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Ecological Risk-O-Meter: a risk assessor and manager software tool for better decision making in ecosystems[†]

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Increased awareness of environmental issues and their effects on ecological systems and human health drive an interest in developing computational methods to reduce detrimental consequences. For example, there are concerns regarding chlorofluorocarbons and their impact on stratospheric ozone, radon and its effect on human health, coal mining and effects on habitat loss, as well as numerous other issues. However, these issues do not exist in a vacuum nor occur just one at a time. There is a need to assess social and ecological risks comprehensively and account for numerous, inter-related potential risks. Given limited funds available for addressing these issues, how can spending for purposes of environmental and ecological mitigation be optimized? What is the magnitude of overall ecological risk for a given region? Novel software, the "Ecological Risk-o-Meter", addresses these questions and concerns. The software tool not only assesses the current environmental and ecological risks, but also takes into account potential solutions and provides guidance as to how spending can be optimized to reducing overall environmental risk. We demonstrate this new tool and show how to optimize the costs of risk reduction in recursive cycles based on feedbacks. Copyright © 2012 John Wiley & Sons, Ltd.

Keywords: ecological systems; vulnerability; threat; countermeasure; Risk-o-Meter

1. INTRODUCTION

There is not a day that passes when one does not hear or read about the adverse effects of climate change and consequent ecological damage occurring on our planet, which we have inherited and owe to the next generation to leave as well as or better than what we received. Recent events associated with global warming, such as record heat, drought, and more intense storms and hurricanes, have highlighted the continuing need to monitor, assess and mitigate ecological and environmental risks in a more holistic fashion. Traditional risk assessments were performed on a case by case basis rather than by using a systemic approach, as in the Ohio EPA DERR document (2008). It is rather a new trend to determine overall risk from a holistic viewpoint so that risk managers can take global, rather than incremental measures, as earth is connected through a common, freely circulating atmosphere and hydrosphere, and therefore, the communities exposed to risks are diverse. Such broad assessments of risk may be termed "ecological risk assessment" (ERA). According to Barnthouse and Suter (1986), ERA is the process of assigning magnitudes and probabilities of adverse effects of human activities or natural catastrophes. There are other resources where one can learn about ERA, such as the ones by Natural Resource Damages, http://www.epa.gov/superfund/programs/nrd/era.htm, and US Environmental Protection Agency http://www.epa.gov/oswer/riskassessment, as well as The Department of Energy & Environmental Protection in Canada, http://www.ct.gov/dep/cwp/view.asp?a=2715&depNav_GID=1626&q=325016.

"A Framework for Ecological Risk Assessment: General Guidance" by the Canadian Council of Ministers of the Environment defines ERA as a formal set of scientific methods for estimating the probabilities and magnitudes of undesired effects on plants, animals and ecosystems resulting from events in the environment, including the release of pollutants, physical modification of the environment and natural disasters. See a related website, http://www.ccme.ca/assets/pdf/pn_1195_e.pdf. In the same reference, a diagram from screening to preliminary and finally to a detailed quantitative ERA is illustrated in Figure 1. A detailed ERA as proposed is not only quantitative, dealing with a complex interaction, but it is also predictive and subject to statistical inference supported by expert field data rather than data obtained from hearsay through common literature.

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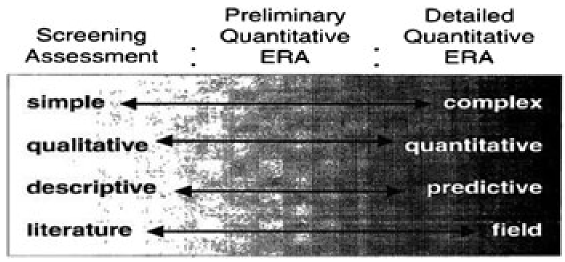


Figure 1. Conceptual structure of tiered approach to ERA with characteristics of each level

What one finds striking in the Canadian Council of Ministers of the Environment Framework is the interaction between the risk assessor and risk manager. The framework text continues, "Although risk assessment and risk management are closely related, the tasks should not be confused". In the USA, risk assessment and risk management have been kept separate since the National Academy of Sciences released the 1983 Red Book to reduce cases where risk management objectives override the risk assessor's impartial evaluation of scientific data, as explained by Jasanoff (1993). The risk assessor must present the results of the risk assessment in a clear and concise way so that the risk manager can make informed decisions. As the ERA process moves through the various stages, the risk assessor and the risk manager should evaluate the progress and determine whether the expectations identified in the planning are being met. Figure 2 illustrates the dynamics between the risk assessor and risk (planning) manager in the overall ERA life cycle, as discussed in the Framework Report (USEPA, 1994) as part of the EPA's long-term effort to develop cumulative risk assessment guidance. This report highlights the importance of understanding the aggregation of risks from multiple environmental stressors. See a related website, http://www.epa.gov/raf/publications/guidelines-ecological-risk-assessment.htm.

The same reference also emphasizes ongoing research and continues that "The framework for ecological risk assessment is the product of a series of workshops and reviews that involved both the Environmental Protection Agency and outside scientists. While the Framework Report has been a first step in developing ecological risk assessment concepts, evolution of the framework concepts is expected and encouraged". In a recent Special Issue of *Environmetrics* in 2011 titled "Quantitative Approaches to Eco-System Services Assessment" by Scott *et al*. (2011), the authors explored ERA and ecosystem valuation techniques with emphases in statistical analyses, both classical and Bayesian, from data analytical and informative prior-based judgmental viewpoints, respectively. ERA also involves the practice of determining the nature and likelihood of effects of our actions on animals, plants and the environment. In terms of existing ERA modeling tools, there are a few tools that specialize in different tasks. One such tool is the RESRAD-ECORISK (developed by Environmental Science Division of the Argonne National Laboratory for the US Department of Energy), which (i) estimates the movement of contaminants through the terrestrial food webs of wildlife receptors, (ii) predicts doses and (iii) quantifies risks for them to optimize site remediation. See the following related website, http://www.evs.anl.gov/project/dsp_fsdetail_new.cfm?id=52. Further, ERA is quite useful for industry, government agencies, policy makers, citizens, legislators and other stakeholders, and for allocation of benefits, equity and costs to support and justify risk management decisions as in the website, http://

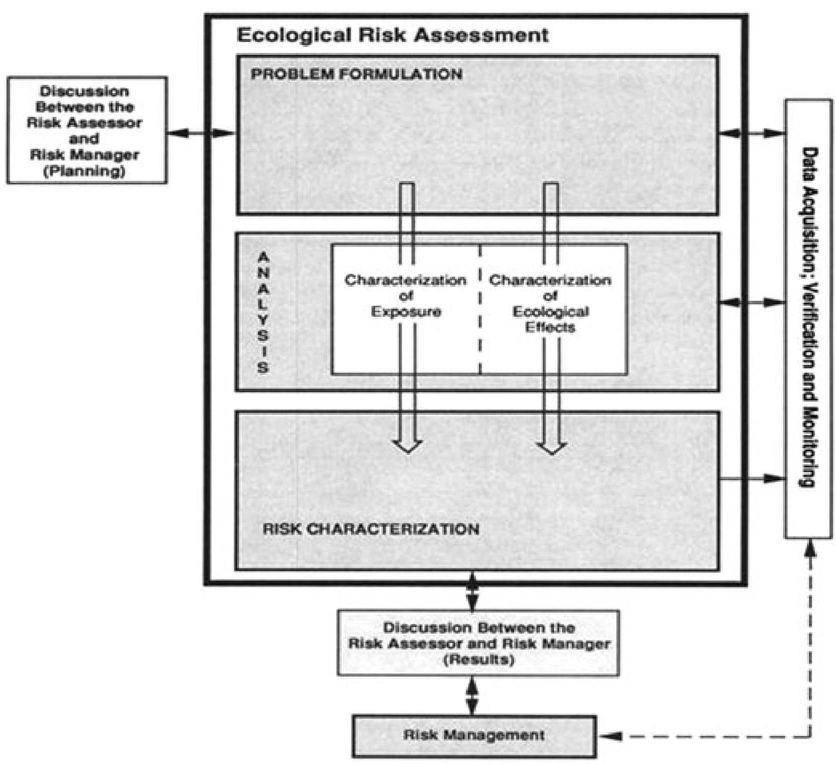


Figure 2. The framework for ecological risk assessment

www.setac.org/node/99. Society of Environmental Toxicology and Chemistry (SETAC) has suggested that a course of action yielding the least ecological risk may be too expensive or technologically infeasible, arguing the need for an optimization approach. Although there are many sources of uncertainty in ERA, one can predict many effects with confidence. SETAC emphasizes that ERA helps organize information and contribute to informed decisions. Moreover, risk assessment and management are iterative processes, incorporating new data, new understanding, changing probabilities and changing costs, thus requiring constant feedback and generating improved assessments. These goals are in harmony with the proposals in this paper, as the Ecological Risk-o-Meter (Eco-RoM) constitutes a software tool that facilitates continuous improvement through iterative assessment and risk reduction.

Examples of issues of importance to environmental decision makers are as follows: (i) What health risks to humans are posed by a new chemical or agent? (ii) Should we use, for example, a new chemical or release a new effluent? (iii) What should we do about the new chemical, for example, ban, restrict use and require further testing? (iv) What methods should we apply to contain the risk, for example, which use, treatment or release methods pose the least risk? As noted in a related website (Suter, 2007), ecological and environmental risk assessors traditionally work in teams that include ecologists, toxicologists, chemists, statisticians, hydrologists, agriculturists, engineers, environmentalists and other specialists such as computer scientists, and system modeling and simulation experts to provide a broader perspective.

An examination of the ERA literature indicates that there are numerous risk assessment and management methods, typically separate and static, thus not integrated or interactive (Figure 2). A holistic and integrated hybrid approach is preferable where an automated software tool would integrate both risk assessor and risk (planning) manager roles, thus creating a comprehensive framework providing a much needed cohesive, global perspective.

2. MOTIVATION

The motivation behind the proposed Eco Risk-O-Meter is therefore the creation of a useful risk assessor and manager tool to (i) highlight the greatest sources of risk, which is helpful for allocating limited resources; (ii) allow decision makers to ask “what if?” questions regarding the consequences of various potential management actions; and (iii) identify critical threats and associated actions, helping to prioritize future research. These goals are similar to the ones emphasized by SETAC and cited earlier in the Introduction.

The Eco-RoM is an automated software tool that is the primary subject matter of this research paper and serves to assess and quantify ecological and environmental risks. The software provides mitigation guidance (cost optimization) by offering objective means for doing so. On the basis of game theory and statistically driven methodologies, it provides objective risk assessment and, unlike any other tool available today, a means of allocating resources for risk mitigation. Beyond its multitasking qualities, the proposed method is evolutionary. In addition, it remedies a failure typical of conventional risk management, which is the general inability to internalize the true costs of environmental and ecological risks. This frequent cause of market failure, in economic terms, leads to massive externalities and cost-shifting to others, often unsuspecting, and with significant time delays, as explained by Cutting and Cahoon (2005, 2006). The quantitative and predictive power of the Eco-RoM approach permits informed and cost-effective efforts to internalize true costs associated with these risks.

3. RISK CONCEPTS AND THE ECOLOGICAL RISK-O-METER FRAMEWORK

The *process* of risk management is an ongoing iterative process and must be repeated indefinitely. The business environment is constantly changing, and new ecological threats and vulnerabilities emerge every day. Furthermore, the choice of countermeasures (CMs), that is, the controls or methods used to counter the risk of the vulnerability or threat and those used to manage risks, must strike a balance among productivity, cost, effectiveness of the CM and the value of the asset being protected. The residual risk (RR), that is, the risk remaining after risk treatment decisions have been implemented, should be estimated to ensure that sufficient protection is achieved. If the RR is unacceptable, the risk treatment process should be re-iterated utilizing scientific feedbacks until an acceptable risk level is achieved. Here is where many private entities differentiate between internal costs, costs they must reasonably be expected to pass along to their customers in the pricing of their goods and services, and external costs, those they pass along to the general public and taxpayers (Cutting *et al*., 2006). It is by introducing the cautionary measures that the risk metric is reduced by the existence of CM action. If for instance, the probability of CM to counteract a certain environmental threat is 1, then the risk of lack of countermeasure (LCM) is $1 - \text{CM} = 0$, thereby reducing the RR to zero because there is no threat. The RR is defined as,

$$\text{Residual Risk} = \text{Risk of Vulnerability} * \text{Risk of Threat} * \text{Risk of Lack of Countermeasure} \tag{1}$$

Equation (1) is bounded between 0 and 1. Notice that the risk in Equation (1) can be defined by a dollar amount and can include the financial liability for failing to take CMs. In this calculation, risk is a traditional definition of risk, as in the likelihood of an outcome or an event (Piegorsch and Bailer, 1994). Instead, the definition is extended also to include the impact and the cost. Therefore, risk of loss can be defined as the product of the likelihood of the event, the impact of the event and the cost of the event.

Innovative quantitative risk measurements are greatly needed to objectively compare risk alternatives and manage existing risks (Sahinoglu, 2005, 2007, 2008; Sahinoglu *et al*., 2012a, 2012b). The proposed Eco-RoM design provides the means in a quantitative manner that is imperative in the ERA world (Sahinoglu *et al*., 2009, 2012a, 2012b). For a practical and accurate statistical design, ecological vulnerabilities, or threats, will be recorded so as to estimate the model’s input probabilities using the risk equations developed. Ecological threats against multiple vulnerabilities can increase the risk level. For example, the vulnerability to global climate changes includes the following threats: heat waves, flooding, drought, coastal storm damages and crop failures, among others. Figure 3 illustrates the constants in the RoM as the utility cost (dollar asset) and criticality constant (0–1.0). The criticality constant is maximally full unity when life and death are at stake such as a nuclear plant accident or a biological weapon release, and conversely, its value becomes trivially small, for example, when a coal stove under scrutiny can easily be replaced by an electric radiator alternative (whereas an exploding nuclear reactor cannot be replaced overnight).

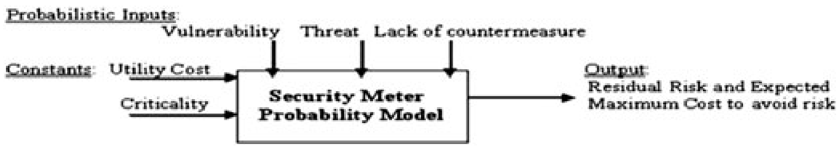


Figure 3. Risk-O-Meter (or similarly security meter) of probabilistic inputs and deterministic constants, and calculated output of residual risk after the countermeasures and expected resultant maximum cost to avoid risk

In Eco-RoM, criticality constant is taken as unity here because of ecological impacts being of crucial significance and irreparable instantly. Therefore,

The probabilistic inputs are ecological vulnerability, threat and lack of CM, all valued between 0 and 1.0. Figure 4 illustrates the general purpose tree diagram in which the main branch of the tree represents the ecological vulnerability (v). There exist, for each vulnerability, certain ecological threats, which are represented as t in the tree diagram. Finally, for each threat, there are CMs and LCMs.

$$\text{Final Risk} = \text{Residual Risk} * \text{Criticality Constant} \tag{2}$$

Basic RoM Variables and Characteristics:

1. *Probabilistic inputs*: The suggested vulnerability probabilities vary between 0.0 and 1.0 and must add up to one, as in Figure 4. If a cited vulnerability is not exploited in reality, then it cannot be included in the model or simulation. Vulnerabilities may be from two to several threats. A threat, as an event, is defined and identified by the risk of exploiting a certain vulnerability occurring within a specific time frame. Therefore, a threat is an environmental or ecological stressor event that exploits or triggers the vulnerability. Each threat is mitigated or remedied through a *CM* that ranges between 0 and 1 (with respect to the first law of probability) whose complement gives the *LCM*. The dichotomous *CM* and *LCM* values should add up to one (with respect to the second law of probability). An ecological working example of a tree diagram is illustrated in Table 1. In this tabulated diagram, there are nine ecological vulnerabilities illustrated and represented as v_1, v_2,. . .,v_9. For example, in vulnerability v_3 (oceanic), the first shown threat is sea-level rise, which is denoted as t_{31}, and the next threat is acidification (t_{32}), and so on. The *CM* and *LCM* will also only have two subscripts. The CM and LCM for the threat of sea-level rise within the vulnerability of oceanic will be represented as CM_{31} and LCM_{31}.
2. *Deterministic inputs*: Criticality constant, a constant that indicates how critical or disruptive or consequential a threat could be to an eco-system or community, ranges from the least severe of 0.0 to the most severe of 1.0. Capital investment or utility cost is the total expected (estimated, given that ecosystems such as Yellowstone National Park are priceless) lump sum asset-loss in monetary units for a particular ecosystem if it is destroyed completely and can no longer be utilized, excluding the other costs had the ecosystem continued to generate added value for the community. However, following the proposed study, it will be observed that only a fraction of the total asset will be lost because the total RR will never rise to 100%. If there is an economic ripple or shadow-cost effect, a multiplier other than the default of unity (1.0) is needed, or else the production or ripple costs can be added to the asset cost. This is an opportunity for externalities, costs passed along to others outside of market pricing, to be assessed.
3. *Probabilistic tree diagram*: Given that a simple ecosystem has two outcomes for each vulnerability (v), threat(t) and *CM*, the following probabilistic framework holds for the sums $\sum v_i = 1$ and $\sum t_{ij} = 1$ for each i, and the sum of $LCM + CM = 1$ for each ij, within the $2 \times 2 \times 2$ sample tree diagram structure in Figure 4. Using the probabilistic inputs, we calculate the RR = P (vulnerability) * P (threat) * P (LCM) as in Equation (1). We can calculate the RRs for all vulnerabilities *exploited* by their related threats, which will be *counter-measured* by their related *CM*s. Then *RR*s summed up will generate the total residual risk (*TRR*). That is, if we add all the RRs due to lack of CMs during the final stage of the tree diagram as in Figure 4, we can calculate the overall or total RR. We multiply the criticality factor with the RR to calculate the final risk as in Equation (2). Then we apply the capital investment cost to the final risk to determine the expected cost of loss, which budgets for avoiding (pre-damage) or recovering (post-damage) a certain portion of the entire eco-risk, where

$$ECL(\$) = \text{Final Risk} \times \text{Capital Cost } (\$) \tag{3}$$

4. *Algorithmic calculations*: The probabilistic tree diagram in Figure 4 explains the calculations in the black-box model in Figure 3. For example, greenhouse gas concentrations rise because of the use of fossil fuels or there is a lack of prevention measures for deforestation. In this situation, the vulnerability to climate change is accelerated, and we can identify the root threat of this vulnerability. This example

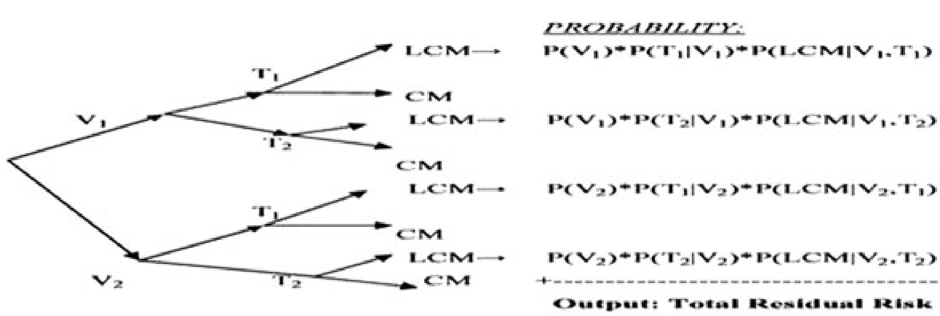
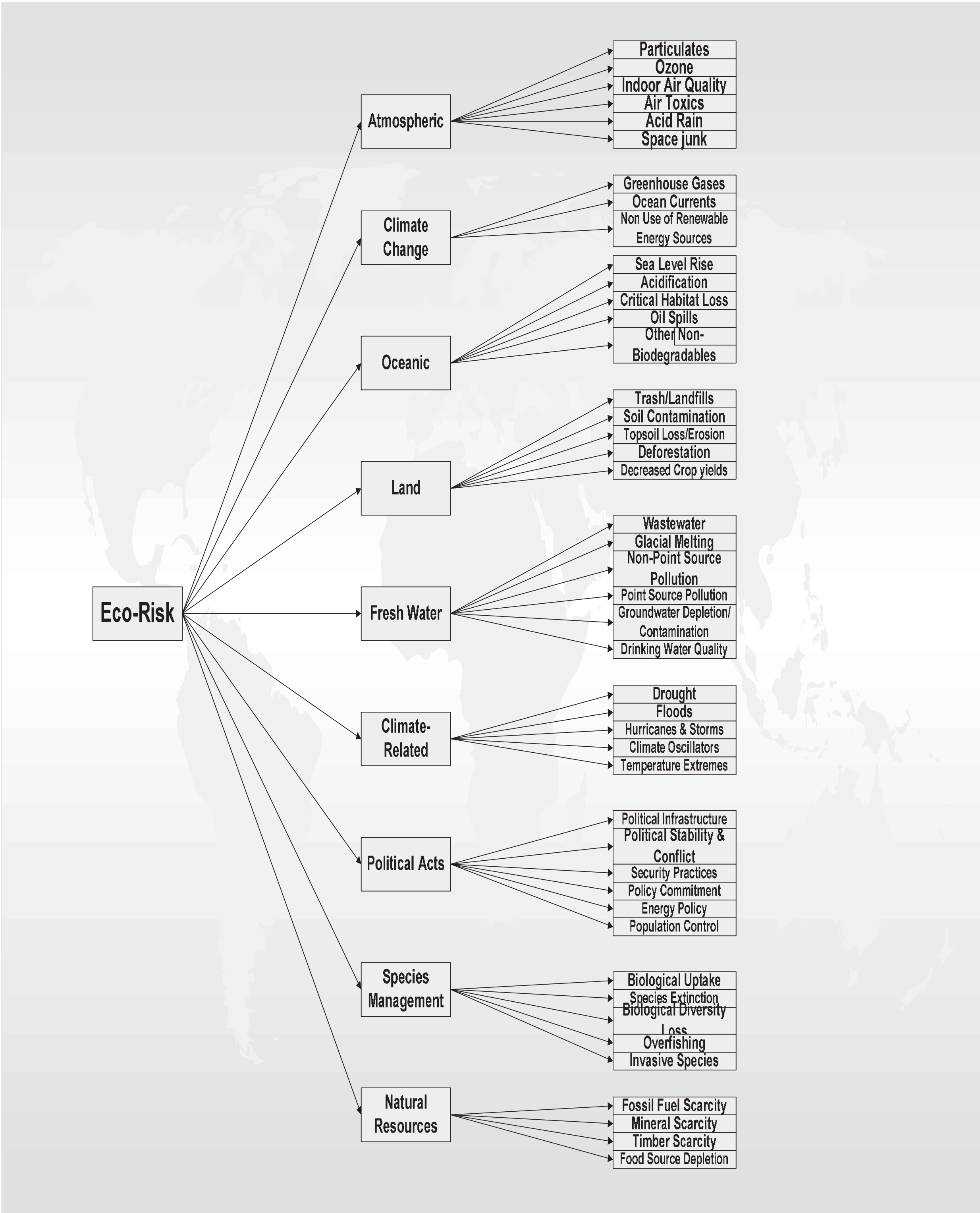


Figure 4. General purpose 2 × 2 × 2 tree diagram (V-branches, T-twigs and LCM-limbs) for the RoM

Table 1. Eco-risk tree diagram with vulnerabilities and pertaining threats listed



illustrates the *line of risk* on the ecological risk's tree diagram of Table 1. Therefore, one needs to calculate for each ending limb in the general tree diagram of Figure 4, the *RR* and then sum up the *RR*s for the, *TRR* (Sahinoglu *et al*., 2010, 2012a, 2012b). *Climate change* exemplifies a complex situation in which the magnitudes of *vulnerability* and *threat* are debated. The RoM model allows iterative improvements as new information is added and uncertainties are reduced by a feedback mechanism.

4. VULNERABILITIES AND THREATS FOR AN ECO-RISK ASSESSMENT SURVEY

Nine vulnerabilities and 45 threats were selected following detailed consultations between the experts from University of North Carolina Wilmington and Auburn University at Montgomery. See eco-risk tree diagram in Table 1. These ecological and environmental vulnerabilities and threats can, of course, be modified to fit particular geographical situations (regional to global scale), temporal scales (past, present or future) to allow hind cast capabilities for method validation, diagnostic or predictive scenario evaluations, or for different economic sectors (agricultural, transportation, maritime trade, etc.). Threats and vulnerabilities were chosen on the basis of comprehensiveness and issue specificity. Contributing expertise can be similarly tailored to particular scenarios.

Questions are designed to elicit the user's response regarding the perceived risk from particular threats (chemical, physical, or biological *stressors*) that can induce adverse effects that exploit vulnerabilities of ecological components. That is, oceanic, climate change and natural resources, and the CMs the users may employ to counteract those threats. For example, regarding the second vulnerability in Table 1, *Climate Change*; questions regarding greenhouse gases include both threat and CM questions. A sample of threat questions would include: Is deforestation ongoing? Are there a large number of fossil fuel-powered vehicles in your area? Are there coal-power generation plants close by? Are there agricultural and livestock facilities in your area? Does your area have industrial facilities that include or require cement production? Is your country unable to adhere to international agreements on reducing greenhouse gas emission? CM questions would include: Does your area limit deforestation or have a program to replant trees and ground cover? Does your state have an emission testing program to ensure that vehicles meet a minimum standard? Are coal-power generation plants equipped to minimize greenhouse gas emissions? Are measures taken to process or recycle agricultural and livestock waste? Are industrial and cement production facilities in your area equipped to minimize greenhouse gas emissions? Essentially, the users respond “yes” or “no” to these questions. Those responses are then used to calculate RR. Using game theory and statistically driven probabilistic methodologies, the calculated risk index is used to generate an optimization or lowering of risk to desired levels (Neumann and Morgenstern, 1944, 1946 and 1967; Sahinoglu *et al.*, 2012a, 2012b; Shubik, 1975). Further, mitigation advice will be generated to show the user in what areas the risk can be reduced to desired optimized levels.

5. AN ECO-RISK CASE STUDY – FIELD APPLICATIONS AND OUTCOMES

We used a volunteer group of 15 survey takers (not a scientifically designed random sample) who exercised the Eco-RoM guided by the ecological risk tree diagram in Table 1, at different times and in varying geographical regions. The 15 survey takers (Subjects A–O) and their geographical locations are listed in Table 2. A screenshot of the results for the median survey taker among the participants displaying vulnerability, threat, CM, RR indices, optimization options, as well as mitigation advice is displayed in Table 3.

The risk scores produced the following summary statistics in terms of probabilities: average (mean): 0.56, standard deviation: 0.18, range (max–min): 0.47, variance = 0.0324, median (50th percentile): 0.53, first quartile: 0.39 and third quartile: 0.79. As there is no perfectly fitting representative or an artificially constructed person among these 15 subjects, we used the median, #8 ranked risk value, as the most representative respondent to demonstrate how the RoM program performs game-theoretic optimizations for the risk management stage (Sahinoglu *et al.*, 2012a, 2012b). Table 2 displays the results after an optimization, on the basis of this risk value, is performed on this respondent's results. One million dollars, including externalities (shadow costs), is selected as a default value for the entire loss of assets because of ecological damages from vulnerabilities and threats listed in Table 1 with their related CMs studied in this single iteration of the RoM software. The initial risk realized by this respondent representing the 15 survey takers was 0.5325% or 53.25%. However, after $132,565 (the cost of CMs) was allocated to mitigate the threats they perceive, the risk is reduced to 0.4 or 40%. To reduce the risk from an undesirable 53.25% to a more

Table 2. Ecological Risk-o-Meter survey outcomes

Subject	Location	Eco-risk estimate (%)	Comments
A	UNCW, Wilmington, NC	0.3424 or 34.24	Minimum
B	AUM, Montgomery, AL	0.3581 or 35.81	
C	AUM, Montgomery, AL	0.3812 or 38.12	
D	UNCW, Wilmington, NC	0.389 or 38.90	First quartile
E	UNCW, Wilmington, NC	0.3929 or 39.29	
F	UNCW, Wilmington, NC	0.4059 or 40.59	
G	AUM, Montgomery, AL	0.5171 or 51.17	
H	AUM, Montgomery, AL	0.5325 or 53.25	Median or second quartile
I	UNCW, Wilmington, NC	0.5575 or 55.75	
J	AUM, Montgomery, AL	0.6308 or 63.08	
K	UNCW, Wilmington, NC	0.7418 or 74.18	
L	UNCW, Wilmington, NC	0.7608 or 76.05	Third quartile
M	UNCW, Wilmington, NC	0.7825 or 78.25	
N	UNCW, Wilmington, NC	0.7919 or 79.19	
O	UNCW, Wilmington, NC	0.8260 or 82.60	Maximum

UNCW, University of North Carolina Wilmington; AUM, Auburn University at Montgomery.

Table 3. Assessment and management results of the Risk-O-Meter for the median (53.25%)

Results Table

Vulnerab.	Threat	CM & LCM	Res. Risk	CM & LCM	Res Risk	Change	Opt Cost	Unit Cost	Final Cost	Advice
0.173651	0.468627	0.500000		0.500000						
		0.500000	0.040689	0.500000	0.040689					
	0.531373	0.483333		0.483333						
		0.516667	0.047675	0.516667	0.047675					
0.195390	0.518939	0.291667		0.999040		0.707373	$69,425.54	$69,000.00	$69,000.00	Increase the CM capacity for threat "Greenhouse Gases" for the vulnerability of
		0.708333	0.071822	0.000960	0.000097					"Climate Change" from 29.17% to 99.90% for an improvement of 70.74%.
	0.481061	0.400000		0.543326		0.143326	$14,066.81	$14,000.00	$14,000.00	Increase the CM capacity for threat "Non Use of Renewable Energy Sources" for the vulnera...
		0.600000	0.056397	0.456674	0.042925					"Climate Change" from 40.00% to 54.33% for an improvement of 14.33%.
0.226820	0.293785	0.500000		0.500000						
		0.500000	0.033318	0.500000	0.033318					
	0.417676	0.500000		1.000000		0.500000	$49,072.77	$48,000.00	$48,000.00	Increase the CM capacity for threat "Oil Spills" for the vulnerability of
		0.500000	0.047369	0.000000	0.000000					"Oceanic" from 50.00% to 100.00% for an improvement of 50.00%.
	0.288539	0.616667		0.616667						
		0.383333	0.025088	0.383333	0.025088					
0.125458	0.214286	0.700000		0.700000						
		0.300000	0.008065	0.300000	0.008065					
	0.464286	0.450000		0.450000						
		0.550000	0.032037	0.550000	0.032037					
	0.321429	0.350000		0.350000						
		0.650000	0.026212	0.650000	0.026212					

Criticality	1.00	Total Risk	0.532565	Total Risk	0.400000
Capital Cost	$1,000,000....	Percentage	53.256507	Percentage	39.999996
Total Threat Costs	N/A	Final Risk	0.532565	Final Risk	0.400000
		ECL	$532,565.07	ECL	$399,999.96
				ECL Delta	$132,565.12

Change Cost | Show where you are in Security Meter | Optimize

Change Unit Cost | Calculate Final Cost | Print Summary | Print Results Table | View Threat Advice | Print Single Threat/CM Selection | Print Advice Threat/CM Selections | Print All Threat/CM Selections | Update Survey Questions

tolerable 40%, we need to perform three CM actions as displayed in Table 3: (i) increase the CM expenditure or eco-relief capacity for the vulnerability or ecological component of "climate change" because of its related threat or stressor "greenhouse gases" from the current 29.17% to 99.9% for an improvement of 70.73%; (ii) increase the CM capacity for the vulnerability or ecological component of "climate change" because of its related threat or eco-stressor, "non-use of renewable energy sources" from the current 40% to 54.33% for an improvement of 14.33%; and (iii) increase the CM capacity for the vulnerability or ecological component of "oceanic" and its related threat or eco-stressor "oil spills" from the current 50% to 100%.

These measures collectively yield a CM improvement value of 135%. This represents a cost-optimal minimum of all possible percentage increases to realize a planned mitigation of eco-risk from 53.25% to 40%. In taking actions as in Table 3, a total amount ≤$132,565 to allocate to (i) greenhouse gases; (ii) non-use of renewable energy sources; and (iii) oil spills, is invested within the constraints of optimal costs annotated to generate the breakeven cost. That is, "Investment" ÷ "Sum of % CM changes" = $132,565 ÷ 135% = $982 is to be invested per 1% improvement in the $1 million default situation, which is only an assumption. The investors should not spend more than $982 per 1% improvement investment to reach the purported goal. The next step may continue with an optimization study to a next desirable percentage once services or acquisitions are provided as feedback, such as to reduce the risk down to 30% from the earlier target of 40%, provided the budget can be met.

6. CONCLUSIONS AND DISCUSSION

Partly inspired by Hurricane Ivan (2004) and Hurricane Katrina (2005) and the catastrophic Deepwater Horizon (2010) incidents that adversely affected Southern and Eastern USA's environment, economy, and tranquility, the Eco-RoM, unique among ecological software tools, possesses both *risk assessment* and *risk management* functionalities as well as remedial *cost optimization* functionality. Powered by a game-theoretical and statistically driven methodology, it is an expert system designed to quantify and assess risk as well as providing an objective set of CMs within a prescribed budget. Additionally, the Eco-RoM offers objective, unbiased and impartial mitigation guidance in real dollar terms. No other tool, public or private, of which we are aware, offers such functionality in one package. Kowalenko (2012) writes, "Too much data coming from too many sources that use too many computer systems can be downright confusing". Notable advantages of the proposed Eco-RoM software tool studied are as follows:

1. Currently existing Eco-Risk *Assessor* and *Manager (Planning)* schemes are conventionally all-in the same tool, not separated, and fail to deliver cost optimization. However, in the proposed Eco-RoM hybrid tool, the interactive assessment and management stages are synergized and linked by a computationally intensive and game-theoretic optimization approach.

2. Diagnostic data questions are subject to improvement by experts over time and as pertinent experiences are incorporated, and consequently therefore, data do not pose an impediment for the software to be efficient and effective.
3. Objectivity and impartiality of the proposed tool (Eco-RoM) are essential and systemic, allowing meaningful and useful comparisons of CM options. Further, the new remedial policy rules are outlined and suggested by the proposed tool in terms of cost factors and what to spend where by utilizing game-theoretic computing.
4. The proposed Eco-RoM automated software tool can be classified as a detailed and predictive ERA, dealing with complex interactions among ecological components (vulnerabilities) and stressors (threats) by avoiding open-ended information gathering using authentic field data using Table 1. Eco-RoM also may facilitate cost auditing procedures due to its scientific "hands-off" objectivity.

This informatics-based research focuses on ecological and environmental vulnerabilities and threats that exploit various vulnerabilities, and preventive CMs that can ameliorate the risk level to our ecosystems from local to global scales. Additionally, the Eco-RoM software tool, an expert system innovated and designed by the corresponding author, will identify optimal mitigation of the assessed undesirable risks by suggesting CMs within a prescribed budget. This is facilitated by asking the diagnostic questions if the numerical risk input data are not already available. Optimally cost-effective policy-making and providing correct physical and cognitive CMs to assess and mitigate eco-risk are the major objectives of this study, guiding environmental agencies, political decision makers, and think-tanks to safer ecosystems in times of tight budgets.

7. FURTHER RESEARCH

The authors plan to reach wider audiences of expertise to collect more aggregate data on ecological vulnerabilities, threats and CMs. Therefore, the draft lists of vulnerabilities, threats and related CM questions presented here are only practice examples and placeholders subject to modification and improvement through an extensive dialog with ecological experts. With fuller development, the proposed Eco-RoM as an automated software can be utilized by the EPA and other State or Federal agencies, not only to assess risk with aggregate metrics but also to provide accurate and exhaustive lists of vulnerabilities and threats. Eco-RoM also outlines a remediation plan through a guided list of cost-effective CMs to leverage the unfavorable risk metric to a tolerable level by minimizing investment costs.

The proposed software also allows estimation of total costs, not just industry-specific estimates of internal costs, so that sometimes massive externalities associated with environmental hazards can be estimated and, through regulatory and market mechanisms, apportioned objectively. The same software tool is also able to incorporate the dollar cost estimates of any informed person taking the survey when one switches the tool's costing function to a more realistic "threats with costs" (assign a "damage" cost to each threat) version from that of the costing function of a "lump sum", such as a default of $1 million. Although the resulting risk estimates from each person taking the survey will still be different, overall investment costs will vary also because of the choice of differing threat values and can be scaled as needed. That said, it is expected that repeated iterations through recursive cycles of the Eco-RoM process should drive toward a consensus solution.

Opportunities to apply Eco-RoM abound. For example, according to a report from the National Resources Defense Council, titled "Ready or Not", released in April 2012, Alabama was one of the 12 states in the nation that had not taken any formal steps to address climate change and the potential impacts as Layman (2012) reports: "To date, the state has not taken concerted action to address either climate change or long-term water management issues", the report stated. "Considering the enormous challenges the state faces from climate change… Alabama should act now to reduce statewide greenhouse gas pollution and develop a plan for protecting water resources from these looming threats. Alabama has demonstrated vulnerabilities to its coastline from oil spills, hurricane damage and sea-level rise, as well as a substantial agricultural sector at risk to drought, flooding, and severe storms".

To circumvent the dire situation for the State of Alabama and as for one alternative policy, the proposed Eco-RoM can be administered to a selected group of experts from different stakeholder groups within the state to reach consensus, cost-effective mitigation and CMs, after having formulated the correct diagnostic questions for the State. The next step would be to follow precautions suggested by the software in a priority order with the associated cost figures based on correctly calculated econometric factors. As a result of which, the prioritized selection of eco-relief operations and investments could be implemented to lower risks to tolerable levels from currently undesirable figures.

North Carolina, with its extensive oceanic and estuarine shoreline, is particularly vulnerable to sea-level rise. Recent legislation (SB 819) put off efforts to adopt state policies addressing sea-level rise issues until 2016, and mandated additional "studies", as competing interests battled over whether sea-level rise is even happening. Eco-RoM offers a method to engage expert opinions from across the spectrum, incorporate disparate views on the types and degrees of risks faced by coastal communities, assess possible costs for different mitigation measures, and derive optimal approaches even as studies and debates continue. Eco-RoM can also be a useful starting tool to brainstorm for policy building and taking preventive measures by assessing risk in NC's ecosystems.

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