A Yanomami settlement is located in the northern Amazon rainforest. Indigenous peoples have historically contributed to the enrichment of tropical forests with food plants.

PERSPECTIVES

FOOD SECURITY

Human-food feedback in tropical forests

Ancient interaction between humans and edible plants can boost tropical food security

By **Bernardo M. Flores** *and* **Carolina Levis**

The image of tropical forests as harsh environments devoid of large human populations has held sway in Western minds for centuries. Since the 1980s, researchers began to learn how these landscapes have been transformed by Indigenous peoples, who developed diverse forest-based food production systems. How did these apparently natural forests come to be dominated by plant species so closely associated with humans? Perhaps ancient societies decided to settle where forests were already abundant in food and medicine, or maybe they were the ones who enriched their homes (*1*–*5*)—but it is probably a bit of both.

These intriguing questions have given rise to a "chicken or egg" dilemma: Which came first in tropical forests—abundant food resources or domestication? Plant domestication is the process by which people of different cultures select, accumulate, care for, and disperse plant individuals, causing changes in the traits under selection (*6*). When applied to landscapes, domestication is the manipulation of ecosystems to expand the cultural niche of local societies and their food supply while expanding the distribution of domesticated species (*1*, *6*). Humans have expended much energy to guarantee the success of domesticated species (*7*)—an interaction that preceded food production systems and advanced slowly (*6*).

When modern humans occupied all tropical forests (13,000 to 45,000 years ago), they began to alter the natural processes that shaped these ecosystems (*7*, *8*). As human societies accumulated knowledge, practices, and technologies, they spread domesticated species and landscapes. For instance, the Brazil nut tree (*Bertholletia excelsa*) has been cultivated by Indigenous peoples for millennia and today is a dominant species in the Amazon basin (*2*, *9*). In Amazonia, many forests are also dominated by pequi and pequia trees (*Caryocar* spp.) with signs of domestication (*2*, *6*). In South America, and later in Central America, cacao has been cultivated for more than 5000 years, which has led *Theobroma cacao* to dominate many forests (*4*, *9*). Araucaria seeds have also been cultivated in the Brazilian Atlantic Forest, which expanded the distribution of *Araucaria angustifolia* (*10*). The same happened with many arboreal species that have edible fruits and seeds in other tropical forests (*1*, *3*, *7*): in Africa with coffee seeds of *Coffea* spp., oil palm groves of *Elaeis guineensis*, and locust beans of *Parkia biglobosa*, and in Borneo and Papua New Guinea with sago palm (*Metroxylon sagu*), breadfruit (*Artocarpus* spp.), pandanus nuts, and marita red fruits (*Pandanus* spp.). Tropical forests are therefore centers of polyculture agroforestry, where numerous edible arboreal species have been cultivated (*1*, *4*, *11*). These areas are also centers of plant domestication, where globally important staple crops originated, such as maize, manioc, yams, and bananas (*7*).

The ancient interaction between Indigenous peoples and tropical forests implies that both are part of a social-ecological system, formed by mutually dependent feedbacks. In particular, the positive feed-

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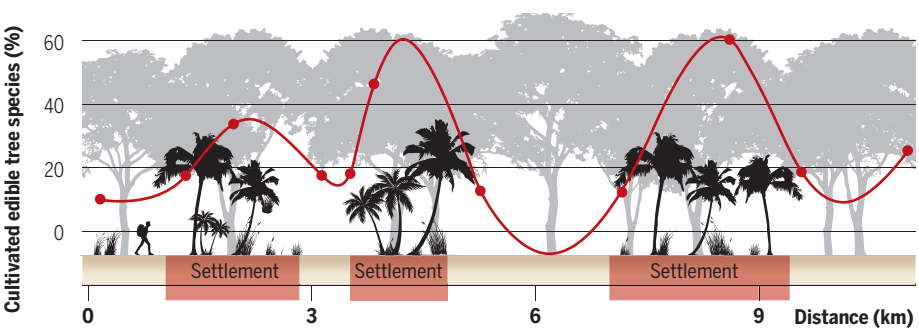
back between Indigenous peoples and food availability is one with the potential to transform forest composition and amplify food production at large scales. Positive feedback is a two-way interaction that may amplify changes in the system (*12*). When Indigenous and local peoples manage tropical forests by selecting, cultivating, and dispersing trees, palms, and other perennial plants, they interfere with ecological processes that shape forest composition, favoring edible species. As a result, patches of edible species increase in abundance. In managed landscapes, plant communities become dominated by multiple edible species clumped together around ancient settlements. To illustrate this, the abundance of edible species is depicted during a walk in the seemingly natural landscape of the Tapajós National Forest (Brazilian Amazonia), where the average distance between ancient settlements is 2 (±1) km (*11*) (see the figure). As one approaches the site of an ancient settlement, the abundance of edible (and cultivated) plant species rises steeply; as one walks away, the abundance diminishes in the same fashion until another ancient settlement site is approached.

One implication of this positive feedback is that where Indigenous and local peoples are excluded from the system, or when their practices are lost, landscapes are expected to change. Initially, the most domesticated plant populations begin to disappear because they depend on local management to persist (*6*). If anthropogenic dark soils erode—for example, owing to unsustainable land use and wildfires—edible species that are more nutrient demanding may also disappear. In the long run, natural ecological and evolutionary processes could reduce the abundance of edible species by up to 80%. With fewer fruits and seeds in the forest, the cascading effects on ecological interactions could negatively affect the populations of frugivore vertebrates, consequently affecting the availability of animal protein. Similarly, where Indigenous and local peoples have no access to the forest, their ancient ecological knowledge fades away over a few generations (*13*).

Globally, more than a billion people rely on forest resources for their nutrition and health, particularly in developing tropical regions (*14*). Indigenous and local peoples have historically contributed to the enrichment of tropical forests with food, and today their territories act as buffers against large-scale deforestation and degradation (*15*). The positive feedback between local peoples and food availability unveils the possibility of conserving tropical forests while boosting food security and sovereignty; hence, it might contribute to achieving the Zero Hunger goal of the Sustainable Development Goals. For this ancient feedback to continue functioning, societies need to recognize Indigenous and local peoples' rights to their ancestral forest lands. ■

A walk in the forest

When passing by ancient settlements, the proportion of edible arboreal species rises steeply as a result of Indigenous and local peoples' management.



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METABOLISM

Supplements to treat prediabetes

Boosting nicotinamide adenine dinucleotide (NAD^+) improves health in a clinical study

By **Chelsea Hepler** *and* **Joseph Bass**

Nicotinamide adenine dinucleotide (NAD^+) is an essential metabolic cofactor that is central to energy metabolism. During aging, obesity, and diabetes, NAD^+ concentrations in cells decline. NAD^+ is synthesized de novo from tryptophan precursors, from nicotinic acid through the Preiss-Handler pathway, or from nicotinamide through the salvage pathway. The rate-limiting enzyme in the salvage pathway, nicotinamide phosphoribosyltransferase (NAMPT), recycles nicotinamide into nicotinamide mononucleotide (NMN), which is converted into NAD^+ (see the figure). Restoration of NAD^+ concentrations in cells of old or diseased mice through administration of NMN improves health; however, it is unclear whether NMN therapy is practical in humans. On page 1224 of this issue, Yoshino *et al.* (*1*) show in a randomized, placebo-controlled, double-blind trial that NMN supplementation promotes NAD^+ metabolism and improves skeletal muscle insulin sensitivity in postmenopausal prediabetic women who are overweight or obese. Thus, NMN may be a viable therapeutic strategy in humans to improve metabolic health during obesity.

Ingestion of NMN from supplements or various types of foods—such as edamame, broccoli, and cabbage—leads to rapid absorption into the circulation where it is used by tissues for NAD^+ biosynthesis. Studies have shown that NMN enters cells indirectly through dephosphorylation into nicotinamide riboside (NR) and subsequent reconversion to NMN inside the cell or directly by transport through SLC12A8 (solute carrier 12 member 8), although it remains unclear whether direct uptake occurs owing to difficulty in measuring NMN and NR

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