Global Environmental Change 25 (2014) 63–68

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

The effort factor: Evaluating the increasing marginal impact of resource extraction over time

Debra J. Davidson [a,*], Jeffrey Andrews [a], Daniel Pauly [b]

[a] Department of Resource Economics and Environmental Sociology, University of Alberta, Canada
[b] Fisheries Centre, University of British Columbia, Canada

ARTICLE INFO

Article history:
Received 1 October 2013
Received in revised form 23 January 2014
Accepted 3 February 2014
Available online 4 March 2014

Keywords:
Ecological impact analysis
IPAT
Natural resource depletion

ABSTRACT

Concern for the increasing impact of human activities on Earth's ecosystems has generated a growing effort to monitor those impacts and measure the success, if any, of mitigation measures. This contribution argues that ecological impact assessments that tend to rely primarily on the volume of natural resources produced and subsequently consumed overlook the degree to which ecological impact can vary significantly independently of production volumes, due to the varying impact that results from production effort. Production effort, in turn, is directly linked to the quality of raw materials, which inevitably tends to decrease over time. As a result, unless technological improvements were able to compensate for the resource quality decline indefinitely, we face a future of increasing marginal ecological impact over time. This is demonstrated here based on three resource extraction systems, coal mining in the UK, grain production in China, and global marine fisheries.

1. Introduction

Contemporary discussions of society's precarious relationship with the ecosphere often start and end with the spotlight on consumption. Such predilections have led to numerous calls for consumer responsibility, with each new "10 Things You Can Do" list including more creative steps individuals can apply to reduce their personal consumption. Even more prevalent are encouraging prescriptions for, and in some case observations of, increased efficiency in resource use, with ecological modernizationists and industrial ecologists offering optimistic accounts of our collective potential for "dematerialization" of our consumptive economies, the implication being that reductions in material consumption represent a key route to ecological improvement. Other lines of inquiry are more nuanced in their treatment of consumption in socio-ecological relations, but the assertion that consumption is the driving force behind changes in ecological well being has now come to frame many debates, with political implications. For example, projections of future impact on the basis of historical consumption (emission) rates have become central to scenario analyses by, for example, the Intergovernmental Panel on Climate Change (IPCC) (e.g. Moore et al., 2012; Galli et al., 2012).

Consumption unquestionably drives ecological impact, but it is by no means the only factor, nor is it the most direct indicator of ecological impact. Importantly, even if demand for ecosystem services leveled off, perhaps a result of population stabilization, redistribution of affluence, or strict sanctions, increases in ecological impact could still result. As first introduced in a recent article in *Science* (identifying citation), ecological impact is a function of effort, not reward. In other words, the relative inputs required to "produce" material commodities through the extraction and processing of natural resources has a more direct causal relationship with ecological impact than does the volume of resulting commodities that are subsequently consumed. More importantly, this effort will tend to increase over time, as reserves of natural resources become degraded due to historical production. This counters two dominant, inter-related paradigms guiding environmental sciences and policy: consumption levels directly affect ecological impact; and secondly, continued improvements in efficiency technologies will enable reduced material consumption without compromising the use values derived from consumption (i.e. we can drive longer using less fuel). We offer a conceptual exploration of the role of production effort in ecological impact, followed by three supplementary examples in the coal, grain and fisheries sectors, illustrating a consistent historical trend toward increasing marginal ecological impact in each case. We conclude

* Corresponding author at: 515 General Services Building, University of Alberta Edmonton, AB T6G2H1, Canada. Tel.: +1 780 492 4598; fax: +1 780 492 0268.
E-mail addresses: debra.davidson@ualberta.ca (D.J. Davidson), abjeffre@ualberta.ca (J. Andrews), dpauly@fisheries.ubc.edu (D. Pauly).

http://dx.doi.org/10.1016/j.gloenvcha.2014.02.001
0959-3780/

with discussion of the implications of these findings for contemporary efforts to ameliorate society's global ecological impact.

2. Theory

Why would ecological impact increase even if consumption were constant? Consider a hypothetical coalfield. When coal is first exploited, the richest, most accessible features of those deposits are exploited first. Over time, deposits further from the surface and of lower density become the sites of exploitation. When this becomes economically unfeasible, more geographically remote deposits are exploited. Finally, as even these become exhausted, investments are made in technologies to squeeze commodities out of lower quality reserves. In each case, the resulting increase in effort required to extract, process and transport those resources for consumption require more raw material and chemical inputs, and create more waste. While for much of our industrial history, global trends of this sort have been masked as depleted mines were replaced with discoveries of richer deposits elsewhere, today declines in the quality of many resource pools can be observed globally.

An analogous story is offered by recent analyses noting the increases in energy investments required to access and process depleted conventional fuels and non-conventional energy sources (Energy Return on Investment, or EROI) (e.g. Murphy and Hall, 2010; Brown and Cohen, 2009; Brown and Ulgiati, 2001), although these accounts tend to focus less empirical attention on the ecological implications of declining energy return on investment, and do not apply their framework to other resource sectors. The growing number of projections (in some cases observations) that the reserves of many non-renewable resources are reaching a maximum threshold of production, most notably oil (Murphy and Hall, 2010; Fantazzini et al., 2011; Prior et al., 2011; IEA, 2010; Campbell, 2002, 1997), renders this finding particularly disconcerting. Popularized forms of these conversations about "Peak Everything" are often misconstrued, however; in most cases we are not running out, we are simply running out of the easy stuff (Fantazzini et al., 2011). We could continue to extract oil, coal, natural gas, and several minerals for many decades, but the escalating ecological and social implications of doing so, more so than forecasts of peak dates, demand attention.

Odum (1971 [2007], 1997) was perhaps the first to highlight this energy input/output relation, initially in 1973, and later with his articulation of the term *emergy*, defined as "the availability of energy (exergy) of one kind that is used up in transformations directly and indirectly to make a product or service" (Brown and Ulgiati, 2001: 62). This statement, rooted in basic principles of metabolism, warrants further elaboration. As noted by Magdoff (2011), the extraction, processing and consumption of natural resources are central pathways in the metabolism of social systems. The metabolic processes performed by any cell or organism require effort. The effort required to support metabolic pathways are not general, however, but specific: some simple compounds, such as sugar, can be quickly metabolized by the human body, while proteins take more work, for example. The amount of effort required can also be affected by the 'fitness' of the laborer: certain illnesses can compromise the efficiency of metabolic processes within an organism; lack of fishing skill would likely translate into longer time requirements to catch a fish than it would otherwise. Effort is also affected by the original condition of the materials being processed: it takes a human body more work, through additional consumption, to extract needed nutrients from foods with low nutrient density (with negative consequences in the form of obesity and/or health complications).

And – the focus of the present paper – it takes more effort to convert lower quality natural resources into something of social use value. 'Quality' in this sense refers to those biophysical characteristics of a natural resource desired for human use that determine the ease with which use value can be derived from it. This includes, for example, the density of a mineral or energy source within the substrate in which it is contained, or the amount of impurities that would need to be removed. The sulfur content of fossil fuels, which must be removed before consumption, for example, can vary tremendously. Quality can also refer to accessibility, such as the depth of an oil reserve, or other conditions restricting access, such as extensive ice cover. The 'Effort' required for society to access natural resources and agricultural products for consumption consists of human labor, the tools and technologies that are extensions of that labor, and the material inputs, including land, water, energy and chemicals, that are employed in extraction, processing, transport and consumption.

Odum's work, and that of more recent energy return on Investment analysts, have been focused specifically on energy flows, however, rather than socio-ecological relations as such, and thus the broader implications of their contributions for global ecosystems have not been taken up to any great extent. One complementary line of inquiry, however, dates further back than Odum's work, with Karl Marx and his employment of the concept of Metabolic Rift. Contemporary environmental sociologists have built upon his foundations for application to current environmental crises. Marx's work was based upon observations made during the Second Agricultural Revolution in the 19th Century, when rapid soil depletion caused by intensive agriculture came to light, inducing the inception of a fertilizer industry. Laid out in detail by Foster (1999), the general rudiments of Marx's theory are as follows: (1) Humans are only able to survive by virtue of their metabolic relation with the natural world. (2) The means by which metabolic relations manifest is labor (technology), which is conditioned by both natural limits and social relations, (3) particular forms of social relations can cause ruptures in this metabolic relationship. (4) The social relations dictated by capitalism have induced just such a rupture. Marx referred specifically to the large-scale agricultural processes associated with capitalism: intensive production robs the soil of nutrients, while depopulation of the countryside prevents the nutrient replenishment embodied in the organic waste produced by humans, who now live in cities. Given capitalism's growth imperative, it depends upon ever-larger inputs of energy and material resources over time to reproduce itself. This has, through the course of history, culminated periodically in significant restructuring as capital confronts the limits of nature, the introduction of synthetic fertilizers being just one example. In each mode of restructuring, however, the Metabolic Rift is not repaired, but merely transformed (Moore, 2000, 2001, 2003).

Contrast these analyses to another formula far more frequently used to capture those broader relationships between societies and ecological impact, IPAT, which states that Impact is a function of the product of Population, Affluence, and Technology. IPAT was introduced by Ehrlich and Holdren (1971) and largely accepted today, with solid empirical support indicating that growing population and affluence in particular have been drawing down earth's biocapacity (Rosa and Dietz, 2012; Liddle, 2011; Liddle and Lung, 2010; York et al., 2003; Schulze, 2002; Fischer-Kowalski and Amann, 2001; Dietz and Rosa, 1997). A more recent line of IPAT-related research that employs an adapted, stochastic model (STIRPAT, standing for Stochastic Impacts by Regression on Population, Affluence and Technology) has offered compelling evidence of the stability of the effect of population size over time (Jorgenson and Clark, 2010, 2012); and the asymmetric, or path-dependent effects of economic development: in essence while CO2 emissions increase with economic growth, they do not tend to decrease at the same rate when those economies shrink (York, 2012).