Conclusion

EWSs provide systematic and objective analyses of macroeconomic and financial market data in predicting financial crisis. This paper reviewed various approaches to the modeling of EWSs for financial crisis and discussed the effectiveness of these systems. Notwithstanding the research efforts and the noticeable progress in this area, there is still yet a sufficiently robust EWS that can be relied upon as the sole system for crisis prediction. Development in other research frameworks that are complementary to EWS such as the resilience framework, is encouraging.

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Ecological Fallacy ***see*** Modifiable Areal Unit Problem (MAUP)

Ecological Risk Assessment

Ecological risk assessment (ERA) is a generic term used to describe any formal process whereby ecological threats are identified, their likelihood of occurrence estimated or guessed, and their consequences articulated. ERA is a subset of environmental risk assessment (*see* **Environmental Hazard**; **Environmental Health Risk**; **Environmental Risks**). It focuses specifically on the elicitation, quantification, communication, and management of risks to the *biotic* environment. While environmental risk assessment dates back to the 1930s [1], ERA is relatively new and commenced as a United States Environmental Protection Agency (USEPA) project in the 1980s to develop tools for environmental regulation and management [2]. Since that time there have been rapid advances in the sophistication and complexity of ERA "tools" although, as noted by Kookana *et al.* [3], ERA currently suffers from a poor understanding of processes governing ecological risks and a paucity of appropriate data. Other challenges exist as well, including the following:

- difficulties in identifying pathways for chemicals in the environment;
- lack of understanding of fate and effect of pollutants in the receiving environment;
- high levels of uncertainty in models and processes underpinning the ERA process;
- unquantified errors in model outputs;
- no agreed approach to combining uncertainties of different kinds comprehensively in a single analysis;
- lack of standard approaches to ERA;
- difficulty in developing and applying a "system-wide" ERA – that is quantifying the overall risk associated with multiple stressors and threats;

- diffuse linkages between the outcomes of an ERA and management responses;
- difficulties in assessing the utility of an individual ERA.

With respect to the last point, Suter [2] notes that "assessors have developed methods for determining the likelihood that a safe exposure level will be exceeded, but have seldom specified the benefits of avoiding that exceedence". Thus, a certain degree of "evaluation bias" tends to characterize ERAs where the risk of an undesirable ecological outcome is rarely evaluated against the benefit of a desirable ecological outcome. In many instances, the framing and the contextual setting of the problem at hand influence the outcomes of the ERA [4]. To a large extent, they determine the set of solutions considered, as well as the focus of the assessment, the kinds of endpoints used, the time frames considered, the data collected, and who is considered to be a "stakeholder".

Components of an Ecological Risk Assessment

As with environmental risk assessment, ERAs have been dogged with multiple definitions of risk (*see* **Absolute Risk Reduction**), a confused lexicon, and a lack of a transparent and consistent framework to guide the ERA process [5]. Most environmental decisions are set in socially charged contexts. People stand to gain or lose substantially. Arguments are clouded by linguistic ambiguity, vagueness, and underspecificity to which analysts themselves are susceptible. Prejudice gets in the way of constructive discussion. A transparent framework helps to relieve these impediments.

We use "risk" here to denote the chance, within a prescribed time frame, of an adverse event with specific (usually negative) consequences. Other terms commonly used in ERAs are hazard and stressor. A *hazard* (*see* **Hazard and Hazard Ratio**) is a situation or event that could lead to harm [6]. Ecological hazards can be natural (e.g., cyclones, earthquakes, fires) or related to human activities (e.g., destruction of a habitat). Hazards are possibilities, without probabilities. They are all those things that might happen, without saying how likely they are to happen [4]. Stressors are the elements of the system that precipitate an unwanted outcome (for example, low dissolved oxygen in a river is a stressor that ultimately results in the death of aquatic life). Suter [7] created a system of thinking to help people to define environmental hazards and their consequences. He defined endpoints as an expression of the values that we want to protect. There are three broad kinds:

1. *Management goals* are statements that embody broad objectives, things such as clean water or a healthy ecosystem. They are defined in terms of goals that are both ambiguous and vague but they carry with them a clear social mandate.
2. *Assessment endpoints* translate the management goals into a conceptual model, and satisfy social objectives. Clean water may be water that can be consumed and bathed in by people. A healthy ecosystem may be one in which all ecological stages are represented, all natural ecological processes continue to operate, and populations of important plants and animals persist. But assessment endpoints cannot be measured.
3. *Measurement endpoints* are things that we can actually measure. They are operational definitions of assessment endpoints that are in turn, conceptual representations of management goals. Thus, measurement endpoints for freshwater may include counts of *Escherichia coli* or the concentration of salt. Measurement endpoints of a healthy ecosystem may be the abundance of several important species (threatened species or game species), and the prevalence of diseases and invasive species.

We have defined risk to be the chance or likelihood of an adverse outcome. Probability is a mathematical construct (a metric) that quantifies the likelihood of uncertain events. In this context, the duality between risk and probability is apparent and these terms are often used interchangeably in ERAs. The "frequentist" definition of probability is based on the statistical frequency (or relative frequency) with which an event is expected to occur. The term *subjective probability* also has two meanings. The first meaning is a lack of knowledge about a process or bias. The second meaning is that it indicates purely personal degrees of belief. Personal beliefs are unknown only insofar as a person does not know his/her own mind [8] (*see* **Bayes' Theorem and Updating of Belief**; **Bayesian Statistics in Quantitative Risk Assessment**).

Standard approaches to risk analysis (*see* **Volatility Modeling**) may be particularly vulnerable to psychological frailties including insensitivity to sample size, overconfidence, judgment bias, anchoring (the tendency to provide subjective assessments similar to those already proposed, or proposed by a dominant individual in a group), and arbitrary risk tolerance (see reviews by Fischhoff [9], Morgan *et al.* [10], and Freudenburg *et al.* [11]). In addition, scientific training fails to acknowledge the pervasive presence and role of linguistic uncertainty [12], particularly the vague, underspecified, and ambiguous language that characterizes many risk assessments.

Challenges for Ecological Risk Assessment

It is challenging to consider the full extent of uncertainty present in any analysis, to characterize it fully and carry the uncertainties through chains of calculations and logic. A host of new methods offer prospects for solutions; in addition to standard treatments such as probability trees (*see* **Decision Trees**) and *Monte Carlo*, emerging approaches include fuzzy numbers, rough sets, evidence theory, imprecise probabilities, probability bounds, game theory, and *decision analysis* (*see* **Decision Analysis**). The task lies ahead to evaluate these methods and develop experience in their use so that they can be applied effectively and routinely.

Adams [13] argued that risk assessments always involve decisions about values and preferences, and are colored by the personal experiences and prospects of the individuals conducting the assessments. He argued that, in general, we get by with crude abstractions shaped by belief. This view objects to the artificial separation of stakeholder, risk analyst, and manager/decision maker [14]. Instead of using technical analysis, risk assessments could be conducted through stakeholder engagement, elicitation of preferences and values, and consensus building. Adams may be right. Certainly, the importance of psychology and context provide strong support. The answers generated by quantitative risk analysts may be little more than smoke and mirrors, reflecting the personal prejudices and stakes of those conducting the analysis. It is likely that at least some of the problems alluded to by Adams will affect all risk analyses. The extent to which they are felt will depend on the nature of the problem, the amount and quality of data and understanding, the personal outcomes for those involved in the analysis, and the degree to which their predispositions can be made apparent.

Many disagreements among stakeholders are resolved by seeing clearly what the other participants want, and why they want it. Risk assessments that combine social preferences with formal analytical tools can have their greatest utility in meeting these challenges. They work when they are logically robust and relatively free from linguistic ambiguity. They are not necessarily any closer to the truth than purely subjective evaluations. But they have the potential, if properly managed, to communicate all the dimensions of an ecological problem to all participants. They may do so in a way that is internally consistent and transparent, serving the needs of communication (assuming appropriate skills in the analyst).

ERA is relatively new and as such is still "finding its feet". While it is acknowledged that more work needs to be done in harmonizing different quantitative approaches, developing a consistent lexicon, and producing robust guidelines, natural resource managers and environmental stakeholders have much to gain from the formalized approach to environmental decision making under uncertainty.

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Economic Criteria for Setting Environmental Standards

The development and choice of standards or guidelines to protect the environment and human health from pollution and other hazards can be achieved by directly controlling emissions of pollutants, by allowing some economic optimization based on legal standards, or a combination of both. As always, the justification for a choice of control system depends on the regulatory context. That is, specific statutes will direct an agency to perform some type of economic analysis, but not permit another to justify its choice of technology and then impose it on the producers of the hazard. For example, a statute may explicitly ask that a standard be set on the balancing of the risk, costs, and benefit; another may limit those analyses to risks only.

Economic costs include the value of all impacts that can be stated in monetary units, that is, these factors are *monetized*. However, some costs and benefits cannot easily be monetized because they are intangible, or not priced by the market, directly or indirectly. For example, the value of improving visibility by reducing air pollution (*see* **Air Pollution Risk**) is an environmental service not generally priced by the market, unlike the value of reductions in morbidity or mortality from the same type of pollution. Nonetheless, economic methods can be used to approximate those intangible costs (e.g., *via* methods such as hedonic pricing) so that the price paid by the consumer correctly *internalizes* (incorporates) all costs, for given levels of social benefit, resulting from a reduction in pollution.

As always, regulatory laws must consider economics as well as the full aspect of regulation: statutes, secondary legislation, and judicial review *via* case law. In the United States, costs have been found by the courts to be important, but not likely to limit the use of expensive technology, unless those costs were disproportionate to the benefits achieved by the selected control technology. The US Federal Water Pollution Control Act imposes a limited form of cost-benefit analysis (CBA) for water pollution control (*see* **Water Pollution Risk**) depending on the level of effluent control (33 U.S.C. Section 1251 *et seq*.). Marginal cost (the cost per unit of mass of pollution removed) analysis of control technology plays an important role in determining the level of effluent discharge permitted. The case *Chemical Manufacturers Association v. EPA* (870 F.2d 177 (5th Cir. 1989)), which dealt with changes in the marginal cost of controlling effluent discharges, exemplifies how cost-effectiveness can be used in risk-based regulations. The US EPA can impose a standard, unless the reduction in effluent is *wholly out of proportion* to the cost of achieving it. In the US case *Portland Cement Assoc. v Ruckelshaus*, the court held that Section 111 of the Clean Air Act (CAA) explicitly requires taking into consideration the *cost of achieving emission reductions* with the *nonair quality health and environmental impacts and energy requirements* (486 F.2d 375, cert. den'd, 417 U.S. 921 (1973)). The court then found that the US EPA met the statutorily required consideration of the cost of its regulatory