# Care to Wager Again? An Appraisal of Paul Ehrlich's Counterbet Offer to Julian Simon, Part 1: Outcomes

Pierre Desrochers, *University of Toronto*
Vincent Geloso, *King's University College*
Joanna Szurmak, *University of Toronto*

*Objective.* This paper provides the first comprehensive assessment of the outcome of Paul Ehrlich and Stephen Schneider's counteroffer (1995) to economist Julian Simon following Ehrlich's loss in the famous Ehrlich-Simon wager on economic growth and the price of natural resources (1980-1990). *Methods.* Literature review, data gathering and critical assessment of the indicators and proxies suggested or implied by Ehrlich and Schneider. Critical assessment of Simon's reasons for rejecting the bet. Data gathering for his alternative indicators. *Results.* For indicators that can be measured satisfactorily, the balance of the outcomes favors the Ehrlich-Schneider claims for the initial ten-year period. Extending the timeline and accounting for the measurement limitations or dubious relevance of many of their indicators, however, shifts the balance of the evidence towards Simon's perspective. *Conclusion.* Although the outcomes favour the Ehrlich-Schneider claims for the initial ten-year period, Ehrlich and Schneider.s indicators yielded mixed results in the long run. Simon's preferred indicators of direct human welfare would yield largely favourable outcomes if the bet were extended into the present. Based on this, we claim that Simon's optimistic perspective was once again largely validated.

> [The] study of the growth of population is often spoken of as though it were a modern one, [but it has] in a more or less vague form… occupied the attention of thoughtful men in all ages of the world. Marshall (1890:223)

Since its conclusion in 1990, the bet between economist Julian Simon and biologist Paul Ehrlich on the relationship between resource availability and population/economic growth has generated much academic and popular interest. In 1995 Ehrlich and his colleague, Stephen Schneider, offered winner Julian Simon a new 10-year wager based on a different set of "indirect measures" of environmental conditions and human health indicators. Simon declined the proposal, claiming it lacked direct and objectively measurable connections to human welfare. While no one has examined the content and actual outcome of this aborted wager in any depth, it is often brought up by Ehrlich and his supporters to challenge Simon's triumphalist narrative and underlying optimistic perspective. This article provides the first comprehensive assessment of the outcome of the Ehrlich–Schneider counteroffer. Our main conclusion is that, for indicators that can be measured satisfactorily or can be inferred from (more or less adequate) proxies, the outcome favors Ehrlich–Schneider. In a second article, we extend the timeline toward the present time

Direct correspondence to Vincent Geloso, School of Management, Economics and Mathematics, King's University College, London, ON, Canada N6A 2M3 ⟨vgeloso@uwo.ca⟩.

SOCIAL SCIENCE QUARTERLY

DOI: 10.1111/ssqu.12928

period, discuss the limitations and validity of the indirect measures and proxies used, and assess Julian Simon's suggested alternatives. In doing so, the evidence shifts toward Simon's perspective.

Concerns over population growthand the limited carrying capacity of ecosystems have been documented in the works of Confucius, Plato, and Aristotle (Simon, 1998). In the last two centuries, "the question of limits to growth and optimism and pessimism regarding the human prospect [has been] debated without consensus" with interest in the issue having "waxed and waned more times than can be counted" (Luten, 1980:125). Conflicting perspectives on the nexus of population growth, resource availability, and environmental impact, however, can only be mutually exclusive, for either valuable resources are finite and natural limits impose strict boundaries on human actions, or else human creativity can find ways around material scarcity and environmental degradation.

These visions clashed prominently in the 1980 bet on future resource scarcity as measured by changes in commodity prices between economist Julian Simon and biologist Paul Ehrlich and his collaborators John Holdren and John Harte. Simon won the bet decisively, but the significance of this outcome still generates much debate (Kiel, Matheson, and Golembiewski, 2010; Lawn, 2010; Becker, 2013; Sabin, 2013a, 2013b; Ehrlich and Ehrlich, 2013). In 1995 Simon refused a counterbet offer by Ehrlich and his colleague, Stephen Schneider, by claiming that it had no directly measurable relevance to human well-being (Ehrlich and Ehrlich, 1996; Simon, 1997; Sabin, 2013a). This declined second wager has ever since been used as a rhetorical tool against Simon's optimistic outlook. Curiously though, the outcome of the Ehrlich–Schneider counterwager, and of Simon's critique and counteroffer to the counterwager, have never been assessed. This article is our attempt to fill this gap.

This two-part discussion of the outcome of the Ehrlich–Schneider proposal is structured as follows. We first summarize the conflicting visions of Julian Simon and Paul Ehrlich, along with their famous initial bet. We then assess the outcome of the Ehrlich–Schneider counterproposal. As discussed in the article, some of their indicators are straightforward but many are not. In this first article, we present the results for the time period specified by Ehrlich and Schneider using either well-established indicators or by surveying the closest available corresponding measurements or proxies. In a second article, we then extend the time period of the wager by another decade to better assess long-term trends and to discuss in more detail the limitations or validity of these indicators in terms of them supporting Ehrlich and Schneider's worldview. We finally summarize and assess the evidence on Julian Simon's alternative wager offer to Ehrlich and Schneider.

Our key results and final assessment are as follows. For indicators that can be measured satisfactorily, the balance of the outcomes favors the Ehrlich–Schneider claims for the initial 10-year period. Extending the timeline and accounting for the measurement limitations or dubious relevance of many of their indicators, however, shifts the balance of the evidence toward Simon's perspective. Simon was also largely proven correct on his counteroffer to Ehrlich and Schneider.

## The 1980 Simon–Ehrlich Bet

### *Conflicting Visions*

The conflict pitting Ehrlich's vision against Simon's revolved around the extent to which natural limits, that is, both resource availability and the capacity of nature to act as a sink for human-generated polluting emissions, constrain human demographic and economic growth. Ehrlich argued that nonrenewable resources exhibit decreasing marginal returns. Their continued exploitation was therefore inherently unsustainable and would inevitably result in progressive environmental degradation and, ultimately, civilizational collapse (Ehrlich, 1968; Ehrlich and Ehrlich, 2009:2–13).

Ehrlich and his collaborators frequently derided the "cornucopian argument" according to which a constant stream of innovation of all kinds can, to the contrary, deliver both increased standards of living and environmental remediation. Their main criticisms were fourfold: (a) the presumption that technological advances will make energy cheaper is incorrect; (b) the presumption that abundant cheap energy would be a sufficient condition for abundance is incorrect; (c) the cornucopian argument frequently and severely underestimates unavoidable environmental degradation; and (d) the cornucopian argument seriously underestimates damages to human well-being caused by environmental degradation (Ehrlich, Ehrlich, and Holdren, 1977/1970:954).

Simon's (1977, 1980, 1981a, 1995a, 1995b, 1996, 2000) response to Ehrlich's perspective centered around the creative ability of human beings, the benefits delivered by an ever broader division of labor, and the feedback mechanism provided by the price system. In a market economy, rising prices would result in resources being used more efficiently, new deposits discovered, and substitutes developed, resulting, in time, in less scarcity and lower prices. Simon's overall conclusion was that "[m]ore people and increased income cause problems in the short run—shortages and pollutions. Short-run scarcity raises prices and pollution causes outcries. These problems present opportunity and prompt the search for solutions. In a free society, solutions are eventually found… In the long run the new developments leave us better off than if the problems had not arisen" (Simon, 1995b:24–25). In Simon's view, the role of institutions crucially modulated the positive effects of population growth. If the institutional environment was one of freely determined prices and secure private property rights, conditions would promote the coordination, development, and utilization of new ideas. For instance, in the United States, "[e]very measure of material and environmental welfare […] has improved rather than deteriorated" and "[l]ong-run trends point in exactly the opposite direction from the projections of the doomsayers" (Simon, 1995b:24–25).

## *The First Bet's Aftermath*

Ehrlich first gained widespread public attention through predictions of imminent environmental and societal collapse, including a famous 1969 statement to the effect that he "would take even money that England will not exist in the year 2000" (Dixon, 1971:606). This was followed in the next decade by numerous—and often apocalyptic—predictions of resource shortages and worsening living standards. In an attempt to challenge Ehrlich, Simon (1981b:39) eventually offered in this journal to bet that "the cost of non-government-controlled raw materials" would not increase in the long run by staking "$10,000 in separate transactions of $1000 or $100 each" on resources of Ehrlich's choosing, with the minimum period of time covered by the bet being one year.[1] Ehrlich (1981:46), again in this journal and with collaborators John P. Holdren and John Harte, accepted "Simon's

---

[1] Simon later noted that there was no particular reason for believing he would win in short time periods. While long-term trends suggest declining prices (Jacks, 2013) for broad indexes of commodity prices, there could be shocks (natural, institutional, etc.) that would create different short-term patterns even if prices were not regulated by governments (Simon, 1996).

astonishing offer before other greedy people" jumped in. They agreed "to pay him on September 29, 1990, the 1990 equivalent of 10,000 1980 dollars (corrected by the [Consumer Price Index]) for the quantity that $2,000 would buy of each of the following five metals on September 29, 1980: chromium, copper, nickel, tin and tungsten." Despite population growth of over 800 million people and rising living standards, between 1980 and 1990 the prices of all these commodities fell, from 3.5 percent for copper to 72 percent for tin, thus handing Simon a resounding victory (Sabin, 2013a).

Ehrlich, his collaborators, and his supporters never acknowledged nor discussed in writing that losing the wager might imply flaws in their assumptions. Some critics of Simon produced results showing that different 10-year windows yielded different outcomes (Kiel, Matheson, and Golembiewski, 2010). Others argued that natural resource abundance is not an especially relevant environmental and overall human well-being indicator when compared to the deterioration of soils, forests, species diversity, and groundwater (Sabin, 2013b).

Simon (n.d.)[2] countered these criticisms by offering to bet on the notion that "just about any trend pertaining to material human welfare [would] improve rather than get worse," but he insisted on using criteria tied to human well-being. For instance, he preferred morbidity instead of cancer rates as an increase in the latter might be the result of fewer individuals dying at younger ages from other diseases. Ideally, Simon argued that one should use long-term and wide-ranging cross-sectional data sets of countries and variables in order to reflect heterogeneity in preferences across regions. Ehrlich rejected Simon's selections and proposed an alternative bet. With his Stanford colleague Stephen Schneider, he offered to bet on indirect environmental and health indicators of their own choosing over a 10-year period (Ehrlich and Ehrlich, 1996:100–104). Simon (n.d.; see also Simon, 1997) refused the wager, alleging that it pertained to "aspects of our environment whose connection to human welfare is questionable and perhaps subjective, instead of being objectively measurable." Simon then reiterated the indicators he would rather use, and his reasons for their selection. Despite Simon's consistent explanations of his rationale, Ehrlich and his supporters have since interpreted Simon's refusal to entertain their counteroffer as a direct challenge to his core beliefs (Ehrlich and Ehrlich, 1996; Ehrlich and Schneider, 1995; Sabin, 2013a, 2013b).

The outcome and validity of the Ehrlich–Schneider wager proposal, however, has never been assessed in detail. What follows is our attempt to do so.

## The Second Bet: Terms, Indicators, Rationales, and Results

### *Terms of the Second Wager*

Paul Ehrlich and Stephen Schneider's counteroffer consisted of 15 "continental and global scale indicators" that they described as "indirect measures" (Ehrlich and Schneider, 1995). Outcomes of $1,000 on each indicator were set and, in order to win, Simon had to be proven correct on "eight out of fifteen indicators" (Petit, 1995). The terms are specified in Table 1.

Ehrlich and Schneider's rationale for using "indirect measures" was the inherent difficulty of determining "exactly how direct measures of human well-being will be impacted by the general deterioration of Earth's life-support systems" (Ehrlich and Schneider,

---

[2] This text is available in Simon's web archives, but the date of its writing is uncertain. 1995 seems most plausible.

TABLE 1

Terms of the Ehrlich–Schneider Counteroffer

1. The three years 2002–2004 will on average be warmer than 1992–1994.
2. There will be more carbon dioxide in the atmosphere in 2004 than in 1994.
3. There will be more nitrous oxide in the atmosphere in 2004 than in 1994.
4. The concentration of ozone in the lower atmosphere (the troposphere) will be greater in 2004 than in 1994.
5. Emissions of the air pollutant sulfur dioxide in Asia will be significantly greater in 2004 than in 1994.
6. There will be less fertile cropland per person in 2004 than in 1994.
7. There will be less agricultural soil per person in 2004 than in 1994.
8. There will be on average less rice and wheat grown per person in 2002–2004 than in 1992–1994.
9. In developing nations there will be less firewood available per person in 2004 than in 1994.
10. The remaining area of virgin tropical moist forests will be significantly smaller in 2004 than in 1994.
11. The oceanic fisheries harvest per person will continue its downward trend and thus in 2004 will be smaller than in 1994.
12. There will be fewer plant and animal species still extant in 2004 than in 1994.
13. More people will die of AIDS in 2004 than did in 1994.
14. Between 1994 and 2004, sperm counts of human males will continue to decline and reproductive disorders will continue to increase.
15. The gap in wealth between the richest 10 percent of humanity and the poorest 10 percent will be greater in 2004 than in 1994.

SOURCE: Ehrlich and Ehrlich (1996:100–104).

1995:n.p.). While Ehrlich and Schneider's contention was not that "there are only unfavorable human or environmental trends," too many significant ones were "very unfavorable" and in need of "prompt attention" (Ehrlich and Schneider, 1995:n.p). Unfortunately, many relevant indicators to assess the indirect measures' trends were not available in standardized data sets. They were also the subject of vigorous methodological debates as to their accuracy and validity. For instance, indicators such as "estimates of… agricultural soils" involved "questions of judgment." In such cases, Ehrlich and Schneider would defer to "a panel of scientists chosen by the President of the National Academy of Sciences in 2005" to determine the "direction of the trends." Another problem was that some of their claims used the qualifier "significantly," as in significantly "greater" or "smaller" concentrations or availability, defined as "5 and 10 above." Because of the "empirical basis" of their claims," however, they were confident that "competent scientists [could] make reasonable judgments" (Ehrlich and Ehrlich, 1996:100–104; see also Ehrlich and Schneider, 1995:n.p.).

The remainder of this section presents Ehrlich and Schneider's indicators, the rationale for their selection, the closest proxy available (when warranted), and the results. Some claims were grouped thematically to facilitate discussion.

## *Outcomes 1–3: Global Temperature, Carbon Dioxide, and Nitrous Oxide*

While a staple of the popular press, the determination of the global average temperature involves complex procedures that, in turn, require judgment and several technical decisions. This is problematic in a short time period and in the presence of multiple data sets

TABLE 2

Global Temperature, Carbon Dioxide, and Nitrous Oxide Concentrations over the Terms of the Second Ehrlich–Simon Bet

| Global Temperature | | | |
|---|---|---|---|
| Data set | Change | 2002–2004 GMST | 1992–1994 GMST |
| NASA GISS | +0.3° | 0.597° above 1951–1980 level | 0.253° above 1951–1980 level |
| UK Met Office HadCRUT | +0.3° | 0.483° above the 1961–1990 level | 0.154° above the 1961–1990 level |
| UAH MSU/AMSU | +0.3° | 0.162° above the 1981–2000 level | 0.182° below the 1981–2000 level |
| Carbon dioxide | | | |
| Mauna Loa Observatory | +18 ppm | 376 ppm | 357 ppm |
| Nitrous Oxide | | | |
| EPA | +7 ppm | 317 ppm | 310 ppm |

SOURCE: NASA GISS, HadCRUT, UAH MSU/AMSU, Mauna Loa Observatory, and EPA.

(Hurrell and Trenberth, 1996a, 1996b). The most cited numbers are based on global mean surface air temperatures (GMST) data, an estimate of the spatial distribution of temperatures derived from thousands of daily surface observations obtained from weather stations, buoys, ships, and other autonomous observing systems. Some of the technical issues involved in deriving GMST data include "difficulties in obtaining data, documenting and accounting for changes in instrumentation and observing practices, addressing changes in station location and local land use, understanding random measurement errors, and deciding where and how to infill missing data in space and time" (NCAR, 2014). Two key research centers produce these estimates: NASA's Goddard Institute for Space Studies (GISS), the United Kingdom's Met Office Hadley Centre (2020)/Climatic Research Unit (HadCRUT).

The first two rows of Table 2 show the results from these data sets. Some scholars (Spencer, Christy, and Braswell, 2015; McKitrick and Christy, 2018) have contested the practice of using raw data from these data sets, pointing out that satellite data vary in quality because of technical issues such as calibrations.[3] These scholars have produced adjusted data sets such as the University of Alabama in Huntsville's (UAH) Microwave Sounding Unit (MSU) and Advanced Microwave Sounding Unit (AMSU) (UAH MSU/AMSU) data, presented as the third row of Table 2. The sets of measures show some differences in long-term trends, the UAH MSU/AMSU being the most divergent. Over the period of the Ehrlich–Schneider wager, however, there is a clear increase in global temperature in all data sets. In fact, the absolute increase is quite similar across the data sets. Ehrlich and Schneider thus win their first claim.

The Mauna Loa Observatory in Hawaii has provided the longest record of direct measurements of $CO_2$ in the atmosphere. It is reported as a dry mole fraction defined as the

---

[3] Spencer et al. (2015:2) wrote that "since 1979 we have had 15 satellites that lasted various lengths of time, having slightly different calibration (requiring intercalibration between satellites), some of which drifted in their calibration, slightly different channel frequencies (and thus weighting functions), and generally on satellite platforms whose orbits drift and thus observe at somewhat different local times of day in different years. All data adjustments required to correct for these changes involve decisions regarding methodology, and different methodologies will lead to somewhat different results. This is the unavoidable situation when dealing with less than perfect data."

number of molecules of carbon dioxide divided by the number of molecules of dry air multiplied by one million, or parts per million (ppm). According to Tans and Keeling (n.d.), "[t]hese values are subject to change depending on quality control checks of the measured data, but any revisions are expected to be small." Table 2 shows the results from this data set. As predicted by Ehrlich and Schneider, $CO_2$ concentration increased over the decade.

Finally, the nitrous oxide data, obtained from the Environmental Protection Agency's database, are also included in Table 2 and once again supports Ehrlich and Schneider's predictions.

### *Outcomes 4 and 5: Tropospheric Ozone and Sulfur Dioxide*

Tropospheric ozone concentrations are problematic because the gas is a component of smog, which has deleterious effects on human health and crop production. Tropospheric ozone concentrations are nevertheless difficult to assess because ozone is formed as a reaction product and it can dissipate at varying rates over periods of 5–25 days depending on altitude, geographic location, season, temperature, and humidity. A small number of observation stations measuring ozone concentrations may thus provide biased data from nonrepresentative samples, a problem made worse by the fact that the number of observation stations was once much smaller (Cooper et al., 2014; Schultz et al., 2017).[4] Aggregating the information to generate global long-term trends poses considerable methodological difficulties. Recent efforts by the International Global Atmospheric Chemistry Project allowed some of the first assessments of global trends, but they come with important cautionary notes. It is certain that ozone concentrations started to decline *circa* 2000 in most western countries (Guicherit and Roemer, 2000; Cooper et al., 2014) and increased in developing countries such as India (Lal et al., 2012) and China (Wang et al., 2012). The trend in the last two decades is clearer: observation stations began to exhibit falling levels of ozone concentrations, especially in advanced economies (Cooper et al., 2014; Gaudel et al., 2018). However, we were unable to find global assessments available for the period of the bet as some continuous observations starting in 1975 from a limited number of stations yield opposing trends (Gaudel et al., 2018:23–26). The winner of this claim cannot be declared decisively.

Sulfur dioxide in the atmosphere becomes sulfuric acid, the principal component of acid rain, and it is associated with direct damage to human health, forests, and crops. The fifth claim is that sulfur dioxide concentrations would have increased in Asia at a time when economic growth was well under way in China and beginning in India. From 2000 to 2006, total $SO_2$ emission in China increased from 21.7 to 33.2 Tg, an annual growth rate of 7.3 percent and a 53 percent increase overall (Lu et al., 2010). This certainly meets Ehrlich and Schneider's "significant" criterion. There was also a continuous increase in India over the period considered (Li et al., 2017; Klimont, Smith, and Cofala, 2013). Other countries in Asia exhibited falling emissions of sulfur dioxide to 2005 (Klimont, Smith, and Cofala, 2013:3), but this was insufficient to compensate for the rise in India and China. On their terms, Ehrlich and Schneider proved correct. Data assembled by Smith et al.

---

[4] One might think that assembling a balanced panel of observation stations and tracking concentrations over time would be sufficient to arrive at acceptable approximations of trends, especially with the use of area fixed effects controls in a regression as long as those fixed effects are constant. However, Schultz et al. (2017) pointed out that area-unique conditions are *not* constant. For example, changes in population density (Schultz et al., 2017:3) or the addition of a power station (2017:15-16) affect measurements considerably, also influencing the quality of the Tropospheric Ozone Assessment Report analysis.

(2011)[5] suggest that all Asian countries saw their emissions of sulfur dioxide rise from 31,388 Gg in 1994 to 42,423 Gg in 2004. There nonetheless remain some uncertainties. First, global trends show that emissions have been falling since 1990, especially since China's emissions peaked in 2006 (Klimont, Smith, and Cofala, 2013; Aas et al., 2019). Second, Aas et al. (2019) have discussed a tendency to overestimate China's emissions, but this has been contested (Lu et al., 2010). However, even if we apply some of the highest values of the overestimation to the actual Chinese data (Wang et al., 2015), we find that the rate of increase from 1994 to 2004 is virtually unaltered. Ehrlich and Schneider can thus be declared winners.

### *Outcomes 6–9: Fertile Cropland, Agricultural Soil, Wheat and Rice Grown, Firewood Availability in Developing Nations (Per Capita)*

Assessing the outcomes for indicators in claims 6 and 7 is problematic because Ehrlich and Schneider did not provide a clear definition of "agricultural soil" (claim 7), while "fertile cropland" (claim 6) is open to interpretation. Cropland is defined by the USDA (n.d.:n.p.) as "areas used for the production of adapted crops for harvest" that can be either cultivated or noncultivated. The UN Food and Agricultural Organization (FAO, 2001) distinguishes between cropland or crop area that is the gross area on which a crop is grown, including ditches and headlands, and agricultural land that includes pastures (Bailey, 2020). Ehrlich and Schneider did not provide a clear definition of "agricultural soil," a concept that is intuitively easily understood, but whose reality is extremely complex. Be that as it may, the combination of significant population growth and a finite surface area can only deliver the predicted outcome even if cropland can be created and soil quality improved through human interventions.[6] Using the arable land per person (in hectares) indicator from the FAO of the United Nations as assembled in the World Bank's World Development Indicators data set, we observed a change of −0.033 hectares per person between 1994 and 2004. Using FAO's definitions, per capita cropland and agricultural land decreased during the wager period (Table 3). Ehrlich and Schneider win the claims concerning the per capita decrease in fertile cropland and agricultural soil per capita. FAO data also indicate that, on average, less rice and wheat per person was grown in 2002–2004 than in 1992–1994 (Table 3).

The overall supply of firewood (technically woodfuel) in the developing world has been increasing because of better conservation and forest management practices, even though productive forest area dwindled at a rate of 0.22 percent annually beginning in 1990 (FAO, 2010:136). Suspecting that woodfuel supply did not quite outpace population growth, we set out to calculate per person woodfuel removal numbers for the developing world. We

---

[5] The data are available online at the Socioeconomic Data and Applications Center (SEDAC): ⟨https://sedac.ciesin.columbia.edu/data/set/haso2-anthro-sulfur-dioxide-emissions-1850-2005-v2-86/data-download⟩.

[6] According to an FAO report, there was an increase in the land area in use for agricultural purposes from the early 1960 to the late 1990s. However, the population increased considerably during the period so that "by implication, arable land per person declined" (FAO, 2020a, Consulted April 2, 2020).

TABLE 3

Agricultural Indicators and Woodfuel Indicators for Claims 6 Through 9

| Agricultural Land | | | |
|---|---|---|---|
| Data set | Change | 2004 | 1994 |
| World development indicators (arable land, hectares per person) | –0.033 ha per person | 0.216 ha per person | 0.249 ha per person |
| FAO STAT (agricultural land, hectares per person) | –0.112 ha per person | 0.753 ha per person | 0.865 ha per person |
| FAO STAT (cropland land, hectares per person) | –0.031 ha per person | 0.233 ha per person | 0.264 ha per person |
| Wheat and rice | | | |
| | Change | 2002–2004 | 1992–1994 |
| FAO STAT (wheat, tonnes per person) | –0.003 ton per person | 0.093 ton per person | 0.096 ton per person |
| FAO STAT (rice, tonnes per person) | –0.006 ton per person | 0.093 ton per person | 0.100 ton per person |
| Woodfuel in developing regions | | | |
| FAO (2010:136) (woodfuel removals, cubic meter per person)[a] | –0.3 $m^3$ per person | 0.23 $m^3$ per person | 0.26 $m^3$ per person |
| FAO STAT (woodfuel production, coniferous and nonconiferous, cubic meter per person)[a] | –55.04 $m^3$ per person | 347.94 $m^3$ per person | 402.98 $m^3$ per person |
| FAO STAT (woodfuel production, coniferous and nonconiferous, cubic meter per person)[b] | –75.98 $m^3$ per person | 682.46 $m^3$ per person | 758.44 $m^3$ per person |

[a] Asia, Central America, South America and Africa.

[b] A specially created FAO region for "least developed countries."

also used woodfuel production reported by the FAO.[7] In Table 3, one can see that Ehrlich and Schneider's claims were correct.

### *Outcome 10: Virgin Tropical Moist Forests*

No official definition exists for Ehrlich and Schneider's notion of "virgin" tropical moist forest. As discussed in more detail later in Part 2, much recent research suggests significant past human interventions in the shaping of tropical forests once considered unaffected by anthropogenic actions. Tropical moist forests, despite the early "lack of consensus on the definition of the term," (Sommer, 1976:n.p.), as well as regional variation in forest type and characteristics, are understood to have "high rainfall (>1,700 mm annually), even distribution of solar radiation throughout the year, constant high temperatures (mean monthly temperature >24°C), and lack of frost" (Holl, 2002:539). The closest proxies for this claim are humid tropical forest data (Hansen et al., 2008, 2013), with the major caveat that these numbers include forest regrowth.

According to Hansen et al. (2013:850), there is no clear consensus regarding humid tropical forest coverage as "spatially and temporally detailed information on global-scale forest change does not exist; previous efforts have been either sample-based or employed coarse spatial resolution data". Achard et al. (2014) provided a series of humid tropical forest measurements from 1990 through 2005, as did FAO (2010). The analysis presented in Figure 1 is based on plotting and interpolating from the two sets of data.

Interpolated results for the humid tropical forest cover in 1994 range from a low of 1,600 million hectares (Mha) to a high of 1,975 Mha. Interpolated results for the humid tropical forest cover in 2004 range from a low of 1,550 Mha to a high of 1,875 Mha. Regardless of the exact forest cover values, the humid tropical forest cover is decreasing slowly at an average rate of 7.5 Mha/year, between a high estimate of 11 Mha/year from FAO (2010) and a low estimate of 6 Mha/year from Achard et al. (2014). This trend aligns with other results and recent analyses, for example, by Hansen et al. (2013:850) who noted that, for the period of 2000–2012, "[t]he tropical domain experienced the greatest total forest loss and gain of the four climate domains (tropical, subtropical, temperate, and boreal), as well as the highest ratio of loss to gain [...], indicating the prevalence of deforestation dynamics."

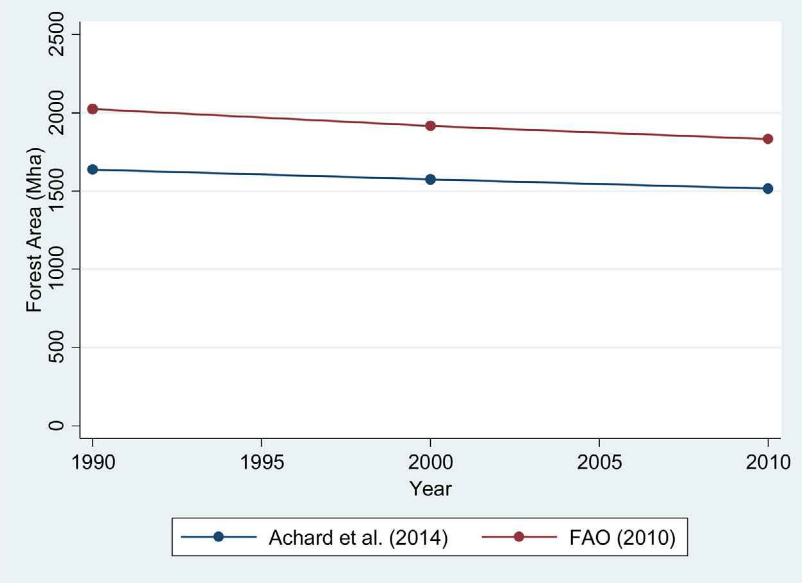
Ehrlich and Schneider's specific claim, however, is that the "remaining area of virgin tropical moist forests will be significantly smaller in 2004 than in 1994," where "significantly" was defined as at least 5–10 percent. The Achard et al. (2014) values are quantitatively lower than those of the FAO (2010), but they also demonstrate a gradual decrease of forest coverage over the decade. Using the Achard et al. (2014) values, there was a loss of 50 Mha over the decade, approximately 3 percent of the 2004 humid tropical forest cover. Similarly, using the FAO (2010) values, there was a loss of 100 Mha over the decade, which is just over 5 percent and would therefore barely meet Ehrlich and Schneider's significance threshold. As mentioned earlier, however, the forest coverage values reported in the literature included forest regrowth (Hansen et al., 2013) and thus do not reflect "virgin" forest

---

[7] FAO distinguished between wood production, including the production of wood intended as woodfuel, and wood removals for various purposes. Removals account for harvesting (Bailis et al., 2017), collection (FAO, 1983) and other behaviors by which people consume the wood, all are variously described in the literature. Production numbers thus tend to be higher than removal figures, although "informally and illegally removed wood, especially woodfuel, is not usually recorded, [thus] the actual amount of wood removals is undoubtedly higher" (FAO, 2010:86).

FIGURE 1

Humid Tropical Forest Area Measurements 1990–2010



loss, an indicator that cannot be assessed. Ehrlich and Schneider were thus not correct on claim 10.

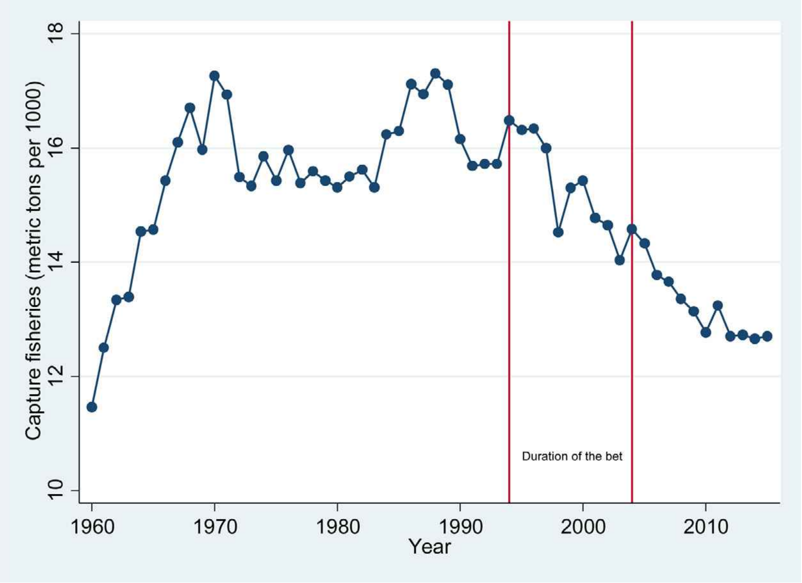
### *Outcome 11: Oceanic Fisheries Harvest Per Person*

The only global data set of fisheries statistics, covering over six decades, is produced by the FAO. The catch data are deemed problematic to various degrees and have been revised over time (FAO, 2016; Garibaldi, 2012; Pauly and Zeller, 2016; Pauly and Zeller, 2017; Ye et al., 2017). Among key issues, several countries "do not regularly report their annual catch statistics to FAO," the data are "not entirely reliable," the amount of fish discarded (i.e., removed from marine environments, but unreported in global marine landings) is hard to estimate and the number of species included in the FAO database has almost doubled between 1996 and 2014 (FAO, 2016:10). Prominent critics (Pauly and Zeller, 2016:2; see also Pauly and Zeller, 2017) have suggested that FAO data "may not only underestimate artisanal (that is, small scale, commercial) and subsistence fisheries, but also generally omit the catch of recreational fisheries, discarded bycatch and illegal and otherwise unreported catch." Indeed, even the "reconstructed global catches between 1950 and 2010 were 50 percent higher than data reported to FAO suggest, and are declining more strongly since catches peaked in the 1990s" (Pauly and Zeller, 2016:2). These high-end estimates, however, have been challenged by Ye et al. (2017:401) who argued that Pauly and Zeller's approach rests "on fundamental misunderstandings caused by mixing up statistical metrics and using simple normative explanations to interpret highly complex datasets."

According to FAO FISHSTAT data, the trend in global marine catches (with or without anchoveta) has remained remarkably stable since the early 1980s with total catches typically

FIGURE 2

Oceanic Fisheries Harvest Per 1,000 Persons, 1960–2015 with 1994–2004 Highlighted



Source: FAO FISHSTAT (2020b).

hovering around 90 million tonnes/year which, because of rising population, means a falling level relative to population (Figure 2).

Keeping in mind the limitations of these data, the production peak of the world's marine fisheries was reached in 1996 at 95 million tonnes (FAO FISHSTAT:2020b) but remained remarkably stable in following years. Ehrlich and Schneider are thus right that "oceanic fisheries harvest per person" diminished with the addition of nearly 600 million human beings during the decade.

### *Outcome 12: Biodiversity*

The unstated problem at the core of this claim is: How can we best estimate the number of extant species in order to know whether their number is changing? The increase in the rate of extinctions is implied in the claim as it is a consequence of a net decrease in the number of extant species. Discussion of the number of animal and plant species in 1994 and 2004, however, requires an examination of the current scientific consensus on the approximate species numbers.

While Stork (1993) logged between 1.4 and 1.8 million described species of plants and animals, Colwell and Coddington, 1994:102) noted that estimates based on "depauperate lineages" such as mammals may underrepresent hyperdiverse organisms such as insects. The Census of Marine Life (2011) project estimated all species at 8.7 million, ± 1.3 million, with 86 percent of all terrestrial species and up to 91 percent or marine species needing to be identified, described, and positioned within the taxonomy (Mora

TABLE 4

IUCN Species Extinction Data for 1996–2004

| | Number of Extinct Species by Major Taxonomic Group | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1996/1998 | | | 2000 | | | 2004 | | |
| Taxonomic Group | EX | EW | Total | EX | EW | Total | EX | EW | Total |
| Vertebrates | 296 | 19 | 315 | 318 | 19 | 337 | 338 | 22 | 360 |
| Invertebrates | 315 | 11 | 326 | 375 | 14 | 389 | 359 | 14 | 373 |
| Plants | 71 | 17 | 88 | 73 | 17 | 90 | 86 | 24 | 110 |
| Protista | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| Total | 682 | 47 | **729** | 766 | 50 | **816** | 784 | 60 | **844** |

NOTE: EW, extinct in the wild; EX, extinct.
SOURCE: IUCN Red List of Threatened Species (2004).

et al., 2011). This number is between Stork's 5 and 15 million and is among the most accurate recent estimates (Pimm et al., 2014:1246752-1).

As Stork (2010:359) confirmed: "Estimates of the number of species on Earth escalated in the 1980s from 1—2 million to 30—100 million due to large increases in the number of species of several key taxa—principally insects and their other arthropod relatives, and to a lesser extent, fungi and nematodes [...] and have been replaced by estimates of 5—15 million species." Barnosky et al., 2011:51) concurred, stating "[d]ocumented numbers are likely to be serious underestimates, because most species have not yet been formally described." Thus, the best estimate of the number of extant species is the range of the 2011 Census of Marine Life number of 8.7 ±1.3 million species. Since it will not be possible to affix specific numbers of extant species to the years 1994 and 2004, respectively, the change in known extinctions between 1994 and 2004 will be used as a proxy for determining whether there were more or fewer extant species at the endpoints of that decade.

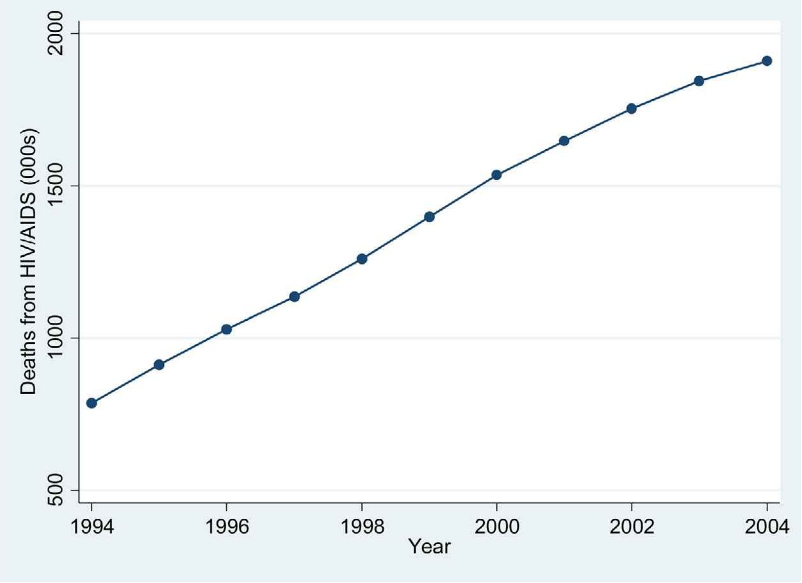
The International Union for the Conservation of Nature (IUCN) Red List of Threatened Species (Baillie, Hilton-Taylor, and Stuart, 2004) outlines criteria for extinction and provides lists of species, both plant and animal, under various levels of threat. The 2020 Red List (IUCN, 2020) reports 959 extinct species (882 extinct and 77 extinct in the wild) in the context of more than 120,000 species assessed compared to 923 extinct species and 65,747 species assessed in 2016 (IUCN, 2016).

Stork (2010:358) provided a corroboration: "The actual number of species that are officially recognized as extinct since 1600, according to IUCN (IUCN, 2009) and other sources, is surprisingly low—around 1,200 species." Stork (2010:359) also offered an important point to consider: "[T]he most recent 2009 IUCN list of extinct species is in large part a list for 1959 since a species has traditionally only been recognised as 'extinct' when no living individual has been seen for 50 years." Thus, the 1994 IUCN numbers document extinctions for species whose last observed members died in 1944 while 2016 numbers reflect extinctions as of 1966, making Ehrlich and Schneider's indicator for assessing biodiversity change in the 1994–2004 decade particularly inaccurate.

One could stop here and declare the indicator of Claim 12 impossible to assess for the 1994–2004 period. However, using the IUCN Red List of Threatened Species for 2004, one may approximate the following numbers for animal and plant extinctions for the mid-1990s to 2004 (Table 4).

FIGURE 3

World Deaths (000s) from HIV/AIDS, 1994–2004



SOURCE: Institute for Health Metrics and Evaluation (2020).

Thus, there were more extinct species listed for the year 2000 than for 1996 and more extinct species for 2004 than for 2000. The IUCN numbers support Ehrlich and Schneider's claim.

### *Outcome 13: HIV/AIDS*

In 1994, as the HIV/AIDS new infection rate soared but relatively few people were reaching the illness's terminal stages, just over 787,000 people died of AIDS and AIDS-related illnesses (Figure 3). In 2004, just prior to the AIDS mortality peak years of 2005–2006, approximately 1.91 million people died of AIDS and AIDS-related illnesses (Institute for Health Metrics and Evaluation, 2020). Ehrlich and Schneider thus won the claim.

### *Claim 14: Human Sperm Count*

An influential 1992 Danish study documented a long-term sperm count decrease (Carlsen et al., 1992). This work, however, was criticized on a number of grounds, including "the selection of subjects with possible fertility problems in the original studies, differences in study populations at different intervals and in different geographic regions over the 40-year time span, comparability of laboratory methods, and the statistical analysis" (Kabat, 2017). Another important critique of existing work is its heavily biased sampling in favor of prosperous developed world participants (Deonandan and Jaleel, 2012). As a result, "[r]eported declines in sperm counts remain controversial today and recent trends are unknown" (Levine et al., 2017:1). While more up-to-date studies of sperm counts in the developing world are needed to settle this issue, the scholarly debate points to an undetermined outcome in this case.

### *Outcome 15: Inequality*

Some widely publicized reports suggest rising wealth inequality (Oxfam, 2019). However, these studies have been criticized on at least four counts. First, they rely heavily on financial assets and, more importantly, net financial assets. As such, heavily indebted people (those with large valuable assets) are at the bottom of the estimated distribution. This would include people with assets worth millions or even billions of dollars. Second, a sizable share of the wealth of the poor is "dead capital," that is, off the books and therefore not measured. Rough and controversial estimates have suggested that in 1997 they might have amounted to $9.34 trillion dollars (De Soto, 2000:36), more than eight times the wealth that Oxfam reported the bottom 50 percent owned, not adjusted for local purchasing power, in 2019. The third issue is that wealth inequality estimates, even if flawed, are not available for the period under consideration. The few available estimates correcting for the above-mentioned flaws have been compiled by the World Inequality Lab, part of the WID World project. These reports show an increase in the wealth share of the top 1 percent between 1994 and 2004, but they do not account for the unrecorded wealth of the poor. The fourth reason is the fact that *income inequality* (rather than wealth inequality) fell during the period (Sala-i-Martin, 2006). The paucity and poor quality of the data make it difficult to declare a winner between Simon and Ehrlich/Schneider.

## Tally and Conclusion to Part 1

Table 5 provides the first tally of the 1994–2004 wager proposed by Ehrlich and Schneider. Simon wins on only one indicator while Ehrlich and Schneider win on eleven. There is too much uncertainty to adjudicate a winner for three claims. Table 5 also includes a column on measurement quality. The use of the word "problematic" in this column refers to the selection and quality of proxy data when the terms used by Ehrlich and Schneider did not match clearly defined or measured quantities in the scientific literature. We also did not refrain from declaring Ehrlich and Schneider winners on their own terms when simple logic dictated the outcome even in the absence of suitable indicators. For instance, while "fertile cropland" is not an indicator found in the technical literature, a significant increase in population that occurred between 1994 and 2004 must mean that less farmland would be available per capita at the end of the time period even if cropland were to be created through, for instance, the draining of wetlands and the conversion of pasturelands.

On their own terms then, Ehrlich and Schneider can be declared the winners of this wager. As we will now argue in Part 2, however, these results can and should be examined critically as they do not necessarily support the Ehrlich-Schneider perspective. We will do so by extending the time period up to the present time to assess long-term trends, and by discussing the shortcomings of some direct indicators and proxies as validating Ehrlich's vision.

TABLE 5

Outcome of the Ehrlich–Schneider (1995) Counterwager Offer

| Ehrlich and Schneider's Indicators and Claims, 1994–2004 | Can the Indicator Be Measured Satisfactorily? | Winner |
|---|---|---|
| 1. 2002–2004 will on average be warmer than 1992–1994 | Yes | Ehrlich and Schneider |
| 2. More carbon dioxide in atmosphere in 2004 than in 1994 | Yes | Ehrlich and Schneider |
| 3. More nitrous oxide in atmosphere in 2004 than in 1994 | Yes | Ehrlich and Schneider |
| 4. Concentration of ozone (troposphere) greater in 2004 than 1994 | No global data available | Uncertain |
| 5. Emissions of sulfur dioxide in Asia significantly greater in 2004 than in 1994 | Yes | Ehrlich and Schneider |
| 6. Less fertile cropland per person in 2004 than in 1994 | Problematic (proxy: farmland) | Ehrlich and Schneider |
| 7. Less agricultural soil per person in 2004 than in 1994 | Problematic (definition and proxy selection) | Ehrlich and Schneider |
| 8. On average less rice and wheat grown per person in 2002–2004 than in 1992–1994 | Yes/yes | Ehrlich and Schneider |

*continued*

TABLE 5

(Continued)

| Ehrlich and Schneider's Indicators and Claims, 1994–2004 | Can the Indicator Be Measured Satisfactorily? | Winner |
|---|---|---|
| 9. In developing nations less firewood available per person in 2004 than in 1994 | Problematic (proxy: woodfuel removal and production data) | Ehrlich and Schneider |
| 10. Remaining area of *virgin* tropical moist forests *significantly* smaller in 2004 than in 1994 | Problematic (proxy: humid tropical forest) | Simon |
| 11. Oceanic fisheries harvest per person will continue its downward trend and thus in 2004 will be smaller than in 1994 | Yes | Ehrlich and Schneider |
| 12. Fewer plant and animal species still extant in 2004 than in 1994 | Problematic (proxy: IUCN Red List) | Ehrlich and Schneider |
| 13. More people will die of AIDS in 2004 than did in 1994 | Yes | Ehrlich and Schneider |
| 14. Between 1994 and 2004, sperm counts of human males will continue to decline | No global data available | Uncertain |
| 15. The gap in wealth between the richest 10 percent of humanity and the poorest 10 percent will be greater in 2004 than in 1994 | Problematic (incomplete data) | Uncertain |
| Tally | | Ehrlich and Schneider: 11 Simon: 1Uncertain: 3 |

## REFERENCES

Aas, Wenche, Augustin Mortier, Van Bowersox, Ribu Cherian, Greg Faluvegi, Hilde Fagerli, Jenny Hand, Zbigniew Klimont, Corinne Aly-Lacaux, Christopher M. B. Lehmann, Cathrine Lund Myhre, Gunnar Myhre, Dirk Olivié, Keiichi Sato, Johannes Uaas, P. S. P. Rao, Michael Schulz, Drew Shindell, Ragnhild B. Skeie, Ariel Stein, Toshihiko Takemura, Svetlana Tsyro, Robert Vet and Xiaobin Xu. 2019 "Global and Regional Trends of Atmospheric Sulfur." *Scientific Reports* 9.1:1–11.

Achard, Frédéric, René Beuchle, Philippe Mayaux, Hans-Jürgen Stibig, Catherine Bodart, Andreas Brink, Silvia Carboni, Baudouin Descleée, François Donnay, Hugh D. Eva, Andrea Lupi, Rastislav Raŝi, Roman Seliger, and Dario Simonetti. 2014. "Determination of Tropical Deforestation Rates and Related Carbon Losses from 1990 to 2010." *Global Change Biology* 20(8):2540–54.

Bailey, Ronald. 2020. *It's Possible to Cut Cropland Use in Half and Produce the Same Amount of Food, Says New Study*. Available at ⟨https://reason.com/2020/04/17/its-possible-to-cut-cropland-use-in-half-and-produce-the-same-amount-of-food-says-new-study/⟩.

Bailis, Rob, Yiting Wang, Rudi Drigo, Adrian Ghilardi, and Omar Masera. 2017. *Environmental Research Letters* 12(11):115002.

Baillie, Jonathan. E. M., Craig Hilton-Taylor, and Simon N. Stuart. 2004. *IUCN Red List of Threatened Species: A Global Species Assessment*. Cambridge, UK: IUCN Publications Services Unit. Available at ⟨https://portals.iucn.org/library/sites/library/files/documents/RL-2004-001.pdf⟩.

Barnosky, Anthony D., Nicholas Matzke, Susumu Tomiya, Guinevere O. U. Wogan, Brian Swartz, Tiago B. Quental, Charles Marshall, Jenny L. McGuire, Emily L. Lindsey, Kaitlin C. Maguire, Ben Mersey, and Elizabeth A. Ferrer. 2011. "Has the Earth's Sixth Mass Extinction Already Arrived?" *Nature* 471:51–57.

Becker, Stan. 2013. "Has the World Really Survived the Population Bomb? (Commentary on "How the World Survived the Population Bomb: Lessons from 50 Years of Extraordinary Demographic History.)"." *Demography* 50(6):2173–81.

Carlsen, Elisabeth, Aleksander Giwercman, Niels Keiding, and Niels E. Skakkebæk. 1992. "Evidence for Decreasing Quality of Semen during the Past Fifty Years." *British Medical Journal* 305:609–12.

Census of Marine Life. 2011. "How Many Species on Earth? About 8.7 Million, New Estimate Says." ScienceDaily. Available at ⟨www.sciencedaily.com/releases/2011/08/110823180459.htm⟩.

Colwell, R. K., and Coddington, J. A. 1994. "Estimating Terrestrial Biodiversity Through Extrapolation." *Philosophical Transactions of the Royal Society of London B* 345:101–18.

Cooper, Owen. R., D. D. Parrish, J. Ziemke, N. V. Balashov, M. Cupeiro, I. E. Galbally, S. Gilge, L. Horowitz, N. R. Jensen, J.-F. Lamarque, V. Naik, S. J. Oltmans, J. Schwab, D.T. Shindell, A. M. Thompson, V. Thouret, Y. Wang, and R. M. Zbinden. 2014. "Global Distribution and Trends of Tropospheric Ozone: An Observation Based Review." *Elementa: Science of the Anthropocene* 2(1). ⟨https://doi.org/10.12952/journal.elementa.000029⟩.

Deonandan, Raywat, and Marya Jaleel. 2012. "Global Decline in Semen Quality: Ignoring the Developing World Introduces Selection Bias." *International Journal of General Medicine* 5:303–306.

de Soto, Hernando. 2000. *The Mystery of Capital: Why Capitalism Triumphs in the West and Fails Everywhere Else*. New York: Basic Books.

Dixon, Bernard. 1971. "In Praise of Prophets." *New Scientist* 51:606–607.

Ehrlich, Paul R. 1968. *The Population Bomb*. Cutchogue: Buccaneer Books.

———. 1981. "An Economist in Wonderland." *Social Science Quarterly* 62(1):44–49.

Ehrlich, Paul R., and Anne H. Ehrlich. 1996. *Betrayal of Science and Reason: How Anti-Environmental Rhetoric Threatens Our Future*. Washington, DC: Island Press.

———. 2009. "The Population Bomb Revisited." *Electronic Journal of Sustainable Development* 1(3):63–71.

———. 2013. "Can a Collapse of Global Civilization Be Avoided?" *Proceedings of the Royal Society B: Biological Sciences* 280. Available at ⟨http://rspb.royalsocietypublishing.org/content/280/1754/20122845⟩.

Ehrlich, Paul R., Anne H. Ehrlich, and John Holdren. 1977/1970. *Ecoscience: Population, Resources, and Environment*. San Francisco, CA: W.H. Freeman.

Ehrlich, Paul R., and Stephen H. Schneider. 1995. "It's No Time to Heed the Brownlash." *San Francisco Chronicle* May 12:A23. Available at ⟨http://www.sfgate.com/opinion/article/EDITORIAL-Head-Goes-Here-3032893.php⟩.

Earth System Research Laboratories. *Trends in Atmospheric Carbon Dioxide*. Available at ⟨https://www.esrl.noaa.gov/gmd/ccgg/trends/data.html⟩.

Environmental Protection Agency. 2016. Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks*: 1990–2014*. Washington, DC: U.S. Environmental Protection Agency.

Food and Agriculture Organization. 2020a. *FAOSTAT*. Available at ⟨http://www.fao.org/faostat/en/#data/RL⟩.

———. 2020b. *FISHSTAT*. Available at ⟨http://www.fao.org/faostat/en/#data/RL⟩.

Food and Agriculture Organization of the United Nations (FAO). 1983. *Wood Fuel Surveys. Forestry for Local Community Development Programme GCP/INT/365/SWE*. Rome: FAO. Available at ⟨http://www.fao.org/3/q1085e/q1085e00.htm#Contents⟩.

———. 2001. *Food Balance Sheets: A Handbook*. Rome: FAO. Available at ⟨http://www.fao.org/3/x9892e/X9892E00.htm#TopOfPage⟩.

———. 2010. *Global Forest Resources Assessment 2010: Main Report*. Rome, Italy: FAO. Available at ⟨http://www.fao.org/docrep/013/i1757e/i1757e.pdf⟩.

———. 2016. *The State of World Fisheries and Aquaculture 2016. Contributing to Food Security and Nutrition for All*. Rome: FAO. Available at ⟨http://www.fao.org/3/a-i5555e.pdf⟩.

Garibaldi, Luca. 2012. "The FAO Global Capture Production Database: A Six-Decade Effort to Catch the Trend." *Marine Policy* 36(3):760–68.

Gaudel, A., O. R. Cooper, G. Ancellet, Barret B. A. Boynard, J. P. Burrows, C. Clerbaux, P.-F. Coheur, J. Cuesta Cuevas, E. D. Doniki, G. Dufour, F. Ebojie, G. Foret, O. Garcia, M. J. Granados-Muñoz, J. W. Hannigan, F. Hase, B. Hassler, G. Huang, D. Hurtmans, D. Jaffe Jones, N. P. Kalabokas, B. Kerridge, S. Kulawik, B. Latter, T. Leblanc, E. Le Flochmoën, W. Lin, J. Liu, X. Liu, E. Mahieu, A. McClure-Begley, A. J. L. Neu, M. Osman, M. Palm, H. Petetin, I. Petropavlovskikh, R. Querel, N. A. Rahpoe, A. Rozanov, M. G. Schultz, J. Schwab, R. Siddans, D. Smale, M. Steinbacher, H. Tanimoto, D. Tarasick, V. Thouret, A. M. Thompson, T. Trickl, B. Weatherhead, C. Wespes, H. Worden, C. Vigouroux, X. Xu, G. Zeng, and J. R. Ziemke. 2018. "Tropospheric Ozone Assessment Report: Present-Day Distribution and Trends of Tropospheric Ozone Relevant to Climate and Global Atmospheric Chemistry Model Evaluation." *Elementa: Science of the Anthropocene* 6:39.

Guicherit, Robert, and Michiel Roemer. 2000. "Tropospheric Ozone Trends." *Chemosphere-Global Change Science* 2.2:167–83.

Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." *Science* 342(6160):850–53.

Hansen, M. C, S. V. Stehman, P. V. Potapov, T. R. Loveland, J. R. G. Townshend, R. S. DeFries, K. W. Pittman, B. Arunarwati, F. Stolle, M. K. Steininger, M. Carroll, and C. Dimiceli. 2008. "Humid Tropical Forest Clearing from 2000 to 2005 Quantified by Using Multitemporal and Multiresolution Remotely Sensed Data." *PNAS* 105(27):9439–44.

Holl, Karen. 2002. "Tropical Moist Forest Restoration." Pp. 539–58 in M. Perrow and A. Davy, eds., *Handbook of Restoration*, Volume II. Cambridge, MA: Cambridge University Press.

Hurrell, James W., and Kevin E. Trenberth. 1996a. "Difficulties in Obtaining Reliable Temperature Trends: Reconciling the Surface and Satellite Microwave Sounding Unit Records." *Journal of Climate* 11:945–67.

———. 1996b. "Satellite Versus Surface Estimates of Air Temperature Since 1979." *Journal of Climate* 9:2222–32.

Institute for Health Metrics and Evaluation. 2020. *Global Burden of Disease*. Available at ⟨http://www.healthdata.org/gbd⟩.

IUCN. 2016. *The IUCN Red List of Threatened Species. Version* 2016-2. Available at ⟨http://www.iucnredlist.org⟩.

———. 2020. *The IUCN Red List of Threatened Species. Version* 2020-2. Available at ⟨https://www.iucnredlist.org⟩.

Kabat, Geoffrey. 2017. *Are Sperm Counts Declining? What's the Role of 'Endocrine Disruptors'?*. Cincinnati, OH: Genetic Literacy Project. Available at ⟨https://geneticliteracyproject.org/2017/09/05/sperm-counts-declining-whats-role-endocrine-disruptors/⟩.

Kiel, Katherine, Victor Matheson, and Kevin Golembiewski. 2010. "Luck or Skill? An Examination of the Ehrlich-Simon Bet." *Ecological Economics* 69(7):1365–67.

Klimont, Z., Steven J. Smith, and Janusz Cofala. 2013. "The Last Decade of Global Anthropogenic Sulfur Dioxide: 2000–2011 Emissions." *Environmental Research Letters* 8(1):014003.

Lal, D. M., Sachin Ghude, S. D. Patil, Santosh Kulkarni, Chinmay Jena, Suresh Tiwari, and Manoj Kr Srivastava. 2012."Tropospheric Ozone and Aerosol Long-Term Trends over the Indo-Gangetic Plain (IGP), India." *Atmospheric Research* 116:82–92.

Lawn, Philip. 2010. "On the Ehrlich–Simon Bet: Both Were Unskilled and Simon Was Lucky." *Ecological Economics* 68(11):2045–46.

Levine, Hagai, Niels Jørgensen, Anderson Martino-Andrade, Jaime Mendiola, Dan Weksler-Derri, Irina Mindlis, Rachel Pinotti, and Shanna H. Swan. 2017. "Temporal Trends in Sperm Count: A Systematic Review and Meta-Regression Analysis." *Human Reproduction Update* 23:646–659.

Li, Can, Chris Mclinden, Vitali E. Fioletov, and Russell Dickerson. 2017. "India is Overtaking China as the World's Largest Emitter of Anthropogenic Sulfur Dioxide." *Scientific Reports* 7:1–7.

Lu, Zifeng, David G. Streets, Qiang Zhang, Siwen Wang, Gregory R. Carmichael, Yafang Cheng, Chao Wei, Mian Chin, Thomas Diel, and Qian Tan. 2010. "Sulfur Dioxide Emissions in China and Sulfur Trends in East Asia Since 2000." *Atmospheric Chemistry and Physics* 10(13):6311–31.

Luten, Daniel B. 1980. "'Ecological Optimism in the Social Sciences': The Question of Limits to Growth." *American Behavioral Scientist* 24(1):125–51.

Marshall, Alfred. 1890. *Principles of Economics* (Vol. 1). London: MacMillan.

McKitrick, Ross, and John Christy. 2018. "A Test of the Tropical 200-to 300-hPa Warming Rate in Climate Models." *Earth and Space Science* 5.9:529–36.

Met Office Hadley Centre. 2020. *HadCRUT4*. Available at ⟨https://www.metoffice.gov.uk/hadobs/hadcrut4/⟩.

Mora, C., D. P. Tittensor, S. Adl, A. G. B. Simpson, and B. Worm. 2011. "How Many Species Are There on Earth and in the Ocean?" *PLoS Biology* 9(8):e1001127.

National Aeronautics and Space Administration. 2020. *GISS Surface Temperature Analysis GISTEMP v4*. Available at ⟨https://data.giss.nasa.gov/gistemp/⟩.

National Center for Atmospheric Research (NCAR). *Climate Data Guide (NCAR CDG)*. Available at ⟨https://climatedataguide.ucar.edu/⟩.

National Center for Atmospheric Research Staff (NCAR). 2014. *The Climate Data Guide: Global Temperature Data Sets: Overview & Comparison Table*. Available at ⟨https://climatedataguide.ucar.edu/climate-data/global-temperature-data-sets-overview-comparison-table⟩.

National Oceanic and Atmospheric Administration. 2020. *NOAA Climate Data Record (CDR) of MSU and AMSU-A Mean Layer Temperature, UAH Version 6.0*. Available at ⟨https://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.ncdc⟩.

Oxfam. 2019. Public good or private wealth? Oxford: Oxfam International.

Pauly, Daniel, and Dirk Zeller. 2016. "Catch Reconstructions Reveal that Global Marine Fisheries Catches Are Higher than Reported and Declining." *Nature Communications* 7:10244. Available at ⟨https://www.nature.com/articles/ncomms10244⟩.

———. 2017. "Comments on FAOs State of World Fisheries and Aquaculture (SOFIA)." *Marine Policy* 77:176–81.

Petit, Charles. 1995. "Two Stanford Professors Offer to Bet Optimistic Economist." San Francisco Chronicle May 18. Available at ⟨http://www.sfgate.com/news/article/Two-Stanford-Professors-Offer-to-Bet-Optimistic-3032757.php⟩.

Pimm, S. L., C. N. Jenkins, R. Abell, T. M. Brooks, J. L. Gittelman, L. N. Joppa, P. H. Raven, C. M. Roberts, and J. O. Sexton. 2014. "The Biodiversity of Species and Their Rates of Extinction, Distribution, and Protection." *Science* 344(6187):1246752. ⟨https://doi.org/10.1126/science.1246752⟩.

Sabin, Paul. 2013a. *The Bet: Paul Ehrlich, Julian Simon, and Our Gamble over Earth's Future*. New Haven, CT: Yale University Press.

———. 2013b. "Want to Bet? We're Gambling over Earth's Future. What Should the Betting Terms Be?" *Salon* September 12. Available at ⟨http://www.slate.com/articles/news_and_politics/science/2013/09/ehrlich_and_simon_bet_what_terms_should_we_use_to_gamble_on_earth_s_future.html⟩.

Sala-i-Martin, Xavier. 2006. "The World Distribution of Income: Falling Poverty and… Convergence, Period." *Quarterly Journal of Economics* 121.2:351–97.

Schultz, M. G., Schröder, S., Lyapina, O., Cooper, O., Galbally, I., Petropavlovskikh, I., …, and Seguel, R. 2017. "Tropospheric Ozone Assessment Report: Database and Metrics Data of Global Surface Ozone Observations." *Elementa: Science of the Anthropocene* 5:58.

Simon, Julian Lincoln. n.d. *Betting All Human Welfare Will Improve*. Available at ⟨http://www.juliansimon.com/writings/Articles/EHRLICH6.txt⟩.

———. 1977. *The Economics of Population Growth*. Princeton, NJ: Princeton University Press.

———. 1980. "Resources, Population, Environment: An Oversupply of False Bad News." *Science* 208(4451):1431–37.

———. 1981a. *The Ultimate Resource*. Princeton, NJ: Princeton University Press.

———. 1981b. "Environmental Disruption of Environmental Improvement?" *Social Science Quarterly* 62(1):30–43.

———. 1995a. "Earth's Doomsayers Are Wrong." San Francisco Chronicle May 12. Available at ⟨http://www.sfgate.com/opinion/openforum/article/Earth-s-Doomsayers-Are-Wrong-3034214.php⟩.

———, ed. 1995b. *The State of Humanity*. Oxford: Blackwell.

———. 1996. *The Ultimate Resource 2*. Princeton, NJ: Princeton University Press.

———. 1997. "Another Sure Bet on Earth Day." *Wall Street Journal* April 22.

———, ed. 1998. *The Economics of Population: Classic Writings*. New Brunswick, NJ: Transaction Publishers.

———. 2000. *The Great Breakthrough and Its Cause*. Ann Arbor, MI: University of Michigan Press.

Smith, Steven J., J. van Aardenne, Z. Klimont, R. J. Andres, A. Volke, and S. Delgado Arias. 2011. "Anthropogenic Sulfur Dioxide Emissions: 1850–2005." *Atmospheric Chemistry and Physics* 11(3):1101–16.

Sommer, Adrian. 1976. "Attempt at an Assessment of the World's Tropical Moist Forests." *Unasylva: Management and Utilization of the Tropical Moist Forests* 28:112–13.

Spencer, Roy W., John R. Christy, and William D. Braswell. 2015. *Version 6.0 of the UAH Temperature Dataset Released: New LT Trend = +0.11 C/decade*. Available at ⟨http://www.drroyspencer.com/wp-content/uploads/Version-61.pdf⟩.

Stork, Nigel E. 1993. "How Many Species Are There?" *Biodiversity and Conservation* 2:215–32.

———. 2010. "Re-Assessing Current Extinction Rates." *Biodiversity and Conservation* 19:357–71.

Tans, Pieter, and Ralph Keeling. n.d. *Trends in Atmospheric Carbon Dioxide—Data*. Available at ⟨https://www.esrl.noaa.gov/gmd/ccgg/trends/data.html⟩.

USDA National Resources Conservation Service. n.d. *Cropland*. Available at ⟨http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/landuse/crops/⟩.

Wang, Siwen, Qiang Zhang, Randall Martin, Sajeev Philip, Fei Liu, Meng Li, Xujia Jiang, and Kebin He. 2015. "Satellite Measurements Oversee China's Sulfur Dioxide Emission Reductions from Coal-Fired Power Plants." *Environmental Research Letters* 10(11):114015. ⟨http://iopscience.iop.org/article/10.1088/1748-9326/10/11/114015⟩.

Wang, Y., P. Y. Konopka, H. Liu, R. Chen, F. Muller, M. Ploger, Z. Riese, D. Cai, and D. Lu. 2012. "Tropospheric Ozone Trend over Beijing from 2002–2010: Ozonesonde Measurements and Modeling Analysis." *Atmospheric Chemistry and Physics* 12(18):8389–99.

World Bank. 2020. *World Development Indicators*. Available at ⟨https://databank.worldbank.org/source/world-development-indicators⟩.

World Meteorological Organization. 2014. *CAIT—Country Greenhouse Gas Emissions Data*. Washington, DC: World Resources Institute. Available at ⟨https://cait.wri.org/⟩.

Ye, Yimin, Manuel Barange, Malcolm Beveridge, Luca Garibaldi, Nicolas Gutierrez, Alejandro Anganuzzi, and Marc Taconet. 2017. "FAO's Statistic Data and Sustainability of Fisheries and Aquaculture: Comments on Pauly and Zeller (2017)." *Marine Policy* 81:401–45.