Managing Overwhelming Complexity In Human-Landscape Interactions

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Abstract

Humans have been altering the natural landscape for millennia (e.g. Pyne, 2001; Fagan, 2004), but increasing population growth and technological innovations are out-pacing management of this landscape (e.g. Hooke, 1994; Haff, 2003). Today's human-ecosystem interactions are overwhelmingly complex, reducing management agencies and policy solutions to ineffective, short-term interventions. The urban- "wildland" interface (UWI) of the Los Angeles basin is the focal research problem of this paper. A system of inquiry is proposed that focuses management efforts on strongly coupled human-landscape interactions and the emergent behaviors that result. This system of inquiry serves as the conceptual framework for a computer model used to examine the dynamic behavior of the urban-wildland boundary.

Current management strategy calls for the suppression of regular fires to minimize the loss of lives and property. However, this management strategy disrupts the natural dissipative processes that stabilize the urban-wildland boundary and creates delayed feedbacks. Management must recognize coupling between system components that may not be apparent in the short term but dominate system behavior on longer time scales. The accumulation of energy (fuel, development, suppression force, etc.) may lead to catastrophic events in the form of large fires and/or landslides. The perceived system behavior is a filtering-out of small, frequent fires on short time scales, and the emergence of catastrophic fire events on longer time scales.

The proposed system of inquiry can be used to focus management solutions on the emergent, synergistic interactions that are driving human-landscape problems. It is a tool that can enable stakeholders to properly manage the coupled interactions between society and the surrounding landscape on multiple time scales.
*Keywords:*Human-landscape interactions; urban-wildland interface (UWI); emergent coupled behavior; delayed feedback.

Introduction

The Urban-Wildland Interface

As a field, environmental management is evolving to adapt to the complexity of today's human-landscape interactions. The urban-wildland interface (UWI) has emerged as a particularly challenging environmental problem as sustainable management solutions remain elusive. The UWI can be defined as the dynamic boundary where human development abuts and interacts with "wildland" (i.e. natural landscape). For many, these areas are highly desirable residential sites offering privacy, unobscured views, and close contact with nature (Paterson and Boyle, 2002). As cities expand with population growth, homes in the UWI are attractive to those escaping crowded urban centers. Technological improvements in rural development, slope engineering, and natural disaster mitigation and prevention have made it possible to develop in these new areas. Both population growth and technological innovations are allowing more people to live in close contact with wildlands. Consequentially, increasing numbers of people find themselves in the direct path of natural disasters.

In the Los Angeles basin, urban sprawl encroaches into foothill ecosystems, as in the lower Santa Monica and San Gabriel Mountains, creating a pronounced boundary between wildland and human development. The area's unique geology and ecology is characterized by numerous natural disasters, such as landslides, floods, debris flows, and wildfires (Cooke, 1984). Regardless, population growth and urban decay perpetuate UWI development and force governments to mitigate and prevent these disasters. However, the expansion of urban boundaries into wildland areas has dramatically increased the loss of lives and property. Increasing amounts of urban extent are burned by wildfires, and property damages are becoming more costly (Goldstein et. al., 2000). In the last two decades, the number of structures damaged annually by wildland fires in California has increased by a factor of five (CDF, 2000). Nearly every decade in the twentieth century has demonstrated an increase in fire suppression expenditures (Calkin et. al., 2005). Land use changes in Southern Californian cities and other parts of the United States have created a patchwork of urban and wildland plots along the interface to accommodate the influx of people (Davis, 1989). Population growth and urban sprawl introduce instability in the urban-wildland boundary, and governments are forced to institute greater mitigation and suppression measures to protect its citizens.

The human-landscape interactions within the Los Angeles basin are especially volatile. The San Gabriel and Santa Monica mountains lie in a tectonically active region and are characterized by steep slopes consisting of a thin soil layer over marine bedrock (e.g. Cooke, 1984). These conditions are particularly conducive to landslides and debris flows when unsupported slopes are exposed to heavy winter rains. Building upon these slopes is dangerous and expensive as homes are often destroyed by natural disasters.

The Mediterranean climate of Los Angeles supports a unique ecosystem with intrinsic management challenges. Vegetative land cover is generally chaparral with transitions to desert and coastal sage scrub at lower elevations and woodland at higher elevations (Schoenherr, 1992). Chaparral vegetation is especially prone to regular fire events, because stands contain high percentages of dead biomass as an adaptation to conserve water. The amount of dead material, or fuel load, increases with age and becomes exponentially more prone to fire (Bolsinger, 1989). Regular fires play a critical ecological role by decreasing dead vegetation, creating space for seedling recruits, and releasing nutrients back into the soil. In addition, seasonal atmospheric conditions create strong, dry winds, called Santa Ana winds, that produce severe "fire weather". High pressure in the area of Las Vegas, Nevada produces an offshore flow that forces hot, dry air from the deserts through southern California mountain passes. These winds bring very low relative humidities (often below 15 percent) that desiccate fine fuels (Raphael, 2000). The result combines dry fuels, high temperatures, and driving winds to create "fire weather".

Additionally, the city of Los Angeles is finished growing. It is contained by mountain ranges to the north and east, and by the Pacific ocean to the south and west. For this reason, the UWI remains the only part of Los Angeles to display continued growth. Economic opportunities have shifted from the urban center to investment around and beyond the city's borders (Cortner and Gale, 1990). Population pressures and technological innovations have motivated policy makers to relax permitting along the UWI to simulate economic growth and expand the market.

The boundary between human development and wildlands is currently unstable. Large fires existed in the surrounding mountains in the past, but life and property losses were dramatically lower than today (Goldstein et. al., 2000; CDF, 2005). Encroachment of Los Angeles's urban sprawl into the surrounding wildlands has created coupled, non-linear human-landscape interactions. Management agents currently have no method to recognize the underlying dynamics of these interactions in the management paradigm. Consequently, management efforts are unknowingly promoting emergent, long term system behaviors that are unsolvable with the current system of inquiry. A new system of inquiry is proposed that focuses management efforts on emergent, coupled interactions as causal drivers of the UWI's evolution. Our understanding of natural ecosystems has progressed rapidly, and the social sciences have gained insight into some of the dynamics that shape human decisions and societies. But the interactions between the two spheres are only recently drawing attention. Current systems of inquiry in such fields as climatology, renewable energy, fisheries management, and others concerned with sustainable practices are evolving to cope with our world's escalating complexity. Yet, for all of these advances, recognition and understanding of the dynamics that govern our interactions with natural systems is still in the early stages. Understanding the human-landscape interactions through a complex systems perspective enables the design of long-term management solutions that can be implemented within the constraints of human-value systems.

A Systemic Perspective

The UWI As A Complex System

Humans are interacting in new ways with the natural landscape, and today's environmental problems can be overwhelmingly complex. Recognizing the dynamics that produce landscape-scale behaviors is difficult in the short term, yet management agents must protect lives and property from an extreme seasonal fire problem. Historical trends demonstrate an increase in very large, destructive fires (Goldstein et. al., 2000). A combination of development policies and management practices are likely to blame. The UWI's complexity on multiple time and spatial scales creates a disconnect between cause and effect of human actions. Management efforts may actually be making the losses of lives and property worse by disrupting long time scale dynamics. Intense, unexpected behaviors have emerged along the UWI. A new system of inquiry must be designed to meet the challenges of long-term management planning.

The fundamental problem for managers of the UWI is difficulty recognizing the organizational dynamics of human-landscape interactions in the short term. The study of complex systems has emerged as a new tool in this pursuit. Complex systems science can help managers to understand the current state of the UWI and the dynamics that promote or inhibit change. As is characteristic of human-landscape interactions, behaviors of individual system components are easily observable on small time scales. The dynamics that organize the UWI's behavior, however, operate on longer time scales than its constituent parts in a process referred to as "self-organization" (Kelso, 1995). Although, a system's constituents display a wide range of behaviors in the short term, their long-term behaviors are organized by feedbacks on longer time scales. In the current system of inquiry, there is no path to investigating or addressing these behaviors, but the nature of complex systems offers hope.

Although human and natural systems are characterized by a multitude of variables, their behaviors fall within a comparatively small range (Waldrop, 1993). The small range of behaviors exhibited by each system is due to the existence of steady state attractors. Attractors are points (modes of behavior) in a system's phase space (range of possible behaviors) to which the system has preferentially evolved (Waldrop, 1993). In other words, attractors are states in which the system have reached a dynamic equilibrium. The system's behavior can then be described by a small portion of all the system's possible variables. Due to this fact, the dynamics of a complex system can be described by two qualities of any self-organizing, chaotic system: non-linear, coupled interactions and dissipation. The proposed system of inquiry and accompanying computer model explore the non-linear, coupled interactions of the UWI, and the dissipative processes that resist change to the current system state. This investigation will facilitate an understanding of the human-landscape interactions driving emergent behaviors along the UWI.

Dissipative Processes and Non-linear, Coupled Interactions of the UWI

In the context of the UWI, the current steady state is the balance between the non-linear, coupled interactions that promote emergent order in system behaviors, and the dissipative processes that stabilize behaviors by resisting change. For the chaparral ecosystems of southern California, the current steady state exists as stable ecological relationships. Ecological relationships and processes maintain ecosystem function and sustain life. The human system's steady state is more transient because economic growth is always held as a priority. But in the context of the UWI, the stability of lives and property along the urban-wildland boundary is a steady state that is actively maintained. However, the existence of these steady states does not imply that there are not other possible system states. In fact, external forces and/or endogenous processes can potentially destabilize the current steady state. Over time, a system will transition from one steady state to another when the forcings upon the system are strong enough to overcome the dissipative processes that maintain the current steady state. The destructive fires that are observed are the result of strong forcings on the system's steady state. Thus, the system's current steady state can be described by the dissipative processes that maintain stability and coupled interactions that introduce instability.

Dissipative processes are those that operate to resist change and maintain a system around its steady state attractor (Bar-Yam, 1997). The steady state of southern California's chaparral ecosystems is maintained by regular fires that perpetuate growth and renewal (Barro and Conard, 1991). Cyclic fires act as a dissipative force that prevent the accumulation of decadent vegetation and stabilize the ecological role of chaparral vegetation. Additional dissipative process of the natural landscape include various geophysical processes such as water and sediment transport, erosion, and vegetative cover for slope stabilization. The steady state of the human system manifests itself as a distinct boundary between urban development and wildlands. Unfortunately, development into southern California's wildlands has placed homeowners in the path of these naturally frequent fires. Fire suppression forces must reduce the frequency of fires near the urban-wildland boundary to protect lives and property. These co-evolving dissipative processes have formed non-linear human-landscape interactions that are unstable in the long term.

Conflicting steady states between the natural and human systems have produced strongly coupled interactions at the UWI, but in ways that are not easily recognized in the short-term. The establishment of strongly coupled, non-linear interactions begins when wildland fires damage property along the UWI giving impetus to increased fire suppression. Local exclusion of fires opens opportunities for economic development. As development grows, more fire suppression force is needed to extinguish any ignition in close proximity to property. Without the threat of fire damage, short-term costs are limited to building, and development in the area will continue as long as it is economically feasible. However, increased fire suppression also allows the unnatural accumulation of fuels from the exclusion of regular, dissipative fires. Eventually, catastrophic fire events are possible with an accumulation of "energy" along the UWI. The actions of one component influence and are influenced by the behavior of another. The complexity of the interactions between the two systems is staggering, as local efforts to prevent the loss of lives and property to wildland fires can have consequences on multiple spatial and time scales.

Problematic behaviors of the UWI are caused by instabilities in the balance between non-linear, coupled interactions and dissipative processes. The following discussion investigates how the disruption of natural dissipative processes is driving the emergence of intensified coupled human-landscape interactions. Also, the ways in which management efforts are creating these conditions and are limited in their effectiveness are explored.

The Problem Dynamics of the UWI

Management's primary problem is delayed feedback created by filtering-out small, regular fires. Organizational dynamics of the UWI are being intensified by the disruption of constituent dynamics (i.e. accumulation of fuels, dense development, lax permitting, fire suppression force, etc.). Fire suppression has become the catalyst for these disruptions, but it is necessary because of continued growth along the UWI. "In response to increased settlement and people's desire to live in and near natural landscapes, the law calls for extinguishing unwanted blazes immediately" (CFP Overview, 2000). Fire suppression has established strong, non-linear human-landscape interactions that delay natural dissipative processes to allow development along the UWI. This has two very important implications. Delayed feedback created by management strategies is driving the emergence of more intense system fluctuations. Additionally, the introduction of artificial delays creates a disconnect between cause and effect of management actions exacerbating the difficulties of long-term management planning. As a result, the UWI's behavior emerges as a delaying of small, regular dissipative fires, and a promotion of conditions conducive to catastrophic events.

Management strategies are acting on the behavior of system components without realizing the system-level impacts. The current system of inquiry approaches management solutions by breaking-down the system and analyzing its behavior at the individual component level. This approach has been found to be flawed by many. In Manual de Landa's book, One Thousand Years of Nonlinear History (1997), he asserts, "Analyzing a whole into its parts and then attempting to model it by adding up the components will fail to capture any property that emerged from complex interactions." The importance of coupled, non-linear interactions is becoming more widely recognized, but few have taken it as far as Dr. Peter Corning in his book Nature's Magic (2003). On the causal role of synergy (i.e. coupled interactions) in evolution he says, "The interactions between the parts [of a system] and their environment(s) may be even more important the the interactions among the parts." Synergistic interactions between the natural landscape and the human system are driving long-term behaviors of the UWI.

Delaying of natural dissipative processes creates new synergistic, human-landscape interactions that are more intense and often unexpected. The delayed feedback created by artificial delays manifests itself in the fire return interval and a lack of information. In addition to allowing fuel accumulation, fire suppression creates a false sense of safety along the UWI. By reducing the frequency at which small fires appear, continued development is perceived as an economically beneficial decision. Economic valuation is limited by a lack of information and does not account for the growing fire threat until losses are apparent. In this way, delayed feedback magnifies the disconnect between cause and effect of management actions. When a large fire finally occurs, the damage is far greater than it would if development had not continued into the wildlands. Feedback from the decision to continue development did not emerge until a fire was large enough to overwhelm suppression forces. Fire suppression is seen as a way to protect development from uncertain future conditions, but it promotes delays in energy dissipation and information flows. Keeley et. al. (1999) assert that fire suppression has no effect on the emergence of catastrophic fires. Comparisons with the "natural" fire regime of Baja, Mexico seem to provide physical evidence to support this claim, but fire suppression certainly does not allow the natural dissipation of fuels. More importantly, fire suppression introduces artificial delays into the dynamics of the UWI that create a false sense of safety, and give impetus to continue building into wildland. The effects of delayed feedback have been observed repeatedly, yet the same behaviors are recurring.

Why Is This Management Problem Occurring?

Why are these dynamics not being recognized? How did the UWI get to this point? Part of the answer is that the dynamics that drive the evolution of complex systems are poorly understood. The current system of inquiry does not recognize these dynamics in the short term. Managers are acting in what they perceive as the best way to protect lives and property, but management solutions are constrained by the current environmental management paradigm. Human value-systems shape the current system of inquiry so that options for management strategies are severely limited. In the proposed system of inquiry, a dynamical complex systems approach will facilitate understanding of human-landscape interactions, and the ways in which system behaviors are interpreted and addressed within the larger cultural context.

A useful metaphor for understanding the dynamics of the UWI comes from Carneiro (1973). The UWI system can be likened to a train of gears in which each gear represents a component of either the human or natural system. The gears differ in that some are larger, have finer teeth, turn faster, etc. More importantly, some gears are drivers that engender motion to others, while other gears are passive and only transmit motion. The gears also differ in the closeness in which they interact. Some gears reproduce the motion of others perfectly, while others may slip out of mesh and move forward without causing perceptible change at the time. Yet, by and large, the train of gears moves together, and the system evolves over time with motion determined by the interactions of the gears. However, if the gears get too far out of unison, the stress causes them to lurch forward producing intense, non-linear changes.

Management agents are creating intense system fluctuations by acting upon seemingly unconnected system components which disrupt larger, long-term dynamics. Returning to our “gear train” metaphor provides an illustration of this process along the UWI. Natural processes can be seen as the larger gears that operate on long time scales, and human development as quickly spinning smaller gears. Larger gears are halted to allow smaller ones to spin freely. As more of the smaller gears are freed (i.e. continued development), managers are forced to delay an increasing number of large gears. Over time, enough energy has accumulated-- in the form of decadent vegetation, dense development, lax permitting polices, suppression forces, etc.-- that the gear train non-linearly resets itself when the restraints on the larger gears are overcome. This is a synergy of scale as the system reaches a “tipping point” (Corning, 2000). Along the UWI, emergent behaviors-- seen as synergies of scale-- are produced and intensified by the introduction of artificial delays. Consequently, they are acting as causal drivers of the system’s evolution through catastrophic events.

A New System of Inquiry

Through the lens of a complex systems approach, the proposed system of inquiry focuses management efforts on the coupled human-landscape interactions that introduce instability into the urban-wildland boundary. Boundary instabilities are driving the emergence of strong, non-linear behaviors, and their dynamics are failing to be recognized before large fluctuations occur. The current approach divides the coupled systems into individual system components to create a management plan for the whole. While this may be easier logistically, it fails to capture the synergistic relationships between each of the components and their environment. The coupled interactions that emerge as causal drivers are often hidden by the more immediate behaviors of the system’s constituents. Individual components, or a “package” of determinants, that seem unconnected can form a synergistic convergence and become coupled once they interact (Corning, 2003). The proposed system of inquiry would shift the management paradigm to one that recognizes coupled interactions as organizational drivers and leverage points for action.

The nature of today’s environmental problems demand a system-level approach. The goal of this system of inquiry is to fill a gap between detailed investigations of component processes and broad brush treatments. The synergistic interactions that connect constituent processes and higher system organization over time are focused upon as targets for effective management. In Dr. Peter Corning’s book, Nature’s Magic (2003), synergies (coupled interactions) are identified in a myriad of natural processes as causal drivers. This approach provides insight into the demanding nature of today’s complex environmental problems. Specifically, coupled interactions that create artificial delays and delayed feedback must be managed on short and long time scales. Therefore, the cause and effect disconnect of management actions needs to be closed. Essentially, management agents are left to act in their immediate best interests-- to protect lives and property-- because their impacts on the dynamics that organize system behaviors on longer time scales are poorly understood.

The proposed system of inquiry does not only facilitate understanding of the UWI’s dynamics, but it also emphasizes designing management solutions with the current cultural context in mind. Economic paradigms, homeowner culture, and conservation values all interact to shape the current management paradigm. In the proposed system of inquiry, human-value systems will be recognized for their feedbacks between management decisions and emergent behaviors of the UWI. The cultural atmosphere surrounding management of the UWI places constraints on management options. In order to successfully implement causal-level solutions, these constraints must be identified and their feedbacks corrected.

Forces That Shape the Current System of Inquiry and Their Assumptions

The current system of inquiry does not provide a vehicle to thinking about environmental management issues from a dynamical perspective. Management efforts are oriented towards tangible, short-term solutions with immediate benefits. This is not to say that management entities do not act in the best interests of the public. Rather, management options have become so limited by the current system of inquiry that designing long-term, system-level solutions may not be feasible. Managers need knowledge of the dynamics that govern human-landscape interactions, and the cultural atmosphere in which their decisions must be implemented.

Human-value systems create powerful feedbacks between management actions and emergent, coupled system behaviors. The cultural atmosphere in which the current system of inquiry operates has established feedbacks that favor short-term solutions. Part of the reason, as mentioned above, is the disconnect of human-landscape dynamics on short and long time scales. Constituent dynamics, such as fire suppression technologies, are the most visible and offer immediate return on economic investment. Human-value systems have influenced the management system of inquiry towards risk adverse strategies. Even with evidence that current management strategies may be ineffective in the long-run, cultural feedbacks resist change to the management paradigm. The focus upon short-term solutions is seen at all levels of the current system of inquiry.

Focus on constituent-level action is evident in the system of inquiry after large, destructive fires. The body of research and recommendations that emerge continually favor strategies that mitigate or attempt to prevent losses -- symptoms of the larger problem. Instead of designing management solutions that address the human-landscape dynamics of catastrophic fires, building codes and development policies focus on symptomatic fixes. After major fires, wildland/urban fire reports are generated providing recommendations, including technical specifications, for urban planning, fire suppression capabilities, vegetation management, and building construction (e.g. California Department of Conservation, 1972; California Department of Forestry, 1980; Moore, 1981; Radtke, 1983) (Cohen, 1991). Incremental changes to individual components of the system are proposed and larger human-landscape interactions are marginalized. Management solutions continually focus on the immediate benefits of technological "fixes". Even those who attempt a systems-level approach, such as Cohen (1991), fall short of addressing synergistic human-landscape interactions. Cohen even asserts, "The wildland/urban fire interface problem would virtually disappear if structures did not ignite; therefore, the emphasis of a wildland/urban interface fire risk assessment should be on structure ignition." The fact is that human presence along the UWI has large-scale, long-term implications that extend past property damage. Consistently, management agents resort to improving fire suppression capabilities, fire-proofing houses, or utilizing mechanical methods to manipulate vegetation. So why do managers continue to seek short-term solutions that may ultimately drive the emergence of catastrophic events?

The answer lies in the complex interplay between valuation, perceived fire risk, conservation values, and the emergent behaviors of the UWI. The exact qualities of human-values systems can vary drastically by location and through time. Therefore, it is necessary to be explicit about current cultural assumptions, because they are basal to investigating feedbacks into management decisions. A fundamental assumption is that both the natural landscape and urban areas are complex systems, and that they interact with each other across a conceptualized boundary. This statement implies that we are not only dealing with natural and human agents interacting with themselves, but with each other. Therefore, human values and beliefs profoundly influence decisions on how, when, why, and to what extent the two systems interact.

A basic assumption is that all human agents (i.e. decision makers, market investors, home developers and buyers, fire suppression forces, etc.) are organized and driven by the current economic paradigm. The exchange of goods and/or services is determined by the market conditions of supply and demand. Home developers and investors will only pursue an economic opportunity if its return is greater than the necessary investment (Tietenberg, 2003). Specifically, homes will not be built on slopes that exceed the capabilities of available building technologies, will be too difficult to sell, or where building permits are unattainable. Home buyers have a set of preferences, such as proximity to natural landscape, climate, view, privacy, price range, and commute distance/time, that they use to choose the most desirable home and/or building sites (So et. al, 2001; Zabel, 2004). Both buyers and sellers are well-informed about the conditions of the market and will respond to changes in supply and demand.

The use of an economic paradigm also implies a process of valuation used to evaluate policy options. Valuation is an inherently subjective process, especially when common resource and non-material goods are involved. Valuation demands the use of discounting future values due to uncertainty, and a weighing of immediate impacts versus long-term consequences. A typical policy situation along the UWI requires the comparison of economic benefits secured from granting building permits to long-term environmental impacts. The house's value and immediate tax revenue are easy enough to calculate, but long-term impacts on the surrounding community and ecosystem are more uncertain. Because the processes that influence the behavior of the UWI operate on many time scales, valuation frequently requires discounting and subjective evaluation. Despite high levels of uncertainty, valuation plays a key role in decision-making and management practices. Consequently, a wide range of risk adverse behaviors dominate current management strategies.

From this perspective, it is obvious why fire suppression has been and continues to be the dominant management strategy in southern California (Miller, 2003). A typical management scenario, as illustrated by Miller (2003), is the fire's ecological benefits and its ability to reduce hazardous fuels must be weighed against the potential threats it poses to human life and property. The decision to suppress a fire is made when the potential negative consequences from fire outweigh its potential benefits. Fire suppression has become necessary because of the continued growth along the UWI, but it delays natural, dissipative fires and maintains a false sense of safety. Despite the long-term impacts, immediate benefits from fire suppression are supported by cultural feedbacks. This situation illustrates economic valuation as a major obstacle in management decisions under the current system of inquiry.

Economic valuation also restricts the operation of fire suppression practices. Considering the spatial extent of the UWI, excluding regular fires in a fire-prone ecosystem is a daunting task. "From local to national levels, managers and planners are seeking to maximize the effectiveness of fuel management programs while controlling costs. . . . Although the goal for the 2002 fiscal year is somewhat higher (2.4 million acres), this is only a small fraction of the total acreage in need of treatment" (Miller, 2003). The total budget directed towards fire suppression activities is not nearly enough to meet their demand. One of the reasons is that many of the factors that affect suppression efforts are difficult to quantify. Factors such as access, suppression availability, and fire severity can not be reliably assessed at an unspecified time (Cohen, 1991). Uncertainty in fire suppression, an adaptive process, forces managers to resort to other methods of fire prevention and mitigation like fuel modification or stricter building codes.

Valuation of natural resources, ecosystem health, and long-term benefits are continual stumbling blocks in environmental management. Several factors are interacting to severely limit management effectiveness by reinforcing a focus on short-term solutions. Well-documented in natural resource economics, natural processes do not lend themselves well to assignment of a monetary value. Although qualities of natural systems, such as scenic views, clear air, and aesthetic appearance, are approximately valued as parts of a "consumer bundle" (Tietenberg, 2003), there is no method to assign value to a stable urban-wildland boundary or sustainable human-landscape interactions. Moreover, the problem of environmental valuation is further complicated because the dynamics of natural systems typically operate on longer time scales than do micro-economic processes. A classic example of this idea is the economic valuation of a commonwealth.

Creating a new system of inquiry and accompanying computer model assumes that there is a desire to balance environmental health with economic growth. Underlying this idea is the belief that a commonwealth or collective good exists that is in everyone's best interest to protect. Although this commonwealth is poorly defined, many examples exist, like fisheries or clean air, that illustrate the importance of common resources. Ecosystem health and economic prosperity qualify as commonwealth, but so does the existence of a stable UWI. Stability in the urban-wildland boundary is desirable for those living along the interface, as well as for insurance companies, financiers of prevention and mitigation of natural disasters, and environmentalists. This is a key concept, and one that has manifested itself as a push for sustainability in our everyday activities. Thus, managing human-ecosystem for sustainability means that we are protecting a commonwealth and striving for a stable coexistence along the UWI.

A variety of conceptualizations can be found for a commonwealth, and all of them imply different approaches to valuation. Various forms include shared natural resources, public goods, open-access resources, and common-pool resources (Tietenberg, 2003). The classic example of this concept is popularly known as the "tragedy of the commons" involving a shared grazing pasture. What is relevant to the UWI is not the fact that many people take advantage of its "services", rather there is real value to all involved in actively managing their interactions with the natural landscape. In the case of a grazing pasture, the value of sustainable management is relatively easy to recognize. The value of managing the UWI, however, is not immediately apparent. Only when the dynamic behavior of the UWI and its potential for drastic fluctuations are understood does the value of long-term management strategies become obvious. A proper valuation of possible long-term, intensified human-landscape interactions is absent in the current system of inquiry. "In most cases, the amenities associated with hillside residences far outweigh the costs associated with a possible future fire occurrence" (Gardner et. al., 1987). The crux of the issue lies in the favorable valuation of immediate benefits versus long-term costs under the current management paradigm and system of inquiry.

Since the majority of environmental benefits are realized far into the future, uncertainty strongly influences cost-benefit analyses of management strategies. The beneficial effects of wildland fire are often realized over much longer time scales than the negative impacts from fire (Miller, 2003). "Landscape mosaics" created by a natural fire cycle are spots of recently burned vegetation that slow down the spread of fires, thus aiding fire suppression efforts. However, successful long-term implementation of management efforts is required. Immediate fire suppression, as the best means of securing short-term benefits, will continue as the dominate management strategy under the current system of economic valuation.

The next assumption involves the role of risk perception in decision-making processes. Specifically, perceived fire risk influences the values and behavior of home-owners, insurance providers, and policy-makers. Although notoriously difficult to quantify, risk is nevertheless critical when weighing the value of current and future policy actions, and must be considered as an essential element in human behavior along the UWI. Risk will be considered in the new system of inquiry according to a comprehensive survey done by Gardner et. al. (1987) of homeowners along the UWI. Assumptions are made that reliable information about perceived fire risk and homeowner values can be obtained from survey/interview methods commonly used in social science studies. Conditions along the UWI have changed little since the study, as perceived risk still influences community action and homeowner values remain consistent. Many critics of risk assessment point-out that the means by which risk is approximated are flawed and subjective. However, the consideration of risk in this system of inquiry is not a quantitative one, rather a qualitative assessment of risk's importance in explaining the construction of the current management system of inquiry.

Perceived fire risk directly influences management decisions, policy options, and homeowner values. The majority of people living along the UWI do not understand the physical and ecological dynamics of the environment in which the have chosen to live (Gardner et. al., 1987). Part of the problem is that risk perceptions are formed on human-oriented time scales, which are typically oriented towards economic decisions. One of the communities studied by Gardener et. al. (1987) illustrates this point. The fire-affected community demonstrated a dampening effect on awareness levels and risk perceptions. Most likely, these residents were basing their assessment on the assumption that the recent fire reduced the vulnerability of the landscape to another fire. Yet, in chaparral ecosystems, major fires occur roughly every 30-40 years (Keeley and Fotheringham, 2001). However, market forces operate on much shorter time scales allowing sufficient time for the opening of economic opportunities. Perceived fire risk reflects homeowner values that are based on principles of economic valuation. Limiting development into the UWI through permitting restrictions may be prudent in the long run, but low perceived levels of risk render development restrictions economically unjustifiable in the short-term.

A "homeowner culture" of the UWI exists that applies considerable influence on management values. Perceived risk acts a template for homeowner attitudes and actions, which in turn affect the rate of compliance to and preference for certain policy options. "Home-owners prefer policy strategies that physically alter the wildland landscape - through prescribed burning programs or greenbelt land uses - or regulations placed on building materials" (Gardner et. al., 1987). Technological "fixes" have vast appeal because their results are observable and immediate. Furthermore, homeowner preferences are forcing management agents to seek-out strategies that align with their values. "Home-owners would rather have the landscape modified for their needs than modify their behavior to live compatibly within the environment. Home-owners were reluctant to support strategies that limited their residential living options. Also, they did not support policies designed to place the burden of protection directly on home-owners, preferring solutions that fall on the shoulders of government" (Gardner et. al., 1987). Unfortunately, managers are placed in a situation where the current valuation system provides for growth into the UWI, but does not allow the use of a wide range of management strategies. Selection of short-term solutions is reinforced by economic incentives and home-owner values. Underlying this situation is insufficient knowledge of the dynamics that drive the long-term behavior of human-landscape interactions. This fact is manifested in the formation of perceived fire risk.

Historical conservation values have also molded the current management paradigm. Until recently, preservation of "wilderness" has been the priority of private and public conservation efforts. The Wilderness Act of 1964 defines wilderness as "an area where the earth and its community of life are untrammeled by man," and "which is protected and managed so as to preserve its natural conditions" (Miller, 2003). This ideal permeated all environmental management strategies for decades. At this point in human history, however, we have extensively altered the natural landscape for our needs. "Nature", in the pristine sense, exists in very few places anymore (Trefil, 2004). Concurrently, management agents have begun to acknowledge the vital ecological role of wildland fires. Although, reintroduction of fire into the natural landscape would require a redesign of current suppression practices, which is strongly opposed by current cultural feedbacks along the UWI. The current situation is such that any change is not economically feasible through valuation, plagued with uncertainty, conflicts with homeowner values, and/or no method currently exists.

The feedbacks produced by the human-value systems surrounding the UWI act to construct the current management system of inquiry. Human-value systems provide the context in which management decisions are implemented, and they ultimately restrict the range of viable management strategies. A bridge between system dynamics and cultural feedbacks is needed. The proposed system of inquiry is designed to recognize the dynamics that drive human-landscape interactions and allow managers to consciously influence a coexistent evolution between the two systems.

Conclusions

A Flawed System of Inquiry

Flaws in the current management system of inquiry are evident in the escalation of annual losses of lives and property along the UWI (CDF, 2005; Goldstein et. al., 2000). Management agents are acting without full attention to the long-term impacts of their actions. A cause and effect disconnect is leading management agents to create conditions that drive the emergence of intensified non-linear behaviors along the UWI. This disconnect is produced by the system's natural complexity and the artificial delays introduced by fire suppression that allow continued development. Management agents are in the difficult situation were they can only accept policies that maintain an environment that protects an amassing human presence.

However, management agents are acting in what they perceive as the best interests of all stakeholders. They cannot be faulted for their mission to protect lives and property. Economic, cultural, and conservation values have shaped the current system of inquiry to favor short-term solutions. However, the current system of inquiry is limited in finding causal-level solutions by cultural feedbacks. Economic valuation is not able to capture the complexities of human-landscape interactions. As a result, development into fire-prone areas continues despite evidence of an intensification of emergent non-linear behaviors along the UWI. Many of the system's qualities, such as long-term benefits of natural dissipative fires, are impossible to quantify under the current system of inquiry. Concurrently, conservation paradigms must be updated to reflect the reality of today's human interactions with natural systems. Finally, homeowners in general are dangerously uninformed about the risks of living in the UWI and the management actions necessary to protect them. These factors form a cultural atmosphere that favors short-term solutions and continual development along the UWI.

Uses of the Proposed System of Inquiry

The proposed system of inquiry emphasizes an understanding of dissipation and non-linearity in complex systems. Managers can utilize this understanding to recognize the dynamics that are producing emergent and strongly coupled behaviors along the UWI on multiple time scales. Such analysis of the behaviors of the UWI can help close the disconnect between cause and effect of management efforts. In addition, the proposed system of inquiry uses a soft systems approach to investigate the influences of human values systems on management decisions. Current and historical economic, cultural, and conservation values have profoundly shaped the management paradigm in operation today. Management solutions that address the dynamics of human-landscape interactions must work within these value constraints. This approach to the proposed system of inquiry provides a framework from which a computer model can be built to couple both systems. This framework is unique in that takes a holistic systems approach to environmental management challenges, and enables managers to consciously influence the evolution of the UWI. By filling a gap in the understanding of the dynamics of human-landscape interactions, it provides a path to designing solutions within the context of human-value systems.

The hope is that this approach engages managers with human-landscape interactions in a process of conscious evolution. Closing the disconnect between cause and effect of management actions is a step towards realizing their potential long-term consequences. Developing an understanding of the multiple time and spatial scales on which humans and landscapes interact enables managers to act at the causal level of problems and plan for long-term impacts. An understanding of the emergent behaviors in human-landscape interactions would have a direct effect on the economic valuation of management and homeowner choices. The long-term risks associated with these emergent boundary fluctuations would then be compared properly to the immediate economic benefits of continued development. Money spent rebuilding property and providing insurance may be better spent on fuel modification efforts and compensation for stricter permitting standards. Of course, forecasting the future behavior of complex systems is also filled with uncertainty. But changes to a system that continues to endanger lives and property along the UWI would not be regretted.

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