

## 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.

## 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 increasingly popular, particularly for the well-educated urban mid-

dle 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 mat-

ters (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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