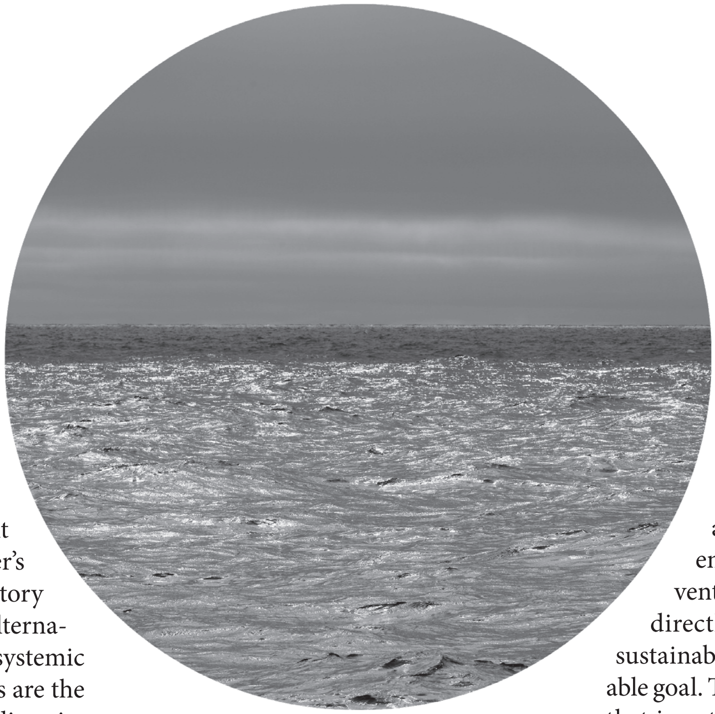
Biodiversity and Evolutionary Empiricism: A Systemic Approach to Fisheries Management

by
Charles W. Fowler



EDITORS' NOTE: Dr. Charles W. Fowler of the Systemic Management Studies Program of the Center's National Marine Mammal Laboratory is a leading proponent of an alternative form of management called "systemic management." Among its objectives are the restoration and preservation of biodiversity that contribute to a healthy biosphere, sustainable ecosystems, and sustainable interactions among all species. Integral to these objectives is a revolutionary management approach that both accounts for the evolved nature of natural systems (based on empirical models) and finds sustainability in the selectivity and intensity of fishery harvests. The following article condenses and highlights a vast literature on systemic management. The opinions expressed in the article are those of Dr. Fowler's and do not necessarily represent those of the agency.

GOALS IN FISHERIES MANAGEMENT include sustainable harvests whether they are from individual resource species, multi-species groups, marine ecosystems, or the world's oceans. Management agencies world-wide face such issues in their responsibility for managing fisheries but are failing in ways that are increasingly evident. Conventional metrics of overfishing indicate that one quarter of the world's fisheries are depleted or overharvested as reported by the Food and Agriculture Organization of the United Nations. The systemic approach to fisheries management takes a holistic view of the issues facing fisheries managers today to include individual species, ecosystems, and the biosphere. Among the products of systemic management is a definition of scientific information that serves the management process much better than the choice of information used today. Information that is best suited for management is defined systemically as the result of research that characterizes, analyzes, and explains patterns that match the management question being addressed. A tight match[1] between empirical pattern and question within this management structure ensures that anthropocentric factors such as economics, emotions, opinions, and politics that have caused problems in conventional management are taken into account as factors that contribute to observed natural patterns. The systemic approach sets goals to avoid the abnormal using empirical models which account for such anthropocentric forces objectively. Management advice based on the analysis of emergent empirical patterns prevents anthropocentric forces from directly influencing policy and makes sustainability a more realistic and attainable goal. This approach achieves objectivity that is not possible in today's management practices.

The systemic approach to fisheries management involves three key elements:

- Goals that are based on avoiding the abnormal.
- Questions that are clear and well defined.
- Patterns, both integrative and emergent, that yield information.

Goals: Successful management requires taking action to avoid abnormal human relationships and interactions with other species, with ecosystems, and with the biosphere. Such relationships include harvesting fish and its effects. In general, such management involves avoiding abnormal, or unsustainable, interactions with the nonhuman. Sustainability is revealed in what we observe to be normal. Conversely, the abnormal or aberrant is not sustainable.

Questions: Successful management requires asking questions that clearly identify the natural patterns that research must de-

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[1] Such matches involve consonance between management question and natural pattern, meaning that they share common units, common circumstances, and common logical typing—there is an isomorphism or congruence between the question and the pattern.

scribe and analyze and clearly specifies the science and information best suited for the task. For example, How many tons of walleye pollock can be sustainably harvested from the eastern Bering Sea each year? The research to address this question focuses on measures of consumption of walleye pollock in the eastern Bering Sea, measured in tons per year. Our harvest is predation by humans; the matching pattern involves predation. No translation or conversion is required.

Patterns: The utility of emergent natural patterns involves their integral nature to account for the complexity of factors involved. Thus, a pattern in the distribution of species within an ecosystem reflects not only the effects of humans (to account for harvesting, pollution, global warming, technology, and past management practices) but also reflects the effects of all factors involving ecological interactions, evolutionary and coevolutionary processes, and the effects of the physical environment, including weather and climate. We humans are integral parts of such systems so that our influence is taken into account.

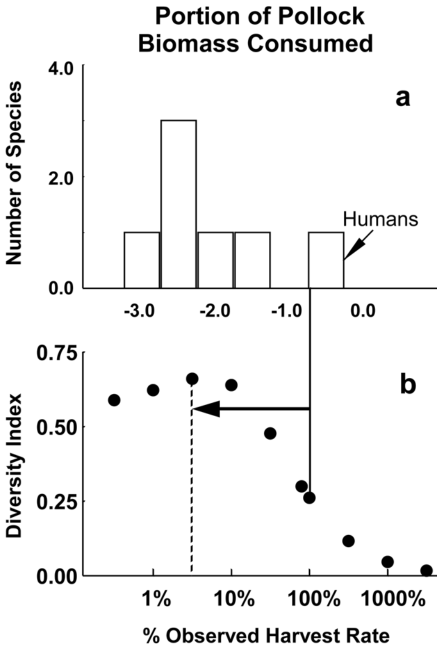

Figure 1. Panel (a) shows the frequency distribution for the portion of the standing stock biomass of walleye pollock in the eastern Bering Sea consumed each year by seven species of mammals (six species of marine mammals and humans through commercial fishing, where the consumption of pollock is shown as $\log_{10}$ transformed estimates) from the early 1980s. Panel (b) shows biodiversity as related to varying levels of commercial harvest, specifically the biodiversity corresponding to observed harvest rates (vertical solid line to the right) and where biodiversity is maximized (at the peak of the curve in panel (b) corresponding to the dashed line to the left). Panel (b) is expressed in relative units such that the observed harvest represents 100%. The arrow indicates the change that would have been necessary to maximize biodiversity (5.9% of the observed harvest rate).

PRESERVING BIODIVERSITY

A primary objective of systemic management is the restoration and preservation of natural biodiversity. In this regard, Figure 1 shows an example of the results of the kind of science involved in systemic management. In this example, an empirical pattern is used for establishing sustainable fishing rates in the harvest of walleye pollock in the eastern Bering Sea—a single-species application. In such applications, we are finding a sustainable (normal) harvest of pollock expressed as a portion of standing stock biomass (assuming that the choice to be one of the species consuming or harvesting pollock is a realistic choice). The pertinent management question is, What portion of the standing stock of walleye pollock in the eastern Bering Sea can we sustainably harvest each year? This question specifies measurements (portion of the standing stock harvested each year) that are in the natural pattern represented in Figure 1—a pattern characterized through research. The pattern involves empirical information for marine mammals in their consumption of this resource species—the pattern shown in Figure 1 where both we and the marine mammals are predatory mammals. Part of the match that is necessary between pattern and question is achieved through using measures of consumption by such species. To maximize biodiversity[2], harvests in the 1980s (when these data apply) would have been reduced from the harvest rates corresponding to the right line connecting panel (a) and panel (b), or harvest rates corresponding to the left line. In other words, using the systemic approach, harvests would have been 5.9% of the harvests observed under the circumstances prevailing at the time these data applied. Research is needed to provide corresponding information for current circumstances.

Purely scientific or academic interest in the system represented by Figure 1 might have been confined to the null hypothesis that commercial fishing does not alter the biodiversity of the pollock ecosystem. Obviously, this hypothesis would be rejected; we do alter the biodiversity of the system. This conclusion, however, merely confirms what we already know: there is human influence in this system as with all such systems. Knowing that we affect biodiversity does not establish a sustainable harvest level. In contrast, finding the harvest rate that maximizes biodiversity fulfills the mission of providing information directly relevant to management in regard to biodiversity. It simultaneously involves a harvest level that is not abnormal in comparison with other species. Research to produce

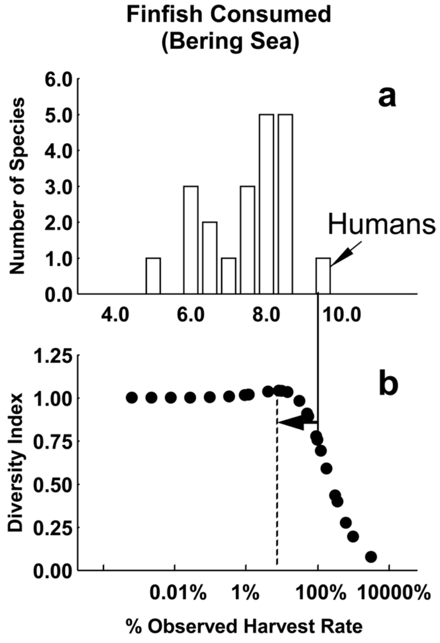

Figure 2. In parallel with Figure 1, panel (a) shows the frequency distribution for the consumption rates of finfish in the eastern Bering Sea consumed each year by 20 species of marine mammals and commercial fisheries (humans) in the early 1980s ($\log_{10}$ kg per year). Panel (b) shows biodiversity as related to varying levels of commercial harvest. As in Figure 1, biodiversity is maximized at the peak of the curve in panel (b) and the corresponding harvest (dashed line) would be 6% of the harvests represented in panel (a), represented by the vertical solid line on the right. The arrow indicates the change necessary to achieve maximized biodiversity.

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[2] Diversity, here, is measured with what is called the Shannon index ($H = -\Sigma p_i \log p_i$) which involves a mathematical combination of the total number of species (N; the summation is over all species for i from 1 to N), the total among the species, and the portion (p_i) of the total contributed by each individual species (i).

information such as that shown in Figure 1 involves the selection of other species to maintain the match between the management question and the pattern that research reveals. These species, and the emergent empirical pattern among them, reflect the information needed in the systemic management of fisheries—the reality behind their emergence.

Single-species applications of the systemic approach to management are a small part of the objective of accounting for complexity. In addition to the species harvested, there are numerous species that are not harvested. Explicit ecosystem-based aspects of management involve asking management questions such as, What portion of the standing stock of walleye pollock in the eastern Bering Sea should not be harvested; that is, how much should be left unharvested to ensure the sustainability of the pollock population itself, the sustainability of other consumer species, and the food webs and coevolutionary webs involved in this ecosystem? Sustainability is a concept that is extended to include the nonhuman. When we ask the question, and find an answer, there is consistency because the answer is also based on the data illustrated in Figure 1. Because the portion harvested and the portion left unharvested sum to 1.0, there is simultaneous consistency. The sustainability of normalcy in harvesting means the sustainability of normalcy in what is not harvested.

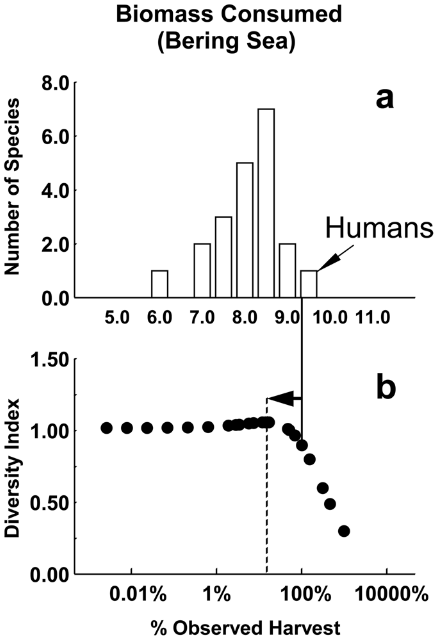

Figure 3. In parallel with Figures 1 and 2, panel (a) shows the frequency distribution for the consumption rates of biomass from the eastern Bering Sea as consumed each year by 21 species of marine mammals and humans (commercial fisheries, in $\log_{10}$ kg per year). Panel (b) shows biodiversity as related to commercial harvests, specifically for the commercial harvest (solid line) represented in panel (a) and the harvest rate that would maximize biodiversity. The latter (dashed line) would be 14.1% of the observed harvest rates shown in panel (a) and achieved by the change represented by the arrow.

How much biomass can we sustainably harvest from the finfish (or any species group) of the eastern Bering Sea (or any other ecosystem)? An example of such a multispecies application of systemic management is shown in Figure 2, again illustrating the results of science best suited to addressing the management question. That is, the pattern represented by the information in Figure 2 is consonant with the question; it involves marine mammals (we are mammals) in their consumption of finfish from the eastern Bering Sea (we are consuming finfish from the eastern Bering Sea). As in Figure 1, biodiversity is maximized at the peak of the curve in panel (b) (and the left dashed line). The maximum of biodiversity is to be compared to observed biodiversity which is depicted at the lower end of the right solid line as it drops from the point representing the harvest rate by commercial fisheries (panel a) to the corresponding biodiversity (panel b). As shown in panel (b), the sustainable harvest of finfish under the systemic approach would have been 6% of the harvests allowed by conventional management at the time and for the circumstances when these data were collected. By harvesting at that rate, a normal amount of finfish biomass is automatically left (not harvested) for the sustainability of the Bering Sea ecosystem.

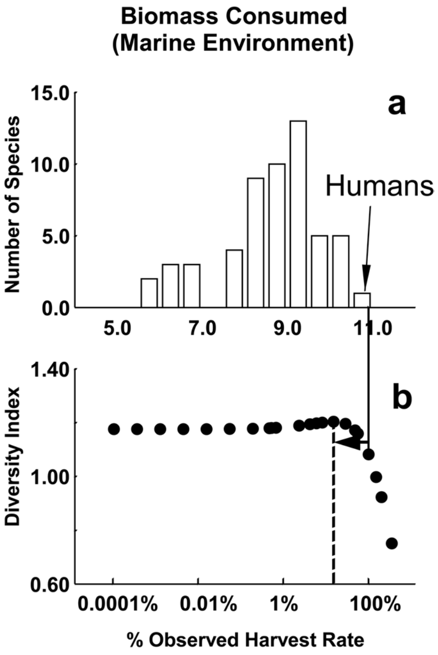

Figure 4. In parallel with Figures 1, 2, and 3, panel (a) shows the frequency distribution for the consumption rates of biomass from the world's oceans as consumed each year by 54 species of marine mammals and humans (commercial fisheries, in $\log_{10}$ kg per year). Panel (b) shows biodiversity as related to varying commercial harvest rates, specifically those for the harvest rates by humans represented by the solid line and the right bar of panel (a), and that which would maximize biodiversity (vertical dashed line on left). The latter represents a harvest that is 15% of observed harvests, a change indicated by the arrow.

Above, we see both single-species and multi-species applications of pattern-based management. Further progress along these lines brings us to ecosystems—all in the mission of dealing with complexity. Now relevant management questions include: How much biomass can sustainably be harvested from the eastern Bering Sea each year? This is another full-scale direct and explicit ecosystem-level management question that can be asked for any ecosystem. Another involves the complementary matter of leaving biomass for the sustainability of other species and their ecosystems with the evolutionary and coevolutionary webs of interactions among those species. How much biomass should be left unharvested to sustain the individuals of all species? How much biomass should be left unharvested for sustainable ecosystem function, properties, coevolutionary interactions and other dynamics? If these kinds of questions are not addressed, we fail to achieve ecosystem-based management. The relevant issues are addressed consistently by using patterns such as the one represented by Figure 3. Here, as in Figures 1 and 2, sustainable harvest rates to maximize biodiversity would have been less than harvest rates observed at the time for which the information applied (in this case, 14.1%).

Moving toward full consideration of hierarchical complexity (individuals within species, species within species groups, species groups and ecosystems within the biosphere) we encounter the management question, How much biomass can we sustainably harvest annually from the world's oceans? Figure 4 shows the information matching this question, again as the kind of information best suited to address the management question (i.e., consumption from the world's oceans, measured in the same units, all for large mammals). As in the previous three graphs, maximized biodiversity would have required a much lower harvest (15% of recent harvests). We could have asked, What portion of the productivity of the world's oceans can be sustainably harvested each year? The complimentary question for full marine systems-based management would be, What portion of the productivity in the world's oceans should be left unharvested for the sustainability of all species, ecosystems and the biosphere? In all cases, there would be consistency in management undertaken to avoid the abnormal in empirical patterns exemplified by Figure 4. Politics, technology, belief systems, economics, past management practices, and other human influences are reflected in the observed pattern. Management to maximize biodiversity accounts for these human influences rather than allowing them to directly influence policy.

The systemic approach to management, to maximize biodiversity, avoids the somewhat arbitrary nature of harvest rates established on the basis of statistical measures of central tendency. Choosing the mean, mode, or median of either raw data or appropriately transformed data involves a subjective choice. The holistic aspect of maximizing biodiversity through systemic fisheries management, based on empirical evidence observed within the biosphere, avoids subjectivity and accomplishes the goal of dealing explicitly with the matter of biodiversity—an issue of serious long-standing concern in conservation and management. The goal of achieving ecosystem-based management is achieved in the application of this approach to individual species, species groups, and ecosystems simultaneously and consistently.

EVOLUTIONARY EMPIRICISM

In recent years, the genetic effects of harvesting fish have been given increasing attention. Scientists around the world are documenting changes in fish growth rates, altered age at maturation, and modified migration time for numerous species. Laboratory studies verify that selectivity alters the phenotypic aspects of these and other components of the life-history strategies of fish. However, such studies merely verify what we should already know: the human species is part of the biosphere and has evolutionary effects on other species and their webs of coevolutionary interactions. Some of these effects may be intentional (e.g., selectively promoting higher growth or reproductive rates) and some are unintentional (e.g., altered age at maturation caused by size selectivity). Studies demonstrating that harvesting affects biodiversity, or has genetic effects, represent good science, but they do not establish or provide estimates of sustainability. They are not measures of selectivity by other species in natural systems and do not show normal selectivity as it occurs among species in their consumption of prey.

Management that explicitly accounts for evolutionary and coevolutionary processes is part of a systemic approach to management. Thus, among the products of the Systemic Management Studies Program are studies that provide management advice regarding the size selectivity of commercial fisheries. As with advice for harvest rates above, such advice does not allow economic, political, or opinion-based influence to interfere in decision making. Such factors, in the ways they have influenced past management, are taken into account a priori through their effects on observed patterns—the patterns used to define what is normal under existing circumstances.

Figure 5 shows an example of data that can be used to mimic nonhuman predators and thereby avoid abnormal selectivity. These data show that the selectivity exhibited in the commercial harvest of Atlantic cod (*Gadus morhua*) was abnormal compared to the consumption of the same species by marine mammals, as revealed in studies of their diets. In this case, our management question is, What should the mean size of fish taken in commercial harvests of cod in the northwest Atlantic be to achieve sustainable selectivity? This adds depth to the question of sustainable harvests, by addressing selectivity in addition to harvest rates, or harvest intensity, covered above. This question defines the pattern to be used in management by specifying selectivity measured in terms of mean size (centemeters). Furthermore, both the ecosystem (northwest Atlantic) and the specific species (cod) are identified—the pattern of Figure 5 matches the question. Harvests with a mean size of 30 cm would match the mean size of fish taken by other mammalian predators and would be more realistic than the mean size in observed harvests.

Management to mimic selectivity in the diets of other mammalian predators is based on both ecosystem and evolutionary dynamics owing to the integral nature of the patterns used. Both ecological and evolutionary factors contribute to the emergence of these patterns and are reflected in the patterns observed. However, we again have the

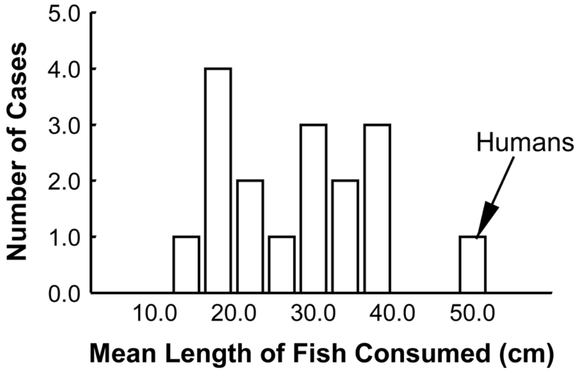

Figure 5. Frequency distribution of the mean size of Atlantic cod in the diets of five species of marine mammals (in 19 studies, 1983-96) compared to the mean size of cod taken by commercial fisheries (humans) prior to their collapse.

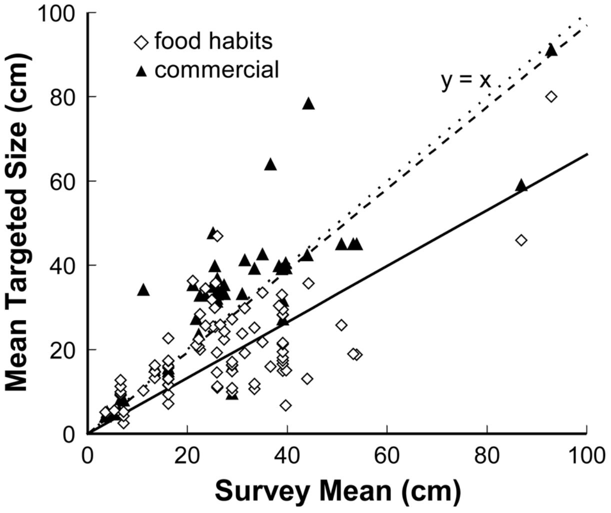

Figure 6. Mean size of individual prey items taken in 85 cases of commercial harvesting and marine mammal food habits as related to the mean size of prey/resource populations (from surveys of commercially valuable fish populations). The solid line represents the linear regression for food-habits means as a function of survey means, and the dashed line represents commercial means. The dotted line represents y = x.

option of extending the single-species application shown in Figure 5 to direct application in the management of harvests from multispecies groups, ecosystems, ocean basins, or the marine environment. If we are harvesting from such multispecies sets, we can ask management questions pertinent to those sets. What should the mean size of our harvests be to achieve sustainability that explicitly accounts for the mean size of fish in the populations of the species being harvested? Current harvests take larger fish in proportion to the maximum size of the fish; is that sustainable? Figure 6 shows the correlation between the mean size of fish in commercial catches and the mean size of fish caught in surveys to assess populations of the resource species (dashed line). Also shown is the mean size of prey taken by marine mammals as a function of the mean size of the prey species (solid line). To be sustainable, on average, the harvest of fish would involve takes with a mean size that is about 60% of the mean size of fish within the resource populations. Across the set of species involved, sustainable harvesting would show a correlation corresponding to that of the solid line in Figure 6.

As in all cases, sustainability trumps other factors in a systemic approach to management; other values such as economics, politics, and opinions are subordinate and are used to ask management questions rather than set management policy. Anthropocentric and anthropogenic factors are behind the differences shown in Figure 6; they are seen in the different slopes between the solid line (representing marine mammals) and the dashed line (representing commercial fishing). These factors are of direct influence in conventional management (i.e., contribute directly to the position of the dashed line) and are indirectly involved in what marine mammals take (and, thus, the position of the solid line). Evolutionary processes contribute to the origin of all patterns, including the pattern depicted in Figure 6, to be taken into account a priori; the application involved in management based on the information in Figure 6 is an explicit consideration of selectivity. Management that achieves normalcy is evolutionarily enlightened.

DISCUSSION

The systemic approach to management completely replaces the decision-making processes of conventional management; it is not a repair of those processes but a replacement of them. Meetings in which people convert relevant data, information, and values (other than that of sustainability) to management decisions or policy are replaced with meetings in which management questions are posed to clearly define the science needed to answer them. These are questions that are confined to what action(s) we (humans) should take in establishing sustainable relationships with the nonhuman. Such questions, in turn, define research to reveal normal or sustainable human interactions with other species, species groups, ecosystems, and the biosphere. Rather than management that manipulates systems to achieve ends based on human values (economic, political, and emotional factors), management to avoid the abnormal revealed by empirical patterns achieves sustainability in each kind of influence to ensure the sustainability of all species. These influences always include interactions that are involved in the manipulative aspects of conventional management. In systemic management, influences of every kind are always treated with information that establishes what is sustainable by revealing what is normal in contrast to what is abnormal.

The reality behind the patterns exemplified above ensures that, when we use these patterns, the complexity of factors involved are taken into account. This reality includes evolution, coevolution, ecological dynamics, risks of extinction, and the influence of the physical environment. It also includes anthropogenic factors and the variety of influences we have had on other species, ecosystems and the biosphere, including historical management practices. Behind our influence and management, of course, are our belief systems and technology. The complexity of factors involved also includes the hierarchical aspects of various levels of biological organization that involve individuals, species, ecosystems, and the biosphere—all involved in the emergence of patterns. This complexity is taken into account indirectly in the contribution of these factors to the origin of the patterns and directly or explicitly if we use such patterns to answer management questions regarding our influence on such systems—always followed by management action to correct any abnormality revealed in the matching natural patterns.

Another way that we account for complexity in systemic management is by asking as many management questions as possible. For example, if populations of sea lions (*Eumetopius jubatus*) and fur seals (*Callorhinus ursinus*) are declining, and there is the slightest potential that pollution is involved in one or the other of these declines, we are faced with a management question such as, What is the sustainable rate of production of estrogenic compounds, in kilograms per year, measured in 17β-estradiol equivalence? A similarly specific question could be posed for any compound that might be contributing to toxic environments for any species for which there is concern that pollution might be a factor—even if that concern is voiced by a single individual stakeholder. After asking the question, the study of natural empirical patterns that match the question can be used to reveal any related human abnormality as a systemic pathology, whether it is within biotic communities, ecosystems, or the biosphere.

Asking questions provides the opportunity for both increasing specificity and developing distinctly new questions. For example, in addition to the harvest rates imposed on resource species, the selectivity of harvests involves many dimensions. What is the appropriate sex ratio (or phenotypic composition with regard to any characteristic) in sustainable harvests of fish? What is the sustainable allocation of harvests across seasons, over alternative resource species, over the different regions of an ecosystem, and in the various depth strata in ocean basins? What portion of the Bering Sea (or any continent, ecosystem, or ocean basin) should be set aside in areas protected from the effects of fishing—where no fishing would be allowed? For the most part, managers fail to ask such questions in conventional management practices. It is nearly impossible to find examples of cases were we have asked good management questions so that they are answered objectively with guidance that is carried through to management action. Human limitations prevent us from asking all possible questions whether in current forms of management or in systemic management. However, in the latter, for the questions we find it possible to ask, consistently objective answers can be provided where funding and resources are made available to conduct research to reveal the matching patterns.

Systemic management treats our (human) species as a part of systems such as ecosystems, affecting and affected by the other components. It treats control over other species and ecosystems as impossible but considers influences to be natural phenomena over which we have at least some managerial control—control of human action to achieve normal interactions with the nonhuman. Complexity is taken into account indirectly in the patterns used to guide action and directly in addressing as many management questions as possible, especially questions specified to treat the detail of circumstances involved. Because the laws of nature cannot be broken, management action based on natural patterns that match management questions is consistent—the tradeoffs are the tradeoffs of nature and include risks that all species encounter in being parts of systems such as ecosystems. Measurable goals for management are provided by information produced by research that characterizes and analyzes patterns that match management questions.

Achieving a full reversal of the burden of proof has been nearly impossible in conventional management. This impasse has prevented setting policy in ways that adequately account for complexity and invites the use of values that prevent objectivity to cause, rather than solve, problems—especially those revealed in abnormality. In systemic management, we are limited only in our ability to ask all management questions—we are confined to asking every conceivable question. For example, if anyone is concerned that global warming is a contributing factor in the decline or redistribution of a population of any species, this concern leads to asking, How much carbon dioxide can we sustainably produce given that we are a mammalian species with our characteristic body size? If carbon dioxide production by our species is abnormal in comparison to other mammalian species of our body size, management to correct that problem is in order—not because the abnormality is, or is not, behind observed population changes but because of all of the impacts the abnormality has, known or unknown. The change we would make involves interconnection with other factors, and the relationships among such factors, to ensure that all associated changes would be consistent; the laws of nature can not be broken. Sustainability is not confined to the human in systemic management; it explicitly includes all systems and their components.

In view of the abnormalities observed in the earth's systems, whether terrestrial, aquatic, or marine, it is clear to many that conventional management is failing. This failure is, in large part, due to a logical or conceptual alchemy in decision-making which uses incorrectly chosen, partial information requiring an illogical conversion. Such decision making involves a misguided use of stakeholder talent; such talent in systemic management instead focuses on asking clear management questions intended to guide science toward the study of matching patterns. These patterns, in turn, are used to find any abnormality in human interactions with other individual organisms, species, ecosystems, and the biosphere. Systemic management to correct these abnormalities is empirically-based and addresses the reality from which the abnormalities emerge.

FURTHER READING

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