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Aggregate, Disaggregate, and Hybrid Analyses of Ecological Risk Perceptions

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Laypeople's perceptions of health and safety risks have been widely studied, but only a few studies have addressed perceptions of ecological hazards. We assembled a list of 39 attributes of ecological hazards from the literatures on comparative risk assessment, ecological health, environmental conservation and management, environmental psychology, and risk perception. In Study 1, 125 laypeople evaluated 83 hazards on subsets of this attribute set. Factor analysis of attribute ratings (averaged over participants) revealed six oblique factors: ecological impacts, human impacts, human benefits, aesthetic impacts, scientific understanding, and controllability. These factors predicted mean judgments of overall riskiness, ecological riskiness, acceptability, and regulatory strictness. In Study 2, 30 laypeople each evaluated 34 hazards on 17 attributes and 3 dependent variables. Aggregate-level factor analysis of these data replicated the appropriate portion of the factor solution and yielded similar regression results. Parallel analyses at the individual-participant level yielded factors that explained less variance in judgments of overall riskiness, ecological riskiness, and acceptability. However, the decrease in explanatory power was much less than is often reported for disaggregate-level analyses of psychometric data. This discrepancy illustrates the importance of distinguishing between the level of analysis (aggregate versus disaggregate) and the focus of analysis (distinctions among hazards versus distinctions among participants). In a hybrid analysis, aggregate-level factor scores predicted individual participants' riskiness judgments reasonably well. Psychometric studies such as these provide a sound empirical basis for selecting attributes of ecological hazards for use in comparative risk assessment.

KEY WORDS: Ecological risk; factor analysis; level of analysis; psychometric paradigm; risk attributes; risk perception

1. INTRODUCTION

Hazards differ in many ways, and it is often fruitful to describe them in multiattribute terms (Fischhoff *et al.,* 1984). The multiattribute nature of risk is particularly important in the context of comparative risk assessment, in which a wide variety of hazards are considered and usually prioritized. In addition to a few national-level efforts (Institute of Medicine, 1998; U.S. Environmental Protection Agency (EPA), 1987, 1990, 2000; U.S. Occupational Safety and Health Administration, 1996), dozens of state and local-level comparative risk projects have been completed (Jones & Klien, 1999; Minard, 1996). Risks have often been evaluated on the basis of human health endpoints (e.g., cancer and noncancer health effects); ecological endpoints (e.g., biodiversity, endangered species, reversibility); and quality-of-life endpoints

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(e.g., aesthetics, economics, fairness), as suggested by the U.S. EPA (1993). However, the specific endpoints and metrics have varied substantially across projects, with no one set being clearly superior to the others.

In recent years, our research team at Carnegie Mellon University has developed a systematic method for conducting comparative risk exercises involving members of the general public, and has assessed this method in the context of health and safety risks to middle-school students (DeKay *et al.*, 2001; Florig *et al.*, 2001; Morgan, 1999; Morgan *et al.*, 1996, 2001). As part of the method, informational materials that describe each hazard in terms of a common set of attributes are used as the basis for group discussions about the relative riskiness of those hazards. Some of the attributes presented in these materials were chosen specifically to reflect findings from the psychometric literature (e.g., Fischhoff *et al.*, 1978; Slovic, 1987; Slovic *et al.*, 1979, 1985, 1986), as reviewed by Jenni (1997) for the purpose of risk ranking. We have now extended this risk-ranking methodology to include ecological hazards as well as health and safety hazards (Willis *et al.*, 2004). Doing so required the development of a small but comprehensive set of attributes for describing ecological hazards.

1.1. Describing Ecological Hazards

In developing this attribute set, we reviewed literature from a number of disciplines that have attempted to describe environmental hazards. In addition to the literature on comparative risk assessment (discussed above) and a few psychometric studies of ecological risk (discussed in greater detail in Section 1.2.1), we considered findings from ecological health, ecosystem conservation and management, and environmental psychology.

Biologists have argued that there are three basic components to ecosystem health: *vigor*, *organization*, and *resilience* (Costanza, 1995). Vigor refers to the level of ecosystem function, productivity, and throughput; organization describes the structure and diversity of habitats and plant and animal populations in the ecosystem; and resilience addresses the ecosystem's ability to respond to stress. The Heinz Center for Science, Economics and the Environment (Heinz Center) and the National Research Council have recently completed notable efforts to develop indicators of large-scale ecosystem impacts. The Heinz Center's (1999) report divided indicators into three subsets. *System dimensions* define the extent of impacts and changes in landscape patterns or management. *Ecosystem condition* describes the state and changes in physical, chemical, and biological systems that characterize the ecosystem (biological components became a separate category in the Heinz Center's 2002 report). Finally, *human uses* incorporate impacts on food and fiber productivity, recreational use, and other land-use activities. The National Research Council (2000) defined ecological condition in terms of the *extent* and *status* of the ecosystems in the United States, their *ecological capital*, and their *ecological functioning*, and recommended several indicators for each component of ecological condition. This body of literature identifies several concepts relevant to impacts on the physical and living systems that make up the environment.

Ecosystem conservation and management are concerned with more than the relatively tangible indicators identified by the Heinz Center and the National Research Council. Conservation and management are also driven by the perceived value of ecosystems. An ecosystem's value is related to the provision of goods and services to humans, but it also reflects less tangible characteristics including the educational, scientific, and cultural values of lands (Spellerberg, 1992).

Finally, studies of environmental psychology describe how people perceive and react to their physical surroundings, with particular attention to interactions between the environment and people's physical senses. For example, visual perception is influenced by variations in the richness and coherence of viewscapes (Kaplan & Kaplan, 1982). Physical characteristics of the environment also affect how people perceive the environment's useful properties (i.e., affordances) and how they react to the uses that different environments afford (e.g., shelter or food; Gibson, 1979). This research suggests including attributes related to impacts on the aesthetic qualities of the environment.

Although these literatures provide a comprehensive set of issues that should be considered when describing ecological hazards, the resulting list of indicators and attributes is too lengthy for use in our risk-ranking exercises. Psychometric studies of risk perception have used data-reduction techniques such as factor analysis to trim the number of attributes to a more manageable number, and this approach seemed suited to our needs.

1.2. Psychometric Studies of Risk Perception

Fischhoff *et al*. (1978) developed the psychometric paradigm to identify characteristics of hazards that affect laypeople's judgments of riskiness. In the traditional psychometric approach, participants rate a large number of hazards on several attributes and provide judgments of hazards on a small number of dependent variables, such as their riskiness or acceptability. These data are averaged over participants to provide more stable estimates of the variables for each hazard. The resulting aggregate-level hazard × attribute judgment matrix is used as input to factor analysis (or some other multivariate procedure), so that hazards may be described in terms of a few underlying factors instead of a larger number of attributes. Finally, multiple regression is used to predict the judged riskiness of hazards (or some other variable, always averaged over participants) on the basis of the factor scores for those hazards.

Using this approach, Slovic *et al*. (1985) found that two factors (*dread risk* and *unknown risk*) explained 77–84% of the variance in ratings of 30 hazards on nine attributes by three groups of laypeople and one group of risk-assessment experts. Riskiness judgments were moderately related to the resulting factor scores of the hazards for the lay groups (R^2 values of about 50–61%, based on the reported correlations), but not for the experts ($R^2 \approx 4\%$), whose riskiness judgments were more closely correlated with the expected number of fatalities. In two additional studies with student participants and larger numbers of hazards and attributes, Slovic *et al*. (1985) reported that three factors (the original two, plus *societal and personal exposure*) accounted for 79–85% of the variance in attribute ratings. The resulting factor scores accounted for about 76–79% of the variance in riskiness judgments, based on the reported correlations. Many additional studies have yielded similar results.

A few studies have used the traditional psychometric approach to explore the structure of ecological risk perceptions. McDaniels *et al*. (1995) investigated laypeople's perceptions of general ecological hazards. Lists of attribute scales and hazards were developed using focus groups of lay and expert participants. Results indicated that five underlying factors could explain 91% of the variance in laypeople's judgments about characteristics of ecological hazards. McDaniels *et al*. (1995) labeled these factors *impact on species*, *human benefits*, *impact on humans*, *avoidability*, and *knowledge of impacts*. These factors were also useful for predicting riskiness judgments. Higher impacts on species, higher impacts on humans, lower human benefits, and greater knowledge were associated with judgments of greater risk. Avoidability was not significantly correlated with riskiness judgments. Based on the correlations reported in McDaniels *et al*.'s (1996) analyses of these data, the five factors accounted for about 96% of the variance in judgments of general risk.

These results were supported by two follow-up studies. McDaniels *et al*. (1997) focused on laypeople's perceptions of water environments, and found that four factors could explain 90% of the variance in participants' attribute ratings. Regression analyses indicated that these four factors accounted for 96% of the variance in judgments of general risk. Lazo *et al*. (2000) considered public perceptions of ecosystem risks from global climate change and identified four underlying factors that accounted for 95% of variance in attribute ratings. Interpretations of these four-factor solutions were very similar to the original five-factor solution reported by McDaniels *et al*. (1995). The primary difference was that the two factors related to impacts on species and impacts on humans in the original five-factor model combined into a single factor in the four-factor model.

1.2.1. The Aggregation Problem

From the earliest days of the psychometric paradigm, it has been noted that performing analyses on mean ratings obscures potentially interesting variation among individual participants, and that results from analyses of aggregate data may not accurately reflect the strength (or even the direction) of relationships that exist at the level of the individual participant (Gardner *et al*., 1982; Harding & Eiser, 1984; Vlek & Stallen, 1981).

Several studies have used the traditional psychometric scales or factors to predict riskiness judgments without averaging responses over participants. For example, Gardner and Gould (1989) asked people in two U.S. states to rate the number of deaths, catastrophic potential, dread, and scientific understanding associated with six human health hazards. Participants also judged the overall riskiness of each hazard. Separately for each hazard, Gardner and Gould regressed the hazard's riskiness score onto the four attributes to determine whether participants' ratings of the hazard on the attributes predicted their riskiness judgments for that hazard. R^2 values for these regressions indicated that the psychometric model explained an average of 29% of the variance in different people's riskiness judgments for a given hazard, with a low of 14% for nuclear weapons (in one state) and a high of 46% for handguns (in the other state). Sjöberg (1996) reported very similar results using nine psychometric scales to predict riskiness judgments separately for 36 different hazards: the mean adjusted R^2 was 22% and the maximum value was 43%. Marris *et al.*'s (1997) analysis of 13 different hazards (repeated in Marris *et al.*, 1998) also yielded similar results. Perceptions of nine hazard characteristics explained an average of 24% of the variance in riskiness judgments (adjusted $R^2 = 6$–41%, depending on the hazard). Harding and Eiser (1984) reported higher R^2 values (mean = 45%, range = 29–64% for 15 different health issues), but they used as many as 18 predictors, and the standard psychometric variables did not perform particularly well.

Sjöberg (2000) reported two additional studies, one on perceptions of nuclear waste and one on perceptions of a Chernobyl-type accident. He used factor analysis of a participant × attribute judgment matrix to identify four factors (the standard three, plus *unnatural and immoral risk*) that explained 66% and 61% of the variation in people's attribute ratings in the two studies, respectively. In turn, participants' scores on these factors explained 28% and 20% of the variance in their riskiness judgments for nuclear waste and a nuclear accident.

Slovic *et al.* (1986) reanalyzed their 1985 data from an individual-differences perspective and found relatively low correlations between the psychometric scales and riskiness judgments. For example, the correlation between dread and riskiness dropped from 0.68 in the traditional psychometric approach to an average of 0.19 when the correlation was computed across participants separately for each of 30 risks. On the other hand, Gardner *et al.* (1982) reported relatively high correlations between psychometric variables and riskiness judgments for nuclear power (e.g., 0.44 for dread, 0.63 for catastrophic potential, and 0.33 for unknown to science). Neither of these studies reported R^2 values for predicting riskiness on the basis of several attributes, but the value could be fairly high for Gardner *et al.*'s study. Finally, Trumbo (1996) reported moderate relationships between psychometric variables and riskiness judgments regarding a small nuclear reactor used for research, although the independent and dependent variables were switched in his analysis (the adjusted R^2 for predicting a risk-perception measure on the basis of riskiness judgments and other variables was 52%).

Table I. Differentiating the Level of Analysis and the Focus of Analysis in Studies of Risk Perception

	Focus of Analysis	
Level of Analysis	Differences Among Hazards	Differences Among Participants
Aggregate	Aggregate-level hazard-focused analysis Data averaged over participants Traditional psychometric approach	Aggregate-level participant-focused analysis Data averaged over hazards Uncommon
Disaggregate	Participant-level hazard-focused analysis Uncommon	Hazard-level participant-focused analysis Standard individual-differences approach

1.2.2. The Confound

Taken together, the studies cited in the previous section indicate that the psychometric method explains less variance when data are not averaged over participants prior to analysis. However, it is generally recognized that these studies differ from the traditional psychometric approach in two ways. They differ not only in the level of analysis (disaggregate instead of aggregate), but also in the focus of analysis (distinctions among participants instead of distinctions among hazards).

Analysis of risk judgments can be performed in two modes and at two levels (see Table I). The approach typically associated with the psychometric paradigm (which we call *hazard-focused* analysis) involves a hazard × attribute judgment matrix. In this method, aggregate-level analysis involves averaging responses over participants, whereas disaggregate-level analysis maintains a separate matrix for each participant. These analyses explain how hazards differ and how this variation can be used to explain other judgments about those hazards (e.g., judgments of their riskiness). Alternatively, *participant-focused* analysis involves a participant × attribute judgment matrix. In this method, aggregate-level analysis involves averaging responses over hazards, whereas disaggregate-level analysis maintains a separate matrix for each hazard. These analyses explain differences among individuals rather than among hazards. Traditional psychometric studies correspond to the upper left cell of Table I, whereas the individual-differences studies cited above correspond to the lower right cell of that table. It is important to be mindful of this confound between the level of aggregation and the focus of analysis when considering differences between these two sets of studies.

In our view, whether hazard-focused or participant-focused analysis is more informative depends on the goals of the study. Hazard-focused analysis is more useful when the primary goal is to differentiate among hazards, as in comparative risk assessment. Participant-focused analysis is more useful for understanding individual differences in beliefs, attitudes, and behaviors, perhaps for the purpose of tailoring risk-communication materials to different segments of the population. On the other hand, aggregate-level and disaggregate-level analyses do not map neatly onto different theoretical or policy issues. Instead, choices regarding aggregation are more usefully viewed in terms of tradeoffs between the representation of variability, practical issues of data collection and analysis, and the interpretability of results. Selecting a particular level of analysis on methodological grounds need not determine the focus of analysis as well.

Of course, it is frequently acknowledged that the traditional psychometric method and the individual-differences approach address different issues. For example, Gardner *et al.* (1982) noted that "the two paradigms ask different questions and have different strengths and weaknesses" (p. 192). However, it is apparently tempting to attribute the observed difference in explanatory power to the level of aggregation rather than the focus of the analysis. For example, Gardner and Gould (1989) argued that "although these differences may be due in part to differences in time and samples, they are most likely due to the fact that Slovic *et al.*'s (1979) correlations were based on aggregate, rather than individual-level data" (p. 230). Similarly, Sjöberg (1996) stated that "the high level of explanatory power found [with the traditional approach] is really mostly a function of aggregation" (p. 221).

A more thorough investigation of these issues requires data from the other two cells of Table I. We have been able to identify only four studies that are directly relevant. Kraus and Slovic (1988) reported both aggregate-level and disaggregate-level hazard-focused regression analyses of the same data. In their Study 1, participants provided riskiness judgments for 32 hazards that were described in terms of seven psychometric attributes. Although the individual hazards were unnamed, participants were told that all of the hazards were associated with one of six different technologies (electrical wiring, pesticides, recombinant DNA, firefighting, nuclear reactors, or railroad trains). In the traditional analysis of mean data (averaged over participants), regressing riskiness judgments onto the seven attributes yielded R^2 values of 92–96%, depending on the technology, with a median of 94%. In an analogous disaggregate-level hazard-focused analysis (the lower left cell of Table I), this regression was conducted separately for each of the 96 participants. The resulting R^2 values were 27–98%, with a median of 69%.

In addition to the analysis reported in Section 1.2.2, Marris *et al.* (1997) also computed correlations among nine attributes across 13 hazards after averaging ratings over participants (a traditional aggregate-level hazard-focused analysis) and separately for each participant (a disaggregate-level hazard-focused analysis). Although the structure of the correlation matrices was similar in the two analyses, the correlations were lower in the disaggregate-level analysis than in the aggregate-level analysis (the mean value of $|r|$ dropped from 0.51 to 0.28). Sjöberg (2002) provided a graph that illustrates these findings nicely. Similar results were obtained for correlations between riskiness judgments and the nine attributes, with the mean value of $|r|$ dropping from 0.53 to 0.28. Unfortunately, Marris *et al.* (1997) did not report the corresponding regression analyses for predicting riskiness judgments at both levels of aggregation. Langford *et al.* (1999) reanalyzed Marris *et al.*'s (1997) data using multilevel modeling to account for variation across participants and hazards simultaneously, but did not consider the relationships between attribute ratings and riskiness judgments.

Bronfman and Cifuentes (2003) computed correlations among 10 attributes across 54 hazards after averaging ratings over participants (an aggregate-level hazard-focused analysis) and separately for each participant (a disaggregate-level hazard-focused analysis). Consistent with the results of Marris *et al.* (1997), the correlations were lower in the disaggregate-level analysis than in the aggregate-level analysis (the mean value of $|r|$ dropped from 0.32 to 0.15). However, analyses involving riskiness judgments were performed only at the aggregate level.

Finally, Barnett and Breakwell (2001) reported two aggregate-level participant-focused analyses (the upper right cell of Table I), one for eight voluntary hazards and another for eight involuntary hazards. In their study, participants rated 16 different hazards on several scales, including three traditional psychometric measures (knowledge, dread, and voluntariness). Voluntariness ratings were used to confirm the authors' original division of hazards into the two groups. All of the other variables were averaged over the eight hazards in each group (not over participants). For each group of hazards, composite ratings of risk concern were regressed onto composites for knowledge, dread, three experience variables, and gender. The adjusted R^2 values for these regressions were 10% and 30% for voluntary and involuntary hazards, respectively. In each case, dread was the variable most closely related to riskiness. The rather low levels of explanatory power observed in these two aggregate-level analyses suggest that the focus of analysis may be as important as (or more important than) the level of aggregation.

Unfortunately, only four of the studies reviewed above (Bronfman & Cifuentes, 2003; Kraus & Slovic, 1988; Marris *et al.*, 1997; Slovic *et al.*, 1986) reported analyses that are relevant to more than one cell of Table I. In order to disentangle the confound between the level of analysis and the focus of analysis in risk-perception research, it would be useful for a single data set to be analyzed in all four ways.

1.2.3. An Intermediate Solution

As noted earlier, our risk-ranking method focuses on differences among hazards, so we are most interested in hazard-focused analyses. That said, we are also very interested in the different ways that individuals might use a common set of attributes when judging the relative riskiness of hazards. Knowing where such disagreements might arise would be very useful in structuring and facilitating group discussions.

Vlek and Stallen (1981) demonstrated an analysis that is very instructive in this regard. Using a multidimensional statistical technique called PRINCALS (PRINcipal Components by Alternating Least Squares), they were able to plot vectors representing individual participants' riskiness judgments in a common multidimensional space. In such a plot, the direction and length of an individual's riskiness vector indicates the strength of the relationships between that individual's riskiness judgments of the different hazards and a set of attributes or dimensions for describing those hazards that is the same for every participant. The extent of variation among individuals may be assessed by inspection or analysis of their riskiness vectors. The PRINCALS procedure has also proved useful in describing the multiple objectives of gamblers (Wagenaar *et al.*, 1984) and was described, along with other multidimensional procedures for modeling risk perceptions and judgments, by Arabie and Maschmeyer (1988).

1.3. Overview of the Current Research

The research presented in this article addresses two primary goals. Our first goal is to develop a definitive set of factors for describing ecological hazards. To this end, we report two studies designed to replicate and extend previous work on ecological risk perception by using new sets of attributes and hazards, and by allowing factors to be correlated across hazards. In Section 2, we report a traditional psychometric study of laypeople's perceptions of ecological hazards (Study 1). Like the original psychometric approach, this study is concerned with differences among hazards (as opposed to differences among participants), and analyses are conducted at the aggregate level. Our second goal is to compare results from aggregate-level and disaggregate-level analyses in a manner that is not confounded with the distinction between hazard-focused and participant-focused approaches. In Section 3, we report a second psychometric study of ecological risk perception that allows for such comparisons (Study 2). We conduct hazard-focused and participant-focused analyses at both the aggregate and disaggregate levels on data collected using an abridged version of the Study 1 survey. In addition, we report the results of a hybrid analysis similar to that used by Vlek and Stallen (1981), but based on more traditional factor-analytic procedures. In the final sections, we compare the results of these studies to those in the previous literature, discuss limitations of the current studies, and develop conclusions relevant to risk-management decision making.

2. STUDY 1: AGGREGATE-LEVEL ANALYSIS OF ENVIRONMENTAL RISK PERCEPTIONS

Study 1 was a traditional aggregate-level hazard-focused psychometric study designed to replicate and extend previous research on ecological risk perception.

2.1. Methods

2.1.1. Participants

One hundred twenty-five participants (71 laypeople from Allegheny County, Pennsylvania and

54 students and staff from Carnegie Mellon University) were recruited through newspaper and electronic bulletin board advertisements. The average age of participants was 30 (range = 18–59), 44% of the participants were male, all had at least a high school education, 30% had earned at least a college degree, and 10% had earned a graduate degree (J.D., M.B.A., M.D., M.S., or Ph.D.).

2.1.2. Materials

Studying ecological risk perception using the psychometric method requires relatively comprehensive lists of ecological attributes and hazards. Creating new sets of attributes and hazards was worthwhile because previous studies of ecological risk perception differed only slightly in the sets of hazards and attributes used.

Our review of the literatures in Sections 1.1 and 1.2 resulted in a broad set of attributes for describing the impacts of environmental hazards (see Table II). In addition to measures of perceived ecological effects (e.g., species affected, habitat affected), this list includes attributes for effects on humans (e.g., mortality, morbidity) to be consistent with previous studies and to distinguish ecological risk from overall risk. It also includes attributes related to human valuation and use of the ecosystem (e.g., visual appearance, recreational opportunities), as suggested by our literature review. Finally, Table II includes four scales for judgments of overall risk, ecological risk, acceptability of current risk levels, and strictness of current regulations, to be used as dependent variables in this study and the next.

After selecting the attributes for this study, we developed the list of hazards shown in Table III. Among other considerations, this list was constructed to include hazards that affect different targets (e.g., humans, animals, or both); hazards that affect different ecosystems (e.g., aquatic or terrestrial); and a variety of hazards that span the full ranges of the selected attributes. We also attempted to maintain consistency with respect to the causal chain of environmental degradation by selecting environmental stresses (e.g., HCFC emissions) instead of causes (e.g., air conditioning) or consequences (e.g., stratospheric ozone depletion). Finally, we excluded some attributes used in earlier studies of ecological risk perception because they seemed conceptually distant from environmental impacts or difficult to measure objectively (e.g., emotionality, ethicality of event, and media attention).

In a written survey, participants evaluated the 83 environmental hazards listed in Table III on subsets of the 39 attributes and four dependent variables listed in Table II. To make the survey task manageable for participants, we divided the 39 attributes and four dependent variables into six overlapping subsets and used these subsets in different versions of the questionnaire. Each survey version asked participants to evaluate the 83 hazards on eight scales (six or seven attributes and one or two dependent variables), for a total of 664 ratings. Scales for overall riskiness, ecological riskiness, and acceptability judgments were each listed in two versions of the survey. Participants made each rating on a seven-point scale. Finally, the questionnaires asked participants to provide demographic information including their age, sex, income, education, race, and number of children.

2.1.3. Procedures

Participants completed surveys during organized sessions at Carnegie Mellon University. We alternated distribution of the six versions as individuals arrived. Thus, approximately 20 participants rated the hazards on most scales, and approximately 40 participants provided judgments of overall riskiness, ecological riskiness, and acceptability. Participants were paid $20 or $30 and typically took between 1 and 1.5 hours to complete the surveys.

2.2. Results

2.2.1. Aggregate-Level Hazard-Focused Factor Analysis

We averaged responses over individuals to produce a matrix of mean ratings for the 83 hazards on the 43 scales (39 attribute scales and four dependent variables). We performed principal factor analysis on the matrix of mean attribute ratings, not including the four dependent variables. The prior communality estimate for each attribute was set equal to the squared multiple correlation with all other attributes, and the factor pattern was rotated using the oblique promax method. To choose the appropriate number of factors, we compared eigenvalues to the average initial communality estimate, inspected the scree plot of eigenvalues, considered the marginal variance explained by each additional factor, and considered the interpretability of the rotated factor pattern. The preferred six-factor solution explained 78% of the total variance in attribute ratings. The rotated factor pattern is shown in Table IV.

Table II. Attribute and Dependent Variable Scales Used in Studies 1 and 2

Description of Scale[a]	Wording of Survey Question	Scale Endpoints: Low (1)	Scale Endpoints: High (7)
Acceptability[b]	How acceptable is the overall risk to humans and the environment from the following activities or environmental stresses?	Not acceptable at all	Completely acceptable
Animal population effects	To what extent do the following activities or environmental stresses decrease or increase the sizes of plant and animal populations in the affected area?	Greatly decreases population sizes	Greatly increases population sizes
Catastrophic potential	To what extent do the following activities or environmental stresses have the potential for causing an environmental catastrophe?	No catastrophic potential	Very much catastrophic potential
Delay of effects	How soon after the occurrence of the following activities or environmental stresses do environmental effects begin?	Immediately	Very much later
Destructiveness	How destructive are the environmental effects of the following activities or environmental stresses?	Not destructive at all	Very destructive
Detectability	How detectable are the environmental effects of the following activities or environmental stresses?	Not detectable at all	Very detectable
Difficulty of regulation	How difficult is it for governments to regulate the following activities or environmental stresses?	Not difficult at all	Very difficult
Duration of effects	Without human intervention, how long do the environmental effects of the following activities or environmental stresses last?	Almost no time	A very long time
Ecological risk[b]	How large is the ecological risk from the following activities or environmental stresses? Please exclude all risks to human health and safety, human uses, and human aesthetic preferences.	No risk at all	Very large risk
Extinction potential	To what extent do the following activities or environmental stresses have the potential to cause the extinction of endangered plant or animal species?	No potential for extinctions	Very high potential for extinctions
Future generations	How seriously do the following activities or environmental stresses affect future generations of humans?	Not seriously at all	Very seriously
Genetic selection	To what extent do the following activities or environmental stresses affect genetic selection for characteristics of plants and animals?	No effects at all	Very large effects
Government controllability	To what extent can governments reduce occurrences or effects of the following activities or environmental stresses?	Not at all	Completely
Habitat affected	How much land and water habitat is affected by the following activities or environmental stresses?	No habitat at all	A large amount of habitat
Habitat variety	To what extent do the following activities or environmental stresses decrease or increase the variety (i.e., diversity) of land and water habitats in the affected area?	Greatly decreases habitat variety	Greatly increases habitat variety
Individual controllability	To what extent can you as an individual reduce occurrences or effects of the following activities or environmental stresses?	Not at all	Completely
Land area	How much land or water area is affected by the following activities or environmental stresses?	Not much area	A very large area
Likelihood of effects	How likely is it that the following activities or environmental stresses will lead to environmental effects?	Not likely at all	Very likely
Morbidity	How many people become ill or suffer as a direct result of the following activities or environmental stresses?	No people become ill or suffer	Many people become ill or suffer
Mortality	How many people die as a direct result of the following activities or environmental stresses?	No people die	Many people die
Natural processes and cycles	To what extent do the following activities or environmental stresses affect the balance of natural processes and cycles such as the food chain, the water cycle, and nutrient cycles?	No effects at all	Very large effects
Naturalness of appearance	To what extent do the following activities or environmental stresses affect how natural the affected area looks?	Area looks much less natural	Area looks much more natural

Newness of hazard	How old or new are the following activities or environmental stresses?	Very old	Very new
Noise	To what extent do the following activities or environmental stresses degrade or improve the level or type of noise in the environment?	Greatly degrade level or type of noise	Greatly improves level or type of noise
Other human uses	To what extent do the following activities or environmental stresses decrease or increase use of scientific, educational, and cultural resources in the affected area?	Greatly decreases these uses	Greatly increases these uses
Overall risk[b]	How large is the overall risk to humans and the environment from the following activities or environmental stresses?	No risk at all	Very large risk
Personal benefit	How much do you personally benefit from the following activities or from the technologies or actions responsible for the following environmental stresses?	Not at all	Very much
Predictability	How predictable are the magnitude and occurrence of the environmental effects of the following activities or environmental stresses?	Not predictable at all	Very predictable
Recovery	Without human intervention, how completely can the environment recover from the following activities or environmental stresses?	Not at all	Completely
Recreational opportunities	To what extent do the following activities or environmental stresses decrease or increase recreational opportunities in the affected area?	Greatly decreases recreational opportunities	Greatly increases recreational opportunities
Revenue benefits	To what extent do the following activities or environmental stresses decrease or increase revenues from natural resources (minerals, lumber, fish, etc.) in the affected area?	Greatly decreases revenues	Greatly increases revenues
Reversibility	To what extent can human actions reverse the environmental effects of the following activities or environmental stresses?	Not at all	Completely
Scientific understanding	How well are the environmental effects of the following activities or environmental stresses understood by scientists?	Not well at all	Very well
Severity	How severe is the environmental damage within the area affected by the following activities or environmental stresses?	Not severe at all	Very severe
Smell and taste	To what extent do the following activities or environmental stresses degrade or improve the smell and taste of air and water?	Greatly degrades smell and taste	Greatly improves smell and taste
Societal avoidance	How difficult would it be for society in the United States to avoid the following activities or environmental stresses?	Not difficult at all	Very difficult
Societal benefits	How much does society in the United States as a whole benefit from the following activities or from the technologies or actions responsible for the following environmental stresses?	Not at all	Very much
Spatial distribution	Do the effects of the following activities or environmental stresses occur locally (near the site of activity or the source of stress) or elsewhere?	All effects occur locally	All effects occur elsewhere
Species affected	How many plant and animal species are affected by the following activities or environmental stresses?	No species at all	Very many species
Species variety	To what extent do the following activities or environmental stresses decrease or increase the variety (i.e., diversity) of plant and animal species in the affected area?	Greatly decreases species variety	Greatly increases species variety
Strictness[b]	Are current government regulations of the following activities or environmental stresses too lenient or too strict?	Much too lenient	Much too strict
Unanticipated consequences	How likely is it that the following activities or environmental stresses will lead to unanticipated environmental effects?	Not likely at all	Very likely
Visual appearance	To what extent do the following activities or environmental stresses degrade or improve the visual appearance of the land, water, and air?	Greatly degrades visual appearance	Greatly improves visual appearance

[a]Scales in italics were used in both Studies 1 and 2.
[b]Scales used as dependent variables.

Table III. Activities and Environmental Hazards Used in Studies 1 and 2

Clear cutting of forests for timber
Selected cutting of forests for timber
Commercial fishing in the ocean
Commercial shrimping (catching shrimp) in the ocean
Fish farming (aqua-culture) in the ocean
Raising livestock (for example, cows, pigs, and chickens)
Irrigating agricultural fields with groundwater
Plowing agricultural fields
Planting genetically modified (pest-resistant or disease-resistant) crops for human food production
Spraying pesticides on fruit and vegetable crops
Spraying herbicides along roadsides for weed control
Planting nonnative plant species for residential landscaping
Watering residential and commercial lawns with city water
Acid rain on forests from burning fossil fuels
Changes in the severity and frequency of extreme weather and flooding (for example, tornadoes, heavy rain, and ice storms) associated with global warming (the "greenhouse effect")
Using freon (for example, HCFCs) and other ozone-depleting chemicals in refrigeration and air conditioning systems
Electric and magnetic fields from electricity distribution
Radon in homes, offices, and schools
Existing asbestos for pipe insulation in schools, offices, and residences
Existing lead paint from street curbs and houses
Painting bridges with paint that contains lead
Damming rivers for electric power, flood control, and recreation
Building locks, dams, and channels for river navigation
Dredging harbors and waterways
Using salt to melt ice on roads and highways
Recreational game hunting (for example, deer, bear, and wild turkey)
Recreational deep-sea and fresh-water fishing
Recreational sailing
Riding snowmobiles, all-terrain vehicles (ATVs), and motor bikes off-road
Operating ski resorts
Recreational cross-country skiing
Recreational mountain biking
Recreational hiking and camping
Recreational motor boating (including jet skis)
Operating golf courses
Illegally hunting and trapping endangered or exotic species
Driving automobiles for personal transportation
Transporting goods and materials by truck
Transporting goods and materials by train
Transporting goods and materials by airplane
Transporting and storing waste from nuclear power
Transporting hazardous materials by truck
Transporting hazardous materials by train
Transporting crude oil by pipeline
Business and personal travel on airplanes
Transporting crude oil by tanker ship
Traditional air pollution from cargo and cruise ships (for example, sulfur oxides, nitrogen oxides, carbon monoxide, and fine particles)
Traditional air pollution from electricity generation (for example, sulfur oxides, nitrogen oxides, carbon monoxide, and fine particles)
Traditional air pollution from industrial activity, not including electricity generation (for example, sulfur oxides, nitrogen oxides, carbon monoxide, and fine particles)
Toxic-metal air pollution from industrial activity
Leaking underground gasoline storage tanks
Radiation from operating nuclear power plants
Water pollution from operating industrial facilities
Discharging warm water from power plants into lakes or rivers
Discharging storm runoff from communities into rivers
Discharging treated sewage in rivers
Discharging untreated sewage in oceans
Water runoff from agricultural lands (including fertilizer, pesticides, and erosion)
Water runoff from construction sites
Abandoned industrial facilities
New residential development
New industrial development
New commercial development
Building new roads and highways
Disposing of residential and commercial garbage in landfills
Disposing of residential and commercial garbage in incinerators
Operating commercial airports
Operating petroleum refineries
Operating automobile assembly plants
Operating food processing plants
Operating primary metal manufacturing plants (for example, steel and aluminum foundries)
Straightening, deepening, and widening stream channels ("stream channelization") for flood control or to allow development in natural flood plains
Destruction of wetlands by residential, commercial, and industrial development
Dropping bombs from airplanes as part of military readiness exercises
The existing network of highways, railroads, pipelines, power lines, and telephones lines
Human population growth
Littering
Drilling for oil and natural gas
Mining metals and minerals (not including precious metals and stones)
Mining precious metals and stones
Mining coal using surface (open pit) mining techniques
Disposing of hazardous waste in specially designed landfills
Disposing of hazardous waste in incinerators

Note: Activities and hazards in italics were used in both Studies 1 and 2.

Table IV. Rotated Factor Pattern from the Aggregate-Level Hazard-Focused Analysis of 39 Attribute Scales in Study 1

Attribute	Factor 1 Ecological Impacts	Factor 2 Human Impacts	Factor 3 Human Benefits	Factor 4 Aesthetic Impacts	Factor 5 Scientific Understanding	Factor 6 Controllability
Natural processes and cycles	**101**					
Extinction potential	**98**					
Habitat affected	**94**					
Species affected	**92**					
Land area	**83**					
Genetic selection	**76**					
Likelihood of effects	**70**					
Duration of effects	**66**					
Detectability	**60**					
Destructiveness	59	45				
Spatial distribution	58					
Future generations	58	55				
Catastrophic potential	53	52				
Unanticipated consequences	53	51				
Recovery potential	−53	−40				
Recreational opportunities	−59					
Delay of effects	**−60**					
Species variety	**−63**					
Mortality		**97**				
Morbidity		**83**				
Severity	47	54				
Revenue benefits		−50	40			
Smell and taste		**−61**		45		
Reversibility		**−68**				
Societal avoidance			**87**			
Personal benefit			**85**			
Societal benefits			**80**			
Other human uses			51			
Animal population effects						
Individual controllability						
Visual appearance				**75**		
Naturalness of appearance				**67**		
Noise				**64**		
Habitat variety						
Scientific understanding					**69**	
Predictability of effects	−53				**64**	
Newness of hazard					**−78**	
Government controllability						**84**
Difficulty of regulation		42				**−73**
Interfactor correlations						
Factor 2	0.509					
Factor 3	−0.095	−0.222				
Factor 4	−0.407	−0.336	0.090			
Factor 5	0.030	−0.044	0.016	−0.193		
Factor 6	0.117	0.149	0.034	−0.064	0.533	

Note: All loadings are multiplied by 100; those ≥0.60 are in bold text; those <0.40 are omitted. For oblique rotations, loadings may exceed 1.0. They can be interpreted as standardized regression coefficients for predicting attribute values on the basis of the three factors, but not as correlations between attributes and factors.

We interpreted the factors by looking for a common concept among the attributes that loaded highly on each factor and by reviewing plots of the hazards in the factor space. As an example, Fig. 1 shows the hazards plotted in the plane defined by Factors 1 and 2.

The four attributes with the highest loadings on Factor 1 were natural processes and cycles, extinction potential, habitat affected, and species affected. All other attributes involving impacts on animals or habitat also loaded heavily on this factor. In addition,

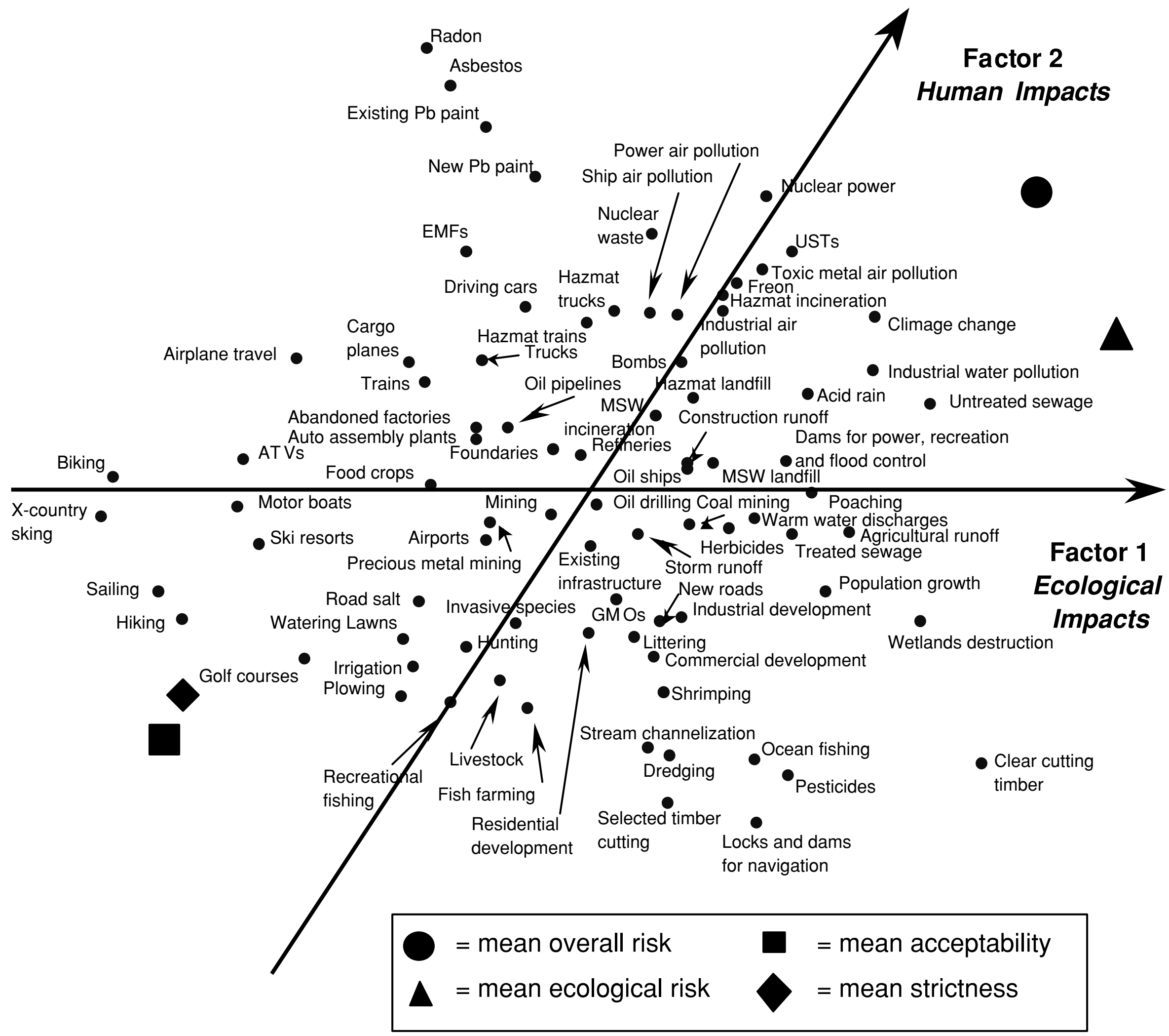

Fig. 1. Aggregate-level hazard-focused factor scores of hazards on Factor 1 (ecological impacts) and Factor 2 (human impacts) in Study 1. In this oblique factor solution, the cosine of the angle between the two factors is equal to the correlation between those factors. The perpendicular projection of a hazard's point onto one of the factors represents the hazard's score on that factor. Hazards that are perceived as having large human and ecological impacts appear in the upper right "quadrant." The endpoints of the vectors representing mean judgments of overall riskiness, ecological riskiness, acceptability, and regulatory strictness are shown as a circle, triangle, square, and diamond, respectively.

several other attributes related to a hazard's environmental effects, such as likelihood of effects, duration of effects, and detectability, loaded on this factor. We labeled this factor *ecological impacts*.

Morbidity and mortality had the highest loadings on Factor 2, so we labeled this factor *human impacts*. Many of the attributes related to the magnitude and likelihood of effects were split between Factors 1 and 2. In particular, severity, effects on future generations, catastrophic potential, and likelihood of unanticipated consequences loaded almost equally on these two factors. These loadings are consistent with the correlation between Factors 1 and 2 in the oblique factor pattern, $r = 0.509$, and with the fact that some previous studies (Lazo *et al.*, 2000; McDaniels *et al.*, 1997) have found four-factor solutions in which attributes similar to these are represented by a single factor.

The only attributes that loaded heavily on Factor 3 were personal benefits, societal benefits, and societal avoidance. We labeled Factor 3 *human benefits*. The revenue benefits attribute was split between Factors 2 and 3, but this result is consistent with our interpretation of both factors.

The four attributes with the highest loadings on Factor 4 were visual appearance, naturalness, noise, and smell and taste. Smell and taste was split between Factors 2 and 4, with a larger negative loading on Factor 2. All of these attributes are related to aesthetics, so we labeled Factor 4 *aesthetic impacts*.

The three attributes that loaded most heavily on Factor 5 were newness of hazard, scientific understanding, and predictability. This factor closely resembles those that others have called *unknown risk* (Slovic *et al*., 1985), *knowledge of impacts* (McDaniels *et al*., 1995), or *understandability* (Lazo *et al*., 2000). We called this factor *scientific understanding*.

The two attributes that loaded heavily on Factor 6, government controllability and difficulty of regulation, led us to label the factor *controllability*. Psychometric risk-perception studies have usually included attributes related to an individual's ability to control a hazard or avoid its impacts. We chose attributes related to controllability by governments rather than individuals because we believed that control or avoidance of most of the environmental hazards listed in our survey was beyond the limits of individual actions.

These six factors are similar to those reported by McDaniels *et al.* (1995, 1996, 1997) and Lazo *et al.* (2000), with the exception of the aesthetic impacts factor, which reflects attributes absent from those studies. As discussed earlier, the promax rotation produced reasonable correlations between Factors 1 and 2. The other observed interfactor correlations were also plausible (see the bottom of Table IV). Factors 1 and 4 were negatively correlated, indicating that hazards with larger ecological impacts are likely to be associated with more negative aesthetic impacts. Factor 2 had modest negative correlations with Factors 3 and 4, indicating that larger impacts on humans are often associated with lower human benefits and more negative aesthetic impacts. Finally, Factors 5 and 6 were positively correlated, suggesting that hazards that are well understood are often the most easily controlled.

Previous psychometric risk-perception studies have usually used orthogonal rotation methods. When the orthogonal varimax rotation method was used for our data, factor loadings were similar to those obtained from the oblique promax rotation and interpretation of the factors remained unchanged. Results presented in the following sections were also similar for the promax and varimax factor solutions. Because oblique rotations require fewer assumptions and because the interfactor correlations discussed above are plausible, we report results from the oblique analysis in this article.

2.2.2. Aggregate-Level Regression Analyses

More detail on the perceptions of specific hazards is provided in Table V, which lists the 10 hazards scoring highest and the 10 hazards scoring lowest on judgments of overall riskiness and ecological riskiness. In order to evaluate the usefulness of the six factors, we regressed mean ratings for the four dependent measures onto the six factor scores for the 83 hazards (see Table VI). The six factors predicted judgments of overall riskiness, ecological riskiness, acceptability, and regulatory strictness very well, $R^2 = 0.942$, 0.949, 0.938, and 0.756, respectively. Greater overall riskiness was associated with greater ecological impacts (Factor 1), greater human impacts (Factor 2), lower human benefits (Factor 3), greater understanding (Factor 5), and greater controllability (Factor 6). Aesthetic impacts (Factor 4) were not significantly associated with overall risk.

Greater ecological riskiness was associated with greater ecological impacts (Factor 1), greater human impacts (Factor 2), more negative aesthetic impacts (Factor 4), and greater controllability (Factor 6), and was marginally associated with lower understanding (Factor 5). When evaluating the ecological riskiness of hazards, participants were instructed to ignore human uses of the environment. Perhaps this is why human benefits (Factor 3) were not significantly associated with ecological riskiness.

In both of these regressions, there was a weak positive relationship between riskiness judgments and controllability (Factor 6). Though this result seems counterintuitive, previous literature provides mixed evidence regarding this relationship. Jenni (1997) found that greater individual controllability was associated with lower riskiness, whereas Morgan *et al*. (2001) found the opposite result. Slovic *et al*. (1985) reported different relationships for different participant groups. Finally, several recent studies of ecological risk perception (Lazo *et al.*, 2000; McDaniels *et al.*, 1995, 1996, 1997) have reported nonsignificant relationships between controllability and riskiness.

The observed relationships between scientific understanding and riskiness judgments were conflicting (positive in the first regression and negative in the second) and only marginally significant in the second regression. Previous studies have shown weak and inconsistent relationships between understanding and riskiness judgments. Jenni (1997) found that greater knowledge was associated with lower riskiness, but Morgan *et al*. (2001) obtained the opposite result. Slovic *et al*. (1985) reported weak positive

Table V. Ten Most Risky and Ten Least Risky Hazards in Study 1

Overall Riskiness		Ecological Riskiness	
Hazard	Mean Riskiness Judgment	Hazard	Mean Riskiness Judgment
Most risky			
Radiation from operating nuclear power plants	5.82	Water pollution from operating industrial facilities	5.74
Discharging untreated sewage in oceans	5.75	Destruction of wetlands by residential, commercial, and industrial development	5.72
Toxic-metal air pollution from industrial activity	5.70	Clear cutting of forests for timber	5.66
Water pollution from operating industrial facilities	5.65	Discharging untreated sewage in oceans	5.63
Dropping bombs from airplanes as part of military readiness exercises	5.63	Illegally hunting and trapping endangered or exotic species	5.61
Leaking underground gasoline storage tanks	5.60	Acid rain on forests from burning fossil fuels	5.58
Transporting hazardous materials by truck	5.54	Toxic-metal air pollution from industrial activity	5.51
Using freon and other ozone-depleting chemicals in refrigeration and air conditioning systems	5.51	Human population growth	5.45
Transporting and storing waste from nuclear power	5.46	Using freon and other ozone-depleting chemicals in in refrigeration and air conditioning systems	5.43
Illegally hunting and trapping endangered or exotic species	5.45	Water runoff from agricultural lands	5.41
Least risky		Raising livestock	3.30
Plowing agricultural fields	3.23	Operating ski resorts	3.28
Recreational deep-sea and fresh-water fishing	3.23	Recreational motor boating	3.24
Recreational motor boating	2.98	Plowing agricultural fields	3.08
Operating ski resorts	2.98	Operating golf courses	3.03
Fish farming in the ocean	2.95	Irrigating agricultural fields with groundwater	2.92
Operating golf courses	2.70	Recreational hiking and camping	2.58
Recreational mountain biking	2.55	Recreational sailing	2.39
Recreational hiking and camping	2.40	Recreational cross-country skiing	2.38
Recreational sailing	2.35	Recreational mountain biking	2.38
Recreational cross-country skiing	2.10		

Note: Scale ranged from 1 = *No risk at all* to 7 = *Very large risk*.

relationships between risk and knowledge in two studies, but weak negative relationships in a third study. Bronfman and Cifuentes (2003) found knowledge to be positively associated with social risk but negatively associated with personal risk. In other recent studies of ecological and health hazards, knowledge has been positively associated with riskiness and worry (Baron *et al.*, 2000; Lazo *et al.*, 2000; McDaniels *et al.*, 1995, 1996, 1997).

In the third regression, greater acceptability was associated with lower ecological and human impacts (Factors 1 and 2), greater human benefits (Factor 3), and lower understanding (Factor 5). Aesthetic impacts (Factor 4) and controllability (Factor 6) were not significantly associated with acceptability judgments.

In the fourth regression, judgments that current regulations are too strict were associated with lower ecological and human impacts (Factors 1 and

Table VI. Unstandardized Regression Coefficients for Predicting Judgments of Overall Risk, Ecological Risk, Acceptability, and Regulatory Strictness with Aggregate-Level Hazard-Focused Factor Scores in Study 1

Dependent Variable	n^a	R^2	Factor 1 Ecological Impacts	Factor 2 Human Impacts	Factor 3 Human Benefits	Factor 4 Aesthetics Impacts	Factor 5 Scientific Understanding	Factor 6 Controllability
Overall risk	83	0.942	0.38****	0.57****	−0.08**	−0.02	0.07*	0.06*
Ecological risk	83	0.949	0.56****	0.26****	0.02	−0.13****	$-0.04^{\dagger}$	0.06**
Acceptability	83	0.938	−0.50****	−0.51****	0.45****	−0.02	−0.10**	−0.05
Strictness	83	0.756	−0.23****	−0.19****	0.16****	$0.07^{\dagger}$	−0.002	−0.04

n^a is the number of observations (hazards) used in the regression analyses.
$^{\dagger}p < 0.1$. $^{*}p < 0.05$. $^{**}p < 0.01$. $^{***}p < 0.001$. $^{****}p \leq 0.0001$.

2) and greater human benefits (Factor 3), and were marginally associated with more positive aesthetic impacts (Factor 4). Scientific understanding (Factor 5) and controllability (Factor 6) were not significantly associated with strictness judgments. The signs of all significant regression coefficients in Regressions 3 and 4 (predicting acceptability and strictness) were the opposite of those in Regressions 1 and 2 (predicting overall and ecological riskiness), as might be expected.

In summary, this study used new sets of attributes and hazards to study laypeople's perceptions of environmental hazards. Results largely replicated previous findings from studies of environmental risk perceptions. Aggregate-level factor analysis identified six factors that explained attribute judgments reasonably well. Five of these factors were similar to those first reported by McDaniels *et al*. (1995) and the sixth, aesthetic impacts, reflected attributes that were first introduced in this study. Regression results for predicting judgments of riskiness, acceptability, and regulatory strictness using the six factors mostly corresponded with expectations and previous literature, although the signs for scientific understanding (Factor 5) and controllability (Factor 6) were somewhat counterintuitive.

3. STUDY 2: AGGREGATE-LEVEL AND DISAGGREGATE-LEVEL ANALYSES

In Study 1, we used the traditional psychometric method to study ecological risk perceptions. This method required averaging responses over participants. To study psychometric factors of risk perception with participant-level data, participants must evaluate each hazard on each attribute scale. For the survey used in Study 1, this would be an impractical task because of the large number of hazards and attributes. For Study 2, we developed an abridged survey to investigate ecological risk perception at the individual level.

We trimmed the original list of hazards while trying to maintain a representative set of activities and environmental stresses. The attribute scales for Study 2 were selected so that we could more closely investigate factors that are directly related to ecological risk perception but are not already addressed in the literature on health and safety risk perception. Based on the results of Study 1, we focused on attributes related to Factor 1 (ecological impacts), Factor 4 (aesthetic impacts), and Factor 5 (scientific understanding). We excluded attributes related to human impacts (Factor 2) because they are well addressed by Study 1 and by previous studies of health and safety, and because our primary goal was to study ecological risk. We excluded attributes related to human benefits (Factor 3) and controllability (Factor 6) because our related research involves methods for ranking risks and not management strategies (e.g., DeKay *et al*., 2001; Florig *et al*., 2001; Morgan *et al*., 1996).

3.1. Methods

3.1.1. Participants

The sample for this study consisted of 30 individuals who were contacted through two school-parent organizations and one church group in Allegheny County, Pennsylvania. The average age of participants was 48 (range = 28–61), 46% of the participants were male, 97% had at least a high school education, 70% had earned at least a college degree, and 43% had earned a graduate degree (J.D., M.B.A., M.D., M.S., or Ph.D.).

3.1.2. Materials

The Study 2 survey asked participants to evaluate 34 hazards on 17 attribute scales and three dependent variables, for a total of 680 judgments. The rating scales and hazards that were used are shown in italics in Tables II and III, respectively. The dependent variables were overall risk, ecological risk, and acceptability of current risk levels. Respondents made each rating on a seven-point scale. Finally, respondents provided demographic information, as in Study 1.

3.1.3. Procedures

Participants took about 1.5 hours to complete the surveys during scheduled sessions on the Carnegie Mellon campus. A donation of $30 was made to each participant's civic organization in his or her name.

3.2. Results

3.2.1. Aggregate-Level Hazard-Focused Analyses

Using methods identical to those in Study 1, we averaged responses over individuals to produce a matrix of mean ratings for the 34 hazards on the 20 scales (17 attributes and three dependent variables). We performed principal factor analysis on the matrix of mean attribute ratings (not including the dependent variables), setting the prior communality estimate for

Table VII. Rotated Factor Pattern from the Aggregate-Level Hazard-Focused Analysis of 17 Attribute Scales in Study 2

Attribute	Factor 1 Ecological Impacts	Factor 2 Aesthetic Impacts	Factor 3 Scientific Understanding
Natural processes and cycles	**107**		
Species affected	**102**		
Habitat affected	**95**		
Extinction potential	**92**		
Likelihood of effects	**91**		
Future generations	**86**		
Duration of effects	**76**		
Destructiveness	**74**		
Unanticipated consequences	**72**		−42
Species variety	**−62**		
Habitat variety	**−63**	42	
Visual appearance		**84**	
Smell and taste		**78**	
Naturalness of appearance		**67**	
Predictability of effects			**86**
Scientific understanding			**87**
Newness of hazard			**−78**
Interfactor correlations			
Factor 2	−0.580		
Factor 3	−0.206	−0.094	

Note: All loadings are multiplied by 100; those ≥0.60 are in bold text; those <0.40 are omitted. For oblique rotations, loadings may exceed 1.0. They can be interpreted as standardized regression coefficients for predicting attribute values on the basis of the three factors, but not as correlations between attributes and factors.

each attribute equal to the squared multiple correlation with all other attributes, and rotating the factor solution using the oblique promax method. The results are shown in Table VII.

As expected, this analysis yielded a three-factor solution, which explained 84% of the total variance in attribute ratings. Factor loadings were very similar to those reported for Study 1. Natural processes and cycles, species affected, habitat affected, and all other attributes related to ecological impacts loaded highly on Factor 1. As in Study 1, items related to the magnitude and probability of the hazard's impacts also loaded on Factor 1. Visual appearance, naturalness of appearance, and smell and taste loaded highly on Factor 2. Finally, predictability of effects, scientific understanding, and newness of hazard all loaded highly on Factor 3. Because of these similarities, we labeled Factors 1, 2, and 3 as *ecological impacts*, *aesthetic impacts*, and *scientific understanding*, respectively. As before, ecological impacts (Factor 1) were negatively correlated with aesthetic impacts (Factor 2 in this study), indicating that participants considered larger ecological impacts to be associated with more negative aesthetic impacts. In a minor deviation from Study 1, ecological impacts (Factor 1) were also weakly negatively correlated with scientific understanding (Factor 3 in this study), suggesting that participants believed that scientists do not fully understand hazards with larger ecological impacts.

Table VIII lists the 10 hazards scoring highest and the 10 hazards scoring lowest on judgments of overall riskiness and ecological riskiness. Regression results indicated that factors from the aggregate-level analysis of Study 2 data were related to riskiness and acceptability judgments in the same manner as in Study 1, with minor exceptions (see Section 1 of Table IX). Greater riskiness was associated with greater ecological impacts, more negative aesthetic impacts, and lower scientific understanding. Higher acceptability scores were associated with lower ecological impacts, more positive aesthetic impacts, and greater scientific understanding. These results for scientific understanding appear to contradict those of Study 1 (see Table VI). As noted earlier, previous studies have also reported inconsistent findings on the relationship between scientific understanding and riskiness judgments.

To further assess the replicability of these aggregate-level analyses, we reanalyzed the data from Study 1 using only those attributes included in the Study 2 survey. The resulting factor pattern was similar to that for Study 2, but had a somewhat more complicated structure. For example, some attributes related to the magnitude and probability of the hazard's impacts (e.g., unanticipated consequences, destructiveness) loaded on Factor 2 instead of (or in addition to) Factor 1. Although unexpected, these results are reasonable given the observed correlations between ecological impacts and aesthetic impacts (see Tables IV and VII). Regression results for the reanalysis of the Study 1 data were very similar to those reported for Study 2 in Section 1 of Table IX. R^2 values were similar for all three regressions, and all nine coefficients were significantly different from zero with the same signs. For more details, see Willis (2002).

3.2.2. *Disaggregate (Participant-Level) Hazard-Focused Analyses*

We also performed a separate principal factor analysis on each participant's hazard × attribute

Table VIII. Ten Most Risky and Ten Least Risky Hazards in Study 2

Overall Riskiness		Ecological Riskiness	
Hazard	Mean Riskiness Judgment	Hazard	Mean Riskiness Judgment
Most risky			
Changes in the severity and frequency of extreme weather and flooding associated with global warming	5.73	Destruction of wetlands by residential, commercial, and industrial development	5.83
Water pollution from operating industrial facilities	5.67	Acid rain on forests from burning fossil fuels	5.67
Acid rain on forests from burning fossil fuels	5.60	Changes in the severity and frequency of extreme weather and flooding associated with global warming	5.57
Radiation from operating nuclear power plants	5.57	Using freon and other ozone-depleting chemicals in refrigeration and air conditioning systems	5.50
Destruction of wetlands by residential, commercial, and industrial development	5.53	Clear cutting of forests for timber	5.43
Using freon and other ozone-depleting chemicals refrigeration and air conditioning systems	5.43	Discharging untreated sewage in oceans	5.37
Discharging untreated sewage in oceans	5.30	Water pollution from operating industrial facilities	5.07
Leaking underground gasoline storage tanks	5.27	Disposing of residential and commercial garbage in landfills	5.00
Spraying pesticides on fruit and vegetable crops	5.20	Human population growth	5.00
Traditional air pollution from industrial activity, not including electricity generation	5.10 5.10	Traditional air pollution from industrial activity, not including electricity generation	4.97
Least risky			
Operating commercial airports	3.90	Planting genetically modified crops for human food production	3.57
Planting genetically modified crops for human food production	3.80	Planting nonnative plant species for residential landscaping	3.50
Operating automobile assembly plants	3.63	Radon in homes, offices, and schools	3.45
Transporting goods and materials by truck	3.48	Transporting goods and materials by truck	3.21
Planting nonnative plant species for residential landscaping	3.24 3.24	Existing lead paint from street curbs and houses	3.11
Recreational motor boating	3.07	Recreational motor boating	3.00
Operating ski resorts	2.68	Recreational game hunting	2.93
Raising livestock	2.50	Raising livestock	2.90
Recreational game hunting	2.27	Operating ski resorts	2.70
Plowing agricultural fields	2.03	Plowing agricultural fields	2.50

Note: Scale ranged from 1 = *No risk at all* to 7 = *Very large risk*.

matrix (hazard-focused analysis). Each of these analyses was performed identically to the previous aggregate-level factor analysis to facilitate comparison of results. If a participant failed to evaluate hazards on all attributes, the hazards with missing data were excluded from the factor analysis. Only 12 participants (40%) provided complete surveys. Two to four of the 34 hazards were omitted from the factor analysis in most of the remaining cases. In three extreme cases, up to 13 hazards were omitted.

Factors extracted from participant-level analyses did not share common orientations (or common interpretations). Furthermore, eigenvalues for participant-level factor solutions did not always indicate three-factor solutions. Neither of these observations is surprising because the factor structures are not unique (i.e., different rotations capture the relationships among attributes equally well) and because disaggregate-level data are expected to be much noisier than aggregate-level data. To allow comparison to aggregate-level results, we constrained each participant-level analysis to three factors. These three-factor solutions explained an average of 68% of the total variance in attribute ratings across individuals (range = 55–83%). This average was lower than the 84% explained in the aggregate-level factor analysis.

Regressions of participants' riskiness and acceptability judgments onto their participant-level factor scores provide further assessments of the usefulness of the factor models. Section 2 of Table IX presents means and ranges for R^2 values from these within-participant regressions. Since the factors from the participant-level analyses did not share common interpretations, Table IX does not list regression coefficients for these analyses. The mean R^2 values for these analyses were between 16 and 27 percentage points

Table IX. Comparison of Regression Results from Hazard-Focused and Participant-Focused Analyses at Both Aggregate and Disaggregate Levels in Study 2

Analysis and Dependent Variable	n^a	R^2	Factor 1 Ecological Impacts	Factor 2 Aesthetic Impacts	Factor 3 Scientific Understanding
1. Hazard-focused analysis (aggregate level)					
Overall risk	34	0.813	0.62****	−0.29**	−0.34**
Ecological risk	34	0.933	0.75****	−0.21**	−0.13*
Acceptability	34	0.691	−0.40**	0.41**	0.32**
2. Hazard-focused analysis (disaggregate participant level)					
Overall risk	16–34	Mean = 0.621 (0.219–0.874)			
Ecological risk	16–34	Mean = 0.667 (0.301–0.884)			
Acceptability	16–34	Mean = 0.532 (0.124–0.864)			
3. Participant-focused analysis (aggregate level)					
Overall risk	30	0.659	0.51****	−0.12	−0.08
Ecological risk	30	0.521	0.45**	−0.21†	−0.29*
Acceptability	30	0.589	−0.50****	0.19†	0.21†
4. Participant-focused analysis (disaggregate hazard level)					
Overall risk	22–30	Mean = 0.479 (0.176–0.774)			
Ecological risk	22–30	Mean = 0.485 (0.136–0.775)			
Acceptability	22–30	Mean = 0.331 (0.153–0.538)			

[a]The number of observations used in the regression analyses, n, refers to hazards in Sections 1 and 2 and participants in Sections 3 and 4.
†$p < 0.1$. *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$. ****$p \leq 0.0001$.
Note: Regression coefficients are not shown for participant-level and hazard-level analyses because the factors do not share a common interpretation.

lower than those for the corresponding aggregate-level analysis. We believe that this decline in explanatory power is probably the result of greater variability in the participant-level data. In later sections, we will also compare these results to the corresponding participant-focused (as opposed to hazard-focused) analyses.

3.2.3. *A Hybrid Analysis: Using Aggregate-Level Factor Scores to Predict Individuals' Riskiness Judgments*

As expected, the explanatory power of the aggregate-level analysis was greater than that of the disaggregate-level analysis. In addition, the aggregate-level analysis yielded interpretable factors that provide insight into relationships between hazard attributes and riskiness judgments. However, these benefits came at the expense of information about variability among individuals. As a potential compromise, we performed a hybrid analysis in which we regressed each participant's ecological riskiness scores onto the factor scores from the aggregate-level analysis.

Results indicate that the aggregate-level factors explained much less variance in individual's ecological riskiness judgments (mean $R^2 = 0.458$) than in mean ecological riskiness judgments ($R^2 = 0.933$). Although the mean R^2 for the hybrid analysis was also less than that for the fully disaggregate analysis ($R^2 = 0.667$), the use of a common set of predictor variables leads to more interpretable results, as discussed below.

Mean unstandardized regression coefficients for ecological impacts, aesthetic impacts, and scientific understanding corresponded to the results of the aggregate-level analysis in Section 1 of Table IX and were all significantly different from zero, $M(b_{F1}) = 0.732$, $p = 0.0001$; $M(b_{F2}) = -0.226$, $p = 0.0024$; $M(b_{F3}) = -0.145$, $p = 0.0013$. Indeed, these mean coefficients would match the coefficients in the aggregate-level analysis exactly were it not for missing data for some participants. In the hybrid analysis, the regression coefficient for the aggregate-level ecological impacts factor was significant and positive for 22 of 30 participants. The coefficients for aesthetic impacts and scientific understanding were significant and negative for nine and six participants, respectively.

In Fig. 2, the results for ecological riskiness judgments are graphed in the manner of Vlek and Stallen (1981), Wagenaar *et al.* (1984), and Arabie and Maschmeyer (1988). For each participant, we calculated the correlations between his or her judgments of

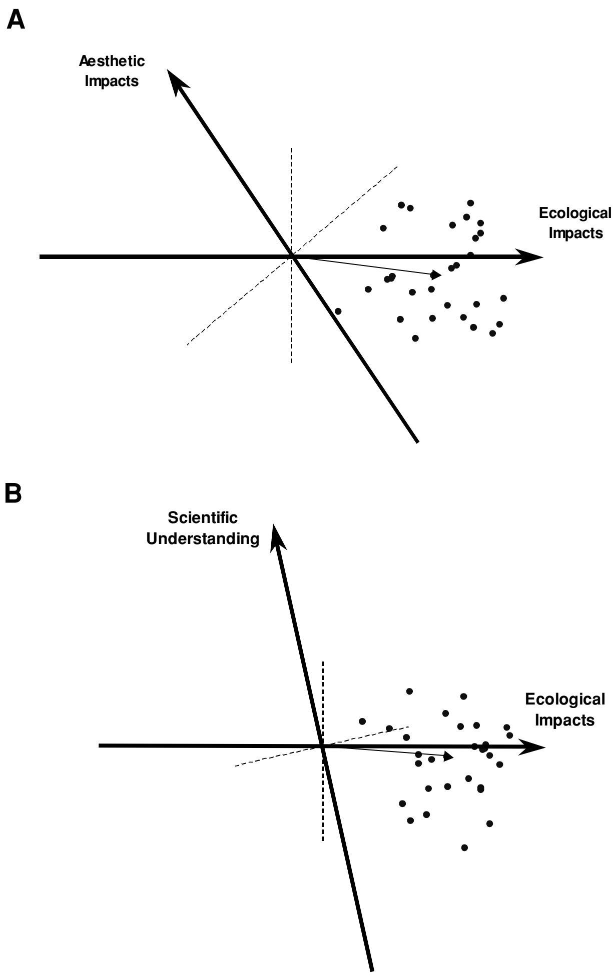

Fig. 2. Individuals' judgments of ecological riskiness plotted in the aggregate-level hazard-focused factor space. In this oblique factor solution, the cosine of the angle between a pair of factors is equal to the correlation between those factors. Dashed lines perpendicular to the factor axes indicate the zero points for those axes. Points represent the endpoints of individuals' ecological riskiness vectors in this factor space. The perpendicular projection of a point onto one of the axes represents the correlation between an individual's riskiness judgments and the aggregate-level factor represented by that axis. The mean of participants' ecological riskiness vectors is shown as a thin ray in the factor space.

the ecological riskiness of the 34 hazards and the factor scores for those hazards from the aggregate-level analysis. These correlations were then used to determine the orientation of each participant's ecological riskiness vector in the aggregate-level factor space. The endpoints of these individual riskiness vectors are depicted as points in the two panels of Fig. 2. In these graphs, the endpoints of the axes define a unit circle, and the perpendicular projection of a point onto one of the axes represents the correlation between a participant's riskiness judgments and the aggregate-level factor represented by that axis. A point that is far from the origin indicates that the participant's riskiness vector is oriented close to the plane defined by the two axes (the length of the projection of the vector onto the plane is close to 1.0), whereas a point that is close the origin indicates that the participant's riskiness vector is more perpendicular to this plane.

Panel A of Fig. 2 reveals that all participants' riskiness vectors pointed in similar direction with respect to ecological impacts (Factor 1) and aesthetic impacts (Factor 2), although several participants had correlations that were close to zero and nonsignificant. Panel B shows that all but five of the participants' vectors pointed in the same direction with respect to scientific understanding (Factor 3). Thus, for most participants, the relationship between their riskiness judgments and the aggregate-level factor scores had the same signs; greater ecological riskiness was generally associated with greater ecological impacts, more negative aesthetic impacts, and lower scientific understanding. However, in both panels, the spread of points indicates substantial variation among participants in the strength of these relationships.

These results demonstrate that differences in hazards' aggregate-level factor scores provide reliable (but not infallible) information about whether individuals' ecological riskiness judgments will increase or decrease from one hazard to the next. The advantage of the hybrid approach is that it reflects the variability among individuals while retaining the interpretability associated with a common set of factors. One benefit of the specific approach used here is that it allows for rotated and correlated factors that may be more interpretable than the unrotated orthogonal dimensions that result from other techniques such as PRINCALS.

3.2.4. Participant-Focused Analyses

The results from the hazard-focused analyses presented above illustrate how the explanatory power of the psychometric risk-perception model declines from aggregate-level to disaggregate (participant-level) analysis. However, as noted in Section 1.2, studies reporting disaggregate-level analyses have often focused on differences among participants rather than differences among hazards. To help discern the implications of this distinction, we performed the corresponding participant-focused analyses at both the aggregate and disaggregate levels.

At the aggregate level, we calculated a matrix of mean attribute judgments by averaging over hazards instead of over participants. We analyzed the resulting participant × attribute matrix using the same principal factor analysis methods used in previous sections. Three factors explained 70% of the total variance in attribute ratings. The factor pattern resulting from aggregation over hazards (see Table X) was remarkably similar to the earlier factor pattern resulting from aggregation over participants (see Table VII), with two notable differences. First, duration of effects shifted from ecological impacts (Factor 1) to aesthetic impacts (Factor 2) in the participant-focused analysis. Second, species variety and habitat variety switched from being split between these factors to loading primarily on aesthetic impacts (Factor 2).

Since attribute loadings were similar in the hazard-focused and participant-focused analyses, we interpreted Factors 1, 2, and 3 from the aggregate-level participant-focused analysis as *ecological impacts*, *aesthetic impacts*, and *scientific understanding*, respectively. However, it is important to remember that these factors explain different correlations. In the earlier hazard-focused analysis, the factors explain correlations among the attributes across hazards. In the participant-focused analysis, the factors explain correlations among the attributes across participants. For example, people who rated hazards as having larger impacts on natural processes and cycles also rated the hazards as affecting larger amounts of habitat. Although one could use the factor scores from the participant-focused analysis to construct a factor plot similar to Fig. 1, the plot would depict the individual participants rather than the hazards as points in the factor space. Trumbo (1996) and Sjöberg (2000) also reported participant-focused factor patterns (for single risks) that were very similar to the traditional hazard-focused pattern.

Table X. Rotated Factor Pattern from the Aggregate-Level Participant-Focused Analysis of 17 Attribute Scales in Study 2

Attribute	Factor 1 Ecological Impacts	Factor 2 Aesthetic Impacts	Factor 3 Scientific Understanding
Natural processes and cycles	**84**		
Species affected	**93**		
Habitat affected	**91**		
Extinction potential	47		
Likelihood of effects	**85**		
Future generations	**94**		
Duration of effects		−59	
Destructiveness	**85**		
Unanticipated consequences	**87**		
Species variety		**81**	
Habitat variety		**85**	
Visual appearance		**72**	
Smell and taste		**78**	
Naturalness of appearance		**89**	
Predictability of effects			**70**
Scientific understanding			**67**
Newness of hazard			**−69**
Interfactor correlations			
Factor 2	−0.379		
Factor 3	0.128	−0.006	

Note: All loadings are multiplied by 100; those ≥0.60 are in bold text; those <0.40 are omitted. For oblique rotations, loadings may exceed 1.0. They can be interpreted as standardized regression coefficients for predicting attribute values on the basis of the three factors, but not as correlations between attributes and factors.

Section 3 of Table IX shows the results from regressing participants' mean riskiness judgments (averaged over hazards) onto the factor scores from the aggregate-level participant-focused analysis. Although the R^2 values for these regressions were noticeably lower than those from the corresponding hazard-focused analysis (see Section 1 of Table IX), all of the regression coefficients had the same signs.

To analyze participant-focused data at the disaggregate (hazard) level, we performed a separate principal factor analysis on each hazard's participant × attribute matrix, as in Trumbo (1996) and Sjöberg (2000). Each of these analyses was performed identically to previous factor analyses in this study to allow for comparisons of results. If a participant failed to evaluate a hazard on all attributes, then he or she was excluded from the factor analysis for that hazard. Typically, three to five of the 30 participants were omitted from the factor analyses. In one extreme case, *industrial water pollution*, seven participants were omitted.

As in the disaggregate (participant-level) hazard-focused analyses, the factors extracted from the disaggregate (hazard-level) participant-focused analyses did not share common orientations (nor common interpretations). To allow comparison to previous results, we constrained each hazard-level analysis to three factors. The resulting factors explained an average of 60% of the total variance in attribute judgments across hazards (range = 49–69%). As might be expected, this figure was somewhat lower than the corresponding percentage of variance explained by the aggregate-level participant-focused analysis (70%).

For each hazard, we regressed participants' riskiness and acceptability judgments onto the factor scores from the disaggregate (hazard-level) participant-focused analysis. Section 4 of Table IX presents the means and ranges for R^2 values from these within-hazard regressions. Since the factors from the hazard-level analyses did not share common interpretations, Table IX does not list regression coefficients for these analyses. The mean R^2 values for these analyses were between 4 and 26 percentage points lower than those for the corresponding aggregate-level analyses in Section 3 of Table IX, and between 14 and 20 percentage points lower than those for the disaggregate (participant-level) hazard-focused analyses in Section 2 of that table.

3.2.5. Summary of Analyses at Different Levels and with Different Foci

In the previous sections, we have presented results from factor analyses that were conducted at two different levels of aggregation and that explained two different sources of variation in attribute judgments. We then used factor scores from each of these analyses to predict riskiness and acceptability judgments. The R^2 values for the disaggregate-level analyses were lower than the R^2 values for the corresponding aggregate-level analyses. Comparing Sections 1 and 2 of Table IX illustrates this result for hazard-focused analyses, whereas comparing Sections 3 and 4 of the same table illustrates this result for participant-focused analyses. As previously mentioned, we believe this decline in explanatory power probably resulted from greater noise in the disaggregate-level data. Using participant-focused analysis instead of hazard-focused analysis resulted in comparable decreases in R^2 values. This result can be observed by comparing Sections 1 and 3 of Table IX for aggregate-level analyses and by comparing Sections 2 and 4 for disaggregate-level analyses. One explanation for these decreases is that the lack of variation in ratings (i.e., agreement among participants) limited the magnitude of the expected relationships for some hazards (Kraus & Slovic, 1988; Slovic *et al.*, 1986).

The observed decline in explanatory power from aggregate-level to disaggregate-level analyses supports claims that the psychometric paradigm explains less variation in riskiness judgments at the individual level. However, these claims have often been based on comparisons of analyses like those in Sections 1 and 4 of Table IX. Such comparisons confound differences in the level of aggregation with differences in the focus of the analysis and overstate the difference between aggregate-level and disaggregate-level analyses. As noted earlier, hazard-focused and participant-focused analyses address different questions. Even so, the decline in explanatory power seen in Section 4 of Table IX is less extreme than is sometimes observed. In this study, factors from the disaggregate (hazard-level) participant-focused analysis explained an average of 48% of the variation in participants' riskiness judgments, compared to 20–29% in previous studies (Gardner & Gould, 1989; Marris *et al.*, 1997, 1998; Sjöberg, 1996, 2000). One possible explanation is that the attribute set used in this study did a particularly good job of differentiating participants who hold different beliefs regarding the riskiness of specific hazards. Another possibility is that the relatively educated participants in this study were particularly consistent in their responses to the rating questions.

4. DISCUSSION

The first study reported in this article builds on a handful of studies of ecological risk perception by using different sets of hazards and attributes, and provides additional evidence for the robustness of factor patterns that have been reported previously (Lazo *et al.*, 2000; McDaniels *et al.*, 1995, 1996, 1997). The six underlying factors shown in Table IV describe lay perceptions of ecological hazards and also predict judgments of riskiness, acceptability, and regulatory strictness (see Table VI). The positive correlation between the first two factors, ecological impacts and human impacts, is consistent with results from previous studies in which these two factors merged into a single factor (Lazo *et al.*, 2000; McDaniels *et al.*, 1997). The results of Study 1 also suggest that impacts on the aesthetic qualities of the environment are an important aspect of ecological hazards. In Study 2, aggregate-level hazard-focused analyses replicated the appropriate portion of the factor solution and yielded similar regression results, thereby providing additional evidence for the usefulness of these factors in understanding distinctions among ecological hazards.

Critics of the psychometric paradigm have often pointed to the method's relatively low explanatory power when data are not averaged over participants. However, some of the empirical results presented as evidence for this assertion have been based on comparisons that confound the level of analysis (aggregate versus disaggregate) with the focus of the analysis (differences among hazards versus differences among participants). Study 2 separates these effects for the first time, and allows clearer distinctions to be made. The psychometric method does appear to explain less variance in riskiness judgments at the disaggregate level than at the aggregate level. For the hazard-focused analyses reported in Table IX, explanatory power was 16–27 percentage points lower for the disaggregate-level analysis, depending on the dependent variable. However, Table IX also reveals that changing from hazard-focused to participant-focused analysis results in a similar decrease in explanatory power. A very similar pattern of regression results was recently reported by Bronfman *et al.* (2004), who used analogous methods to reanalyze data from Bronfman and Cifuentes's (2003) study of risk perception in Chile.

What combination of focus and level of analysis is most appropriate when studying risk perception? In our view, the first consideration should be whether one is primarily interested in differences between hazards or differences between participants. The traditional psychometric approach explains how riskiness judgments differ based on characteristics of the hazards. As mentioned earlier, this is the appropriate issue to study when the primary goal is to help people make distinctions among hazards, as in comparative risk projects and our own risk-ranking efforts (DeKay *et al.*, 2001; Florig *et al.*, 2001; K.M. Morgan *et al.*, 2001; M.G. Morgan *et al.*, 1996, 2000; Willis *et al.*, 2004). On the other hand, focusing on differences among participants seems more appropriate when the goal is to understand the relationships between beliefs, attitudes, and behaviors in the context of individual hazards (e.g., Gardner *et al.*, 1982).

Regardless of the focus of the analysis, disaggregate-level analyses are always better than aggregate-level analyses, at least in principle. One should always want to avoid glossing over important individual differences (differences among participants in hazard-focused analysis, or differences among hazards in participant-focused analysis). However, there are practical considerations that may make fully disaggregate analyses difficult and less informative than one might imagine. These include the necessity for very long and tedious (for the participants) data collection efforts, the increased noise in individual data, the greater number of subjective judgments required of the researcher (e.g., decisions in interpreting and comparing individual participants' rotated factor patterns), and the difficulty in succinctly summarizing the results for use in risk-management decisions. Although these methodological issues are important, they are secondary to matching the focus of analysis to the theoretical or policy question of interest.

Other studies have indicated that different groups of people perceive hazards relatively similarly, although they may relate the characteristics of hazards to riskiness judgments in slightly different ways (Slovic *et al.*, 1985; Vlek & Stallen, 1981; Willis & DeKay, 2004). These results suggest that a hybrid strategy involving aggregate-level factor analyses to model risk perceptions and disaggregate (participant-level) analyses for important dependent variables, such as riskiness judgments, might provide an excellent solution to the aggregation dilemma. Such analyses are useful not only for illustrating the extent to which respondents agree or disagree about what makes some hazards more risky than others, but also for understanding how such differences are related to the characteristics of the respondents themselves (Arabie & Maschmeyer, 1988; Vlek & Stallen, 1981; Wagenaar *et al.*, 1984). For example, Willis and DeKay (2004) recently used the hybrid approach to assess the moderating effects of group membership, worldviews, and other individual differences on the relationships between hazard attributes (as captured by aggregate-level factors) and individuals' riskiness judgments. Results of such analyses are particularly relevant for comparative risk assessment, where a common attribute set is useful for creating informational materials and for facilitating group discussions about the ways in which these attributes are related to the relative riskiness of hazards.

5. LIMITATIONS

The studies reported here are subject to some of the same limitations as other psychometric studies. Results are at least partially dependent on the hazards and attributes chosen and the participants involved. The similarity of factor patterns from the aggregate-level hazard-focused and aggregate-level participant-focused analyses suggests that the results of such procedures depend in part on the semantic associations among the attribute scales used to rate the hazards. Nonetheless, the resulting factors may be very useful in predicting riskiness judgments or other dependent variables.

Although our initial list of attributes in Table II was extensive, it is possible that we omitted some attributes related to the riskiness or acceptability of hazards. For example, Sjöberg (2000) reported that perceived interference with nature is related to riskiness judgments for nuclear issues, a result that is consistent with findings that people are more concerned about environmental damage when human actions rather than natural causes are to blame (Kahneman & Ritov, 1994; DeKay & McClelland, 1996).

Finally, our convenience samples of participants cannot be considered representative of the general population, although the consistency of our results with those of other studies provides some evidence for generalizability. Larger, more representative samples could help answer questions about the prevalence of differing views regarding the relationships between the characteristics of ecological hazards and the riskiness of those hazards.

6. CONCLUSIONS

Given the apparent robustness of results from several studies of ecological risk perception, researchers and practitioners engaged in risk-communication efforts should consider addressing each of the six factors identified in Study 1. Results from hazard-focused psychometric studies can also guide the development of informational materials and multiattribute decision models for ranking ecological and public health hazards (Willis *et al.*, 2004). Although differences among participants may sometimes take priority in other behavioral contexts, focusing on differences among hazards makes more sense when the goal is to determine people's relative concerns about different hazards for the purpose of informing risk-management priorities. So long as procedures are sensitive to individual differences regarding the relationships between hazards' characteristics and judgments of riskiness or acceptability, it appears reasonable to describe hazards in terms of characteristics that are chosen partly on the basis of aggregate-level factor analyses of risk-perception data.

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