

Is humanity sustainable?

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The principles and tenets of management require action to avoid sustained abnormal/pathological conditions. For the sustainability of interactive systems, each system should fall within its normal range of natural variation. This applies to individuals (as for fevers and hypertension, in medicine), populations (e.g. outbreaks of crop pests in agriculture), species (e.g. the rarity of endangerment in conservation) and ecosystems (e.g. abnormally low productivity or diversity in 'ecosystem-based management'). In this paper, we report tests of the hypothesis that the human species is ecologically normal. We reject the hypothesis for almost all of the cases we tested. Our species rarely falls within statistical confidence limits that envelop the central tendencies in variation among other species. For example, our population size, CO₂ production, energy use, biomass consumption and geographical range size differ from those of other species by orders of magnitude. We argue that other measures should be tested in a similar fashion to assess the prevalence of such differences and their practical implications.

Keywords: pathology; sustainability; species; management; humans

1. INTRODUCTION

Avoiding abnormal or pathological conditions has long been standard practice in medicine. In recent decades, this has become recognized as a critically important tenet of management at all levels of biological organization (Christensen *et al.* 1996; Mangel *et al.* 1996; Fowler *et al.* 1999; Fowler & Hobbs 2002). That is, management and restoration have the objective of keeping components of complex systems (e.g. individuals, species, ecosystems and the biosphere) within their normal range of natural variation in much the same way we do medically with body temperature, body mass (Calle *et al.* 1999), pulse or blood pressure for the individual human. Another tenet of management requires that we consider humans to be part of ecosystems and the biosphere, subject to the same natural laws and benefiting from the same supporting services as other species (Christensen *et al.* 1996; Mangel *et al.* 1996; Fowler & Hobbs 2002). We are thus confronted with the question of where *Homo sapiens* falls within the spectrum of variation observed among species. Here, we test the hypothesis that the human species falls within the normal range of natural variation observed among species for a variety of ecologically relevant measures.

2. METHODS

To evaluate the human species, we searched the literature for various measures of species (Fowler & Perez 1999; Fowler 2002; Fowler & Hobbs 2002). Data were found for a variety of measures, including CO₂ production, biomass consumption, geographical range size, energy consumption and population size, all of which have been recognized as fundamentally important issues.

The data from different samples of species were then subjected to simple statistical analysis to find the probability of

values equal to, or more extreme than that observed for humans. These tests were based on assuming a normal distribution for the observations and required log transformations in most cases. We then calculated the confidence limits for the normal distribution of the natural variation among the non-human species and expressed the measure of humans as a multiple of the mean, the 95% and the 99% confidence limits (Fowler & Hobbs 2002).

In several cases, it was necessary to choose species that are otherwise similar to humans to make realistic comparisons. For example, population density is known to be related to body size (Damuth 1987). Therefore, it is unrealistic to compare the density of humans with that of organisms of significantly different body size (e.g. bacteria) without accounting for the effects of body size. In such cases, we used data for species that are similar to humans in body mass.

3. RESULTS

We found it possible to compare humans with 31 samples of non-human species in a variety of measures (Fowler 2002; Fowler & Hobbs 2002). These include measures of biomass consumption, global energy consumption, population size and extent of unoccupied areas. Figures 1–8 show how humans compare with the 95% confidence limits (one measure of the normal range of natural variation) among samples of non-human species, for 11 cases. Measurements corresponding to the data shown in figures 1–8 are presented in table 1. Further detail, sources and statistical tests for all 31 samples are available elsewhere (Fowler 2002; Fowler & Hobbs 2002).

All but nine out of the 31 tests showed humans to be outside the 99% confidence limits for variation among the other species. In only one case was the measure for humans not significantly different from the mean of other species at the 90% level of confidence. This involved consumption of biomass (fishery catches) from the Georges Bank ecosystem, in comparison with a sample of non-

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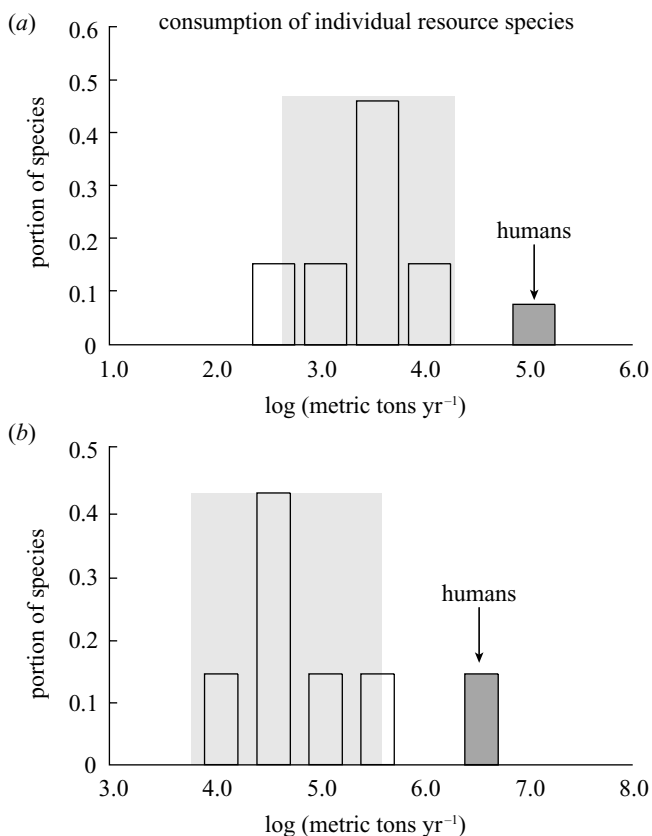


Figure 1. Human consumption of biomass (dark grey bars) from two single resource species in comparison with that of (a) 12 species of birds, mammals and fish (predators on northwest Atlantic herring, *Clupea harengus*), and (b) six species of marine mammals (predators on east Bering Sea/North Pacific walleye pollock, *Theragra chalcogramma*). The 95% confidence limits among non-human species are indicated by the right and left edges of the pale grey shaded area.

human species that included fish and seabirds. In another case, human consumption of mackerel, *Scomber scombrus*, in the northwest Atlantic was not statistically significantly different from the sample of non-human species at the 95% level (again including seabirds and fish predators). Including fish in the sample of non-human species makes the comparisons less valid than when the samples are restricted to mammals (e.g. figures 1b, 2a, 3a,b and 4). We conclude that the human species is often an outlier in comparison with other species, a point well illustrated when the data for these tests are displayed graphically (figures 1–8). The probability that all of these measures would simultaneously show such high levels of significance by chance alone is infinitesimally small.

Some of the more prominent differences between humans and other species involve population size and factors that are closely related. These include measures for energy consumption, biomass consumption and CO₂ production. The human population is over two orders of magnitude greater than the upper 95% confidence limit of populations for non-human mammalian species of similar body size, and over four orders of magnitude (36 760 times) greater than the mean (table 1; figure 8). Humans produce CO₂ at a rate that is three orders of magnitude greater than the 95% confidence limit of CO₂ production

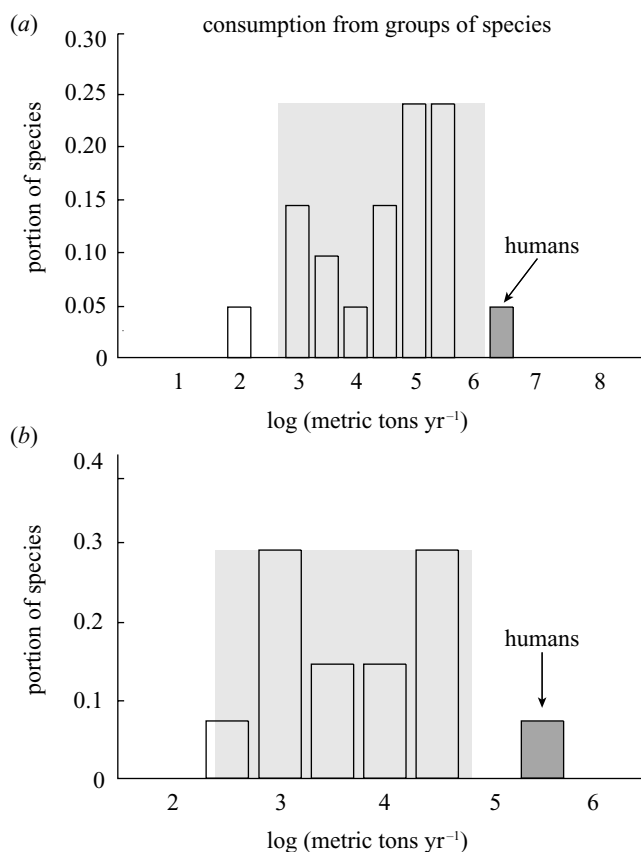


Figure 2. Human consumption of biomass (dark grey bars) from two groups of resource species in comparison with that of (a) 20 species of marine mammals (predators on east Bering Sea finfish), and (b) 13 species of seabirds and marine mammals (predators on northwest Atlantic hake, *Merluccius bilinearis*; herring; and mackerel, *Scomber scombrus*). The 95% confidence limits among non-human species are indicated by the right and left edges of the pale grey shaded area.

estimated for other similar species. Total energy consumption by humans is two orders of magnitude larger than the upper 95% confidence limit for the estimated energy consumption among mammals of similar body size (Fowler & Hobbs 2002).

Similar differences, although often not as large, are noted for biomass consumption, whether from individual species (figure 1), groups of species (figure 2), ecosystems (figure 3), the marine environment (figure 4) or the biosphere (figure 5). See Fowler & Hobbs (2002) for more examples involving resource use from individual species (four more cases), multi-species groups (two more cases) and ecosystems (four more cases). The pattern of abnormality is also observed for geographical range (figure 7). By extension, the pattern holds for areas free of, or protected from, direct impacts (Fowler & Hobbs 2002). For biomass consumption by commercial fisheries (figures 1–4), the ratio of consumption by humans to that of the mean observed among other species is a systemic index of excessive harvesting: a factor behind altered marine and freshwater ecosystem states (Christensen *et al.* 1996; Pauly *et al.* 1998; Myers & Worm 2003). In general, the factors that we have measured are among the contributing causes behind changes (usually judged as degradation and including the current extinction crisis) being documented

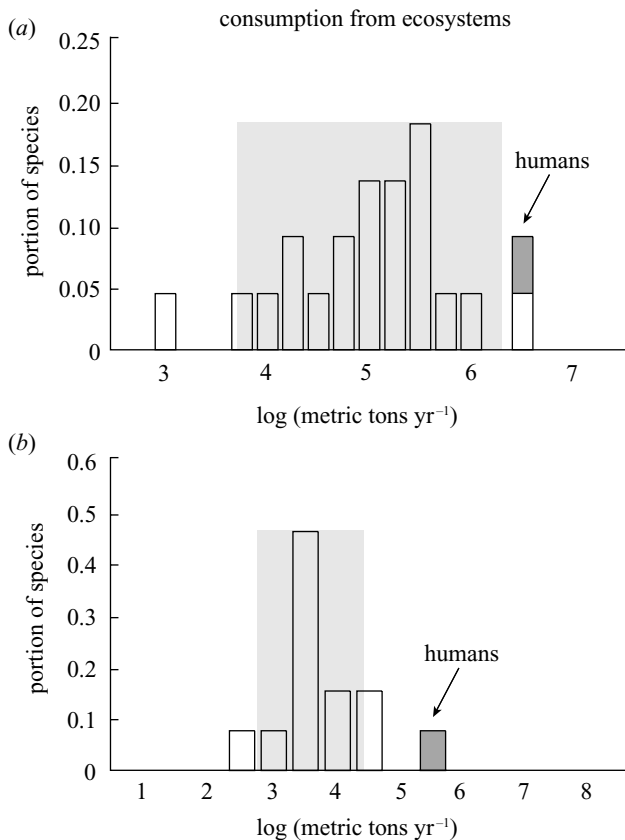


Figure 3. Human consumption of biomass (dark grey bars) from two ecosystems in comparison with that of (a) 21 species of marine mammals (consumers in the Eastern Bering Sea), and (b) 12 species of marine mammals (consumers in the Georges Bank ecosystem). The 95% confidence limits among non-human species are indicated by the right and left edges of the pale grey shaded area.

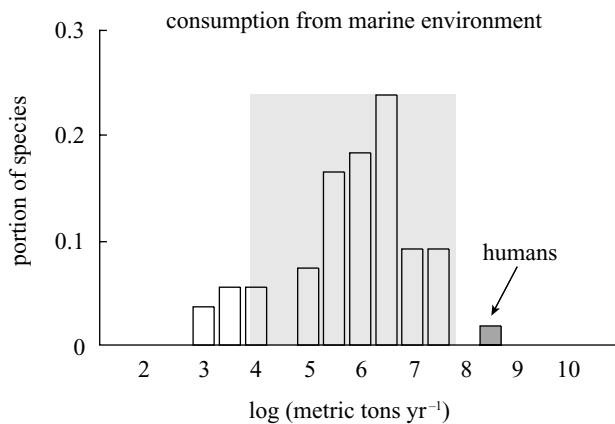


Figure 4. Human consumption of biomass (dark grey bar) from the marine environment in comparison with that of 54 species of marine mammals. The 95% confidence limits among non-human species are indicated by the right and left edges of the pale grey shaded area.

globally (Woodwell 1990; World Conservation Monitoring Centre 1992; Christensen *et al.* 1996; Watson *et al.* 2001).

Based on these findings, we reject the hypothesis that the human species falls within the normal range of natural variation among species for the measures that we tested,

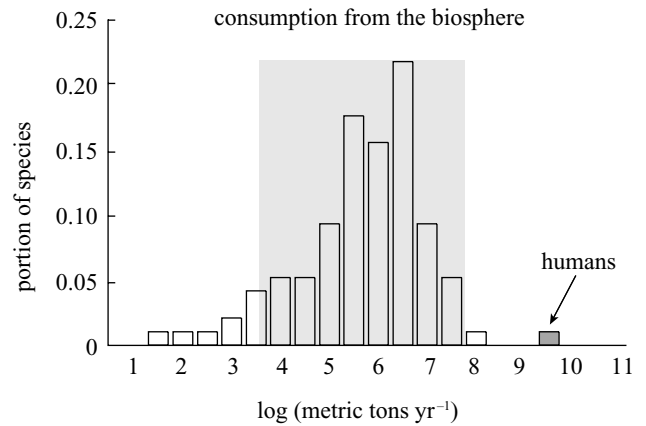


Figure 5. Human ingestion of biomass (dark grey bar) in the biosphere in comparison with that of 96 species of mammals. The 95% confidence limits among non-human species are indicated by the right and left edges of the pale grey shaded area.

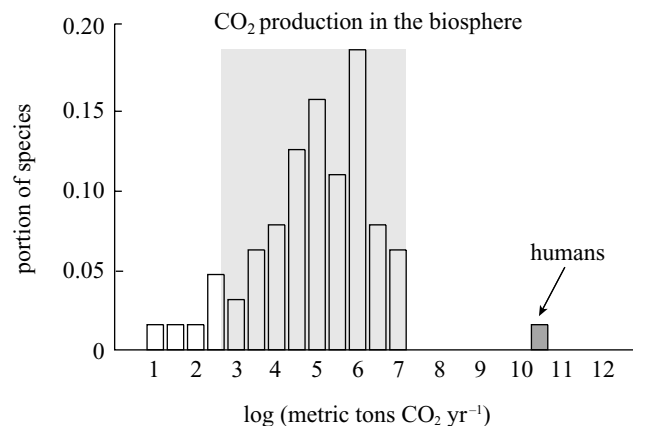


Figure 6. Production of CO₂ by humans (dark grey bar) within the biosphere in comparison with that by 63 species of mammals approximating human body size. The 95% confidence limits among non-human species are indicated by the right and left edges of the pale grey shaded area.

and conclude that these and other similar atypical elements of human ecology are among the primary factors contributing to environmental problems facing the world today.

4. DISCUSSION

The principles and tenets applicable to the management of human affairs are based on the laws of nature and related principles critically important to health at all levels of biological organization (Christensen *et al.* 1996; Mangel *et al.* 1996; Fowler *et al.* 1999; Fowler & Hobbs 2002). We humans have the choice of whether or not we accept that we are part of nature (e.g. ecosystems and the biosphere), begin to move our species to within the normal range of natural variation, and thus avoid abnormal or pathological conditions and their consequences. Whether we accept or reject this way forward, we are subject to the same risks faced by all species when they fall outside the normal range of natural variation, especially over the long term. Such factors make up the natural

Table 1. Humans compared with other species for several species-level measures. (This table presents results of statistical tests of the hypothesis that humans are within the normal range of natural variation among other species for a variety of measures in log scale and the corresponding graph numbers. See Fowler & Hobbs (2002) for further details regarding sources, sample size, locations and types of species.)

figure	type of measure ^a	type of non-human species ^b	mean for non-human species	value for humans	probability of human value or more extreme	humans as multiple of measures among other species	
						mean	upper 95% limit
1a	BCSS	SB,MM,F	3.122	4.929	0.0003	64.2	8.77
1b	BCSS	MM	4.360	6.072	0.0011	51.5	6.21
2a	BCSG	MM	4.170	6.301	0.0244	135	2.25
2b	BCSG	SB,MM	3.344	5.218	0.0059	74.8	4.47
3a	BCE	MM	4.865	6.301	0.0351	27.3	1.35
3b	BCE	MM	3.294	6.049	0.0004	56.9	7.96
4	BCME	MM	5.572	9.478	0.0006	8070	83.6
5	BCB	TM,MM	5.391	9.478	0.0007	12 200	93.9
6	CO2B	TMhbs, MMhbs	4.650	10.301	0.0000	448 000	215
7	GRB	TM	2.355	5.030	0.0067	473	7.84
8	PSB	TMhbs, MMhbs	5.196	9.761	0.0005	36 760	190

^a BCSS, biomass consumption, single species; BCSG, biomass consumption, species group; BCE, biomass consumption, ecosystem; BCME, biomass consumption marine environment; BCB, biomass consumption biosphere; CO2B, CO₂ production, biosphere; GRB, geographical range size, biosphere; PSB, population size, biosphere.

^b SB, seabirds, MM, marine mammals; F, fish; TM, terrestrial mammals; MMhbs, marine mammals of human body size; TMhbs, terrestrial mammals of human body size.

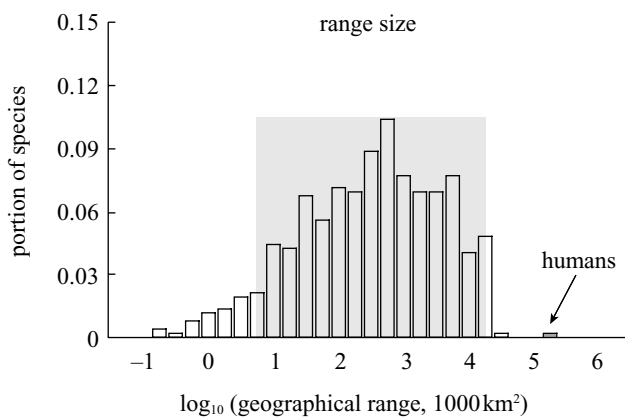


Figure 7. Geographical range occupied by humans (dark grey bar) in comparison with those of 523 species of mammals (assuming that humans have a geographical range covering 70% of the terrestrial surface of the Earth). The 95% confidence limits among non-human species are indicated by the right and left edges of the pale grey shaded area.

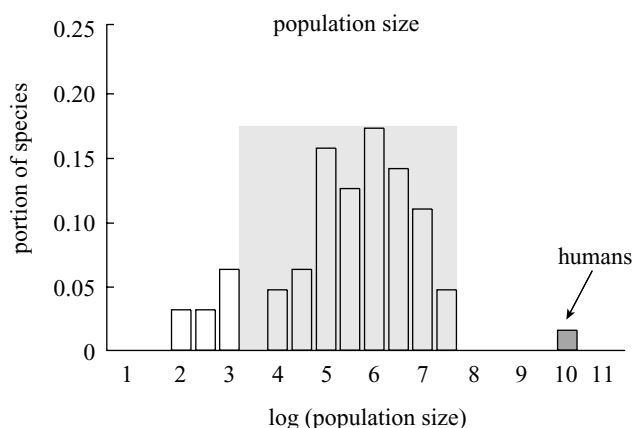


Figure 8. Population size of humans (dark grey bar) in comparison with that of 63 species of mammals similar to humans in body size. The 95% confidence limits among non-human species are indicated by the right and left edges of the pale grey shaded area.

forces that prevent the accumulation of species outside the normal range of natural variation, and analogous to the forces that make rare the occurrence of individual humans outside the normal range of natural variation for attributes such as body temperature, body size or blood pressure.

Whether we attempt to change or not, feedback (including relevant and often delayed risks) includes evolutionary forces, not the least of which are the risks of extinction. As Rees (2002) argues, the history of our species is not encouraging; it is easy to see ourselves as

repeated victims of our own genetic nature. We posit here that sustainability must involve long time-scales, broad spatial scales and scales of complexity from cells to the biosphere. In deciding on the future of our species, it easily can be argued that the abnormality we exhibit is a measure of our superiority, especially our advanced technology (see Rees (2002) for both the argument and counter-arguments). There is no question that we, along with every other species, are unique. The question before us, however, remains: is our particular uniqueness sustainable or a source of extreme risks, including extinction? Empirical

information such as we have presented would argue that, currently, humanity is not sustainable.

Enormous challenges face us if we are to achieve sustainability. Hints of the magnitude of such challenges can be seen in the extreme difficulty of doing no more than taking the first steps towards falling within the normal range of natural variation observed among species. The complex nature of such challenges is beyond the scope of this paper (various elements of the problem are discussed by others (e.g. Rees 2002)). Equally complicated and numerous are the consequences of our decisions, regardless of what they are. However, we scientists have the responsibility to produce information that is of practical importance and draw it to the attention of everyone possible. We urge other scientists to extend the work that we have initiated by conducting similar analyses to determine the extent to which humans appear as outliers for other measures such as the production and use of nitrogen, numbers of species used as resources, water consumption, rates of extinction caused and the production of waste and toxic materials. Further studies of this kind will help to identify, measure and understand the predicaments we face, as well as produce quantitative goals for management. With the results of such work, managers (both members and leaders of society faced with making changes) will have the information that they need to make informed and realistic decisions. Such studies will provide wise guidance for action, should we choose to work towards sustainability in a fully systemic way.

We thank Jeff Breiwick, Dorothy Craig, Gary Duker, Jean Fowler, Jim Lee, Sharon Melin, William Rees and two anonymous reviewers for their comments in reviews of previous versions of this paper.

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