TOWARD A UNIFIED ECOLOGY

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WITH ILLUSTRATIONS
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MANAGEMENT OF ECOLOGICAL SYSTEMS

THE IMPORTANCE of land to grow into was established in the very first years of the American Colonies and even before the colonies broke away from Great Britain. It is witnessed by both personal and national interest in acquiring as much territory as possible. George Washington demonstrated his sense of the value of land for expansion from his earliest years as a land surveyor, as a military leader protecting the western territories for the British general Braddock, and in his acquisition in the Ohio territory for his personal estate. In England, land was power. The land base significantly defined the great titled houses of England, and the ruling classes' fiat had land as their footing. Management of the English landscape was intense, not just for cropping but also for wildlands managed for producing wildlife for the hunt. The tradition of hunting in Britain is gentlemanly and aristocratic, far from what it is in the United States. English commoners hunt vermin, like rabbits. Only the gentry hunt deer and grouse. The dramatic reorganization of Britain in the twentieth century was caused by industrialization, making land a secondary source of resources. Industry brought land to a value where it could barely support itself, let alone be the power base of the aristocracy. The great families were caught between the cost of managing land and an inability to sell the estate. The cost of wages for farm managers, laborers, gardeners, verderers, and game keepers was significant. Many aristocratic families lost their grip completely.[1]

But at the founding of the nation, American leaders like Washington were functionally English gentlemen, with their values and attitudes. Along with Washington, other early leaders like Madison, Monroe, and Jefferson all had their personal wealth rooted in the size of their estates. This was the time before the Industrial

Revolution, when agrarian values associated with land were key to personal and national success. Jefferson, pushing some of his federalism aside when president, worked out a deal with France to purchase the Louisiana Territory, multiplying the new nation's land base several times. He then chartered the expedition of Lewis and Clark to the Northwest and the Pike expedition to the Southwest to learn more of what the new territory contained and offered the new nation. Lewis and Clark did not fully understand what they were going to find. For instance, the expedition bought dogs for food, while they were on the banks of the Columbia River, the greatest salmon run in the world. The nation's founders could only have sensed the value of land through an agrarian lens, with no way to anticipate the productivity that emanated from belief in the value of land.[2]

In his book *Seeing like a State*, Scott (1998) presents the conflicted story of governments' evolving policies toward the appropriation of the land base. Initially, the land base was largely in social and ecological equilibrium, but changed to one that is highly organized and far from equilibrium. Scott's account of scientific agricultural and forestry production has metaphorical value. It points to the dangers of dismembering an exceptionally complex and poorly understood set of existing social and ecological relations and processes. Such dislocation isolates attention on a single agriculture or forest of high value by its professional managers. From the purchase of the Louisiana Territory to the current time, land managers have evolved their practices one mistake after another as the land has taught them the error of their ways. It has been an unconscious, and so a fairly ineffective version of adaptive management. Whether the grand experiment will be successful is yet to be determined. We believe that the information in our book can begin to help land managers ask the right questions and seek the best scientific advice.

When George Washington routed the British, one of his key interests was to gain access to a much larger territory into which to grow the new country. Jefferson had the same motive when he negotiated the Louisiana Purchase from the French. They saw the land as a resource to grow a nation. They gave little consideration to the Native Americans who already fully occupied the land. We would do well to remember them better and take their advice now. Henry Lickers is a Seneca based in Akwesasne. He is a scientific leader in his community. He said to Allen, "We are still here and are waiting to help."

Management can invoke any of our criteria. But two very different criteria prevail, usually in parallel. Management raises human action to the fore, and we live and experience in the world of landscape. Things happen on landscapes to the point that we can see processes unfolding. The other criterion that dominates management is the ecosystem. But we have been at pains to emphasize that landscapes and ecosystems are more at odds than most criteria. In fact, they are put together at the beginning of our chapter-based treatments of criteria precisely so as to show how incompatible are landscapes and ecosystems. We act in the tangible spaces of landscapes, but the consequences of our action come to pass significantly through invisible ecosystem process. Thus, management action can work mysteriously and raise surprises. The surprises often appear in the other criteria, such as organism sickness or health, population increase or decline, and community collapse or biome shifts. Thus, management is the acid test of our whole approach. It forces integration of all our criteria; it is the unification process in unified ecology toward which we strive. Management is a perturbation of the land base and is likely to have an effect on many criteria. It is therefore important to use the tools of complexity, which function to link across criteria and scales. This is not going to be easy and will need an orderly plan.

Accordingly, we need some principles and guideposts so that management is more predictable and rational. These principles will touch most of the separate criteria, from which we have tried to construct a unified view and a unified plan for action.

1. Do as little management as possible. Apply management perturbations of natural systems only as necessary.
2. Do what the natural system does; then you will have fewer, smaller, and less surprising side effects.
3. Be careful to distinguish productivity that is integral to ecological function from productivity that can be taken and diverted toward human uses and consumption.
4. Realize that the criteria we have used for our chapters are not the types of ecological things that necessarily have privilege in nature, but they can still be useful organizers for multiple-use activities. The criteria are separate, but remain nevertheless connected.
5. Everything is not connected to everything else, but there are unexpected connections, precisely because it is the same physicality that emerges ordered in the criteria we choose.
6. Expect surprises anyway.
7. Expect an action under one criterion to have effects under another, to the point that you are always keeping an eye open for such effects.
8. The things that appear in ecosystem function will often have lead indicators on the landscape.
9. The capacity for narrative to deal with contradictions makes it a likely tool for assessing, describing, and understanding management action.

The intention in this chapter is to make what has gone before useful for the manager. There cannot be a recipe book for management because management prescriptions weave ecological narratives, not models. We can offer an intellectual framework that will help bridge the abstractions of basic science into application so that the manager can see where to translate narratives into management action by extending ecological science. It may appear a bit esoteric to traditional managers, but we can also try to persuade basic scientists that management issues are a wonderful place to test theory. Theorists working with managers may build the bridge to what managers can actually use. To get to the point where such recommendations make sense, we first develop a clear view of ecological management and its relationship to both pure and applied ecology. Given what we have learned about narrative, it is no surprise that we will use them to weave stratagems for integrating management.

We start with a particular narrative and associated models to show how the previously mentioned principles apply to particular management schemes, and how they turn up repeatedly. An example of a complex narrative is presented in chapter 1, and we use that again. Holling's work on modeling budworm outbreaks (figure 9.1) illustrates how to use several of the management criteria discussed earlier.[3]

The first principle is: *Do as little management as possible*. Holling's solution is to avoid spraying insecticide completely if possible, preferring to employ the second principle.

The second principle is: *Do what the natural system does; then you will have fewer, smaller, and less surprising side effects*. If there is to be spraying to kill the budworm, Holling recommends spraying not artificial chemical insecticides, but rather a fungus that makes the budworm sick. Chemical insecticides would bioaccumulate in the birds, eventually lowering their numbers, and making it easier for the insect to break out. But the fungi are part of nature and will not bioaccumulate, and the fungus is focused on the budworm with few side effects. The fungus does not eliminate the budworm wholesale, but it does slow them down.

In figure 9.1, one unstable equilibrium and two stable equilibria are presented. Between the unstable equilibrium (point B) and the low-density stable equilibrium (point A) is a trough in the graph wherein budworm density naturally declines through bird predation. Insect outbreaks occur as the trees get bigger and the budworms have more to eat and so can handle more predation. The effect of more food for budworms is to reduce the effectiveness of bird control. The effect of the fungus sprayed in management action is to suppress budworm populations to deepen the trough between A and B. This counters the effect of tree growth in increasing budworm populations, but in doing so only delays the eventual natural outcome of the outbreak. This delay in the outbreak gives more time for the trees to grow, making them more useful for forest products. A way to foil a pending outbreak is to harvest trees preemptively. In this way, the beetle food supplies are reduced. Harvesting need not be all or nothing. A clear-cut of trees takes all the food away, but if the manager only reduces tree density during the time interval between A and B, it will mitigate the impending epidemic. Without harvesting, the trees will be destroyed by the budworm anyway, so in a sense, the managers substitute their

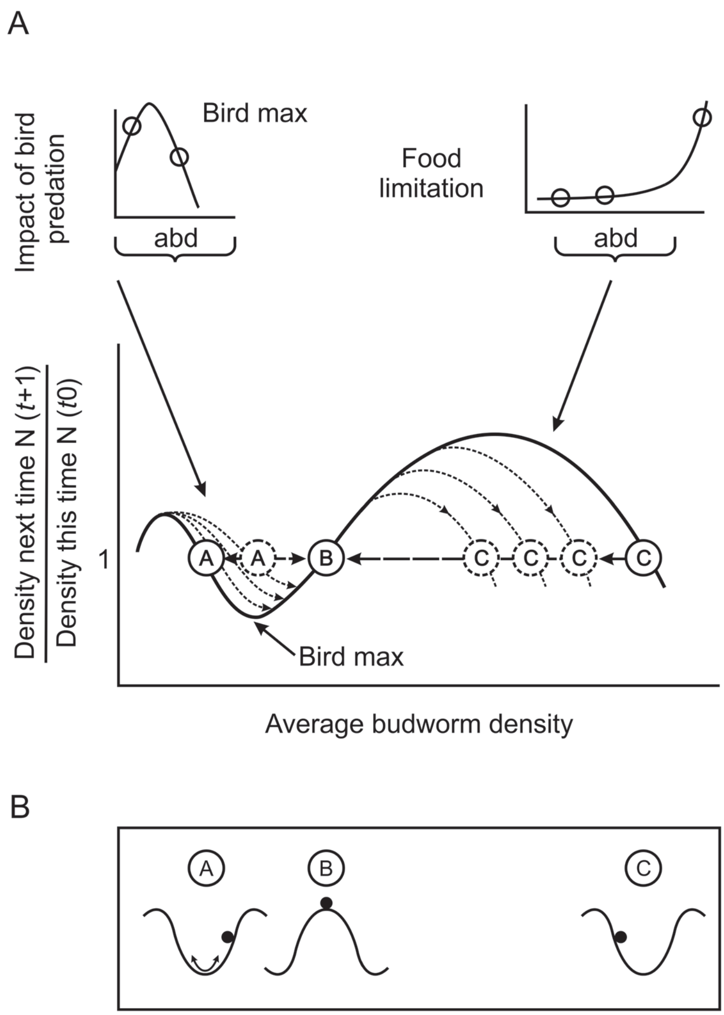

FIGURE 9.1. *A*. Reproduction of figure 1.13, but this time distinguishing between stable and unstable equilibria, as well as showing how the line of response deforms. The horizontal dashed line is the unitary equilibrial condition where the density this time equals next time. Therefore, any circle on the dashed line is at equilibrium. All the circles represent no change in the population at equilibrium, but two are stable equilibria while one is unstable. Circle A is a stable equilibrium point because local budworm densities move toward point A from a little below or from above in the trough between A and B. Circle B is an unstable equilibrium point because higher or lower densities of budworm tend to move away from B. C is another stable equilibrium point of sorts. The budworm densities at C stay on the unitary dashed line, where food supports high density. But at a higher level of analysis, C itself moves along the unitary line (arrows show where it will go). The line of the response deforms (see the sequence of dotted lines) as the food is eaten away. As trees get bigger before the outbreak, the line of response deforms at lower densities. The deforming line pushes stable equilibrium A toward B. Better-fed budworms can hold a higher population under bird predation. The stabilizing trough erodes away. Eventually, the trough between A and B disappears as A and B merge, and so lose the properties of equilibrium. The whole system then moves to C under the positive feedback of budworm growth with insufficient bird control to hold the budworm back. *B*. The lower panel shows equilibrium density points represented by balls on a surface. At A is a stable equilibrium ball in a cup, as is C. Move either ball from A or C and it returns to the bottom of the cup; the equilibria are stable. See the ball at equilibrium B, but poised on a peak, so that if anything moves the density (ball) either way from equilibrium, it keeps moving. B is therefore at an unstable equilibrium.

own strategic harvesting for budworm feeding. Harvesting denies the food source that budworms require to cause outbreaks. The manager does what nature would do in the form of budworms. This invokes the principle of "do what nature would do, and side effects will be minimized."

The third principle would note: *Productivity that is integral to ecological function must be carefully distinguished from productivity that can be taken and diverted toward human uses and consumption*. Holling recommends harvesting the trees at thirty to forty years, that is, before the budworm go into an epidemic outbreak. The populations of trees are to an extent adapted to outbreaks, and so harvesting trees at that age is what the budworms would do anyway. That is a harvest that the system expects and is ready to give up. With fungus spraying, the trees survive longer so as to increase tree growth as an integral part of ecosystem function. The manager separates integral growth from harvesting resources. The managers would prefer trees that are about seventy years old. Their preemptive cutting drives down regional budworm populations, allowing managers eventually to get closer to being able to harvest seventy-year-old trees.

It will take several cutting cycles to bring a managed forest to a stand rotation age that is consistent with the objective that has trees harvested on a rotation age closer to seventy years than forty years. All the while, the manger controls budworm populations and maintains other ecosystem components. We harvest trees on the budworm's schedule at first, so we can get the upper hand. As the regional budworm population comes under control, we can move the rotation age for tree harvest closer to our preferred longer harvest schedule. At first there is minimal tree value because of harvesting before the preferred rotation age. This is the cost of our previous failure to manage the forest with planned action rather than let the budworm manage the forest. However, that cost does underwrite a management plan that takes control back from the budworm. Implementing the management prescription over time continues iteratively to evolve the multiple-use management plan narrative and the management model.

The fourth principle is: *The criteria that we have used for our chapters are not absolutely the type of ecological things that necessarily have privilege in nature, but they can still be useful organizers for multiple-use management plan activities*. The criteria are separate but remain nevertheless connected. The ecological forest/budworm system from the managers' scientific point of view is a population issue of epidemic and predator-prey relationships. The controls on the system are bird predators and ecosystem primary production. Management perturbations substitute tree harvesting for beetle killing. A wrinkle in all this is the loss of organic matter returned to the soil. A solution to entertain is to leave a component of some downed trees during each cutting cycle, particularly the ones of little or no commercial value. Budworm beetle feeding infestation is on the leaves so there is little need to consider that whole downed trees will be a source of infestation. Downed trees might still provide a small reservoir of beetle pupae that emerge as adults to lay eggs; the magnitude of that implication deserves further attention. The expectation is never to rid the forest of the budworm, but rather to manage them at low population levels. The trade-off here is population considerations of beetles and ecosystem considerations of returning carbon to forest soils. All these factors need to be weighed against each other. Ecological activity under separate criteria is not physically separate; there is a crucial if somewhat mysterious material connection.

The fifth principal is: *Everything is not connected to everything else, but there are unexpected connections*. This is precisely because it is the same physicality that emerges when ordered under the criteria we choose. When managers normally spray chemical insecticides, they do so only when they can see a burgeoning insect population. At that point, it is too late and the outbreak is already in progress. One might imagine that careful spraying of powerful insecticides would knock out the pestilence, particularly since the spraying is exquisitely executed. Fixed-wing crop dusters can cover whole stands of trees, with less than a foot of overlap between passes. The bad news is that the insecticide simply holds the outbreak on the steep part of the insect population growth curve because the food supply is still abundant; it maintains the epidemic. This translates to endemic high populations that do not follow the natural rhythms of a thirty-to-forty-year cycle, but rather infest the landscape on a large scale. Preemptive harvesting might give managers more control at that regional scale. What was a western mountain problem has been able to move across the landscape such that spruce budworm now progressively threatens forests across northern North America when, before birds, mountains and prairie landscapes contained it.

The sixth principle is: *Expect surprises anyway*. The change from quiescent endemic to epidemic outbreak has sharp attack, and is a classic surprise in a technical sense. We know it is coming, but not exactly when; that is how surprises often come about. In fact, Holling introduced the model in the first place as an illustration of ecological surprise. As long as the spruce budworm/tree system is in the predator-prey cycle of birds and budworms, the long-term equilibrium changes little. An actual outbreak is a surprise in that little indicates it is coming immediately. The trigger for the outbreak is any of a large number of causes. It might be an adjacent outbreak. It might be a storm that brings in many insects synchronously in a pocket of fast-moving air. It might be a local bird flu that sets the birds back temporarily. It is a medium-number issue: any of a large number of causes could be the trigger. Of course, experience indicates that the attack is coming sometime, but we cannot say exactly when or where. Narrative has no trouble with the counterintuitive notion that surprises should be no surprise.

Petroski's work on bridge collapse makes the point exactly.[4] Any given bridge collapse is generally unknowable and an unexpected surprise. However, a dissertation by Paul Sibley in 1977 showed some unnerving patterns, revisited by Petroski (1993). Bridges that fall down are not generally the ones with distinctive daring design. They tend to be of a conventional design about thirty years after its original inception. Apparently, it takes engineers that long to become too confident about how to make incremental increases in size. We were due for a cable-stayed bridge to come down in 2005. Usually it is some recent new design that collapses, which explains Petroski's prediction. The exception here might be not a fairly new design, but a fix on an old design. So perhaps the collapse he anticipated was in 2007 on I-35 in Minneapolis. It was an old bridge, but one overhauled by adding a huge extra layer of roadbed.

The details of the collapse are not predictable, such that there can be planning so as to avoid it specifically. The narrative of the collapse of the Tacoma Narrows Bridge is harrowing, a gripping story (figure 9.2). Leonard Coatsworth, an editor at the Tacoma *News Tribune,* had the following eyewitness account from when he turned as he drove past the tollbooth of the bridge:

> I drove on the bridge and started across. In the car with me was my daughter's cocker spaniel, Tubby. The car was loaded with equipment from my beach home at Arletta.

FIGURE 9.2. The Tacoma Narrows Bridge, moving like a bullwhip as it collapsed. (Photo courtesy of University of Washington, University Libraries Special Collections, UW20731.)

> Just as I drove past the towers, the bridge began to sway violently from side to side. Before I realized it, the tilt became so violent that I lost control of the car. . . . I jammed on the brakes and got out, only to be thrown onto my face against the curb.
>
> Around me I could hear concrete cracking. I started back to the car to get the dog, but was thrown before I could reach it. The car itself began to slide from side to side on the roadway. I decided the bridge was breaking up and my only hope was to get back to shore.
>
> On hands and knees most of the time, I crawled 500 yards or more to the towers. . . . My breath was coming in gasps; my knees were raw and bleeding, my hands bruised and swollen from gripping the concrete curb. . . . Toward the last, I risked rising to my feet and running a few yards at a time. . . . Safely back at the toll plaza, I saw the bridge in its final collapse and saw my car plunge into the Narrows.
>
> With real tragedy, disaster and blasted dreams all around me, I believe that right at this minute what appalls me most is that within a few hours I must tell my daughter that her dog is dead, when I might have saved him.[5]

In engineering, there is commonly overbuilding so the structure remains. Nevertheless, things can go wrong. In biology, systems are engineered to fail. Beavers expect dams to fail and so they use a design for easy replacement. If in biology we manage too closely and achieve a far-from-equilibrium solution, such as we do in agriculture, we can expect failure as something comes along and starts cheating. At one level, we manage agriculture so as to hold it too close to an emergent equilibrium of massive sustained yield. At another level of analysis, that massive sustained yield is very far from the equilibrium or homeostasis that would pertain in hunter-gatherer peoples. If there is large capital, something will start to game the system, and not just in human systems. For instance, *Atta* ants raise fungi in a highly organized scheme that goes to the point of focused genetic strains of fungus with seven times the normal potency of wild fungi. The ants, like humans, are managing very close to a high yield with a steady level of massive stable production. It is telling that there is a pest that steals the ants' resource base, and more to the point, the ants raise a species of bacterium that has an antibiotic effect on the cheating pest species (figure 9.3).[6] Only the most highly organized ants have to make pesticides, so there is a principle at work here for all highly organized biological production systems. Indications are that technical management will always look something like agriculture. But notice that the ants use a biological agent as their control device, and we should also. If the control is biological, management has evolution working as an ally as long as it sets the environment to select for better or at least stable control. We can expect surprises when we impose tight control far from equilibrium.

FIGURE 9.3. *Atta* ants cut leaves that they take to their nests, where they grow fungi. (Photo courtesy of Martin Burd.)

Our seventh principle is: *Expect an action under one criterion to have effects under another*. That is often where the surprises come from. When an issue arises, it seems at first to be entirely a matter under the criterion where it first appears. But often better, more useful explanations arise under some other criterion. Remember the failure of the salmon.

Our eighth ecological management principle extends our seventh principle and argues how best to apply it. The eighth principle is: *We can expect the tangibility of the landscape criterion to give lead indicators on ecosystem management*. The general argument is that there will be lead indicators under the most tangible criteria, but the application for management is likely to be found elsewhere. The message is: in preliminary research, use signals that enter our sensory portals most easily. In other discourses, the same principle applies, but the lead indicators will be different from the landscapes of ecology. They will still be in the most tangible criterion for that discipline. For instance, the tangible entity in medicine is a human person who is compromised in some way.

Work at Oak Ridge investigated the influence of a heavy metal smelter on a forest and found landscape to be the primary indicator.[7] They were looking for lead to damage biota at large, but found no such thing. Cored trees showed the appearance of lead in the wood as the smelter started up, but when the smelting stopped, the wood reverted to the condition before the insult occurred. But the landscape told all. The forest toward the lead smelter had unusually deep leaf litter. The lead had killed the fungi (they are sensitive to heavy metals) so the mycorrhizae died. The litter showed failed decomposition. That told the researchers to look at nutrient loss, and there they found the heavy metal damage. Biota were mostly not influenced, but ecosystem function was destroyed. Landscapes tell the tale first.

In infectious diseases, the nature of the sickness might become understandable in spatial population terms, something we can see. The lead indicator is that there is illness in a person, and then some additional people. Cholera was not understood to be a waterborne disease; it was generally thought to be caused by "bad air." In 1854, there was an epidemic in Soho, London. Dr. John Snow mapped the incidences and that gave him the answer that it was waterborne. He wrote in a letter to the editor of the *Medical Times and Gazette*:

> On proceeding to the spot, I found that nearly all the deaths had taken place within a short distance of the pump. There were only ten deaths in houses situated decidedly nearer to another street-pump. In five of these cases the families of the deceased persons informed me that they always sent to the pump in Broad Street, as they preferred the water to that of the pumps which were nearer. In three other cases, the deceased were children who went to school near the pump in Broad Street . . .
>
> With regard to the deaths occurring in the locality belonging to the pump, there were 61 instances in which I was informed that the deceased persons used to drink the pump water from Broad Street, either constantly or occasionally . . .
>
> The result of the inquiry, then, is that there has been no particular outbreak or prevalence of cholera in this part of London except among the persons who were in the habit of drinking the water of the above-mentioned pump well.
>
> I had an interview with the Board of Guardians of St. James's parish, on the evening of the 7th inst and represented the above circumstances to them. In consequence of what I said, the handle of the pump was removed on the following day.

Our ninth and final management recommendation is: *Rely on narrative*. In any problem so large that we really want to fix it, there is almost always contradiction. Our pressing ecological issues are so large that we cannot expect to be able to create models to capture the whole issue. Chapter 8 focuses on narratives, showing how they are fully adept in the face of contradiction. In management, landscape and ecosystem are often bedfellows, although they are the most different of all the criteria. The two criteria do not map one onto another. This is bound to lead to inconsistency. Narrative is a likely way to straddle the divide.

An outbreak of budworm is most simply a process of impressive consumption focused on a local spot on the landscape every thirty to forty years. Tangible pattern appeared in tangible places. But Holling had difficulty making his model pulse when he put realistic movement on the landscape. It cycled just fine when he made the assumption of mass balance, common in physics, that as many budworms were entering a site as leaving it. But we know that epidemics are triggered by local influx. It took a holistic narrative approach to solve the issue. He calculated that he needed a certain pattern to slow the budworm, but could not find the empirical data to support that constraint. From his ecosystem/landscape pattern, he said he did not know what in nature he needed to create the pulses of epidemics, but it would have to have a particular signature of a process of certain intensity with a certain focus in space. In the end, he found the entity he needed. It was the combination of warblers and squirrels feeding on budworms. When he saw it, he knew that was what it had to be. Reductionists assert at the outset what they should model and investigate. Holists look for signatures and then only give them names when they find them. Warblers and like birds could not do it alone, but with squirrels, he got his thirty-to-forty-year outbreaks while still including realistic spatial movement. It yielded to a narrative approach that identified a critical unforeseen relationship.

Holling developed the budworm model in parallel with a general model called "panarchy."[8] With Lance Gunderson, Holling has written a whole book on it, and it is one of the more important narratives for management. We might say it is a general model, but would hasten to add that it is really a narrative. Narratives are improved by models, but have the added advantage over models that they do not have to be internally consistent, as we explain in the chapter 8. The internal inconsistency arises out of a change in level of analysis. It is not possible to get a consistent mapping across levels of analysis. In physics, their best shot at it is in statistical mechanics, where the contradiction is across determinate particles on the one hand but stochastic indeterminacy on the other.

Let us lay out panarchy and then explain the inconsistency within it. The chart that captures panarchy has two axes (figure 9.4*A*). The abscissa is complicatedness, organization, or otherwise degree of connectedness. The ordinate is capital in the system. The first two stations in the cycle are the bottom left and top right. The system spends most of its time moving between the r station, bottom left, and K, top right, in process of capital accumulation. The r station has low capital and low organization. The K station has high capital and intense organization. These terms are related to the r and K for growth rate and carrying capacity in the basic equations for population growth and limitation. At r, growth prevails. At K, constraints are great.

At K, the system is brittle. It is an accident waiting to happen. For the spruce budworm system, the K phase is thirty-year-old trees just before the epidemic outbreak. The next phase arises quickly in what Schumpeter, the mid-twentieth-century

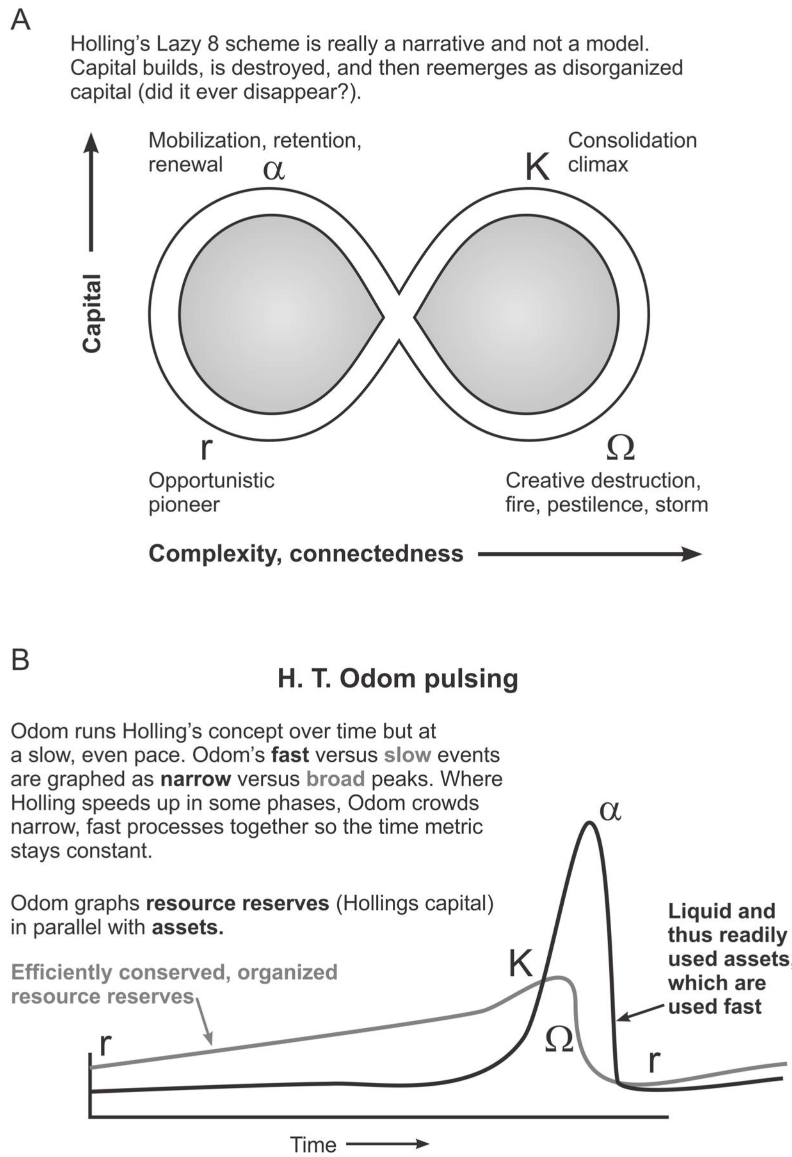

FIGURE 9.4. *A*. Holling's Lazy 8 narrative, which has come to be known as panarchy. The Lazy 8 scheme is really a narrative, not a model. Capital builds, is destroyed, and then reemerges as disorganized capital (did it ever disappear?). The track is from r to K, to Ω, to α, and back to r. At K, the system has much capital but is brittle and fragile. As in all fragile systems, collapse to Ω is fast. At α and K, capital is high. At α, H. T. Odum would say that capital is converted to liquid assets. For Holling, the distinction is that α is not organized. *B*. More like a model than figure 9.4A, Odum's maximum power principle plots capital on one line and liquid assets on the other. The two lines sidestep the inconsistency of panarchy, making it more of a model. In terms of high and low gain, K to Ω is the high-gain harvesting of standing crop. But the whole cycle for *r* to *r* is a low-gain scheme that keeps r to K growing with maximum power. From Ω to α to r to K is not just a passive phase of not harvesting; it is part of the low-gain strategy of maintaining maximum power. While the panarchy cycle has fast and slow transitions, Odum's scheme moves through time at the same pace, but the passage across the narrow (short time) α peak is where panarchy cycle appears to speed up. Without the Ω and α phases where there is lots of action, both systems would stagnate at K. Odum says maximum power always pertains.

economist, called creative destruction.[9] It is a creative destruction because it releases capital. Expressed in H. T. Odum's terms for the maximum power principle, capital is transformed into liquid assets (figure 9.4*B*).[10] This is not exactly destruction, but certainly a radical reorganization that removes capital as capital, converting it into something else. Holling labels the destructive phase Ω. In Odum's terms, Holling's creative destruction is just to the change from capital to liquid assets. In Holling's panarchy, the system moves from top right to bottom right on the diagram as capital is liquidated. Holling does not refer to liquidation, but only notices that capital recedes quickly. Liquid assets can be rapidly drawn down. Once the buying power is moved into liquid form under Odum, Holling moves his scheme up to the top left, his α phase. He is saying that something like capital has reappeared. But Odum emphasizes a critical difference that changes the name of buying power from capital to liquid assets.

Regarding the narrative nature of Holling's Lazy 8 chart (figure 9.4*A*), there is a contradiction. It comes in the disappearance of the capital and its creation anew. Capital reappears in the α phase, so the dilemma is, did it ever disappear? But it is a narrative, so dilemma and contradiction are all right. Odum's scheme is more model-like and is therefore internally consistent. He is simply graphing capital and liquid assets together over continuous time. He thus avoids the dilemma of one thing being two. The pulses of Holling's scheme are captured in the short time that Odum's graph collapses capital and shows only a narrow peak for liquid assets.

As happens with liquid assets, they are quickly spent. This moves the system briskly, but not instantly from top left, α, to bottom left, *r*. In Holling's budworm model the liquid assets in α would be dead trees after the budworm have killed them. Without the constraining organization that accompanies capital, the liquid assets are frittered away. In Odum's terms, there has been a transfer of high capital to high liquid assets, which are then spent on woody decomposition and disappear into the forest soil. After the budworm outbreak the dead trees simply fall and rot. If this were the end of the Roman Empire, the fungi consuming the dead trees might be Attila the Hun, who must have thought the collapse of Rome was a good idea. Attila takes the capital, but cannot hold on to it. This, of course, leads back to the r phase, where the system is open to opportunity, which unfolds as feudalism.

So a management question is how much of the liquid assets can be extracted for human use without removing necessary soil carbon resources to restart the capital accumulation in a new cycle. It is much easier to liquidate assets than it is to build capital. That is why K to Ω, to α, to r is fast, while r to K is slow.

With regard to management, we discuss the Tsembaga pig men in chapter 6 on population in terms of differential equations and basins of attraction.[11] As to the Lazy 8 diagram of panarchy, the Tsembaga build pig capital and then liquidate it. A slaughtered pig does not last long. The system pulses as it moves around the panarchy. Holling makes the point that the Tsembaga show resilience, like that of the host-parasite system of Holling and Ewing (see chapter 6, figure 6.9).[12] The pulses of pig growth and consumption also represent an example of Odum's maximum power principle.

Carpenter and Brock recently started to model management of lakes.[13] They modeled water quality from eutrophic to clear with a good fishery. At first they expected to have gradual change, with managers reaching and holding the desired condition. Immediately they discovered that folded-response surfaces were universal for almost all reasonable models. The models appeared to fit the data well. It seems that there was tension between a gradient toward a desired state and the opposing gradient of the expense of management. It gave a pattern of clear lakes becoming eutrophic, as effluent is cheaply dumped. The desired condition persists for a certain amount of time, and all appears well. But suddenly the lake passes to eutrophic, with attendant smells and green water. After the collapse of water quality, deep dissatisfaction leads to variously strenuous remedial measures. However, the lake usually stays eutrophic. There is a certain irreversibility to going over the fold in the surface. The shallow, clear prairie lakes, such as Clear Lake in Iowa, flipped in the early twentieth century to strongly eutrophic and have remained so despite a century of remedial action. The budworm outbreaks have a similar folded response surface, with a slow variable, the tree growth, and a fast variable, potential growth of unconstrained budworm. Some management does exist in zones of continuous change, but human reactions are generally so much faster than the variables that it is trying to control that folded pleats and surprises in behavior should be expected. Surprise occurs when a positive feedback is let loose. A case in point was the change in albedo with snow cover that can lead to rapid cooling into ice ages. The ice at the base of Greenland suggests that the change to permanent ice happened in just four years' time.

THE SUBCULTURES IN ECOLOGY

At professional meetings, groups of ecologists concentrate their attendance on particular sessions. The same faces are seen at either the landscape meetings or the population sessions, but not usually both. There are silos of interest, and only a minority moves between them. This political structure within the discipline seems innocuous enough. However, a price is paid when one group ignores the work of another as irrelevant when a cross-fertilization of ideas would, in fact, be helpful. A particularly wasteful schism is the one between pure and applied ecology. As we explain in following discussion, there is some contact across the divide, but there is also enough disjunction to waste opportunities for cooperation.

To meet this issue, the Ecological Society of America started a new journal for practical application of ecology. The British Ecological Society has published the

Journal of Applied Ecology since 1964, separately from its pure-science counterpart, the *Journal of Ecology*. Similar structure occurs in forestry with *Forest Science* and the *Journal of Forestry*. Thus, the division receives official sanction, albeit inherited from times when pure science was more confident and autonomous. The basic scientists' grants to applied agencies and programs start with: "To solve this applied issue we need basic science in such and such an arena," which is that of the proposer. The pressure to make basic science more obviously useful to the public that pays for it mostly gives rise to token window-dressing outreach, and not a move away from what basic scientists have always done.

One of the early big, important, and excellent works by Henry Horn is *The Adaptive Geometry of Trees*. It makes the distinction between monolayer trees and multilayer trees. The big oak trees and elms are monolayer, with leaves creating a sort of skin on the outside. The strategy of monolayers is to intercept all of the light in the vicinity of the canopy with no overlap. With such strong competition for light, self-shading must be avoided. Multilayer trees, by contrast, grow in relatively open habitats, where sidelong light hits the leaves up and down the tree early and late in the day. Multilayered trees capture the light of Gray's churchyard. "The curfew tolls the knell of parting day, the lowing herd wind slowly o'er the lea." We have never seen trees quite the same way after reading Horn.

We mention Horn because of an unwarranted, harsh review of Horn's book by John Harper, indicating dissatisfaction with the divide between basic and applied ecology. The review is a paradigm defense of crop and weed research. Paradigm defense and attack is often not fair, with mockery used here as a literary device.

> Much of this type of canopy analysis has been done before and in a much more sophisticated manner; reading this book is therefore rather like discovering a tribe lost to civilization that has quite independently discovered a primitive form of the internal combustion engine. Does one praise the originality or sympathize with the ignorance. There is a tragedy here, not just in Horn's book but in the failure of most ecologists to make the slightest attempt to follow the literature of agronomy and forestry. Ecologists must read this literature even if it shatters some of their conceit. For those many readers who will find that Horn's monograph opens a new vision on the nature of vegetation we append a brief bibliography to correct the perspective. (Harper 1972:662)

Harper's complaint, while unfair to Horn, was justified with regard to the separation of basic and applied research. Harper's influence over the mainstream of both applied and basic plant ecology persists today, more than thirty years after his retirement. That influence is captured, as Caccianiga and colleagues complained in 2006 (quoted in chapter 4 here), that the reductionist focus of theory comes from the fact that "the contemporary ecological mindset borrows heavily from agriculture." Harper's plants of choice were weeds and crop plants, though he was also in command of basic science ecology. With plants in cultivated fields, the larger picture of plants chronically and acutely limited is not seen as applicable. Finally, we are getting beyond the tight reductionist focus that yielded much but is now suffering diminishing returns. Zhu et al. (2000), working with rice, did indeed move to the wider view, their plant being a crop notwithstanding. They looked at their system in community terms and the whole system, which is an encouraging sign. Harper was right in the 1970s, in his general complaint about basic ecologists needing their "conceit" bruising. He would be less right today about that particular gripe because the better scholars do read applied and basic work, and it is time.

MANAGEMENT UNITS AS DEVICES FOR CONCEPTUAL UNITY

A significant part of the field manipulation conducted by the U.S. Forest Service (USFS) is imposed not on areas defined by community type or ecosystem function, but is applied to land management units that span community types and watersheds (figure 9.5). There is sometimes compromise between the definition of management units and terrain—a general community type, economic, or social factors—but management units are formally delimited to work largely as homogeneous production systems at the scale they represent. Management units may be defined on purely geographic convenience. Some cultural demarcation, such as a road, might cut across the middle of a homogeneous example of community or ecosystem, and yet for the management unit, the road might provide a very workable boundary (figure 9.5, right-hand photograph).

When it is to be seen through the eyes of the manager, a landscape falls into pieces whose identity turns on production of resources based on a complex of social, ecological, and economic considerations. Heterogeneous management units are common in initial management applications, becoming more homogeneous as management cycles play out over time. Only incidentally might a production unit map onto a homogeneous plant community or an area of homogeneous ecosystem function. The degree of homogeneity of the management unit is based on several ecological conditions: for example, geology, soils, topography, vegetation type, and, importantly, operability considerations. Tree age is a lesser consideration in early applications of management planning. It is an objective in longer-term management planning, as it will be the organizer for either a heterogeneous or homogeneous plant community at a particular successional stage. Land management units are a mixture of community, ecosystem, and landscape entities, ranging in scale from tens of acres to several hundred acres, depending on the heterogeneity in the major factors listed previously. Legislation requiring consideration of

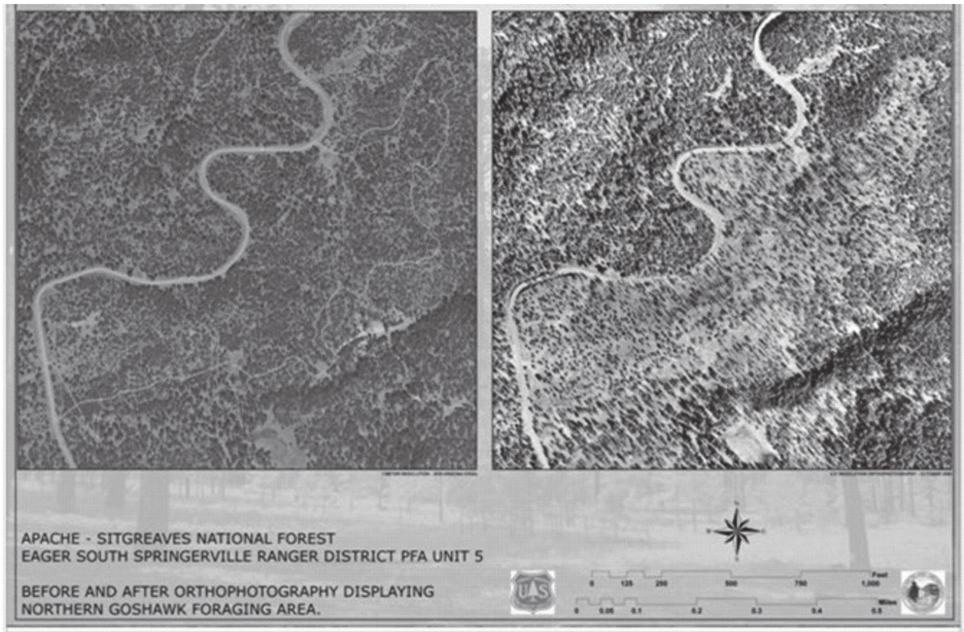

FIGURE 9.5. Orthographic pictures of portions of adjacent land management units showing before (left photo) and after (right photo) management treatment. The area to the right of the sigmoid-curved road (top to bottom left in the right photograph) shows the area treated to restore the habitats of the plants and animals in the goshawk food web within a northern goshawk foraging area. The management objectives were to create an open, uneven-aged, ponderosa pine condition with a balance of age classes. Desired elements were groups of trees, scattered single trees, open interspaces (grass, herbaceous), snags, logs, and woody debris. The cutting method was individual tree selection. (Reynolds et al. 2013. Photo courtesy of USDA Forest Service, Apache-Sitgreaves National Forest.)

joint production of public lands has increased the degree to which modern land management units are multifaceted entities.

Once the land management units are established, silvicultural prescriptions, such as a clear-cut or individual tree selection cut, are usually applied to the best degree possible in a homogeneous way. Details of past influences such as fire or management actions do introduce heterogeneity on the ground that can lead to some variation in the application of a management prescription across the area at a given time. A strategic forest plan is largely a narrative developed by the managers through review of alternative options with the various public stakeholders. Originally, management alternatives were created with multiple-use optimization models. These optimization models received a wealth of information and, for example, use minimum/maximum devices to find an optimal management scenario for a given set of assumptions. In the series of books on complexity of ecological systems at Columbia University Press, in which this book is included, Hof and Bevers have two books on the techniques of optimization for management of ecological systems.[14] National forest planning today is less about optimization and more about public collaboration/involvement throughout the process. Today, the USFS seeks the public's involvement to jointly assess current conditions and trends of a national forest's ecological/social/economic resources. Also, they involve the public in identifying where the current, existing plan needs to change in order to better address the sustainability of the forest's ecological/social/economic resources. They solicit the public's involvement in developing and analyzing the components of the revised plan in response to the need for change that better address the forest's ecological/social/economic resources. And, finally, they involve the public in a predecisional objections process, instead of a postdecisional appeals process used originally to develop forest plans. The current forest planning process more closely follows the principles developed in chapter 8, especially Checkland's Soft Systems Methodology.

It is a mistake to dismiss studies arising from management goals as unnatural and therefore less likely to yield ecological understanding with general application. The power of multiple-use narratives for land management units as a basis for national forest plan revisions is crucial to understanding this messy situation. Resource use is no more arbitrary and anthropocentric than are the academic ecological entities; a nitrogen atom does not care if it is in the leaf of a community dominant, part of an ecosystemic nitrogen retention pathway, or located in a landscape entity like a hedgerow. Like land management units, communities, ecosystems, landscapes, and biomes are reflections of human ways of thinking, not reflections of ecological reality beyond perception and conception. Tansley's prescient comments on hypostatization (reification), quoted in chapter 1, are again pertinent. As a way to deal with the undefined fluxes of matter, energy, and information in ecology, land management units can be seen as just another conceptual tool to be used alongside academically defined ecological criteria.

There is a tradition of pragmatism in applied ecology. Academic ecological criteria are often applied in a manner that is just as ad hoc as management criteria. Therefore, it seems a pity that, since academic ecologists also pay the price of pragmatism, they often do not fully avail themselves of its utility. We might ask, "How do we get an additional 10,000 board feet out of here without negatively influencing water quality and elk habitat?" The power of using such management questions is that it forces a simultaneous application of narratives and models across conventional academic criteria.

Although nature functions simultaneously as communities, ecosystems, and landscapes, even dual, let alone tripartite, structural and process descriptions are rare in the literature. Since they introduce an ecological entity new to many students of natural systems, land management units may be used as a helpful device to pry open new intellectual possibilities. By considering management not only as a tool to achieve effective resource use but also as a tool for experimental manipulation in basic ecology, it is our intent to break old habits of using only one conception at a time.

Using land management units applies a perturbation across the major academic criteria. In management, we have a wealth of experience with many "experiments" already reported in the literature. Employing management action as an experimental manipulation, we can build a composite description using the power of the three conventional principles (community, ecosystems, and landscape) without being limited to any one of them. In fact, environmental impact statements legally require this rich conception of the manager. Adaptive management can use the wealth of reported management actions as superior starting places for their process of iteration.

Management plans for land management units are effective in satisfying narratives for ecological management. They establish a monitoring program that provides the basis for testing narrative outcomes of management in satisfying the narrative. In a North American (Canada, United States, and Mexico) test, Wright et al. (2002) put forth such a monitoring program in *Monitoring for Forest Management Unit Scale Sustainability*: the Local Unit Criteria and Indicators Development (LUCID) test was heavily based on and used the principles in the first edition of this book. The test was a technical test, and like many projects of this nature, the policy and political decision makers did not adequately understand the utility of the narrative-management-monitoring test. Such a monitoring process that interfaces land management and policy/political arenas could be important to the long-term social, economic, and ecological benefit of North American natural resources. One of the unique components of this effort was the structure and process criterion of social systems developed by Joseph Tainter (appendix 8.1).

If we are able to identify community criteria as well as ecosystem criteria that both map onto a given management practice, we may well be able to identify circumstances where a community entity is also a functional ecosystem flux. In tropical agriculture, the landscape mosaic of slash and burn allows community recovery. However, agricultural return time that is too short or fields that are too extensive both interfere with mycorrhizae and nutrient cycling. The degradation of communities therefore can be an ecosystem-related problem. We hope that our approach will uncover similar cross-links that were unsuspected until recently; it is designed to do so.

THE DISTINCTIVE CHARACTER OF THE MANAGED WORLD

At an autumn 1988 workshop held in Santa Fe, New Mexico, on the topic of ecology for a changing earth, one working group focused on the human component.[15] The group made three critical observations that can be woven together to give a broad picture of the world under human influence. It is on the parts of this world that managers focus their attention. The first point was that food webs containing humans have very indistinct boundaries. The second point was that the larger the human presence, the more leaky the ecological system. The third point was that, relative to the historical and prehistorical past, even the major ecological subsystems in the biosphere are now out of equilibrium.

Food Webs Have Distinct Boundaries

When the working group started to consider what was missing in the database to address their charge, Joel Cohen pointed out that very few published food webs have humans as one of the nodes. Human food webs are distinctive because of certain qualities pertaining to the system boundary. Putting humans in ecological systems does give a new perspective since we are so involved. New perspectives came out of comparing the University of Wisconsin, Madison campus, in terms of its watersheds and its sewersheds. When Cassandra Garcia presented her sewershed maps to water managers on campus, she could immediately see the excitement in her audience about a new set of insights.[16] In the same spirit, Bruce Milne is developing a science of foodshed analysis.

Africa is not well served by landline telephones.[17] The arrival of cell phones in Africa has changed networks considerably, to the advantage of local producers.[18] Groups of producers can now pitch in to buy one cell phone as a group, and in this way access more information about their network foodshed. The local buyer can no longer hold them hostage. There is much wealth at the bottom of the social pyramid, but it usually cannot be leveraged in a global system. Cell phones also provide a currency of cell phone minutes, which are valuable and readily transferrable great distances, allowing access to global markets with real capital.

The Leakiness of Human Systems

The second critical observation of the 1988 working group was that pollution problems appear to be more deeply rooted than we first thought. Part of the problem is agricultural land use, where fertilizer gets into the aquatic system. Less expected, but very important, is the nutrient input that sheets off of suburban areas. This suburban runoff is not collected sewage or point discharge; rather, it is a reflection of the nutrient leakiness of suburbia as a whole. The points of nutrient enrichment on the Hudson River have been identified and mostly shut down; now unmasked, the full impact of suburban runoff is apparent. In the Lake Wingra project of the International Biological Program, the scientists found that the kick start of the eutrophic cycle in the spring came from the simultaneous melting of accumulated dog feces on suburban lawns, frozen through the winter.[19] By contrast, the forested lands on the opposite side of the lake contributed almost no nutrient

FIGURE 9.6. An aerial photograph of Lake Wingra showing the suburban areas in contrast to the forested vegetation of the University of Wisconsin Arboretum just south of the lake.

load, and certainly not the pulse that was felt from the spring thaw of front yards (figure 9.6). Predominantly, natural ecological systems retain their nutrient material, and forests are masters at the game. It is by holding nutrients inside the forest through cycling that woodlands escape the pressing constraint of low nutrient input from the air. A nitrogen atom entering a forest system can be expected to be held for 1,810 years, even though it is likely to be mobilized for new growth at the beginning of most growing seasons.[20] The contrary characteristic of the suburban landscape applies to all other intensive human uses of the landscape. Human-dominated systems leak material.

Biosphere Out of Equilibrium

The third observation of the working group was that human-dominated systems, even at the scale of the whole biosphere, are undergoing radical changes of state, such that the old equilibria are dysfunctional.

The changes of which we speak are so profound that wild and heavily managed systems alike are all casualties. Even situations that have already been fully impacted by humans, like the tall-grass prairie region that became the American corn belt appear not to be stabilizing in a new configuration. The continuous production of corn masks radical changes that are still happening on the farm. Prairie soil is still deep, but is eroding at a rapid rate by geological standards. Should the predicted, anthropogenic, global climate warming and attendant climatic shifts occur, the whole Corn Belt will move north to Canada. The trouble is that the Canadian Shield has no soil to grow corn, although the Canadian prairies do, and that is starting to happen. We note the concept of agrobiome in chapter 8, and it applies here as the description preferred over agroecosystem.

In forested areas, the changes are even more apparent. Vast areas of forest are being converted to grasslands across the tropics. Even areas that felt the heavy hand of humans long ago show this global pattern of change. The long-deforested lands of Atlantic Europe are accumulating organic material in bogs in a way that did not happen in the ancient forests. Monoliths of the first agriculturalists are found resting on soil not greatly different from that in the primeval forest, but whose stones are now buried under tons of peat.[21] Ironically, there are protests that the increasing mining of this peat for fuel is destroying the Irish landscape.

Certainly, very large changes have occurred in the biosphere before, but they have generally been so slow in coming that the major subsystems of the biosphere could accommodate them by moving to a new latitude. The speed of the change is presently so great that there is not enough time for natural systems to move with them without going out of equilibrium and losing integrity.

At the outset, the 1988 working group couched this observation in terms of an uncertain future. They were not prepared to predict the future of large-scale ecological systems because humans are changing the world so fast and so extensively. A view was expressed that we cannot predict because the system will be out of equilibrium for some time. However, it appears to us that the future envisaged by the working group is already here. There is no point in waiting for equilibrium because it will never come. At least it will be postponed indefinitely, until the human race is broken on the wheel of its own deeds.

The new entity, which we call the anthropogenic biosphere, is much smaller-scale than the entire global system, and is constrained by it (figure 9.7). Nevertheless, the anthropogenic biosphere is larger-scale than the major natural systems that it contains. The emergence of this new entity explains that (1) human food webs do not have discernible boundaries; (2) human-dominated systems are leaky, and (3) few, if any, major ecological systems can be adequately described with equilibrium models that would have applied before human intrusion.

The biosphere is large enough to leave plenty of slack for the old natural systems to relax close to some sort of equilibrium, but the anthropogenic biosphere works faster, imposing tighter constraints. That explains the apparent lack of equilibrium in the quasi-natural ecological systems in a human-impacted world. It is in the nature of the new anthropogenic upper-level structure that the parts will remain held out of equilibrium indefinitely. The anthropogenic biosphere is a local

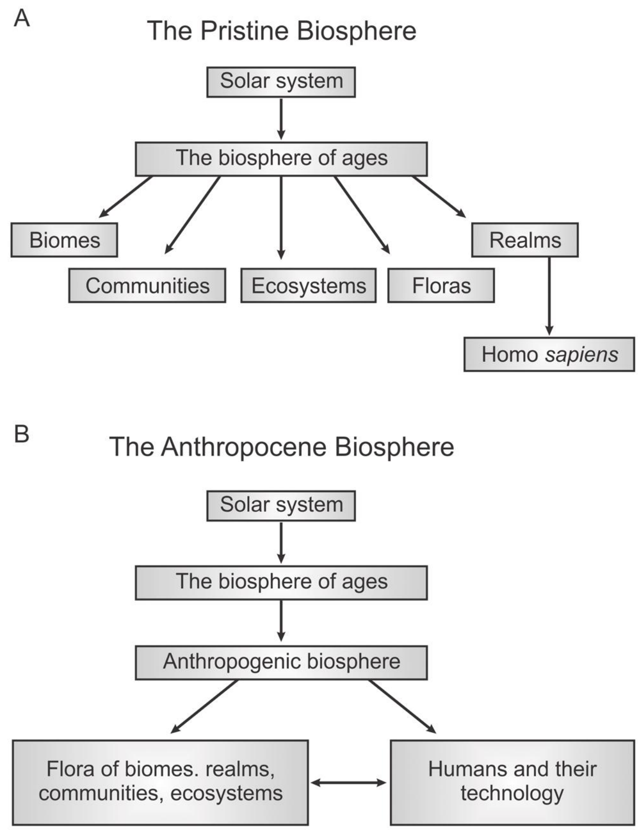

FIGURE 9.7. *A*. The biosphere of ages has our species as a small part of a realm. We were then an uncommon, incidental omnivore. *B*. In the Anthropocene, humans are more significant, but certainly are not in control.

phenomenon relative to the long-term biosphere driven by volcanism, catastrophic meteors, and ice ages. Ice ages will come again, no matter what humans want or try to control. There have been much warmer epochs than this. Therefore, despite anthropogenic global climate change, we should not overestimate the significance of human activity at the scale of eons. Equally, we should not underestimate its effect on human systems, such as farming, fishing, or living close to water.

The anthropogenic biosphere is scaled much closer to the major ecological subsystems than was the primeval biosphere. Accordingly, the anthropogenic biosphere forces a much greater degree of integrity on the globe's biota, and not a good integrity. In the new biosphere, matter, energy, and biota are moving around the globe as never before. These fluxes are the connections that reflect the greater integrity.

In general, management is best achieved by playing to the ways of nature. The chinampas of Mexico take advantage of a natural process.[22] Tropical forest soil is nutrient poor because of high temperature mobilizing nutrients and high rainfall washing them all away. That water ends up in lakes. Thus, the nutrient status of many lakes in the tropics is high. If those lakes are shallow, there are possibilities for farming them with chinampas. The Aztecs farmed most of the lake that is now gone under development of Mexico City. They dug channels by scooping up mud and depositing it in long barrows. Thus, canoes could go in between these artificial islands to scoop up more mud and pondweed. Crops were then grown intensively.

Cortez reported the floating gardens of Montezuma. He was wrong. The barges with plants on them were for only small transplants in transit. The Spanish thought that the chinampas were sunken barges. A problem with this system is that the land for growing crops is highly derived and expensive. Another problem is that the tropical sun does not produce longer days in the summer. Normally, crops in north temperate regions suffer self-shading in June, but the extra summer sunlight compensates for the effects of crowding. Increased day length is not available in the tropics. The good news about the tropics is continuous cropping year-round. Transplanting allows valuable cropping space to be used intensively. Plants are grown very close together in seedbeds. When the plants get bigger, such that they would crowd badly, they are transplanted to a lower density. This is like extra light in the summer of temperate regions. It is a sort of time for space substitution. Plants grow all year, and in the extensive growing areas, the plants are always growing fast on the steep part of the growth curve with space to grow. Chinampas are one way of going with nature in the tropics. Pulsing allows for maximum growth all the time. This is the basis of H. T. Odum's maximum power principle to which we refer earlier. It would appear that harvesting is a high-gain activity of taking it all. But if the cropping system actively retreats, unconstrained growth is at its maximum. It is cropped again only after a significant period of release. This strategy allows for maximum growth in a low-gain, organized, long-term scheme.

Swidden agriculture is a pulse-and-rest system that has advantages over permacropping. The pre-Columbian natives of California lived in a pulsing environment of El Niño/La Niña, and the classic Mediterranean pulsing climate of cool, wet winters and hot, dry summers. That pulsing productivity creates a maximum power situation that in those times led to extraordinarily high human densities. With the prescription always to manage like nature, there comes the issue of "what is natural?" It appears that fields are natural. The native Californians had inherited chieftains, which hunters and gatherers cannot usually afford. Their population was about ten times the density of most hunter-gatherer systems. They dealt with the landscape by burning. Areas were burned and then left to regrow to an extent. The hunters would then return and hunt the edge of the open area. Game would concentrate there. The critical point is that when human density is high, open areas are a natural emergent property. The hunters were making fields; it is just that they were not doing agriculture on them.[23] So with a world of seven billion people, fields are a natural emergent. The point is that we now live in a world where steep gradients are presenting natural emergent entities. Whirlpools are strange but natural. Fields are a sort of human-induced whirlpool.

Fields follow the pattern of management units; that is, there is a homogenous application of human management. We might object to the way monoculture in industrial agriculture resembles a petri dish; industrial society can go too far. But, since our first edition, some remarkable achievements have been made public—yes, with fields, but with a new sort of homogeneous management strategy. Near Viola, in the poor, nonglaciated southwest of Wisconsin, Mark Shepard has taken a 106-acre farm that was in row crops.[24] He farms it with fields that are savannas. Our species evolved in savannas, and the New Forest Farm is an American savanna that feels like home.

Shepard uses natural selection to force his trees to produce early and in high densities. Those selected out are used for burning; others are for toy making in a local cottage industry. He farms the New Forest Farm very intensively, but with high diversity. He has bred hazelnut bushes to reach production very fast. They reproduce vegetatively, and he sells the stock. His hybrid chestnuts are resistant to the blight and produce early and heavily. The ground is hilly and is a poor part of the state. Shepard farms it with perennial crops that offer high added value. The produce of his apple trees is sold as hard cider. He uses grazing to recycle mineral nutrients. His system is complicated but highly organized, making it a complex emergent. While he does a lot to the land, he rides with nature. Shepard's book, *Restoration Agriculture: Real World Permaculture for Farmers,* tells how to do it.

One of the reasons that first world agriculture can be so damaging and inhumane is outside pressures on the farmer. Farmers often do what they do because they cannot afford to do anything else. Farmers pressed by bankers are an example of how important is context, but this time a bad context with sad outcomes. Shepard speaks of organic methods and multicropping, but most significantly, he has a chapter on making a profit. He has worked out how to create a fully functioning context for himself and his fields.

We have recommended to our students that they become lawyers, since humans act coherently with the law. We might also suggest that they go into business with the New Forest Farm model. Mainstream farming is a relatively high-pressure, high-gain system because of economic pressures. But what Shepard is recommending is a highly organized, low-gain way of increasing constraints and efficiencies. High gain is by definition short-lived and not sustainable. Low gain emerges when sustainability becomes an issue. Two years ago was a drought across the state; field crops from corn to hay were a disaster. But New Forest Farm had a great year, a bumper crop of hazelnuts, berries and apples, all species that are drought tolerant. Shepard has created a set of landscape berms that direct water across the slope and conserve it. It was a good year for "Shepard's Hard Cider." Shepard does impose homogeneity, as is characteristic of fields, but it is in the spirit of multiple-use management. The difference is that it is with multiple crops instead of multiple uses. Of course, multiple crops are common in tropical agriculture, but Shepard does it in a temperate region.

MANAGING ECOLOGICAL SYSTEMS AWAY FROM EQUILIBRIUM

Having recognized that the systems we are to manage will function away from equilibrium, we are now in a position to use an explicitly hierarchical approach to management. It is in the nature of hierarchical control that lower-level entities are held away from equilibrium by the constraints imposed by upper-level contexts. In this way, the second law of thermodynamics, the one about gradients, is not in contradiction of life but rather drives it. Life is held away from equilibrium by constraints at many levels, and the gradients thus created, drive organization (Schneider and Kay 1994).[25] Effective management needs to be particularly mindful of two points that follow from an explicitly hierarchical approach: (1) the system being managed will be out of equilibrium, all the more so because it is being managed, and (2) as a higher-level context, the management practice must offer a viable context for the system under its charge.

SUPPLY-SIDE SUSTAINABILITY

With Tainter, we wrote our book *Supply-Side Sustainability*.[26] The chapter so far has spoken in the spirit of that work, but let us be explicit about that scheme. The name, supply-side sustainability, comes from a set of principles laid out in that book. We have been talking around these principles heretofore, but now let us lay out those principles here.

The first principle says: *Do not manage for the resource, but rather manage for the health of the system that produces the resource.* If we manage for the resource in a fishery, we would harvest fish that give the greatest immediate weight of catch. That would take fish at the size when they are at their steepest part of their individual growth curve. When individuals are growing fastest, they are most efficient at converting the ecosystem into fish biomass. Older, bigger fish convert less, so the strategy would be to fish out the older fish. But the effect of that is to take out the context of the whole system. The old fish may not convert much ecosystem input to fish biomass directly, but they are stabilizers that offer the best-quality fingerlings to the next generation. Work to manage the whole system that produces coupled to the sun, and it will continue to produce.[27]

Thus, the second principle of supply-side sustainability is*: Manage from the context*. First, it is easier than managing the details, which will be different in each local setting. In fisheries that have been managed for maximum biomass of desired fish, one species at a time, the desired fish have been driven close to extinction. Apparently, backing off to allow recovery is action too late. The cod fishery is not coming back for reasons that are not transparent. The great fishery of the Georges Bank in Maine is now down to trash fish, whose growth rate is fast enough to survive intense human depredation. With such fast growth rates, the fishery now yields only to chaotic equations. Chaos cannot be managed even in the midterm. In other words, the fishery is not only being badly managed, it is unmanageable.

The lobster fisheries are doing well enough in Maine because they are managed from their context, the big old lobsters. Maine has legislated the use of lobster pots; bottom dredging is not allowed. The small lobsters can get out of the pots, while the big ones cannot get in. This preserves the young and gives the next generation a source of high-quality genetics. Any big lobsters that provide the context are not fished by lobster pots. The fisheries are also being heavily supported through hatcheries.

The third supply-side principle is: *If the system finds itself in a workable environment, it will support the sustainability effort*. The extra productivity can be taken. The manager has earned it by looking after the internal production needed for ecosystem function.

The fourth principle is: *If you want to shift the system, do it with positive feedbacks*. Simply pulling the system to where you want it is expensive and it will likely slide back once you stop paying for the engine that is doing the pulling. With positive feedbacks, the pressure to change takes the system into the new position and continues to hold it there with the feedback alone. It is best if the desired system state is an emergent property driven by feedback. Government regulation is important, but only as a catalyst.[28] Regulations are constraints.

The major positive feedback in the first world is at the heart of the mercantile system. Trade works with positive feedbacks. Without a healthy economy, there is no one to pay for environmental action. It is therefore appropriate to rely upon business to make the environmental changes. Business is often efficient in solving its problems. It can be directed to use that efficiency to the public good by government manipulation of its environment. Given regulation that tilts the landscape in a public-spirited direction, business can be trusted to make the best of that situation and act for profit in the public good. While government is well equipped to be a catalyst that tilts the landscape, it cannot work as the engine that actually delvers the change. Government constrains; it does not have positive feedbacks. It ratchets and does not come down in size when the pressure is off. So a mixed economy is probably the only way to put in place the feedbacks for change that we recommend.

Parts of business have discovered the principles of supply-side. There is a group of businesses applying supply-side principles, and is accordingly creating value much faster than that reflected in the major market indices such as the Dow Jones. The movement calls itself "Conscious Capitalism," and its proponents include: Whole Foods Market, Panera Bread, Southwest Airlines, The Container Store, Nordstrom, The Motley Fool, Stagen, Joie de Vivre hotels, and Trader Joe's. Their mantra is unleashing stakeholder value.

This view of the firm was presented thirty years ago by Russ Ackoff in his *Creating the Corporate Future*. It is not the usual top-down hierarchical control system view. The CEO is not the functioning head. The shareholders may have certain rights in the eye of the law, but they do not trump the other organization stakeholders because if they do, shares collapse in value. The company is beholden to its employees, creditors, customers, suppliers, and to the local government. If it does all that, it will deliver for its shareholders. Empower the stakeholder and the workers will be invested, the customers will be loyal, the government will be cooperative, and the creditors and suppliers will give good terms. And the outcome will be for the general good. It is a rational approach to collaboration that serves multiple self-interests. It works toward sustainability. We make similar points when we discuss commensurate experience in the chapter 8.

If management can achieve what we prescribe, then the managed unit should be serviced as if it were in context. Accordingly, well-managed units should behave as if the context were indeed there, even though it is not. Then the managed unit should be free to function without deprivations; what the extant context cannot offer, the human management system provides instead.

This leads to a principle of management that at present is only a hypothesis but may in time be verified: *If the management regime is effective, the managed unit will offer a maximum subsidy to the management effort.* If the managed unit is being provided with all it might expect from a natural context, then it can function to full effect. Humans get to choose the context, to an extent. Effective management would provide infusions of genetic diversity from a distant wild population or, if necessary, from a zoo. The Isle Royal wolf population is now down to eight, and inbreeding depression is suspected. Normally, the context would offer genetic diversity in the form of outcasts or strays from neighboring populations, but in their absence, human contrivance plays that role instead. The effect of these infusions should be to maintain the managed population as a vigorous unit, making it appear as close to self-sustaining as possible. Of course there is a cost to management, and the system is not self-sustaining in the normal sense. But if we cast humans and their management as being inside the system, then the larger scheme is self-sustaining. Part of the system feeds us, and we humans sustain what is not human in the system. The management cost must be sustainable, raising the questions of sustainability of what, at what cost, and for how long. Lower cost is likely to contribute time to the issue of how long. On the positive side, breeding in a managed population subsidizes the management effort. This feedback is what allows many management regimes to persist to the point where they are significantly sustainable with workable effort.

There is a difference between managing the system from outside, which is what we recommend, and forcing the system to perform in some focused, prescribed way aimed at the inside. Get the context right, and you do not need to understand the mechanisms of the managed system or the one it replaced. Do it right, and the system does what you want. See what works, and simply keep doing it. "Keep doing it" may itself invoke a sort of metalevel management that is the management of management.

In exactly that spirit, Eduardo Sousa makes foie gras. In 2006, his Extremeña Company, La Patería de Sousa, won first place at the International Food Products Exhibition in Paris, SIAL 2006. He is Spanish, and the French were incredulous and upset. Some of the outrage was that Sousa did not gavage his geese. Gavage involves force-feeding geese with a funnel and a tube into the stomach. In a few weeks of being involuntarily gorged, the goose liver expands to eight times normal. The livers make foie gras, a great delicacy. But fully deserved bad press has foie gras banned in Chicago, San Francisco, and New York. World-renowned chef Dan Barber went to visit Sousa, and gave a wonderful TED talk on the experience.[29] Sousa has his geese in a fenced-in area. The purpose of the fence is not to keep the geese in but to keep predators out—the electric wire is on the outside. He plants everything the geese want, a great diversity of plants. His geese are so happy that wild geese hear their calls and come, not just to visit but to stay. The geese know Sousa and appear to love him. Foie gras is usually bright yellow, but Sousa's foie gras, not involving corn, was gray. So he gathered seeds of a local yellow lupine. His geese loved the seeds and gobbled them down. His foie gras turned bright, bright yellow. The flavors in the foie gras come from his pepper plants and from plants he uses to control salinity. The geese are thus naturally salted. Sousa lets nature do it all for him.

Barber goes on to say that gavage is in fact a perversion, yet another example coming from a dysfunctional context. He reports that foie gras is an ancient Jewish device, raising the geese in the manner of Sousa. But in slavery, the story goes; the pharaoh demanded their foie gras from them in quantity. The only way to achieve such production was through gavage. The story may or may not be true, but it makes a point. Foie gras is made the Sousa way under low-gain constraints and complications. Gavage is a high-gain method that increases the flux on production. And so it is with mainstream agribusiness: focus on quantity lowers quality and generates instability. In a piece on the ecology and culture of Western European peasants, Estyn Evans makes exactly the same point. Abundance lowers quality. He says that if you want the best cheese, go to areas that produce little milk. There, they divert valuable milk into an even more valuable cheese. Heavy milk-producing regions that have excess characteristically dump the over-production into cheese as food preservation. Wisconsin, "America's Dairyland," as it says on vehicle number plates, does make some world-class cheese, but the bulk of it is for mass-produced pizzas and processed cheese.

In the management of the Great Lakes Ecosystem Basin, the International Joint Commission has adopted an approach that, like ours, explicitly includes humans and human activities. The "Ecosystem Approach," as it is called in the international agreements, argues that (1) ecological, (2) sociopolitical, and (3) economic systems all coexist in the functioning of the basin.[30] The "Ecosystem Approach" requires an integration of all three sectors in the search for management solutions. The emphasis is only slightly different from ours, for the absence of the natural context is just another way of pointing to the presence of the human sociopolitical and economic sectors. Ours is not a management scheme for a pristine world, but one for a world full of human activity, where even the fragments that resemble the primeval condition are artificial islands. If we manage them as pristine wilderness, all will be lost. If we acknowledge it is not nature that we manage, but managed units, there is a shot at competent intervention.

Ecosystem services have been a buzzword recently, but its very name indicates a fundamental misconception.[31] In the service sector of the economy, one party offers service as something good for some other party. The service provider works to satisfy the customer in return for money. Since ecosystems are not sentient, they are not in a position to offer service per se. They do have resources taken from them, but they do not offer services. In fact, it is the user of the so-called services who must offer service to the ecosystem. Normally, those receiving the service pay for those services. It is the ecosystem that pays, and it is the ecosystem that needs service as compensation for what it pays. Ecosystem services are simply backwards. Ecosystem service should be service offered by human consumers.

THE SOCIAL SIDE OF SUSTAINABILITY AND LIVABILITY

The manner of exploitation of ecosystems is generally not focused on sustainability. If a system is to reach a state of sustainability, it has to pass through a process that people living find acceptable. In other words, to reach sustainability, the system must meet criteria for livability. High and low gain again pertain. Livability is high gain in that there are no plans, and it is simply what the people living want.[32] Often the standards of livability are at odds with sustainability. The continued exploitation of fossil fuel is not sustainable, but its exploitation is left to the market. The market has no values; it just responds to flux and process. So exploitation will always follow the path of livability, which has little conscience and only addresses the short term.

The good news is that livability is labile. When resources are limited by depletion, the market dictates higher prices. In the end, they become prohibitive and a new livability is imposed, like it or not. When the price of gasoline doubled in the United States to reach four dollars per gallon for the first time, a new livability was imposed. The Hummer production line was abandoned because the American public had been awakened to the real cost of personal transportation.

There is always the danger of Jevons paradox blunting changes in livability. On the face of it, efficiency should save fuel because less is used for a given amount of work achieved. But increased efficiency usually leads to more, not less, consumption. Jevons in 1865 first wrote on "The Coal Question." He told of steam engines and coal consumption. An efficiency of steam engines increased from 0.5 percent (95.5 percent up the flue) to 2.5 percent around 1850. Efficiency of 2.5 percent may not seem like much, but it was a 500 percent improvement that made steam engines worthwhile. More steam engines came on line, so increased efficiency actually increased coal consumption.[33] The same thing happened in the mid-1980s, when internal combustion engines finally were made more efficient. The response was the sudden popularity of sport-utility vehicles (SUVs) that drivers could afford to run, even at higher fuel costs caused by scarcity. Increased efficiency in the face of declining resources allows rapacious consumption to persist. The villain in the coming crisis of petroleum is the Prius, not the Hummer. The latter simply goes extinct, but the hybrid car lets consumers continue to consume. As notions of livability change, values shift. We can see the very same people with opposite values some time later.

An example is values in England with regard to enclosing spaces. With quite opposite land ethics and values from today, the creation of British hedgerows angered common folk. With the Elizabethan Acts of Enclosure in Shakespeare's time, commons lands were fenced off, angering commoners. Later, parliamentary acts enclosed larger parcels. Common folk were forced off the land and into cities and industry. Their resentment is captured in an anonymous folk song of 1764:

The law doth punish man or woman
That steals the goose from off the commons,
But lets the greater felon loose
That steals the commons from the Goose.

Big landowners were the beneficiaries and, of course, approved of enclosure. And it was not all a bad thing, as overgrazed land was brought under private ownership with its built-in self-regulation to avoid overexploitation. But over the centuries, the common folk have come to appreciate hedgerows as part of their heritage, in a change of values as to what is livable. There is also a change in values of the big landowners, who used to protect ancient sites. Now they are desecrating valuable old places, building shopping centers and the like, any place they can get around regulations. As we mention at the beginning of this chapter, the land of big landowners was their power base, but it is no longer economically sustainable. Values for livability have flipped between aristocrats and common people. Values for livability are labile.

With the industrialization that followed enclosure, a change in fuel was forced on the populace. There was resistance because wood was free but coal had to be bought. Forest people in Epping Forest used to be entitled to lop trees at head height for fuel. Queen Victoria withdrew lopping rights, and in 1884, compensated the common people with Lopping Hall, a civic building. The trees still show the change in policy. Thick boles up to head height now have long, tall branches growing from them. That is the growth in the century and a quarter since lopping ceased (figure 9.8). The trees show the change in livability in the forest.

But resistance to changes in livability has produced a certain retrenchment in values, with some very strange patterns of land use. Regulations going back to 1790 give anyone with sizable land adjacent to Epping Forest open grazing rights

FIGURE 9.8. Trees in Epping Forest showing a hundred years of growth from a lopped old trunk. (Photo courtesy of T. Allen.)

in the forest. Grazing practices more appropriate to Wyoming interdigitating with urban London make no sense! Allen lived on Whipps Cross Road, the North Circular Road, a main trunk route. But his mother would from time to time have to protect her flowers in the front garden by chasing cows out into the four-lane roadway traffic. Even when a motorcyclist was killed in 1977 from a collision with a steer in dense fog, it took another two decades for the grazing rights to be suspended. So livability is labile, but it takes pressure to change it.[34]

Another bizarre example is the entranceway to Whipps Cross Hospital, which serves the east quadrant of London with about a thousand beds. Allen's father, Frank Allen, was chief hospital pharmacist from the 1940s to the 1970s. The hospital is some thirty yards back from Whipps Cross Road, with what is technically part of Effing Forest between the hospital entrance and the road. It is a sad strip of trees, not really part of the forest in any functional terms. When Allen himself was a teenager, that entranceway was only a single lane. Ambulances would have to wait their turn to come out if another was coming in, and vice versa. Frank Allen reported that it took twenty years of negotiation with Epping Forest authorities to widen it to a rational two lanes so ambulances with the sick and dying could pass. In the end, livability will yield and values will change, although the examples above attest to how values can be entrenched until the last. We are not likely to move off fossil fuels until a decade or so too late.

Raw flux does not govern sustainability, planning does. It appears futile to hope to wrest control over careless resource use by populist politicians. Jimmy Carter had the solution to the gas crisis of his time. He proposed increasing tax on fossil fuel until use was diminished. Had he won out, this would be a different world now. But Congress members put the need to be reelected ahead of a rational energy policy, and they blocked him. To be fair to the politicians, the voters would probably have exacted their price in the cause of the livability they wanted. Even so, sustainability might be possible, at least in the midterm, because the present greedy livability will yield to shortages.

The danger is that running resources to too low a level might deny society enough energy to make the prudent shift. It takes resources to switch to low gain. But plans for sustainability do not go unnoticed. A more measured livability might emerge ahead of its time, before it is absolutely forced by lack of resources. The environmental moves made in the 1970s were not so much driven by actual poisoning of humanity at large as they were by wiser sentiments coming from seeing the whole planet from space, and feeling lost. Ironically, Richard Nixon was the last environmental president, forced there by popular sentiment. Some of the green parties of Europe do have enough seats in the government to be crucial players in some ruling coalitions. Even the U.S. presidential candidate of the Right in the 2012 election openly talked of energy independence in the short run. Whether or not it was a sincere statement, it was made under pressure of acceptance of the need for a sustainable policy perceived as a desire of the electorate. Sustainability must yield to livability, but livability is labile enough for it to be worth some low-tain planning toward sustainability.

CONCLUSION

To summarize this chapter, the world that includes modern humanity is held far from primeval equilibria. From this it follows that management is not only of systems that are out of balance, but management itself explicitly holds the system away from equilibrium. Out of this emerges a management strategy that is explicitly hierarchical, where management is a required substitute for defunct natural constraints. The central concept is subsidy: subsidy of the managed system in recompense for the destroyed context (absent forest, grasslands, and wetlands); subsidy of the human management activity by the managed unit.

The central theme of this whole book is a contrast between different ways of looking at ecological systems. In this chapter, we emphasize that the manager is forced to look at nature using several criteria simultaneously. The contrast of the manager with the restorationist is helpful because the latter generally deals with one ecological category at a time. The use of multiple criteria at one time, as is demanded of the manager, does present difficulty but also it exposes the richness of ecological material. We have analyzed what this means for management in contrast to basic research. Further implications for basic research of a multifaceted view of ecology are explored fully in chapter 10.

The different facets of ecology are not so much a matter of nature as they are a matter of divergence in human perception; the material system does not function discretely as a community or ecosystem, or any other conceptual categorized entity. By being forced to deal with several ecological categories at once, the manager comes face-to-face with the human subjectivity that makes ecology more a soft than a hard science. Lynton Caldwell once noted that when professionals manage an ecological system, they do not manage the ecological system itself; rather, they manage the people who live in and act upon the system.

Ecology is a fairly soft science. We have shown that the softness of a scientific endeavor is related to the changes in human value systems that occur when the object of study is raised. Hard science ecology would not only be impotent when it comes to management it would also be intellectually sterile. The essential beauty of ecological material can be seen with remarkable clarity through the eyes of the manager. The naturalist and the preservationist do not have a monopoly on the joy that is to be had from being an ecologist in the woods. Management is a very aesthetic matter. In the modern biosphere, human activity is part of the system in a new dynamic interplay. Our species has the next dance with nature, and it is the ecological managers who should be the dancing masters and the orchestra leaders.