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Are We Asking the Right Questions in Science and Management?

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C. W. Fowler and L. Hobbs

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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ABSTRACT

In this paper, we focus on the importance of asking effective questions in both management and the science that serves the management process. Part of this process involves making a clear distinction between management questions and scientific (or research) questions. A closely related component of asking good questions is a clear definition of each kind of question. We emphasize how both the distinction and the definitions are necessary for effectively linking science and management. Questions of both kinds must not only be asked, but they must also be asked as a tightly related pair for each management application. We show how this relationship contributes to the definition of both kinds of questions. The effective pairing of management questions and scientific questions involves a consistency far beyond anything achieved in today's management. Once achieved, the match between the two kinds of questions helps remove barriers experienced between science and management. For years there have been legal requirements to utilize the best available science and information in management. Here, we demonstrate the fulfillment of those legal mandates by clearly defining, and showing how to use, the kind of science and the kind of information that best serve management purposes.

In this paper, we use this perspective to show how the process of management is complete only when the match between questions is extended to include empirical patterns that guide management and management action itself – management to avoid the abnormal to achieve health at all levels of biological organization (holistic or systemic management). We also emphasize the fact that a key element in this process is asking clear, well defined questions at the outset. Asking effective questions relieves the decision-making process in management of human bias, human limitations, politics and values secondary to that of sustainability and systemic health or health that includes individuals, species, ecosystems and the biosphere. Using examples, we show how we currently fail to understand what a good management question is, and thus fail to ask effective research questions, without which we fail to produce information that adequately serves management. The failure to ask good science and management questions is one of the primary factors involved in causing the problems we observe in our environment today (e.g., global pollution, the current extinction crisis, global climate change, overfishing, and oceanic acidification).

CONTENTS

The key to wisdom is knowing all the right questions.
- John A. Simone, Jr.

The job is to ask questions – it always was – and to ask them as inexorably as I can. And to face the absence of precise answers with a certain humility.
-Arthur Miller

The art and science of asking questions is the source of all knowledge.
- Thomas Berger

Effective management always means asking the right question.
-Robert Heller

INTRODUCTION

It is crucial that both scientists and managers recognize and ask their respective questions and ask them well. The failure to recognize the difference between a science and a management question usually leads to ill-advised decisions. Both scientists and managers need to realize the importance of the differences between the two kinds of questions to prevent errors in decision-making. In asking questions, it is important that scientists understand the responsibility of managers in their roles as decision makers and managers must understand the responsibility of scientists in providing information. Both must be involved in asking appropriate questions to lead to research consistent with management needs. Managers who understand the importance of clear management questions contribute to clear and appropriate science questions – leading to science appropriate for management. We are faced with the realization that an understanding of what are clear and appropriate questions for both research and management is of fundamental importance. Not only must we ask the questions, we must ask the right questions – in both science and management. These issues are central to the message of this paper.

We face a plethora of discoveries as well as problems unearthed by science. The discoveries help contribute to the principles upon which management must be based. However, the problems being documented are clearly accumulating and of growing magnitude. We maintain that these problems are the result of a historical failure to ask the right questions, not only in management but in the science used to inform management. Management is a complex process, many parts of which result in failure if any one of them is not executed effectively; asking the right management questions is one such part. We face a major problem: realistic management cannot happen if we do not ask clear, well defined, management questions. As with the other critical parts of management, we are destined to failure if we are not asking the right questions.

Another critical part of management is asking research questions. Asking clear consonant[1] research questions is as crucial to effective management as is the asking of clear well defined management questions. Although the distinction between management questions and research questions is not the only matter of crucial importance, serious problems will persist to the extent that there is confusion in the science/management interface. In this paper, we argue that such confusion is the primary component in the gulf between science and management – a problem that leads to mistakes, mismanagement and most of the problems we face in today's world. It is a problem involving our thinking, habits, and the belief systems brought to conventional management processes.

The essence of the argument we are developing in this paper is that the transfer of useful information between scientists and mangers will continue to result in failure without clearly understanding:

- what a good management question is,
- what a good science (or research) question is,
- how to distinguish the two kinds of questions, and,
- how to effectively link management and science through the clear and precise formulation of the respective questions (i.e., consonance).

We are witnesses to a history of management that has failed to achieve sustainability, failed to adequately conserve resources, and resulted in more problems than are solved. Observations of our environment show disturbing changes. Such changes are documented through observations made by the scientific community in two of their very valid kinds of contributions (observation and documentation). Empirical science has resulted in products that include the documentation of global warming, depleted resources, oceanic acidification, loss of topsoil, an anthropogenic extinction crisis, acid rain, global pollution, and a variety of abnormal genetic effects on species around us (Millennium Ecosystem Assessment 2005). One of the responsibilities of science is to point out problems. Scientists join all stakeholders in bringing problems to the attention of the public, managers and policy-setting officials. However, it is critical that the information produced by science include realistically and objectively useful information so that problems can be solved rather than simply documented. Bringing a problem to the attention of managers places them in a bind if they are not given quantifiable goals and objectives for their actions (Fowler 2003, 2009). Hence, one of the qualities of a good management question is that of having units of measure that can be used to establish and distinguish the normal from the abnormal, to monitor progress, and provide researchers with the metrics to be used in research (e.g., in fisheries management: portion of production consumed annually, tons of biomass consumed each year, portion of harvest made up of females, or portion of harvest made up of any particular phenotype).

[1]Consonance involves the mapping of a management question to: a research question, an empirical pattern, and management action. Patterns, questions and actions that are fully consonant involve completely identical units of measure, are of identical logical type, and are perfectly isomorphic. It involves a one-to-one mapping, or congruence among questions, patterns, and action (Belgrano and Fowler, 2008).

If managers are not asking the right questions, or are not asking questions with enough specificity, science cannot provide useful information. If scientists are producing information that is only tangentially, partially, and vaguely related to the management question, the gulf between science and management is perpetuated. Scientists can provide useful information only if they understand, or are presented with, clear management questions. As will be developed below, a clear understanding of the distinction between science and management questions helps define and then remove the gap between both science and management and between scientists and managers. This happens when we understand how to link the questions asked in management with questions asked in science and, conversely, how to link questions asked in science with questions asked in management; it is a reciprocally consonant process. A clearly framed management question defines the science needed to provide the answer.

One of the qualities of a good management question is that of specifying conditions important to the direct use of relevant information. Measures of body size are not consonant with the management question: *What is the sustainable harvest of walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea?* The management question inherently involves the body size of walleye pollock, but we, the predator, are also involved. Good management questions always involve sustainable human actions as they involve relationships or influences on the nonhuman (the intransitive, Fowler 2003). Inherent to asking what we can do sustainably is our characteristic body size and the fact that we are mammals. Asking a clear management question, therefore, involves refining the above question to: *At what rate can we sustainably harvest walleye pollock in the eastern Bering Sea to account for being a mammalian species of human body size?* Explicit recognition of body size accounts for the well known interrelationships between body size and many life history traits, and ecological interactions (e.g., Peters 1983, Calder 1984). The consonant research question is then: *What are the harvest (consumption) rates of walleye pollock in the eastern Bering Sea by mammalian species of human body size?*

Management questions cannot be confined to finding sustainability in our interactions with other species. It must also include our interaction with, and influence on, ecosystems. The last several decades have seen a variety of efforts to develop a new management paradigm that is ecosystem-based. Part of the motivation for achieving such management is a result of the variety of problems that are observed in today's world. Further motivation is found in the complexity of factors that should be taken into account in decision-making. We are also prompted to move toward different management by the realization that there is a hierarchical organization to nature in which we (the human species) are a part – along with other species. This line of thought extends recognized needs to include ecosystems in management to the need to include various levels of biological organization: from individuals to the biosphere – complexity. What are the questions that lead us to achieving management that accounts for and applies to the various hierarchical levels of biotic organization simultaneously? What are the scientific questions that lead to science that will provide the guidance we need? A number of the questions we pose in this paper, as examples, illustrate the kind of question that needs to be asked: questions about sustainable influence on systems at each hierarchical level.

Achieving effective questions in both science and management depends on a clear distinction between the two endeavors. To most, this distinction is anything but new; and, along with most of what we present is, as Bateson (1979) called it, "…what every school boy knows…". Management involves establishing objectives, making decisions, and taking action. By contrast, science observes, predicts, characterizes, explains, understands, publishes and documents. On the surface, it is clear that science produces information and management uses information. In reality, however, when we look behind the scenes, we begin to encounter serious problems. As currently practiced, there are striking mismatches between information produced scientifically and the information needed in management. The information chosen is used in a way that is woefully inadequate and fails to account for the complexity involved in decision making. It requires conversion to be useful; and the conversion process is vulnerable to human values that completely overshadow any realistic management actions that would both account for the complexity of biological systems, such as ecosystems, and apply to our interactions with such systems. It has become increasingly clear that this conversion precludes ecosystem health.

It is apparent to most that management must be based on good science. However, it remains to be understood that errors are inherent to management based on the conversion of non-consonant scientific information to management action. It is currently taken for granted that our best option is to translate or convert scientific information to management action through the actions and involvement of human institutions (e.g., special scientific committees, teams of industry representatives, and other organizations – including the niche for translational scientists; Brosnan and Groom 2006). It is assumed that we have the skills, knowledge, and power to make such conversions. This 'we' includes scientists, managers, and other stakeholders exemplified by politicians, non-governmental organizations, citizens groups, and native organizations – anyone involved in decision making, policy setting, and action. This misleading 'translation and conversion' of information is exemplified by our use of information about production in attempts to address questions about consumption (harvests) in application of the maximum sustainable yield (MSY) approach to the management of our use of resources (Fowler and Smith 2004, Belgrano and Fowler 2008, Hobbs and Fowler 2008). This approach has not led to ecosystem health or sustainable harvests (Millennium Ecosystem Assessment 2005) and it is easy to argue that it will fail to do so in the future (Fowler 2009). The alternative is to adopt an approach wherein little, if any, conversion is necessary – thus largely removing human constructs (other than the value of sustainability, and our representations of patterns), limitations, and bias from the process (i.e., systemic management, Fowler 2003). As is becoming increasingly clear, in current practice, the conversion of scientific information to guidance for management is subject to errors that mislead management and cause or contribute to the problems we face today.

Is the gap between scientists and managers one of ineffective communication? Wilson (2006) proposes that the errors behind observed problems may involve imperfect communication between scientists and managers. There is always room for improving communication, however such issues are minor in comparison to the main problem before us: communicating (or attempting to communicate) the wrong or misleading information. On the surface, at least, there appears to be little problem in the ability of the two groups to talk to each other and understand the information produced by science. However, in current forms of management, the choice of information to transfer from science to management is not the set of information that management needs. People do not realize that management is asking for, and scientists are providing, misleading information (Fowler and Smith 2004, Belgrano and Fowler 2008). Perfect communication of the wrong information perpetuates such problems rather than solve them.

Thus, rather than communication, the problem being addressed here is the mismatch between the scientific information produced and its use in management – we choose the wrong information. This mismatch results in a gulf between science and management. This gulf can be removed by finding a good match between science and management as defined for each specific management issue. A good match requires consonance among the relevant management and science questions, the pattern used to reveal any human abnormalities, and the management action. With consonance, conversion is unnecessary and there is no need for panels, committees, or other organizations to translate information. Current attempts to convert information (to overcome the mismatch) contribute to the failures we see in today's management. By default, our ignorance, judgment, values, opinions, and faulty logic are made part of the process. Fortunately, this mismatch can be corrected. Solving this problem is a matter of asking clearly defining management questions early in the process so that they lead to clearly defined matching science questions, guidance and action. Although there must be a strict match between a management and corresponding science question, the two must be distinguished. As developed above, and as will be seen below, a key factor involves clearly posing management questions in a way that clearly defines the matching scientific questions. A desirable match between management question and its scientific counterpart involves, among other things, identical units (e.g., grams, tons/year), and contextual circumstances. As is hopefully clear at this point, the two questions must be consonant, isomorphic, and congruent so that conversion/translation is unnecessary in finding good quantifiable goals.

THE PROBLEM IN GREATER DETAIL

What are the specifics of the problem we have introduced above? Consider conventional management in comparison to systemic management (Figure 1) looking first at conventional management. The difficulties of conventional management are nothing new to those with any experience in the way decisions are made today. Bryan Norton's (2005) story of working with the Environmental Protection Agency is nothing out of the ordinary – a confusion of debate, lack of clarity, and administrative chaos. We are familiar with such experiences and recognize the pattern in the flow of the decision-making process in management today as shown in the top row of Figure 1. Typically, in Step 1, a problem, such as the decline in the population of a particular species, is brought to the attention of the world by scientists. If it is an endangered species, legislative mandates emphasize the importance of action – a source of stress, conflict and polarization.

For example, scientists may have conducted studies showing that the population of a particular marine mammal is declining – the mammal's diet includes one or more fish species that the fishing industry maintains are important to them as resources and crucial to their economic well being as well as the economy in general. The recognition of the problem is followed by awareness that something needs to be done, but little effort is put into formulation of a clear management question, especially one that conforms to the overarching tenets and principles of management (Fowler 2003, 2009). Step 2 is given little attention.

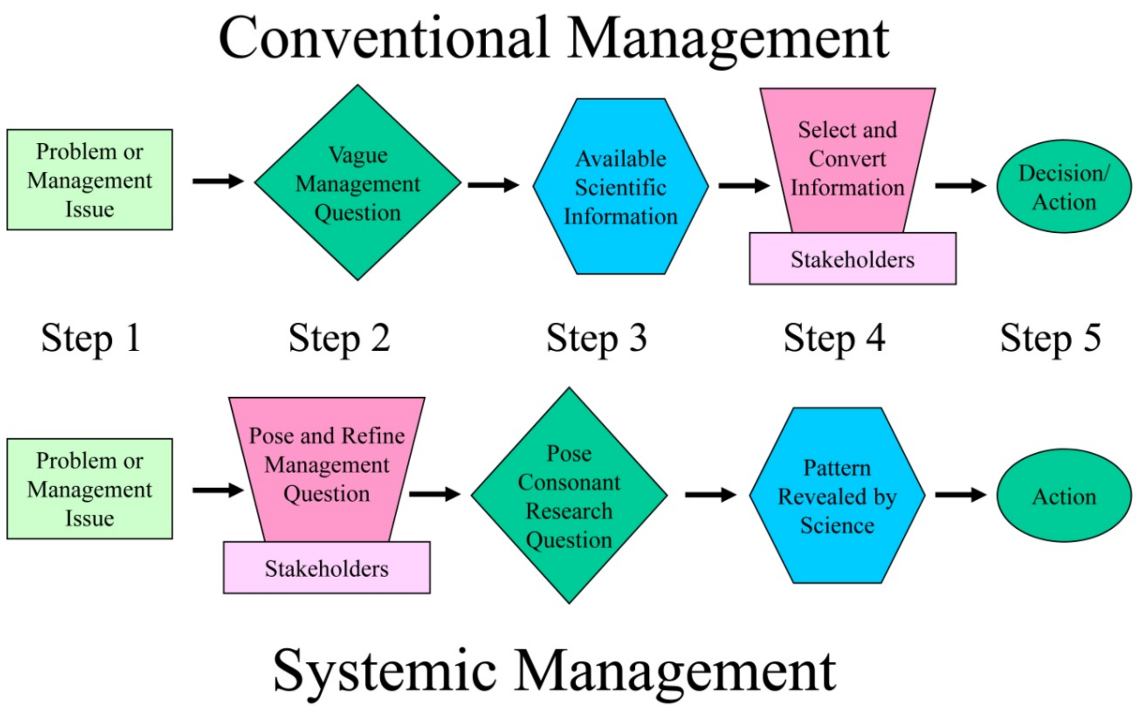

Figure 1. Schematic comparison of conventional and systemic management showing the difference in the role of stakeholders (Belgrano and Fowler 2008).

Step 3 in conventional management involves getting "better" scientific information, reviewing the information in hand, and bringing stakeholders to the task of identifying needed information. In our example of a declining marine mammal population, stock identification is emphasized; dietary studies examine food habits as they relate to fish taken in commercial fisheries, and stock assessments are carried out for both the mammal and its prey species. Isolated elements of the connectivity of the system are the subjects of intense research. Models of the system are constructed. New research is often demanded. Funding for more scientific studies often delays definitive and responsible action. The mass of data that can be brought to bear is synthesized with the best techniques available and its intensity reflects legislation, public interest, and stakeholder concerns. Database managers accumulate data, bibliographies are produced and special panels are formed.

In reaching Step 4, people with vested interests chose data and models that substantiate their position; heated debates frequently follow. In the case of a declining marine mammal population, environmentalists stress the risks of the decline and representatives of the fishing industry stress the economic hardship of reducing commercial harvests. Our value systems play an integral and massive role. These often lead to court battles; politicians enter the fray – often the basis for demanding more research (all too often as a delay tactic that generates funding and political support rather than taking substantive action). All stakeholders work toward a solution that will be mutually acceptable. Economic factors, social factors, belief systems, and human limitations become integral to the process – a process exceedingly vulnerable to human bias (e.g., anthropocentrism). Polarization becomes painfully evident and compromises are worked out with the intention of diplomacy, fairness, and justice.

The actions taken (Step 5, Fig. 1) are based on goals set by human design (Step 4) and are rarely systemic in nature; there is a serious lack of holism. Nobody involved feels that he or she is being malicious; however, some may find malice in the arguments made by others. If not outright malice, such interpretations often lead to strong differences of opinion. In this design, the action, or change, required of stakeholders (through decisions in Step 4 and action taken in Step 5) is often minimized or avoided.

When we reach Step 4, in conventional management, we encounter a critical problem – the fallacy of false equivalence. Goals are based on a conversion of information – a form of logical alchemy. Advice is offered in units derived from measures (information) that are almost always of entirely different kinds from that which a good management question would have demanded (Fowler and Smith 2004, Hobbs and Fowler 2008, Belgrano and Fowler 2008, Fowler 2009). Ecological, behavioral, taxonomic, and even in some cases, evolutionary information is brought to the table. Economic, sociological, industrial, environmental and historical factors are included. Such understanding is taken into account in processes that simultaneously, and without trying, also involve the ignorance of those involved – human ignorance is manifest in the resulting policy. The decline of the marine mammal population produces the uneasy feeling that maybe we should reduce the harvest of fish, but science that measures the harvest of fish by other species (truly systemic and consonant information regarding harvests), if considered at all, are made subsidiary to other considerations. Systemic sustainability is undermined by other, logically inconsistent, human values.

Step 4 is recognized as difficult (but rarely, if ever, recognized as impossible, erroneous, and misleading). Owing to what we perceive as difficult, rather than impossible, we put special emphasis on training specialists to convert our understanding (and ignorance, mixed with bias, human values, and economic factors) to goals for management. This conversion is a matter of alchemy. It converts one thing (or set of things) to another (Belgrano and Fowler 2008); human values and a huge mix of scientific information, are converted to recommendations that, more often than not, lead to little more than a superficial step (e.g., a 10% reduction in the harvest of fish). Scientists and mangers are trained to play the role of alchemists and perceived difficulties result in calls for intensified training (e.g., Brosnan and Groom 2006) in conventional management. Such efforts are all well intentioned – they are aimed at improving what we are doing. However, they perpetuate doing things the way we are doing them, and continue to result in increasing the number and severity of problems instead of solving them. In spite of the continuing failure of this way of management, a different way of doing things has not been an option.

SOLVING THE PROBLEM

Is there an alternative to conventional management?

We believe there is. The second row of Figure 1 shows a different approach. It involves different thinking, and requires what is essentially a complete change in one of the roles of stakeholders. In both the case of conventional management and the case of systemic management, we begin with a recognized problem. Consider again the problem of a declining population of a marine mammal species. Revealing problems is part of good science whether used in conventional or systemic management. Systemic management also ends in the same place; the last step (Step 5) is management action. However, systemic management takes an entirely different path in getting to this last step.

The second step in systemic management (Step 2, bottom row of Fig. 1) involves stakeholders directly. It depends on stakeholders, scientists, managers, and interdisciplinary collaboration; the success of management depends on asking the right question and everyone is involved in the asking of a series of clearly framed, well defined, specific management questions. This is a critical step and is fundamentally different from the practice of conventional management. Continuing with our example, the declining marine mammal population gives rise to emotions, concerns, and the expression of human values. There is no magic that will make such factors disappear; instead of ignoring them, they collectively serve to drive the formulation of clear and useful systemic management questions.

It bears emphasizing that we see, in Step 2 of systemic management, a major distinction between conventional and systemic thinking. The mix of factors misused in Step 4 of conventional management contributes to the commitment to ask and refine good management questions in Step 2 of systemic management. Thus, based on basic principles regarding ecological systems (e.g., knowing that competition and predation involve the interactions of prey and predator populations), we press on to ask management questions. We can start with: *What portion of the biomass produced annually within the ecosystem should* <u>*not*</u> *be harvested so that it is left for the sustainability of the ecosystem and other species, to include the marine mammal with its declining population?* This question meets the criteria for a good management question by addressing how we should limit ourselves, has a quantitative character so that units are defined (portion of biomass production), and involves our interaction with the nonhuman (e.g., ecosystems, other species). To deal with natural complexity, other management questions should be asked to involve the variety of things that may be contributing to the decline in the marine mammal population − things such as pollution (production of toxic substances), and global warming (production of greenhouse gases).

Following the posing of a good management question, Step 3 of systemic management entails formulation of the science question defined by the management question. Scientists are heavily involved here, and other stakeholders (especially managers) participate in ensuring that the science question matches (is consonant with) the management question. Step 4 is carried out primarily by scientists; however, anyone can be involved in seeing patterns and certainly in understanding their integrative nature (integrative to account for the influence of humans along with the similar complexity of other evolutionary and ecological factors). In our example (the question posed in the last paragraph), we have initiated the process, in Step 2, by formulating one of many management questions regarding how much ecosystem production should not be harvested. Going on to Step 3, the consonant research question is: *What portion of the biomass produced annually within the ecosystem is* <u>*not*</u> *consumed (harvested) by nonhuman mammalian species of human body size?* There is consonance between the two questions because we are dealing with the same kinds (categories) of things. Humans and marine mammals are of the same taxa; the specified body size is the same in each case; it involves the same units (portion of biomass produced that is <u>not</u> consumed annually); and, the ecosystem identified is the same in each case.

Following the posing of each research question, research is carried out (Step 4) to provide an answer. In our example, research starts by producing estimates of the consumption rates by nonhuman mammalian species of human body size. Also essential are estimates of the production of biomass by the ecosystem. These data are then combined to estimate the portion of production *not* consumed. The resulting estimates reveal a pattern in which there are limits to the observed variation and the normal and abnormal can be seen and evaluated. This pattern is defined by both the management and the corresponding (matching or consonant) science question. Consonance is carried forward so that the management question, the research question and the pattern are all consonant (no conversion is required). The pattern in our example is the pattern of ecosystem-level biomass production that is *not* consumed by marine mammals of human body size. Such patterns are described and characterized as a normal activity of science; theoretical and academic research emphasize the origins and explanation of such patterns to understand their complexity and integrative nature – general principles.

In systemic management, Step 5 involves everyone. All stakeholders take action to avoid the abnormal or pathological as revealed by the pattern when we compare humans to other species. If the biomass that we do not harvest in current management is abnormal, we have the responsibility of changing that harvest to achieve health and sustainability. This is not sustainability confined to the fishing industry as a short-term or anthropocentric objective; it is sustainability for all elements of the system: fisheries, other species, ecosystems, and the declining species that led to the question at the outset – all in consideration of time scales well beyond those involved in conventional management.

SYSTEMIC MANAGEMENT IN MORE DETAIL

The nature of the preliminary description of systemic management in comparison to conventional management above demands more specificity. All of us involved in the management of use of resources are familiar with the detail of conventional management; we are immersed in it. It is happening all around us and we are a systemic part of it – making change extremely difficult. It is not confined to the treatment of a declining marine mammal population, the spotted owl or the Hayden penstemon (an endangered plant in North America); it involves our treatment of the extinction crisis, global warming, and the host of other problems science has brought to our attention. With the backdrop of a growing list of such problems, more of the detail involved in systemic management is helpful for understanding it advantages. Because readers have their own experiences of conventional management to draw upon, we now turn to more detail regarding the progression of steps involved in systemic management. Because Step 1 is the essentially the same in each case, we begin with Step 2.

Step 2

We return here to Step 2 (bottom row of Fig. 1) to treat the multiplicity of questions and their refinement – parts of the second step in systemic management where stakeholders as a group play a crucial role. Each stakeholder uses his/her values, insight, beliefs, concern, and emotions, to participate in the common goal of asking management questions. All management questions must adhere to the tenets of management (Fowler 2003, 2009). This includes approaching management intransitively to avoid the impossibility[2] of controlling the nonhuman. In our interactions with other species and ecosystems this means asking what we (humans) can do sustainably as normal parts of such systems in our interactions with, and influence on, the nonhuman. When it is suggested that we manipulate, modify, or 'try' to 'control' the nonhuman, we are drawn to question the sustainability of the influence such 'control' involves (e.g., in systemic predator "control" we are led to questions such as: *How many whales [or other predator with which we compete] can we sustainably kill?)*.

Multiple questions: Natural systems are complex and interconnected – one of the general principles developed by science but appreciated by everyone. In addition to making it impossible to control them, the complexity of such systems leads to numerous questions. In Step 2, all scientists, stakeholders, managers, politicians, and other interested parties are involved. In the example initiated above, regarding a declining marine mammal population, it may be that an environmental organization is concerned that the effects of fishing are contributing to the population decline. This leads to the management question of: *At what rate can we sustainably harvest the resource species of concern?* The fishing industry may be concerned about pollution. This prompts the question: *At what rate can we sustainably produce DDT* (distinct but similar questions would treat any other toxin that the fishing industry representatives may have in mind)*?* Evolutionary ecologists might be concerned about the genetic effects of fishing. In addition to the intensity of the effect (which bears on the question regarding harvest rate); they might argue that the selectivity by sex is an issue because of sexual dimorphism in the resource species. This leads to the question: *At what rate can we sustainably harvest males and females of fish species X, to achieve an appropriate ratio of males to females in the harvest?* Questions exemplified by these are asked so as to account for all of the concerns of all stakeholders. They may not be satisfied with the answers, but satisfaction is one of the human values brought to current management in ways that are often counterproductive. More such questions will be considered below.

Refinement: Refinement, as part of the process of asking management questions in the second step, involves more clearly defining the management question using more specific terms. We might begin with a general question such as: *At what rate can we sustainably harvest a particular resource species?* Achieving specificity, we recognize, for example, that the species of concern (e.g., walleye pollock) occurs at a particular latitude, has a characteristic life history feature, and a recognized adult body size. The management question can then be rephrased as: *At what rate can we sustainably harvest resource species of the specified body size, latitude, and life history feature(s)?* Every question can be made more specific in this refinement process.

[2]The extreme difficulty of controlling ourselves, both as individuals, and as a species, provides basis for understanding the impossibility of controlling the nonhuman.

This leads to questions refined in a way that assists scientists in their asking of consonant science questions; they are provided with clear direction for their research.

Step 3

Step 3 follows naturally from the formulation of clear management questions. It is achieved by asking specific science questions – questions that specify the research to be conducted. With a clearly posed research question, scientists can go to the field (or to the literature, and maybe the laboratory) to produce consonant information. This information will characterize patterns defined by both the management question and the corresponding science question (Belgrano and Fowler 2008). Consonance is preserved throughout so that no artificial conversion is necessary at any step. The management question defines the science question. The science question defines and leads to research that characterizes patterns that match (are consonant with) the management question.

For example, the management question *At what rate can we sustainably harvest males and females, respectively, to achieve an appropriate sex ratio in the harvest?* leads to several research questions. Two involve the sustainable rates of harvest for males and females of the resource species (e.g., *At what rate do non-human mammalian species consume males of the resource species for which we have specified body size, latitude, and life history feature(s)?*). Importantly, we now also have a science question regarding sex ratio: *What is the sex ratio of the specified fish species consumed by other (non-human, mammalian) predators of human body size?* Sex ratio among fish consumed is measured; the two questions involve the same units (sex ratio) so that conversion is unnecessary. Consumption rates and sex ratios are treated so that the two are dealt with consistently. The associated patterns contain information on what is normal, defines the limits to natural variation, and provides examples of what is sustainable under existing conditions (Fowler and Hobbs 2002, Fowler 2009). The patterns are those to be analyzed in Step 4.

Step 4

Step 4 involves the results of studies in which the research questions are addressed by scientists. For each research question, a pattern (often macroecological, Belgrano and Fowler 2008, Fowler 2009) is sought in natural systems, characterized, and analyzed. The analysis often involves procedures akin to analysis of covariance – a procedure familiar to statisticians. These analyses involve the study of a statistical model (Pilkey and Pilkey-Jarvis 2007) of the pattern defined in Step 3. Such analyses can (and should) include Bayesian approaches (Fowler 2009). The results are made available to managers with information about what is normal and what is not (e.g., see Fowler and Hobbs 2002). Assessment of human relationships with other species, ecosystems and the biosphere can be made to determine if there is any abnormality. When human abnormality or pathology is discovered, science has revealed a problem that we can take action to solve – taking responsibility for our contribution(s) to problems we cause.

Step 5

The final step, then, is the management action that corrects any abnormality exhibited by human interactions with the non-human (Fowler 2003, 2008, 2009). This step follows directly from the work in Step 4 and involves no conversion or interpretation. The action to achieve normalcy in the system is clear and the pathway to carry out that action again involves all stakeholders.

It is important to re-emphasize the difference between conventional and systemic management insofar as it involves stakeholders. Little changes in the first and last steps in converting from conventional to systemic management: all involved notice problems and participate in management. There is, by comparison, a major change in Steps 2-4. Stakeholders change roles; they, along with scientists and managers, are removed from the misleading process of converting information as currently practiced in conventional management (Step 4 of the top row). Instead, stakeholders are directly involved in asking the right questions in Step 2 and in making sure that consonance is maintained through Steps 3, 4 and 5. Everyone carries out management action in Step 5 where stakeholders are involved in action that is consonant with what works in natural systems.

In the switch from conventional to systemic management (from the top row of Fig. 1 to the bottom row) we account for complexity in an entirely different way; in this sense, systemic management replaces conventional management (rather than being an improvement on conventional management). Steeped in conventional thinking, and driven to a large extent by emotions such as fear, many may see this switch as counterintuitive. If we are to 'consider' complexity, it might be asked, how can we not set our minds to the task of *thinking* about evolution, ecological interactions, the economy, and make our values and reasoning, or critical thinking (Browne and Keeley 2001), the basis for a decision? How can we avoid trying to synthesize and combine all of the information at hand, when building models with existing information seems so logical (and involves a set of skills that have become so well developed)? If we are to account for the complexity of issues before us, how does removing humans from the 'accounting' process (Step 4 in the top row of Fig. 1) help?

In systemic management, the 'accounting' happens through very careful use of empirical information. As described earlier, and as developed in Fowler (2008, 2009), the empirical patterns themselves involve an integration of the complexity that needs to be taken into account (Belgrano and Fowler 2008); the 'accounting' is done for us in the emergence of the patterns (the information they embody is cybernetic, Fowler 2009). We get involved directly by using correlative relationships within patterns. This is in contrast to conventional management wherein the 'accounting' involves politics, opinion, and thinking that, by comparison, are extremely vulnerable to human limitations, bias, and values. These lead to errors. In systemic management, the emergent empirical patterns consonant with good management questions contain an integration of information that accounts for the variety of factors involved in their emergence (including human influence, Belgrano and Fowler 2008). As such, emergent patterns (rather than teams of experts, managers, and stakeholders) account for complexity – all of the factors involved. These factors include historical management practices, economics, belief systems, politics and vested interests as they played into past management. In addition the effects of evolutionary dynamics, ecological mechanics, the physical environment and its variation, are all reflected in these patterns so that they need not be translated by special panels, stakeholder lobbying, politics or economic pressures.

One of the features of such patterns is change; the rates of change among the elements of a pattern, as part of the pattern, reflect current human influence along with all other contributing factors. Systems free of abnormal human impacts will result in a far better idea of what is fully sustainable than what we see now. What we see now, however, is a reflection of what is sustainable now and provides initial goals given current human impacts. The change itself accounts for all contributing factors; it too is integrative.

Thus, in systemic management (as depicted in the bottom row of Fig. 1), fears, emotions, insight, opinions, critical thinking, and understanding are used to ask questions rather than to set policy directly. Policy is based on increasingly well defined empirical information consonant with the management question. For integrative empirical patterns to be more useful and accurate in setting policy, scientists can look for correlative relationships involving factors such as environmental conditions (e.g., ambient temperature, season, latitude), life history attributes of species involved (e.g., body size, adult mortality, generation time) and anthropogenic effects (e.g., past harvest rates, pollution levels, size selectivity). We know *a priori* that economic factors play a role because the economic effects of change to avoid the abnormal count among the strongest arguments for resisting such change. Our value systems, beliefs, and politics, play similar roles; we cannot make them disappear. Such factors are inherent to the patterns (the real-world patterns being represented by statistical information or models; Pilkey and Pilkey-Jarvis 2007) rather than basis for ignoring the patterns. Thus, science that reveals patterns consonant with the management question can be funded to produce information that answers management questions rather than simply adding to the monumental accumulation of information (Step 3, top row of Fig. 1) most of which is impossible for us to unravel, interpret, and translate to policy correctly and objectively if it is not done through correlative analysis of consonant information. In following the path of the lower row of Figure 1, people with vested interests have had their concerns dealt with in the posing of clear and refined management questions. There are no court battles; legislators and politicians have made their contribution in posing questions. Funding non-consonant science as a delay tactic is not an option; there is no excuse for putting off the solving of clear problems of human origin, specifically problems in the form of human abnormality. Scientists continue in their role of identifying problems, now with emphasis on problems of human abnormality – problems most directly solved by human action (management). All stakeholders are involved in a process aimed at achieving sustainability for systems at all hierarchical levels (individuals, species, ecosystems, biosphere) and in regard to all of the ecological and evolutionary processes involved. Human limitations (effects of past mistakes) are reflected in the patterns used for management and not made part of the decision-making leading to ineffective or even harmful ongoing/future management action. Again, what we see now provides guidelines (a sense of direction and degree); in the future, systems free of abnormal human impact will better reveal fully systemic goals.

STEPS TO REALISTIC MANAGEMENT ACTION

Where do we find ourselves today? Largely unasked, we face management questions so numerous as to defy the imagination. Objective answers are essentially nonexistent; the quest for objectivity is even discouraged by characterizing objectivity as a myth (Norton 2005). When asked, science and management questions are confused. This is seen in the questions posed in Appendix 1 where the bulk of questions that were supposed to be management questions were actually research questions. Most questions we do ask are science questions; as a result, we are surrounded with huge quantities of relevant (but mostly non-consonant) information. Even the relevant information is incomplete, and we are faced with the inability to realistically fill in the holes, combine, and/or convert that information to useful management action. Much of this information can be used in correlative analysis (as covariants in the refining of management questions and their consonant patterns). However, only very small parts of the information before us are consonant with good management questions. We face this situation, in part, because we fail to ask clear management questions. That failure is compounded by a failure to recognize appropriate scientific information that lead to effective management free of political bias. Politics, conflicting human values, and human error play a direct role in current decision making (Step 4 of the top row of Fig. 1). The introduction of human bias and error in decision making is made possible by either the lack of management questions, or, if they are asked, vague management questions. We are forced to use these error-prone procedures owing to the lack of clearly posed management questions. Instead of posing clear management questions that lead to clear and useful management actions (via clear and consonant research questions), today's thinking leads to efforts to train experts to combine and convert incomplete and non-consonant information. This creates a niche for employment of specialists and educators to train such specialists (Brosnan and Groom 2006) to take on the responsibly of converting information in a way that leads to the inappropriate management actions behind current problems (as depicted in Step 4 in the top row of Fig. 1). One of the points of this paper is that, rather than continue with the status quo (conventional management), we need to learn how to ask management questions and ask them in a way where the science best suited to provide objective answers is well defined. With objective answers, conversion is unnecessary: the alchemy of conventional management is avoided.

Questions:

We now turn to an examination of examples of specific questions. This set of examples (including those found in Appendix 1) shows that even applied scientists confuse research and management questions. However, the problem extends beyond the realm of scientists. As shown in the examples below, questions that are asked by managers (as well as by scientists) today are vague and others are research questions that do not show consonance with any management question.

Questions we pose below demonstrate the process we outlined above and include examples of good management questions (i.e., adhere to the tenets of management, Fowler 2003, 2009). In all cases our mission is to exemplify the processes of distinguishing, asking, refining and finding consonance between management and scientific questions.

For example, a question often asked today is: *What changes will we observe in the distribution of species as they respond to global warming?* Is this a management question or a scientific question? It is purely scientific. It clearly relates to management issues, as does virtually everything in our complex interconnected universe. However, it is a question that has no inherent component relating to actions, objectives, or decisions (parts of an effective management question) in the way it is phrased. It relates directly to predicting, observing, and explaining – all elements of good science rather than management.

*How much biomass can we sustainably harvest annually from the sockeye salmon (*Oncorhynchus nerka*) population of the Fraser River in British Colombia?* Is this question one that represents research or management? It is a management question. The question involves reference to a goal or an objective ("How much") along with the 'should' of sustainability – commitment to taking action with the overarching goal of sustainability. It relates to action that we can take ("harvest annually"). It specifies some of the circumstances (salmon from the Fraser River in British Colombia, and humans as large mammalian predators). It is clearly based on science (or information) in recognizing that there are sockeye salmon in the Fraser River (keeping in mind that more specific questions of the same kind can be asked about any subpopulation, or for any tributary, within the Fraser River). It is based on our knowledge that consumption is a process to be asked about. Consumption is an ecosystem process wherein predators consume and humans are acting as a predator in our harvest of salmon. Through science (or other means of observation) we have documented salmon and consumption as elements of the system under consideration. We know we are a large mammal. When we conduct consonant research to answer the management question, there is no need for conversion of that information to management advice – the answer *is* management advice. If the advice is accepted without modification and leads directly to responsible action ("management action" – praxis), then management is based on that scientific information.

How much will we reduce a resource population by harvesting 20% of the individuals in the population annually? Management or science? Science. There is no component involving an objective; it is not prescriptive. We are not asking how much we *should* reduce a resource population, how much is a *sustainable* reduction, or how much we would reduce a population as a *normal* reduction? Although the action of harvesting is clearly a managerial action, the question leaves it treated only as a process (a process science recognizes for all consumer species); there is no basis for making a decision or taking action inherent to the question (i.e., the extent to which we *should* harvest or *should* reduce populations). The question involves prediction, another aspect of good science. However, it does not specify that, for use in management, science needs to produce information showing what a sustainable population change (or harvest rate) might be: the question specifies no *basis* for establishing what is sustainable vs. unsustainable. The appropriate management question is: *To what extent can we sustainably reduce the population of a specified resource species?* The 20% harvest, as a component of the original question, was unquestioned regarding its sustainability. However, if sustainable harvest rates were made the focus of management, the initial management question would have been something like: *At what rate can we sustainably harvest a specified resource population?* The question as originally posed leaves us with the implicit management assumption that we can judge the sustainability of the 20% harvest rate based on the predicted reduction in the population. Here we encounter another conversion – harvest and population reduction are not the same thing even though they are clearly related. Harvest is the consumption of resources (often involving the death of individuals but something done by a consumer) and population reduction is a decline in numbers of individuals (something that can happen as the result of death but through a complex systemic process). Harvest and population change are obviously related (as most things are) and often show correlative relationships. However, they are not the same thing. Judging one on the basis of the other independent of empirical information relating the two is conversion subject to error. Without such correlative information, we are left with little, if any, objective basis for judging the sustainability of the reduction. In particular, we are left without a good management question regarding the sustainability of the reduction.

At what rate should we harvest biomass from the populations of both a predator and its prey? This is a management question, although it lacks specificity (e.g., does not identify a particular predator and its specific prey, the location, or the sex or age to be harvested from either species). It opens the door to consideration of science that provides quantitative answers with information that establishes a goal, objective or standard (it is prescriptive: "…what rate should…"). It specifies an action ("harvest"). It specifies some of the conditions for the action in that the harvests are to be taken from predators and their prey populations. It takes advantage of the ecological knowledge (basic principle) that there are predator/prey relationships in ecosystems. The question might be more clearly expressed as: *At what rates can we simultaneously and sustainably harvest biomass from the populations of both a predator and its prey?* With the door open to more specificity (e.g., direct mention of life history stage, age, etc.) we see progress while maintaining consonance. The "should" becomes "sustainable" so that we adhere to the general objective of achieving sustainability – a mission commonly accepted in efforts to achieve a realistic form of management. Inherent in the concept of identifying the sustainable is the complementary and consistent matter of identifying what is not sustainable.

At what rates do killer whales (<u>Orcinus</u> <u>orca</u>*) consume from California sea lion (*<u>Zalophus</u> <u>californianus</u>*) and steelhead (*<u>Oncorhynchus</u> <u>mykiss</u>*) populations as two species that themselves are predator and prey?* This is a science question. It involves a measurement or characterization of a process that we know occurs in a natural system. Very importantly, however, this question illustrates steps toward a match (consonance) with the management question asked in the last paragraph – specific species are identified and the processes are the same. The science question just posed might be made more specific by asking: *At what rates do killer whales (*<u>O.</u> <u>orca</u>*) consume from California sea lion (*<u>Z.</u> <u>californianus</u>*) and steelhead (*<u>O.</u> <u>mykiss</u>*) populations off the coast of Oregon and Washington as two species that themselves are predator and prey?* Phrased this way, the science question specifies a particular location in addition to the processes, and the species. It could have been made even more specific if it had addressed predation rates under condition of an *el Niño* event, for water temperatures 0.5°C above average, or any number of other climatological circumstances. Further specificity would involve age and sex, phenotype, and behavioral characteristics of the two harvested species – increasing specificity limited by our ability to list factors thought to be relevant.

Repeatedly asking and answering scientific questions of one kind leads to informative patterns (i.e., multiple observations of one kind). Questions such as the last question in the last paragraph can be asked about the many cases of predators feeding on other predators and their prey. Such predation occurs in many cases in many natural systems. Funding from sources such as the National Science Foundation could be requested to address such questions by considering them as relevant to academic science with attention to the matters of destabilization/stabilization of predator/prey cycles, food web dynamics, top-down and bottom-up food-chain functions, and a long list of other interesting and relevant issues. Such science would be good science insofar as it provides explanation, makes predictions, establishes (or confirms) basic principles and characterizes empirically observed elements of nature. If, however, over the course of many years of research, science produced a collection of results from such studies, there is the high likelihood that a macroecological pattern would come to our attention. With this thought in mind, we might ask a slightly different scientific question: *At what rate do predators consume individuals from another predator population and simultaneously from one of its prey populations when the higher-level predators consume both the predator and prey?* This is the general question for which the killer whale question above was a specific example. Numerous such examples would result in a pattern showing limits to simultaneous predator/prey predation and especially useful would be information regarding this pattern as it relates to factors such as body size, tropic level, life history parameters, and environmental circumstances.

How many prey species do predators use as prey? Is this question a scientific question or a managerial question? It is scientific. Its answer would be information but that information is not identified in terms of guidance regarding what we should (or should not) do or what is (or is not) sustainable. A slightly different science question would be: *How many prey species do predators with the body size of humans consume?* Here we can proceed from a science question to a management question – an example of generating a management question where Step 1 in Figure 1 is not the identification of a problem as much as it is simply a managerial issue generated by good science. It might, however, result in finding human abnormality and would then represent another case of science discovering, describing and documenting a problem worthy of management action. In this case, the corresponding management question can be posed as: *How many prey species can we humans sustainably consume?* Here we see a pair of questions, one scientific, and the other a management question, that are consonant. Both questions involve numbers of prey (the same units). Both questions involve predators in that humans are the predators in the management question. Both questions involve the matter of species (number of prey species, predators as species and humans as a species). The distinction between questions is obvious. The science question is informative (observations, measurements, characterizations) while the management question is prescriptive, or one of objectives, goals, or sustainability – what we 'should' do. The match between the two questions involves the common ground of units and system components.

As with all management questions, refinement is important to directly account for factors any stakeholder or scientist may have in mind (as a concern, or based on theory, understanding, or opinion). The last question (*How many prey species can we humans sustainably consume?*) should be made more specific. In view of the effort to develop ecosystem-based management, we can ask: *How many prey species can we sustainably consume in the eastern Bering Sea (or any other ecosystem)?* The circumstances of management action are of central importance to the refinement of questions if those circumstances are to be dealt with (accounted for) directly.

How much recruitment is expected from the 2006 year-class of pollock (T. chalcogramma) to the Bering Sea population? This is a scientific question. It involves prediction – another of the many valuable roles of science. When science answers this question, it is producing information that is relevant to management, but relevance alone falls far short of being sufficient (i.e., a corresponding consonant management question has not been identified so interpretation, often misleading, will be required for management action). The information in the answer to this question would have to be treated as one of many sets of information that are relevant. Such sets include environmental circumstances, genetic influences, the role of evolution, behavioral factors, and many more. Importantly, many sets of relevant information are sets that scientists are unable to produce (owing to the complexity of the full set of relevant factors). All are sets of information that are no more than relevant, whether we have them in hand or not; they are sets subject to interpretation and interminable debate regarding their relative importance. Such matters become more objectively treated as they become matters of concern in statistical analysis of patterns – refinement of science questions that lead to analysis of covariance and the identification of sub-patterns within larger patterns. Information about recruitment can be used in addressing questions about sustainable consumption rates correlatively if consumption rates among nonhuman predators are influenced by recruitment in their prey populations (which we know to be the case, based on the principles behind functional responses among predators to their prey).

There is thus a distinction to be made between mere relevance and full consonance. There is also the matter of the options for action we (humans) can take – management. In terms of consonance, the question posed in the last paragraph would represent a partial match with a borderline management question such as: *What should the recruitment of the 2004 year-class of humans be to the 2020 human population?* This question, however, is not a good management question as recruitment is not something that we do, even though it is something that happens in our population as a result of things that are part of management action. Thus, it can lead to management questions that involve the many things that we do as they contribute to recruitment (e.g., feed ourselves, practice medicine, avoid risks – many things which lend themselves to study by science and are things that are more directly, and at least partially, under our control).

In the commercial catch of pollock (T. chalcogramma) in the eastern Bering Sea, what should the genetic composition be (e.g., what portion of the catch should have a particular allele)? What is a sustainable allocation of catch across the various genotypes of pollock caught in the eastern Bering Sea? Both of these management questions directly exhibit the 'evolutionarily enlightened' form of management that has been advocated for decades (e.g., Thompson 2005). These questions are two of many management questions that such an approach demands. They are expressions of a more generic question: *What is a sustainable genetic influence on other species?* These two questions contain the elements of a quantifiable goal or objective; guidance would be in terms of the portion of the catch that would fall in any genetically or phenotypically identifiable category. A management question more likely to result in implementation would be: *At what rates can we sustainably harvest two specified phenotypes so that the ratio of the two phenotypes in the harvest is itself sustainable?* Management action would be action that leads to meeting the objectives of normal harvest rates among nonhuman species; harvesting would be conducted so that harvests would have the genetic composition (or phenotypic composition) observed to be normal among nonhuman species otherwise similar to humans. The more specific question at the top of this paragraph denotes particular system components (the two species, pollock and humans as prey and predator) and a particular area or ecosystem (eastern Bering Sea). There are other conditions or circumstances that could easily be added to the question. For example, the sustainable genetic composition of the catch by season could be specified. In other refinement of the questions, the trophic level of the harvested species is a factor to take into account, as would be its body size and other life history attributes (all of which can be treated correlatively). Climatic conditions could be added in search of the advisable genetic/phenotypic composition of the catch when the mean sea surface temperature is 0.75°C above average for the season in question. Management questions can be refined this way in a virtually endless process – a process in which stakeholders, managers and scientists all can participate objectively (Step 2, bottom row of Fig. 1).

Defining a genetic category is not a trivial challenge. However, we can identify some phenotypes relatively easily and phenotypes are, at least in part, genetically determined. Thus, we can ask: *What is the size distribution of pollock (*T. chalcogramma*) in the diets of predators feeding on this species in the eastern Bering Sea?* This is not a management question owing to the fact that it does not ask about what we should do, or seek to establish goals/objectives. It is, instead, a research question in that it seeks observation and characterization – long-recognized valuable kinds of contributions by science. The information resulting from studies to address this question would be measures of the relative abundance of pollock of different size categories as consumed by non-human predatory species. Research would involve studies of the diets of the predators that feed on pollock and the results would be observations (or estimates) documented in reports or peer-reviewed literature (e.g., Etnier and Fowler 2005). Such measurements are part of the healthy conduct of science. Observing, characterizing and documenting are parts of science but not management; management involves the goals set, action taken and goals achieved. In the case of systemic management it involves relieving nonhuman species, ecosystems and the biosphere of abnormal human influence.

As in previous examples, there are obvious elements of consonance between the last management question and the last science question. There is a match that involves congruence, identical units, and similar circumstances – an overall isomorphism. There is a one-to-one mapping between the science question and the corresponding management question. More can be achieved with further refinement; this would deal with more of the complexity of the situation (and more correlative statistical analysis). The management question might have been rephrased in terms more reasonable for management: *What is an appropriate size composition for the commercial catch of pollock (*T. chalcogramma*) in the eastern Bering Sea?* A corresponding (consonant) science question, then, is the question posed above: *What is the size distribution of pollock (*T. chalcogramma*) in the diets of predators feeding on this species in the eastern Bering Sea?* Thus, consonance is maintained in the pair of questions throughout the refinement process. The management question is about us (humans) as a predatory species through our commercial harvests. To preserve logical integrity in the pair of questions, the science question also involves species, specifically predatory species to address predation (because we are functioning as a predatory species when we harvest); information is consistently focused on the consumption of pollock. The management question specifies the prey species (pollock) and it is pollock (or species otherwise like pollock) that would be the focal prey in research to answer the science question. Further specification can involve overt recognition that we humans are a large mammal. This further defines the corresponding science question: *What is the size distribution of pollock (*T. chalcogramma*) in the diets of large mammal predators feeding on this species in the eastern Bering Sea?* This refinement of the pair of questions goes hand-in-hand – preserving the consonance throughout the process. It is clearly an endless task – the complexity of nature prevents full refinement. However, the most important correlative information should be obvious to most scientists – and discoverable through good statistical analysis. The refinement of the pair of questions becomes an interdisciplinary exercise that can draw on all fields of science (making the exercise interdisciplinary) as well as the interests of any stakeholders to which the management issue is important.

A question very prominent in a number of recent publications (e.g., Springer et al. 2003 – and the dozens of papers in which the Springer et al. paper is cited) might be posed as: *Have the effects of commercial whaling earlier this century been influential in the declines observed recently among several species of marine mammal populations in the north Pacific and eastern Bering Sea?* Is this a science question or a management question? It is purely scientific and stimulates a great deal of scientific curiosity, debate, and further research – nothing new to scientists passionate about their work. Furthermore, as with anything, it is relevant to management owing to the fact that to varying degrees everything is interconnected in one way or another, directly or indirectly – the very nature of complex systems and their collective interactions. Predatory/prey interactions and coevolutionary relationships count among the complex set of processes that guarantee relevance. Confined to simple relevance, however, the meetings of experts to deliberate, and publications by scientists about, this question, done conventionally, do not address any management issue in a way that achieves consonance. In other words, even if there were a clear, definitive answer to this question, there would be no guidance for management contained in that information – largely because we lack a consonant management question. We would have to convert the answer to management advice/action and would be doing so for a non-consonant management question. Such conversion would be partial and biased by human limitations and values in a process where such values are almost uniformly used to override the value of health and sustainability for all natural systems (systems that include humans). The scientific question posed at the beginning of the paragraph involved whaling and its effects. This brings us to the potential for a focus on whaling. If we follow this lead, we ask a very real management questions such as: *If we are going to harvest humpback whales (*Megaptera novaeangliae*), at what rate can they be sustainably harvested? At what rate can we sustainably harvest sperm whales (*Physeter macrocephalus*)?* or, more generally: *At what rate can we sustainably harvest marine mammal species "X"?* In all cases, it must be recognized that we are making the assumption that we have already addressed the management question: *Should we harvest marine mammal species "X"?* and have decided to harvest them (This is an extremely complex question as exemplified by the controversy over the Japanese research whale harvest [Clapham et al. 2003, Corkeron 2009] which serves as a very good example of the problems created in conventional management when stakeholders participate in Step 4 of the top row of Fig. 1 instead of participating in Step 2 in systemic management).

Questions such as those above regarding harvest rates from marine mammal populations have consonant scientific questions: *What are the predation rates of large mammal predators that consume humpback whales?* and generically: *What are the predation rates of large mammal predators that consume marine mammal species "X"?* The questions are phrased in terms of predators that are large mammals to account for the fact that humans are a large mammal – an element of consonance. As with earlier examples, the pairs of management/science questions can be refined to account for location, latitude, climate, population levels of the marine mammals (thus accounting for functional response variation), and so on, *ad infinitum*. The correlative analysis of statistical patterns can never be completed, thus providing basically unlimited opportunities for quantitative scientists. However, even initially observed patterns consonant with management questions always provide information on the limits of variation to enable the identification of the abnormal – when abnormality is identified it is an indication of even more severe abnormality once more complete analysis can be conducted. Refinement brings to bear the complexity of the reality pertinent to the issue being faced in management, and the specific, consonant reality subject to the focus of science. Information revealed by science in answering the consonant science question is not the subject of confusing and contentious deliberation in committees or scientific panels that we observe in today's management, even though the scientific processes themselves are heavily scrutinized. It is a critical change to a process where the framing of the question that led to the information *is* a matter that involves panels, experts, scientists, managers and other stakeholders (bottom row, Fig. 1). This places all stakeholders in a position of achieving consistency (Hobbs and Fowler, 2007) and objectivity (Belgrano and Fowler 2008). This process is limited only by the limits of science and our capacity to think of related matters that lead to further refinement of scientific questions. Throughout the refinement process, the pair of questions remains consonant with more and more factors considered overtly. Overt or explicit consideration is achieved to the degree we make progress in the refinement process. This kind of 'consideration' or 'accounting for' in systemic management replaces that of Step 4 in conventional management to achieve a great deal of objectivity.

*How does commercial fishing affect northern fur seals (*Callorhinus ursinus*)?* The northern fur seal population on the Pribilof Islands is currently declining (Towell et al. 2006). Science observes and documents such phenomena. Such information is often interpreted as evidence of a problem, not only by environmentalists, and often the public, but also by scientists. The problem in this case would be particularly obvious if the population is at an abnormally low level, or if the decline is occurring at an abnormally high rate. Bringing manager's attention to problems is one of the roles of science. Management is called for when problems are identified. However, the question is a scientific question; the answer, if attainable, would do no more than contribute to explanation and understanding and would add substantiation to the fact that there are interactions through which fishing and fur seals are interconnected. The answer to this question would not provide guidance regarding what to do other than through the process of interpretation (prominent in conventional management) that would reflect the bias of politics, economics, human limitations and special interests (i.e., the information would be put through a conversion – the conceptual alchemy depicted in Step 4 of the top row of Fig. 1). The issues raised in the exposure of concerns (exemplified by population declines among many species) obviously lead to many management questions since the components of complex systems are interconnected (a general principle). This fur seal example leads to management questions such as: *At what rate can we sustainably harvest fish from the Bering Sea (or of pollock in the Bering Sea, of finfish in the Bering Sea, and many other similar questions)? What portion of the annual production in the Bering Sea (or production by pollock, production by the species of fish consumed by fur seals, production by finfish or any other species, or group of species) should be* *left unharvested for the sustainability of fur seals (and all other species and the Bering Sea as an ecosystem)?* Again, the mere potential for relevance leads to an interminable set of questions stimulated in the minds of anyone faced with the observed decline in the fur seal population. Asking such questions is something in which everyone can be involved (Step 2, bottom row of Fig. 1).

*How does pollution affect northern fur seals (*C. ursinus*)?* This is yet another scientific question related to the decline observed in this species (i.e., we here have a specific species involved in concerns about pollution as it may contribute to population declines as raised earlier in this paper). Its answer tells us nothing about what to do but does lend to an understanding of the problem. Because we already know about the existence of cause-and-effect relationships, interactions, and various processes within complex systems (scientific principles), this question leads (without an answer) to management questions such as: *At what level can we (the human species) sustainably produce estrogenic compounds (or other toxic material)"* or *At what level can we produce dichloro-diphenyl-trichloroethane (DDT) so that our influence through the effects of our production of DDT are not abnormal or pathological?*

There are no limits to the number of management questions before us. We started this section with a question about the redistribution of species in the face of global warming. Many related management questions can be posed: *"How should we redistribute our harvesting of resources in response to the movement of the species we harvest as they respond to global warming?" At what rate can we sustainably produce CO_2 (or other gases contributing to global warming)?* Note that this question can be, and should be, asked whether or not CO_2 is actually contributing to increasing atmospheric temperatures. *At what rate can we sustainably consume resource species "X", group of species "Y", or the Bering Sea ecosystem as a whole, as they change with respect to trends in sea temperature? What portion of the Bering Sea ecosystem should be left free from the direct impact of commercial fishing as it changes in the face of global warming (or ocean acidification)? Where should we locate marine protected areas (MPAs) in the Bering Sea and relocate them in response to changes in sea-surface temperatures? How should we allocate our harvests over time (i.e., seasonally) and space within the Bering Sea in response to changing ice cover?* Each such question can be refined to overtly account for temperature, ice cover, or other aspect of global warming (whether or not there is an anthropogenic contribution). The process of asking questions can be undertaken repeatedly, with, for example, pH substituted for temperature in the above questions. With the specificity achieved in refinement, the corresponding consonant and refined science question can be posed. Such refinement leads to very clearly defined science – research conducted to provide management advice free of political bias, free of the agendas of special interest groups, and free of misinterpretation (all of which are already accounted for in the empirical patterns). The research resulting in the observation of patterns consonant with the management question is the best science upon which to base management decisions. The resulting information serves best as the foundation for management (Belgrano and Fowler 2008). It is important to stress that the conduct of science is never to be free of intense scrutiny regarding the extent to which it complies with the standards for scientific investigation.

Obviously, only a fraction of the science questions that we can ask are going to be found to be consonant with management questions. The question at the outset of this section (*What changes will we observe in the distribution of species as they respond to global warming?*)

would have certain elements of consonance with the management question: *How should we relocate the distribution of humans in response to global warming?* But as a science question on its own, its main contribution would be confirmation that species move in response to changes in their environment – a principle that is already widely accepted. The history of science has given rise to this particular principle and will continue to provide basis for such general principles – academic research is well known for its production of information that pushes forward the frontiers of knowledge. Science also provides information that gives rise to management questions, exemplified by research on oceanic acidification (Feely, et al. 2004). This particular work leads to the management question(s): *At what rate can we sustainably produce CO_2 (or any other gas or chemical that contributes to the pH of marine waters)?* Managers have the responsibility of taking such observations from the scientific community and working with scientists and other stakeholders to pose good consonant questions. If science produces observations exemplified by the documentation of the current extinction crisis, managers and scientists alike must shoulder the task of knowing that things are interconnected and ask management questions regarding sustainability in regard to levels of production for CO_2 and toxic chemicals, the sustainable levels of consumption of energy, biomass, and water, and the sustainable use and occupation of space – all, in some way (directly or indirectly), related to the anthropogenic aspects of the current extinction crisis. Again, the complexity of issues (and related management questions) is virtually endless.

Our examples have hopefully made it clear that science is not confined to research defined by questions consonant with management questions. There is another important role for science. Scientists, along with other stakeholders (Steps 2 and 3, bottom row, Fig. 1), contribute directly to the refinement process. This aspect of science involves the characterization and analysis of patterns that generate more specific management questions. Management questions, followed by science questions can be refined with insight gained from any field of science, including what are often seen as purely academic investigations. The information produced may very well be shown to explain some of the variability as a covariant. With such information, patterns resulting from science conducted to answer questions consonant with management questions may be analyzed and produce information for further refinement of both the management question and the corresponding research question. This refinement was exemplified above where generic questions such as: *What is an appropriate size composition for the commercial catch of pollock (*<u>T. chalcogramma</u>*) in the eastern Bering Sea?* were introduced. The corresponding science question would be: *What is the size distribution of pollock (*<u>T. chalcogramma</u>*) in the diets of predators feeding on this species in the eastern Bering Sea?* Through the refinement process we add overt consideration of the body size of humans and the fact that humans are mammals by asking the science question: *What is the size distribution of pollock (*<u>T. chalcogramma</u>*) in the diets of human-sized mammalian predators feeding on this species in the eastern Bering Sea?* New questions and refined questions result from the collaboration among scientists, especially scientists of different disciplines. Interdisciplinary approaches constitute one of the objectives of management (e.g., Arkema et al. 2006) in order to account for complexity.

The interdisciplinary aspect of question refinement is an endless task owing to the infinite complexity of factors contributing to observed patterns but the more obvious correlative aspects of patterns are unlikely to be missed by attentive scientists. Examples are found in the correlation between population density and body size (Damuth 1981) that typify the discoveries of research involving allometry and its focus on the relationships between body size and many ecological species-level characteristics (Peters 1983, Calder 1984, Belgrano and Fowler 2008, Fowler 2009). Research behind the discovery of these relationships exemplifies the correlative analysis of a general pattern (e.g., the overall frequency distribution of population density) to find a relationship between density and body size (and, thus, the frequency distribution of density for any particular body size). With the results of this research we can overtly take account of body size in formulating and refining the pairs of questions involving both science and management. The reciprocity of interaction between science and management is clear in this refinement process – a process confined to no particular focus of interest, but of ever-increasing specificity. Both the science question and the management question become more specific as a result of the refinement process. This specificity is a key factor in linking management and science as is the wealth of questions that can be asked to initiate the refinement process.

Part of the importance of this specificity involves its reductionism. Reductionism is recognized as one of the characteristics of the scientific process − often seen as its Achilles heel. Repeated measurements are key to avoiding the trap of reductionism while preserving its specificity; repeated measurements show patterns. Patterns resulting from repeated measurement provide a means of taking advantage of emergence and emergence involves the holistic (Morowitz 2002). Thus, patterns are the union of reductionism and holism – emergence involves the complexity of the origin/explanation of every pattern so that everything is accounted for and reflective of its realized (actual, not as evaluated by humans) importance in the emergence of patterns (Belgrano and Fowler 2008). The explicit characterization of the correlative relationships within observed patterns (represented by statistical models; Pilkey and Pilkey-Jarvis 2007) presents science with an endless task. The results of research not only have the potential for identifying issues that give rise to different management questions (and thus the potential for being information consonant with a management question) but have the potential for being relevant in correlative analysis of patterns consonant with the initial management question. Thus, embryological research in conventional management might do little more than explain development in the growth of fish. By contrast, in systemic management, scientists can contribute questions such as: *At what rate can we sustainably harvest fish species with internally fertilized eggs compared to that for species with externally fertilized eggs?* Any embryological growth pattern can become a potential correlate in questions of when, where and how much to harvest.

Distinguishing and asking science and management questions

As exemplified in the examples above, science questions lead to the production of information through exploration, description, characterization, and explanation. Science questions lead to prediction and the exposure of problems. The problems we can most directly solve involve those of human origin; especially where we humans are shown to be abnormal or pathological compared to other species. Management questions involve goals, what we should do, action, objectives, sustainability, normalcy, health, and responsibility. Both science and management questions can be very specific (reductionistic), and refinement leads to such specificity.

Either science or management questions can be asked in ways that, on close examination, are largely independent of the other, as has been the case in conventional management. This often leads to confusion and mismanagement. Alternatively, management and science questions can be asked so that they occur in pairs to obtain a match (consonance) between the pair – where one maps isomorphically to the other. Consonance involves reciprocity in this process. For the most part, conventional management fails to find consonance between the two types of questions. With nonconsonant information in hand, the conversion required (Step 4, top row, Fig. 1) results in the gulf that we see today between science and management because realistic conversion is impossible. As a result, we see the problems that confront us in today's world.

To ensure the responsibility of human action in management, it is imperative that management questions be asked with the component of "should" to achieve sustainability. Management questions involve prescription. *How can we participate in ecosystems so that our influence is not abnormal? What should we do? What is a sustainable interaction with the nonhuman? What harvest rate should we implement in our take of salmon? At what rate can we sustainably harvest salmon?* Phrasing management questions in this way helps prevent asking science questions that seem like management questions (see Appendix 1). Questions like the last two are specific enough to direct the process toward action and goals rather than being confined to understanding that is relevant, but partial and easily misdirected.

People involved in conventional management realize that the science questions that are currently being asked are relevant to management − we know that everything is interconnected to varying degrees. That there is relevance is without debate; what the relative and specific relevance actually is, however, is a matter beyond resolution. Training "translational specialists" (Brosnan and Groom 2006) will not solve the problem. This is where conventional management gets trapped; the specific aspects of relevance are usually a matter of debate and opinion that lead to polarization, and compromise of human design. Debate and opinion then become manifest as factors involved in goal-setting and management action making the process prone to error. Politics, vested interests and economics are major factors in today's management and contribute to the emergence of many of the abnormal patterns we observe in natural systems today. In contrast to relevant information, consonant information largely precludes interpretation. In achieving consonance, people are involved in the asking of questions and obtaining a match between paired scientific and management questions. Scientists, managers and other stakeholders are largely removed from the interpretation process when consonant information is available because conversion is not necessary.

Thus, the matching of questions is an important theme (pattern) illustrated in the examples presented in the previous section. Within each pair of management/science questions, the questions are asked so as to be fully dependent on each other. Management and science questions must both be asked. Each one must be asked by being fully conscious of the match between it and its corresponding question of the consonant pair. Throughout the process an important distinction is made. This is the distinction between science and management; science provides information and management uses that information for taking action or setting policy. In systemic management, goals for management are based on scientific information. The science question is always distinct from the management question, but always consonant.

LINKING SCIENCE AND MANAGEMENT

What is it about consonance between the questions of science and management that bridges the gulf between these two human endeavors?

Consonance in matching pairs of questions in science and management involves common units and circumstances – a one-to-one mapping from one to the other. This consonance is carried forward beyond the pattern revealed by research to management itself – it involves consonance among four components: management questions, science questions, the empirical pattern and management action. The point here is that the consonance provides common ground all the way through to management action. When there are common units and circumstances it is possible to prevent most, if not all, of the problems caused by debate, interpretation, politics, and special interests prevalent in current forms of decision-making. In systemic management, the influence of such factors is relocated (compare top and bottom rows of Fig. 1). Emotions, concerns, lobbying, conflict, beliefs, and scientific principles serve to motivate or stimulate the posing of good management questions rather than serving, by themselves, as basis for policy. These factors are very useful components in refining pairs of management/science questions – a much more objective process. If we have achieved consonance between the pattern revealed by science and each management question, there is no need to convert information. Thus, rather than bridging the gulf between science and management, the gulf is removed by bringing the two together. The human element of converting scientific information to management advice is a process confined to the posing and refining of questions. When the science has been conducted to address the consonant science question, the results answer the matching management question; objectives and action become consistent (Hobbs and Fowler 2008). The process remains vulnerable only to the human limits experienced in posing and refining questions, in conducting the consonant science, and in carrying out management action. We cannot do everything, but everything done with consonance would have consistent consequences.

How does research conducted to answer scientific questions answer consonant management questions? This happens through the common ground and consistency among the management questions, patterns, and objectives: achieving healthy systems, avoiding the abnormal or pathological, and achieving sustainability – all treated as paramount to other human values in systemic management (Belgrano and Fowler 2008, Fowler 2009). Because the patterns used for guidance reflect the reality behind them (all of the contributing factors), distinct (but systemically inseparable) management questions get answered consistently. For example, the ratio of males to females, and overall harvest rates will be consistent in our take of resources. The establishment of MPAs would be consistent with our production of pollutants. A sustainable harvest from an ecosystem would be consistent with harvests from individual species, the number of species harvested, as well as the seasonal and spatial allocation of harvests.

The terms normal and abnormal bring to management the matter of definition: sustainability is defined as what works in natural systems (Fowler 2003, 2009, Belgrano and Fowler 2008). Consistent with the field of medicine, the abnormal or unusual is a condition to be treated as a problem and one of the roles of science is the exposure of problems measurable in terms of abnormality. Normalcy and health go hand-in-hand. One of the objectives of management is to avoid the abnormal (McCormick 1999, Fowler and Hobbs 2003, Fowler 2009); one of the central objectives in the mission of agencies such as the National Oceanic and Atmospheric Administration (as well as many other national and international institutions) is healthy ecosystems. The North Pacific Fishery Management Council (NPFMC, 2006) proposed the following definition for Ecosystem-based Fishery Management (EBFM): "*Ecosystem-based approach to fisheries management is defined as the regulation of human activity toward maintaining a long-term system sustainability (within the range of natural variability as we understand it) ......*" The linking of science and management thus becomes a matter of refining pairs of questions as exemplified above so that scientists can inform managers of what is abnormal or atypical in order for management to take action to achieve health. Ideally, what scientists do is provide empirical information; they do not interpret it, convert it, or offer advice or opinion regarding management. Advice and opinion among scientists are confined to three things: 1) the quality of science used to produce information resulting in the representation of observed patterns, 2) the quality and process of science involved in revealing and measuring abnormality, and 3) participation in the posing of good management questions. When we find human abnormality, we continue in one of the main, and important, roles of science: bringing to the attention of the world problems to be dealt with in management.

We are thus left with pattern-based management, systemic management, or reality-based management (Belgrano and Fowler 2008, Fowler 2009). Taking this approach, science provides information that needs no conversion to be used in management. Managers see and distinguish the normal from the abnormal and take action or set policy to relieve systems from abnormal human influence. That is, conditions in which humans are the aberrant part of systems present us with problems for which we can take action to solve; management is action and the best option for control, as limited as it may be, is human self-control (Fowler 2003, 2009). Pathological conditions involving the non-human (e.g., an abnormal ecosystem condition, or endangered species) lead to exploring the wealth of contributing (relevant) factors among which are those involving the direct or indirect abnormal influence of humans (the indirect being an implementation of the principle of complexity from which we know that things are interconnected in various ways in complex systems – in reality). When it is the human elements of nature that are abnormal, we have the option of taking action wherein there is at least some control.

Key to moving forward is the realization that achieving the objectivity of consonant pattern-based management is overcoming our tendency to undermine sustainability and health with values, such as economics, that we believe trump sustainability (in conventional thinking) – even to the point of assuming that there is sustainability in the unsustainable (e.g., 'sustainable' economic growth or development). In systemic management, actual real-world sustainability prevails (Belgrano and Fowler 2008). Not only are the risks of extinction for other species at stake, but also the risk of extinction for *Homo sapiens* (Fowler 2003, 2009); systemic management is reality-based and risks of all kinds are part of reality. Economic factors (including beliefs) are among the elements contributing to problems observed in our environment and we have to be open to very penetrating and fundamental management questions such as: *Should economic value be a determinant in management decisions?* or: *Should we attach economic value to anything?* "Sustainable development" and "sustainable growth" give way to questions such as *What is a sustainable rate of energy consumption (CO_2 production, estrogenic compound production, genetic influence,....)?* The objectivity of policy based on patterns solves the dilemma of finding balance between anthropocentric and biocentric values; the values we place on such issues are subsumed by the objective of sustainability – all species are confined by the limits imposed by their environments and empirical patterns display the balance among the systemic forces involved.

DISCUSSION

There are innumerable management questions before us, mostly unasked at this point. If they are asked, they generally go unanswered objectively. Experience shows that the predominant tendency (at least for many people trained as scientists) is to ask research questions rather than management questions. These science questions are asked regarding things that are relevant to (but rarely consonant with) management questions (e.g., see Appendix 1). Without a clear management question the appropriate (consonant) science questions are not asked. Managers are not skilled in asking, nor trained to ask, clear management questions, and are especially prone to responding to political pressures. This often leads to the erroneous conversion of partially relevant and incomplete information to guidance for management action (top row, Fig. 1) and subsequent failure of these actions. There is much progress to be made, starting with knowing how to ask a management question. With a management question in hand, we must have the training, experience and skills to know how to ask the consonant science question so that the answer is free of politics, values other than that of avoiding the abnormal, and free of other anthropocentric/biocentric tendencies among special interest groups. With answers to skillfully asked science questions in hand, we have information inherent to integrative patterns that provide objective guidance for management rather than biased guidance filtered through teams of experts, committees, stakeholders, or politicians.

In conventional management, managers and stakeholders often find themselves facing a problem involving the nonhuman. The temptation in conventional thinking often leads to attempts to solve that problem directly, to take control of the nonhuman, rather than ask a good management question to address the root causes where humans are involved. Thus, a decline in killer whale (or other endangered species) population often leads to mitigating action rather than solving problems that are identifiably human and therefore amenable to direct solution. If a killer whale population is believed to be declining with possible causes including toxins such as PCBs, this leads to management questions such as: *At what rate can PCBs be sustainably produced?* If prey levels (such as salmon populations) are suspected to be a contributing factor in such a decline we face the question: *At what can we sustainably harvest the salmon populations on which killer whales feed?* This moves the role of stakeholders from their position in Step 4 of the top row of Figure 1 (the alchemy of information conversion) to Step 2 in the bottom row (posing clear well formulated management questions). Emotions, politics, understanding, human values, education, experience, scientific observations – basically anything – can be used to initiate the process of asking a good management question. Advice, lobbying, law suits, and vested interests are allowed as part of the process only to ensure that clear management questions are asked and that management is carried out to avoid the abnormal. In systemic management, politicians, either representing themselves, or responding to constituents, move to the question-asking role and resist the temptation to think that they can find a solution (or procrastinate in facing reality) through funding non-consonant research, setting up special panels of experts, or otherwise avoid having to take responsibility for the problems caused by human action, activities, policy and decision-making in current management. Stakeholders of every kind remain in their role of taking management action in Step 5 to solve problems of human origin.

The tenets of management (e.g., Fowler 2003, 2009) serve to guide us in asking management questions. They establish the definition of a good management question. We must be capable of asking questions about the sustainability of our influence on other species in order to have a realistic form of management at the species level. We must be capable of asking questions about the sustainability of our influence on ecosystems in order to involve ecosystem-based approaches to management. We must be capable of asking questions about the sustainability of our influence on groups of nonhuman species in order to embrace multi-species approaches to management. We must be capable of asking questions about the sustainability of our influence on landscapes in order to make management at the level of landscapes part of our management process. We must be capable of asking questions about the sustainability of our influence on ecological communities in order to have management that applies at the level of ecological communities. We must be capable of asking questions about the sustainability of our influence on the biosphere in order to fully include the biosphere. We must be capable of asking questions about the sustainability of our influence on other individuals (human and nonhuman) in order to carry forward with management at the individual level. The simultaneous treatment of such hierarchical complexity contributes to the systemic quality of resulting management.

The pattern involved in the last paragraph involves the matter of intransitive management in recognition of the impossibility of taking action without systemic consequences (Fowler 2003, 2009). Management questions must always be framed in terms of what we (the human species or humans as individuals) can do to achieve sustainable relationships with the other elements of our environment, whether they be other individuals (regardless of species), other species, ecosystems or the biosphere. We are all parts of the complexity of nature, all of which are interrelated, directly or indirectly. When we ask questions in terms of *at what rate, how much* or *to what extent*, we orient the science toward the production of patterns that provide quantitative goals and objectives. Risk averse consistent applications (Hobbs and Fowler 2008) are inherent to the use of patterns for guidance; through the pattern-based nature of systemic management we achieve an automatic accounting for complexity to include risks. This renders unnecessary the current interdisciplinary efforts to convert information (Step 4, top row of Fig. 1), and places emphasis on the importance of science to reveal informative integrative patterns consonant with the management question. The role of scientists becomes defined as one of helping to ask clear management questions, ensuring that the research questions are consonant (Steps 2 and 3, bottom row, Fig. 1), and carrying out the research thus defined. Academic or theoretical research can be used to both lead to the posing of good management questions and to the identification of correlative relationships within patterns. Achieving sustainability is not confined to something humans do in the goal setting process of management; it includes action taken to achieve those goals − goals of being involved in normal interactions in our relationships with the non-human (Fowler and Hobbs 2002, Fowler 2003).

The interconnected and complex nature of reality behind the emergence of integrative patterns (Belgrano and Fowler 2008) guarantees that every policy based on patterns will be ecosystem-based because the physical, biological and evolutionary aspects of ecosystems of the world are included in the complex set of factors that contribute to the formation of patterns. This includes all management questions informed by patterns involving direct interactions with ecosystems (e.g., *What portion of biomass production within the Georges Bank ecosystem of the Northwest Atlantic should be left for sustainable dynamics of this ecosystem and all of the ecosystems containing populations of the same species?* paired with the consonant science question: *What portion of the biomass production within the Georges Bank ecosystem is not consumed by non-human mammals of human body size?* − see Hobbs and Fowler 2008). The same holds true for evolutionary factors. Evolutionary forces, processes and history (including human influences) are integral to empirical patterns. Overt consideration of genetic effects and selectivity is possible in specifically refined questions. Thus, evolutionarily enlightened management becomes possible. It becomes possible by first asking management questions that overtly involve selectivity. Science then reveals the patterns regarding that selectivity (e.g., Etnier and Fowler 2005). When action is taken based on the consonant patterns, it is both ecosystem-based and accounts for all evolutionary factors by virtue of the complexity of ecosystems and all processes of natural selection involved in the emergence of the patterns. It directly applies to ecosystems when we avoid abnormal selective influence on and within ecosystems.

The objective of maintaining health and sustainability and the objective of avoiding the pathological find common ground in the ways they guide science in its function of observing, characterizing and analyzing patterns that are consonant with management questions (Belgrano and Fowler 2008). This results in a union of science and management that obviates the practices of current management in which teams of scientists, managers, stakeholders, and special interest groups inject human limitations into the process of establishing objectives for management. In systemic management such groups continue to be involved in the exercise of managing by asking management questions and taking action to achieve sustainability, normalcy, and health. The objectives, however, are established with information showing what is normal and what is abnormal – objectives that are consistent among all applications (Hobbs and Fowler 2008).

A common reaction by stakeholders to the use of a consonant pattern for management is the feeling their concerns are not heard or not addressed. Any stakeholder may experience such a reaction. Addressing a question of sustainable production of PCBs in the face of a killer whale decline may be met with "yes, but what about the PCBs that are already out there?" A program for removing PCBs from the environment is an example of 'conscious purpose' (Bateson 1972) or 'misdirected reductionism' (Belgrano and Fowler 2008). The effects of management to remove PCBs from the environment will include unintended consequences, many of which may be counterproductive and cause more harm than good. The temptation to rid the environment of PCBs manufactured by humans is not the intransitive of systemic management (action that controls human interactions with the non-human, Fowler 2003). The concerns about PCBs in the environment need to be understood as having been accounted for in the patterns used for management. We can not change the past. The presence of PCBs in the environment is a part of what contributes to current sustainability of harvests, sex ratios, and marine protected areas indicated by patterns among other species. That is, existing patterns are not necessarily normal or healthy in long-term standards and cannot be until we humans achieve normalcy in the variety of ways we currently affect the systems with which we interact and of which we are a part. Natural degradation of PCBs will happen. Knowing that PCBs cause problems generates the management question: *At what rate can we sustainably produce PCBs?*

Along similar lines are different concerns. For example, one reaction (to declining killer whale populations) might be: 'yes, but what about the effects of fisheries?' This leads directly to new management questions: *At what rate can we sustainably harvest fish that killer whales consume?* and (the complementary question): *What should be left for the rest of the ecosystem (the non-human, including killer whales)?* Stakeholder concerns are thus addressed in the question asking component of systemic management (Step 2, bottom row, Fig. 1). They are addressed either as a refinement of an existing question, a new question, or both. In all cases, the mission is one of avoiding the abnormal to achieve sustainability as these questions are used to generate science questions that lead to the characterization and analysis of consonant patterns that show us the difference between normal and abnormal.

There are no singular or simple reasons for avoiding the abnormal; it always involves the complexity of systems. Action to achieve consonant pattern-based goals is not taken merely to achieve normalcy or to avoid the abnormal/pathological in any one of the many ways aberrant conditions can be observed. The motivation for avoiding the anomalous involves a huge wealth of factors. Achieving a normal level of harvesting in commercial fishing provides an example. Certainly, harvesting fish at levels that are 2% of current harvest levels (Fowler and Hobbs 2002) would achieve the objective of avoiding the aberrant in consumption rates. Reductionistic confinement of our motivation to no more than that, however, is too simplistic to meet the need for management that accounts for the complexity involved in the reality within which we find ourselves. Reducing the commercial harvest of fish in the Bering Sea, for example would be carried out to account for the effects of fishing on the decline of Steller's sea lions (NRC 2003), for the effects of fishing on the decline of northern fur seals (Towell et al. 2006), and for the effects of fishing on the seabird populations (declining or otherwise; Hunt and Byrd 1999). Relieving the system of the abnormal influence of commercial harvests would be carried out to account for *all* the effects of commercial fishing on *all* aspects of the Bering Sea ecosystem as a whole – the effects on each and every species from the viruses to the whales and every process from primary production to evolution and coevolution. These effects would include all of the direct effects as well as all of the indirect effects, regardless of how indirect they might be and regardless of their magnitude, quality, or kind (Belgrano and Fowler 2008). Thus, accounting for complexity in systemic management goes well beyond the complexity involved in the guiding information (the integral nature of patterns); it also includes the full complexity of factors involved in achieving healthy interactions with the non-human (Fowler 2003, 2009).

Among these effects would be the genetic effects of commercial fishing. Thompson (2005) and many others have urged a form of management that is 'evolutionarily enlightened.' Among the elements of genetic effects is their intensity. The intensity of the genetic effects of the selectivity of commercial fishing is directly proportional to the intensity of the fishing rate. Thus, the entire spectrum of genetic effects, whatever they are, would be reduced by reducing the rate at which fish are harvested. The selectivity itself can be dealt with directly (Etnier and Fowler 2005) as exemplified by the pair of questions (above) regarding size distribution in the diets of marine mammals (science) and in commercial catches (management). Again, management would be carried out not simply to avoid abnormal genetic effects on harvested species, but to also avoid abnormal genetic effects on other species throughout the system in the web of coevolutionary interactions.

The importance of the point exemplified in the last two paragraphs cannot be emphasized enough. Management action to achieve normal interactions between humans and the nonhuman amounts to measures taking into account all of the ripple effects of all of the influences we have on the systems around us. It accounts for higher order effect and indirect effects – all systemic effects. In other words, systemic management accounts for the general principle that the reality of which we are a part is composed of other parts, all of which are interconnected to one extent or another, directly or indirectly (Belgrano and Fowler 2008, Fowler 2009). To achieve the general goals of ecosystem-based management, all indirect and higher order effects of our management must be taken into account and taken into account in asking ecosystem-based questions such as *"What portion of the production by pollock (*T. chalcogramma*) should we leave for the rest of the ecosystem in the eastern Bering Sea?"* (Hobbs and Fowler 2008). The longer term effects of our actions must be taken into account. This happens when we take action to avoid the pathological in our interactions with other species, ecosystems, and the biosphere. Thus, harvesting fish, harvesting timber, and producing CO_2 (and other interactions with the non-human) at rates that are normal is done to account for the contribution such influence has on the risk of extinction for all species (non-human as well as human, Fowler 2003).

It has long been recognized that the management decisions we make must be based on the best scientific advice available (NRC 2004). The refinement of consonant pairs of management/scientific questions leads to that advice. The best science is the science conducted to expose, document and analyze patterns that are consonant with the corresponding management question (Belgrano and Fowler 2008). This involves a distinction between the quality of the scientific process and the kind of scientific product (Fig. 2).

Scientific training and a great deal of experience lend to a history of learning what qualifies as adequate research practices (the 'y' axis of Fig. 2). The products of science do not work well in decision making if they are not produced through research that meets the standards of repeatability, being subject to peer review, and other matters of concern in conducting our science very well. However, this is not the focus of the definition of best available science or scientific information for management that is being developed here. Here, we are focused on the choice of information produced by science (the 'x' axis of Fig. 2), knowing that they have to be produced through acceptable processes (the 'y axis'). Among the products of science are the exposure of problems, explanation, discovery, characterization, prediction, analysis, and categorization. Science finds, describes, and explains patterns. Out of the huge array of information produced by good science, the best scientific information available for management is the information in patterns consonant with the management question being addressed (Belgrano and Fowler 2008, Fowler 2009). The best science for management is that which exposes, analyzes and documents such patterns − a small portion of the voluminous fruits of science. The more refined the pair of questions (each pair being a management question and its consonant science question) the more we can rely on the information to meet our needs in management if it is a pattern defined by both questions. The more refined the management question, the more we can refine the scientific question. The process of refinement brings overt treatment of specific elements of concern – elements of concern that can be brought to the management process early in the process (Step 2, bottom row of Fig. 1) by anyone, any organization, or any piece of legislation. This hinges on the acceptance of health, sustainability and normalcy as values that both have common ground and are paramount to other values (Belgrano and Fowler 2008).

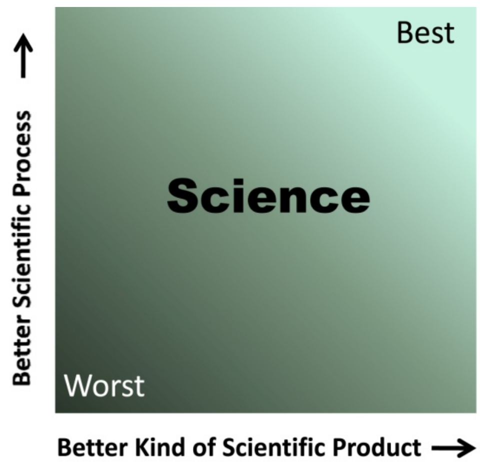

Figure 2. The best science for management is that which is both conducted well (involves the quality of the scientific process) and produces the kind of product that management can use effectively and realistically. The latter is to be evaluated in terms of the consonance between the management question being addressed and the pattern observed, analyzed and documented.

Consonant reality-based management (consonant pattern-based management, or systemic management, Belgrano and Fowler 2008, Fowler 2003), is management that accounts for everything to the degree that we

1) ask the right management questions,
2) achieve progress in the defining and refining of both the management question and its consonant scientific question (a reductionistically holistic process), and
3) carry out management to avoid the abnormal as revealed by patterns that are consonant with the two questions as they are characterized by science (Step 4 in systemic management, Fig. 1).

Because of the immense complexity of systems, we can complete only a portion of tasks before us, just as it is impossible to conduct perfect science. In systemic management (logically consistent pattern-based management) those things that we successfully achieve will be in the direction of sustainability, health and normalcy free of the logical errors, inconsistency and mistakes that we are making now.

As a society and as scientists and managers, we have tried for many decades to manage our resources (transitively) through conventional thinking – thinking that developed the concept of maximum sustainable yield and its derivatives. Experience has shown that way of thinking to be flawed because it does not account for systemic effects. Its applications to management (both personal and societal) have led to the crises (human, ecosystem and biosphere) that we experience in the world today. What we are proposing here and in other publications (e.g., Fowler and Hobbs 2002, Fowler 2003, 2008, 2009, Hobbs and Fowler 2008) is not a way of fixing the conventional way of thinking by refining or expanding on those applications. Systemic management is an entirely different way of thinking; it replaces conventional thinking rather than repairing it, fixing it, or changing it. The resulting approach to management is systemic, not only because it involves change that is systemic to human endeavor, but also because it incorporates the fundamental truth that things are intricately interconnected in the systems of which we are a part – infinitely more than accounted for in conventional thinking. Any realistic management scheme must emerge from that reality – something that we argue is fundamentally integral to systemic management. Conventional thinking will never lead to sustainable ways for our species to interact with our fellow species, or the Earth's ecosystems and biosphere, of which we are a part. It is being increasingly recognized that our very survival may depend on our changing the way we think.

SUMMARY

Knowing how to distinguish and ask good management and science questions is a core element in solving the ecological problems we face in today's world. This involves the basic distinction between science and management (observing, analyzing, documenting in science vs. decision making, action, and policy setting in management). The posing of questions involves achieving a match between a specific management question and a specific science question. The match in such pairs of questions is consonance, i.e., each pair has identical units and logical type and specify similar circumstances and conditions. The more refined the pair of questions the more the circumstances and conditions are specified. In other words, the factors involved are accounted for overtly rather than being lumped in a simple one-dimensional treatment. Overt treatment of correlative patterns revealed by science is simply an analysis of variance – a statistical exercise. This is an option owing to the fact that the model of sustainability being used is an empirical model − reality represented by statistics. These statistics (a statistical model, Pilkey and Pilkey-Jarvis 2007) are what we have to work with. The posing of questions so as to obtain these statistics needs to be improved through the perspective we bring to the interface of management and science.

The refinement in pair-wise posing of management and science questions is a critical element in bringing out the best of science and demonstrating the ways science can contribute to effective management. The wealth of scientific work to be done emphasizes the importance of science – true management science. The exposure of a pattern consonant with a specific management question results from the effective definition of the consonant scientific question. The information representing the pattern is the best scientific information to be used in management with the goal of health, sustainability and normalcy (thus avoiding the unhealthy, unsustainable and pathological). The science that exposes the pattern is the best science for providing information to be used in management, followed by science that analyzes and characterizes such patterns, including the use of correlative variables derived from a variety of fields of science. Academic, exploratory or theoretical science is very important to the refinement of paired scientific/management question through the exploration of correlative subpatterns in addition to establishing basic scientific principles. Involved, as a crucial form of research, are the scientific endeavors that expose problems that give rise to new management questions. When the problems exposed are problems of human abnormality compared to the non-human, we can take action to solve them.

The change we call for in this paper (moving from the top row of Fig. 1 to the bottom row) involves an entirely different way of thinking – an entirely different approach to management. Although the structural changes may seem simple and perhaps even trivial, they actually represent a deep change in thinking – a change from seeing the world as discrete manageable units to seeing it as a complex system that defies control at any level. Whether we have the self-control, the will, or sufficient wisdom to make the changes remains to be seen.

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APPENDIX 1

QUESTIONS ASKED AT THE ALASKA FISHERIES SCIENCE CENTER, 2005

Following is an annotated list of responses by program leaders at the Alaska Fisheries Science Center (AFSC, a programmatic element of the National Marine Fisheries Service, National Oceanic and Atmospheric Administration) in Seattle, Washington when asked to pose management questions in preparation for their annual Program Leaders' Meeting in January, 2005.[3] These questions were intended for a brainstorming session during the meeting and are listed below verbatim, most followed by notes regarding the quality and nature of the question in light of the definitions, distinctions, and concepts developed in the main text of this paper. Keep in mind that these are questions asked by people who are primarily scientists rather than managers, but, also, that these same scientists are employed in an agency with mandated responsibility for managing our use of marine resources. The questions reflect not only the training of the individuals involved, but also their unique experiences and differing backgrounds, the time spent employed in various current and prior positions, as well as their personal perception of what constitutes a valid management question. Thus, in parallel to the ways patterns are integrative of the suite of factors which contribute to their origins, the questions asked by the program leaders reflect the full suite of contributing factors in their thinking, training, and experience.

Many of the responses (those following the numbered questions below) were not considered to be real questions and are not annotated although each raises elements of concern to management. Of the responses that were considered to be real questions, only questions 12, 15, 25, 44, 45, 46, 87, 88, 93 (~9%) are true management questions in terms of objectives for our (human) interactions with the non-human (other species, ecosystems or the biosphere). A number of questions are management questions regarding the conduct of science (e.g., no. 22, 24, 27). Others relate to management of the function of the AFSC (e.g., no. 2 involves management of the Center as an organization). Most of the remaining questions are science questions (many related to understanding, characterizing, predicting, or explaining things such as population dynamics, ecosystems and their properties or functioning, etc.), or questions regarding the conduct of science (i.e., the management of research efforts rather than management of our interactions with other species, ecosystems, etc., e.g., no. 5, 6). As with the non-questions, many (possibly most) of the science questions relate to factors that would be important to correlative analysis of patterns consonant with good management questions.

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[3]The exercise of asking management questions was discussed at administrative meetings prior to the center-wide Program Leader's Meeting in 2005. In a message sent to all division directors and program leaders prior to the center-wide meeting program leaders were reminded that "…everyone has been asked to provide their list of management questions…[verbatim quote with original formatting]." This list was subsequently provided to the senior author by the Center Director.

Good examples of management questions regarding our use of resources are posed in the main text (involving quantified sustainability of our [human] interactions with other species, ecosystems, or the biosphere). The lack of such questions in the following list does not detract from the utility and importance of asking good management questions regarding the conduct of science/research, the function of organizations like the AFSC, or training and education of scientists. In all cases, the answers are found in information regarding what works – patterns in successes achieved in the trial-and-error process of learning through experience, whether that be at the human management level or the level of macro-evolution. Systemic management, as described in the body of this paper, can be applied to find sustainable human interactions and relationships with systems in general.

It is worthy of note that many of the questions in the following list involve habitat (no. 5-9, 11-17, 20-24, 42, 48, 51, 53-55, 61, 62, 83, 90, 91, 93, and 98). Ecosystems and habitat share the common features of being subject to human definition as areas that can be mapped − spatially defined pieces of the biosphere. The matter of defining habitat is the subject of a number of questions. In our annotation of many of the habitat related questions, we relate the issue to questions that can also be asked of ecosystems. As management questions these include: *At what rate can we sustainably harvest biomass from habitat X?* See, for example, questions 5, 9, and 11. Another habitat-based question is: *What portion of the production within habitat X should be left for the sustainability of that habitat (and the associated set of populations representing various species)?* Thus, another feature of all habitats is that they are occupied by populations of a variety of species. As has been recognized for decades, finding a sustainable harvest from multispecies complexes is one aspect of management that has presented challenges to managers and scientists alike. Any subset of species within a particular habitat presents the opportunity to carry out systemic management. Thus, we are faced with questions such as: *How much of the productivity by the finfish in habitat X should be left (unharvested) for the sustainability of that habitat?* The consonant research question then is: *What portion of the productivity by the finfish in habitat X is not consumed by each of the nonhuman mammalian predators of human body size?* As in all cases, management would avoid the abnormal as seen in empirically observed patterns. To deal with the complexity of natural systems, this exercise can (and should) be repeated for all habitats within an ecosystem (as well as the ecosystem itself).

This process should be repeated for all groups of species defined independently of any particular habitat (i.e., in addition to those defined by the populations in any particular habitat). Such groups would include all species that serve as prey for any particular predator (especially predatory species for which there is concern about population status), various taxonomic groups (e.g., finfish, cephalopods, or crustaceans), and species whose life history strategy fall into identifiable categories (e.g., subdivisions of the range of age-at-first reproduction, range of r_{max}, or range of adult survival rates). Managing our harvest of any multispecies group is one of the applications of systemic management that, when applied, achieves consistency with other applications (e.g., harvests from ecosystems, sustainable selectivity, allocations over space and season, or production of pollutants).

Annotated list of management questions proposed by program leaders of the Alaska Fisheries Science Center in 2005.

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1. *What determines recruitment of our managed populations?*
   This is a research question involving explanation. It does not involve a sustainable human/nonhuman interaction. However, any of the factors that determine recruitment can be seen as potential correlative variables in patterns of direct importance to management (e.g., sustainable harvest rates found in research reveal patterns in consumption rates among nonhuman species).

2. *How can the AFSC integrate ecosystem information into the management process?*
   This question involves the use of information (and thus management of people's activities in decision making), but does not directly involve human-nonhuman interactions. It exemplifies the tacit assumption that people can do the integrating rather than taking advantage of the integral nature of empirical patterns. All kinds of information have the potential for being used in correlative analysis of patterns consonant with a good management question.

3. *What are the best ecosystems to examine?*
   This question involves the conduct of science (not human-nonhuman interactions). If our management question involves sustainable consumption of ecosystem production in marine ecosystems, then marine ecosystems are likely to better serve a useful purpose than terrestrial ecosystems, but cross comparisons are likely to be informative (i.e., likely to reveal correlative patterns at the ecosystem level).

4. *What environmental factors affect recruitment?*
   This is a research question involving explanation. It does not involve a sustainable human/nonhuman interaction. The results of science conducted to address this question are likely to reveal correlative factors important to good management questions.

5. *What constitutes habitat?*
   This question involves definition of a term. It does not involve a sustainable human/nonhuman influence on habitat. The consonance of questions and pattern depend on consistent definitions (e.g., sustainable harvests in a particular habitat depend on having a definition of the habitat that guarantees consistency between management question, research question, pattern and management action). Habitat of any definition involves an area in which many management questions apply (e.g., *How much biomass can be sustainably harvested in habitat X? How many species can be sustainably harvested in habitat X? What portion of the productivity of species Y can be sustainably harvested in habitat X?*)

6. *How should we assess habitat function and quality?*
This question involves the conduct of science and, therefore, the management of human activities in research. It does not involve a sustainable human/nonhuman influence on habitat or any of its dynamics, qualities, or characteristics. If the results of related research reveal abnormal conditions, such information provides motivation for asking management questions regarding any known or potential anthropogenic contributions to the abnormality.

7. *Is recruitment limited by available suitable habitat?*
This is a research question involving explanation. It does not involve a sustainable human/nonhuman interaction on either recruitment or habitat. The portion of an ecosystem comprised of a particular habitat can easily be expected to be of correlative importance in sustainable harvest rates, selectivity, and other human interactions with the nonhuman.

8. *What are the impacts of fishing on demersal habitat?*
This is a research question involving the identification of human influence. It does not involve sustainability of that influence. If any of the influences of fishing (commercial or otherwise) are abnormal compared to the same influences by other species, there is basis for corrective management action.

9. *Which habitats are affected by fishing and for how long?*
This is a research question involving the identification of things influenced by fishing. It does not involve sustainability of that influence. Because we know *a priori* that fishing involves influence, this leads to management questions such as: *At what rate can we sustainably harvest fish in habitat X?* This leads to the research question: *At what rate do mammalian consumers of human body size consume fish in habitat X?* See question no. 5.

10. *Can the ecosystem approach to management reduce population declines relative to single species management?*
This is a question about the efficacy of management and would involve monitoring systems in their response to management (whatever it is), and involves research more than management. It prompts questions about the definition of "ecosystem approach to management" which lead to management questions such as: *What portion of the production of biomass in ecosystem X should be left unharvested for the sustainability of other species and the system as a whole?*

11. *Can fishing pressure be rotated to maintain habitat integrity?*
This is a question about the efficacy of management and would involve monitoring systems in their response to management (whatever it is), and involves research more than management. It does not involve the sustainability of fishing pressure. However, it does relate to variation in the spatial distribution of fishing and gives rise to management questions such as: *In achieving sustainability, how much variability in the spatial distribution of commercial fishing effort should we require?* The consonant research question is then: *How much variability do we observe in the location of consumption by*

nonhuman mammalian species of human body size? How much biomass can be sustainably harvested from habitat X in season Y?

12. *If fishing pressure can be rotated to maintain habitat integrity, on what time scale should it be done?*
    This comes close to being a clear management question. *How often should we relocate our fishing pressure in a sustainable fishery?* The consonant research question would be: *What is the temporal variation in the location of predation by mammalian predators of human body size in their consumption of fish?* See questions 5 and 11.

13. *Can habitat function be restored?*
    Because no other species restores habitat, the answer is no. However, the question can be used to proceed to different questions, keeping in mind that habitats will continually change in response to natural change in the environment. A generic question that lacks specificity but covers the kind of questions exemplified in the main text would be: *What can we do to restore our role in ecosystems to normal levels given current circumstances?* On the path to greater utility (allowing natural systems to undergo natural recovery from human disturbance) we can ask the question: *What kinds of management can we undertake to promote homeostatic change in communities and ecosystems so that they regain their health (i.e. ecosystem level characteristics that themselves are normal – e.g., mean tropic level, numbers of species, diversity, extinction rates, etc.)?* This would be basis for more specific management questions such as: *What portion of the productivity of an ecosystem should not be harvested so that it is left for the sustainability of the other species in that ecosystem, its structure, and its function both ecologically and evolutionarily?*

14. *In which habitats should function be restored?*
    This question assumes a transitive option for restoration rather than asking what we can do so that homeostatic processes can play out. In terms of intransitive action (management of human activities), the answer would be: *in all habitats* (otherwise we fail in the objective of application to entire ecosystems). Specific management questions in this regard then include: *What portion of the productivity of habitat X should not be harvested so that it is left for the sustainability of the other species in that habitat (and ecosystem), its structure, and its function both ecologically and evolutionarily?*

15. *How would/should we go about restoring habitat?*
    This is a question about the management process and the answer is: Take action to ensure that all habitats, the species in those habitats, and ecosystems within which the habitats occur are free of any abnormal influence by humans. Management questions then involve the sustainability of any influence and the consonant research questions reveal the patterns of such influence by other species so that any abnormality by humans can be measured. See question 14.

16. *Can habitat damage/loss be mitigated successfully?*
Conventional mitigation is largely symptomatic relief of problems that need direct solution. Damaged habitat needs to be freed of abnormal human influence so that it can regain a normal state through the homeostatic processes of biotic systems. Mitigation is a transitive (manipulative) form of management that results in problems different from those for which mitigating action is taken. The observation of damaged habitat (often a product of research) is basis for asking management questions that lead to the identification of abnormal human influence – any influence that may be contributing to the identified problem.

17. *If habitat damage/loss can be mitigated successfully, which habitats are most likely candidates for such action?*
See questions 14 and 16. In general, habitats subject to the most extreme of abnormal human influence, or more abnormal traits for such habitats, would likely be given higher priority for restoration of normal human influence than for habitats subject to less extreme human influence or less extreme habitat-level abnormality.

18. *What is the impact of global warming on the distribution of commercial fish?*
This is a research question involving explanation. It does not involve a sustainable human/nonhuman interaction. It leads (via the interconnected nature of systems) to management questions such as: *At what rates can a mammalian species of our body size sustainably produce carbon dioxide?* Other green-house gases and particulate materials could be substituted for carbon dioxide in this question to result in a variety of distinct management questions (one of the ways we deal with complexity in systemic management).

19. *What if the impact of global warming results in fish moving outside of U.S. controlled waters?*
This is a research question related to monitoring (observing the effects of global warming). Implied, however, are issues of global warming (see question 18). We might also take this question to management in reaction to the relocation of fish: *What is a normal relocation of fishing effort in response to movement in resource species (in reaction to climate change)?* The research question that matches this is: *To what extent do mammalian predatory species of human body size relocate their foraging range in response to changes in the location of prey species as they react to climate change?*

20. *What is the impact of trawls on the benthic fish habitat?*
This is a monitoring (research) question. The results of research to answer this question would be compared to the results of research to determine the effects of other species on habitat. Any abnormality on the part of fisheries would be subject to corrective management action.

22. *How do we define essential fish habitat?*
This is a question regarding definition rather than sustainable human influence on fish habitat. Whatever 'essential' is, research to define normal influences on that habitat would be conducted to guide management. However the habitat is defined, it leads to management questions regarding our influence on that habitat.

23. *How are the essential features of Essential Fish Habitat jeopardized by fishing activities?*
This is a research question involving explanation (documenting the effects of fishing). It does not involve finding sustainable human/nonhuman interactions with, or influences on, such habitats.

24. *How do we measure the essential features of Essential Fish Habitat so that they can be mapped?*
This is a question about the conduct of research (managing human activities in science, but not in human interactions with the nonhuman). It is a step toward asking management questions related to the spatial allocation of harvests, and area-specific harvest rates, in sustainable fishing.

25. *How do we control fishing to prevent excessive damage to essential features of ecosystems?*
This is a question related to the kind of management we undertake. It provides a good example of control over fisheries (intransitive management) rather than manipulation of ecosystem. In systemic management, abnormality is avoided in all of the ways we influence ecosystems. The ways we control fishing involve all the ways we control fishing now (e.g., laws, quotas, area and seasonal allocation, and gear restrictions), with such control aimed at avoiding the abnormal.

26. *Is Ecosystem Management really just an effort to manage commercially important species (high trophic level)?*
This question deals with the definition of ecosystem-based management. It involves a transitive component (managing species at higher trophic levels) and is in violation of the tenet of management requiring that we confine control to ourselves. It leads, however, to good management questions such as: *What portion of the productivity of species in the fourth trophic level can we sustainably harvest?* The consonant research question is then: *What portion of the productivity of species in the fourth trophic level is consumed by the nonhuman mammalian species with body sizes similar to humans?* Any abnormality in human harvests would be subject to managerial correction. See the main text for consideration of the allocation of harvests over several trophic levels.

27. *Can ecosystem health be assessed by monitoring status of commercial fish stocks/complexes?*
This question involves the interpretation of information produced by research. In systemic management, any abnormality is interpreted as a problem involving the health of the system involved. If it is a nonhuman system, any abnormal human influence on that system (direct or indirect) is subject to correction.

28. *Would ecosystem health be better assessed by monitoring benthic and planktonic communities?*
Abnormality in any system (e.g., species, community, habitat, ecosystem, biosphere) or ecological relationship (e.g., predation rates, selectivity, energy transfer, distribution) is a matter of pathology. Correcting abnormal human influence is the only realistic option for management (i.e., where we have the option of control with realistic systemic consequences).

29. *What tools and skills are available to monitor benthic and planktonic communities?*
This question has to do with the quality of science/research conducted (and any related education involved) rather than human influence on the nonhuman.

30. *Do recruitment processes in apex predators better reflect long term trends in ecosystem?*
This question has to do with choices regarding what to use in assessing ecosystems. In systemic management, any aspect of ecosystems that shows abnormality is basis for searching for abnormal human influence(s) and taking corrective action (management).

31. *Aside from fishing, what other anthropogenic components affect ecosystem health?*
This question is a good example of the kind of question that any stakeholder can ask in the process of getting to actual management questions. It leads to the identification of influences in which any human abnormality can be corrected. For example, pollution may be suspected as an element of concern. This leads to management questions such as: *At what rate can we sustainably produce estrogenic compounds (measured in kg per year, in 17β-estradiol equivalence)?* An example of a consonant research question is then: *At what rate do nonhuman mammalian species of human body size produce estrogenic compounds, in kg per year, measured in 17β-estradiol equivalence?*

32. *What tools and skills are available to monitor other anthropogenic components?*
See question 29.

33. *Does AFSC have quantitative skills and will to share databases to develop ecological models?*
See question 29, now with specific reference to the staff of the Alaska Fisheries Science Center.

34. *What is the reference point for determining when an ecosystem is in trouble?*
This is a question regarding the interpretation of data collected in ecosystem monitoring. In systemic management, any ecosystem attribute that shows abnormality (above or below the normal range of natural variation) is a sign of trouble. Any abnormality is always basis for asking questions regarding potential abnormal human influence of any kind.

35. *Can current physical data and weather data be accessed and integrated with biological data?*
This question relates to what we can and cannot do as scientists in the synthesis of information. Owing to the impossibility of realistically recombining fragmentary information (the Humpty Dumpty syndrome, Fowler 2003) in models of ecosystems, the remaining option is to use such information in correlative analysis of patterns consonant with management questions. Thus, if the management question is: *What portion of the total productivity of an ecosystem should be left in the ecosystem for the sustainability of the ecosystem, the sustainability of all populations of the species involved, and the sustainability of all interspecific interactions?*, the consonant science/research question is: *"What portion of the total productivity of the ecosystem is not consumed by mammalian consumer species with the body size of humans?* The pattern revealed by research to answer this question can then be analyzed to determine if there are correlative relationships in which consumption rates are a function of physical, climatic variation, or changes in the weather (e.g, seasonal variation).

36. *Can entire ecosystems be assessed as to health, or must they be partitioned?*
This question deals with the relative merit of assessing the health of whole systems (ecosystems) or their parts (e.g., species, communities, predator/prey systems, coevolutionary systems). Making this a decision based on human judgment perpetuates the subjectivity of conventional management. In order to be realistic, and holistic (account for complexity), systemic management requires both consideration of entire ecosystems and any subsystem (as well as the biosphere). Any abnormality in any system, or any of its parts, is basis for searching for abnormal human influence and taking corrective action.

37. *Can we identify keystone or indicator species for each component of an ecosystem?*
In regard to the 'indicator species' aspect of this question, see question 36. In regard to definitions, see questions 5 and 22. Regarding the 'keystone' aspect of this question, keystone influence is part of the natural variation against which abnormality is determined quantitatively. It should be noted that 'keystoness' is a reflection of influence and any abnormality among other species is of less concern to us than is human abnormality. The existence of 'keystoness' in not necessarily a critical indicator of ecosystem health.

38. *What kind of ecological data are required for ecosystem health assessment?*
In systemic management this involves measuring ecosystem-level properties (e.g., biodiversity, mean trophic level, mean population variability, size selectivity as a function of body size, or total productivity). With data to establish normal variation in such measures, the abnormal can be detected to establish what is healthy and what is unhealthy (abnormal).

39. *How can AFSC ecological data be integrated for use by cross cutting programs?*
See questions 29 and 35. This has less to do with organizational structure ("rearranging the deck chairs on the Titanic") than what the Center does independent of structure (correlative

analysis could easily be promoted or facilitated by a special organizational structure, but it is the correlative analysis that is important).

40. *Are there indices of ecological health for a component of an ecosystem that apply to entire system?*
This question relates to the analytical processes involved in ecosystem assessment (research, and the management of research processes, but not the management of human interactions with the nonhuman). It is entirely possible that future research will show that some ecosystem-level metrics (e.g., biodiversity) are correlated with measures of components or the parts of ecosystems (e.g., spatial distribution of a particular species). Regardless, any abnormality revealed is basis for addressing any abnormal human influence on the system whether determined by direct, or by indirect, measurements.

41. *Do human impacts alter the timing, distribution, amounts, and pathways of production in Alaska ecosystems?*
This is a research question involving connection, characterization and explanation, especially as it involves human influence. It does not involve finding sustainable human influence. If the timing, distribution, amounts, and pathways of production are abnormal, it is important to relieve the system of any abnormal human influence. Reversing the burden of proof dictates that we not wait until connections are proven.

42. *Do fisheries influence habitat boundaries and characteristics, community composition, dynamics, etc.?*
See question 41.

43. *Is the overall production and composition of Alaska Large Marine Ecosystems influenced by climate regimes and fishing?*
See questions 35 and 41.

44. *What portion of the Bering Sea should be set aside in Marine Protected Areas?*
This is a good management question. It involves human action (setting aside MPAs) and prohibiting certain human activities in those areas (not specified in the question). It involves the specification of a quantitative goal (portion of the ecosystem). It is an ecosystem-level question so meets the need for applicability at the ecosystem level. It specifies a consonant research question (assuming MPAs involve no consumption/harvesting of fish): *What portion of the Bering Sea is not occupied by each species of marine mammal of human body size?* Correlative analysis could easily find any pattern revealed to be related to season (or other variables).

45. *What portion of the geographical range of northern fur seals should be set aside as a Marine Protected Area?*
See question 44 now in relation to the geographic range of northern fur seals rather than the entire ecosystem.

46. *What portion of the geographical range of key indicator species should be set aside as a Marine Protected Area?*
See questions 44 and 45. This may involve MPAs established only to prevent harvesting of the particular species in question.

47. *To what degree are trophic dynamics of apex predators coupled to annual variation in primary production in the North Pacific?*
This is a research question involving explanation, characterization, and establishing interconnections. It does not involve a sustainable human/nonhuman interaction. It leads to the potential of primary production being a potential and significant correlative variable in finding sustainable harvests from predatory species, predator/prey pairs, or the set of species that serve as prey for an apex predator.

48. *Is climate induced change in fish habitat faster in the Arctic and sub-Arctic than in temperate ecosystems?*
This is a research question involving observation (and possibly explanation). It does not involve a sustainable human/nonhuman interaction or advisable change in fishing in response to climate change.

49. *What are the fundamental life history aspects of living marine resources that affect how environmental perturbations affect fish abundance?*
This is a research question involving explanation. It does not involve a sustainable human/nonhuman interaction. However, the life history features of species are very likely to be important correlative factors in systemically determining sustainable harvests.

50. *Are atmospherically-delivered pollutants from Asia limiting factors in the productivity of Arctic ecosystems?*
This is a research question involving explanation and interconnection. It does not involve a sustainable human/nonhuman interaction. See also question 31. Such questions lead directly to questions about the sustainability of producing any of the pollutants involved.

51. *Can total fixed carbon give us a surrogate measure of the relative importance of fish habitats?*
See questions 35, 36, and 41. Carbon fixation rates are of likely correlative importance in finding sustainable harvest rates, allocation of harvests over space, and numbers of species that can be sustainably harvested.

52. *What is the role of submerged aquatic vegetation in supporting fish assemblages in the Gulf of Alaska?*
This is a research question involving explanation. It does not involve a sustainable human/nonhuman interaction. Submerged vegetation would be one of the factors involved in the emergence of patterns of sustainability.

53. *What is the role of watersheds, near-shore habitat, Alaska Coastal Current, and offshore habitat in the dynamics of fish resources?*
This is a research question involving explanation. It does not involve a sustainable human/nonhuman interaction. See the introductory section of this appendix regarding the role of habitat in defining what to measure regarding empirical examples of sustainability, the definition of species groups, and allocation.

54. *What are the primary factors that cause change within key habitats in Alaska (e.g., watershed, nearshore, etc.)?*
This is a research question involving explanation. It does not involve a sustainable human/nonhuman interaction. Such factors are involved in the set of factors behind the emergence of empirical patterns in sustainability and hold promise of being useful in correlative analysis of patterns in the refinement of management questions.

55. *What are the effects of habitat alteration on recruitment processes?*
This is a research question involving explanation. It does not involve a sustainable human/nonhuman interaction. See question 54.

56. *What are the primary causes of mortality in fish populations?*
This is a research question involving explanation and interconnectivity. It does not involve a sustainable human/nonhuman interaction. See question 54.

57. *How does energy flow through a given food web in Alaska ecosystems?*
This is a research question involving process and interconnectivity. It does not involve a sustainable human/nonhuman interaction. Research to define rates of flow would reveal patterns that would be consonant with the management question: *At what rate can we sustainably harvest the production of walleye pollock, measured in terms of energy (rather than biomass)?* The specific consonant research question (as part of the original question) would then be: *What are the rates of energy consumption (measured as energy in the production by walleye pollock) for mammalian predatory species of human body size?*

58. *What are key behavioral and physiological aspects of key indicator species of fish in Alaska?*
This is a research question involving process and interconnectivity. It does not involve a sustainable human/nonhuman interaction. The results of such research could easily become part of correlative analysis in refining and addressing management questions such as: *What portion of the production by pollock (*T. chalcogramma*) should we leave for the sustainability of the pollock population and the rest of the ecosystem in the eastern Bering Sea to account directly for the fact that pollock begin reaching reproductive maturity at about age 3?*

59. *What are the trophic linkages of key indicator species to oceanographic processes?*
This is a research question involving interconnectivity. It does not involve a sustainable human/nonhuman interaction.

60. *What are the dominant multi-species interactions in a given ecosystem in Alaska?*
This is a research question involving interconnectivity. It does not involve a sustainable human/nonhuman interaction. This question leads to knowing that it is important to ask management questions regarding our interactions with multispecies groups (in the many ways they can be defined).

61. *What are the primary fish/habitat associations in Alaska?*
This is a research question involving interconnectivity. It does not involve a sustainable human/nonhuman interaction. As with the case of any habitat, it can lead to questions such as those asked for questions 9 and 14. See also, question 5.

62. *What are the primary impacts of human activities on fish populations (including fishing, pollution, habitat destruction)?*
This is a research question involving interconnectivity. It does not involve a sustainable human/nonhuman influence on fish populations, but leads to asking management questions regarding the sustainability of such activities. See questions 18, 19, 20, and 31.

63. *What are the key indicators of a healthy population of fish (e.g., disease incidence, lipid stores, etc.)?*
See question 28. Any abnormality is basis for searching for anthropogenic contributions involving abnormal influence.

64. *All models are wrong, but some models are less wrong than others (Orwell) - which of our models are less wrong?*
This is a question regarding the conduct of science involving both quality and kind of product (Fig. 2 in main text). In systemic management empirical patterns consonant with a well framed management question serve best for setting goals and policy. Models of such patterns do not involve simulation but do make use of statistical representations (statistical models; Pilkey and Pilkey-Jarvis 2007). The consonance avoids conversion and achieves objectivity. The empiricism avoids human limitations in synthesis so that complexity is inherently accounted for within the pattern.

65. *There is nothing so practical as a good theory (Feynman) - do we need better theories?*
This question involves the philosophy of science. It does not address sustainable interactions between humans and the nonhuman. Theory, concepts, emotions, politics, concerns, beliefs, insight, and understanding are all good as starting points in asking good management questions, but introduce error into the management process when used to set policy more directly.

66. *Can we understand underlying interactions and bioenergetics of lower trophic marine food webs in Alaska?*
This is a question regarding human limits, but leads to research questions involving interconnectivity. It does not involve a sustainable human influence on marine food webs.

It begins to address the identification of the infinite set of factors behind the emergence of empirical patterns of sustainability.

67. *What is the appropriate life stage for measuring recruitment in key indicator species?* This is a question regarding the definition of a characteristic to be measured in research. It relates to the conduct of research so that results are repeatable and consistent − the quality of science (Fig. 2 in the main text). Whatever is chosen, it can become a focus of research to either find abnormality or refine management questions through correlative analysis.

68. *When has recruitment occurred or been accomplished for a given organism (does this vary among organisms)?*
See question 67.

69. *How important are recruitment processes of lower trophic organisms?*
This is a research question involving explanation and interconnectivity. It does not involve a sustainable human/nonhuman interaction. It involves an issue of judgment (importance) that runs the risk of eroding the objectivity needed in management. The importance of such processes is realized in natural systems and manifest in the integral nature of natural patterns.

70. *Can we describe the temporal sequence of life history events that lead to recruitment of a year class?*
This is a question regarding human limits, but leads to research questions involving interconnectivity. It does not involve a sustainable human influence on life history or recruitment. Life history events are to be treated as potential correlative variables in the analysis of empirical patterns of sustainability.

71. *Can we describe fluctuations and cycles in populations of phytoplankton and zooplankton?*
This is a question regarding human limits, but leads to research questions involving description – description being one of the activities of science. It does not involve a sustainable human influence or role in the population dynamics of other species.

72. *How are fluctuations in lower trophic levels reflected in recruitment strength of upper trophic levels?*
This is a research question involving explanation and interconnectivity. It does not involve a sustainable human/nonhuman interaction. If recruitment strength can be predicted based on relevant research, it serves only as a correlative variable useful in setting harvest standards (not as measurements to be converted without correlative information in which consumption rates among nonhuman species are related to recruitment).

73. *Are Pacific salmon a keystone group of species in the North Pacific Ocean?*
This is a research question involving characterization – another of the functions of research. It does not involve a sustainable human/nonhuman interaction. If ‘keystoneness’ can be predicted or measured based on relevant research, it serves only as a correlative

variable useful in setting harvest standards (not as measurements to be converted without correlative information in which consumption rates among nonhuman species are related to 'keystoneness').

74. *How do Pacific salmon respond to changes in oceanic and climatic conditions?*
This is a research question involving explanation and interconnectivity. It does not involve a sustainable human/nonhuman interaction. Oceanic and climatic conditions serve as correlative variables that may be important in patterns of consumption by nonhuman mammalian predators and thus to realistic advice to managers.

75. *What is the impact of 25 billion young salmon (hatchery and wild) entering marine ecosystem on recruitment?*
This is a research question involving explanation and interconnectivity. It does not involve a sustainable human/nonhuman interaction. See question 72.

76. *What constitutes long term inappropriate use of hatcheries in salmon enhancement and production?*
This question is close to a good management question. A question that might be considered would be: *Should we use salmon hatcheries?* or, better: *Is the use of salmon hatcheries sustainable?* Making another species dependent on us is an unstable way to interact (a form of transitive manipulation); thus, even these questions fall short of good management questions. Relevant questions would involve: *What is a sustainable rate of energy consumption for our species (and what portion of it should be used in mitigation for other effects we are having)?* More properly, declines in salmon populations would be seen as potential symptoms of such things as overfishing, pollution, obstruction of water flow (dams), and diversion of water (e.g., irrigation). Each issues would be treated with it own management question(s). *What is a sustainable rate of harvest for each species and population of salmon? At what rate can we sustainably produce compound X (where X is a pollutant)? How much damming of (or diversion of water from) a river is sustainable?* Each would be translated to the corresponding research question to find what is normal among other species, accounting for things like tropic level, body size, and taxonomic category.

77. *Does the current hatchery program for salmon in Alaska pose a threat to sustained production of wild salmon?*
This is a research question involving explanation (not management question about sustainable effects). See question 76.

78. *How can information in the Environmental Considerations chapter of the SAFE document be incorporated into stock assessments?*
This is a question about the conduct or management of science (estimating stock size as part of the assessment process) along with the management of both AFSC and North Pacific Fishery Management Council activities. Stock assessments are not management advice (are not consonant with our interaction with fish species), but would contribute to

patterns consonant with questions such as: *What is a sustainable population level for our species?* That is, the units of the pattern involving stock estimates are population size or density and would apply to questions wherein such units are inherent (so that no conversion would be necessary).

79. *Do we need to convene annual workshops at AFSC to address specific HEPR questions?* This is a question regarding the management of the function of the AFSC (not management of our interactions with other species). Experience (historical patterns in the success of workshops to address such matters) would be used to answer the question. The important questions with regard to management of our interactions with other species would be the questions generated by HEPR. The quality of those questions determines whether or not the appropriate science is conducted to provide answers that lead to management free of political, economic, or other anthropocentric or biocentric bias.

80. *What will be the impact on the Bering Sea ecosystem when we no longer have winter ice pack on the shelf?*
This is a research question involving explanation and prediction (not management question about sustainable effects). Following known or suspected connections, it leads to questions such as: *What rates of carbon dioxide production are sustainable (normal) for a mammalian species of our body size?*

81. *What information is needed to predict the impact of climate change on the Bering Sea ecosystem?*
This is a research question involving prediction (one of the functions of science, but not management question about sustainable effects). See question number 80 as well as questions considered in the main text.

82. *What criteria can be developed to avoid developing overspecified models relative to available data?*
This is a question about the conduct or management of science (involving models to represent parts of reality). This can apply to models representing patterns that help distinguish normal from abnormal systems.

83. *What criteria should be used to characterize EFH [essential fish habitat] (location, characteristics, quality)?*
This is a question about the conduct or management of science (defining and characterizing parts of reality). The characteristics can be used in the analysis of variance within statistical patterns to respond to refinement of management questions.

84. *What criteria should be developed to address the extent to which fishing is allowed to impact EFH?*
This is a question related to the refinement of management questions (i.e., not a management question itself). Parallel to other questions regarding habitat (e.g., questions 5, 9, 14, and 87), the specific management question would be: *What is a sustainable*

harvest rate in the area defined as EFH? The consonant research question is: *What are the consumption rates by marine mammals of human body size as they are observed in the area defined as EFH?* Fishing rates that are abnormal in comparison would not be allowed.

85. *Are crabs keystone species in the Eastern Bering Sea?*
This is a research question involving definition and characterization that may relate to management of the thought process but not human interactions with other species.

86. *Why have certain overfished or depleted stocks of Eastern Bering Sea crab not recovered in the absence of fishing pressure?*
This is a research question involving explanation.

87. *How much of species X can we sustainably harvest in area Y?*
This is a good management question, but only a start toward direct accounting for the complexity of the system involved. That is, *"we"* can be assumed to be a mammalian species of human body size, but the resource species may be one with a life history that can be specified, and the oceanographic features of *"area Y"* may be correlated with harvest (consumption) rates observed among other mammalian predators. The consonant research question is: *What are the consumption rates of mammalian predators of human body size in their predation of species X in area Y?*

88. *How can we reduce the bycatch of species X in the fisheries for species Y?*
This is a question of implementation. The trial-and-error process of experience in developing gear and techniques (e.g., speed, timing, location, and depth) provide information that, after numerous attempts, begins to take shape in a pattern of ways that work.

89. *What factors explain the changes in recruitment for a given species (e.g., sablefish or ocean perch)?*
This is a research question involving explanation and interconnection. The results could easily lead to the identification of correlative variables important in the pattern of consumption rates used to avoid the abnormal in management.

90. *Are corals/sponges essential fish habitat for FMP managed species in BSAI or GOA?*
This is a research question involving explanation. Any area identified as habitat of any kind for any species can lead to asking questions about the sustainability of our influence on that habitat.

91. *Are corals/sponges essential habitat for growth, reproduction or foraging of managed species in BSAI or GOA?*
See question 90.

92. *What factors are required for the successful settlement of corals (or other living substrates)?*
This is a research question involving explanation. Any area identified as habitat of any kind for any species can lead to asking questions about the sustainability of our influence on that habitat. Any factors identified as important have the promise of being correlatively related to (or within) patterns that reveal the abnormal and normal for finding sustainable influence.

93. *What is the sustainable yield (or removal rate) of* Primnoa *(or other benthic invertebrate) in GOA[Gulf of Alaska] or BSAI [Bering Sea – Aleutian Islands]?*
This is a genuine management question. The consonant research question is: *What are the consumption rates by nonhuman mammalian consumers on* Primnoa *in the GOA or BSAI?*

94. *How fast do tunicates, bryozoans, sponges, and corals grow?*
This is a research question involving characterization. It involves measuring growth rates. Characterization is the kind of science that best serves management, but it must involve characterizing a pattern that is consonant with a genuine management question. Growth rates of resource species may be important in correlative patterns so as to help refine management questions and be of use in answering the refined questions.

95. *At what size do tunicates, bryozoans, sponges and corals become mature?*
See question 94 (substituting size at maturity for growth rates).

96. *How quickly do sessile benthic organisms recolonize after severe disturbance?*
See questions 94 and 95 (substituting recolonization rates for growth rates and size at maturity).

97. *Are successional processes involved/required prior to recolonization by long-lived sessile fishery resources?*
This is a research question involving explanation.

98. *Are estuarine and other nearshore habitats important to reproduction or survival of groundfish or forage fish?*
This is a research question involving explanation. See questions 83 and 84 regarding habitat.

99. *Should we focus research on a small number of species (learn a lot about each species) or a large number of species?*
This is a question about the conduct of science (i.e., the management of research). In terms of practical application, the question that seems to be more important is: *What attributes, characteristics, processes, are important to study?* Thus, if our management question has to do with sustainable harvest rates, the process of greatest importance to research is consumption rates (i.e., ‘harvest’ rates by other species). The more species or predator-prey pairs for which this can be determined, the better our chances of defining

sustainability in terms relevant to other ecological, morphological, taxonomic, and environmental variation. The latter, of course, involves the need to include such factors in research.

100. *How important are top-down processes relative to bottom-up process in understanding recruitment of key species?*
This question relates to understanding (through 'evaluation') rather than management. Understanding alone is not basis for management, although it substantiates basic principles (e.g., there is explanation behind everything, complex systems involve a great deal of interconnectivity, there are consequences to our choices and actions). These principles are fundamental to asking the right questions. The actual (realized) importance of any process is reflected (accounted for) in empirical patterns.

101. *How important are abiotic factors relative to biotic factors in understanding recruitment of key species?*
See question 100. Here, there is enough specificity to note that the clarity (e.g., R^2 values) and extent of correlative relationship (size of regression coefficients) play a role in answering the question. The important point here is that recruitment would serve best as a correlative variable in determining a sustainable harvest rate (using empirical patterns in consumption rates) and less as something to be converted in the processes used in conventional management.

102. *Should we focus research on a few species or a few communities or direct research more broadly?*
This is a question about the conduct of science (i.e., the management of research). See question number 99.

The following do not qualify as questions (many are simply terms naming things the individual thought were important) but, in the interest of being thorough and complete, were included verbatim as part of the response to the request for questions for the 2005 meeting of Program Leaders of the Alaska Fisheries Science Center. Relevant abbreviations include: EBS = eastern Bering Sea, CHPZ1 = Crab and Halibut Protection Zone 1 (of the eastern Bering Sea), EP = eastern Pacific, GOA = Gulf of Alaska, FIT = Fisheries Interaction Team, and MPA = marine protected area.

Habitat study - eastern Bering Sea

Habitat study - nursery grounds for groundfishes (shelf< 50 m deep)

CHPZ1 - relatively undisturbed and productive nursery for crabs and groundfish

EP - larval production - reproductive processes

EP - larval delivery systems

EP - settlement processes

EP - juvenile growth

EP - juvenile survivorship and migration

EP - maturation and migration

EBS benthic community

EBS pelagic community

Research to describe and understand seasonal and long term movements of animals

Pavlof Bay- small ecosystem with long time series of data

Prince William Sound - moderate size ecosystem with lingering pollution effects

Eastern Bering Sea - large ecosystem, primary importance to AK fisheries management

Recruitment process

Parasites- require multiple hosts between benthic, planktonic and pelagic communities

EBS pelagic community

EBS demersal community

Aleutian Island community

GOA community

FIT studies along the east side of Kodiak Island

MPAs for the Eastern Bering Sea

Ecosystem Process must be studied by integrating ecological function with habitat function

We should focus community based research in SE Alaska and adjacent coastal regions.

Characterize interannual, spatial patterns of inverterates in the EBS (inside and outside 50 m isobath)

Characterize how climate change might change the long-term pattern of invertebrate distribution in the EBS

Characterize recover of benthos following disturbance caused by fishing practices

Establish program to systematically study the effects of mobile fishing gear on the ecosystem

Establish long term study sites to investigate the impact of fishing gear on the benthos (CACI experiments)

Undertake basic recruitment studies on benthic species (i.e., infauna and off-bottom fauna)

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