Toward a Definition of Sustainability

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Abstract — Sustainability is not an absolute, independent of human conceptual frameworks. Rather it is always set in the context of decisions about what type of system is to be sustained and over what spatiotemporal scale. There is a duality of the material system itself, as opposed to human frameworks for communication or management action. Exclusive focus on the material system gives the decision-maker an impossible number of choices, and no definitions; exclusive focus on scale and type gives narrowly directed capricious action that ignores lessons from the material system. An ideal is guided by the principal physical and biological material flows, as the scientist erects a rich system definition that explicitly links different types of system, like landscape and ecosystem, across a range of scales, in a coherent complex management scheme. Sustainability is not a matter of degree, because the material imbalances of incomplete sustainability will bring all down like the ancient failure of Sumerian agriculture through salination. True, sustaining at one scale may deny sustainability at another, but if it is in a scale- explicit framework, trade-offs can be calculated and weighed. Sustainability must work with natural processes, but they are not those of the pristine system. Rather management must accommodate to new structures and their patterns of process which naturally emerge far from equilibrium as a result of a substantial human presence. In a world with 5 billion people, managing towards a pristine system is irresponsible.

INTRODUCTION

Sustainability, An Emerging Concept

Over the last decade a set of terms has emerged in the arena of resource management that indicate an alternative style of applied ecology. This new vocabulary is a response to past and present piecemeal approaches to natural resources, research and management. Terms include biodiversity, ecosystem health, ecosystem management, viable populations, conservation biology, restoration ecology, and global change. One of the most important of these terms is sustainability. Like the other concepts listed above, sustainability is an immature notion. It conjures up different images for each environmental scientist and manager, although there is a common, general understanding. For example, everyone agrees that sustainability is a good thing, and that desirable situations last longer under it. Sustainability is appealing because, despite differences as to how to achieve sustainability, both "green" environmentalists as well as those investing in commodity production favor it. Not only is sustainability a desirable ecological condition, but its reliable context is a requirement for a return on long-term capital investment. The wide spectrum of agreement on the virtues of sustainability make sustainability a touchstone for mutual consent.

Problems Of Defining Sustainability

These new terms, including sustainability are somewhat vague. Many of them have arisen because modern problems require environmental scientists and managers to grope up-scale to larger issues, such as global warming and global amphibian decline, where we have little experience to date. We have found it very helpful to fall back on the ideas and protocols of our new book, *Toward a Unified Ecology* (Allen and Hoekstra, 1992). In this paper, we will apply the general approach used

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in our book to defining and unraveling the notion of sustainability. By the end of this presentation, we hope to have given a rationale for a definition of sustainability that will offer common ground for future communication and management action.

Defining sustainability is not simple because it must apply to many ecological and social situations. To make this point, we need to draw attention to the difference between the observer and the material system. We must therefore define what we mean by the term "material system." The material system is the physical substance toward which a discussion is directed, as opposed to the abstraction of that system which emerges in words and concepts (figure 1). The material system includes humans, if they are physically present.

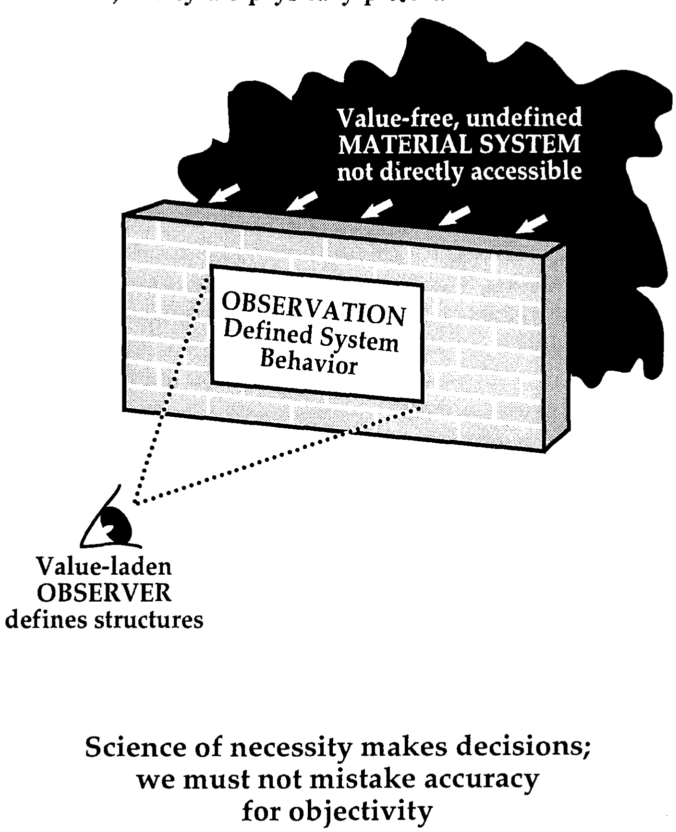


Figure 1. — Scientists do not have access to the complete material system as such, they can only collect and analyze data. The full material system is undefined and involves no values in and of itself. By contrast, the human observer experiences the material system through a set of value judgements and decisions as to observation protocol. The observation is of the behavior of a defined system.

Sustainable ecological systems can be different in two separate ways. First sustainable systems can be different because the observer recognizes different aspects of the material system as important. Those characteristics define what is in the foreground. Different material systems will suggest different criteria for what is important, but even one material situation can be viewed according to many criteria such that the ecologist recognizes an ecosystem as opposed to a community, population or landscape. For example, a given tract of land that makes up the material system can be viewed as a spatially defined and ordered place, a landscape; however, that same piece of land may be seen as a physical setting in which a population is growing or declining. Both views can be reconciled with the material system, but in the first case the system is identified as a landscape, while in the second case it is a population and its environment.

The second way that sustainable systems can be different is a matter of scale. Scale is entirely separate from differences of system type. A given material system will appear very different when it is viewed at a different scale, even if the observer recognizes the same system type. A physically small landscape can appear as different from a large landscape as it can from viewing the same material system in population and population environment terms. Appropriate action for achieving sustainability will be altered by the spatial or temporal extent of the universe to be sustained.

SYSTEM TYPE AND SCALE

Richness Of Perspective

In our book (Allen and Hoekstra, 1992) we point out that the type of ecological system must be explicitly identified by the scientific manager. System type is not self-evident and needs to be stated before any discussion. Even in the simplest setting, no two observers will recognize exactly the same features of the material system as being critical. Observers will disagree on what is in the foreground, and conversely what is in the background (figure 2). An example might be when focus on genetic variability in a population may involve ignoring the processes of nutrient flow in which the population participates; genetics comes to the foreground while nutrient cycling becomes part of the background. Choosing a point of view is an inescapable responsibility of the manager and scientist alike. Neither serious science nor effective management can proceed until the type and scale of the system to be sustained is stated explicitly.

The whole material system cannot be sustained in its every facet, and we would not want to do that if we could. Life precisely works as a process of building up and breaking down materials and relationships. In all healthy biological functioning, things persist and grow because other things are not sustained, as when prey succumbs to predator. Absolute sustainability where nothing is broken down might be possible on the moon, for that is a suitably static place, but here on Earth, a completely sustainable system in every detail cannot, and has never existed on it. So by sustainability we must mean something different from the potential for absolute and complete persistence.

Various criteria or perspectives on the ecological system are more popular than others, sometimes because they have become mistaken for the perfect or somehow true sustainability. One such criterion, which is now being redefined by a more diverse

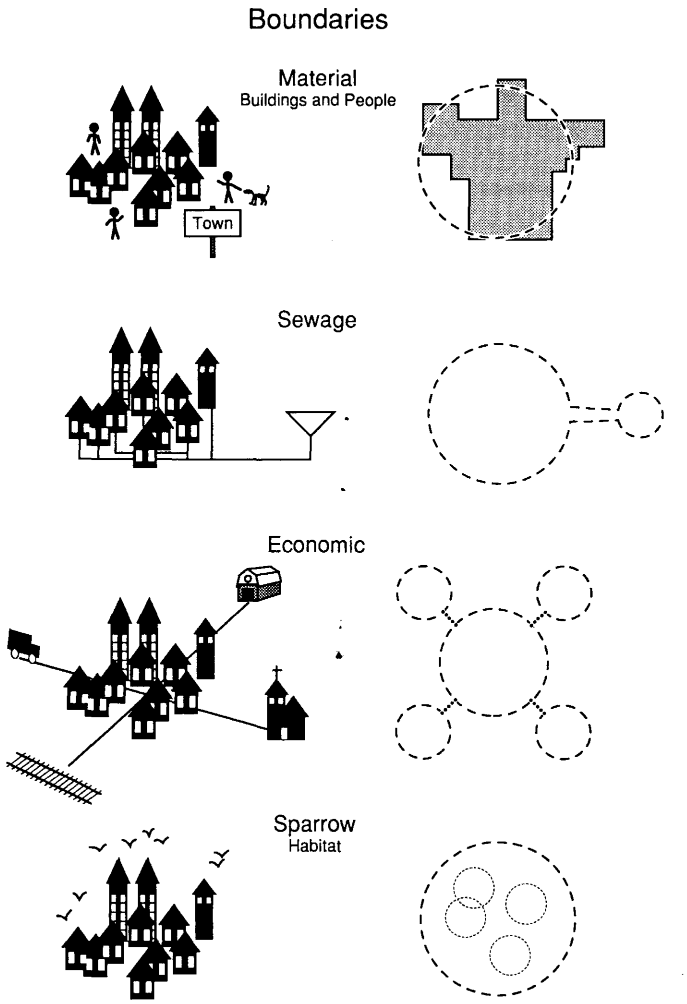


Figure 2. — A material town consists of all the buildings, ground, air and biota, including humans (top). Sustainability may involve mineral nutrient flow for recycling and waste heavy metals that must be kept out of the local food chain. The town in those terms involves connecting buildings to the sewage works. However, ecological remedial action will cost money, and so an equally valid perspective on sustainability and the town will emphasize economic considerations. Yet a third perspective might view the town in terms of the habitat for birds or other biota. Under this view, the town takes on yet another form with yet other parts (eg. nesting sites) linked together by connections important to the animals in question, but unimportant for sewage collection and economics.

ecosystem management approach is sustainable production of commodities such as timber, livestock and minerals. Another criterion that has become iconic is sustaining populations of individual species identified as critical, like the Spotted Owl. These criteria are valid for at least local, particular situations and intentions, but the mistake is using them zealously and extensively for profit or preservation to the exclusion of other criteria for sustainability. The requirement for being explicit as to criterion is not an excuse for fixating on a narrow criterion when the situation demands subtlety and complex criteria to deal with competing interests. Other different criteria for organizing sustainability might include aesthetics or human cultural preservation.

The critical point here is that sustainability must always involve a chosen perspective if it is to be meaningful. Without a suitable definition of ecological system type, it is not possible to set unequivocal standards of achieving sustainability. Without a criterion to assess results, sustainability is vacuous. Nevertheless, a criterion is a matter of human decisions, not something that follows in any necessary way from the material system, and so explicit statement of system type must be tempered by a willingness to suspend one definition and turn to another as the situation warrants. Intellectual flexibility is crucial, because rational action to make a system sustainable under one criterion might well create surprises under another that has not been considered. The problem may well be a great shock as we let the consequences of the planned management action take their course in real time. The challenge is to link different explicit types of sustainability so that a suitably rich management process is set in place. That may be something of an iterative process tested by upsets.

Scale Of Sustainability

Just as no one criterion is particularly correct, there is no nature-given scale at which a system is sustainable or otherwise. Sustainability without a stated scale has no meaning (figure 3). Since the biosphere is only as sustainable as the sun that supports it, then all ecological sustainability has an upper temporal limit. "Sustainable for how long?" then becomes a fair question. Therefore, a system that is only sustainable for a relatively short time may be well worth sustaining over that brief period. Sustainability applied to a microcosm is likely to be a critical aspect of it, even though a matter of months may be enough. Most uses of the concept of sustainability will be in between months and eons. Although the options for scale of sustainability are many, failure to be explicit makes plans ambiguous. Allen & Starr (1982) identify a corn field as sustainable over a period of two years to about half a century, but not sustainable at temporal scales of only a single growing season including the first frost or periods longer than a few centuries.

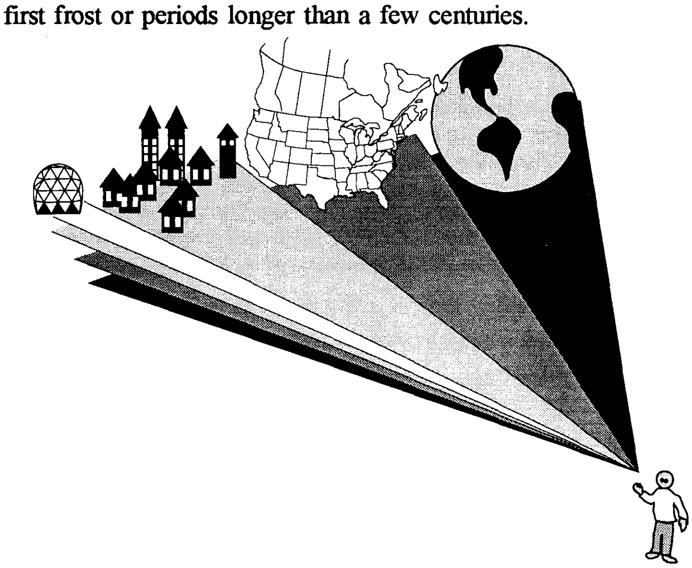


Figure 3. — Sustainability without a stated scale has no meaning.

Both the spatial and the temporal extent of sustainability must be stated for each case. Actions to sustain a local rare population are likely to be different from sustaining a large landscape mosaic across which the species moves over millennia. Often we will want sustainability for a larger spatial area to pertain to longer time frames, but the link between temporal and spatial scales is not a requirement. It may be appropriate to sustain for a very long time a small system of special cultural significance, such as a grove of sacred trees. It may also be appropriate to sustain very large systems for only a few years, as in the genetic characteristics of the crop across the entire corn belt.

CONCEPTUAL FRAMEWORK VERSUS THE MATERIAL SYSTEM

Although ecology is a matter of modeled types and scaled conceptions, do not forget that the discourse relates to a material system. It is easy to put too much emphasis either on the complete material system, on the one hand, or the conceptual framework, on the other hand. An overcommitment to either the material system or the conceptual aspects of sustainability will have unfortunate results. A complete focus on the material system leads to undefined and therefore unscientific understanding. Conversely, a complete focus on the conceptual framework leads to decisions that are not only arbitrary but also capricious. We recognize two classes of misconception about sustainability. One comes from placing an overemphasis on the observer side of the duality as opposed to the observed system. The other comes from an overemphasis on the material, observed side of the duality.

An overemphasis on the material system relates to some of the problems mentioned above in failing to type and scale the system under discussion. One manifestation of this error would be an insistent focus on the material system that existed before there was any significant human influence. We see this archaic system before the coming of our species as being of historic interest, but irrelevant to current management. It is inappropriate to strive for a completely pristine system without humans and use that as the benchmark for sustainability. The first problem with that agenda is that it cannot be achieved, even to a significant degree. Second, we would not want to do it if we could. Sustainability is appropriately set in the context of material human presence and must be prescribed by human value systems (figure 4).

All material systems can be observed in an enormous number of ways without much effort on the part of the scientist. This fact presses itself upon us when the material system offers as rich a primary experience as does ecological material. Therefore it seems particularly inappropriate in an ecological setting to hold up the full, somehow "natural," material system as the standard against which management action should be judged. If one happened to achieve sustainability of an ecological material system independent of any values, nobody would be able to tell that to be the case. There would be no way to know whether

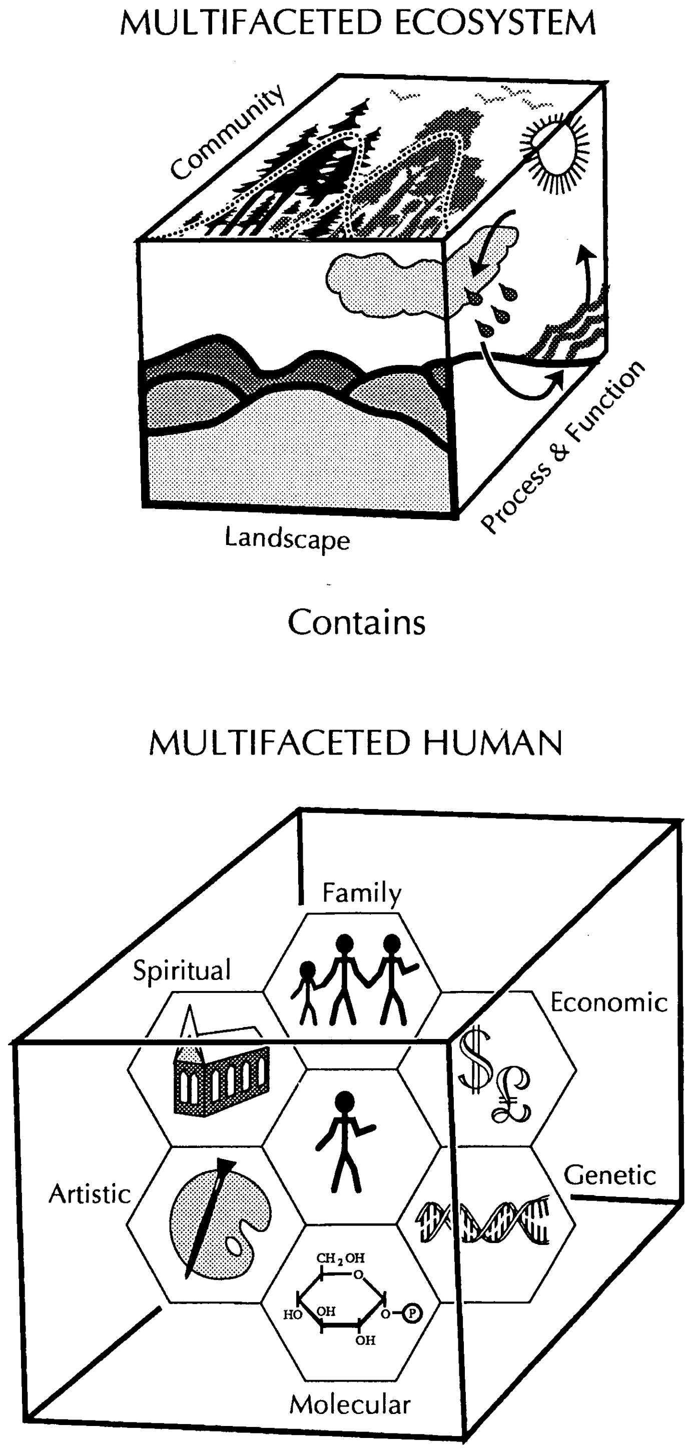


Figure 4. — Not only does an ecological assessment of a system involve particular views of the ecological context in which humans are set (eg. landscapes, process/functional ecosystems, or communities) but the humans that are an integral part of all contemporary ecological systems are themselves multifaceted. Criteria for ecological sustainability must be explicitly stated, but in a system requiring so many different perspectives, they must be employed with flexibility.

some as yet neglected perspective would indeed indicate a lack of sustainability. A manager using the undefined material system as the reference, attempting to achieve complete sustainability in every way, could only expend large amounts of energy and resources to no avail.

Having warned against oversubscription to a "natural" system as the one which is most ultimately sustainable, there are caveats for the obverse position. It is inappropriate to insist on the pristine material system as the reference, but even so this is not a license to ignore the material system and manage for capriciously chosen intensive commodity production. An attempt to maintain an untenable intensive production system is not only doomed to failure, but it is likely to have deeply undesirable side-effects. Just because there is utility in holding a system in a certain state, it does not mean that it is possible or is, in the long run, desirable. As human observers of the material world, we cannot prescribe situations to be sustained that are at odds with the way the material world works.

In the crudest version of this caveat, we humans cannot do the impossible, no matter how much we may desire a particular outcome. Beyond that, long before the impossible appears on the agenda, insurmountable problems will emerge if the intended human manipulation flies in the face of significant material flows. We refer here not to the particulars of the pattern of flow, but to inexorable forces that underlie those patterns, like the truism that water always flows down hill. For example, it is possible to change a pattern of flow as in a large river diversion, but the new pattern cannot defy gravity without unimaginable expenditures of energy spent in pumping. Note that large dams use rather than defy the force of gravity. There are subtle inexorable processes that, if ignored, will bring the best laid plans crashing down. The same applies to plans that may not be the best laid, but are plans to which society is prepared to devote enormous resources anyway. For example, fighting against processes of evaporation by flagrantly introducing yet more water will end, as it did for the Sumerians, with irretrievably salinated soils. California beware; even the greatest economic profits will be unable to bear the cost of restoring a heavily salinated Central Valley to a sustainable condition. Much better to recognize the process of evaporation, and drip water to the plants underground.

Ecological theory suggests that sustainability must involve general systems principles that relate to the tightness of control of the system. In formal analyses of ecological systems (Holling and Ewing, 1971; Holling, 1986) and more intuitive analyses of the course of civilization (Jenkins, 1973) it emerges that systems become fragile unless they have a significant amount of slack. The constant pressure used against inexorable forces of nature in an over-managed system leaves very little slack in the system. The tightness of the control required for system maintenance leaves the system with very little resilience. If a system is to persist a relatively long time, then it must have resilience so that it can come back from inevitable large perturbations, like a hundred year flood, that must come eventually. Thus part of the problem with fighting against principal material flows in management is loss of system slack. This leads to a system that is less sustainable. In a changing society with new demands, loss of slack might also lead to an inability to meet changing demands. A very tightly run timber production system with no slack invites an inability to respond to different timber quotas.

Thus insistence on a capriciously chosen system configuration undermines sustainability, while the converse striving for an undefined "natural" sustainable situation is impractical. Fortunately, there is a middle position that neither aims for an undefined utopia nor a narrowly specified, capriciously set action plan. Management operates on a material system that has a prescribed spatiotemporal extent. Given the infinite possibilities, management also comes from a position that recognizes a given type of system. Necessarily this means that other facets of the system, real as they may be, are put in the background. The most effective efforts to achieve sustainability will be guided by explicit definitions of the system scale and type, and specifications of goals. Action plans will also have to be cast so that the influences they exert line up with the principal material flows in the system, given the definitions and objectives. Rich definitions of the system will be required of course, and they might not fall neatly into conventional types of ecological systems, such as a highly focused population view, or a conventionally specified community perspective. Imaginative solutions are to be found working unlikely interfaces among all sorts of conventional ecologies.

Process And Structure

The caveat about material flows denies a strategy that might otherwise have appeal. Given that perfect sustainability is impossible, it is tempting to consider sustainability to a degree. However, sustainability to a degree is an internally inconsistent notion, it is an oxymoron. Theorists have identified (Allen & Starr, 1982) the need for a clear distinction between system structure and system behavior. This analysis turns on the concepts of rate-dependent dynamics and rate-independent structure. While an ecosystem may recycle nutrients at a rate, it is not an ecosystem at a rate. The ecological system either meets one's definition of an ecosystem, or it does not; "ecosystem" is a state of being not a process of becoming.

In a similar vein, a system is either sustainable or it is not. Sustainability is a state, not a process. Accordingly, degrees of sustainability make no sense. Leave even a subset of processes at work that undermine sustainability, and even if they are slow and are a small part of the material flow, it is only a matter of time before they take the system their own way. The accumulation of salt in Sumerian irrigation was a gradual process. The agroecosystem was almost sustainable. It took a thousand years, with the center of culture being pressed to the northwest from the Persian Gulf, for Sumerian civilization to disappear two millennia before Christ. "Almost sustainable" means "not sustainable." Therefore, seeking sustainability to a degree denies sustainability altogether. Sustainability to a degree is a cruel trick, for it appears an innocuous compromise, but in fact it compromises the entire enterprise.

SYSTEM FRAGILITY AND FREQUENCY CHARACTERISTICS

Relative to robust systems, fragile systems can go wrong in a larger number of ways. Also they will break down more suddenly and with less warning signs. In a fragile system, there is a larger number of local components with narrow tolerances, the failure of any of which would bring the entire system down. Thus a fragile system could be less stable than a robust system, but the message we wish to give is that, if fragile systems are to be as stable as robust systems, they will require more maintenance and planning.

When an ecological system is altered by human activity, it often becomes more fragile. While this fragility may play a role in ecosystem collapse, fragility does not necessarily lead to lack of sustainability. Indeed, the whole discourse of sustainability through management action turns exactly upon how systems greatly changed by man may be maintained. In pristine systems that can quietly evolve and function indefinitely without intervention, the ecologist seeking sustainability is an irrelevance. Sustainability only becomes an issue when one accepts human presence and influence as something that will not go away and with which we must deal.

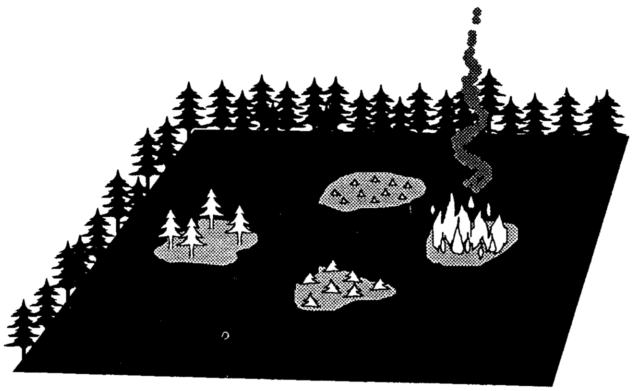
To get a clear picture of the role of fragility, we may learn more from systems that have been greatly modified. Appropriate action that sustains such systems should be able to sustain systems where more of the original fauna and flora are in place. Consider the modern landscape of Greece. It may be beautiful, but it is far from unspoiled, with its topsoil washed into the Mediterranean, it is a clear victim of lack of sustainability. However, the story of how it got to the modern condition is complicated, and is not a matter of the Ancient Greeks failing to sustain their ecosystem. It was more that Greek civilization itself was destroyed from the outside. The role of the Greeks was to make their system fragile and dependent on their civilization. It fell apart when they were not there to maintain it.

With the coming of Iron Age technology, Ancient Greece flourished under wise agricultural management. However, sound as the land ethics of the Greeks may have been, their landscape was importantly altered by their civilization. On many criteria, such as faunal diversity, the system was drastically altered, although Aristotle, who lived early in the process of change, reported unusual amphibia that nurtured their young, and they are found today in the place where he saw them. Development of agriculture caused the significant removal of forests. The second century A.D. traveler, Pausanius, commented on trees when he found them, implying that the primitive forest was essentially gone (Hughes, 1975). However, deforestation appears not to have been the direct cause of the lack of sustainability. The system was surely highly modified by deforestation, but it was not at that time critically damaged. With a full human population to tend the terraces, the agroecosystem was stable; it was not only sustainable, but it was being sustained, and might have been sustained until today but for outside pressures.

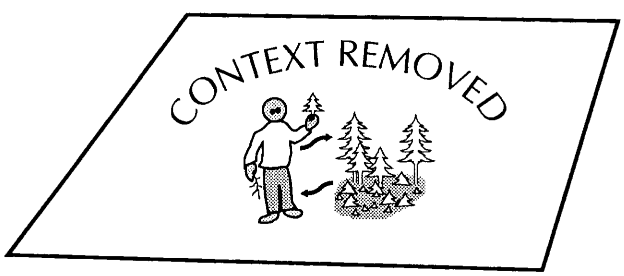
While it did not make the system unsustainable, the human modifications of the Classical Greek landscape had made it fragile. The ultimate destruction of the ancient ecosystem was the consequence of Romans taking slaves and reducing the population. With too few people to tend the fragile landscape, it was washed off into the sea (Heichelheim, 1956). Thus human modification will often lead to fragility, although fragility does not mean that the system is unsustainable. For example an equivalent agroecosystem that was equally fragile did survive, even in the face of the collapse of the central power. Roman agriculture left Italy in a sustainable but fragile condition. Aerial photography by the RAF during World War II revealed landscape patterns of a fully functional farming system well after the decline of Rome (Heichelheim, 1956). The destruction of the landscape of the Italic Peninsula did not occur for a thousand years after the Romans, being caused by "Spanish destructive methods of sheep-breeding after A.D. 1300," (Heichelheim 171, 1956).

The source of the fragility in heavily human influenced systems is twofold, one relating to slow and the other to fast behavior. First, the altered system has lost at least some of its controlling negative feedbacks. This is a matter of the removal of the slowest system components, the reliable context in which the system normally functions. The second source of system fragility is the high frequency behavior that commonly accompanies human system modification. Humans work to maintain the system in a state that they desire. Since that state is not where the system would rest left to its own devices, maintenance requires many fine grain adjustments. Management involves constantly directing the system to where we want it to be.

The two sources of system fragility deserve to be put in more concrete terms. In the example of Ancient Greece, the alteration of the context was the removal of the forest. In less human impacted systems, the context will remain without any particular effort to maintain it. The context of a modified ecosystem needs to be substituted by humans performing the services of the primitive context (figure 5). On the landscape that existed before Ancient Greek agriculture, the forest had been there for thousands of years, maintained by processes normal to forest regeneration, making sustainability a moot point. The problem was not the removal of that forest by agriculture; rather it was an inability of the society debilitated by slaving to continue to perform the functions of the forest, like soil conservation (figure 5). Thus, promoting sustainability is almost never the preservation of a primeval condition, but rather it means maintaining the critical functions of the primeval system, or something like it. Allen and Hoekstra (1992) have argued that management exists to perform the services normally provided by the now removed context. When that is done effectively, the fully serviced, orphaned system functions as it would in the pristine setting. In Ancient Greece, crop cover and holding walls held the soil in place as the forest would have done.



Mosaic of Patches in a Contextual Matrix



Humans Subsidize Local Unit

Figure 5. — In a pristine system, or even one with minimal human intrusion, local ecological systems rely upon a context for services. Perhaps primeval context is a forest matrix that offers a humid nursery for the local patch after a fire, or supplies seeds that will start the process of recovery. The reason management is necessary is to make up for the absent context removed by human resource consumption. The manager offers the services of the missing context. Management is best conceived as contextual.

Now let us expand on the second cause of fragility, the high frequency behavior that comes from humans constantly grooming the system. System modification amounts to moving and keeping the system away from the equilibrium that would prevail if the system were unmodified. The high frequency human activity keeps moving the system up a gradient away from the more primitive condition and counteracts any tendency for the system to regain that condition. In Ancient Greece this was the constant tilling and weeding of woody plants that, left to grow, would lead back to the forest through succession. In structured systems that exist far from equilibrium, like convection cells that make thunder storms, whirlpools, or agroecosystems, energy is dissipated particularly rapidly in the maintenance of the distinctive structure. The distinctive structures in the three examples are the thunderhead, the vortex, and the plowed field respectively. If the high frequency control of the system is suspended, there will be rapid change as the system moves down a steep gradient, sometimes back to the primitive condition, but sometimes to something else (Kay, 1991). In the case of the wholesale abandonment of intensive agriculture in Classical times, the system moved quickly to a condition where the unprotected soil washed away.

Another example of a highly contrived human system that was sustainable, but also collapsed when invaders altered the pattern of exploitation, was the chinampa agriculture of the Aztecs. In that example, the importance of dependence on a viable context is even more apparent than in the Greek case. The Aztec system too had all the properties of fragility and great effort put into persistent local management action to maintain the system. In the tropics, decomposition and high rainfall puts mineral nutrients at risk. Those that are not captured and stored in vegetation flow away in watercourses and end up in the lakes. The Aztecs cleverly recycled those nutrients by scooping them up onto raised beds in marshes. The raised beds were called chinampas and the Aztecs grew crops on them.

By recycling inside the nutrient sink, Aztec farming diverted the flow of energy through humans without long-term depletion. In no way do the Aztecs represent a return to nature, for their system was intensely worked. However, they did form a subtle accommodation with the natural flows of nutrients into the marshes. Unlike the Greek system, deforestation in Mexico not only modified the landscape, but it also made it non-sustainable. Deforestation on the surrounding hills following the Conquistadors, not collapse of the farming system itself, brought the sustainable Aztec system down. The Mexican botanist, Gomez-Pompa has suggested that chinampa farming is the only way to deal with tropical farming and burgeoning populations in an ecologically sound but humane fashion. This suggests the general model of using historically sustainable management, but in the knowledge of how such systems were turned from fragile to non-sustainable.

MANAGING FAR FROM EQUILIBRIUM

Often there will be important turnover rates that indicate different levels of functioning, all of which must be preserved in a sustained system. Some models of grasslands have been able to show the link between cropping and system sustainability by putting carbon into three pools, one with fast turnover, another with moderate turnover rates, and a third which constitutes the long term storage of carbon in the system. Production of human resources often involves cropping the small pool in the highest frequency compartment. The slower compartments replenish the carbon removed. Sustainability involves keeping viable quantities of carbon in the slowest storage compartment. Thus human activity may be local, but it is importantly linked to long term aspects of the system.

The contextual temporal frame of reference for sustainability could be short for microcosms to very long for forests. However, in both cases, relative to the specific time frame in question, sustainability is by definition concerned with the long run. The long run for microcosms may be months, while in forests it is at least millennia. Once again relative to the time frame in question, human management generally involves short term manipulation of the ecological system: perhaps second by second in microcosms to decade by decade in forests. Thus extending long term aspects of the system through sustainability does not fit intuitively with the immediate effects of human manipulation of ecosystems. Local adjustment is used to enhance long term outcomes.

Expressing this in more explicit systems terminology, in efforts to achieve sustainability, dominant aspects of system behavior are made to operate more slowly with longer cycle times through enhancing high frequency, energy demanding activity. That activity fights the tendency to degeneration of the emergent structure. Such energy demanding systems with rapid internal functioning are now recognized as stable energy dissipating structures that exist far from equilibrium. They are the appropriate model for the nature of sustainable systems.

Kay and Schneider (1992) suggest that life itself is exactly such a dissipative structure that requires energy dissipation for its continued existence. Sustainable systems owe their long term persistence to energy dissipation. In the creation of a sustainable system, one does not seek a low level of organization that persists only by being torpid. Rather one seeks stable configurations that may well be demanding of considerable energy inputs and work to keep the system going. Life in general does it by capturing more energy through photosynthesis. It does this using precisely the structure created by the energy dissipation that demands that increased energy capture in the first place. Leaves do not come cheaply, but plants are ruthless in their abandonment of leaves that fall below the compensation point; expensive structure that cannot pay for its structural maintenance has no place in a far-from-equilibrium system. Parts of far-from-equilibrium systems that are not critical to the maintenance of the special configuration are usually pruned away.

In the systems that ecologists wish to make sustainable, it is not a primitive unorganized condition that is sought. Rather the existence of human activity as part of the system is taken as a given. The goal is a system where the human presence bears the cost of its own inclusion by actively maintaining the context. Humans will have to pay energetically for that activity by channeling the energy of the biosphere increasingly through human institutions. All major primitive ecological systems have already succumbed to that diversion of resources, so a program of sustainability of humanly altered systems is the only course left. It is crucial that the energy diverted through society be used to maintain viable ecological regimes that are stable in the long term. It will not be possible to force our way past ecological impasses with the expenditure of material resources. Pumping the ozone smog of our industrial centers up to the stratosphere to replace lost ozone there is so far from being an option that anything of that ilk must be laughed out of consideration.

Our energies, in literal terms, must be pointed toward achieving ecological balances in line with principal flows of the system. Once again lessons are to be learned from generalized far-from-equilibrium systems. A whirlpool dissipates the kinetic energy of the head of water particularly fast. It is through that vigorous expenditure of energy that the whirlpool maintains other very unusual gradients. In a whirlpool, the spinning water allows the water in the middle of the vortex to stand vertically. Of course, water does not usually form vertical surfaces with air, and it is that striking gradient that is maintained by the increased energy dissipation of the flow that characterizes whirlpools (figure 6).

So it is with human activity in agroecosystems and other highly manipulated systems. The energy generated by agriculture is used to pay for plowing the field, thus keeping the site permanently in the first helter-skelter phase of succession. In sustainable systems, energies entrained by system structure must be employed in the careful maintenance of those aspects of the system that perform the entraining. Since water is being held in a vertical wall in the vortex of the whirlpool, the energies entrained by the system are employed in the most efficient manner possible to hold the water in that configuration.

In similar manner, far-from-equilibrium, human-controlled systems may hold the material system in some extremely unlikely and highly contrived configurations, but they must do it in the manner that employs system energies most effectively. Human activity involves highly contrived ecological circumstances, so the pristine natural configuration is irrelevant. However, the energy entrained by human activity must be in line with the principal flows and gradients that emerge in the far-from-equilibrium configuration. Thus human activity directed toward sustainability does not promote the pristine, but it must line up with the natural ecological flows that emerge in anthropogenic settings.

As a way out of finding and holding the system in some unworkable pristine straitjacket, there are moves to declare human-manipulated systems as sustainable so long as they vary within the range of variability manifested by unspoiled primitive systems. In that range-of-variation management strategies demand less precision and look close to achievable, such approaches appear at first sensible and attractive. Of course, the variation of the primitive system is often calculated rather than observed, but that is not the problem with the approach.

The error of managing within ranges of natural variation is in the assumption that natural ranges of variation have anything to do with normal behavior of a system that contains large human populations and the large expenditures of energy that come with modern human occupancy of a site. If the human system is characterized as being a far-from-equilibrium dissipative structure, then the close to equilibrium variation of

Far From Equilibrium – Dissapative Structure

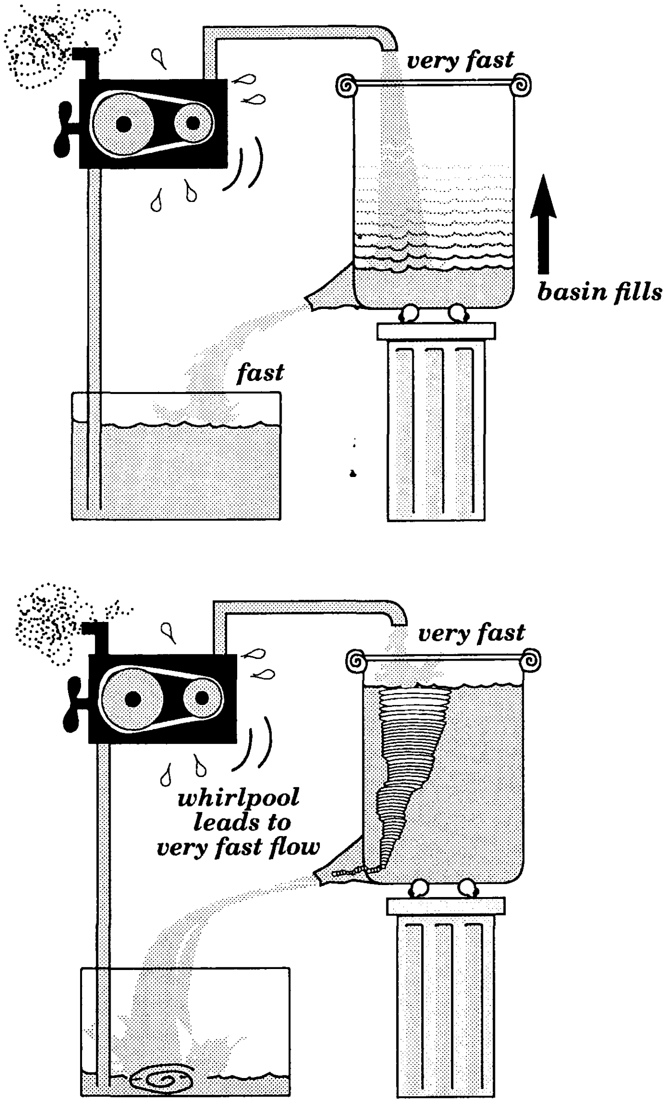


Figure 6. — If water input to a system is great, a large head will be created. Consequently, water pressure will become so great that laminar flow out of the bottom will organize so as to maximize water flow. A whirlpool will emerge that 1) increases flow, and 2) uses the increased energy dissipation to maintain an interface in the vortex.

Homeostasis – Dynamic Equilibrium

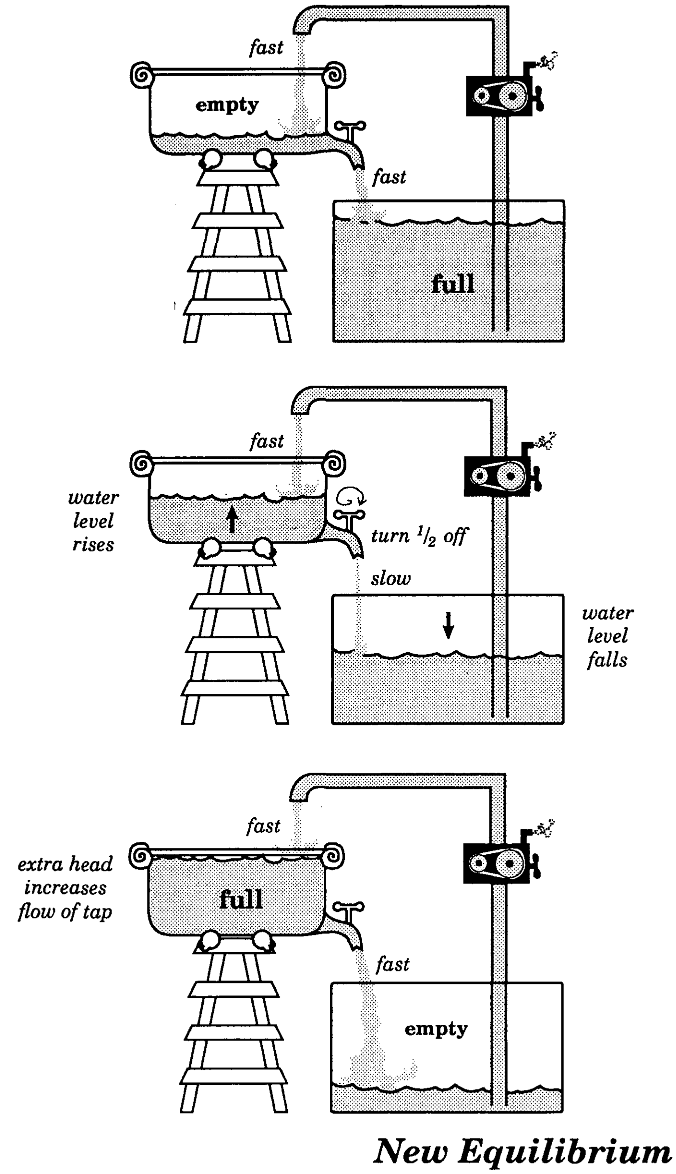


Figure 7. If a whirlpool is analogous to the highly contrived, energy-dissipating system that emerges naturally with dense human populations and anthropogenic manipulation, then a simple tap with a moderate flow, as figured here, is analogous to the pristine ecosystem that pertained before the coming of our species. A simple and unstructured homeostatically balanced flow of water clearly operates over a different range than the spate and the whirlpool. Similarly, highly contrived, energy-dissipating, human-dominated systems would be expected to function normally and healthily outside the range of variation of the pristine ecosystem. Range-of-variation management that uses the pristine system as its benchmark is ill-advised.

a system without humans in it is irrelevant (figure 7). A perfectly healthy dissipative system may exist well outside the range of the primitive system, in fact we would expect that to be the case.

Consider for the last time the whirlpool. The variation of states in which a whirlpool exists occur well outside the range of variability found in a pond with a trickle of water coming in and another leaving. If the pond is the pristine system without humans, the whirlpool is the system with present human populations in it. We cannot abandon agriculture, and the structures that occur therein are held well outside the range of natural variation. It is no response to say that if water flowed in and out of the pond in a torrent, then whirlpools would become a natural part of the system, so whirlpools are natural and therefore cannot correspond to unnatural human influenced systems. It is our point exactly that when more energy goes through a system, far-from-equilibrium structures arise spontaneously and naturally. It is to that far-from-equilibrium nature that we must accommodate. Fields are as natural in a world with five billion people in it, as whirlpools are natural in a spate. Sustainable ecological systems with the present human population in the world will occur naturally well outside the range of ecological systems before agriculture 12,000 years ago.

Thus sustainability is precisely not a matter of a return to some mythical pristine past, nor even an attempt to approach such a condition. Rather it is a process of evolution that is incorporating humans and their institutions into a larger ecological system. In this new ecological arena, the human creature must pay its way in maintaining system structure. This is precisely a cooperative enterprise, for our species does not have the resources or cunning to dominate nature for very long. That is why it is so important for sustainability to work with the major processes in our material setting. Thus efforts to achieve sustainability are neither a journey back to nature nor a dominance over it. In positive terms, it is a new collaboration with nature that will produce something not often seen in the world before.

CONCLUSION

Our arguments with respect to sustainability also apply in large part to the other concepts mentioned at the outset of this paper: biodiversity, ecosystem health, ecosystem management, viable populations, conservation biology, restoration ecology, and global change. All those issues share with sustainability the need to define what we mean with respect to scale and system type. They all require a more sophisticated view than a return to an undefined nature. Elsewhere we have laid out these arguments with regard to restoration ecology (Allen and Hoekstra, 1987). The position we take does not support either commodity exploitation at the expense of environmental preservation nor its opposite. It can help to bring otherwise extreme positions into an arena of rational discussion. Application of the principles we suggest should help bring the virtues of sustainability as seen by environmentalists closer to the value of sustainability that applies to those concerned with commodity production.

Other major civilizations have exploited resources and paid the price. Less grand cultural adventures, that have lasted longer, have been held in the vice grip of what nature can spare: the hunters and gatherers. We as a civilization find ourselves at a cultural watershed where we cannot return to the existence of a noble savage, nor can we persist in the reckless activities of rapacious exploitation. A rapprochement is required; we must take a third path, that of seeking sustainability and positive solutions associated with conservation of viable populations to maintain adequate levels of biodiversity, in the face of global change. It will involve working with processes in the world around us but without the sentimentality of a search for a mythic natural world. We seek something as unromantic as a stable configuration with post-industrial production systems as a working component. Only through hard-nosed decisions mediated by recognition of our special role is sustainability going to be achieved. Without it ours will come crashing down, like 21 major civilizations before us (Moore, 1973).

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