird watchers are attracted by high diversity and the opportunity to see rare species, but casual visitors to parks in the USA preferred to see an abundance of flowers rather than a diversity of flowers (Graves et al, 2017). All these services, however, are underpinned by the supporting services that maintain the ecosystem and here there is good evidence that biodiversity matters (Oliver et al, 2015; Oliver, 2016; Duffy et al, 2017). Ecological theory, experiments, and field studies all show that biodiversity increases the productivity and carbon storage of ecosystems (Duffy et al, 2017) as well as other ecological functions, because different species play complementary roles. Moreover, diversity increases the resilience of ecosystems under climate change and other long-term impacts (Oliver et al, 2015). In this way, therefore, biodiversity contributes directly to long-term ecological security.

How many species do we need to maintain ecosystem services? The loss of 10% of species from local ecosystems has been suggested as a safe threshold value, below which services are threatened (Oliver, 2016), although the evidence presented for this so far is weak. In a global assessment, 58% of the Earth's land surface had already fallen below this threshold (Newbold et al, 2016). In practice, the threshold is likely to vary between ecosystems and depend, in part, on which species are lost. Also, in species-rich ecosystems, the changes are likely to be gradual without a sudden 'tipping point', and they may be delayed for decades or even centuries in ecosystems that are dominated by long-lived trees.

3 Natural Capital

Natural capital is the total stock of natural resources, including minerals, soils, air, water, species, and ecosystems, and physical, biological, and chemical processes (Mace et al, 2015). In practice, vegetation and soil are often the most important components. Natural capital can be seen as the natural equivalent of financial capital. The ecosystem services discussed above are derived from this natural capital, so if this capital is depleted the services it can produce decline. Forest clearance, soil erosion, overexploitation of wild species, and air and water pollution are examples of human activities which deplete natural capital and reduce the provision of ecosystem services. Provisioning services are particularly vulnerable to overexploitation, but even cultural services, such as recreation, can be degraded by excessive use. To some extent, human technologies can substitute for this loss of natural capital: agricultural crops can replace wild foods, synthetic medicines can replace traditional ones, pesticides can replace natural pest control, and polluted water can be made drinkable. However, there are limits to this substitutability and some ecosystem services can either not be replaced, or only replaced at great cost. The natural capital needed to satisfy these basic human needs is known as 'critical natural capital'.

4 Ecological Security

The term ‘ecological security’ has been used in many different ways, but here refers to the preservation or restoration of the critical natural capital needed to maintain vital ecosystem services in the region. There has been no comprehensive assessment of the overall status and trends of ecosystem services in the region, but the continuing decline in natural forest area in Southeast Asia (FAO, 2015) must have reduced some provisioning, regulating, and cultural services. Total forest area is increasing in China and several other countries in the region, but most of this additional forest consists of plantation monocultures that cannot provide the full range of services provided by natural forests (Hua et al, 2016). Most countries in tropical and subtropical East Asia have adopted a strategy of compensating for losses of natural capital by investing in manufacturing and services (Carrasco et al, 2017). This has been largely successful so far in some countries, such as China and Thailand, but less so in others, where losses in natural capital have not been offset by gains in other forms of capital. In the long term, a continued decline in wild species and ecosystems threatens many of services described earlier, and there is a risk that economic gains will be offset by environmental losses, leading to an overall decline in human well-being in some areas. In some parts of Laos, for example, land-uses changes and agricultural intensification have reduced the supply of wild foods, leading to a nutritionally poorer diet (Broegaard et al, 2017). Increased income from cash crops has not offset the loss of wild foods because remoteness from roads and markets limits access to alternative sources of food.

The recent improvements in some ecosystem services in China have resulted, to a large extent, from an investment in natural capital in response to the environmental crises at the end of the 20th century, including the 1998 flooding along the Yangtze River that killed thousands of people (Ouyang et al, 2016). This example illustrates two important points: that rapid economic development can lead to a catastrophic loss of ecological security and that government policies can help to prevent and reverse this loss. Recent changes in China also illustrate a third important conclusion: that the conservation of biodiversity and ecosystem services does not need to be in conflict with economic development. In China, the need for development that is compatible with nature has been encapsulated in the concept of ‘ecological civilization’, which incorporates both environmental and social aspects of sustainability, so it is more than just ecological security. Alternatively, ecological civilization can be viewed as a form of generalized human health, broadened to include not only personal and social health, but also the environmental health on which these two depend (Zhang et al, 2017).

5 Discussion

Assessments of ecosystem services at the regional or national scale are necessarily very simplified, usually focusing on a few, easily quantified services (Carrasco et al, 2017; Han & Dong, 2017; Zhang et al, 2017). A common approach is to use easily measured proxies for the ecosystem services of interest. Zhang et al (2017), for example, use a combination of Net Primary Production (estimated from remote sensing and climate data) and climatic, topographic, and soil variables, to map trends in carbon capture, soil protection, water provision, and habitat provision across the whole of China. These assessments often fail to include the services which are of most importance to local people and, as a result, can be misleading and potentially lead to incorrect policy decisions. Similar problems arise with estimates of the total monetary value of ecosystem services provided by an area or ecosystem, since these estimates usually omit services that also contribute greatly to human well-being but are hard to measure, such as spiritual values and artistic inspiration. There is thus a need to both expand the set of ecosystem services that are quantified nationally and to carry out local assessments in order to link these services directly to human health, livelihoods, and happiness (Ouyang et al, 2016).

For many people, nature also has other values, including an intrinsic value that does not depend on its usefulness to people. It is possible to stretch the definition of ecosystem services to include such values under cultural services, but this is not a satisfactory solution. The Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services (IPBES) has tried to incorporate a diversity of values into its assessments by recognizing the central role of human cultures in the valuation of nature (Díaz et al, 2018). This is to be achieved by incorporating indigenous and local knowledge wherever possible and by allowing for a variety of different perspectives on ‘nature’s contributions to people’. This flexibility has advantages in comparison with the oversimplification that has dominated the ecosystem services literature. However, in practice, ecosystem services that can be valued in financial terms tend to dominate the discussion because they are easier to compare with the benefits of economic development.

6 Conclusions

Achieving ecological security in a human-dominated

world will require global, regional, national, and local action. Global action is most urgent for climate change, and the 2015 Paris Agreement was a large step in the right direction. Regional collaboration is needed on many issues, including controlling pollution and invasive species, stopping the illegal trade in plants and wildlife, transboundary protection of key species and ecosystems, and sharing of biodiversity information. National governments set out policies, pass laws, and punish those who disobey them. China's 'ecological redline policy' is an example of a national action aimed at protecting ecological security (Bai et al, 2016). In many cases, however, the most effective actions will be local, at the level of single water catchments, single protected areas, and single villages or urban districts. Global agreements, regional collaborations, and national policies cannot be effective without local action on the ground. It is at this local level where threats to ecosystem services are likely to be a more persuasive argument for conservation action than threats to biodiversity. And it is also at the local level where assessing the full diversity of ecosystem services is most important.

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