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INTRODUCTION

Lawrence A. Kapustka and Wayne G. Landis

Environmental management evolved considerably in the last quarter of the 20th century, passing from an era of human dominance over nature toward an ideal of sustainability. The earlier period was emboldened in North America by the philosophy of manifest destiny. The new era is marked by self-awareness of our limited capacity to tame nature. The vague constructs of sustainability are tested by desires to hold onto the luxuries of developed societies while striving for environmental and social equity; a struggle captured in the tension between romantic illusions and pragmatic actions.[1] New ways of thinking about resources and resource use are permeating debate among intellectuals, politicians, and common people (McKibben 2007).

The complexities of human interactions across different ethnic, social, cultural, religious, and political perspectives have shown that environmental management is fraught with truly wicked problems—situations for which there are no right answers, but there are many wrong ones.[2] If the movement embracing sustainability is to succeed, surely there will need to be greater acknowledgment and understanding of ecological systems. There also needs to be a dampening of rhetoric that erupts from

[1] Johann Hari. Move Over, Thoreau. Posted January 12, 2009. As viewed on January 14, 2009 at http://www.slate.com/id/2207168/pagenum/all/p2.

[2] The concept of wicked problems was introduced by Rittel and Webber (1973).

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normative science (Lackey 2001, 2007). A landscape perspective can begin to inform this quest.

A landscape perspective requires that attention be given to the relevant temporal and spatial scales for the issues to be addressed. It also demands that humans be considered to be part of the ecological systems being interrogated and managed. But for many pragmatic reasons, as well as many short-sighted excuses, the proper scales are seldom considered. Obviously, there is a vast spread in spatial scale that is required to sustain populations across the spectrum of plants, animals, microbes, and even humans (detailed discussions of scale appear in Chapter 4). For some microbes in soils, the relevant scale to observe population dynamics or functional processes is in the realm of mm^3 to cm^3; for vertebrate populations, home ranges (excluding migratory species) span four or five orders of magnitude with some exceeding 100,000 ha. In contrast, most contaminated sites are measured in tens of hectares with the rare site exceeding 5000 ha. Similarly for temporal scales, microbial events can be measured in minutes or less, but most ecological developments affecting humans occur over decades to tens or hundreds of millennia—except of course those events that follow chaotic patterns associated with a tipping point. Most risk assessments focus on a few years; the rare risk assessment projects out to 100 years or more. Accordingly, there often is a considerable disconnect between the spatial and temporal scales relevant to ecological developments and the respective scales of investigations used in ecological risk assessments (EcoRAs) or in risk management (Fig. 1.1).

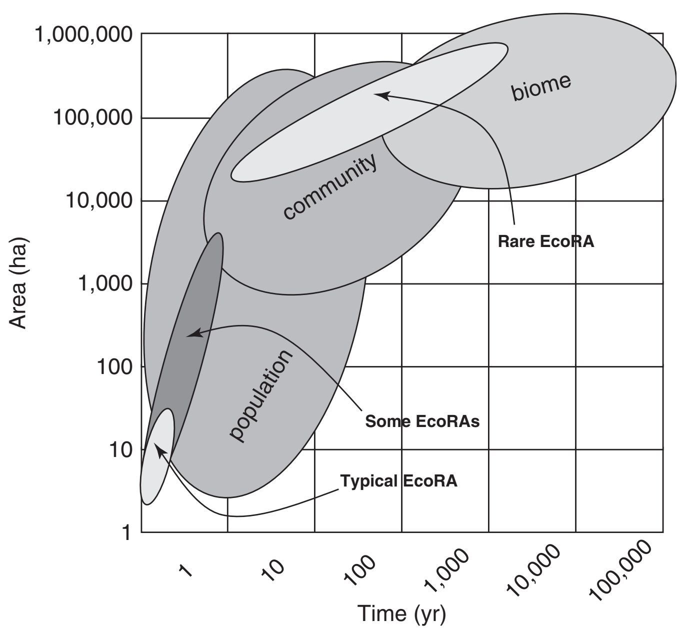

Figure 1.1. Relationship between spatial and temporal scales for ecological developments and risk assessments. [After Fig. 1 in Kapustka (2008).]

The consideration of the scales (as in Fig. 1.1) also will mandate a change in perception of rare, yet important, events. Events that are rare at the scale of a Superfund site or most risk assessments are seen as anomalies. These events, such as a fire, flood, extinction, or the introduction of an invasive species, are anomalies because the arbitrary scale of the site does not include an ecological context. For an individual Superfund site the likelihood of invasion may be low. However, within a landscape an invasion event has a high probability and, depending upon location, may impact the remediation of a contaminated site. Within a landscape, fire, floods, invasions, and extirpations will be occurring and will have important impacts at a variety of scales and to a number of ecological services.

The modern era of environmental management followed the passage of the National Environmental Protection Act (NEPA) of 1969 that was signed into law in the United States in January 1970.[3] There were other events in the arts and cultural circles, politics, and economics that set the stage for the environmental movement, which led to this remarkable document that had as its primary purpose:

> To declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation.

The opening of Sec. 101 [42 USC § 4331] of NEPA provides a remarkable framing of the national environmental policy:

> The Congress, recognizing the profound impact of man's activity on the interrelations of all components of the natural environment, particularly the profound influences of population growth, high-density urbanization, industrial expansion, resource exploitation, and new and expanding technological advances and recognizing further the critical importance of restoring and maintaining environmental quality to the overall welfare and development of man, declares that it is the continuing policy of the Federal Government, in cooperation with State and local governments, and other concerned public and private organizations, to use all practicable means and measures, including financial and technical assistance, in a manner calculated to foster and promote the general welfare, to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans.

A series of US federal laws designed to address environmental issues followed. This included the Clean Air Act (1970), the Water Quality Improvement Act (1970), the Water Pollution and Control Act Amendments (1972), the Resource Recovery Act (1970), the Resource Conservation and Recovery Act (1976), the Toxic Substances Control Act (1976), the Occupational Safety and Health Act (1970), the Federal Environmental Pesticide Control Act (1972), the Endangered Species Act (1973), the Safe

[3] The full act can be viewed at http://ceq.hss.doe.gov/Nepa/regs/nepa/nepaeqia.htm (accessed July 2009).

Drinking Water Act (1974), the Federal Land Policy and Management Act (1976), and the Surface Mining Control and Reclamation Act (1977). Similar lists of legislative acts were passed in countries throughout the world.

As with many lofty political ambitions, translating policy into actions takes many twists and turns. Well-intentioned actions can often have devastating unintended consequences, in part due to imperfect knowledge or unawareness of how things really work. Efforts to suppress forest fires in the early and mid-1900s led to massive buildup of understory and litter—fuel that, once ignited, burns through the canopy and results in markedly different successional trajectories of the affected landscapes. Environmental management decisions that focus on narrowly constructed goals are just as likely to have unintended consequences. Strikingly different recommendations emerge if the objectives are to protect or enhance specific wildlife populations versus elimination of contaminants from a site. Indeed the focus on eliminating contaminants tends to lead to destruction of habitat needed to harbor the valued wildlife purportedly being protected. Thus, from a landscape perspective we ought to promote holistic examinations that are more likely to explore alternative scenarios and lead to very different decisions (a theme developed in Chapters 8 and 17).

The language in the US NEPA appeared to foster holistic approaches to environmental management. It prescribed a multidisciplinary focus to evaluate environmental impacts of projects and activities that would significantly affect the human environment. So why have so many environmental management problems emerged?

Implementation of the lofty aspirations of the US NEPA was not so easy. Challenges emerged quickly due to the very different approaches across the disciplines of engineering, ecology, economics, and sociology. Though project designs typically contained discretely bounded and quantified estimates of monetary costs for engineering, there were no equivalent metrics to characterize costs of ecological resources or the well-being of human communities. Project benefits resulting from construction of a road or a reservoir easily trumped vague concerns about the loss of habitat for an obscure fish or butterfly, or the displacement of a few farmers who's land would be inundated. Welfare economics were used or misused to justify the greater good of society over the losses of a few individuals, in part due to attention solely on readily monetized factors and assigning many factors to a category of "externalities" that conveniently (though not necessarily by being mean-spirited) could be dismissed from consideration. Sociologists in the early 1970s relied largely on generalized narratives; biologists seemed to do little more than generate lists of species expected to occupy the affected area. When pressed for answers, biologists and sociologists could not match the apparent certitude of the engineers.

Indeed, the field of ecology in the late 1960s and early 1970s was not prepared to provide quantitative answers that were useful for environmental management decision-making. The work by May (1973) on the relationship between species diversity and community dynamics occurred after the major environmental legislation was enacted, and his work on nonlinear dynamics occurred later in the decade (May and Oster 1976). Ecology and related sciences were still mired in the clutches of Clementsian ecology that emphasized stability and climax systems (Clements 1916); however, competing theories were gaining traction, at least in the academic community. The resurrection of Gleason's (1926) ideas on the role chance plays in the organization of communities resulted in the continuum concept (Curtis 1955, Curtis and McIntosh 1951, Whittaker 1953) and provided a counterpoint to Clementsian ecology, but application of the continuum concepts to address environmental management issues was quite limited. Ecology shifted into a new realm with the groundbreaking research by Wu and Loucks (1995) into new formulations of community dynamics.

Similarly, ecotoxicology was nonexistent at the onset of the modern environmental movement. It was the passage of the environmental legislation described in this chapter that provided the impetus for developing the field. Initially (through the 1970s), studies were focused largely on determining the concentrations that resulted in mortality in situations of acute exposures. Development of ecological risk assessment did not even begin until the mid-1980s.

The needs of environmental management were far ahead of the science of both ecology and environmental toxicology at the time. And so, by default the processes of environmental management came to be dominated by the linear problem-solving approach of engineers. That legacy still remains.

A decade into the modern environmental era, the disaster of Love Canal[4] in upper New York state led to additional legislation in the United States to deal with hazardous waste sites. CERCLA (aka Superfund in 1980 and amendments in 1986) created a need to document the effects of chemical releases on exposed humans and ecological resources, to identify causal linkages between the chemicals and the observed biological responses, and forecast the benefits of remediation. Though aspects of ecological risk assessment were embodied in pesticide and chemical registration as well as water quality standards for discharge permitting, it was the institutionalization of Superfund in the mid-1980s that expanded the depth and breadth of ecological risk assessments. By the end of the 1980s the general framework for EcoRAs was established (Suter 2008). Field observations pertaining to the nature and extent of contaminants were evaluated against toxicity responses to the chemicals. Forensic ecology[5] was used to establish weight-of-evidence linkage of chemicals to effects, and EcoRA was used to evaluate alternative remedies that either eliminated the offending chemicals or restricted exposure to receptors.

Risk assessment is performed in many disparate disciplines and can be expressed in qualitative or quantitative terms. It is used in engineering to evaluate the probability of structural failures and to forecast design requirements for flood control, building design, slope stability, driving a car, flying an airplane, walking in the city, or keeping foods and drinking water from being tainted with various toxic chemicals. Financial institutions and individuals employ risk assessment to evaluate investment opportunities, set insurance premiums and payouts, weigh potential liabilities, and structure

[4]See *The Love Canal Tragedy* at http://www.epa.gov/history/topics/lovecanal/01.htm as viewed January 14, 2009.

[5]The term "retrospective risk assessment" has been used to identify plausible causal relationships. However, as risk is inherently a forward looking attempt to describe likelihood of occurrence, the term is convoluted. Also see Taleb's (2007) discussion of retrospective distortion.

contracts. Most readers of this book will be familiar with human health and ecological risk procedures that estimate cancers occurrence, mortality rates, morbidity rates, and so on. Regardless of the type of assessment, risk procedures examine possible scenarios by estimating the magnitude of exposure to the stress element, relating effects to different magnitudes of exposure, and concluding with a description of the likelihood of the events occurring in each scenario. Ultimately, the purpose of the risk assessment is to inform decision-makers tasked with managing the risks. In assigning probability of certain scenarios, informed management decisions can be structured to avoid, minimize, or mitigate adverse consequences in a manner that is proportional to the risks and consequences.

The most important part of the risk assessment process is the Problem Formulation stage in which the questions to be addressed are refined so that the analysis and characterization stages are relevant to the management goals. More details pertaining to Problem Formulation are presented in Chapter 2.

The marriage of risk assessment and multicriteria decision analyses approaches provides a formal approach to consider tradeoffs and assist decision-makers as they navigate through challenging problems. Risk assessment procedures are sufficiently flexible to accommodate mixes of quantitative and qualitative information (illustrated in Chapters 6, 7, 12, and 13). Furthermore, the advanced methods are robust in handling varying degrees of uncertainty and natural variations (see Chapter 6), both normal attributes of biological and sociological data. Recent advances in risk assessment include alignment with comparative risk and multicriteria decision analysis tools (Linkov et al. 2006). Also, computational models that account for variability and uncertainty provide powerful insights that aid the evaluation of scenarios through identification of the most influential parameters also known as sensitivity analysis.

There are many challenges involved in making sound environmental management decisions. Environmental management issues are complex due to inherent characteristics of the environment we attempt to manage, but also due to the many competing interests expressed by various stakeholders. Unaided, humans are not particularly good in processing all the information that comes from assessment of these multifaceted issues, such as those that face regulatory bodies; what may seem perfectly logical in terms of engineering feasibility or legal/regulatory compliance can be viewed very differently by other stakeholders.

Information comes to decision-makers in many different forms (e.g., modeling/monitoring data, environmental risk analysis, benefit–cost analysis, and stakeholders' preferences). In the public sector, adherence to an agreed process can be of equal or greater importance when compared to the actual decision. The process must be understood by stakeholders, and it must be seen as being fair, equitable, and consistent. Yet, if each of these overarching aims is to be met, the process must also be flexible (that is, it must accommodate project- or site-specific information). Perhaps most importantly, the process should be constructed in such a manner that it can reward innovation and good-faith efforts. In other words, there should not be built-in disincentives that stifle creative environmental management.

Decision-makers typically receive different types of technical input. But how can individuals or groups integrate (or judge) the relative importance of information from each source? While modeling and monitoring results are usually presented as quantitative estimates, risk assessment and benefit–cost analyses incorporate higher degrees of qualitative judgment. Structured information about stakeholder preferences may not be presented to the decision-makers at all, and it may be handled in an *ad hoc* or subjective manner that exacerbates the difficulty of defending the decision process as reliable and fair [see Kiker et al. (2005)]. Moreover, where structured approaches are employed, they may be perceived as lacking the flexibility to adapt to localized concerns or faithfully represent minority viewpoints. There has been considerable activity in recent years that has examined formal approaches to guide the decision process, ones that handle both quantitative and subjective preference information equally well.

Fundamentally, the design elements of the risk framework either constrain or expand the utility of the information that will be used to make decisions. Deciding on issues of scale, both temporal and spatial, becomes one of the most important challenges. If not constructed properly to account for both ecological realities and socioeconomic interests, the resulting analysis may be irrelevant to the problems being addressed or they may be tautological—that is, circular arguments that dictate the "answers" that emerge, thereby giving a false sense of validity to the regulatory decisions that ensue. Great care must be exercised during the design phase so that equity, fairness, openness, clarity of purpose, and agreement on terminology are recognizable features of the approach. A most important consideration of the framework is to ensure that the breadth of affected stakeholders' values is captured in the explicit delineation of endpoints to be assessed.

In the interplay of policy and regulatory actions, inevitably there are varying degrees of tension that arise due to differences in stakeholders' tolerance or acceptance of environmental risks. These tensions often are created as a direct consequence of the processes followed in reaching decisions, but there is much more. Explorations from nearly two decades ago into risk perception have provided powerful illustrations into the way people handle multiple forms of information as they make decisions. In general, we can conclude that scientific or technical descriptions of a risk event or activity form only a small part of the body of information that people process as they consider accepting or rejecting the risk [see Gladwell (2005) for his discussions of the theory of thin slices]. Those science-based or technological features are largely limited to understanding the mechanisms and characterization of uncertainty. From the regulatory side, the most critical feature influencing public acceptance of decisions is trust in the responsible institution (Peters et al. 1997). Many of the remaining features relate in one form or another to communications and the degree of control that the public feels they can exercise, either directly or indirectly. Historically, public notice and public hearings/comment periods have been the primary means for public input into the environmental management regulatory process. However, all too often, at least to the affected public, it appears that the crucial decisions have been made by government officials and industry proponents well before public input is sought. As the regulatory process evolves to meet current challenges, there are opportunities to achieve the goals of public input in ways that are more satisfying to all stakeholders and simultaneously streamline the process so that efforts can be focused on issues in proportion to the importance of the issues.

Our society has shown a particular inability to consider scale, especially for events that are rare and consequential. Taleb (2007) calls such events *Black Swans*. Black Swans are events that are rare, essentially not predictable as to a specific type of event, but have high consequence. The dot com downturn, the subprime lending mortgage meltdown, World War II, and the fall of the Soviet Union are all examples of societal events that represent Black Swans. Ecological events include the influenza outbreak of 1914, the invasions of zebra mussel and sea lamprey into the Great Lakes, and the impacts of persistent organic pollutants on wildlife populations popularized by *Silent Spring* (Carson 1962).

It is not clear that our current regulatory and management structure for the environment in Western society can manage future Black Swans at the proper scales. Each type of activity or event tends to be regulated by a specific statute by a specific agency, and without a landscape context. The context of the regulations can be traced to the early 1970s when our understanding of landscapes was nascent. If landscapes are to be managed to perpetuate ecological services, sustainability, or other societal goals, then a change in perception and approach is required.

At the core of this book and as detailed in subsequent chapters, a landscape perspective is crucial in addressing contemporary environmental management concerns. The scale of time and space dictate the appropriate focus: Using the wrong scales leads to asking the wrong questions, resulting in irrelevant "answers." Choosing the proper scales for assessment seems intuitively obvious, but as we consider conflicting objectives, disparate values, and multiple receptors, one quickly realizes the enormity of the task.

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