Certain remarkable similarities can be found between the concerns of ecologists and planners. Like complex urban systems, ecological systems appear to be characterized by four distinctive properties. These include their functioning as interdependent systems, their dependence on a succession of historical events, their spatial linkages, and their non-linear structure. Both systems appear to have considerable internal resilience within a certain domain of stability. However, programs such as insecticide spraying or urban renewal, that disturb the complex balance of either system, can generate unexpected and undesirable results. Use of an ecological framework for planning suggests new principles based more on recognition of our ignorance than presumption of our knowledge about the systems in which we try to intervene.

To offer an ecological view of urban systems to a planning audience is risky. But, the possibilities for collaboration appear to outweigh the risks. Ecologists and planners have much to learn from each other.

Since ecology emerged from its descriptive phase in the 1920's, its emphasis has been on understanding the operation of complex ecological processes and ecological systems. There has been little effort to develop effective applications of ecological principles. Within the last few years, however, there has been a major shift toward an interest in application; but ecologists' first efforts in this direction have been blundering and naive. The central role of planners, on the other hand, has been application and policy formulation and implementation. Ecologists can benefit enormously from an infusion of the pragmatic realism that is, of necessity, forced upon the planning profession. Perhaps, at the same time, planners may gain some insights about urban systems from ecological theory.

As a basis for dialogue between planners and ecologists, we propose a conceptual framework based on ecological concepts of ecosystem structure and stability. This framework suggests an approach for planning based on a presumption of ignorance rather than on a presumption of knowledge. Since the area of our knowledge of man/environment interaction is minuscule small in comparison with our ignorance, this conceptual framework may have some merit for the planning process.

The Nature and Behavior of Ecological Systems

Rather than presenting an exhaustive treatment of ecological concepts and terms, we hope to apply the philosophy of the ecological approach to solve problems of a kind that recur in all complex systems. The key insight of this approach is that ecological systems are not in a state of delicate balance. Long before man appeared on the scene, natural systems were subjected to traumas and shocks imposed by climatic changes and other geophysical processes. The ecological systems that have survived have been those that are able to absorb and adapt to these traumas. As a result, these systems have considerable internal resilience, but we know that this resilience is not infinite. A forest can be turned into a desert, as in the Middle East, or a lake into the aquatic analog of a desert. The key feature of the resilience of ecological systems is that incremental changes are absorbed. It is only when a series of incremental changes accumulate or a massive shock is imposed, that the resilience of the system is exceeded, generating dramatic and unexpected signals of change.

This has considerable consequence for planning, since, inherent in the philosophy of planning and intervention, is the presumption that an incremental change will quickly generate a signal of whether the intervention is correct or not. If the signal indicates the intervention produces higher costs than benefits, then a new policy and a new incremental change can be developed. But because of the resilience of ecological systems, incremental changes do not generate immediate signals of their effect. As a result, planners can set in motion a
sequence of incremental steps and face the reality of the inadequacy of the underlying policy only when the interventions accumulate to shatter the bounds of resilience within the system. By that time it can be too late. In order to demonstrate these features of ecosystems we will discuss two specific case histories, each based on man's intervention. The consequences of the interventions reveal some of the key properties of ecosystems.

MALARIAL CONTROL IN BORNEO

Since the Second World War, the World Health Organization (WHO) has developed a remarkably successful malarial eradication program throughout the world. We wish to emphasize that, in this example of intervention, there is no question that there has been a dramatic improvement in the quality of life of people in affected regions. But, we wish to explore a specific case in which the World Health Organization sprayed village huts in Borneo with DDT in order to kill the mosquito that carries the plasmodium of malaria. This case has been documented by Harrison (1965).

The inland Dayak people of Borneo live in large single homes or long houses with up to 500 or more under one roof. This concentration of population allowed WHO to develop a thorough and orderly spraying of every long house, hut, and human habitation with DDT. The effect on health standards was dramatic with a remarkable improvement in the energy and vitality of the people—particularly those remote tribes who had not previously had access to medical aid. Nevertheless, there were interesting consequences that illuminate some of the properties of ecological systems.

There is a small community of organisms that occupy the thatched huts of these villages—cats, cockroaches, and small lizards. The cockroaches picked up the DDT and were subsequently eaten by the lizards. In consuming the cockroaches, the lizards concentrated the DDT to a somewhat higher level than was present in the cockroaches. The cats are the lizards and, by eating them, concentrated the level of DDT still further—to the point that it became lethal. The cats died. When the cats disappeared from the villages, woodland rats invaded, and it suddenly became apparent that the cats had been performing a hidden function—controlling rat populations. Now, with the rat came a new complex of organisms—flies, lice, and parasites, and this community presented a new public health hazard of sylvatic plague. The problem became serious enough that finally the RAF was called to parachute living cats into these isolated villages in order to control the rats.

The story isn't finished at this point, however, since the DDT also killed the parasites and predators of a small caterpillar that normally causes minor damage to thatch roofs (Cheng 1963). The caterpillar populations, now uncontrolled, increased dramatically, causing the roofs of the huts to collapse.

We cite this example not because it has great substance, but simply because it shows the variety of interactive pathways that link parts of an ecological system, pathways that are sufficiently intricate and complicated that manipulating one fragment causes a reverberation throughout the system. In addition, this case provides a simple example of a food chain in which energy and material moves from cockroaches to lizards to cats. Typically, in these food chains the number of organisms at a higher level in the chain are less abundant than those lower in the chain. This is the inevitable result of the loss of energy in moving from one trophic or nutritional, level to another, and the consequence is a biological amplification that concentrates certain material at higher and higher levels as one moves up the chain. A contaminant like DDT, for example, can be present in the environment in very low, innocuous levels but can reach serious concentrations after two or three steps in the food chain. Actually, this example is highly simplified; usually in such situations there is a food web rather than a single linear food chain. Several species operate at more than one trophic level. Moreover, there are competitive interactions that further complicate
and link species within an ecosystem. Even in this example, however, it is clear that the whole is not a simple sum of the parts and that there are a large number of components in a system acting and interacting in a variety of complex ways.

**A COTTON ECOSYSTEM IN PERU**

Unlike the preceding example, the case of cotton agriculture in many parts of the world has had a more serious outcome. Pest control practices in cotton have, until recently, been both ecological and economic disasters. A particularly well-documented case has been prepared by Smith and Van den Bosch (1967).

There are a series of valleys on the coast of Peru formed by streams running from the high Andes to the Pacific Ocean. Many of these valleys are under intensive agriculture and, because of the low rainfall, are irrigated. The result is that each valley is essentially a self-contained ecosystem isolated from others by barren ridges. In one of these valleys, the Canete, during the 1920’s, the crop shifted from sugar cane to cotton. Over the years a group of seven native insects became significant cotton pests, including plant sucking insects, the Boll Weevil, the tobacco leaf worm, and some moths. The pest problem, however, was essentially modest, and the farmers of the region lived with the resulting economic damage. In 1949, chlorinated hydrocarbons like DDT, Benzene hexachloride, and toxaphene became widely available, and the opportunity to dramatically decrease pest damage and increase crop yields arose. The characteristics of these insecticides seemed admirably suited to achieve the goal of pest reduction or elimination in this case:

1. The insecticides are lethal to a large number of insects and are so mobile that they quickly and easily concentrate within insects.
2. They are highly toxic to invertebrates and less so to mammalian forms.
3. They have a long life in the environment so that, in theory, one application can have an effect over some time. It has been shown, for example, that DDT and its biologically active breakdown products have an environmental half-life of over a decade.
4. They can be easily and inexpensively applied from aircraft.
5. The contained nature of the valley ecosystem made it possible to spray the entire area with the insecticide.

We emphasize these details because the general features of this policy seem to be shared by many of man’s actions. First, the objective is narrowly defined—in this case elimination of seven insect pests. Second, the plan developed is the simplest and least expensive means to achieve the narrow objective. But the consequences of this approach generated a series of unexpected and disastrous consequences explicitly because of the narrow definition of the objectives and the intervention.

The initial response to the insecticide treatment was a dramatic decline in pests and a one and one-half times increase in cotton production. This lasted, however, for only two or three years, when it was noticed that new pests were appearing that had never been a problem during the history of cotton production. Six new species of insects became as serious a problem as the original seven. The reason for the appearance of these new pests was the elimination of parasites and predators that were selectively killed because of the biological amplification of the insecticides through the food web. Within six years the original seven insect pests began to develop resistance to the insecticide, and crop damage increased. In order to control this new resurgence the concentration of the insecticide had to be increased, and the spraying interval reduced from two weeks to every three days. As these responses began to fail, the chlorinated hydrocarbons were replaced by organophosphate insecticides which deteriorated more rapidly in the environment. But even with this change the cotton yield plummeted to well below yields experienced before the synthetic insecticide period.

The average yield in 1956 was the lowest in more than a decade, and the costs of control were the highest. The agricultural economy was close to bankruptcy, and this forced the development of a very sophisticated ecological control program that combined changed agricultural practices with the introduction and fostering of beneficial insects. Chemical control was minimized. These new practices allowed the reestablishment of the complexity of the food web with the result that the number of species of pests was again reduced to a manageable level. Cotton yields increased to the highest level experienced in the history of cotton production in the valley.

As in the Borneo example, this case demonstrates the complexity and the structure of one ecological system that gives the system the resilience to absorb unexpected changes. Application of the insecticide enormously reduced the comm-
plexity and diversity of the ecosystem with a dramatic loss in resilience. But there is a difference between the two examples. In the first example, the area of intervention was local, and although there was destabilization within the local region, the consequences never became serious enough to defeat the original purpose of the intervention. In the Peruvian example, on the other hand, the intervention was more global since the whole valley ecosystem was literally blanketed with insecticide. As a result, the short-term success of the narrow intervention led in the longer term to the complete opposite of the original goal.

**NATURE OF ECOLOGICAL SYSTEMS**

These two examples illuminate four essential properties of ecological systems. By encompassing many components with complex feedback interactions between them, they exhibit a systems property. By responding not just to present events but to past ones as well, they show an historical quality. By responding to events at more than one point in space, they show a spatial interlocking property, and through the appearance of lags, thresholds, and limits they present distinctive non-linear structural properties. First, ecosystems are characterized not only by their parts but also by the interaction among these parts. It is because of the complexity of the interactions that it is so dangerous to take a fragmented view, to look at an isolated piece of the system. By concentrating on one fragment and trying to optimize the performance of that fragment, we find that the rest of the system responds in unsuspected ways.

Second, ecological systems have not been assembled out of preexisting parts like a machine: they have evolved in time and are defined in part by their history. This point does not emerge clearly from the examples quoted; nevertheless, the resilience described in the examples is very much the consequence of past history.

When a large area is stripped of vegetation, an historical process begins that leads to the evolution of a stable ecosystem through a series of successional stages. Early in this succession, pioneer species occupy the space, and the diversity and complexity are low. The species that can operate under these circumstances are highly resistant to extreme conditions of drought and temperature and are highly productive. Competition is low, and a large proportion of the incident solar energy is converted to the production of bio-mass (the standing stock of organic material). As this accumulates, the conditions of the area begin to improve and to permit the appearance of groups of plants and animals that otherwise could not survive. The result is a gradual increase in the variety of species and in the complexity of interaction, and this increase in complexity is accompanied by an increase in the resilience of the system and a decrease in productivity. Under stable conditions this successional history can continue until a stable climax ecosystem evolves.

Man's objective in agricultural management is to halt this history at an early successional stage when the productivity is high. The price of doing this is a continual effort to prevent the system from moving to its more stable and less productive stage: hence herbicides and cultural practices eliminate or reduce those organisms that compete with man for food. But by emphasizing high productivity as a narrow objective, man develops the simplest and most direct policy, and the result leads to decreased complexity—large monocultures, heavy use of chemical herbicides, insecticides, and fertilizers. For the short term, the narrow objective of increased productivity is achieved, but the price paid is a dramatic decline in the resilience of the system. Third, complex ecosystems have very significant spatial interactions. Just as they have been formed by events over time so they are affected by events over space. Ecosystems are not homogeneous structures but present a spatial mosaic of biological and physical characteristics. The differences noted above between the Borneo and Peruvian examples are explained, in part, by the difference in the spatial scale of the intervention. In the Borneo example, the intervention was local and, in fact, increased the spatial heterogeneity. In the Peruvian example, the intervention was global and dramatically decreased the spatial heterogeneity. The consequence was that the resilience in the cotton ecosystem vanished. Finally, there are a variety of structural properties of the
processes that interrelate the components of an ecosystem. We do not wish to dwell on these details other than to say they present singular problems in mathematical analysis for they relate to the existence of thresholds, lags, limits, and discontinuities.

BEHAVIOR OF ECOSYSTEMS

The distinctive behavior of systems flows from these four properties. Together they produce both resilience and stability. Even simple systems have properties of stability. Consider the example discussed by Hardin (1963). Every warmblooded animal regulates its temperature. In man the temperature is close to 98.6°F. If through sickness or through dramatic change in external temperature, the body temperature begins to rise or fall, then negative feedback processes bring the temperature back to the equilibrium level. But we note this regulation occurs only within limits. If the body temperature is forced too high—above 106°F, the excessive heat input defeats the regulation. The higher temperature increases metabolism which produces more heat, which produces higher temperature, and so on. The result is death. The same happens if temperature drops below a critical boundary. We see, therefore, even in this simple system, that stability relates not just to the equilibrium point but to the domain of temperatures over which true temperature regulation can occur. It is this domain of stability that is the measure of resilience.

In a more complex system, there are many quantities and qualities that change. Each species in an ecosystem and each qualitatively different individual within a species are distinct dimensions that can change over time. If we monitor the change in the quantity or quality of one of these dimensions, we can envisage results of the kind shown in Figure 1. Within the range of stable equilibrium, if we cause a change in the quantity being measured, it will return to equilibrium over time. But there is a limit to which we can perturb these quantities, and that limit is defined as a boundary of stability.

The domain of stability is contained within the upper and lower boundaries. In simple physiological and engineering control feedback systems, regulation is strong enough and conditions are stable enough that most of our attention can be fixed on or near the equilibrium. This is not true of ecological systems (Holling and Ewing 1969). Ecological systems exist in a highly variable physical environment so that the equilibrium point itself is continually shifting and changing over time. At any one moment, each dimension of the system is attempting to track the equilibrium point but rarely, if ever, is it achieved. Therefore, each species is drifting and shifting both in its quantity and quality. Because of this variability imposed upon ecological systems, the ones that have survived, the ones that have not exceeded the boundaries of stability, are those that have evolved tactics to keep the domain of stability, or resilience, broad enough to absorb the consequences of change. The regulation forces within the domain of stability tend to be weak until the system approaches the boundary. They are not efficient systems in an optimizing sense because the price paid for efficiency is a decreased resilience and a high probability of extinction.

This view of stability is, of course, highly simplified. There may not be just one stable equilibrium at any instantaneous point in time; there may be several. Moreover, the stable condition might not be a single value but a sequence of values that return to a common starting value. This stable condition is termed a stable limit cycle.

FIGURE 3 An Example of a Bounded Stable Trajectory Analogous to that Found in an Ecological Succession
(Figure 2). Finally, the sequence of stable values need never return to some common starting point. The earlier description of an ecological succession really represents such a condition—a stable trajectory as illustrated in Figure 3.

But, however the equilibrium conditions change, they are all bounded, and what we must ask in judging any policy is not only how effectively an equilibrium is achieved, but also how the resilience, or the domain of stability, is changed. The two insecticide examples illustrate the point. The policies used in these cases were characterized by three conditions:

1. The problem is first isolated from the whole; that is, pests are damaging cotton.
2. The objective is defined narrowly; that is, kill the insect pest.
3. The simplest and most direct intervention is selected; that is, broad-scale application of a highly toxic long-lived insecticide.

Each of these conditions assumes unlimited resilience in the system. By adopting these policies, the problem and the solution are made simple enough to be highly successful in the short term. So long as there is sufficient resilience to absorb the consequences of our ignorance, then the success can persist for a very long time. It is successful in the sense that the agriculturist can return his system almost instantly to an equilibrium point of one crop and no competing pests. The price paid, however, is the contraction of the boundaries of stability, and an equilibrium-centered point of view can be disastrous from a boundary oriented view.

It is this boundary oriented view of stability emerging from ecology that can serve as a conceptual framework for man’s intervention into ecological systems. Such a framework changes the emphasis from maximizing the probability of success to minimizing the chance of disaster. It shifts the concentration from the forces that lead to convergence on equilibrium, to the forces that lead to divergence from a boundary. It shifts our interest from increased efficiency to the need for resilience. Most important, it focuses attention on causes, not symptoms. There is now, for example, growing concern for pollution, but the causes are not just the explosion of population and consumption, but also the implosion of the boundaries of stability.

The Nature and Behavior of Urban Systems

Arguments related exclusively to the nature and behavior of ecological systems obviously cannot be uncritically transferred to urban systems. Analogies are dangerous instruments, and in this case the transfer should be made only when the structure and behavior of urban systems appear to be similar to the structure and behavior of ecological systems.

Ecology is the study of the interactions between organisms and the physical environment. Planning concerns itself with the interaction between man and the environment of which he is a part. But does this analogy go deeper than a simple verbal parallelism? There are specific examples that point to similarities between certain ecological and social processes. But the real substance of an analogy between ecological and urban systems lies not in the similarities between parts or processes, but in fundamental similarities in the structure of entire systems. We earlier described four key properties of ecological systems which concern system interaction and feedback, historical succession, spatial linkage, and non-linear structure. The same properties seem to be important for urban systems.

In the first place, both urban and ecological systems are true systems functioning as a result of interaction between parts. Just as a narrow intervention in an ecological system causes unexpected reverberations, so will it in an urban system. A freeway is constructed as an efficient artery to move people, but the unanticipated social consequences stimulate urban sprawl and inner city decay. A ghetto is demolished in order to revitalize the urban core, and disrupted social interactions trigger violence. A tax subsidy is given to attract industry, leading to environmental pollution deteriorating the quality of life. Such narrow interventions demonstrate that the whole is not a simple sum of the parts.

Second, the city region, like an ecological system, has a history. The modern cities of North America are, to a major extent, the product of history since the industrial revolution. The technology of the industrial revolution removed the constraints imposed by limitations in the environment, permitting development to take place as if there were no environmental limitations. If, for transient moments of time, the signals of these limitations became apparent through the appearance of plague or famine, the problems were generally resolved by looking elsewhere for the solution. So long as there was an “elsewhere”—an undeveloped continent, an undeveloped West—then this approach provided the quickest solution. The only constraints were placed by economic needs, hence the great emphasis on economic growth. The result, therefore, is an urban system with many of...
the characteristics of an early stage in an ecological succession. The system is changing rapidly in time and is not closed. Without any apparent limitation, water and air are considered as free goods to receive, at no cost, the wastes of the system. Only now is it becoming generally recognized that there are environmental constraints, that water and air are not free goods, and that wastes cannot simply be transported “elsewhere.” In a sense, the urban system, like an ecological one, has a memory which constrains it to respond to current events only as it has been conditioned by past events. In a rapidly changing present the responses can become dangerously inappropriate.

Third, the urban system has significant spatial characteristics and interactions. Just as the city has been formed by events over time, so it is affected by events over space. The city is not a homogeneous structure but a spatial mosaic of social, economic, and ecological variables that are connected by a variety of physical and social dispersal processes. Each individual human has a variety of needs—for shelter, recreation, and work. These activities are typically spatially separate, and any qualitative or quantitative change of a function at one point in space inevitably affects other functions at other points of space.

Finally, the same non-linear, discontinuous structural properties noted in ecological systems apply to urban systems. Thresholds and limits exist with regard to city size. We know that a city of 500,000 residents has more than five times the variety of activities a city of 100,000 has. We also know that below certain threshold levels, certain activities do not occur. Thus, suburban areas and smaller cities just do not have great art museums, operas, symphonies, and restaurants. These activities appear to occur above certain population, or density, thresholds. Finally, such notions as agglomeration and per capita servicing costs are all non-linear relationships with respect to city size.

Both the structure of the parts of an urban system and the whole system itself appear to have close similarities to ecological systems. Since we have argued that in ecological systems these distinctive structural features account for their behavior, it follows that urban systems must behave in similar ways. There must be a set of urban equilibrium conditions. But more important, these equilibrium states must exist within a domain of stability that defines the resilience of the urban system. And, as in ecological systems, the consequences of intervention in a city can be viewed very differently depending on whether we take an equilibrium conditions. But more important, these one. If this is true, then we should be able to demonstrate, through samples of interventions, the same kinds of effects we showed with the insecticide examples.

**URBAN PROGRAMS WITH UNANTICIPATED CONSEQUENCES**

For this purpose, we have selected examples of reasonably narrow interventions. A number of unexpected consequences emerge, and from them we can infer that the internal dynamics of urban systems are similar to ecological ones, and continued narrow interventions can lead to effects analogous to those which occur in natural systems. Our examples are chosen to demonstrate that simplification of urban systems, through such simple but large-scale interventions as urban freeway programs, urban renewal, and rent control, leads to large-scale unexpected consequences and a high likelihood of failure even with respect to the narrow objective of the intervention. This is the lesson from natural systems, and this, we think, is the experience to date in urban systems.

Three examples should suffice. The first two—rent control and residential urban renewal—represent simple and direct approaches to housing lower income people. Our third example is freeway construction which represents a similarly simple and direct approach to the “urban transportation problem.” Each of these solutions has been carried out on a broad scale; each represents a considerable simplification of the real world; and each has had either little effect or negative effects vis-a-vis the original objective.

Rent control is a reasonable starting point. As in the insecticide examples there are three explicit policy conditions. First, the problem is isolated from the whole; in this case it is defined as inadequate low-cost housing. Second, the objective is narrowly defined: to limit the price increase in rental housing during periods of rapid economic growth. Third, the simplest and most direct policy is proposed: to apply government control of prices. Finally, the implicit assumption is that there is sufficient resilience in the system to absorb unexpected consequences.

Strong economic arguments have been presented against this narrow approach to rent control by Turvey (1957), Needleman (1965), and Lindbeck (1967), and empirical evidence supports the thesis that rent control in the long run can diminish the supply of housing and therefore extend or guarantee a shortage (Fisher 1966, Gelting 1967, and...
Available evidence thus indicates a negative effect.

*Residential urban renewal* yields another instance where the desired result is reversed. Slum clearance programs have been aimed at revitalizing the hearts of urban regions. In their broadest context, they include a multiplicity of land uses. For present purposes we are interested only in slum clearance programs aimed at providing better housing for low-income families and individuals.

It is fairly clear at present that these programs have not had the intended effect of providing more low-income housing. Hartman (1964) presents strong evidence that the programs have failed. Gans (1968) and Anderson (1964) have documented the shortcomings and have demonstrated that the reverse effect has often been achieved. They claim that the program has resulted in a decline of housing for low-income people and that the price of the remaining housing has in fact increased in the face of dubious increases in quality. In light of this evidence, Fried's (1963) criticisms of the social impact of relocation appear especially damning. It appears, therefore, that slum clearance has failed to provide more housing to low-income people, has failed to significantly upgrade the quality of their housing, has imposed a high psychic cost on slum residents, and perhaps has even had the reverse effect of removing low-income housing stock from existence.

Our final example concerns freeways and is meant to illustrate a variety of unexpected consequences, not only those that have effects opposite to the desired ones, but also those that produce significant "side effects" outside the narrow bounds of the original intervention. Our scenario runs as follows. Current dependence on the automobile has led to urban sprawl and congestion. This, in turn, has induced us to treat these symptoms with large-scale urban freeway programs. These have induced further sprawl and changed land use patterns which, in turn, have generated the need for more travel and therefore more traffic. The positive feedback of freeways to create traffic is illustrated in almost every major urban freeway system. Peak capacities are reached well ahead of design. The need for a more integrated and comprehensive transportation and land use planning program has been called for every year during the 1960's. Levinson and Wynn (1962) and Wendt and Goldberg (1969) summarize the arguments for such an integrated approach. Without it, freeway programs are bound to have an effect opposite to that desired (that is, creation of traffic congestion rather than alleviation of congestion).

Freeways have also brought with them a wide variety of environmental side effects. Freeways have changed the morphology of cities, stimulating sprawl that typically utilizes agricultural land. Each city can argue, with reason, that increased efficiency of agriculture and the development of marginal agricultural lands can partially fill the gap. But the price paid for this increased efficiency is the consequence of yet another "quick technological fix"—the increased dependency on chemicals to control insect pests and weeds and on chemicals to fertilize the land. Initially, the natural environment can absorb and cleanse these additives, but this resilience is limited and, when exceeded, results in the signals of pollution that are now so evident.

Interestingly enough, freeway planners have claimed that freeways should reduce air pollution by increasing average vehicle speed and facilitating the more complete burning of gasoline. Bellome and Edgerly (1971) provide interesting evidence that this is not necessarily the case. They note that there are three major automobile pollutants: carbon monoxide, hydrocarbons, and oxides of nitrogen. Both carbon monoxide and hydrocarbon emissions are reduced as a result of increased speed and more complete burning. Oxides of nitrogen, however, are produced in proportion to fuel consumption which increases with vehicle speed. Thus, the Los Angeles freeway system, by increasing vehicle speeds, does produce both carbon monoxide and hydrocarbon emissions. Unfortunately, it also increases the production of oxides of nitrogen, and it is these oxides that give Los Angeles its notorious photochemical smog. Here again we have the reverse of the desired state of affairs.

These examples illustrate the dangers inherent in focusing too narrowly on a component or symptom of a system problem. They have been chosen to relate the ideas developed for biological systems to urban systems to demonstrate that there are functional analogies that can be drawn from one to the other. Having illustrated these relationships, we can move on to some system oriented solutions of the kind that are evolving in the biological sciences and that (again hopefully) can successfully be transplanted to urban systems.

**ECOLOGICAL PRINCIPLES AND URBAN PLANS**

A variety of suggestions that have been made for urban systems are analogous to ecological control schemes in nature. They revolve around smaller
scale interventions and decentralized efforts rather than large-scale monolithic approaches.

There is a common theme running throughout the criticisms of the approaches to urban housing and transportation problems as well as through the suggestions for change. The criticisms concern the narrowness of the original approach and the failure to achieve stated goals while causing a variety of side effects. The suggestions for change are analogous to ecological control schemes and basically state that the system can cure itself if given a chance. The chance is provided if our interventions give credence to the basic complexity and resilience of our urban systems. Such basic respect for the system eliminates a host of policies like those that have been previously sketched out. The idea is to let the system do it, while our interventions are aimed at juggling internal system parameters without simplifying the interactions of parameters and components.

In this vein, Gans (1969), Anderson (1964), Fried (1963), and Cogen and Feldelson (1967) argue for increased flexibility and more decentralized approaches to the urban housing problem. Instead of large-scale clearance and public housing programs or rent control, they advocate smaller scale projects of rehabilitation, rent and income subsidies, tax credits and subsidies for property owners, and so on. These solutions allow individuals to make decisions as they see fit, while government decisionmakers provide them with information in the form of subsidies and credit as to the kinds of decisions society is willing to pay for. This decentralized approach will likely be more efficient in the long run and certainly more humane and enduring, since individuals will be making decisions about their future and will necessarily feel more a part of that future.

Completely analogous suggestions have been made for transportation planning. Again the central concept is to let individuals choose for themselves their transportation, the locations of their housing relative to their jobs, and the convenience they desire for their travel. Transportation and urban planners again merely provide information that will guide people toward socially desirable ends.

Pricing is the most widely mentioned means of achieving this end. Meyer, Rain, and Wohl (1966) describe pricing schemes both for congestion and peak hour use of roads and for parking. By changing the prices the individual traveller faces, he will more nearly bear the social costs that he creates in the form of congestion, pollution, and dispersed land use patterns. It is then up to him whether or not he chooses to pay these new prices or switch his travel mode, house location, job location, or time of travel to a pattern that is more consistent with broader social goals of reasonable urban form, uncongested roads, and reasonably clean air. At the same time a variety of modes of travel and housing locations must be provided so that meaningful choices exist. Provision of such alternatives is entirely consistent with our thesis since it does not diminish the basic complexity of the urban system (it may even add to it) and does not diminish the system’s resilience (again we may score gains where previously the system was stretched to capacity of the preexisting mode be it freeway, subway, or ferry).

**Conclusion**

Given an intuitive understanding of our complex urban system, we would hope that practicing planners and other private and public decision-makers would draw several conclusions for themselves about the nature of their actions in the system. First, and most important, is that their actions be limited in scope and diverse in nature. Actions of this sort do preserve the complexity and resilience of the urban system and will limit the scale and potential harm of the inevitable unexpected consequences. Second, we feel that complexity is a worthwhile goal in its own right and should be preserved and encouraged. Finally, and really encompassing the above, we would hope decision-makers and their advisors will adopt a more boundary oriented view of the world. We should be much more wary of success than failure. Again, rather than asking project directors to substantiate the ultimate success of their projects, they should be asked to ensure that unexpected and disastrous consequences be minimized. This is turning things around 180 degrees, but we feel this is the only way to proceed. Success has given us freeways, urban renewal, and public housing projects. We must reduce the size of our institutions to ensure their flexibility and respect for the system of which they are a small interacting part.

Authors’ Note: This paper is very much a joint effort. Since both our names could not go first, the decision was relegated to a simple stochastic process—we tossed a coin.

**NOTES**

1. The reader specifically interested in an introduction to ecology can refer to Odum (1963) and Whitaker (1970).
2. The notion of incremental (or “marginal” in the economist’s jargon) changes is part and parcel of cost-benefit analysis. Nonmarginal investments, which can change the structure of prices and the allocation of resources, are difficult to deal with under present...
cost-benefit approaches. Thus, resilience is usually assumed by ignoring changes in prices induced by large-scale projects. See Prest and Turvey (1965) for a discussion of the assumptions concerning marginal and non-marginal projects.

5 In one example (Holling, 1969), a simulation model of recreational land use was developed. It was clear from this study that many of the qualitative and processes in land acquisition were similar to those found in the ecological process of predation. Moreover, the similarity between land acquisition and predation extended to the structure of the interactions among the components of each. They differed only in the specific form of the functions describing the interaction of each component. Therefore, even at the level of processes there is at least a structural identity that can be usefully explored so long as it is recognized that there are functional differences.

4 See, Jacobs (1961, Chapter 13), for some interesting descriptions of the destruction of formerly diverse and stable urban systems.

The most complete study of the subject to date, by the RAND Corporation in New York, is not yet available, but preliminary evidence supports this statement.

REFERENCES
THE GREENING OF PUBLIC POLICY
Planning the Natural Environment

INTERPRETATIONS
211  INSIGHTS INTO POLLUTION
    Richard L. Maier
218  RESIDUALS AND ENVIRONMENTAL MANAGEMENT
    Blair T. Bower

ARTICLES
221  ECOLOGY AND PLANNING
    G. S. Holling and M. A. Goldberg
231  ENVIRONMENTAL QUALITY AS A POLICY AND
    PLANNING OBJECTIVE
    Maynard M. Hufschmidt
243  MULTIDISCIPLINARY ENVIRONMENTAL ANALYSIS:
    JAMAICA BAY AND KENNEDY AIRPORT
    Dorn C. McGrath, Jr.

REPORTS
253  NEW DIRECTIONS IN STATE ENVIRONMENTAL PLANNING
    Elizabeth Haskell
258  THREE FRONTS OF FEDERAL ENVIRONMENTAL POLICY
    Richard N. L. Andrews
266  PRESERVING A HUMAN ENVIRONMENT AT THE
    WORLD SCALE
    Richard May, Jr.

RESEARCH NOTE
269  PLANNING LITERATURE AND THE ENVIRONMENTAL CRISIS:
    A CONTENT ANALYSIS
    Thomas D. Galloway and Ronald J. Huelster

REVIEW ARTICLES
274  THE "NEW" ENVIRONMENTALISM: AN INTELLECTUAL
    FRONTIER
    George Hagevik and Laurence Mann
280  THE FUTURE OF THE ADIRODACK PARK
    William K. Verner and Mark B. Lapping

BOOK REVIEW
284  Joseph L. Sax: DEFENDING THE ENVIRONMENT: A STRATEGY FOR
    CITIZEN ACTION and Malcolm F. Baldwin and James K. Page, Jr.
    (eds.), LAW AND THE ENVIRONMENT
    by Marc Messing

REVIEW COMMENTS
286  John S. Adams
288  John R. Morris

Environmental Policies
The assurance of a high quality environment is a valid national goal. AIP affirms the following as essential elements of an approach to environmental quality control:

Conservation and Management of Resources: Conservation and management of basic environmental resources (air, water, land, open space, nature, quiet, safety and beauty) should include the following principles: minimization of the consumption of non-replaceable resources; replenishment or recycling of replaceable resources; and absolute protection of unique or critically endangered resources. Federal and state governments should initiate research aimed at identifying critical environmental resources, their rates of consumption under the impact of urbanization, and strategies for their protection and conservation.

Planning and Plan Implementation: Planning, including plan implementation, can and should be used to abate and prevent pollution of all kinds, to assure balances between land use and density of development and the capacity of supporting systems, to provide and promote suitable development standards for planning in relation to existing and desired environmental quality, and to minimize the impact of unavoidable pollution on populations through the appropriate arrangement of land uses.

Environmental Design: High quality for the built environment should be promoted through land use planning, urban design, and the systematic application of multidisciplinary planning and development techniques.

Social Responsiveness: Environmental protection, control, and restoration of quality should seek equity in the distribution of unavoidable adverse surmounted effects, in the availability of access to amenities and in the provision of suitable institutional mechanisms for the representation of all citizen interests.

(Official AIP policy statement, Adopted March 1971.)
THE GREENING OF PUBLIC POLICY
Planning the Natural Environment