

Limits to natural variation: implications for systemic management

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Abstract

Limits to natural variation: implications for systemic management.— Collectively, the tenets and principles of management emphasize the importance of recognizing and understanding limits. These tenets require the demonstration, measurement and practical use of information about limits to natural variation. It is important to identify limits so as not to incur the risks and loss of integrity when limits are exceeded. Thus, by managing within natural limits, humans (managers) simultaneously can achieve sustainability and minimize risk, as well as account for complexity. This is at the heart of systemic management. Systemic management embodies the basic tenets of management. One tenet requires that management ensure that nothing exceed the limits observed in its natural variation. This tenet is based on the principle that variation is constrained by a variety of limiting factors, many of which involve risks. Another tenet of management requires that such factors be considered simultaneously, exhaustively, and in proportion to their relative importance. These factors, in combination, make up the complexity that managers are required to consider in applying the basic principles of management. This combination of elements is reflected in observed limits to natural variation that account for each factor and its relative importance. This paper summarizes conclusions from the literature that has addressed the concept of limits to natural variation, especially in regard to management. It describes: 1. How such limits are inherent to complex systems; 2. How limits have been recognized to be important to the process of management; 3. How they can be used in management. The inherent limits include both those set by the context in which systems occur (extrinsic factors) as well as those set by the components and processes within systems (intrinsic factors). This paper shows that information about limits is of utility in guiding human action to fit humans within the normal range of natural variation. This is part of systemic management: finding an integral and sustainable place for humans in systems such as ecosystems and the biosphere. Another part of sustainability, however, involves action to promote systems capable of sustainably supporting humans and human activities, not only as individuals, but also as a species. It is important to distinguish what can and what can not be done in this regard.

Key words: Systemic management, Limits, Variation, Ecosystems, Single species, Resources.

Resumen

Límites a la variación natural: implicaciones para el manejo o gestión sistémica.— En conjunto, los dogmas y principios del manejo enfatizan la importancia del reconocimiento y la comprensión de los límites. Estos principios requieren la demostración, medida y uso práctico de la información sobre los límites de la variación natural. Es importante identificar los límites para no incurrir en riesgos y pérdida de integridad cuando dichos límites se sobrepasan. Con el manejo dentro de unos límites naturales, el hombre (el responsable del manejo) puede conseguir simultáneamente sostenibilidad y minimización de riesgos, así como explicar la complejidad. Ésto está en el núcleo central del manejo sistémico. El manejo sistémico engloba los principios básicos de cualquier tipo de manejo. Uno de los principios requiere que el manejo asegure que nada exceda los límites observados en la variación natural. Este principio se basa en que la variación está condicionada por varios factores limitantes, muchos de los cuales conllevan riesgos. Otro principio del manejo requiere que estos factores sean considerados simultáneamente, exhaustivamente y en proporción a su importancia relativa. Dichos factores, en combinación, constituyen la complejidad que los responsables del manejo deben considerar

al aplicar los principios básicos de su función controladora. Esta combinación de elementos se refleja en los límites observados en la variación natural referentes a cada factor natural y su importancia relativa. El presente artículo resume conclusiones extraídas de la literatura científica respecto el concepto de variación natural, especialmente en el ámbito del manejo describe: 1. En qué medida estos límites son inherentes a los sistemas complejos; 2. Cómo se ha reconocido la importancia de estos límites para el proceso de manejo; y 3. Cómo pueden utilizarse para el manejo. Los límites inherentes incluyen tanto los establecidos por el contexto donde los sistemas se desarrollan (factores extrínsecos) como los establecidos por los componentes y procesos internos de los sistemas (factores intrínsecos). La información sobre los límites es útil como guía de la acción humana para acomodar los seres humanos al espectro normal de la variación natural. Esto forma parte del manejo sistémico: encontrar un lugar integral y sostenible para el hombre en sistemas tales como los ecosistemas y la biosfera. Otra parte de la sostenibilidad, sin embargo, implica acciones destinadas a promover sistemas capaces de proporcionar apoyo sostenible al hombre y a sus actividades, no sólo como individuo sino también como especie. Es importante distinguir qué puede y que no puede hacerse a este respecto.

Palabras clave: Manejo o gestión sistémica, Límites, Variación, Ecosistemas, Especies individuales, Recursos.

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Introduction

Considerable time and effort has been devoted to defining "ecosystem management" (e.g., VAN DYNE, 1969; CLARK & SAROKWASH, 1975; AGEE & JOHNSON, 1988a, 1988b; MITCHELL et al., 1990; COSTANZA, 1992; COSTANZA et al., 1992; GRUMBINE, 1992, 1994a, 1997; SLOCOMBE, 1993a, 1993b; WOODLEY et al., 1993; MAERZ, 1994; MOOTE et al., 1994; WOOD, 1994; ALPERT, 1995; LACKEY, 1995; MALONE, 1995; PASTOR, 1995; STANLEY, 1995; UNITED STATES INTERAGENCY ECOSYSTEM MANAGEMENT TASK FORCE, 1995; CHRISTENSEN et al., 1996; COOPERRIDER, 1996; MANGEL et al., 1996; NOSS, 1996; SAMPSON & KNOPF, 1996; SCHRAMM & HUBERT, 1996; NATIONAL MARINE FISHERIES SERVICE ECOSYSTEM PRINCIPLES ADVISORY PANEL, 1998; COMMITTEE ON ECOSYSTEM MANAGEMENT FOR SUSTAINABLE MARINE FISHERIES, 1999; MCCORMICK, 1999 and the references therein). This collective effort, in part, was a reaction to the trouble that is encountered in pursuing other forms of management, especially management historically practiced at the single-species level and particularly when management is aimed at non-human species rather than humans. These traditional approaches include resource management with approaches based on the concept of maximum sustainable yield (MSY, and its failures; LUDWIG et al., 1993; GOODLAND, 1995; CALLICOTT & MUMFORD, 1997; STRUHSAKER, 1998), pest and predator control, and crop management.

However, management cannot proceed by focusing on ecosystems to the exclusion of comparable consideration of species or individuals. A form of management is needed that includes consideration of individuals, species, and the biosphere—in other words, all of the various levels of biological organization. These have to be considered in addition to ecosystems. If other levels of biological organization are excluded by restricting focus to ecosystems, management will get into even deeper trouble than already experienced—trouble stemming, in part, from a focus that is too narrow, as experienced by focusing on individual species, or on individuals (e.g., individual humans). Especially problematic is management that assumes that humans can control other species or ecosystems and simultaneously avoid the side effects or unintended consequences of management action (ROHMAN, 1999). Systemic management (management that embodies the principles and tenets of management as developed in the literature on management, to represent the best thinking available, and as shown in appendix 1; see also: FOWLER, 1999a, 1999b; FOWLER & PEREZ, 1999; FOWLER et al., 1999; FOWLER, 2002) avoids these problems by considering and accounting for all levels of biological organization as part of an application of the tenets of management in general. It extends beyond the management of human use

of natural resources; it also applies in other realms (e.g., CO₂ production or energy consumption: FOWLER & PEREZ, 1999; or social and psychological issues: JOHNSON, 1992; CONN, 1995).

Management, regardless of its form, is based on tenets and principles that are seen as important. Systemic management is no different in this regard, and is based, in part, on the principle requiring that elements of various natural systems be maintained within their normal range of natural variation (RAPPORT et al., 1981, 1985; CHRISTENSEN et al., 1996; HOLLING & MEFFE, 1996; MANGEL et al., 1996; FOWLER, 1999a, 1999b; FOWLER et al., 1999; MCCORMICK, 1999 and references for appendix 2) —a theme treated more thoroughly below as a primary point in this paper. In developing this point, there is documentation of the recognition of this principle, the full history of which deserves more extensive treatment than is possible here. Part of this history involves the conclusion that adhering to this principle requires the use of empirical information about variation and its limits (FOWLER, 1999a, 1999b; FOWLER & PEREZ, 1999; FOWLER et al., 1999).

The existence of a normal range of natural variation implies that there are limits to such variability, but does not rule out the possibility that natural variation will change over time, space and environmental circumstances (e.g., weather and climate). Thus, variation is itself one of the things that varies; but even it has limits. It is often pointed out that everything has its limits (PIMENTEL, 1966; HYAMS, 1976; RAPPORT et al., 1981; PIMM, 1982; RAPPORT et al., 1985; SALTHER, 1985; O'NEILL et al., 1986; SLOBODKIN, 1986; KOESTLER, 1987; CLARK, 1989; GRIME, 1989; ROUGHGARDEN, 1989; ORIAN, 1990; ANDERSON, 1991; MEADOWS et al., 1992; PICKETT et al., 1992; MCNEILL, 1993; MOOTE et al., 1994; WILBER, 1995; AHL & ALLEN, 1996; CHRISTENSEN et al., 1996; HOLLING, & MEFFE, 1996; MANGEL et al., 1996; NATIONAL MARINE FISHERIES SERVICE ECOSYSTEM PRINCIPLES ADVISORY PANEL, 1998; MULLER et al., 2000; UHL et al., 2000).

Limits are one of the more recognized elements of nature, as frequently seen in the study of ecology. Limits define natural patterns. Most general ecology texts address this concept and many contain words such as *limits*, or *limiting factors* in their indices (e.g., ALLEE et al., 1949; BROWN, 1995; DIAMOND & CASE, 1986; EMLEN, 1973; KREBS, 1972; ODUM, 1959; PLATT & REID, 1967; RICKLEFS, 1973). Any automated search of the available ecological or biological literature by using the term "limits" reveals the extent of its importance, especially in the titles and key words of many papers published in the biological sciences. Limiting factors are often treated in terms of the constraints posed by available nutrients, or other resources, but also include the effects of predation and disease on population numbers, biomass, productivity, or species

numbers. While the concept is generally well developed in a variety of ecological settings, it is most commonly used to describe constraints on population size (and the variation of population numbers or biomass in space and time).

Some aspects of limits are straightforward (usually hard limits, see below). A population cannot use more resources than are available, either in total biomass or numbers of species. Similarly, consuming nothing is not an option for any species because zero consumption guarantees extinction. An ecosystem cannot constitute more than 100% of the biomass in the biosphere. Other limits are more complicated as exemplified by the population dynamics of any species. The limits set on populations result in central tendencies (commonly called carrying capacity, K) such that any species' numbers ordinarily tend away from zero and cannot be infinite—they find a dynamic balance. These are systemic limits set by combinations of both intrinsic and extrinsic factors (INGRAM & MOLNAR, 1990), or the soft limits of processes, competing or opposing forces, and related rates. For a population, these factors include disease, resource limitations, metabolic needs, density dependence, social dynamics, life history, body size, temperature, habitat, behavior, reproductive strategy, environmental variation, and predation—the list is virtually endless (PIMENTEL, 1966).

This paper includes a partial review of the literature that addresses limits inherent to natural variation to help bring the concept of limits to its proper place in management. The following material presents a much broader perspective, however, than any focus on populations would allow. There is a bias, nevertheless, in consideration of biological and ecological systems at the expense of attention to physical systems (e.g., variation in tidal cycles, climate change, or river flow). This bias tends to place emphasis on factors exemplified by consumption of energy (by biotic systems), consumption of biomass from the biosphere, production of CO_2 , and predation rates. It is a primary goal of this paper to stimulate recognition of the concept of limits as a way to guide human action in regard to influence on living systems, as well as finding an appropriate place for humans within such systems. A major question is faced in management: "Can scientifically meaningful 'limits' or 'boundaries' be defined that would provide effective warning of conditions beyond which the nature–society systems incur a significantly increased risk of serious degradation?" (KATES et al., 2001).

The sections below begin with a consideration of the terminology used to discuss and characterize limits and limitations along with terms used to describe the results of such factors. Following this, there is a section on the factors that contribute to limitations—those things that do the limiting. It contains a sample of what

collectively comprises the full complexity of nature—or what many call reality. Next is a section containing examples of the kinds of things that are limited. Again complexity or reality is involved because virtually everything finite is limited. The fact that there are risks involved in exceeding the normal range of natural variation is emphasized. These risks are among the factors that contribute to establishing limits (e.g., there are risks to each individual human, exemplified by the risk of death associated with body temperature outside the normal range of natural variation). The paper ends with consideration of the application of information about limits, the role of such information in management, and the definition of management based on such information—systemic management.

Terminology

It is helpful to recognize two categories of limits introduced above, each of which will be involved in the remainder of this paper: soft limits and hard limits. Soft limits arise from a balance of forces or competing rates in natural processes. They are usually invoked long before hard limits are approached and can be exceeded for various periods of time, but not indefinitely. Hard limits include physical limits such as space, or the energy content of a resource. Thus, true sustainability exists only within the combination of limits that govern natural systems, each with its own time scale. Temporal scales for soft limits involve the length of time such limits can be exceeded before systemic restorative (homeostatic) forces prevail.

Appendix 2 presents various quotations from the literature where it is seen that a wide variety of terms are used to deal with the concept of limits to natural variation. Equivalent terms are used in both the scientific and management literature, but in different ways. In scientific publications, various words are used to represent limits that are identified, observed, described and measured. Descriptions often include the ways in which limitation is brought about by the factors involved—the processes of limitation or the elements that contribute to limitation. The terms used in scientific work also describe and identify the things that are limited. In contrast, the literature on management uses the same terminology to stress the point that it is important to do what is possible to maintain systems (such as ecosystems, and their component species or populations) within the normal range of natural variation (tenet 3, appendix 1). The literature also makes it clear that managers are increasingly aware that limiting humans becomes both paramount and the only viable option. It is important to limit action so as to avoid risks, including those of doing things that make other systems fall outside the normal range of their natural variation (appendix 1, MCCORMICK, 1999).

Constrain

Variations on this term are often used to characterize nature and natural processes (appendix 2; FARNWORTH & GOLLEY, 1974; ALLEN & STARR, 1982; PIMM, 1982, 1984; SALTHER, 1985; FISHER, 1986; O'NEILL et al., 1986; STEARNS, 1986; BROWN & MAURER, 1987; GLAZIER, 1987; KOESTLER, 1987; AGEE & JOHNSON, 1988a; GRIME, 1989; GRUBB, 1989; TILMAN, 1989; BURNS et al., 1991; PONTING, 1991; HANNON, 1992; NARINS, 1992; BROWN, 1995; AHL & ALLEN, 1996; HOLLING & MEFFE, 1996; MANGEL et al., 1996; MULLER et al., 2000). As will be seen below, systems place limits on their components and the term *constrain* is used along with others to convey this concept (e.g., BURNS et al., 1991). Constraining effects are involved in species interacting with each other (e.g., KNOLL, 1989). The term *constrain* is also used in the literature on management but it is applied in two ways. First, it is used in terms of action (constraining human options, and as a matter of exhibiting constraint). Second, it is used interpretively. That is, empirical information observed in scientific studies is seen as guidance for action—what to achieve in carrying out constraining action. The guidance to be used in management is provided by information about natural limits (AGEE & JOHNSON, 1988a; PICKETT et al., 1992; PONTING, 1991; CHRISTENSEN et al., 1996; FOWLER et al., 1999).

Limit, limitations, limiting

These words, and other derivatives of the word *limit* are used often, again both with respect to characterizing nature (DARWIN, 1953; PIMENTEL, 1966; BATESON, 1972; HYMANS, 1976; LEVINTON, 1979; STANLEY et al., 1983; YODZIS, 1984; O'NEILL et al., 1986; AGEE & JOHNSON, 1988a; BUSS, 1988; CLARK, 1989; ROUGHGARDEN, 1989; ORIAN, 1990; WOODWELL, 1990; ANDERSON, 1991; PONTING, 1991; PICKETT et al., 1992; MCNEILL, 1993; SWIMME & BERRY, 1994; WOOD, 1994; ROSENZWEIG, 1995; AHL & ALLEN, 1996; CHRISTENSEN et al., 1996; NATIONAL MARINE FISHERIES SERVICE ECOSYSTEM PRINCIPLES ADVISORY PANEL, 1998) and as important to management (HYMANS, 1976; AGEE & JOHNSON, 1988a; ANDERSON, 1991; PONTING, 1991; PICKETT et al., 1992; MCNEILL, 1993; MOOTE et al., 1994; WOOD, 1994; HARDIN, 1995). The concept of management as a process of limiting human influence is interwoven with the observation and characterization of natural limits.

Threshold, boundary, border

The concept of limits is also embodied in words that refer to transition points (see the use of these words or their derivatives in references such as BROWN, 1995; BROWN & MAURER, 1989; CLARK, 1989; ELDREDGE, 1991; HASSELL & MAY, 1989; HENGEVELD, 1990; FUENTES, 1993; MANGEL et al.,

1996; NATIONAL MARINE FISHERIES SERVICE ECOSYSTEM PRINCIPLES ADVISORY PANEL, 1998; SALTHER, 1985). In predator/prey interactions, for example, there are various component processes that result in cyclic or chaotic population dynamics when they exceed certain levels, often referred to as thresholds or boundaries, also reflected in certain forms of single-species population dynamics (e.g., HASSELL et al., 1976). However, bounds and borders also refer to the combination of upper and lower limits that confine sets of viable options (BOTKIN & SOBEL, 1975; CHRISTENSEN et al., 1996). As with other terms, these are also used both in defining and guiding the process of management (e.g., see SCHAEFFER & COX, 1992; FUENTES, 1993) as well as in scientific characterization of nature.

Control

This word is also used in reference to the concept of limits, especially in regard to the constraining effects of a system's influence on its components (e.g., KOESTLER, 1987; O'NEILL et al., 1986; SALTHER, 1985; WILBER, 1995). The collective effects of all parts of a system on any one part are greater than the effects of the one on any other (single part). Following this observation, it is recognized that management cannot ignore the fact that human influence on one component of any complex system results in indirect effects on other parts of the system as well as those systems in within which it occurs (secondary effects: PIMM & GILPIN, 1989; second order effects, ripple effects: DIAMOND, 1989; non-linear effects, domino effects: STANLEY, 1984; "down stream" effects, delayed effects, side effects: PONTING, 1991—all parts of the unintended consequences of human influence: ROHMAN, 1999) and control is seen as a concept restricted primarily to human endeavor (HOLLING & MEFFE, 1996; MANGEL et al., 1996). Humans have no control over other systems in the sense that no one can change the fact that there will always be secondary (or higher order) effects of human influence, even when control is attempted. This includes the feedback of such effects on humans. *There are always unintended consequences (ROHMAN, 1999) to management action and one of the limits experienced in management is the inability to change this fact.*

Other terms used in regard to limits and limiting processes include *regulated* (LEVIN, 1989), *governed*, *restricted*, *restrained*, *confined*, *proscribed*, *suppressed*, *curtailed*, *channeled*, *circumscribed*, *curbed*, *contained*, *barriers* (CLARK, 1989), and *resistance*.

Still more terms are involved in characterizing the results of limitations seen in the empirically observed limits to variation. Such characteristics are the qualities of the limits seen in variation (e.g., range spanned), and the kinds of variation observed (e.g., bimodal or unimodal) within the normal ranges of variation between upper and

lower limits. Natural variation is constrained by both upper and lower limits. Limits, constraints and risks do not always increase or decrease monotonically. The combined effects of the numerous limitations, as they act in concert, are even more complicated. An example that is easy to relate to as individual human beings is the risk of mortality from various factors—risks that increase for body weight, blood pressure, and body temperature both above and below the midpoints of the ranges that they span (e.g., see CALLE et al., 1999, and references therein, regarding weight). Therefore, upper and lower limits preclude many options; they function to allow as the only viable alternatives those seen between upper and lower limits. The remaining options are usually realized with their greatest frequency at some midpoint between the limits. Thus, there is always an emergence of central tendencies between upper and lower limits. Limits often operate as opposing forces (often soft limits), and the collective balance found in such opposition contribute to the formation of patterns in nature (e.g., see the stochastic analog of equilibrium; BOTKIN & SOBEL, 1975; CHRISTENSEN et al., 1996). There is terminology associated with these patterns, or central tendencies, just as there is for the consideration of any single component among the factors that contribute to limiting natural variation.

Mean, mode and median

Statistical names for the measure of central tendencies include terms such as these (SNEDECOR, 1956) to refer to the magnitude of the central tendency (i.e., its position) within the infinite range of options among real numbers.

Kurtosis and skewness

These terms refer to the position and concentration of central tendencies with respect to the upper and lower bounds of variation (SNEDECOR, 1956). *Kurtosis* refers to the distance between the central tendency and its limits, the concentration of observed measures near the central tendency, or the flatness and spread of the distribution. *Skewness* relates more to the degree to which there is a lack of symmetry in the variation. Thus, both terms are used in regard to the shape of the frequency distribution (or probability distribution) of empirically observed variation. Various mathematical models (e.g., log normal, binomial, Poisson, and others, SNEDECOR, 1956) are available to represent the probability distribution of variation in its different forms. Transformations are often used to convert measures showing non-symmetric distributions to more symmetric or normal distributions (especially log transformations, LIMPET et al., 2001).

Terminology is not confined to the concept of limits, measures of limits, or the characterization

of variation within limits as treated above. Various terms are also used in reference to the processes that contribute to the production or origin of central tendencies, especially their positions. Naturally, these include the limiting processes that affect constraint above and below the central tendencies. However,, such processes also include other factors, such as processes involving replication or positive feedback that contribute to the position of central tendencies through the accumulation of more numerous examples in the regions of central tendencies.

Homeostasis, balance and feedback

These terms are examples of words regarding the processes that contribute to the origins of central tendencies (as opposed to simple constraint). Specific examples of the elements involved in these processes will be considered below. These processes operate in conjunction with all other processes in nature as none can operate in isolation from the others. The results of the synergistic combination of all the processes are the patterns observed to characterize nature (ALLEN & STARR, 1982)—often seen as emergent patterns (KAUFFMAN, 1993; EL-HANI & EMMECHE, 2000) that include the stochastic analog of equilibrium (BOTKIN & SOBEL, 1975; CHRISTENSEN et al., 1996). These processes are part of what the various species (including humans, tenet 9, appendix 1) are exposed to by being part of systems such as ecosystems.

Integrity, balance and normal (or natural)

These are terms related to such patterns as those that make up, or characterize, natural systems (e.g., GRUMBINE, 1994a) often found in the titles of papers describing nature (e.g., WILLIAMS, 1964). Many of these patterns are correlative, meaning that the magnitude of the mean of a variable is related to that of another variable (measure) as exemplified by the relationship between the central tendency of population density and body size for animals (fig. 1, see also DAMUTH, 1987; PETERS, 1983). Others relate to the physical environment as found in relationships between geographic range size and latitude (e.g., STEVENS, 1992) or predation rates and temperature. The word *integrity* is sometimes used with regard to management objectives in the sense of achieving normal states of nature (e.g., KARR, 1990). *Balance* is often seen as a property of nature in view of the limits to variation (e.g., PIPER, 1993) and something that occurs in spite of variation (i.e., equilibria are rarely static properties of nature, especially biological systems; BOTKIN & SOBEL, 1975; CHRISTENSEN et al., 1996).

There is yet another set of terms used to characterize statistical outliers, extremes, or things beyond the normal range of natural variation (e.g., beyond the limits, MEADOWS et

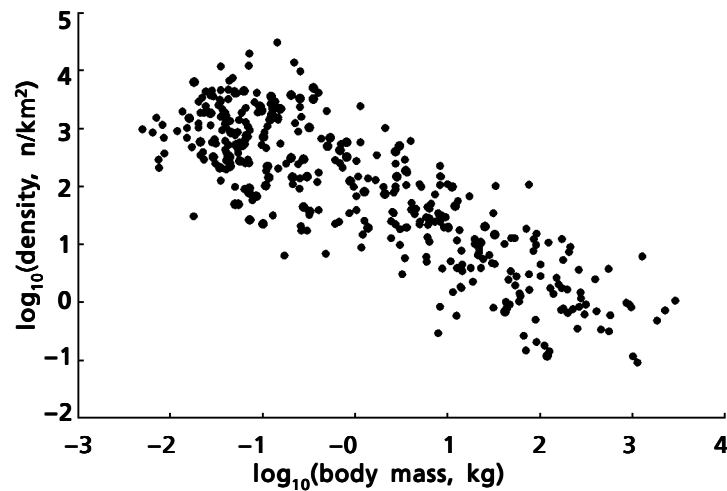


Fig. 1. Population density of 368 terrestrial mammalian herbivore species in relation to adult body mass (DAMUTH, 1987; FOWLER & PEREZ, 1999) as an example of variation in one measure of a species in relationship to variation in another.

Fig. 1. Densidad de población de 368 especies de mamíferos herbívoros terrestres en relación con la masa corporal de los adultos (DAMUTH, 1987; FOWLER & PEREZ, 1999) como ejemplo de variación de una medida en una especie respecto a la variación en otra especie.

al., 1992), especially as cases subject to the risks of limiting factors and include words such as *abnormal*, *pathological*, *deviant*, *aberrant*, *atypical*, and *anomalous*. The word *unnatural* is also used but must be treated with care. Everything happens naturally and extremes beyond the normal ranges of natural variation are subject to the natural limits and risks that make such extremes rare. Thus, it is not so much unnatural, as it is abnormal, to observe a characteristic or condition (such as a fever) as an extreme. Extreme fluctuation is abnormal (CHRISTENSEN et al., 1996) as is often observed for populations. Thus the term *pathological*, or *carcinogenic* is used in reference to human overpopulation (CALHOUN, 1962; BATESON, 1972; HERN, 1993). At the ecosystem level *pathology* is also used to describe problems when atypical conditions arise (e.g., RAPPORT, 1989a). These are words that help clarify the distinction between the natural occurrence of extremes and things that fall in the normal range of natural variation.

Factors contributing to limits: complexity I

Limiting factors combine in nature to make up an interconnected set of forces, risks, and constraints. A major part of scientific endeavor is dedicated to documenting these factors and the lists that are available now, while long, only scratch the

surface of the complexity of reality—even in their combination. The entire complexity within and among natural systems contributes to both the collective constraints on variation and to the formation of the central tendencies within such variation (e.g., see PIMENTEL, 1966 regarding limits to population size) as introduced above. Research on the limits to variation in biological systems has resulted in the recognition of a great many contributing factors and an exhaustive list is beyond the scope of this paper. However, there are examples worth mention, some of which are found in appendix 2.

A great deal of literature has accumulated from studies of the factors that limit population size. There is a long list, and various categories of such factors are considered to be of importance. Among such categories are parasites, predators, disease, behavior (COHEN et al., 1980), energy, resources (food, prey), space, competition, and nutrition (including needs for individual elements and their compounds such as amino acids)—all subjects of a long history of research on population ecology and represented by a sample of references in appendix 2 (e.g., PIMENTEL, 1966; FARNWORTH & GOLLEY, 1974; O'NEILL et al., 1986; TILMAN, 1989; MCNEILL, 1993). Other factors include limits on the options for life history strategy especially as related to body size (DAMUTH, 1987), or the options for population growth and kinds of mortality as related to life history strategy (FOWLER, 1988).

The limitation of populations by microorganisms (diseases or pathogens) or other pests has been of special focus in many studies and are factors recognized by PIMENTEL (1966), FARNWORTH & GOLLEY (1974), STANLEY et al. (1983), and TILMAN (1989). A review of such limitations has been conducted by MCCALLUM & DOBSON (1995). However, it is clear that microscopic or small bodied consumers are not the only category of species known to contribute to the limitations on the population size of their hosts. Consumer species that are of larger body size than their consumed prey/resources are also involved (e.g., predators and herbivores; STANLEY et al., 1983; O'NEILL et al., 1986; MCNEILL, 1993). Whether microscopic or not, the degree to which one species acts to limit the population of another varies from case to case. Removing predators experimentally to rid their resources of such influence often results in population increases, but not always. Limiting influence is thus only a tendency and rarely predictable owing to the complicated nature of the interactions and factors that influence them (PIMM, 1991). In the final analysis, mortality caused by consumers or disease count among the many factors that contribute to limiting population size but are not the only factors involved.

Sunlight provides the energy that is passed through the food webs of communities and ecosystems. This energy is involved in metabolism, growth, reproduction and survival. It is not limitless in its flow through biological systems, however, and is among the factors that have been studied for a variety of such systems from cells to the biosphere. As such, energetic constraints are not confined to setting limits on population size and the various limits involving energy are represented by a voluminous literature. Energy has been noted as a limiting factor in a variety of biological systems by BROWN (1981), PIMM (1982, 1984), YODZIS (1984), BROWN & MAURER (1987), GLAZIER (1987), GASTON (1988), TILMAN (1989), and HANNON (1992). Energy is clearly not the only limiting factor for biological systems. The more general issue of resources (including nutrients of various kinds) as constraining factors is often noted (STANLEY et al., 1983; O'NEILL et al., 1986; MCNEILL, 1993), occasionally as expressed through competition (PIMENTEL, 1966; STANLEY et al., 1983).

Another important resource is space (or habitat size). Thus, space is also frequently identified as a limiting factor, including its limitations on species numbers in addition to its constraints on population size (e.g., STANLEY et al., 1983; O'NEILL et al., 1986; ROSENZWEIG, 1995; BROWN, 1995).

Extinction is also a limiting factor (BROWN & MAURER, 1987), perhaps an ultimate limiting factor (at times a soft limit with a long time scale), and one that has its effects on species numbers, diversity, communities (ARNOLD & FRISTRUP, 1982; FOWLER & MACMAHON, 1982; GOULD, 1982;

ELDRIDGE, 1985; KITCHELL, 1985; LEVINTON, 1988; BROWN, 1995; ROSENZWEIG, 1995), and body size (i.e., as a contributing factor in limiting the maximum size observed among species, e.g., see VAN VALEN, 1973; BARANOSKY, 1989; FOWLER & MACMAHON, 1982; BROWN, 1995). Thus, extinction at the species-level, like death at the individual-level, is one of the risks associated with the extremes characterized as pathological or abnormal. Extinction is a limiting factor that also exemplifies a process rather than a physical entity in its limiting action (soft limit in involving long time scales).

Other limitations involve morphological factors (PIMM, 1982, 1984; FISHER, 1986; BROWN, 1995), functional, historical, and evolutionary elements (PICKETT et al., 1992), physiology, and behavior (BROWN, 1995), various population dynamical forces (as well as other dynamics; PIMENTEL, 1966; LEVINTON, 1979; PIMM, 1982, 1984; ROSENZWEIG, 1995), environmental predictability (LEVINTON, 1979), environmental heterogeneity (PIMENTEL, 1966), evolutionary forces (including genetic feedback mechanisms, PIMENTEL, 1966; FOWLER & MACMAHON, 1982; PIMM, 1984), and the availability of genetic (raw) material (GRUBB, 1989). Nutrition, space, toxic materials, competition, predation, cannibalism, and stress are all limiting factors (ROSENZWEIG, 1974). There is little, if anything, that can be ignored in the complexity of factors that limit variability (PIMENTEL, 1966).

It must be recognized that there are two more closely interrelated categories of limiting factors (each involving both hard and soft limits) depending on whether they are extrinsic or intrinsic to the system showing variation (INGRAM & MOLNAR, 1990). Variation limited by extrinsic factors in biological systems includes the effects of disease, predation, competition, habitat size, and resource availability on population size. Intrinsic factors limiting population size include, body size, behavior, and the birth and death rates involved in life history strategies. At the same time such factors are observed to contribute to limitations, they also have their influence on the position of central tendencies. Intrinsic and extrinsic factors are involved in the limitation of any system and its interactions with other systems.

As amplified in the next section, there are a variety of levels of biological organization to which limiting factors apply. These span the range from sub-cellular structures, to cells, organs, individual organisms, populations, species, communities and ecosystems, through to biomes and the biosphere. It is easy to find examples of limiting factors for each level of biological organization. At the individual level, body size is limited by extrinsic factors such as food availability, and intrinsic factors such as metabolic dynamics. This list goes on to include mortality at the individual level, and extinction at the species level. At the community or ecosystem level, species numbers are limited

extrinsically through factors exemplified by energy and space, and intrinsically by evolutionary factors and population dynamics. Collectively, all species in an ecosystem interact with each other such that each one is subject to the constraints emergent from the combined effects of the others. This happens in all systems such that the extrinsic factors that impose limits include those through which a system poses limits to its parts or its components (e.g., AHL & ALLEN, 1996; MULLER et al., 2000). These include the processes of natural selection involving death and extinction.

Both intrinsic and extrinsic factors operate simultaneously and collectively in natural systems (INGRAM & MOLNAR, 1990)—sometimes reinforcing, sometimes nullifying each other. The degree to which such things happen varies from case to case. Furthermore, synergistic effects and interactions among such factors are common. The combined action of such factors result in observed patterns (e.g., as observed in the results of various forms of natural selection; ARNOLD & FRISTRUP, 1982; FOWLER & MACMAHON, 1982; GOULD, 1982; LEVINTON, 1988). Thus, patterns are the results of systemic effects, or the effects of the entire suite of limiting factors and all of their interactions. Some of these patterns in nature are partially explained by the balances that result from limiting factors that function to reinforce or oppose one another. Balances resulting from the latter are especially important in observed patterns. Extinction acting to limit the options for natural selection at the individual level provides a good example (ALEXANDER & BORGIA, 1978; FOWLER & MACMAHON, 1982; GOULD, 1982; LEVINTON, 1988). Other patterns result from parallel, or reinforcing, effects. Examples of factors that may work in concert are seen in the interplay of body size, population size and geographic range (BROWN & MAURER, 1987; GASTON & BLACKBURN, 2000) on extinction rates. Species of large body size and species with small geographical ranges appear to have higher extinction rates. This may contribute to there being fewer species that are large bodied with small geographic ranges compared to species with small bodies and large ranges.

The things with constrained variation: complexity II

Limitations are imposed on all components and processes at each level of biological organization. Whether it be a cell, physiological process, population, predation rate, total population biomass, speciation, or number of species, it is something with variation that is subject to limits. This section turns from the things that exert limiting influences reviewed in the previous section to examples of the things that are subject to limitations. These include such things as body size, blood pressure, and heart rates for individual animals. The components of ecosystems and

ecosystems themselves are also subject to limitations (NATIONAL MARINE FISHERIES SERVICE ECOSYSTEM PRINCIPLES ADVISORY PANEL, 1998; HAGEN, 1992).

Population size and population variation are limited. There is a voluminous literature treating limits to population size (e.g., HOLLING, 1966; PIMENTEL, 1966; FARNWORTH & GOLLEY, 1974; O'NEILL et al., 1986; GLAZIER, 1987; SINCLAIR, 1989; TILMAN, 1989) that cannot be ignored. Many things that limit population size *per se* are also factors that limit population variation which is limited within species as well as among species (SPENCER & COLLIE, 1997; FOWLER & PEREZ, 1999). Variation in general is limited and population variation is an example (BUSS, 1988; HOLLING, 1966; O'NEILL et al., 1986). The results of work on populations serve as an example of insight that would be expected for other aspects of biological systems had they been the subject of equivalent study.

Other factors are far from ignored, however. In addition to population size and variation, the limits in variation have been shown for a variety of biological processes and dynamics. The evolutionary process is not free of limitations (e.g., GRUBB, 1989). For example, the extent of evolutionary change is limited (FISHER, 1986) because evolution is "channeled" by various constraints (GRIME, 1989). The general concept is exemplified by the lack of evolutionary options as limited by cell structure. There are no single celled organisms that weigh a metric ton. Other processes are also limited. The behavior of organisms and its evolution is limited (NARINS, 1992). The variety of dynamics of (and within) communities and ecosystems are limited (LEVIN, 1989; PIMM, 1982). These include the flow of energy among species (owing to the limitations established by the inefficiency of metabolic, photosynthetic, and digestive processes). As will be seen, processes such as predation, CO₂ production, reproduction and mortality all fit within limits.

The size of cells and the qualities of individual organisms are limited just as the qualities of populations and ecosystems are (again by both intrinsic and extrinsic factors, INGRAM & MOLNAR, 1990; HAGEN, 1992; TILMAN, 1989). The characteristics and qualities of species are limited by, among other things, a variety of evolutionary processes as well as intrinsic factors. Among species groups, attributes are limited by selective extinction which often involves intrinsic and extrinsic factors operating in concert (ARNOLD & FRISTRUP, 1982; FOWLER & MACMAHON, 1982; GOULD, 1982; STANLEY et al., 1983; LEVINTON, 1988). There are limits to diversity (HUTCHINSON, 1972; INGRAM & MOLNAR, 1990).

Other factors that are subject to limits include range size (PAGEL et al., 1991; STANLEY, 1989; GASTON & BLACKBURN, 2000), the total number of species (VALENTINE, 1990) and length of food chains (PIMM & LAWTON, 1977; LEVINTON, 1979; PIMM, 1984; YODZIS, 1984). Variation within and among ecosystems and that of ecological

communities are constrained by the influence of factors such as selective extinction (ALEXANDER & BORGIA, 1978; FOWLER & MACMAHON, 1982; ARNOLD & FRISTRUP, 1982; GOULD, 1982; ELDREDGE, 1985; KITCHELL, 1985; LEVINTON, 1988; HERRERA, 1992; GASTON & BLACKBURN, 2000), including limitations on the numbers of species (e.g., the size of the membership of a community as the count of species, ROUGHGARDEN, 1989; GLAZIER, 1987) or species richness (LEVINTON, 1979). The numbers of species consumed by a consumer and the number of consumers that consume a particular prey species are constrained (MARTINEZ, 1994). The qualities of species involved in communities and ecosystems are limited as exemplified by the small number of species with large body size compared to small-bodied species (FOWLER & MACMAHON, 1982; BROWN & MAURER, 1987). Within communities and ecosystems the number of trophic levels are limited (ROSENZWEIG, 1995). Constraints influence most of the patterns and dynamics of (and within) communities and ecosystems (LEVIN, 1989; PIMM, 1982).

The components of systems are limited, among other things, by the systems of which they are a part. There is a substantial body of literature that presents a helpful interpretation of the collective effects of limiting factors—that is, the limitations resulting from the suite of all factors acting together, regardless of what is being limited. In such work, it is pointed out that the collective effects of complex systems control, constrain or otherwise limit their components (e.g., DYLE, 1988; KOESTLER, 1987; O'NEILL et al., 1986; SALTHER, 1985; WILBER, 1995; MULLER et al., 2000). An example would be the limiting influence of an ecosystem on its component species and their populations (O'NEILL et al., 1986).

Such work adds to the importance of the observation that everything is subject to limits. Everything (everything finite) is part of a more inclusive system which includes all of the factors that contribute to setting limits. Thus, within biological systems, each thing chosen for scientific study will be limited by the more inclusive or collective level of biological organization of which it is a part, along with the non-biological elements and processes of its environment (sometimes referred to as context, appendix 1). This is a matter of scale as noted by AHL & ALLEN (1996) who point out that small-scale entities are limited by the larger scale entities. Much of the literature makes the point more generally: all components of more inclusive systems are limited by the collective influence of the factors to which they are exposed (e.g., BATESON, 1972; ALLEN & STARR, 1982; MAYR, 1982; SALTHER, 1985; O'NEILL et al., 1986; KOESTLER, 1987; BUSS, 1988; ORIAN, 1990; BURNS et al., 1991; MCNEILL, 1993; AHL & ALLEN, 1996; MULLER et al., 2000). And everything finite is a component of some larger system (WILBER, 1995). It must be concluded that everything is subject to limits in its natural variation.

Personal experience emphasizes this fact. Perhaps this is recognized most clearly in observing that humans are limited in what can be known (FOWLER et al., 1999) or what can be conceptualized (MCINTYRE, 1997). Thus, not only are there limits to what can be done and what humans can be, but humans are limited in what can be understood. Knowledge itself is limited. In part, the experience of these limits, along with other limitations, is related to the fact that finite things are, by their very nature, limited. The models used to represent things can not be all inclusive and the results of exercises based on models are thereby subject to error; being limited, models are real but not reality, just as maps are not the territory (BATESON, 1972, 1979; models are never the reality they represent). Thus, science is limited. This is experienced in the inability to recombine information from the things that are studied (what might be called the Humpty-Dumpty effect, or syndrome, NIXON & KREMER, 1977; DUNSTAN & JOPE, 1993; REGAL, 1996; HORGAN, 1999). Even more of the limits of science are experienced in the inability to adequately or accurately assign importance to the influence (limiting or otherwise) of each factor made the focus of research (ALLEN & STARR, 1982; BARTHOLOMEW, 1982; ROSENBERG, 1985; SALTHER, 1985; GROSS, 1989; PETERS, 1991; PICKETT et al., 1994).

There is a continued experience of limitations in progression from science (e.g., PETERS, 1991; STANLEY, 1995) to management. As already mentioned, the options for management are limited in that humans cannot control the fact that there will always be unintended consequences to management action. There is no control over other systems to avoid such effects. The tenets of management limit what can be done; they are based on principles that exert a form of natural selection among the options. Humans are limited, as in everything else, in management. It is time to manage with limits in mind.

Utility / practical application

Patterns arise, in part, from the limits to variation resulting from the vast array of inter-relationships among the various elements of nature operating simultaneously. Variation itself, both within, and as a part of pattern, is also a product of this complexity. Everything is subject to the influence of the elements in its environment (context, BATESON, 1972, and extrinsic factors) along with the influence of its components (WILBER, 1995; intrinsic factors). Are these observations of no more than philosophical interest? Many can be easily documented or experienced personally, but of what use are they?

One tenet of management requires that things (e.g., biological systems and processes) be maintained within the normal range of natural variation (tenet 3, appendix 1). There is an

especially important element of responsibility for implementing this element of management with respect to biological systems. Such requirements have long been recognized in human and veterinary medicine. This is now being extended to ecosystems and all of their components, including humans (e.g., CHRISTENSEN et al., 1996; MANGEL et al., 1996; McCORMICK, 1999, appendix 1 and 2). Various panels and groups convened to address the management process (especially at the ecosystem level) have reached the conclusion that this is an essential tenet of management (e.g., NATIONAL MARINE FISHERIES SERVICE ECOSYSTEM PRINCIPLES ADVISORY PANEL, 1998, appendix 2). MOOTE et al. (1994) were clear that ecosystems and natural patterns are the result of limits and that humans have the responsibility to fall within such limits. Managers are responsible for doing what can be done to ensure that ecosystems fall within the normal range of natural variation. However, this conclusion is not restricted to individuals, species, ecosystems or communities. It applies to nature (e.g., combinations of biological systems) in general (e.g., DARWIN, 1953; PICKETT et al., 1992; SALZMAN, 1994; WOOD, 1994; CHRISTENSEN et al., 1996; NATIONAL MARINE FISHERIES SERVICE ECOSYSTEM PRINCIPLES ADVISORY PANEL, 1998). Management should be carried out by doing everything possible to ensure that biological systems fall within their normal range of natural variation. Doing so is at the core of systemic management.

Part of the concept of *normal* involves what is *natural*. Much of the literature on management emphasizes the importance of doing things to maintain or recover natural states regardless of whether it is for individuals, species, communities or ecosystems. Recent literature regarding ecosystems illustrates the progression in the development of this concept from its acceptance at the individual level to its application at higher levels of biological organization (HOLLING & MEFFE, 1996; MANGEL et al., 1996; RAPPORT et al., 1981, 1985; DAVIS & SIMON, 1994; CHRISTENSEN et al., 1996; FOWLER, 1999a, 1999b; FOWLER et al., 1999). The word *intact* is used to refer to systems that are "healthy" or "undamaged" (ANDERSON, 1991). Such concepts are meaningless without frames of reference. Thus, "natural" patterns are often seen as those that fall within the normal limits of variation, not only for physical *structure* but also for natural *processes*. There is need for care here. It is important to be mindful of the fact that it is natural for there to be occasional outliers as examples beyond the normal range of natural variation and when such occasions arise, they are subject to the natural effects of limits (i.e., the natural phenomena that set limits, pose risks, and prevent the occurrence of more such extremes—risks exemplified by death and extinction).

It is also important to account for human influence. There are few if any systems left on the planet that have not been subjected to abnormal human influence and the problem of providing

reference points is growing (DAYTON, 1998). However, all species influence their ecosystems and the other species in such systems. The extent of human influence would not be a particularly large problem if anthropogenic effects were not themselves abnormal as will be seen in the sections ahead. As a result of the extensive human influence it is important to define "normal" and "natural" so as to focus more on situations wherein human influence itself is not abnormal; that is, within the range of natural variation of influences that other species exhibit.

Attempts to apply the concepts of "normal" and "natural" include efforts to return ecosystems to normal states. However, restoration (e.g., ecosystem restoration, JORDAN et al., 1987) cannot be a recovery of the past—a clear hard limit is the irreversibility of time. It is possible to learn from history, and seek guiding information from patterns historically observed, but it is impossible to reconstruct what existed in the past. Change is a permanent part of the processes that cannot be avoided, especially change resulting from action taken in management.

When considering management, it is impossible to escape the concept of *what should be* and hence, the matter of ethics. The material presented here is based on the assumption that the tenets that have been accepted in the literature are, in fact, important. Tenet 3 (appendix 1) emphasizes the importance of acting so as to facilitate any biological system's falling within its normal range of natural variation (whether such a system be a cell, organ, individual, population, species, ecosystem or the biosphere). It is worth pointing out, however, that there are religious elements to the ethic behind this tenet that are of long standing importance (e.g., CLARK, 1989; PONTING, 1991). An in-depth treatment of ethical issues, or their history, is beyond the scope of this paper.

Another tenet of management is that of having measurable goals and objectives; there need to be norms, standards, reference points, guidelines and criteria to go by (tenet 7, appendix 1). These are provided through systemic management: the central tendencies and statistical confidence limits observed in natural variation provide such guidance. They represent options that are optimal in minimizing risk—not just any particular set, but all risks working in concert. These risks and constraints are the entire suite of factors experienced by systems such as cells, species, or individuals in the real world. Thus, the empirically observed central tendencies fall between the upper and lower limits observed for variation subject to the all limiting factors of the real world acting synergistically. Therefore, understanding limits, and taking advantage of the results of their action, provides a great deal to go on in this regard and provides hope of implementing sound management (DARWIN, 1953).

This is the concept behind the medical perception of health when action is taken to

restore body temperature, blood pressure, or body weight that is abnormal. Thus, the normative concept of health can be applied whether to individuals (e.g., in maintaining proper cholesterol or blood sugar levels) or ecosystems (RAPPORT, 1989b; EHRENFELD, 1993; HOLLING & MEFFE, 1996) by implementing the concept of evaluation with regard to normal variation (KING, 1993). Just as processes within individuals (e.g., metabolism, digestion, respiration) are important to management in this regard, so are the processes within the higher levels of biological organization, such as nutrient flow in ecosystems (e.g., HOLLING & MEFFE, 1996). Other ecosystem features that are subject to limited natural variation include numbers of species, trophic structure, energy storage, population variation and total biomass levels.

How are the goals and standards from central tendencies of use? Such information can be used to evaluate both human and non-human systems. What happens if the characteristics of an ecosystem are outside the normal range of natural variation? Direct management of ecosystems is impossible because of the lack of control over ecosystems (EHRENFELD, 1981; MCNEILL, 1989; HOLLING & MEFFE, 1996; MANGEL et al., 1996; COMMITTEE ON ECOSYSTEM MANAGEMENT FOR SUSTAINABLE MARINE FISHERIES, 1999; FRANCIS et al., 1999). That is, management cannot be carried out to avoid many of the effects of attempted control (whether it be control of other individuals, species ecosystems, or the biosphere); many such consequences are unintentional and unpredicted. However, humans do influence ecosystems, as do all species. Both past and present human influence has resulted in ecosystems that exhibit abnormal qualities, but influence is something that every species has. Human influence may be interpreted as a limited form of control over ecosystems, but management can not control the fact that there will be unintended consequences (ROHMAN, 1999) as the side effects of influence. This lack of control is one of the limitations that is experienced in management in general. It is impossible to exert influence and, at the same time, know or control all of the effects. In part, the lack of control stems from being a part of ecosystems—humans are components (and the human species is a component, tenet 9, appendix 1) subject to the collective limits described above (BATESON, 1972; O'NEILL et al., 1986; KOESTLER, 1987; O'NEILL et al., 1986; SALTHER, 1985; WILBER, 1995).

So where do the central tendencies have practical application? How can management use such information in view of the fact that all influences lead to secondary (or other higher order) effects, at least some of which will result in feedback over various scales of time that places (or will place) limits on humans? The 8th tenet of management (appendix 1) is based on the fact that the elements over which there is most control are the human elements, recognizing that even in self control there will be

ramifications in the rest of the systems of which humans are a part. Some of these effects will be desirable from certain points of view, but others will be negative (that is, many of the effects of management action will result in feedback that will have limiting effects on individual humans and our species). All effects would be positive if managers had full control, but it is humanly impossible to control or predict which will be beneficial and which will not (WOOD, 1994). Even taking mitigating action to avoid influences beyond those intended will always have its unintended consequences. There is one remaining alternative. It is the option of exerting self control (*intransitive* or *passive* management in which humans regulate what humans do, MCCORMICK, 1999). To exercise this option *humans* do everything possible so that *humans* fall within the normal range of natural variation, guided by central tendencies.

This is a critical point. What it means to management is: *humans* undertake change to exert influence and exhibit characteristics so as to be a part of biological systems in which *humans* fall within the normal range of natural variation (DARWIN, 1953; OVINGTON, 1975; PICKETT et al., 1992; FUENTES, 1993; MCNEILL, 1993; GRUMBINE, 1994b; MOOTE et al., 1994; SALZMAN, 1994; WOOD, 1994; MANGEL et al., 1996; CLARK, 1989; UHL et al., 2000). As suggested by APOLLONIO (1994), humans have the alternative of mimicking other species. Other species serve as empirical examples of sustainability. Mimicking can be accomplished by ensuring that humans fall within the normal range of natural variation (especially in finding positions near central tendencies as standards of reference, or management guidelines, FOWLER et al., 1999). This amounts to an extension of biomimicry (BENYUS, 1997) to the species level to address not only questions about how to feed ourselves, *but also* how many humans there should there be to feed. Alternatively it can be viewed as parallel to the process of benchmarking in business management (SPENDOLINI, 1992; BOGAN & ENGLISH, 1994; BOXWELL, 1994; CAMP, 1995), with hierarchical options. First, managers can find the advisable constraints on what businesses are and do (as in conventional benchmarking), *and* secondly, managers can address the meta-level question of whether or not any particular business should even exist, and if so at what level they carry out their functions and influence. It is an application of restoration ecology to restore human involvement in nature so as to fall within the normal range of natural variation. Nature has been carrying out a form of adaptive management (HOLLING, 1978; WALTERS & HILBORN, 1978; WALTERS, 1986) over evolutionary time scales so that it is now possible to take advantage of eons of natural experiments with sample sizes involving millions of trials. In short, it is possible to learn from nature (GRUMBINE, 1994b), or learn to live as humans by observing other species, much in line with the philosophy of Thoreau and Muir

(who saw "...sensitive observation of nature as the source of wisdom," NORTON, 1994), or Leopold "who pointed out that wilderness provides a 'base-datum of normality'" (CHRISTENSEN et al., 1996).

The degree to which current forms of management are transitive varies. Terrestrial systems are often more engineered in agricultural practices than are marine systems (however, aquaculture is quite transitive in this regard). Most fisheries are managed by controlling the fishing effort; nevertheless fish populations are transitively driven to predetermined levels to elicit desired productivity without serious or exhaustive consideration of the systemic consequences. No such transitive management has withstood the test of evolutionary time scales and such approaches fail to acknowledge the track record of human failure in similar circumstances in terrestrial settings (e.g., PONTING, 1991).

Regardless of context, however, what is being done in most of current management ignores limits as they apply to humans. Management fails to place humans within the normal range of natural variation in conventional approaches—a fact that is often mentioned in the literature on management and especially in literature critical of conventional management practices (e.g., GADGIL & BERKES, 1991). This point is made repeatedly in work that draws empirical information produced in scientific studies to the attention of society, particularly managers. Shortcomings and failures are most clear with regard to management at the ecosystem level where the need for changes and alternatives are emphasized (e.g., AGEE & JOHNSON, 1988a). However, among scientists, the full importance of limits is not always recognized (GRUBB, 1989). Socially, freedom is often confused with ignoring the laws of nature (JOHNSTON, 1991). PIANKA (1974) sees a generic pattern in human failure to see the wisdom of finding a place ("balance") between upper and lower limits. Many of the world's problems today can be attributed to the lack of this mode of management (WOODWELL, 1990). Continuing to ignore limits is no longer a tenable option (CLARK, 1989; MANGEL et al., 1996; NATIONAL MARINE FISHERIES SERVICE ECOSYSTEM PRINCIPLES ADVISORY PANEL, 1998). It is of paramount importance to find a place for humans within the normal limits of natural variation. As will be seen later in this paper, there are many cases where humans are so far outside the normal range of natural variation that other elements of biological systems have responded to show abnormal variation themselves (CHRISTENSEN et al., 1996). In the end, there is really no choice but that of finding the human place within the limits of the systems of which humans are a part (MCNEILL, 1993). The effects already caused by the cases of human abnormality, or pathology, continue to unfold through delayed consequences. Hopefully these are not so extreme as to preclude otherwise viable options for management. The risks resulting

from past actions are risks that are yet to be faced (OVINGTON, 1975) and the remaining hope is that actions taken now will both avoid further risk as well as reduce risk from past mismanagement. One of the challenges will be to conduct research that provides needed information (ORIAN, 1990; KATES et al., 2001, tenets 5 and 6, appendix 1). This clearly includes demonstration of the central tendencies of natural variation, and displaying them in graphic form (FOWLER & PEREZ, 1999). These central tendencies occur between limits. As maintained by CLARK (1989), one of the main functions of scientific endeavor is the production of information about limits—they bound the central tendencies and present managers with viable options to address one of the main questions of sustainability science (as quoted in the introduction, KATES et al., 2001).

Discussion: systemic management, a move in the right direction

What happens if management follows the guidelines established to avoid the problems created by current approaches? The various tenets of management in appendix 1 have been developed over the last several decades in trying to solve management problems (e.g., CHRISTENSEN et al., 1996; MANGEL et al., 1996; NATIONAL MARINE FISHERIES SERVICE ECOSYSTEM PRINCIPLES ADVISORY PANEL, 1998; UNITED STATES INTERAGENCY ECOSYSTEM MANAGEMENT TASK FORCE, 1995; COMMITTEE ON ECOSYSTEM MANAGEMENT FOR SUSTAINABLE MARINE FISHERIES, 1999; MCCORMICK, 1999). Can management adhere to them? Is it possible to avoid exacerbating problems inherited from past actions while expanding the scope of management? *Is it possible to include ecosystems or the biosphere without giving up on species or individuals as important levels of biological organization to which management applies?* The implementation of systemic management will lead toward accomplishing these objectives (even if there is no guarantee that future problems from the failures of past management can be avoided). It is a form of management that emerges from past practices and draws on the lessons learned from experience. As stated at the outset, it embodies the principles that have emerged from concerted effort to deal with problems that have not been avoided in traditional management. The following sections provide more depth to the definition of systemic management.

There is progress toward systemic management seen in some of the conclusions reached in attempts to develop management at the ecosystem level ("ecosystem management"). One conclusion is particularly important. As reviewed above, it is not possible to manage ecosystems, but, at the same time, it is imperative that ecosystems be taken into account—along with the rest of complexity (especially in managing

human interactions with various biotic systems). It is important that management proceed in ways that apply, not only at the ecosystem level, but also at the levels of individual, species, and the biosphere. Single-species approaches should not be abandoned to focus on ecosystems, or vice versa. How are such multiple goals accomplished by systemic management? How can management deal with the fact that the forces and process of individuals, populations, species, ecosystems and the biosphere are often in opposition (e.g., WILSON & SOBER, 1989; WILLIAMS, 1992)? Highly trained and experienced specialists are often at odds with each other based on conflicting interpretations in conventional management, in part because of the many opposing forces of nature. How does adopting the principle of confining variation to within its normal limits lead to adhering to the tenets of management, one of which requires that such issues be dealt with consistently (e.g., across disciplines)?

Limits to management options

There are limitations on the options for management, consistent with there being limitations on everything. This is seen in the application of the tenets of management. Such limits lead to the elimination of many management options. Applying these limits is a process that helps focus on what is possible and avoids the waste and problems created by trying things that will not work. Within the *full*, or unlimited, suite of options are those that involve controlling non-human species, ecosystems, or the biosphere, as often attempted in the past. Attempts have been made, and more might be undertaken, to directly control these systems without fully considering the effects, especially those that result in risks—particularly to humans, and particularly in the long run. However, it is increasingly clear that these options can no longer be considered (tenet 8, appendix 1 and 2, and as concluded in the literature referred to above) because, in each and every case, there are always uncontrollable side effects that are systemic in nature—some with negative consequences for ourselves (e.g., through the effects on the human environment that result in problems such as emergent diseases, RAPPORT & WHITFORD, 1999, or loss of resources). There are unintended consequences (negative or positive, ROHMAN, 1999) to every management action. They may involve humans directly as participants in various systems, or indirectly through effects on other members of such systems (whether individuals, species, ecosystems). It is impossible to control the fact that such things happen. This leaves only options involving the control of human activities and the regulation of human influence (e.g., fish can not be regulated but commercial fishing can). By taking this approach, management involves finding appropriate levels of influence by humans (complete with all of their ramifications,

positive or negative). Management can, for example, proceed by addressing appropriate levels of biomass consumption, whether from a species or an ecosystem, the numbers of species used as resources, or the extent of habitat to be protected (habitat for which direct influence is prohibited).

Considerable progress has been made in the step outlined in the previous paragraph—progress made by eliminating options, as tempting as they might be, that would be counterproductive, wasteful or impossible. This is an important juncture—that of recognizing what remains as viable management options. Among the remaining possibilities is that of finding sustainable levels of human influence. Human influences on each level of biological organization are things that can be addressed and things that are critically important to be addressed. However, the list of such things is enormous; this again brings managers to a confrontation with the complexity of nature, but all as part of considering complexity in achieving sustainability. Here it appears in regard to the wealth of ways in which humans (and all individuals and species) exert influence or interact with other elements of the human environment. This diversity is only superficially exemplified by measures of such things as how much humans eat, the quantity of fish harvested from a population, volume of CO₂ added to the atmosphere, or the portion of the various habitats that humans occupy in any ecosystem.

Using empirically observed limits

This section returns to the point of addressing how information on variation, and especially information on the limits to variation, is useful. At this point, what might appear esoteric regarding the concept of limits becomes practical through empirically observed limits. How can management make the transition from traditional to systemic?

Every species has a wealth of influences on the other elements of related systems—all consistent with, and emergent from, the complexity of reality. The limits that they experience are those observed. Observed limits include both the characteristics of other species as well as their influences. Thus, what is seen are the things that work, the things that can be done to minimize the risk of failure as exemplified by death or extinction. Other species survive the full range of consequences of such influence, whether on other species, ecosystems or individuals. Managers thus have the full benefit of knowing that the influences of other species, along with all related processes and consequences, have normal ranges of natural variation—limits. There are empirical limits to the variation of such influences because the influence species have on each other and other systems also has limits. In this regard, existing species represent empirical examples of sustainability.

However, some alternatives within the normal

range of natural variation are better than others. These are the various alternatives between the upper and lower limits of natural variation that are emphasized in being represented by a predominance of examples—by their abundance, or frequency of occurrence. For individual organisms this is exemplified by the abundance of people with body temperatures close to 37°C compared to the less frequent occurrence of individuals at either the high or low extremes bounding variation in body temperature. For species, it is the same. Better examples are found in the abundance of species representing a particular measure, especially the cluster of species near the central tendencies of natural variation. Species, as empirical examples of sustainability, represent the successes in nature's multi-level, trial-and-error, game of survival (FOWLER & MACMAHON, 1982; LEVINTON, 1988). Measures of other species reveal probability distributions as naturally occurring Nash equilibria (NASH, 1950) in which the central tendencies change over time and space according to environmental conditions. Nash equilibria are defined in terms of game theory, and, in this case, the games involve players (such as species) which are parts of systems (such as ecosystems) involved in their own games. Things have to work for both the systems and their parts at multiple levels.

Beyond the limits of variation among species, examples are rare because, by definition, risks and limits prevent the occurrence of such species. For example, there are no 100 ton mammals that give birth to one offspring at the end of a 400 year lifetime, that consume only one carnivorous species from the 14th trophic level, and that are confined to arid deserts—they don't exist (FOWLER & MACMAHON, 1982). Likewise, there is so much influence exerted by species that consume all of their resources that their existence is precluded. By confining human species-level influence to within the normal range of natural variation, it is possible to simultaneously avoid risk and achieve sustainability. Decisions to seek the extremes, tacit or overt, are actions bound to lead to increased and unwanted risks. It is impossible to avoid the side effects of any action, but there is emphasis to be placed on the need to avoid the risks that prevent the accumulation of species beyond the normal range of natural variation. It is possible to achieve sustainability as exemplified by empirical examples that have faced the complexity of risks and constraints over various time scales—time scales that include the evolutionary and geological.

Accounting for complexity

How does systemic management account for complexity (tenet 2, appendix 1)? There are three ways in which complexity gets taken into account if humans manage by finding and achieving a

place within the normal range of natural variation (as amplified in the following paragraphs). Two of these are matters of human activity—where managers and scientists do the accounting/considering. The third, and most crucial, is an automatic process central to the guiding information used in systemic management.

The three ways complexity is taken into account are:

1. Addressing variety in management issues/questions, the identification of which is a management responsibility,

2. Making use of correlative relationships, a matter of importance in science for translating information into appropriate guidance, and

3. Using empirical patterns in limited variation as automatic integrations of complexity. All three can involve human interactions with ecosystems (to solve the problem of management at the ecosystem level).

However, it should be noted that it is not "ecosystem management" as *transitive* management wherein managers would manipulate ecosystems to achieve some desired state, but rather *intransitive* management wherein humans fit in sustainably. All three also involve human interactions with the biosphere (to include "biosphere management"—but, again, not as a transitive form of management). All involve species-level variation, and all involve interactions with the various levels of biological organization. The following paragraphs examine how all three are treated in systemic management.

First, complexity is involved in the wide variety of management questions that have to be addressed. It is not just a matter of finding, achieving and maintaining individual sustainability such as appropriate body temperature or blood pressure; it includes sustainability in the species composition of fisheries catches, the amount of CO₂ released to the biosphere, the consumption of biomass from ecosystems, the habitat preserved for other species, the age composition of harvested resources, the numbers of species that humans drive to extinction, the number of prey organisms consumed, and the places where humans live or exploit resources. The relevant questions involve the countless ways in which species interact with other species, their ecosystems, and the biosphere. To account for complexity in this regard, managers are faced with the responsibility of addressing *all* such issues, at least all that they can think of (and it is impossible to think of them all). It is insufficient to simply find a sustainable rate for consuming biomass from a particular resource species. Managing fisheries systemically is not enough; carbon dioxide production must be included. Complexity is involved in the huge variety of issues to be addressed, issues that do not go away. They are also issues that can only be addressed by what humans do; nobody else, and certainly no other species, is going to do the work that only humans can do.

Second, complexity is involved in recognizing that the limits to variability are interrelated (e.g., fig. 1) and function jointly. In nature, things are correlated. Thus, the appropriate limits must be chosen carefully (FOWLER, 1999a; FOWLER et al., 1999) to account for relationships among various measures of biological systems. The frequency and kinds of such relationships have yet to be appreciated but can not be ignored. For example, judging the status of a marine mammal population by using comparisons with bacterial populations is not an option (fig. 1), any more than is an attempt to find a sustainable level of net CO₂ production for humans with information from species capable of photosynthesis. Managers would need to take the physical environment into account in correlative relationships such as these and the relationship between range size and latitude (STEVENS, 1992; GASTON & BLACKBURN, 2000). For example, climate change would be taken into account through correlative relationships in which climate is known to be related to patterns in limited variation relevant to any specific management question (e.g., rate of biomass consumption from a resource species).

Third, as described in earlier sections, complexity is automatically involved in the patterns of variation that provide empirically observed guidance for systemic management. Such patterns are of systemic origin. Complexity is behind the measurable limits and central tendencies involved in the variation inherent to such patterns. These patterns represent an integration of all of the factors important to their origin. Importantly, this integration involves an accounting of these factors in proportion to their relative importance. This third point deserves further consideration even though it is something that happens automatically when empirical information is used in systemic management.

The empirical examples of sustainability embodied by other species are informative because these species have survived an evolutionary history of exposure to all the risks and factors that are to be taken into account. They have survived the multitude of risks that constrain variation, including the risks of extinction. These species, and the patterns of variation they exhibit, are products of complexity. In other words, what is seen in empirical information about natural variation and its limits is the result of the collective influence of all limiting factors, the aggregate of forces that come into play in producing the distributions. Forces or factors that are relatively unimportant are taken into account in proportion to their effects and the weight of their influence in the origin of observed patterns (including the variation of such patterns). If the rotation of the Earth influences biomass consumption (e.g., by determining the amount of daylight), then this factor is included in the empirical variation, *with its limits*, seen in observed rates of biomass consumption. Perhaps of equal importance, such

factors are included in proportion to the strength of their influence; each factor is considered completely objectively relative to the influence of all other factors (i.e., without direct human involvement in the consideration—thus avoiding the risk of misleading human choices based on human values). The same holds true for other factors as well, whether they be the forces of evolution through natural selection, the nature of the carbon/oxygen chemical bond, extinction, the spectral composition of ambient light, the relative abundance of elements in the universe, or the structure and composition of cells.

Thus, this third point is that complexity gets taken into account automatically in systemic management. This happens by virtue of the fact that empirical examples of sustainability show natural variation that is both produced and limited in ways that integrate contributing factors amongst all aspects of complexity. They do so through their exposure to the collective set of factors that make up the context within which they occur and have occurred over geological time scales. This happens in a natural Bayesian-like integration process (FOWLER, 1999a, 1999b; FOWLER et al., 1999). This integration happens in reality, as opposed to through manmade models that cannot capture the full extent of reality (BATESON, 1972). Perhaps of greatest value is the fact that this integration happens in a way that gives proper emphasis or weight to each of the factors involved. This relieves managers of the need to decide whether embryological factors are more or less important than evolutionary factors, or long time scales are more important than short time scales. There is a synthesis of such information that scientists are incapable of achieving, thus overcoming reductionism as one of the limitations of science (ALLEN & STARR, 1982; BARTHOLOMEW, 1982; ROSENBERG, 1985; SALTHER, 1985; GROSS, 1989; PETERS, 1991; PICKETT et al., 1994; STANLEY, 1995) while taking advantage of the strength of this facet of science to find the empirical information about variation that is so critically important to management regarding each specific management question.

It is important here to emphasize the limitations inherent to science because in human culture it is often thought that science is capable of providing answers to all questions. First, it is important to remember that science is merely a methodology—a formula for inquiry that seeks truth, understanding and explanation of the universe in which humans find themselves. Science, by definition, seeks knowledge. The pursuit of knowledge, however, explores components of systems and will, by definition, have limited success in knowing the system itself, especially the full system of reality. Part of this stems from the fact that the whole is always more than the sum of its parts. Part of the limitation stems from each system being part of more inclusive

systems. Bateson (e.g., BATESON, 1972, 1979) spoke of a knowledge and understanding of the greater system as wisdom. It is wisdom that is sought in management rather than merely more knowledge of system components and it is wisdom which science does not, and is not designed to, address. It is the deeper understanding or wisdom that is used in systemic management—where science is a tool for seeing useful information exemplified in the probability distributions that characterize patterns of limited variation.

Thus, it should be emphasized that the automatic aspect of the integration described above works two ways. Empirical information is informative as guidance *and* it accounts for the consequences of management action. The impacts of human actions are part of what is considered. The complexity of these impacts is automatically taken into account because all components of complex systems (e.g., species) have the kinds of effects that humans have, and of the magnitude that humans will have if it is possible to manage to fit within the normal range of natural variation. These impacts include those that generate risk through feedback in proportion to their relative importance. Thus empirical information accounts for complexity both in its informative role (based on the products of complexity) and in its accounting for the effects of human actions (nature in its complexity has experienced such effects over evolutionary time frames).

An overview of systemic management and the nine tenets

Systemic management was introduced above as a form of management that adheres to basic tenets and principles of management that have been established in trying to deal with the inadequacies of conventional approaches. It is important to have a more detailed understanding of what systemic management is, in order for it to be implemented. It is important to understand how it should be carried out to meet the requirements embodied in the tenets of management found in appendix 1. How does it comply with basic principles? The following paragraphs consider the answer to this question in a way that simultaneously emphasizes the interrelated nature of the tenets and principles of management.

Natural systems are internally consistent and fully interconnected; no laws involving the conservation of mass and energy are broken in nature. Thus, empirical examples of sustainability embodied in species and their interactions with their environments are role-models of consistency. In addition to this, humans, as participants in ecosystems and the biosphere, are required to apply information about natural variation in sustainability to all management questions (thus involving both tenets 1 and 2, appendix 1). Therefore, consistency is accomplished in applying

these principles of management by achieving a position for humans within the normal ranges of natural variation, not by choosing a few easy or simple cases, but by doing so broadly. This automatically involves consistency in application, but does so while simultaneously accounting for complexity. This, of course, would be a direct adherence to tenet 3 while also complying with tenet 8 (appendix 1) because managers would be choosing to act only on those issues where there is most control. This form of management would directly place humans into a sustainable role in the systems of which our species is a part (but not just as parts of ecosystems, tenet 9, appendix 1). It would do so by taking action to fall within the normal range of natural variation so as to avoid the risks and constraints reviewed above (tenet 4, appendix 1). Science would be crucial to the production of information on the limits to natural variation (CLARK, 1989, tenets 5 and 6).

There remains the need to meet the requirements of the tenet 7. How is it possible to establish goals, standards of reference, and guidelines? The answer to this question was introduced above in the discussion of central tendencies between upper and lower limits. Figures 2–6 (with relevant information and sources identified in appendix 3) show empirical data regarding variation and its limits (see also FOWLER & PEREZ, 1999; FOWLER et al., 1999; FOWLER, 1999a, 1999b; FOWLER, 2002), and the deviation of humans from the normal ranges of natural variation (with quantitative measures shown in table 2, appendix 3). The goals and objectives for systemic management are found near the central tendencies of frequency distributions (FOWLER & PEREZ, 1999) such as shown in these figures (recognizing that there are imperfections in current data and that systems change; e.g., FOWLER, 1999a; FOWLER et al., 1999). By virtue of their relative numerical abundance, the species in the region of the central tendencies emphasize the forms of sustainability they represent. These figures also emphasize the breadth of application of management that can be used to fit within the normal range of natural variation (FOWLER & PEREZ, 1999).

It should be clear that systemic management is, strictly speaking, neither restricted to being a conventional systems approach to management, nor merely a holistic approach. One distinction between traditional systems approaches and the systemic approach is particularly important. Systems approaches usually focus on a single complex system like a population, ecosystem, family, community or individual that give it, and its components, a form of significance or relevance different from the significance it actually has in nature in relation to other systems, especially those of which it is a part. Thus, systems approaches that exist as precedents lack sufficient consideration of complexity, especially context, which is necessary for a fully developed systems approach to adequately account for hierarchical structure of reality (GRUMBINE, 1994a). Part of

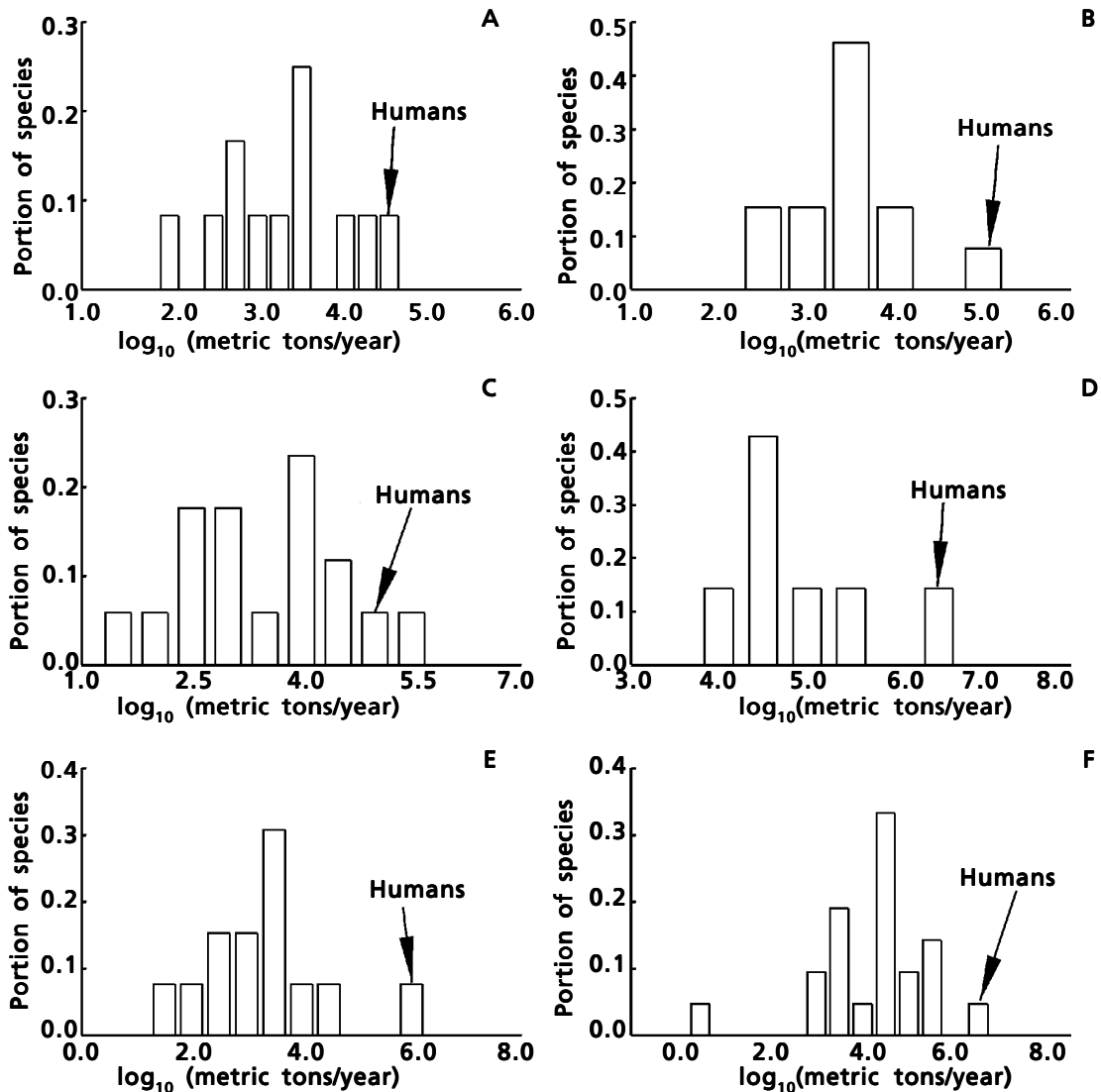


Fig. 2. Six frequency distributions showing a comparison between the rates at which humans consume biomass from individual resource species compared to the rates other species consume the same resource, all measured in units of \log_{10} metric tons per year: A. Eleven species of marine mammals as consumers of hake; B. Twelve species of bird, mammals and fish as consumers of herring; C. Sixteen species of birds, mammals and fish as consumers of mackerel; D. Six species of mammals as consumers of walleye pollock; E. Twelve species of birds as consumers of anchovy; F. Twenty species of birds, mammals and fish as consumers of walleye pollock. Further details are provided in appendix 3 (tables 1 and 2).

Fig. 2. Seis distribuciones de frecuencia en las que se comparan los índices de consumo de biomasa procedente de una especie utilizada como recurso por el hombre y los de otras especies que consumen el mismo recurso, todos medidos en \log_{10} toneladas métricas por año: A. Once especies de mamíferos marinos como consumidores de merluza; B. Doce especies de aves, mamíferos y peces como consumidores de arenques; C. Dieciséis especies de aves, mamíferos y peces como consumidores de caballa; D. Seis especies de mamíferos como consumidores de colín de Alaska; E. Doce especies de aves como consumidores de anchoas; F. Veinte especies de aves, mamíferos y peces como consumidores de colín de Alaska. Para más detalles ver apéndice 3 (tablas 1 y 2).

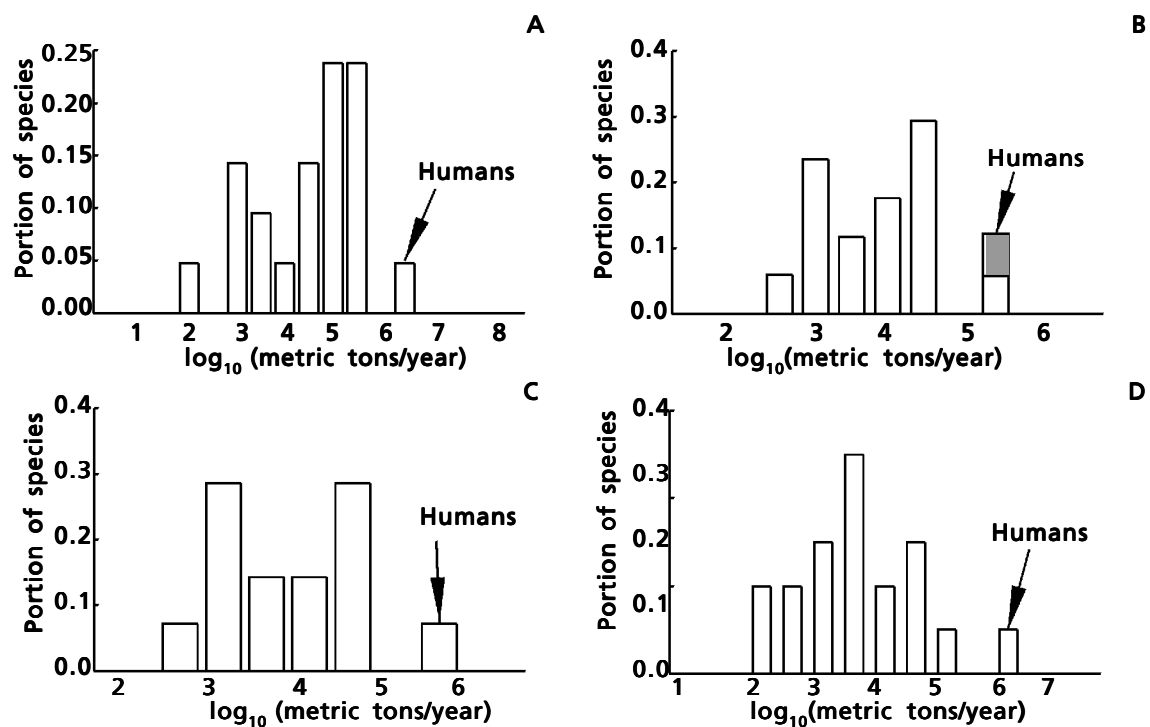


Fig. 3. Four frequency distributions showing a comparison between the rates at which humans consume biomass from various *groups* of resource species compared to that of other consumer species, all measured in units of \log_{10} metric tons per year: A. Twenty species of marine mammals as consumers of finfish; B. Sixteen species of birds, mammals, and fish as consumers of hake, herring and mackerel (with humans in the same bar as dog fish); C. Thirteen species of birds and mammals as consumers of hake, herring and mackerel; D. Eighteen species of birds as consumers of anchovy, lanternfish, lightfish, and hake. Further details are provided in appendix 3 (tables 1 and 2).

Fig. 3. Cuatro distribuciones de frecuencia en las que se comparan los índices de consumo de biomasa de varios grupos de especies utilizadas como recurso por el hombre y por otras especies consumidoras, medidos en \log_{10} toneladas métricas por año: A. Veinte especies de mamíferos marinos consumidores de peces óseos; B. Dieciséis especies de aves, mamíferos y peces, consumidores de merluza, arenques y caballa (con el hombre en la misma franja que la lija); C. Trece especies de aves y mamíferos, consumidores de merluza, arenques y caballa; D. Dieciocho especies de aves, consumidores de anchoas, pez linterna, luciérnaga perlada y merluza. Para más detalles ver apéndice 3 (tablas 1 y 2).

what has to be embraced in management are the more inclusive systems within which the focal systems occur (e.g., the biosphere that contains ecosystems). As such, existing attempts at systems approaches find it difficult to address questions regarding desirable emergent or aggregate qualities of a focal system, or even more difficult questions such as whether or not the system should exist at all. Insufficient importance is attached to the interactions of any particular system with other systems or the physical environment. For biological systems the other systems would include those at the same

level of biological organization, such as individuals interacting with individuals, species interacting with species, or ecosystems interacting with other ecosystems. Of possible greater relevance is the lack of attention given to the interactions between a system and the more inclusive systems of which they are a part. The interactions between a species and its ecosystem would be an example, as would the effects of an individual on its species, or a species on the biosphere. Perhaps of greatest importance is the fact that previous attempts at a systems approach have not accounted for the relative importance

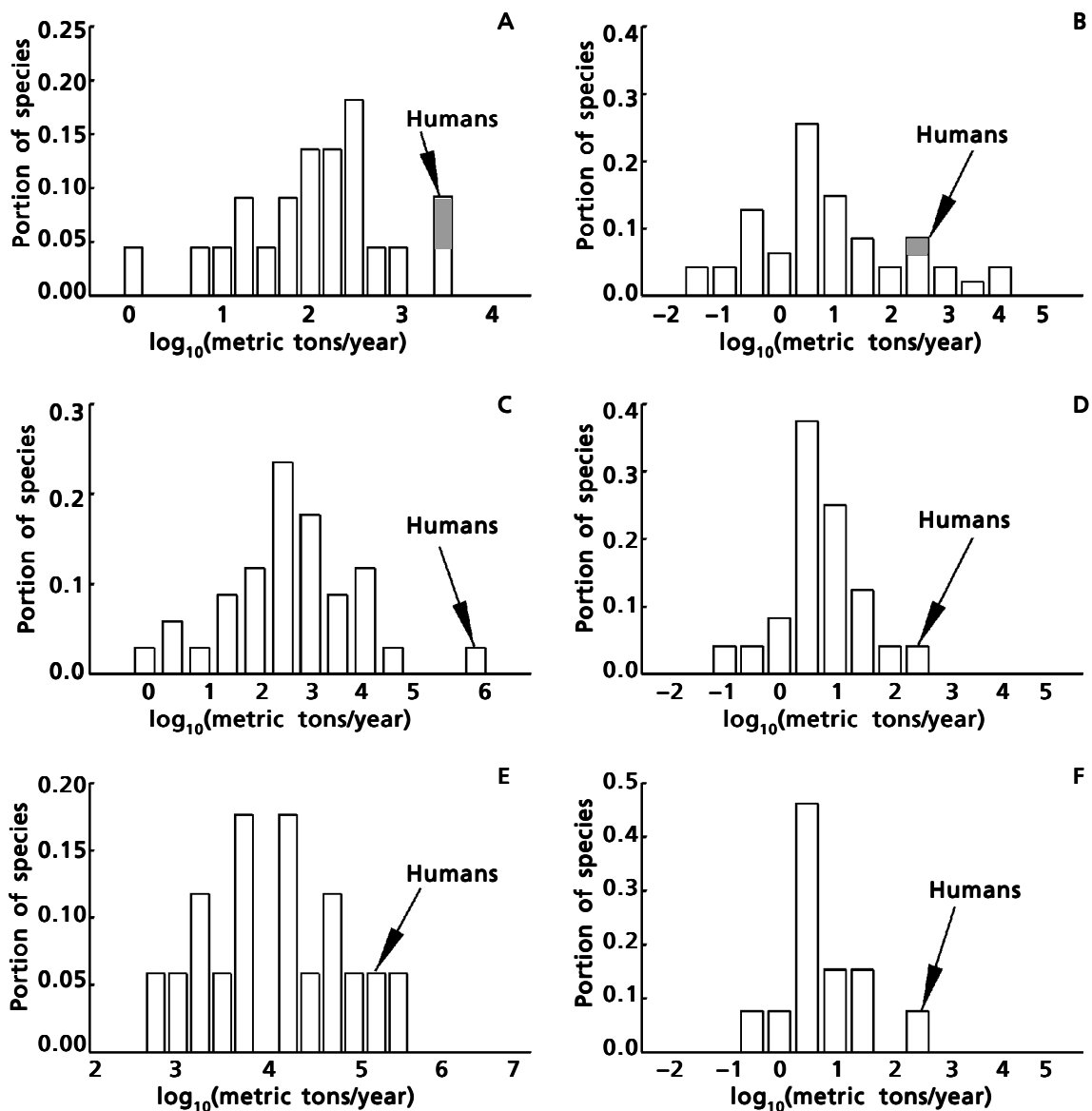


Fig. 4. Six frequency distributions showing a comparison between the rates at which humans consume biomass from various ecosystems compared to that of other species, all measured in units of \log_{10} metric tons per year: A. Twenty-one species of mammals in Eastern Bering Sea (two species, including humans, in the bar representing the highest consumption rates); B. Forty-six species of fish, birds, and mammals from the Georges Bank; C. Thirty-three species of birds off the southwest coast of Africa (with humans sharing one bar with two species of birds); D. Twenty-three species of birds and mammals from the Georges Bank. E. Sixteen species of birds, mammals and fish from the Northwest Atlantic. F. Twelve species of marine mammals from the Georges Bank. Further details are provided in appendix 3 (tables 1 and 2).

Fig. 4. Seis distribuciones de frecuencia en las que se comparan los índices de consumo de biomasa procedente de varios ecosistemas por el hombre y por otras especies, todas las medidas en \log_{10} toneladas métricas por año. A. Veintiuna especies de mamíferos del este del mar de Bering (dos especies, incluido el hombre, en la franja correspondiente a la mayor tasa de consumo); B. Cuarenta y seis especies de peces, aves y mamíferos del banco Georges; C. Treinta y tres especies de aves en el litoral de la costa suroeste de África (con el hombre compartiendo una franja con dos especies de aves); D. Veintitres especies de aves y mamíferos del banco Georges; E. Dieciséis especies de aves, mamíferos y peces del noroeste Atlántico; F. Doce especies de mamíferos marinos del banco Georges. Para más detalles ver apéndice 3 (tablas 1 y 2).

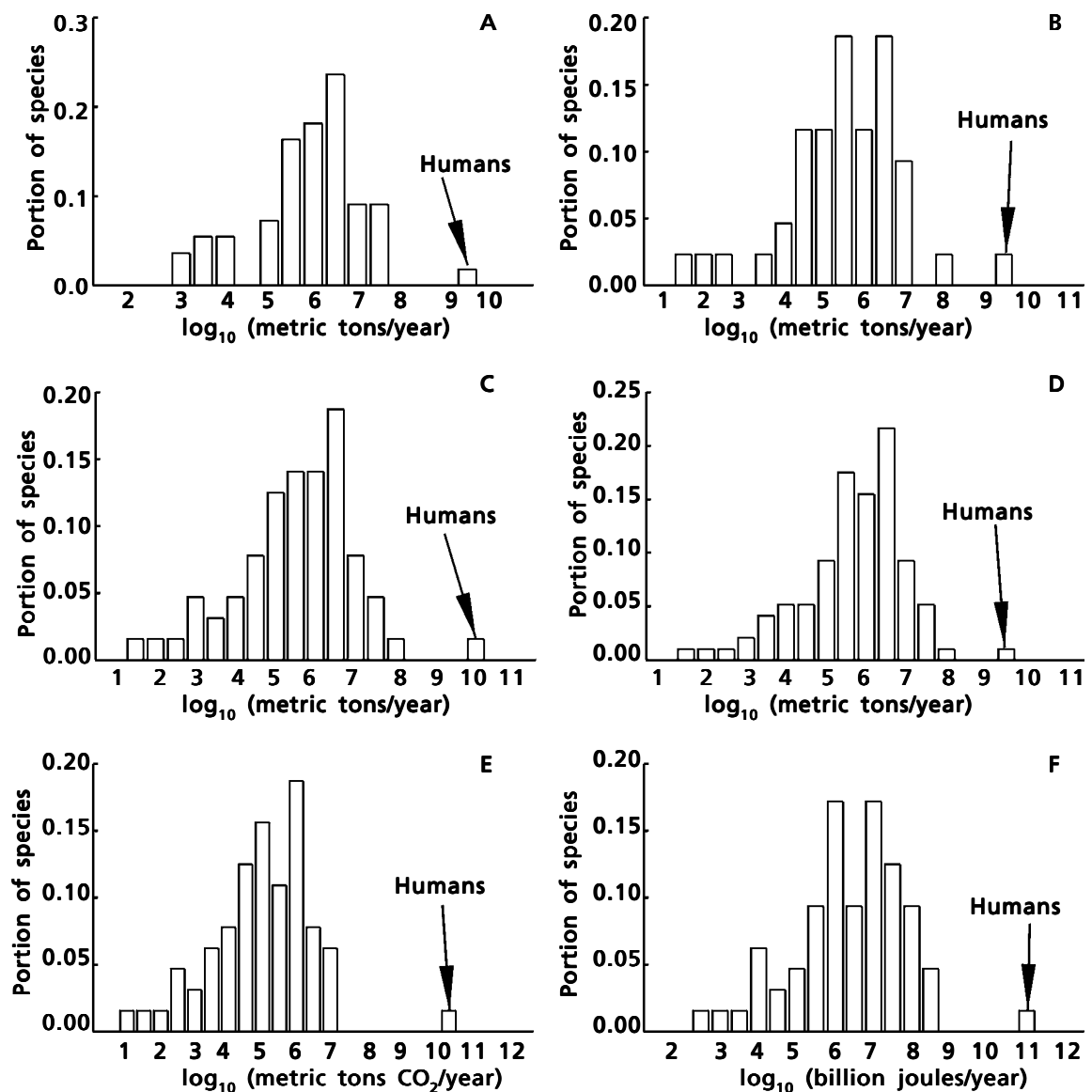


Fig. 5. Six frequency distributions showing a comparison of humans with other species: four in regard to the rate of consumption of biomass (A–D), CO₂ production (E), and energy ingestion (F), with biomass consumption and CO₂ production measured in units of log₁₀ metric tons per year, and energy consumption measured in log₁₀ billion joules per year: A. Fifty-four species of marine mammals as consumers of biomass; B. Forty-two species of terrestrial mammals as consumers of biomass; C. Sixty-three species of mammals of body size similar to humans and as consumers of biomass; D. Ninety-six species of mammals as consumers of biomass; E. Sixty-three species of mammals of human body size as producers of CO₂; F. Sixty-three species of marine mammals of human body size as consumers of energy. Further details are provided in appendix 3 (tables 1 and 2).

Fig. 5. Seis distribuciones de frecuencia en las que se compara el hombre con otras especies: cuatro referidas a la tasa de consumo de biomasa (A–D), producción de CO₂ (E) e ingestión de energía (F), con el consumo de biomasa y la producción de CO₂ medidos en log₁₀ toneladas métricas por año, y el consumo de energía medido en log₁₀ 1.000 millones de julios por año: A. Cincuenta y cuatro especies de mamíferos marinos, consumidores de biomasa; B. Cuarenta y dos especies de mamíferos terrestres, consumidores de biomasa; C. Sesenta y tres especies de mamíferos de tamaño corporal similar al del hombre, consumidores de biomasa; D. Noventa y seis especies de mamíferos, consumidores de biomasa; E. Sesenta y tres especies de mamíferos de tamaño corporal equivalente al del hombre, productores de CO₂; F. Sesenta y tres especies de mamíferos marinos de tamaño corporal equivalente al del hombre, consumidores de energía. Para más detalles ver apéndice 3 (tablas 1 y 2).

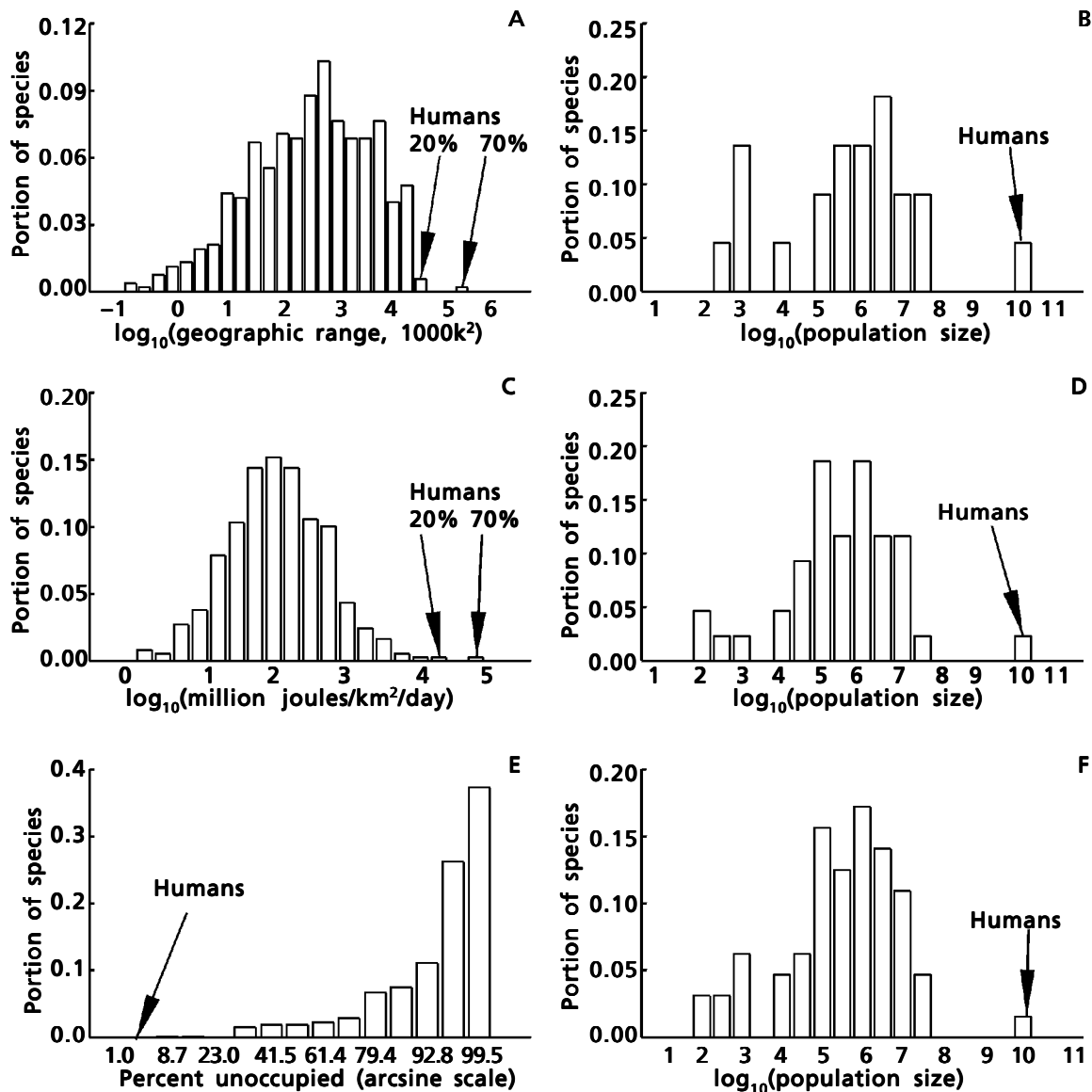


Fig. 6. Six frequency distributions showing a comparison of humans with other species in regard to geographic range size (A, \log_{10} 1,000 k²), population size (B, D, F, \log_{10} numbers), energy consumption per unit area (C, \log_{10} million joules per k² per day), and percent of North America unoccupied (E, arcsine scale): A. Five hundred and twenty-three species of terrestrial mammals and their geographic range, in comparison to humans assumed to use either 20% or 70% of the non-Antarctic land surface area of the Earth; B. Twenty-one species of marine mammals of human body size and their total population size; C. Three hundred sixty-eight species of mammals in their consumption of energy per unit area in comparison to humans assumed to use either 20% or 70% of the non-Antarctic land surface area of the Earth; D. Forty-two species of terrestrial mammals of human body size and their total population size; E. Five hundred twenty-three species of terrestrial mammals with the portion of North America that they leave unoccupied. F. Sixty-three species of mammals of human body size and their total population size—a combination of B, and C. Further details are provided in appendix 3 (tables 1 and 2).

of these categories of interactions. Conventional systems approaches can not assign importance in proportion to the importance realized in nature.

Systemic management builds on the components provided by analogous approaches exemplified by biomimicry (BENYUS, 1997) or benchmarking (SPENDOLINI, 1992; BOGAN & ENGLISH, 1994; BOXWELL, 1994; CAMP, 1995). In addition to asking how to feed ourselves there has to be a way to address the question of how many of humans there should be to feed. In addition to asking how to run a business enterprise, it is necessary to be able to address the matter of whether or not there should be such a business. In the use of tools, it should be possible to ask whether their manufacture, use and disposal have effects that are within the normal range of natural variation. In order to use technology to solve problems, it must be possible to address the effects of such technology (e.g., manufacture, disposal, side effects). Management must apply at various levels of complexity and systemic management accomplishes this task.

Systemic management is an outgrowth of the systems approach and it accounts for the nature of systems, including the limits of human systems. However, the systemic approach (as used here) is based, in part, on the fact that each system is part of a more inclusive system, such that an individual is part of a species, an ecosystem is part of a biosphere and a cell is part of an organism. In addition, systems (e.g., ecosystems, individuals, cells, species) interact with each other. Thus, systemic management is based on the recognition that the limits discussed in the earlier sections of this paper (i.e., the limits of nature or reality on its components) are limits that include those stemming from each system being parts of systems on larger scales. This means that a sustainable population is one that is sustainable by its supporting ecosystems *and* that the ecosystems providing the support to the population are in a state that can sustainably provide the support—balance (dynamic) within limits.

There is another difference between systems approaches and systemic management. The latter is not merely holistic. It is not restricted to considering whole systems (i.e., an ecosystem, or a species) because it is also based on recognition of *intrinsic* limits, and that every system has components. The intrinsic limits are the limits imposed by virtue of systems being made up of components that themselves contribute to limits. That is, systemic management recognizes there are both intrinsic *and* extrinsic factors that come to bear in all cases, and their influences are considered in proportion to their relative effects in nature. Thus, part of sustainability at the population level involves the effects of a population or species on the ecosystems of which it is a part *in combination* with the effects that individuals have from within the population.

Perhaps most importantly, systemic management requires that action and decisions be based on observed limits to natural variation. These include the ways that humans interact with other systems (e.g., consuming resource species, release of CO₂ to the biosphere, or sharing habitat with other species). This is done, while avoiding being confined to focus on any one level or system, while clearly acknowledging the importance of the limits that systems place on their components (e.g., species and the limits that are placed on them by the ecosystems and all of the species of which they are comprised; KOESTLER, 1987; O'NEILL et al., 1986; SALTHER, 1985; WILBER, 1995). Finding what can effectively be controlled and acquiring information to guide control may be challenging, but gathering such information is a crucial scientific exercise in management (CLARK, 1989). Scientists cannot control things to make management happen at the species level (and higher levels) but can, and must, be part of the process, especially by discovering, observing and measuring limits, then contributing the resulting information for use in guiding management (e.g., FOWLER & PEREZ, 1999). Many forms of conven-

Fig. 6. Seis distribuciones de frecuencia en las que se compara el hombre con otras especies en relación con el tamaño de área de distribución geográfica (A, \log_{10} 1.000 k²), tamaño de población (B, D, F, números en \log_{10}), consumo de energía por unidad de superficie (C, \log_{10} millón de julios por k² y día) y porcentaje de América del Norte no ocupada (E, escala en arcoseno): A. Quinientas veintitrés especies de mamíferos terrestres y su distribución geográfica comparadas con el hombre suponiendo el uso del 20% o el 70% de la superficie no Antártica de la Tierra; B. Veintiuna especies de mamíferos marinos de tamaño corporal equivalente al del hombre y el tamaño total de su población; C. Trescientas sesenta y ocho especies de mamíferos y su consumo de energía por unidad de superficie en comparación con el hombre suponiendo el uso del 20% o el 70% de la superficie terrestre no Antártica; D. Cuarenta y dos especies de mamíferos terrestres de tamaño corporal equivalente al del hombre y el tamaño total de su población; E. Quinientas veintitrés especies de mamíferos terrestres con la porción de América del Norte no ocupada por ellos; F. Sesenta y tres especies de mamíferos de tamaño corporal equivalente al humano y el tamaño total de su población —es una combinación de B y C. Para más detalles ver apéndice 3 (tablas 1 y 2).

tional management can no longer be used owing to their failure to adhere to one or more of the principles of management and the resulting failures observed as the consequences of such management. The question before managers is: Is it possible to manage to achieve sustainability? It is our species (and the individuals who are members of our species) that must do what is necessary to undertake the needed change. In navigation, knowing where one is and where one wants to be are *both* crucial pieces of information necessary to getting there. The path is then specified by other information. Likewise, the path for change is not specified in systemic management by information confined to establishing the endpoints or objectives. The details of actually undertaking change involve separate questions also to be addressed systemically as further steps in accounting for complexity.

It is now possible to see how the tenets of management laid out in appendix 1 actually define systemic management. These tenets owe some of their origins to efforts to move forward by amplifying upon and solving the problems of conventional practices. However, even though the tenets have been well developed in the literature, they have made little difference in what is actually done in management. Nevertheless, these tenets, provide a basis for doing things differently to achieve a realistic management process. Many of the roots of these tenets can be found in consideration of the inadequacies of past practices. In this regard, systemic management holds promise in that it is different enough to be the change called for by those seeing a need for a completely new approach (CLARK, 1989; SANTOS, 1990; NORTON, 1991; GRUMBINE, 1992; KNIGHT & GEORGE, 1995; COMMITTEE ON ECOSYSTEM MANAGEMENT FOR SUSTAINABLE MARINE FISHERIES, 1999). Systemic management is management through human action to find a sustainable role in the systems of which the human species is a part. It is systemic in that it accounts for complexity, applies broadly, and involves all levels of biological organization. However, to fully account for complexity it *must* be applied broadly *in practice*, not just in concept. It is also systemic in that it requires dealing with the complexity of human systems by achieving change in human behavior, human influence, and human qualities through management. It should be noted that the complexity of this process involves social, economic, political, religious, scientific, and psychological issues—anything but a simple process and one that includes each and every person (CLARK, 1989). Thus, changes required of the human species do not free individuals from their part in the process. Individuals are also parts of natural systems and individual humans are components comprising our species. Individuals, regardless of species, contribute to what such systems (e.g., species) are and, as parts of such systems, are subject to the natural laws involved

in limits and constraints. The daunting nature of this task lends to the personal experience of the challenge of systemic management.

Systemic management has to be applied with regard to every system, emphasizing action where there is most control, especially in making decisions. There are “systems” components of systemic management in a variety of realms (CONN, 1995; O’CONNOR, 1995; O’NEILL, 1999). However, to be truly systemic, it is imperative to go beyond dealing with the internal workings of the respective systems to address questions regarding the interactions of such systems with others—their context. Systemic management emphasizes the responsibility shouldered by individuals, society, and the human species for the consequences experienced from failing to undertake such management all levels (PIANKA, 1974; CLARK, 1989; MOOTE et al., 1994; WILBER, 1995). To consider humans part of ecosystems or the biosphere (tenet 9, appendix 1) it is also necessary to consider humans subject to limits and risks (ROSENZWEIG, 1974).

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Appendix 1. A list of tenets (criteria and principles) that must be met, or adhered to, in management. These tenets define systemic management (e.g., see FOWLER et al. 1999), however, they are extracted from a large body of literature dealing with management, especially in regard to management at the ecosystem level, most published in the last several decades of the 20th century (with references found throughout the text of this paper).

Apéndice 1. Relación de dogmas (criterios y principios) que deben conocerse u observarse en el manejo. Dichos dogmas definen el manejo sistémico (ver FOWLER et al., 1999), aunque se han extraído de una amplia literatura relacionada con el manejo, en especial con el manejo a nivel de ecosistemas, la mayoría publicada en las últimas décadas del siglo XX (las referencias aparecen a lo largo del texto de este trabajo).

1. Any application of management must be consistent with other applications and any form of management must apply simultaneously at the various levels of biological organization. For example, the harvest of biomass from individual resource species can not be in conflict with management of the harvest of biomass from the ecosystems in which the harvested species occur. Similarly, biomass consumption by humans from the biosphere must be guided by principles that are not in conflict with those guiding the harvest of biomass from either an individual resource species or any particular ecosystem.
2. Management action must be based on an approach that accounts for reality in its complexity over the various scales of time, space, and biological organization. The context of environmental factors (e.g., ecological complexity) must be accounted for along with the elements of stochasticity and the diversity of processes, mechanics, and dynamics. The complexes of chemical and physical substances and processes as well as energetic dynamics must be taken into account, along with evolutionary processes at all levels. These factors must be given weight in decision-making that is in proportion to their relative importance and all must be dealt with simultaneously. Furthermore, managers must be able to deal with uncertainty, including what cannot be known.
3. A core principle of management is that of undertaking actions that ensure that processes, relationships, individuals, species and ecosystems are within (or will return to) their respective normal ranges of natural variation as components of the more aggregated levels of biological organization. Included are evolutionary processes, and all those involved in ecosystem dynamics, as well as physiological and embryological processes. Any form of management must apply this principle (appendix 2, and the central theme of this paper).
4. Management must be risk averse and exercise precaution in achieving sustainability. Sustainability is, by definition, not achieved by any form of management that generates risk rather than minimizing it.
5. Management must be information based. Guidance must be available to management in the form of useful information that enables managers to develop meaningful, measurable and reasonable goals and objectives (tenet 7). This information must be based on interdisciplinary approaches involving science (tenet 6) to adhere to the principle behind tenet number 2 above.
6. Management must include science (scientific methods and principles) in research, monitoring and assessment, not only to produce the information that is used for guidance (tenet 5), but also for evaluation of progress in achieving established goals and objectives (tenet 7).
7. There must be clearly defined goals and objectives that are measurable to provide quantitative evaluation of problems to be solved and gauge progress in solving them. There must be guidelines, criteria, and standards of reference.
8. It must be recognized that control over other species and ecosystems is impossible. The only option for control is the control of human action (CHRISTENSEN et al., 1996; MANGEL et al., 1996; HOLLING & MEFFE, 1996). For example, it is possible to control fishing effort but not the fish nor the fact that fishing will have its consequences, many of which will be both unintended and undesirable. It is not possible to control resource populations or ecosystems. It is possible to influence any resource population and its ecosystem, but not to control them to avoid indirect changes, side effects, or secondary reactions brought about by our influence. The guidance (tenet 7) needed for management is guidance regarding the level of influence (e.g., harvest rate) that meets the other criteria of this list.
9. Humans must be considered as parts of complex biological systems. Humans must have the option of being components of at least some ecosystems to avoid the unrealistic option of precluding human existence. Humans are not separate from, unaffected by, or free of the limits of the systems of which any species is a part.

Appendix 2. Limits to Natural Variation (including biophysical limits): quotations from the literature.

Apéndice 2. Límites de la variación natural (incluye límites biofísicos): citas de la literatura.

AGEE & JOHNSON (1988a): "...limits and constraints.. [are not a] ...commonly understood concept of ecosystem management..."

AHL & ALLEN (1996): "By being unresponsive, higher levels constrain and thereby impose general limits on the behavior of small-scale entities."

ALEXANDER & BORGIA (1978): "One implication is that while ecological communities may often be significantly affected by differential extinction of species, species are not necessarily likely to have been greatly influenced by differential extinction of populations or demes..."

ALLEN & STARR (1982): "It is sometimes advantageous, however, to view organization not positively as a series of connections, but rather negatively, as a series of constraints. Ordered systems are so, not because of what the components do, but rather because of what they are not allowed to do."

"Thus the large reductionistic ecosystem models may tell something of the how of ecosystems but lose much of the why. They focus on system dynamics rather than rate independent system constraints..."

ANDERSON (1991): "*Intact* suggests that all of the critical ecosystem components are present and structured in such a way that processes function within normal limits...over the long term."

ANGERMEIER & KARR (1994): "[Integrity is] the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region."

APOLLONIO (1994): "[Fisheries] ...must have characteristics comparable to apex predators if the systems are to be manageable, that is, the vessels must emulate the essential characteristics of K-selected species."

ARNOLD & FRISTRUP (1982): "Selection at a given level can be opposed, reinforced, or unaffected by processes operating at other levels."

BATESON (1972): "...the steady state and continued existence of complex interactive systems depend upon preventing the maximization of any variable, and that any continued increase in any variable will inevitably result in, and be limited by, irreversible changes in the system." "In principle, the homeostatic controls of biological systems must be activated by variables which are not in themselves harmful."

BROWN (1995): "...morphology, physiology, and behavior of individual organisms play major roles in causing, or at least constraining, large-scale patterns of distribution and abundance, both within and among species." [others have] "...recently developed a statistical method to fit lines to the boundaries of ... two-dimensional scatter plots of data to represent estimates of constraints."

BROWN & MAURER (1987): "Since species of large body size are constrained to have low population densities, such species with small geographical ranges should have high probability of extinction because the total species population is small." "A more interesting example of an apparently absolute constraint is an energetic trade-off between maximum population density and body size."

BURNS et al. (1991): "Existing theories of evolution as a general process of ordered change have come not from biology, but from physics and general systems theory... In addition, a great deal of corroborating evidence is accumulating in the study of chemical reaction systems..., life's origin..., epigenetic systems..., cell evolution... and the biosphere... that there is a common and fundamental description of self-organizing change in far-from-equilibrium systems. What these theories share is a recognition that entities are systems evolving within still larger interactive systems, entities with environments both modified by and constraining their evolution."

BUSS (1988): "*Traits expressed in the higher unit now act as selective agents on the variation arising in the lower unit.* The organization of the higher unit is, however, a function of prior variation in the lower unit. Thus, the lower unit can influence the replication of the higher unit by modification of its organization to suit the lower unit, but only to the extent that replication of the lower unit does not disadvantage the higher unit in its interaction with

the external environment." "The external environment will act solely on the higher unit *only* if the lower unit is physically contained within the higher unit, as in the case of genes within cells or cells within multi-cellular organisms. When the lower unit is not physically enclosed within the higher unit, e.g., organisms within species, the external environment may actively select *both* units." "A second factor, however, is equally important. Variance will also arise which disrupt the higher unit, that is, they will favor the lower unit at the expense of the higher unit. The rate and magnitude of such conflicts must be limited, or the higher unit will perish. If variants arise in the lower unit whose affect is to limit the occurrence or magnitude of subsequent variation, then the higher unit will eventually become resistant to further perturbation."

CHRISTENSEN et al. (1996): "Extreme fluctuation is abnormal in most ecosystems and, when caused by human activity, is what often threatens ecosystem functioning."

CLARK (1989): "Science, by illuminating for us at least some of the complexities of Nature, can provide us with an ultimate *boundary* for our actions. If we perceive how Nature works we can tell when we are threatening its ability to function in a healthy fashion." "Science can only tell us, *if* we decide we want to survive, what the boundary conditions are, what the 'rules of the survival game are', so to speak." "Science is for discovering the limits of the natural world and the laws by which it proceeds and within which we are free to act. This aspect of science can add greatly to the maps and signposts we need to guide us into the future."

DARWIN (1953): "...we certainly can do something to control the world around us, and if we can appreciate the limits of what is possible, we may have some hope..."

EHRENFELD (1993): "So it is with communities in the organismic view. They have recognizable identity, and in the final stage of community embryology, or succession, that identity becomes fixed and normative: a prairie, a beech-sugar maple forest, a desert. Because communities have fixed identifies, because they are normative likes organisms, we can easily apply the normative idea of health to them: if they are functionally and structurally similar to their abstract ideal, they are healthy; if they deviate significantly, they are sick."

FARNWORTH & GOLLEY (1974): "Both plant and animal pests challenged the progenitors of domesticated species long before the invention of agriculture, but counter selection pressures constrained their populations within the long term carrying capacity of their environments and regulated the virulence of pathogens at moderate levels that would preserve the hosts."

FISHER (1986): "Thus, on average, the most conspicuous, sustained trends will be in the direction of least morphological constraints."

FRANCIS et al. (1999): [Ecosystem Management should:] "Strive to retain critical types and ranges of natural variation in ecosystem. That is, management should facilitate existing processes and variabilities rather than changing and controlling them."

FUENTES (1993): "...we should concentrate on defining the borders of a sustainability space..."

GOODLAND (1995): "Humanity must learn to live within the limitations of the biophysical environment."

GLAZIER (1987): "The present hypothesis represents a modified version of a model used to explain correlations between species diversity and productivity among ecological communities... According to this modified model, an increase in energy availability and/or a decrease in energy demand permits more congeneric species to subdivide the energy supply of a given generic niche such that each species still obtains a sufficient portion to maintain a population size having a low probability of extinction. This model assumes that evolution tends to produce increasingly specialized species (i.e., those having a narrower range of resources), because they are more efficient at using resources than generalized species."

GRIME (1989): "These appear to reflect fundamental constraints of habitat and organism which channel evolution into predictable paths. A current challenge is to assess the extent to which recognition of these patterns provides the essential clues to community and ecosystem structure."

GRUBB (1989): "It seems that increasingly practitioners write explicitly that optimization is constrained by the available genetic material. However, I seriously doubt whether that point is sufficiently emphasized to beginning students."

GRUMBINE (1994b): "...our purpose in protecting wildness is not to preserve nature or to improve it, but rather to learn a sense of limits from it and to model culture after it."

HAGEN (1992): "[Odum] stressed the homeostatic nature of ecosystems such that they should be expected to have properties... [and] the much stronger claim that all living systems—cells, organisms, populations and ecosystems— share this common self-regulatory property."

HANNON (1992): "We will be required to reduce our GNP per capita and probably our population to comply with this solar constraint. Such a change is unprecedented in recorded world history, except perhaps for Ireland."

HOLLING (1966): "Those organisms, those communities that lacked the mechanisms necessary to permit adaption to major changes cannot survive the many short- and long-term dislocations of the environment that occurred long before man appeared. These mechanisms are homeostatic or feedback processes that tend to resist change and promoted stability. Any departure from a norm tends to be opposed, and opposed with increasing vigor as the departure becomes greater and greater. One example is found in the not necessarily controversial idea of density dependence, so familiar to students of population dynamics."

HOLLING & MEFFE (1996): "Natural resource management should strive to retain critical types and ranges of natural variation in ecosystems." "...when the range of natural variation in a system is reduced, the system loses resilience." "That is, management should facilitate existing processes and variabilities rather than changing or controlling them." "...effective natural resource management that promotes long-term system viability must be based on an understanding of the key processes that structure and drive ecosystems, and on acceptance of both the natural ranges of ecosystem variation and the constraints of that variation for long-term success and sustainability."

HYAMS (1976): "It is possible to rearrange the parts within the whole without permanently impairing the balance; but only within certain limits."

INGRAM & MOLNAR (1990): "Overall, nature is not very diverse." "When one looks at the living world, what impresses is the lack of diversity. While there may be a multitude of entities, what is noticeable is their sameness."

JOHNSTON (1991): "...fallacy of equating freedom with "soft" containers."

KING (1993): "Maintenance of an ecosystem integrity implies maintenance of some normal state or norm of operation (e.g., homeostasis or homeorhesis). Measuring or observing ecosystem integrity, or its loss, thus requires observations over sufficient temporal extent to identify and characterize this normalcy. We are prisoners of perspective, and our concept of normal is empirically bound to the scales with which we observe a system. ...concepts of normalcy, constancy, variability, and thus, ecosystem integrity, are only meaningful within bounds set by the scale of observation."

KOESTLER (1987): "...while the canon imposes constraints and controls on the holons activities, it does not exhaust its degrees of freedom... guided by the contingencies of the environment."

LEVIN (1989): "What are the natural patterns and dynamics of ecosystems, how are they regulated, and how robust are they to perturbation?" "We must develop a theory for the response pattern of different ecosystems to stresses. We must develop standards of comparisons among ecosystems, based on the identification of common, functionally important processes and properties. Such understanding can emerge only from theoretical syntheses based on a comprehensive program of microcosm research and experimental manipulation coupled with the retrospective studies."

LEVINTON (1979): "Therefore, the equilibrium species richness is less in unpredictable environments." "...length of food chains may also be limited by population dynamical forces..."

MANGEL et al. (1996): "The goal of conservation should be to secure present and future options by maintaining biological diversity at genetic, species, population and ecosystem levels; as a general rule neither the resource nor other components of the ecosystem should be perturbed beyond natural boundaries of variation"

"The best possible relationship between humans and nature safeguards the viability of all biota and the ecosystems of which they are a part and on which they depend, while allowing human benefit (for present and future generations) through various uses. Conservation thus includes the consumptive and non-consumptive use of resources (management) and the preservation of critical resources so that future options can be kept open and so that normal ecological structure and function may continue. The challenge is to determine the appropriate balance between the health of resources and ecosystems and the health and quality of human life."

"...economic interests are given priority over biological reality and constraints. ...The disparity between economic and ecological time scales presents a great challenge because the economic system responds to change much faster than the ecological system; that is, biological systems are constrained by much slower time scales than economic systems."

"Treating wild living resources as has been done in the past is untenable for the long term. The fundamental relationship between people and the rest of nature needs to be rethought, and policies developed that fully recognize the realities of the biophysical constraints under which humans must function."

- MCCORMICK (1999): "When limits of acceptable change are exceeded, the corrective action most often required is regulation and restoration of human intervention."
- MCNEILL (1993): "We will never escape the ecosystem and the limits of the ecosystem. Whether we like it or not, we are caught in the food chain, eating and being eaten. It is one of the conditions of life."
- MOOTE et al. (1994): "Ecosystem management focuses on the maintenance of an ecosystem's natural flows, structures, and cycles, displacing the traditional emphasis on the protection of such individual elements as popular species or natural features" "Ultimately, we shoulder the responsibility to live within the limits of our environment or to decide not to..."
- NATIONAL MARINE FISHERIES SERVICE ECOSYSTEMS PRINCIPLES ADVISORY PANEL (1998): "Ecosystems have real thresholds and limits which must not be exceeded."
- O'NEILL et al. (1986): "Each level in the hierarchy can be over ridden by the next higher level, and is thereby under the constraint or control of the next higher level. The higher-level control in a sense is pursuing a more general strategy to which the more local strategy of the lower-level controls are subordinated." "The higher level appears as an immovable barrier to the behavior of the lower level. This constraint is a natural consequence of the asymmetry in rate constants." "In the natural world, population growth rate cannot approach its maximum because of limited food, space, predators, and so forth."
- ORIANI (1990): "Ecological theory is currently insufficient to predict when such limits may be reached." "Simple solutions are not possible and should not be sought. However, determining system specific limits is nonetheless vital."
- OVINGTON (1975): "...it is possible that the impact of man can be accommodated within the foreseeable future until the disturbing influence of man can be brought into a more stable and intimate balance with the global environment realities."
- PIANKA (1974): "[Balances] are obvious and incontestable, yet modern man has largely failed to appreciate their relevance to his own existence."
- PICKETT et al. (1992): "If nature is a shifting mosaic or in essentially continuous flux, then some people may be wrong to conclude that whatever societies choose to do in or to the natural world is fine. The question can be stated as, 'If the state of nature is flux, then is any human-generated change okay?' The answer to this question is a resounding 'No!' ... Human-generated changes must be constrained because nature has *functional*, *historical*, and *evolutionary* limits. Nature has a range of ways to be, but there is a limit to those ways, and therefore, human changes must be within those limits."
- PIMENTEL (1966): "To date no one has described all the factors which limit the numbers in any population of a natural community. One factor is clear: no population can increase indefinitely and convert all the food of its environment into itself and its seed. The number of all populations is limited. The mechanisms which regulate and limit populations are numerous and varied, but basically all are density-dependent. The various limiting mechanisms can be classified into four general categories and are listed according to their relative speed of action: (1) interspecific competition, (2) natural enemies (parasites and predators), (3) environmental heterogeneity, (4) genetic feedback mechanisms." "The action of the genetic feedback mechanism leads to regulation of numbers of parasites, predators, herbivores and competitors into the gradual evolution of species toward ecological homeostasis with the community associates..."
- PIMM (1982): "...Constraints on population dynamics, energy flow, and the structural designs of animals explain... [observed patterns]."
- PIMM (1984): "The causes of the short food chains, so frequently observed in the real world, are far from certain. There are four hypotheses: energetic constraints, size or design restrictions, a balance between evolutionary tendencies to lengthen and shorten chains, and dynamical constraints."
- PIPER (1993): "A major theme running through the book is the conceptual problem between such ecosystem-level phenomena as the apparent balance and homeostasis of nature and such population-level phenomena as competition, randomness, and chaos."
- PONTING (1991): "Other religious traditions in the world did not place humans in such a special and dominant position. Chinese Taoist thought emphasized the idea of a balance of forces within both the individual and society. Both ought to try to live in a balanced and harmonious way with the natural world." "Human history is, at one level, the story of how these limitations have been circumvented and of the consequences for the environment of doing so. Overwhelming the most important departure from basic ecological constraints has been the increase in human numbers far beyond the level that could be supported by natural ecosystems. ...this depended on a number of special attributes stemming from their greatly increased brain size-speech, social cooperation and the development of various technologies..."

- RAPPORT et al. (1981): "Distress would be reflected in abnormal values for vital signs and/or preclinical indicators." "Diagnosis involves pattern recognition, or correlating the abnormal values of signs with ecosystems breakdown syndromes."
- REICHEL et al. (1975): "Ecosystems... all appear to exhibit common properties of persistence and growth." "...all ecosystems have also developed mechanisms for energy storage as an operational basis for maintaining homeostasis."
- ROSENZWEIG (1995): "Perhaps some combination of the thermodynamic hypothesis, the area hypothesis, and the dynamics hypothesis limits the number of trophic levels in all systems."
- ROUGHGARDEN (1989): "The first generation of models traces to Hutchinson's ...conceptualization of the ideas of limited membership."
- SALTHER (1985): "Everything controls its parts and, as a part is controlled by the whole it is a part of." "In it the dynamics of upper and lower levels produce output that can influence the dynamics of the focal level. Lower level constraints, dubbed initiating conditions, will be seen to give rise autonomously to focal level dynamics which exemplify some law(s) of nature, while higher-level constraints, which I propose should be referred to as boundary conditions, regulate the results of focal level dynamics."
- SALZMAN (1994): [We need to] "...agree to abide by the same ecological and evolutionary rules of behavior governing nonhuman species and ecosystems."
- STANLEY et al. (1983): "Species selection may be driven by internal factors, such as traits that endow a particular kind of species with a propensity to speciate, or it may be driven by external agents. The external agents of species selection are ecological limiting factors, the biotic varieties of which are predation (including parasitism), competition, and provision of food or substratum."
- SWIMME & BERRY (1994): "It was a moment when the human was able to establish its species identity with new clarity, an achievement that had it admirable but also its dangerous aspects since this clarity of species identity tended toward isolating the human within itself over against the nonhuman components of the larger Earth community. Once again we can observe that every perfection imposes limitations."
- TILMAN (1989): "As has long been recognized, the most general constraint comes from the universal requirement of all living organisms for energy and matter. ...Each individual organism exists within a web of consumer-resource relations. Its reproductive rate is constrained by the availabilities of the items it consumes—its resources. Its survivorship is constrained by the organisms that attempt to consume it. The universality of consumer-resource interactions has motivated both theory and experiments..., but has not yet become as central a concept in ecology as its universality demands. ...Conversely, if population ecologists had started in 1916, to seek the causes of the broad, general patterns Clements described, that subdiscipline could have advanced much more quickly. There is much about the evolution of the organismal traits that can be best understood in terms of ecosystem-level constraints, just as there are many ecosystem-level patterns that are best explained in terms of constraints on the evolution of individual organisms. ...In this paper, I have suggested that we should study broad, general patterns. In studying such patterns, we should pursue ecological abstraction by using the simplest possible approach that explicitly includes the most universal constraints of the environment and the unavoidable trade-offs that organisms face in dealing with these constraints. The most universal constraints may come from consumer-resource interactions because all species are, of necessity, parts of food webs."
- UHL et al. (2000): "Live within limits." "Recognize that our natural resources are finite endowments to be used with care and prudence at a rate consonant with their capacity for regeneration." "There are limits to growth and consumption..."
- WOOD (1994): "Respecting limits to land use and acknowledging that we often lack the ability to predict the land's response to management activities are critical points of departure for the ecosystem management concept." "...ecosystem management entails setting limits on the use of the land."
- WOODWELL (1990): "The cause of the disruption is a single species, *Homo sapiens*, which has escaped the normal limitations that keep the numbers of individuals of each species in check and has swarmed over the earth as no species has ever done previously."
- YODZIS (1984): "If there is any property of whole ecosystems that almost every ecologist would regard as universal, it is the limitation of food chains to two or three links for the most part, with food chains having more than five links being rare." "The data are consistent with the hypothesis that food chain lengths are limited by the available energy."

Appendix 3. Empirical data on observed limits to natural variation and the degree to which humans exceed such limits.

Apéndice 3. Datos empíricos sobre límites observados en la variación natural y el grado en que los humanos exceden estos límites.

Table 1. A list of descriptions for the data shown graphically in figures 2–6 with sample sizes for the nonhuman species (units for the measure are indicated in corresponding graphs): F. Figure; N. Number of species; C. Category of species (B. Birds; F. Fish; M. Mammals; MHbs. Mammals of human body size; MM. Marine mammals; MMHbs. Marine mammals of human body size; TM. Terrestrial mammals; TMHbs. Terrestrial mammals of human body size); S. Source (1. FOWLER et al., 1999, 2. OVERHOLTZ et al., 1991; 3. LIVINGSTON, 1993; 4. FOWLER & PEREZ, 1999; 5. CRAWFORD et al., 1991; 6. BACKUS & BOURNE, 1986).

Tabla 1. Lista de descripciones para los datos que se muestran en las figuras 2–6, con indicación del tamaño de las muestras para las especies no humanas (las unidades de medida se indican en los gráficos correspondientes): F. Figura; N. Número de especies; C. Categoría de especies (B. Aves; F. Peces; M. Mamíferos; MHbs. Mamíferos de tamaño corporal similar al humano; MM. Mamíferos marinos; MMHbs. mamíferos marinos de tamaño corporal similar al humano; TM. Mamíferos terrestres; TMHbs. mamíferos terrestres de tamaño corporal similar al humano); S. Fuente (1. FOWLER et al., 1999, 2. OVERHOLTZ et al., 1991; 3. LIVINGSTON, 1993; 4. FOWLER & PEREZ, 1999; 5. CRAWFORD et al., 1991; 6. BACKUS & BOURNE, 1986).

Topic						
F	N	C	Measure	Region / Location	S	
2A	11	B, M & F	Biomass consumption of hake (<i>Merluccius bilinearis</i>)	Marine ecosystem off NE coast of North America	1,2	
2B	12	B, M & F	Biomass consumption of herring (<i>Clupea harengus</i>)	Marine ecosystem off NE coast of North America	1,2	
2C	16	B, M & F	Biomass consumption of mackerel (<i>Scomber scombrus</i>)	Marine ecosystem off NE coast of North America	1,2	
2D	6	MM	Biomass consumption of walleye pollock (<i>Theragra chalcogramma</i>)	Bering Sea and North Pacific ecosystem	1,3,4	
2E	12	B	Biomass consumption of anchovy (<i>Engraulis capensis</i>)	Marine ecosystems off SW coast of Africa	4,5	
2F	20	B, M & F	Biomass consumption of walleye pollock	Eastern Bering Sea and North Pacific	1,3,4	
3A	20	MM	Biomass consumption of finfish	Eastern Bering Sea	4	
3B	16	B, M & F	Biomass consumption of hake, herring, and mackerel	Marine ecosystem off NE coast of North America	2,4	
3C	13	B & M	Biomass consumption from hake, herring, and mackerel	Marine ecosystem off NE coast of North America	2,4	
3D	18	B	Biomass consumption of anchovy, lanternfish, lightfish, and hake (<i>E. capensis</i> , <i>Lampanyctodes hectoris</i> , <i>Maurollicus mulleri</i> , and <i>Merluccius</i> spp.)	Marine ecosystems off SW coast of Africa	4,5	
4A	21	MM	Total biomass consumption	Eastern Bering Sea	4	
4B	46	F, B & M	Total biomass consumption	George Bank ecosystem	6	
4C	33	B	Total biomass consumption	Marine ecosystems off SW coast of Africa	5	
4D	23	B & M	Total biomass consumption	Georges Bank ecosystem	6	
4E	16	B, M & F	Total biomass consumption	Marine ecosystem off NE coast of North America	2	
4F	12	MM	Total biomass consumption	Georges Bank ecosystem	6	
5A	54	MM	Total biomass consumption	Marine environment	4	

Tabla 1. (Cont.)

F	Topic		Measure	Region / Location	S
	N	C			
5B	42	TM	Total biomass consumption	Entire Earth	4
5C	63	MHbs	Total biomass consumption	Entire Earth	4
5D	96	M	Total biomass consumption	Entire Earth	4
5E	63	MHbs	CO ₂ production	Entire Earth	4
5F	63	MHbs	Energy ingestion	Entire Earth	4
6Aa	523	TM	Geographic range (humans at 20% of Earth's non-Antarctic land surface)	Entire Earth	4
6Ab	523	M	Geographic range (humans at 70% of Earth's non-Antarctic land surface)	Entire Earth	4
6B	21	MMHbs	Total Population size	Entire Earth	4
6Ca	368	M	Consumption of energy per unit area (human value based on consumption spread over 20% of the Earth's terrestrial surface)	Entire Earth	4
6Cb	368	M	Consumption of energy per unit area (human value based on consumption spread over 70% of the terrestrial Earth's surface)	Entire Earth	4
6D	42	TMHbs	Total population size	Terrestrial environment	4
6E	523	TM	Portion of North America unoccupied	North America	4
6F	63	MHbs	Total population size	Entire Earth	4

Table 2. 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 (listed for the corresponding graph numbers in table 1, with units shown in the corresponding graphs) and measures of humans expressed as multiples of measures of non-human species (expressed as the antilog of differences between columns): F. Figure; Mean. Geometric mean among non-human species; V. Value for humans; P. Probability of human value, or more extreme; * The measure of humans expressed as a multiple of non-human species is based on the raw values corresponding to the arcsin measures rather than log values.

*Tabla 2. Resultados de las pruebas estadísticas referentes a la hipótesis de que los humanos se encuentran dentro del espectro normal de variación natural entre otras especies para una variedad de medidas (consignadas para los gráficos correspondientes en la tabla 1 y con las unidades indicadas asimismo en los gráficos correspondientes) y medidas de humanos expresadas como múltiplos de las medidas de especies no humanas (expresadas como el antilogaritmo de las diferencias entre columnas): F. Figura; Mean. Media geométrica entre especies no humanas; V. Valor para los humanos; P. Probabilidad del valor humano, o más extremo; * La medida de los humanos expresada como múltiplo de especies no humanas está basada en mayor medida en los valores brutos correspondientes al arcoseno de las medidas que en los valores logarítmicos*

F	Mean	V	P	Confidence limit		Human value as multiple of		
				0.95	0.99	Mean	0.95 limit	0.99 limit
2A	3.068	4.255	0.043	4.209	4.681	15.4	1.1	0.4
2B	3.122	4.929	0.000	3.986	4.344	64.2	8.8	3.8
2C	3.127	4.792	0.055	4.840	5.549	46.2	0.9	0.2
2D	4.360	6.072	0.001	5.278	5.659	51.5	6.2	2.6
2E	2.829	5.681	0.000	4.202	4.770	712.3	30.2	8.1
2F	3.866	6.072	0.028	5.760	6.546	160.7	2.0	0.3
3A	4.170	6.301	0.024	5.949	6.686	135.2	2.2	0.4
3B	3.870	5.218	0.038	5.118	5.635	22.3	1.3	0.4
3C	3.344	5.218	0.006	4.567	5.074	74.8	4.5	1.4
3D	3.209	5.681	0.002	4.575	5.141	296.4	12.8	3.5
4A	1.865	3.301	0.035	3.170	3.711	27.3	1.4	0.4
4B	0.613	2.049	0.137	2.770	3.664	27.3	0.2	0.02
4C	2.294	5.681	0.000	3.964	4.655	2,436.8	52.2	10.6
4D	0.389	2.049	0.005	1.460	1.903	45.7	3.9	1.4
4E	3.870	5.218	0.038	5.118	5.635	22.3	1.3	0.4
4F	0.294	2.049	0.000	1.149	1.502	56.9	8.0	3.5
5A	5.572	9.478	0.001	7.556	8.378	8,066.1	83.6	12.6
5B	5.158	9.478	0.001	7.396	8.323	20,900.6	120.9	14.3
5C	5.222	9.727	0.001	7.538	8.497	31,979.3	154.6	17.0
5D	5.391	9.478	0.001	7.506	8.382	12,234.0	93.9	12.5
5E	4.650	10.301	0.000	6.969	7.930	447,951.9	2,148.8	235.2
5F	6.067	10.572	0.001	8.383	9.342	31,979.3	154.6	17.0
6Aa	2.355	4.318	0.035	4.135	4.873	91.9	1.5	0.3
6Ab	2.355	5.030	0.007	4.135	4.873	473.0	7.8	1.4
6B	5.235	9.761	0.002	7.789	8.848	33,627.9	93.7	8.2
6Ca	1.912	4.719	0.000	2.992	3.440	640.5	53.3	19.0
6Cb	1.912	4.020	0.001	2.992	3.440	128.1	10.7	3.8
6D	5.265	9.761	0.000	7.250	8.072	1,370.3	324.9	48.9
6E*	1.295	0.030	0.000	0.801	0.597	0.0010	0.0017	0.0029
6F	5.196	9.761	0.001	7.483	8.430	36,762.0	190.0	21.4