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# Expert and Lay Mental Models of Ecosystems: Inferences for Risk Communication

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# Expert and Lay Mental Models of Ecosystems: Inferences for Risk Communication*

Jeffrey K. Lazo, Jason Kinnell, Toby Bussa, Ann Fisher & Nathan Collamer**

## Introduction

There is relatively little systematic information about how lay people think about ecosystems and risks to them. For example, how do they describe their perceptions of ecosystems and ecosystem changes? Even less is known about the relative importance (i.e., values) laypeople place on different types of ecosystem risks.

Also, little is known about how well lay and expert assessments match. A mismatch may mean that policies advocated by one group will not be supported by the other. Effective communication about ecosystem risks can lead to more informed judgments by both.

The research reported here uses a mental modeling approach to elicit and summarize similarities and differences between expert and lay understandings of ecosystems. It is intended to be an initial step in examining perceptions of values for ecosystem risks. Results of this research suggests ways to improve ecological risk communication and implement economic valuation of risks to ecosystems.

### *Linking Ecosystem Risks, Perceptions and Values*

Few researchers have examined communication about ecosystem risks caused either by natural or anthropogenic factors.[1] Most

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ecosystem risk communication data deal with specific animal species or the loss of habitat to economic development. Understanding how people perceive ecosystems and ecosystem changes would provide useful input for linking models of ecosystem changes with models of people's perceptions and preferences.

Modeling ecosystem changes requires understanding (1) how ecosystems function and evolve, (2) how they react to forcing factors ranging from natural events (e.g., a hurricane) to human actions (e.g., development of a wetland, or a spill of hazardous materials), and (3) how socio-economic systems create and mitigate forcing factors as well as adapt to the impacts that forcing factors present to ecosystems.

Identifying and understanding the relationships between people's perceptions of ecosystems and their values for ecosystem changes builds on interdisciplinary work in the social sciences. For example, input from psychology helps in understanding how people perceive ecosystems and ecological change. Political science and economics aid in exploring the relative importance people place on different ecological risks, and whether they are willing to take actions, such as voting, spending money, or changing individual behavior to prevent undesirable (or accelerate desirable) ecological changes. Understanding people's preferences and values for ecosystem risks can provide guidance for communicating effectively about them, as well as insights about what risk mitigation policies they are likely to support.

There has been little attention to the intersection between ecosystems and economic systems.[2] The most related valuation work has focused on individual species within an ecosystem in one of four manners: (1) indicator species, (2) threatened or endangered species, (3) high-value marketable species, or (4) high profile (i.e., emotional)

Economics) from Pennsylvania State University.

1 *See* Alyce M. Ujihara, et al., Perception and Communication of Ecological Risks (1991) (unpublished report from *Washington D.C.: Resources for the Future, Center for Risk Management*); *see also* Michael J. Dover & Dominic Golding, *Communicating with the Public on Ecological Issues: Workshop Report,* U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation (1995).

2 The work of the International Society for Ecological Economics (ISEE) and the related publication, *Ecological Economics,* attempts to bring these two fields together. *See* Robert Costanza et al., *The Value of the World's Ecosystem Services and Natural Capital,* 387 Nature 253 (1997), for an interesting approach to placing values on all the Earth's ecosystem services.

species.[3] Very little work has been targeted toward perceptions of "ecosystems" as distinct from ecosystem components. A series of articles by McDaniels et al. are the primary source of published work on layperson and expert perceptions. The authors have subjects evaluate hazard items on each of several psychometric scales for ecosystem impacts concepts such as natural disaster incidence, biodiversity, habitat, or recreation.[4] This method leads to a rating system and quantitative analysis using multivariate statistical methods. McDaniels et al. also report on perceptions of ecological risks from global change, including climate change, ozone depletion, and species loss.[5] They further examine perceptions of ecological risks to water resources.[6]

In research reported here, we begin by eliciting both expert and lay perceptions (or mental models) of ecosystems. Identifying and comparing the models are essential for (1) communicating with individuals about how different forcing factors might affect ecosystems, (2) helping experts understand why ordinary citizens are alarmed (or not alarmed) about specific ecosystem risks, and (3) developing methods for eliciting lay individuals' values of these impacts.[7] Without this knowledge, risk communication strategies and valuation methods may be misguided and less effective.

## Mental Modeling

There is no unified method for preparing, analyzing, and presenting mental models. Bostrom et al. propose a four step process for using mental models to identify differences between experts and laypeople: "(a) create an expert influence diagram, (b) elicit laypeople's relevant beliefs, (c) map those beliefs onto the diagram, and (d) identify gaps

3 *See* Dover & Golding, *supra* note 1, p. 6. Bryan Norton has noted that many people's values for ecosystem risks may be "under the rocks" in the sense that they are largely unconscious rather than clearly understood.

4 *See* Timothy McDaniels et al., *Characterizing Perception of Ecological Risk,* 15 Risk Anal. 575 (1995).

5 *See* Timothy McDaniels et al., *Perceived Ecological Risks of Global Change,* 6 Global Environmental Change 159 (1996).

6 *See* Timothy McDaniels et al., *Perception of Ecological Risks to Water Environments,* 17 Risk Anal. 341 (1997).

7 *See* Philip Nicholas Johnson-Laird, Mental Models: Towards a Cognitive Science of Language, Inference, and Consciousness (1983); *see also* Helmut Jungermann et al., *Mental Models in Risk Assessment: Informing People About Drugs,* 8 Risk Anal. 147 (1988).

and misconceptions."[8] A mental model may emphasize understanding interrelationships, an expert influence diagram goes beyond understanding to show the risk control decision points. Carley refers to the models as maps and presents statistical as well as graphical representations of mental models.[9] Others refer to the development and presentation of mental models as concept maps.[10] The variation in terminology suggests flexibility for representing, analyzing, and comparing mental models.

The elicitation task for creating an expert mental model depends primarily on complexity and scientific consensus. Concepts with a strong scientific consensus require less effort to elicit than concepts which experts disagree on, and perhaps should even be approached differently. This contrast can be seen in the work of Bostrom et al. and Morgan.[11] For example, Bostrom et al. found that multiple experts concurred with their expert influence diagram (mental model) of "Risk of Radon in a House with a Crawlspace" constructed by a single physicist. However, greater complexity and less scientific consensus led Morgan to plan an intensive survey of a "small number of leading ecologists" for constructing a model of how global climate change will affect ecosystems.[12]

The purpose of the work can help in choosing among elicitation methods. Kempton used ethnographic interviews to study lay perceptions of climate change.[13] Carley employs a more structured verbal protocol approach for eliciting a mental model, losing freedom in exchange for standardizing her data.[14] Bostrom et al. explore native

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8 Ann Bostrom, et al., *Characterizing Mental Models of Hazardous Processes: A Methodology and an Application to Radon,* 48 J. Soc. Issues 89 (1992).

9 *See* Kathleen Carley, *Extracting, Representing, and Analyzing Mental Models,* 70 Social Forces 601 (1992).

10 *See* Allen Brent Griffith, A Contingent Valuation Analysis of the Value of Tropical Rain Forest Protection by Pennsylvania Citizens (1991) (Masters' Thesis); Joseph D. Novak & Bob Gowin, Learning How to Learn (1984).

11 Bostrom et al., *supra* note 8; Morgan Granger, Carnegie Mellon University, personal communication.

12 *Id.*

13 *See* Willet Kempton, *Lay Perspectives on Global Climate Change,* 1 Global Envtl. Change 183 (1991).

14 Carley, *supra* note 9. The verbal protocol method is described in K. Anders Ericsson & Herbert A. Simon, Protocol Analysis: Verbal Reports as Data (1984); *see also* Gordon B. Willis et al., *The Use of Verbal Protocols in the Development and*

concepts through one-on-one interviews and then uses the results to develop a protocol that begins with open-ended questions and ends with more directed ones.[15] Extending the work of Bostrom et al., Read et al. developed a written survey, generating a larger standardized data set.[16]

After elicitation, results for each individual can then be represented as a mental model. These mental models can be compared, integrating shared meanings into a general model.[17] The lay mental model can be compared to the expert influence diagram to reveal "correct, incorrect, peripheral, background evaluative, and nonspecific" concepts.[18] This information can provide a basis for developing risk communications. Bostrom et al. compared mental models by coding transcriptions of lay open-ended interviews on radon risks into an expert influence diagram. Bostram et al. identified (1) misconceptions, (2) peripheral beliefs (i.e. correct but not particularly relevant), (3) indiscriminate beliefs (i.e. correct but imprecise), (4) background beliefs, and (5) valuations.[19]

The concept map approach develops a schematic representation of a set of concept meanings embedded in a framework of propositions. The propositions are simple statements describing the relationship between concepts.[20] The concept map is an attempt to clearly and concisely present an individual's perceptions regarding the relationships between key ideas for a specific topic. The concept map taps the individual's cognitive structure and visually presents what the person knows. Externalized expression of propositions makes concept maps effective for showing understanding as well as misconceptions.[21]

Concept maps can be used to identify misconceptions when non-expert concepts involve a linkage between two concepts that lead to a

*Testing of Survey Questionnaires,* 5 Applied Cognitive Psych. 251 (1991).

15 *See* Bostrom et al., *supra* note 8; *See also* Ann Bostrom, et al., *What Do People Know About Climate Change? 1. Mental Models,* 14 Risk Anal. 959 (1994).

16 *See* Daniel Read et al., *What Do People Know About Climate Change? 2. Survey Studies of Educated Laypeople,* 14 Risk Anal. 970 (1994).

17 *See* Carley, *supra* note 9.

18 Baruch Fischhoff et al., *Risk Perception and Communication*, 14 Ann. Rev. of Pub. Health 195 (1993).

19 *See* Bostrom et al., *supra* note 8.

20 *See* Novak & Gowin, *supra* note 10.

21 *See* Novak & Gowin, *supra* note 10 at 20.

false relationship or proposition, or a gap that misses key relationships between two or more concepts. Concept maps can be used to determine specific ways for organizing and presenting information, addressing misconceptions, and separating trivial from important information.

Concept maps are hierarchical, with more general, inclusive topics at the top. Moving down the map, the concepts and relationships progressively become more specific and less inclusive. Arrowed lines can show both the linking of concepts and the direction of the relationship. Specific examples can be provided at the bottom. The complexity of the map can be measured by the overall level of detail, depth, and breadth of the map. Depth refers to the vertical strings of propositions, and breadth refers to the number of propositions provided horizontally. Based on these criteria, different maps can be ranked and compared.

Because they are flexible in construction and application, knowledge elicitation techniques that enable representation of mental models as concept maps can be customized to specific research needs. Mental models and concept map analysis are efficient and effective communication materials that can educate the public on important issues with the goal of improving decision making and policy processes.

## Expert Mental Models of Ecosystems

We did not rely on a single expert to develop an influence diagram because at this stage we were more interested in determining the degree of expert consensus than in identifying risk control points. "Ecosystem" is a very broad concept. Consequently, there are a multitude of pathways that allow various factors to impact ecosystems. This suggests that understanding risks requires a broad conceptual map of ecosystems. Our early investigation showed a lack of consensus among experts in how they discuss and conceive ecosystems. Anticipating difficulties in eliciting a consensus expert mental model, we adapted the Bostrom et al. procedure.[22]

We started with a focus group of five university professors having expertise in aquatic and wetland ecology, forestry, and watershed management.[23] Such diversity provided balance and depth to the

22 *See* Bostrom et al., *supra* note 8.

23 *See* William H. Desvousges & V. Kerry Smith, *Focus Groups and Risk*

initial mental model and a check for the subsequent results. Participants were asked to discuss what "ecosystem" means. Their various responses suggested that the term ecosystem is extremely elastic and requires context and classification.

One particularly elastic aspect is scale. The ecologists discussed the ecosystem for a worm as having a relatively small scale, while the ecosystem of a migratory duck can span North, Central, and South America. Then the group was asked to describe and diagram the components of an ecosystem. Using the diagram and their suggestions, a group mental model was developed. The experts briefly discussed important interconnections between elements in the model, specific processes by which the elements interact, and how those processes dictate the way the entire system works.

Using the terminology obtained from the focus group, a set of "concept cards" was created. Each card represented one term from the focus group mental model. In one-on-one interviews, six university ecologists were shown a concept map on meat quality as an example of a concept map.[24] Each were then asked to arrange the concept cards as they saw fit in relation to the term ecosystem. We encouraged each expert to add missing cards or remove nonessential cards. Once the cards were arranged, interconnections and relationships were drawn with lines and arrows and described in words. A concept map was drawn for each interview.

To ensure the reliability of the technique and validate the interview results, we used blank concept cards in the final one-on-one interview. The presentation was the same, but the expert was instructed to develop the concepts for each card. The results were similar to the previous sessions, indicating that the concept card method provides the desired level of information.

The individual interviews added depth and revealed more complex relationships compared with the findings of the focus group. The focus group model displayed the components that make up an ecosystem and their fundamental organization. The individual interviews revealed

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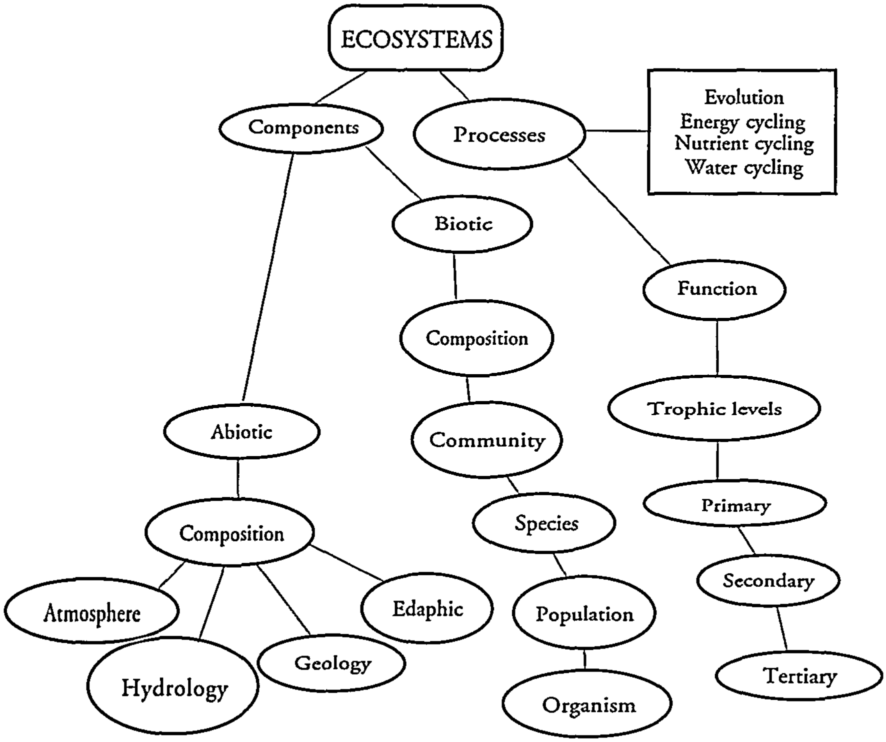
*Communication: The "Science" of Listening to the Data*, 8 Risk Anal. 479 (1988); *see also* Richard A Krueger, Focus Groups, A Practical Guide for Applied Research (2d ed. 1994).

24 *See* Novak & Gowin, *supra* note 10.

that the concept of processes (e.g., nutrient cycling, energy cycling, and evolution) needed to be included because of the relationships among elements. Furthermore, the description of an ecosystem varies depending on the specific process being considered.

Figure 1
Expert Consensus Mental Model




Experts perceive ecosystems as being made up of fundamental elements that are hierarchically organized. However, these elements interrelate infinitely. While the experts' viewpoints can be integrated so that the fundamental organization of an ecosystem is defined, "ecosystems" themselves are not easily defined. A simple elemental model is inadequate for completely describing an ecosystem, because it is of limited dimension and is static. A simple two-dimensional elemental model may capture the basic conceptual framework and be adapted to other dimensions. The result is a generalized expert "consensus" mental model of the elements of an ecosystem that provides the basis for comparing lay and experts' perceptions.

The expert consensus mental model in Figure 1 was developed by identifying shared meanings among the six mental models derived from the one-on-one interviews. This did not include the model from the focus group that may have been influenced by the interactions between experts. Any concept that was present in 50% or more of the expert models was included in the general model. The literature does not suggest a cutoff point, but the frequency of concepts tended to cluster well below or well above 50%.

Developing the expert consensus model solidified findings from the expert focus group. Although each expert has their own view, common characteristics emerged. The biotic and abiotic elements of increasing depth are common to all experts, and interconnections between the elements of the model dictate how the entire system functions.

"Processes" can take various forms such as evolution, energy, nutrient, or water cycling. Therefore, we focused on components at this stage of our research. Abiotic components are generally categorized into atmosphere, hydrosphere, and geologic components. Edaphic components (i.e., related to or determined by conditions of the soil) were separately identified in the focus group and most one-on-one interviews. These components can be combined to define other common concepts raised by experts, such as climate, microclimate, physiography and topography. These concepts relate more to descriptions of ecosystem characteristics than components. Biotic components were generally modeled by experts in terms of "highest" to "lowest" level: from community to species to population to organism.

Although this model is presented in a static, two-dimensional framework, it is truly n-dimensional and dynamic: Each ecosystem process has a unique elemental hierarchy and design. The expert consensus model simply summarizes the main concepts in a general framework for comparison with the layperson consensus mental model.

## Layperson Mental Models Of Ecosystems

### *Focus Groups and Protocol Development*

Elicitation of lay perceptions of ecosystems began with four focus groups totaling 26 subjects (groups 1 through 4 with 8, 8, 4, and 6 participants, respectively). Recruited in central Pennsylvania through an advertisement in a local newspaper, participants only knew they were to discuss "local policy issues." We had no a priori indication of whether "ecosystem" would be a term laypeople easily recognize or understand.

The discussion in the first two focus groups centered on five themes: (1) understanding of interrelationships; (2) characterizing an ecosystem; (3) balance and sustainability; (4) global climate change risks to ecosystems; and (5) environment versus ecosystem. The first two focus groups suggested the need for more effort on our part to extract what individuals think about nature, ecosystems, and ecosystem change. They also reinforced the usefulness of eliciting comparisons between the concepts of "environment" and "ecosystem."

Focus groups 3 and 4 began with each participant listing parts and characteristics of an ecosystem, and explaining how to group the parts. This process was similar to that conducted with the expert group. The lay focus groups revealed that, although "ecosystem" is not an unfamiliar term, they had difficulty defining it. They perceive ecosystems as complex, interrelated, and bounded areas that are difficult to characterize. Thought processes were elicited about what comprises an ecosystem. By having them group the parts and characteristics, we could examine concepts of complexity, interrelationships, and scale. The grouping provided a schematic of the parts and their interrelationships, an initial mental model for laypeople. These focus groups results were used to design the protocol for one-on-one interviews to elicit layperson mental models of ecosystems.

*One-on-One Layperson Interviews*

Thirty-two central Pennsylvania residents were recruited through a newspaper advertisement and random digit dialing. Respondents were paid $20; the interviews lasted between 45 minutes and two hours. The one-on-one interview protocol combined "focus interviews" (unstructured discussion of the survey topic) and "free and dimensional sorts" (respondents sort lists or similar items into groups that go together and rank the items according to specified scales).[25]

The first section of the protocol used open-ended questions to elicit individuals' concepts of the parts and groupings of ecosystem components (Figure 2). In the first nine one-on-one interviews, we

25 *See* Jared B. Jobe & David J. Mingay, *Cognitive Research Improves Questionnaire,* 79 Am. J. of Pub. Health 1053 (1989).

elicited information for developing a diagram of a consensus lay mental model of ecosystems. The balance of the interviews covered the same material but did not include individuals diagramming their mental model. We used a "parts and grouping" method similar to that for eliciting the expert mental model. We found a basic similarity among the individual groupings. Each individual included some form of at least three of the following group headings: life, earth, air, and water. We label this an Aristotelian model of an ecosystem. The layperson models range from the simple Aristotelian model to intricate models resembling the complexity of the expert mental models.

Figure 2
Layperson Parts and Grouping Protocol

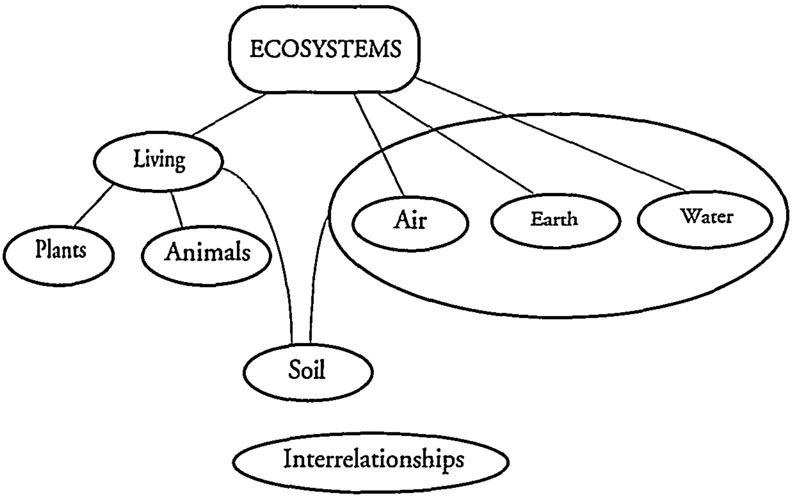
Methods

Parts
I would like for you to start by listing the parts and/or characteristics of an ecosystem.
*--Is there a difference between parts and characteristics?*
Explain the significance of each of these items.

Grouping
If you were to organize these into groups, how would you do so?
*--Why did you pick these groups?*
*--Terms can be in more than one group.*
*--There is no minimum to the number in one group.*
*--Is there anything else you need to know before establishing these groups?*

Figure 3 presents the consensus layperson mental model derived from the first nine one-on-one interviews. It relies on the same process as used in the expert mental model. Any concept present in 50% or more of the individual models was included in the consensus layperson model. Unlike the experts, laypeople seldom mentioned a dichotomy between living and non-living; perhaps it seemed too obvious to mention. Most individuals revealed breadth similar to that shown in Figure 3, but there were significant differences in the depth of their mental models.

Figure 3
Layperson Consensus Mental Model




The consensus lay mental model shows that while laypeople are unfamiliar with expert terminology for specific ecosystem concepts, they recognize the importance and significance of interrelationships. Specifically, laypeople note that disturbances to one element can disrupt the entire system.

*Content Analysis of Layperson One-on-One Interviews*

We used content analysis to examine the layperson consensus mental model. All 32 one-on-one interviews were recorded and transcribed, with the interviewers' questions and neutral prompts removed from the transcript. A ranked word frequency list was created using a document search program developed with the statistics program, SAS. The program was used to remove articles (e.g., the, that, a); prepositions (e.g., of, to, in); pronouns (e.g., I, they, we); and conjunctions (e.g., and, but, so). Plurals and singulars of the same root word were combined, as were words with common meaning (e.g. interacts, connected, linked, and interconnected were recoded to interrelationships). The top 16 words are listed in Table 1 by frequency, including the number of the respondents who mentioned each word.[26] Table 1 also lists illustrative quotes to provide context for each term.

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26 Individual counts for these 16 words for each interviewee are available from the lead author.

Table 1
Word Count Totals (32 Respondents) and Examples of Context from One-on-One Layperson Interviews

| *Word(s)* | *Frequency* | *Number Of Individuals Mentioning Term* | *Quote* |
|---|---|---|---|
| Things(s) | 215 | 28 | "Things working together. The species all working together to make an ecosystem." |
| Water | 164 | 27 | "I mean quality of both of them. I can't really think of anything else other than water and air and greenhouse what else could I mean." |
| Interrelationships | 94 | 23 | "Its interrelation between plants and animals, you know how they relate to one another; you know it's like an interwoven concept." |
| Environment | 91 | 20 | "The environment, generally, and how one phase of the environment, one aspect of the environment affects other aspects of the environment." |
| People | 86 | 22 | "I do see it as a whole system and probably people should be in there too, I mean I guess we could go along with us being fauna also, but we don't really think of us that way." |
| Animals | 83 | 21 | "It is the whole link between the plants, the animals, the food, the air, and the water that kind of addresses my concept of what an ecosystem has to be." |
| Air | 82 | 24 | "The ecosystem has to have air." |

Table 1 (continued)

| *Word(s)* | *Frequency* | *Number Of Individuals Mentioning Term* | *Quote* |
|---|---|---|---|
| Earth | 81 | 13 | "The ecosystem is probably the whole earth maybe and then you break down into different ecosystems." |
| Plants | 72 | 21 | "The exchange of plants giving off the oxygen and we give off the carbon dioxide. Isn't that what an ecosystem is all about?" |
| Life | 53 | 19 | "Everything in the system itself. The water, the air, the food, the life." |
| Everything | 51 | 19 | "Everything that comes to mind is essentially everything. It is a web. Everything is connected to everything else. Air, land, water, it affects everything else no matter where it is." |
| Fish | 50 | 14 | "An ecosystem would involve our affecting fish by what we place into the environment." |
| Humans | 46 | 11 | "I would include human beings in the ecosystem." |
| Trees | 43 | 16 | "My thoughts on an ecosystem are the fact that you have to have plants to maintain the soil. Plants are necessary." |
| Land | 38 | 9 | "Well, land, air, water systems, oceans, the whole environment." |
| Processes | 36 | 6 | "...the word "system" infers that there is a process. Plants producing oxygen & waste producing $CO_2$ so plants are sustained." |

Factor analysis was applied to the word count data to understand laypeople's shared meanings by reducing many perceptions and judgments into common explanatory factors.[27] Principal components analysis was used first to determine the number of factors to retain. Six eigenvalues greater than one indicated that six should be kept. Next, varimax rotation was used to derive their factor loadings. Table 2 summarizes the results for the sixteen most frequently used concepts

Each of the six factors was labeled according to the elements it contains. Factor 1, which we label "Biotic", explains 29% of the variation in subjects' responses. This factor includes plants and animals identified as "living" in Figure 3. It also includes the concepts "humans", "interrelationships", and "processes". Contrary to the qualitative conclusion that interrelationships are suggested to occur between all elements of the mental model, the factor analysis suggests that individuals view and describe the interrelationships as mainly occurring between and within the biotic components of an ecosystem. This does not imply that laypeople do not recognize interrelationships within the abiotic components and between all elements of an ecosystem; rather, they understand and describe the biotic interrelationships more often and more clearly.

Factor 2, "Abiotic", explains over 12% of the variance and includes air and water, which show up on the right side of Figure 3. Also included in the abiotic factor is the term "things". This suggests the difficulty laypeople have labeling specific elements of ecosystems beyond a general level. For example, one subject responded to the interviewer's question of what is and makes up an ecosystem with, "I think of it as a group, the whole thing. Then there are the separate things...". Another subject suggested that, "we have really interrupted many things in the ecosystem."

The third factor, "People", describes the importance that laypeople place upon the biotic component of ecosystems, specifically related to human beings. It is interesting to note that this concept is distinct from "humans" in the "Biotic Factor" (Factor 1). Also, the concept "life" is associated with people and not with the biotic concepts in Factor 1.

27 *See* Samuel Shye et al., Introduction to Facet Theory: Content Design and Intrinsic Data Analysis in Behavioral Research (1994); *see also* Larry Hatcher, A Step-by-Step Approach to Using the SAS System for Factor Analysis and Structural Equation Modeling (1994).

Table 2
Factor Analysis: Most Frequent 16 Words (32 Respondents)

| | Factors | | | | | |
|---|---|---|---|---|---|---|
| Words | *"Biotic"* Factor 1 | *"Abiotic"* Factor 2 | *"People"* Factor 3 | *"Soil"* Factor 4 | *"Fish"* Factor 5 | *"Trees"* Factor 6 |
| Interrelationships | 92 | | | | | |
| Processes | 87 | | | | | |
| Humans | 83 | | | | | |
| Animals | 82 | | | | | |
| Plants | 73 | | | | | |
| Air | 87 | | | | | |
| Water | | 73 | | | | |
| Things | | 54 | | | | |
| People | | | 88 | | | |
| Life | | 57 | | | | |
| Land | | | | 86 | | |
| Earth | | | | 64 | | |
| Everything | | | | | 86 | |
| Fish | | | | 50 | | |
| Trees | | | | | | 90 |
| Environment | | | | | | 51 |
| Variance explained by each factor: | 29.0% | 12.6% | 10.9% | 10.0% | 9.6% | 9.0% |

Total Variance Explained: 81.1%

Factor loadings are shown multiplied by 100. Those below 40 are omitted from the table. Labels for factors are discussed in the text.

The fourth factor, "Soil", supports the conclusion from the consensus lay mental model that individuals see the soil as a distinct component, containing direct links and interactions between the abiotic and biotic components. While the two elements of the factor are earth and land specifically, we label the factor soil because of the context in which the subjects mentioned earth and land. For instance, one individual said, "they keep depleting the soil and the earth."

Factors 5 and 6 pick up two additional biotic components, fish and trees, respectively. Fish and trees associate with the concepts "everything" and "environment", respectively, but not strongly with the other biotic components in Factors 1 and 3 (e.g., animals or plants).

The consensus lay mental model of an ecosystem (Figure 3) suggests a division between two distinct groups of factors similar to the expert mental model: the biotic, Factors 1, 3, 5, and 6, and the abiotic, Factors 2 and 4. To explore a possible dichotomy, we forced the 16 word matrix to fit into only two factors to see if these would fit nicely into "biotic" and "abiotic" factors (see Table 3).

Table 3
Constrained "Two Factor" Analysis of Primary Word List (32 Respondents)

| | Factor 1 | Factor 2 |
|---|---|---|
| Interrelationships | 92 (1) | |
| Processes | 89 (1) | |
| Humans | 85 (1) | |
| Animals | 76 (1) | |
| Plants | 73 (1) | |
| Earth | 69 (4) | |
| Environment | 54 (6) | |
| Life | 49 (3) | |
| Land | 26 (4) | |
| People | | 80 (3) |
| Water | | 64 (2) |
| Fish | | 63 (5) |
| Everything | | 56 (5) |
| Things | | 49 (2) |
| Trees | | 42 (6) |
| Air | | 12 (2) |
| Variance explained by each factor | 30.2% | 15.1% |

Factor loadings are shown multiplied by 100. The numbers in parentheses indicate which factor the word loaded on in the unconstrained factor analysis (see Table 2).

The results suggest that individuals may not simply dichotomize the world into living and non-living. Factors 1 and 4 from the unconstrained factor analysis grouped into one factor and Factors 2 and 5 into another. Factors 3 and 6 from the unconstrained analysis split into the two factors in the constrained analysis. One interpretation would be that individuals have a richer set of concepts of the structures and relationships within ecosystems than the simple dichotomous "biotic" and "abiotic". The total variance explained in the constrained factor analysis (45.3%) suggests that the six factors of the unconstrained factor analysis, as shown in Table 2 (81.1% variance explained), better describe the structure of individuals' mental models.

The results of the factor analysis lend quantitative support to the qualitative development of the consensus lay mental model shown in Figure 3. Furthermore, combining the results of the factor analysis with quotes from the individual interviews offers suggestions for how and why individual components and elements emerged in the order and organization of the consensus lay mental model.

## Conclusions

Previous literature implied that developing an expert mental model would be straightforward and the depth and breadth of expert knowledge would produce a detailed representation of ecosystems. The complexity of ecosystems makes mental modeling more difficult than anticipated. Despite diversity among ecologists' views, individual expert models reveal a consistent level of breadth and depth and a consistent set of component elements. Our consensus expert mental model captures this in a static or hierarchical perspective, but can be expanded to a dynamic, multidimensional perspective when viewed from different ecosystem processes. These common themes are expressed as the consensus mental model of Figure 1. It may be crucial to include processes more explicitly in the mental model representation.

In general, laypeople are unsure what ecosystems are. Even so, they reveal a notion of natural systems and processes that may be called their ecosystem mental model. Generally, laypeople revealed similar breadth in their mental models, but the depth of elements and complexity of interrelationships varied significantly among individuals.[28] Interrelationships represent an important common idea between expert and layperson models. Experts can explain the interrelationships (e.g., which elements are interrelated, how they are interrelated, and why they are interrelated). In general, laypeople can only express that there

28 *See* Peter Reimann & Michelene T. H. Chi, *Human Expertise,* Human and Machine Problem Solving (K. J. Gilhooly, ed. 1989). At 173, comparing novice and expert understanding of concepts in physics, they state that "experts have developed several layers of this hierarchy, whereas only the first level of the hierarchy seems to be developed for the very beginning novices. As skill is developed, the hierarchy develops into a complete tree with many levels of embedding."

are interrelationships. This research suggests that many individuals have difficulty explaining the basic elements of ecosystems and interactions among the elements. Furthermore, elements and interactions that laypeople perceive as minuscule and less valuable may be of the utmost importance and value from the expert perspective.

The protocol developed to elicit individuals' mental models focused on components of ecosystems using a "parts and grouping" approach because of the difficulty individuals had in expressing an understanding of ecosystem processes. As revealed in the individual interviews, laypeople are aware that ecosystems involve significant interactions. Risks to "components", such as threats to individual endangered species, may be relatively easy to communicate. However, communication about several types of ecosystem risks needs to focus on inherent interdependencies and processes. Risks involving complex processes, such as sub-lethal impacts of hazardous chemicals or changes in stream temperature due to logging that affect aquatic biota, likely require more in-depth efforts to communicate the nature of the risks.

Regarding risk communication issues, Paul Slovic found that people (1) often have inaccurate risk perceptions, (2) are frightened or frustrated by risk information, (3) have strong beliefs that are resistant to modification and (4) are open to manipulation when they lack strong prior opinions. Based on the limited sample examined here, we expect that, with respect to ecosystem risks, (1) lack of prior knowledge will make people more apt to have inaccurate risk perceptions of ecosystem processes than ecosystem components, (2) communications about ecosystem risks are likely to frustrate and/or frighten laypeople because of the complexity and magnitude of ecosystem risks and laypeople's perception of a fundamental reliance on ecosystems, (3) people do not have strong beliefs about ecosystems and are open to information regarding ecosystem risks, and (4) because of the lack of prior knowledge regarding ecosystem processes, laypeople are susceptible to manipulation in communication about ecosystem risks.[29]

Similar to the results of other mental models research, we found that lay mental models are less specific and more general than the expert mental model.[30] In contrast to mental modeling of radon

[29] *See* Paul Slovic, *Informing and Educating the Public About Risk,* 6 Risk Anal. 403 (1986).

exposure, laypeople did not reveal specific misperceptions (in the sense of counterfactual information) that conflict with the expert mental model of ecosystems. At the same time, the less detailed breadth and depth shows gaps in the lay mental model, and a focus that maybe inappropriate for some ecosystem risks. Generally, individuals recognize that their knowledge of ecosystem processes is limited. Combined with a deep concern for ecosystem risks, laypeople were very receptive to information about ecosystem impacts. This suggests that risk communication efforts may be productive in informing them about ecosystem risks if carefully, e.g., non-manipulatively, designed.[31] The results from this study provide a starting point for designing such communications. More generally, the results suggest the potential for the mental modeling approach to assist in designing effective risk communication by identifying commonalities and differences between lay and expert mental models of ecosystems and ecosystem risk.

30 *See* Jean Bédard & Michelene T. H. Chi, *Expertise,* 1 Current Directions in Psych. Sci. 135, 136 (1992) ("expert's knowledge is extensively cross-referenced, with a rich network among concepts. Novices have fewer and weaker links among concepts.")

31 *See* Milton Russell, *Risk Communication: On the Road to Maturity,* Evaluation and Effective Risk Communications Workshop Proceedings, U.S. Environmental Protection Agency (Ann Fisher et al., eds. 1991) (a discussion of circumstances under which some forms of manipulative risk communication might be socially acceptable).