Appendix 6.4

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1 The human population evaluated by interspecific comparisons

Information on the limits to natural variation among nonhuman species that can be used to assess the human population measured either in terms of density or total population (Fowler 2005). Density is considered first.

1.1 Density

Peters (1983) argued that the observed relationship between density and body size (as was shown in Fig. 2.31, and Fig. 6.21) can provide estimates of population density when body size is known (for racoons in his example). Alternatively, one can evaluate a population with known density. In particular this can be done for humans (Cohen 1997, Fowler 2005). Species with either very sparse or very dense populations may be compared to normative values within the density/body size relationship to determine the degree to which they depart from such levels—the comparison is consonant. As mentioned in Chapter 2, relationships between body size and density has been examined and debated in a number of studies (Blackburn *et al.* 1993, Brown 1995, Damuth 1981, 1987, Lawton 1990, Peters 1983, Schmid *et al.* 2001).

This approach can be applied to humans, by comparing human population density with the mean population density of species the same size as humans (Cohen 1997, Fowler 2005, Fowler and Perez 1999). Damuth's (1987) data for herbivorous mammals were reanalyzed using geometric mean regression resulting in the linear relationship shown in Figures 2.31 and 6.21.[1] Using a mean adult human body weight of about 68 kg (150 pounds),[2] and the equation representing the relationship between density and body size, the mean density of herbivorous species that exhibit the body size of humans was estimated to be about 2.3 per square kilometer (6 per square mile). Spread over the entire surface of the earth, the current human density of 11.7 per square kilometer (Appendix 6.3) is 5.1 times the mean expected for herbivores the size of humans (Table 6.2). Of all the species in Damuth's (1987) sample, 85% were found at population densities that, for their size, were less than that of humans spread over the entire surface of the earth.[3]

Restricted to terrestrial areas except Antarctica, the mean density of humans (57.7 per square kilometer) is over 24 times the mean for similar-sized species of herbivorous mammals. Of the 368 species of herbivores in Damuth's work, only 1.6% (6) were more densely populated for their body size than humans dispersed over all land areas. Finally, at over 288 people per square km of agricultural land, the current human population is overpopulated by a factor of over 120 when compared to the mean of herbivorous mammals of the same body size.

A normal human population consistent with herbivores of similar body size would be about 48 million people if we allow ourselves 20% of the earth to live on. Yet there are over 130 times that many. Although there may be exceptions when local densities are considered, no species in Damuth's sample is found at such high average densities for their body size. This is true even if 40% of the earth's land surface is considered habitable by humans. Humans are the most densely populated species of mammal for their body size and exhibit clear abnormality in comparison to mammalian herbivore species (Fig. 6.22).

Because humans are not strictly herbivores, estimates of overpopulation based on comparison with herbivores are biased. Due to our higher trophic position, the optimal human population would probably occur at even lower density. To demonstrate, we consider a relationship between body size and population density for carnivores (Marquet 2002, Peters 1983). Table 6.2 shows overpopulation indices for a number of density and body-size relationships, including that for carnivores.[4] Thus, for similarly-sized carnivorous mammals, the human population is 2470 times more dense than expected as more optimal. Compared to a mixture of species from a variety of trophic levels, the overpopulation factor is 578. Tudge (1989) stated: "There is an ecological law—a simple extrapolation of bedrock physics which says that large, predatory animals are rare. We break that law: we are large and we have a penchant for predation, and our population now stands at 5 billion…". The comparison made here examines the extent to which we "break this law" to exhibit abnormality in violation of one of the tenets of management (Tenet 5, Chapter 1) and underlying principles laid out in Mangel *et al.* (1996).

The pattern in distribution of species across density is very asymmetrical. Without log transformation, most species occur at densities well below the mean. More than 73% of Damuth's sample for herbivorous mammals exhibit densities below the mean of about 119 per square kilometer. Another way to evaluate human overpopulation is to contrast human population density with the modal (most frequent) densities for other species.[5] Such a comparison should again account for the recognized effects of body size. To do so, population density can be expressed as a multiple of the value expected from the regression in Figure 6.21. Figure 6.22A is the frequency distribution of the subsample of species that fall in the range of 0 to 2 for such multiples as compressed into one bar in the graph of Figure 6.22B.

An evaluation of human overpopulation in this way results in even more extremes. Figure 6.22B covers values beyond the multiple of two to include humans. The human population is about 600-fold more densely populated than the most common kinds of herbivorous species. This mode occurs at about 20% of the expected levels for their body size as shown in Figure 6.22A (as a result of the skewed nature of this species frequency distribution). Figure 6.22C shows our species' location in $\log_{10}$ scale where we find ourselves at over 120 times the population density of other species after accounting for body size.

Figure 6.23 shows a comparison of the estimates of human population size sustainable for the earth as a whole, based on three approaches. One (top panel) is based on conventional scientific considerations (derived—the combination of data from Fig. 6.20 and Table 6.1). The second (middle panel) is an interspecific comparison (empirical) assuming we can sustainably occupy about 20 million square kilometers of the earth's surface as vegetarians (i.e., the density information from Fig. 6.22 converted to numbers). The third (bottom panel, Fig. 6.23), shows the population size that approximates the mode of geographic range size for species of our body size (a geographic range of approximately 2 million sq. km., Figs 2.14 and 2.28). It adds another order of magnitude to the difference between measures based on conventional approaches and those based on interspecific comparison. It also corresponds to the estimated population level of about 5 million for prehistoric humans and is within the range of variation observed for populations of other large mammals (Freedman 1989, see below) of our body size. We must remain mindful, however, that trophic level has not been adequately accounted for in that the data used to present the distributions for the bottom panels is based on data from herbivores. As a world society, we may wish to retain the capacity to consume some meat.

Even though there are obvious further refinements needed in this process, the bottom panel of Figure 6.23 would have to serve as a better basis for management (e.g., establishing goals, and points of reference for measuring progress in solving the problem of overpopulation) than either of the top panels. To avoid having any component of ecosystems exhibiting abnormality (Tenet 5, Chapter 1, Mangel *et al.* 1996) and avoid the combination of risks involved, our species would be much better off with a population within the range of the bottom panel. It might be argued that it would be preferable to be near the mode as the example of sustainability represented by most species as it would be consistent with attempts to maximize sustainability. But, as always, things are not as simple as this and a precise location within the normal range of natural variation is debatable (a point visited in Chapter 5 in consideration of maximizing biodiversity). A point estimate cannot be entertained as an option if we are to integrate into management the consideration of data such as that of Figures 2.20–2.22. A population with no variation is exhibiting abnormal population variation—no species has a constant population. Now, however, debate over which metric and statistical distributions are most important for accurately providing guidance is overshadowed by the degree to which humans have departed from all of them at this point in time. To account for trophic level, the human species would arguably be most risk free at even lower population levels than accounted for by comparisons with herbivores.

Figure 6.23 illustrates the difference (about three orders of magnitude) between results obtained in comparing conventional approaches to evaluating our population with those based on information on the limits to natural variation—to integrate a much more complete consideration of complexity. It also indicates that the overpopulation factors in Table 6.1 are underestimates by an order of magnitude or more. This graph brings us through a more complete appraisal of overpopulation by humans when based on density. It accounts for bias in the initial calculation of density based on assumed habitat following conventional approaches. But geographic range size must be dealt with directly (as a distinct management question) and the advantages of direct comparisons with population numbers *per se* are clear.

1.2 Total population

Complications arise in comparisons such as those above, when we address a question with nonconsonant information; the question of sustainable density is better addressed with information on density and addressing questions of sustainable total population with density information involves assumptions, models, and calculations that inject errors, bias, and uncertainty. In the case of density, geographic range size is a complicating factor when it is not known on a species-by-species basis. In the above, it is not clear what the normal geographic range might be for humans. This emphasizes the importance of making comparisons between humans and other species with measurements as consonant as possible (identical units, and categories, with isomorphic information) to the question being addressed. To assess human population size directly, it should be compared to information on the limits to natural variation among the mean population size of other species, rather than density. Density can be used directly on an area-by-area basis. Most countries of the world have densities higher than the mean or modes of frequency distributions above (Appendix 6.5).

As a total population, however, the human population is also the largest for its body size (Freedman 1989, Nowak 1991). The human population is at least two orders of magnitude larger than the largest populations for other large mammals (Fig. 6.24). The crabeater seal (*Lobodon carcinophagus*) has a population of less than 15 million (MacDonald 1984[6]). The white tailed deer (*Odocoileus virgianus*) has a total population perhaps as large as 28 million. Mule deer (*Odocoileus hemionus*) may number as many as 6 million. Other similar sized species with large populations include wildebeest (*Chonnochaetes taurinus*, about 3.1 million), pronghorn antelope (*Antilocapra americana*, approximately 1 million), several species of dolphins (*Stenella*, each less than 20 million), and northern fur seals (*Calhorinus ursinus*, about 2 million). Humans are over two orders of magnitude more numerous and two to three orders of magnitude more densely populated than these extremes.

However, these extremes are limited basis for comparison if the question involves sustainability. Current circumstances include the effects of many human abnormalities (a few of which are exemplified in this chapter). Some of these species (e.g., white tailed deer, crabeater seal) may exhibit large populations because of the disrupting influence of humans—many in ways we are outside the normal range of natural variation. Some species of nonhuman mammals are in marine environments that collectively make up about 70% of the earth's surface, compared to the 20% represented by terrestrial surfaces outside the Antarctic. Population sizes, taken individually, are poor standards of reference, especially our own in its current state in that the integrative power of a pattern of multiple observations is lost.

The point of mentioning these extremes is that all other species of mammals of our body size have much smaller populations than that of humans (Fig. 6.24). For most species, of course, populations are much smaller than these extremes. The mean population size for species of body mass similar to that of humans, shown in Figure 6.24, is about 2.34 million. The current human population is about 2500 times that large or over three orders of magnitude more numerous than this mean. The geometric mean of these populations is 157 thousand (i.e., when based on $\log_{10}$ transformations). Based on comparison with this mean the human population is 36.7 thousand-fold larger than the mean (over four orders of magnitude larger). Such comparisons are also subject to bias if the question is: What is a sustainable human population in the absence of abnormal human impact? Again, this is because of the reduced nature of many of the populations as contributed to by the host of historical anthropogenic effects. Many species included in Figure 6.24, plus even more that are not, are endangered largely as a result of human influence.

Whether with or without abnormal human influence, the extent of human overpopulation evaluated with the preliminary comparisons of total populations are comparable to results based on density as well as those based on estimated prehistorical population levels. The human population is approximately 1000-fold overpopulated if assessed as falling between the two categories in the lower right of Table 6.2. These two categories are: species in general and carnivores more specifically. Humans are assumed to have a habitat involving 20% of the earth's terrestrial surface. This approximate 1000-fold overpopulation assessment is not unlike those obtained from Figure 6.24, even is we account for human influence through assumption. For example, if we assume that our influence on the populations of other species has been to reduce them, on the average, to 10% of normal levels, the approximately four orders of magnitude difference between human and the mean (based on log transformations) of other population levels is reduced to three. Our population is about 700-fold larger than that which would maximize diversity based on population size (Fowler 2008).

It is difficult to escape the conclusion that our population is close to three orders of magnitude too large—there are about a 1000-fold too many of us. This is a problem that, like our CO_2 production and energy consumption (among others as shown in this chapter) are problems much larger than previously recognized.

Notes

1. This form of regression analysis takes into account the fact that there is variability in the estimates of adult body mass as well as in the estimates of population density and better represents the underlying relationship between the two variables. Debate and discussion of the issue of regression techniques is found in a number of related papers (see Blackburn *et al.* 1993, LaBarbera 1989, McArdle 1988, Ricker 1973, 1984). Also, the data used in this regression do not include domestic species.

2. The body mass used here may be slightly large compared to the world average of mean adult body size of humans (65 kg from Nowak 1991). It is not clear what mean body weight would reflect that of the human as a species independent of petro/technical influence. The average weight of women and men in the 30–39 age group for Americans (1994 World Almanac) is 152 lbs (68.9 kg) based on the midpoints of the size ranges (170 lbs—77.1 kg—for men, 134 lbs—60.8 kg—for women). It can be assumed that at least part of a desirable index of standard of living is reflected in body weight. Thus, in looking for sustainable population size one option that serves as a standard of reference is the body weight (mass) of Americans although it is potentially biased.

3. Species that occur under any line parallel to the regression line in Figure 6.21 exhibit densities less than some fixed multiple of the expected density represented by the line. Eighty-five percent (313 of 368) of the species in Damuth's (1987) work showed densities that place them under such a line located to pass through the point where humans are represented as spread over the entire surface of the earth.

4. These comparisons ignore the effects of ordinary linear regression as conducted in the original analysis and presented here without reanalysis. The effects of geometric mean regression would be to accentuate estimated overpopulation.

5. This corresponds to what may be the peak of overall risk aversion represented by naturally occurring species treated as nature's Monte Carlo sampling procedure or examples of natural Bayesian integration (Fig. 1.4). This is to be contrasted, however, with values that maximize biodiversity (Fowler 2008) which are higher than statistical measures of central tendency.

6. Recent populations have been at least 7 million (Boveng 1993, Erickson and Hanson 1990). Kooyman (1981) emphasizes the uncertainty in estimates of the population for this species with estimates ranging from 2 to 75 million.

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