HANPP

Subjects: Others
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Human appropriation of net primary production (HANPP) is a substantial improvement upon 20th century attempts at developing an ecological footprint indicator because of its measurability in relation to net primary production, its close relationship to other key footprint measures, such as carbon and water, and its spatial specificity. HANPP informs different sustainability narratives at different scales. At the planetary scale, HANPP is a critical planetary limit that improves upon areal land use indicators. At the country macroscale, HANPP indicates the degree to which meeting the needs of the domestic population for provisioning ecosystem services (food, feed, biofiber, biofuel) presses against the domestic ecological endowment of net primary production. At the county mesoscale, HANPP reveals the dependency of metropolitan areas upon regional specialized rural forestry and agroecosystems to which they are teleconnected through trade and transport infrastructures. At the pixel microscale, HANPP provides the basis for deriving spatial patterns of remaining net primary production upon which biodiversity and regulatory and cultural ecosystem services are dependent. HANPP is thus a sustainability indicator that can fulfill similar needs as carbon, water and other footprints.

human appropriation of net primary production | ecological footprint | planetary limits

1. Background

In the 1990s, Wackernagel and Rees developed the ecological footprint concept as the area of biologically productive land and ocean that is required to continuously provide the resources consumed by a group of people (such as a country), and to process their wastes [1]. According to their analysis, the average human used 6 to 7 acres; since the Earth contains 5 “productive” acres per capita, a figure that declines with population growth, humans were overshooting planetary limits. They identified substantial variation due to consumption differences, with, for example, the average person in India using 2 acres, China 3, Germany 13, Canada 19, and the U.S. 25. For countries such as the U.S. that were exceeding domestic carrying capacity, the difference had to be made up through imports from lands abroad, or by utilizing domestic natural capital unsustainably. This ecological footprint framework also enabled the analysis of temporal trends, and the partitioning of ecological footprints into their components, such as diet, raw materials, energy needs (including carbon absorption), land development, and land contaminated by nuclear weapons and power development.

As an important innovation in its time, these comparisons yielded insights and illustrated relevant temporal and geographical trends; they were fraught, however, with conceptual weaknesses and scientific imprecision. A generic, geographically unidentified acre of “biologically productive land” was the currency through which the ecological footprint was measured, yet the biological productivity of ecosystems varies enormously. Resource consumption that was not inherently land-based had to be converted to acreage using questionable stoichiometries. For example, how many acres are committed when a ton of coal is surface mined, burned in a power plant, and emits carbon dioxide that must either be sequestered or allowed to change the climate?

2. HANPP as a Modernized Ecological Footprint

A more precise and broadly useful approach to measuring ecological footprint is offered by the Human Appropriation of Net Primary Production (HANPP). HANPP is defined by Haberl et al. (2007) [2] as the difference between potential net primary production (NPP) and the NPP remaining post-harvest. This is the NPP made unavailable to ecosystems by human use of land. By using this externally consistent approach, the problem of "generic" land inherent in the ecological footprint concept is solved on two fronts. First, enormous variations in the ecological productivity of land, which range from 0 to about 1500 $gCm^{-2}yr^{-1}$ [3][4], are incorporated into the analysis. Second, the varying degrees to which this productivity is appropriated or colonized by human use are measured, whether by changing the ecological productivity of the land (HANPP-land use) or by harvesting it (HANPP-harvest). In this manner, it is not the land area of the Earth that constrains human carrying capacity, but the Earth's terrestrial ecological productivity. Rather than geographical space, the human ecological niche is compared to photosynthetic capacity that can be measured at scales from the planet to a 30 m pixel, as explored below.

Third, HANPP is also identifiable to specific plots of land, thus enabling spatially-specific and geospatial analysis. Critically, by tracing HANPP (harvest) in the form of biomass products such as food or lumber, from the point of production to the point of consumption, a spatially-specific ecological footprint can also be developed on the basis of the consumption of biomass products at specific times and places (this is termed embodied HANPP) [5].

Fourth, HANPP is quantifiable in relation to carrying capacity limitations—among which NPP is perhaps the most critical (Running 2012)—and a safe operating space within those limits [6]. For HANPP, the local safe operating space can be defined as a maximum percentage of NPP, or as a minimum NPP remaining post-harvest—termed NPP (ecological). Moreover, a focus on HANPP as the core of an ecological footprint takes into account the dominant effect HANPP has, through photosynthesis, on water [7], nitrogen [8] and phosphorus [9] use, the profound effect land use and habitat change have on biodiversity loss [10], and the substantial effect, both positive and negative, land use has on atmospheric carbon through Forestry and Other Land Use (FOLU) [11]. HANPP is often measured in terms of dry organic matter but can be easily converted to carbon simply by taking the carbon content of plant biomass—usually 45% [3], or sometimes 47% [12], though there is some variation in individual plants and species [4]. This enables HANPP to be related to carbon footprint, such as the land use component of net carbon emissions.

Fourth, carbon can be readily converted to an energy measure, (e.g., 1 g C = 32,800 joules) so that energy-based comparisons can be drawn. For example, the energy content of global gross terrestrial primary production (GPP) of about 110–120 $PgCyr^{-1}$ is about 37–39 × 10^{20} joules, and NPP, using the 56.8 $PgCyr^{-1}$ estimate, is 18.6 × 10^{20} joules—0.15 percent of the 37,693 × 10^{20} joules yr^{-1} of radiant solar energy reaching Earth. In comparison, global commercial energy consumption is about 6–7 × 10^{20} joules yr^{-1} and rising (International Energy Administration 2020). In fact, HANPP is an energy-based concept at its heart, and this enables analyses founded in energy accounting, such as energy return on investment (EROI).

Fifth and finally, like other footprints that have withstood the test of scientific critique, such as water and carbon footprints, HANPP is closely tied to fundamental, measurable earth system processes. Water footprint is measured as evapotranspiration, carbon footprint as net CO_2-equivalent emissions to the atmosphere, and HANPP is net primary production made unavailable to ecosystems.

3. Limitations of HANPP

While the advantages of HANPP as an ecological footprint measure are dispositive, there are important measurement and definitional issues [4], as is the case with all footprint analyses. First, the definition of HANPP (land use) is the difference between potential and actual NPP, yet the former is hypothetical and can only be simulated using ecosystem models such as Lund–Potsdam–Jena [13], or the Carnegie–Ames–Stanford Approach [14]. Different ecosystem models have been shown to generate quite different results, with none of them achieving accuracy within the bounds of flux tower measurement uncertainty [15]. While gross primary production can be directly measured using flux tower data, albeit on a course and unrepresentative spatial framework, net primary production can only be estimated indirectly from remote sensing data.

Human “appropriation” of ecological energy flows also brings to bear definitional issues. For example, in a grain field, the yield of grain is clearly appropriated but the roots of annual crops and much of the straw or stover remain in place, providing ecological energy to detritus cycles. Are these then “appropriated” by humans? Partitioning HANPP into above and below-ground, and into economic yield and unused components, enables calculation of it under a variety of definitions [16][17].

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