Appendix 6.3

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1 Conventional assessment of human population size

Attempts that have been made to estimate the magnitude of overpopulation have been based primarily on simplistic approaches that consider isolated subsets of the factors actually involved in the systemic determination of population size within ecosystems and the biosphere. Such approaches are exemplified by consideration (e.g., conscious thought, models, or meetings) of factors such as resource requirements, space, food, water, and soils, usually individually, sometimes in small sets, but never in a way that exhausts the complete list to include those things about which we do not yet know. Examples of such approaches are compiled in Table 6.1[1] and Figure 6.20 (from Cohen 1995b).[2]

As is obvious, the perceived degree of overpopulation varies. The FAO estimate in Table 6.1 indicates that the human population of the earth is roughly half of sustainable levels ("overpopulation" index of about 0.6). Cohen (1995b) found even more extreme estimates. These include a 1978 estimate indicating one trillion people are supportable through technology; another was an estimate indicating that a billion billion people could coexist on this planet! The human population in the early 1980s was about 13 times too large according to Catton (1980).[3] The more extreme estimates of overpopulation are those attributed to Soulé by Tudge (1989) in which the earth was evaluated to have 54 times too many humans in the mid 1980s and that of Walker (1984), in which humans were estimated to be overpopulated by a factor of 206 (by considering humans as carnivores that would occupy particular habitat types). The mean index of overpopulation from Table 6.1 is 18.6 (indicating that there are 18.6 times more people than are sustainable). In contrast, the mean estimated sustainable human population for the earth is about 2.01 million. In other words this collection of scientific opinion would indicate that an optimal human population would be between 5% and 35% of recent numbers (about 6 billion).

In contrast we see a different assessment in the mean of estimates of the earth's carrying capacity for humans represented by Figure 6.20 (55.02 billion, based on the sampling of the literature from Cohen 1995b). This would indicate that the world is not overpopulated yet, and our population could continue to grow almost tenfold and still be sustainable. There is a difference of note between these two sets of assessments. It is the degree to which estimates in Table 6.1 are based on consideration of combinations of ecological factors (or simple systems approaches) while Figure 6.20 is based primarily on consideration of single factors (in few cases are more than two or three factors considered simultaneously) or single species population models for humans—often simple projections based on recent history. Approaches based on many population models involve the assumption that the human population will find its own natural carrying capacity; they assume that because the population is growing it must be below carrying capacity.[4] Lag effects and the complexity of systems with their long-term lag effects in evolutionary feedback are not considered.

Most important in considering this information collectively, is the degree to which conventional applications of science gives rise to variety in estimated optimum level for the human population.

Conventional approaches have not been particularly helpful in providing advice in dealing with what is clearly considered a problem both because of variance (uncertainty) and results inconsistent with measures of the symptoms of what is perceived as a major contributing problem.

1.1 Symptomatic measures

Most evaluations of human overpopulation examine symptoms (e.g., the variety of changes observed in ecosystems, including evolution of pesticide resistant pests, habitat loss, etc., Appendix 6.1). Individually and systemically, each of these observed phenomena accounts for the synergistic nature of combined effects (including overpopulation, belief systems, evolution; Belgrano and Fowler 2008) leading to its origin. However when considered as an index of overpopulation, this set of factors replaces the set of factors accounted for in population size itself—the set of factors to be accounted for in evaluation of population size and its sustainable levels. Even so, such approaches lead to the understanding that solutions to overpopulation will involve constraints on individuals as part of the solution to the problem (Holling and Meffe 1996). For direct (consonant) evaluation, the factors involved in these constraints need to be compared themselves to the corresponding patterns among individuals (both within and among species). A very important point here is that observation of any problem (abnormality), symptomatic of overpopulation or not, leads to the addressing of a multitude of real management questions as we trace known or suspected interconnections (Appendix 5.2).

Growth, rather than magnitude, is often identified as the main problem (see Appendix 6.2) in many attempts to characterize overpopulation. The Earth's human population was experiencing a growth rate of about 3.1 people per second in 1993. This translates to the population of the United States being added every 31 months. Growth is clearly a problem if the population is already too large. In other words, in correlative patterns, the fact that our population is growing is abnormal given the extent to which our population is itself too large in comparison to that of other species (Fig. 5.3, Fowler 2008). Population growth rates are important when the management question is "At what rate can a population grow sustainably?"—the answer to which is, of course, 0.00. The question being addressed here, however, is "What is a sustainable population for our species?" It is population size that is of concern. If the human population were 500 individuals and growing at 4% per year, it would be normal for the circumstances. There would be little effect compared to current effects of a world population numbering over 6 billion people and growing by about 3% per year. The number of people currently added each second could also be achieved with a human population of 146 billion growing at 0.1% per year. If growth were the only problem, a zero growth rate and a population of 146 billion would be of no concern. Obviously, such is not the case.[5] If the mountain gorilla population were 6.6 billion and there were 800 humans to pass judgment on the gorillas, the consensus would surely be that the gorillas represented a pestilence of major proportions.

Direct treatment of human population size helps guide attention to its contribution to the magnitude of related impacts, each of which would be reduced if the human population were reduced.[6] Several are shown in this chapter; another is the production of fecal material. At the current size of the world population, fecal material is produced by humans at the rate of 12 cubic meters per second (over 300 cubic feet per second).[7] There are about 133 billion kg of human biomass (146 million tons—133 million metric tons: Fig. 6.25) that respire about 4.2 million tons (3.8×10^9 kg, Fig. 6.14) of carbon dioxide each day. Thus the "size" of the human species translates to products and processes that have innumerable ecological effects. These include extraction of coal and oil, maintenance of agricultural areas for raising food and producing fiber, harvesting of living resources, and occupation of space for these activities. But the ecological complexity of net effects and long-term implications are not considered by these indices without evaluating them with the directly corresponding (consonant) information on limits to natural variation—asking individual management questions and using the corresponding consonant pattern in each case.

1.2 Human density

Knowing the numbers and density of humans is important, but this information cannot be evaluated without normative frames of reference. The following is a brief presentation of human population data used in this chapter in applying normative information derived from observed variation in the density of other species. This is information that is consonant with the management question: "What is a sustainable density for the population of *Homo sapiens*?"

To determine human population density, one must consider habitable area. In the approach that follows it is assumed that suitable human habitat can be found in 20% of the earth's terrestrial surface—an unrealistically large portion (see the discussion regarding Fig. 6.19[8]).

The total human population for the earth was estimated at about six billion at the turn of the century (6.6 billion in 2007; Population Reference Bureau, Inc. 2007). The surface of the earth is about 0.51 billion square kilometers (e.g., Whittaker 1975, World Almanac 1998). Thus, the average density of humans, if spread over the entire planet, was about (11.8) humans per square kilometer in 1996. However, the earth is only about 20% land (excluding Antarctica), so the mean density of humans on dry land was 55.7 per square kilometer (about 1.3 hectares or 4.2 acres per person). However, not all land on the earth's surface can sustain humans. As mentioned above, only about one-fifth of the earth's land might be considered suitable for agricultural purposes,[9] ignoring the question of whether or not agriculture is a sustainable practice. This is land of the quality that can meet the needs for human habitation, complete with the production of food.

Thus, spread over the land assumed suitable for human habitation, the human population has a density of over 288 per square km. This amounts to less than 0.35 hectares (about 0.9 acre) per person. Such densities are abnormal (Fig. 6.21).

1.3 Normative information from historic population levels

Historical population levels can be considered indicative of typical circumstances for a species like humans. Comparison to historic levels involves the consonance of population to population comparisons. It is also, however, an application of the self-referential approach to assessment (considered in Chapter 4) and is consistent with evaluation as applied to individuals, species, or ecosystems in general with risk that there is systemic abnormality on a larger scale. Following this approach, nevertheless, the state of a system at any one time can be compared to historical states. More realistic comparisons involve other systems of the same kind and at the same level of biological organization (individuals, species, or ecosystems). Comparisons of the latter kind were carried out in the main body of the text of this chapter.

Human influence on ecosystems has increased over time (Talbot 2008). In the last 20,000 years of human history, what are considered "primitive" modes of life such as hunter-gathering were transformed to systems largely dependent on energy from outside the living ecosystem (Mannion 1991, Ponting 1991). The early influence of humans on ecosystems depended on energy restricted to sources within the living ecosystem (e.g., food humans consumed). The use of fire brought with it a significant increase in the ability to change ecosystems—to maintain them in states somewhat different from what would be expected with fires originating only from nonhuman sources and an early example of human ingenuity contributing to abnormal conditions. The energy used for practices such as cooking and firing pottery was derived from living ecosystems with a dependence on specific species (primarily woody plants). Domestication of beasts of burden and draft animals (6–12,000 years ago) brought about more directed use of energy but still from within ecosystems—a form of interspecific dependence that has its own natural limits. Eventually, human-induced changes in ecosystems were based on energy from outside the living ecosystem (i.e., noningested sources of energy such as water power, nuclear power, coal, and oil) and the technology that magnifies the impact of humans on ecosystems today.

With energy from outside living ecosystems, humans have temporarily escaped many limits, especially the short-term limitation from complete dependence on ecosystems (Catton 1980). Much of

today's energy use is focused on maintaining ecosystems in abnormal states for the production of food: pesticides, fertilizers, cultivation, irrigation, and protection of monocultures of various kinds. Other technological advances have provided temporary reprieve from the limiting effects of diseases and predation (e.g., see Ausubel 1996), again with abnormal production, use, and effects. Human numbers and, thereby, their increasing influences, are not presently limited to historic levels by dependence on, and limitations of, the ecosystems of which they are a part. However, the dependence on extinct species (oil, gas, and coal) guarantees long-term consequences because these resources are not renewable in the time scales they are being used (Raven and Cracraft 1999). Being dependent on a species that *may* go extinct is one problem, being dependent on species that are *already* extinct is yet another.

The concept of carrying capacity (the number of individuals of a particular species that are sustainable) is a matter of balance expressed as tendencies within population variation. Such variation is limited and limited to be expressed as patterns determined by the full suite of factors involved. The list of these factors is immense (infinite, Fig. 1.4) but includes the positive effects of resources and other services provided by the ecosystem and the negative effects of consumer species, diseases, parasites, and the limits to renewable resources—especially in sustainable competition with other consumers. There is tradeoff between the ability of the environment to support and to limit the population of any particular species. These tradeoffs include the effects of a species on its environment and the responses among the supporting and limiting processes. Included are all interactions among species, being more supportive at low population levels and more suppressive at high population levels (and the resulting phenomenon of density dependence). Species fall into at least two groups depending on their sources of energy. Lithotrophic species live independently of light (microbial species that may represent more biomass and species than others; Pace 1997) while phototrophic species (of which humans are one) depend on light via the photosynthetic process. Humans, primary producers, and lithotrophic species have energy sources that do not depend on biological sources (ingestion). Humans, as a species evolved to ingest the bulk of their energy, have now subsidized their supplies with energy from sources outside living ecosystems—an abnormal situation.

Naturally occurring populations vary, and the carrying capacity of a wildlife population is the mean population level, determined over a period of time[10] under normal natural circumstances (i.e., undisturbed by petro/technologically supported human influence that is itself outside the normal range of natural variation). The carrying capacity is a frame of reference against which to evaluate current population levels. Owing to complexity we are unable to evaluate ecosystems (e.g., a species' relationships with other species) to estimate either historic or current carrying capacity for any particular species. In lieu of such an estimate, historic population levels (or population levels free of abnormal human impact in systems largely recovered from such influences) can be assumed to represent the carrying capacity under normal circumstances; they reflect an integration of all prevailing factors to serve as a measure of carrying capacity in the absence of abnormally high human impacts (e.g., harvests, CO_2 production, pollution). Consistent with species seen as Monte Carlo or Bayesian estimators (themselves capable of change, see Chapters 4 and 5), historic population levels are used as frames of reference (as has been done in assessing marine mammal populations for classification as depleted by the US National Marine Fisheries Service under terms of the Marine Mammal Protection Act (16 U.S.C. 1361(6)). A very similar approach has been used to assess whale populations by the scientific committee of the International Whaling Commission (IWC 1977).

Such an approach is a means for assessing the population of any species. Current population levels are compared to levels prior to the pervasive influence of human numbers and their technology. Humans evolved in the same ecosystems as other species and must be regarded as subject to the same kinds of criteria for evaluation and assessment as any other species. One way of approaching the evaluation of population is to compare the size of the current human population with historical

human populations under conditions more like those in which our species evolved.

Hassan (1981) presents a compilation of information relating to the density of humans under conditions of prehistorical hunter-gatherer societies. The mean population density for hunting and gathering peoples from Hassan's compilation is 0.672 humans per square kilometer with a minimum of 0.01 and a maximum of 9.5 (standard deviation of 0.820). The current estimated human density of 288 per spare km is 428 (= 288/0.672) times higher than the mean from Hassan's work. These density estimates are for habitats specifically known to support humans and do not include areas that have been modified agriculturally. Taking the approach outlined above, 428 serves as a measure of overpopulation; a human population of about 14 million would be more likely to be sustainable than the current six billion. But this assumes that humans at such a population level, with current standards of living, would have no more influence on their environment than did hunter-gatherers.

Another approach to estimating overpopulation factors is to compare simple human population numbers rather than densities. Today's human population of over 6 billion is more than 1000 times larger than the estimated population of about 5 million 10,000 years ago (ranges from 2–20 million, Catton 1980, Coale 1974, Cohen 1995b, Dumond 1975, Ehrlich 1995, Freedman 1989, Hassan 1981, Santos 1990).

Notes

1. In their initial form, some of these estimates were expressed as average density (regardless of location); others were for total numbers. Some were estimates for specific areas (such as the United States). In cases where estimates were for specific areas, it was assumed that similar densities would apply worldwide.

2. The data used here do not include one estimate of one billion billion and several for which there was only a bound (either lower or upper but not both). When ranges were presented in the original literature, the midpoint was used.

3. This is not a direct estimate but an interpretation of Catton's work, i.e., derived from information he provides.

4. As pointed out by Catton (1980), what we are seeing in human population growth, however, is analogous to outbreaks by pest species. Following further destruction of the environment the population is likely to decline rapidly for combinations of reasons—some given in various parts of this chapter. To use some of the simple population models (e.g., logistic) fitted to the data for population growth of humans over this eruption is similar to fitting the same model to data for the populations of pests confined to the eruptive phase of their population growth. We must deal with the risk that a systemic reaction will result in a catastrophic decline if we do not take action soon enough (Pimentel and Dodds 1999).

5. This is not meant to deny the fact that growth makes the problem worse. See the parts of this chapter where growth is a species-level characteristic that is also abnormal. This exemplifies the importance of consonance, or correct match, between management question and empirical pattern.

6. This raises the matter of objectivity. Some of these changes are changes that humans would judge to be positive, others would be seen as negative. Such evaluations as basis for decision-making are a perpetuation of conventional management/thinking and fail to find sustainability free of the potential for being an evolutionary dead-end (or on the path of evolutionary suicide, Table 3.1).

7. This can be compared to the mean discharge of the following rivers (country and discharge in cubic meters/second in parentheses, Showers 1979): Itapicuru (Brazil, 17), Flinders (Queensland, Australia, 16), Castlereagh (New South Wales, Australia, 8), Grand (South Dakota, USA, 8), Souris (Manitoba, Canada, 13), South Platt (Nebraska, USA, 6), Powder (Montana, USA, 17), White (South Dakota, USA, 15), Little Missouri (North Dakota, USA, 16), and Gudena (Denmark, 16).

8. This value (about 20 million square kilometers) is chosen only for illustrative calculations. By comparison, as explained in other parts of this chapter, other species of human body size occupy less than 6% of the earth's terrestrial surface on average. It is also a very generous area, as pointed out in the section dealing with geographic range directly (Fig. 6.19), when using information on the limits to natural variation among all mammalian species as a basis for evaluation.

On more conventional grounds, of course, there are a variety of ways to evaluate the lands humans would be able to occupy. Lands are being opened up for human use in the tropics while others are being overused and abandoned. According to Ponting (1991) "...about 11% of the world's surface is now used for growing crops and there is little land left suitable for agriculture.... About a quarter of the world's surface has been taken over for

grazing animals and although arable land could extend into this area the net increase in food production would be small…". Sisk *et al.* (1994) indicate that 13.6 percent of the terrestrial portions of the earth are used in agriculture and that about 5% is grasslands. Ehrlich and Ehrlich (1996) say that the Food and Agriculture Organization has classified over a third of the land surface of the earth as cropland or permanent pasture. Pimentel *et al.* (1992) indicate that about 50% of the area of the earth's land is under agricultural management. Whittaker (1975) indicates that temperate grass lands and cultivated land comprise 9 million and 14 million square kilometers, respectively.

9. Keep in mind that the exercise here is one of conventional approaches estimating range size. Thus it ignores the information on the limits to natural variation in geographic range size among species. Progress in conventional thinking would recognize that land such as that covered by glaciers and deserts cannot support humans without immense energy expenditure. The amount of land that is habitable is debatable (and would be in conventional thinking, see previous endnote). The World Conservation Monitoring Centre (1992) indicates that the total of all forests, woodlands, grasslands, pastures, and croplands is less than 25% of the earth's land surface (a total of 24.7 million square kilometers). Using one-fifth of the earth's land area as hospitable to humans seems generous (it is twice the amount under cultivation as reported by Whittaker in 1975) in that not all of the forests and woodlands would be as habitable as the grass and croplands. Using such a number oversimplifies the adaptability of humans but is a conventional attempt to strike a balance between the low densities of such areas with the higher densities supportable in cropland areas. This point, and the debate it involves, are moot when range size itself is considered directly (Fig. 6.19, again the importance of consonance).

10. This needs to be a period of time sufficient to capture the range of fluctuation to avoid randomly measuring a population at levels that are low or high relative to the mean, and to integrate the effects of positive factors involving food and space, and the negative factors of limited food and space along with those of predators, pests, diseases, and parasites. Carrying capacity varies with time but shows a pattern exemplified by the relationship between density and body size (Fig. 6.21).

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