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Integrating human health and ecological concerns in risk assessments ☆

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Abstract

The interconnections between ecosystems, human health and welfare have been increasingly recognized by the US government, academia, and the public. This paper continues this theme by addressing the use of risk assessment to integrate people into a single assessment. In a broad overview of the risk assessment process we stress the need to build a conceptual model of the whole system including multiple species (humans and other ecological entities), stressors, and cumulative effects. We also propose converging landscape ecology and evaluation of ecosystem services with risk assessment to address these cumulative responses. We first look at how this integration can occur within the problem formulation step in risk assessment where the system is defined, a conceptual model created, a subset of components and functions selected, and the analytical framework decided in a context that includes the management decisions. A variety of examples of problem formulations (salmon, wild insects, hyporheic ecosystems, ultraviolet (UV) radiation, nitrogen fertilization, toxic chemicals, and oil spills) are presented to illustrate how treating humans as components of the landscape can add value to risk assessments. We conclude that the risk assessment process should help address the urgent needs of society in proportion to importance, to provide a format to communicate knowledge and understanding, and to inform policy and management decisions.

Keywords: Human health risk assessment; Ecological risk assessment; Integrated assessment; Comparative risk; Conceptual models; Risk assessment case studies

1. Introduction

The application of human health risk assessment in decision making in the United States Federal Government was formalized with the publication of the National Re-

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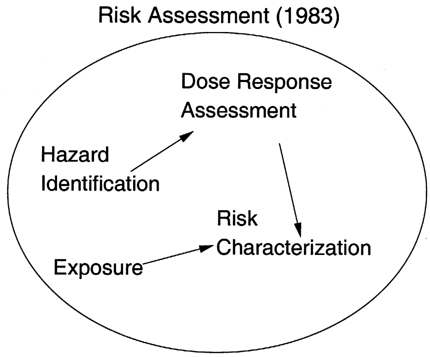

Fig. 1. NRC paradigm. Risk as a function of hazard and exposure.

search Council report in 1983 [1]. In their report, the National Research Council proposed a paradigm (Fig. 1) that defined risks to people as a function of hazard and exposure. Since that time the United States Environmental Protection Agency (USEPA) and other US agencies have developed formal methodologies for evaluating risks to human health.

Proponents and opponents to the human health risk assessment paradigm have spoken out through journal articles and the mass media (see Text Boxes 1 and 2). In addition to these comments on risk assessment there have been suggestions to broaden the factors evaluated through this process. The National Research Council published a report suggesting that risk assessment should consider social and ethical factors, economics, and ecology [2]. In 1997, the Presidential Commission on Risk Assessment and Risk Management completed a report calling for a more holistic view of risk assessment by incorporating "stakeholders" as collaborators in the process [3].

At the same time the USEPA instituted a community-based environmental protection program [4] and completed guidelines for ecological risk assessment [5]. In each of these documents the USEPA offered guidelines or recommendations to expand the elements that are integrated into risk assessment. As Fig. 2 illustrates, people were added to the equation shown in Fig. 1. These individuals can be sources of information, decision-makers, or simply interested in the outcomes. Humans are components of the landscape. In many cases, the stressor and effects are brought full circle from the entity initiating

Text Box 1. Risk assessment proponents

The proponents stated that risk assessment assures that there will be:

- predictability which is logical
- an integration of findings from various disciplines
- an increase in public understanding [2]
- application of fundamental principles
- an index of the quality of information [3]

Text Box 2. Risk assessment opponents

Opponents say that risk assessment is:

- a process which ignores the intricate complexities of environmental problems [4]
- an extremely limited method because of the lack of knowledge; assumptions are made for biological mechanisms which are not well understood [5]
- a disconnect between what is measurable and what are the greatest threats to human health [4]
- a mix of scientific knowledge and policy
- not a substitute for values; the concept of risk is meaningless until we decide what risk of what harm to what values we wish to consider [4]
- not a resolution of environmental problems
- "... a blind blunt, and unwieldy tool to facilitate and scientifically rationalize incremental degradation of the integrity of landscapes and ecosystems". [6]

the stress (humans) to the biota (humans, plants, wildlife, fish, etc). There is an increased recognition by ecologists of this concept of the interconnections between ecosystems, human health and welfare [6]. Likewise, ecologists are incorporating human activities into their concepts and models even though such integration can be difficult [7]. Similarly, human health is increasingly recognized as being strongly influenced by environmental components such as clean air, water, food, land-use practices, climatic change, population density, and transmission of diseases. However, the full consequences to human health of large-scale alterations in biogeochemical cycles are not yet known [7,8].

Fig. 2. Adding people into the equation illustrated in Fig. 1.

In addition to lack of integration, there has been little or no attempt to look for cumulative, synergistic, or antagonistic responses. Regulatory decision-making in the United States generally follows a chemical-by-chemical or pollutant-by-pollutant process (Clean Water Act, Safe Drinking Water Act, Clean Air Act). If we converge the ideas of landscape ecology as envisioned by Odum [7] with risk assessment, we begin to acknowledge the interaction of stressors with all biota (including people) and can begin to address the cumulative responses. This unnatural decoupling of humans and nature [7] will be repaired.

One way to accommodate the human and ecological endpoints is to expand the scale of the assessment [9]. We have found that increasing spatial scale to at least the level of watersheds or counties facilitates evaluation of the association between multiple stressors and ecological habitats within geographical management units (*sensu* [10]). For example, the USEPA Region 10 comparative risk project [11] looked at the relationship between multiple stressors and valued ecological resources within watershed units in the State of Washington. Fig. 3 is an example of the output in terms of possible management decisions that could be made.

In this paper, we will present an approach for integrating people and ecological entities into risk assessment. We also propose a convergence of landscape ecology and evaluation of ecosystem services with the risk assessment paradigm. The integration of ecological and human health concerns will be discussed with respect to the stages of risk assessment shown in Fig. 2 with emphasis on problem formulation.

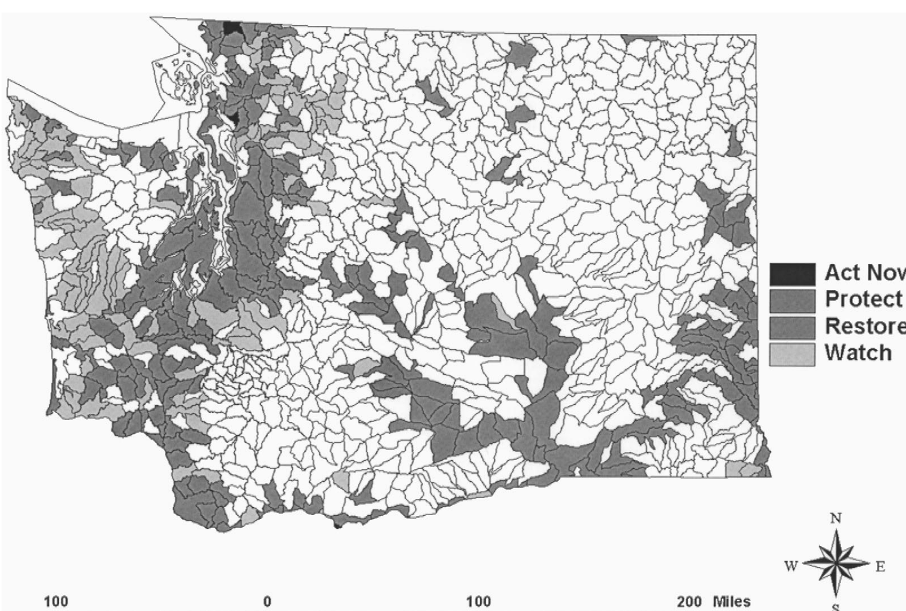

Fig. 3. Examples of management decisions based on the relationship between stressors and resources for watershed units across the State of Washington.

2. Planning

Prior to doing an assessment, there needs to be a meeting of interested individuals who will work together to articulate their goals and objectives, share information, and express their concerns. At the outset, it is important that each group is willing to share their knowledge. As planning evolves there will be a need to separate into more focused interest groups [12]. In the focused groups, the methodologies are worked out and the analytical framework is laid down. However, these groups must continue to inform each other all through their analysis. The dynamics of cross-cultural multidisciplinary interactions can be quite stimulating [12]. In addition to simply expanding the general knowledge of ecological, social, and economic processes, new avenues for solutions may be opened up. For example, in the USEPA Region 10 Comparative Risk Project, evaluating risks to human health across the State of Washington was done by inviting experts from the USEPA and other organizations to several meetings and asking for their collective best professional judgement on stressors and effects by county across the State (Mike Watson, personal communication, 1998).

One challenge in the planning step is that people may not have a common value system or knowledge base with respect to ecological or environmental issues [13]. Numerous articles on community-based environmental protection, risk management, and goal setting, etc., [4] provide an excellent source of suggestions and examples for how to increase our understanding of the values of different people [14].

Risk assessments generally rely on observations of the environment. To this we need to add observations of human behavior, land use, and exposure processes. In this way we can better address solutions that will achieve sustainable ecosystems. Natural processes are a solution to many of our environmental damages. The problem of such inclusive planning and analysis appears daunting, but it is really a matter of identifying the natural and anthropogenic processes controlling the ecosystem at risk, working with the knowledgeable people [12] to analyze these factors, and characterizing risk from those factors which are determined to be stressors.

3. Problem formulation

Through problem formulation one can characterize the spatial and temporal boundaries of the assessment. These boundaries will vary for the individuals or populations being investigated. The assessment can encompass social, political or economic boundaries as well as landscape and ecological life histories. Regardless of the biota in question, the problem formulation should include a conceptual model and an analysis plan.

Conceptual model. After reviewing the background information, a conceptual model of the elements of the assessment is developed. The conceptual model includes the endpoints to be assessed and the measures, which will be used to complete an analysis of exposure and effects. The assessment endpoints may be defined for any organism, population, community, or ecosystem. Available guidance on selecting ecological assessment endpoints (e.g., Refs. [15,16]) defines assessment endpoints as explicit expressions of the environmental value that is to be protected [5] and gives some criteria

Table 1
Example of assessment endpoints

People
Morbidity in children
Mortality in inner city populations
Visibility in National Parks
Subsistence fishing
Availability of food crops
Drinking water supply
Ecological entities
Diversity of fauna and flora
Survival of salmon
Integrity of the hyporheic zone in freshwater streams
Phytoplankton productivity
Growth, reproduction, and survival of wild insects
Climate change

that can help in their selection. These criteria include: ecological relevance, susceptibility of the environmental value to the stressor suite, and relevance to management goals. The likelihood of actually measuring or modeling the relationship between the stressor suite and the responses should be added to this list. Examples of assessment endpoints that might be selected from an initial description of environmental values are in Table 1.

Although terms like assessment endpoints, value, and relevance seem clear to those producing guidance documents, applying the guidance may produce responses such as shown in Table 2.

The reason there can be confusion is that assessment endpoints can seem very general and vague whereas measures that will be used seem detailed and focused. The confusion disappears if one uses these terms to help facilitate reaching the risk analysis step rather than requiring rigid adherence to a dichotomy between assessment and measurement endpoints. For example, a vague goal such as "protect human health," may gradually transform into selection of a minority group for analysis of certain exposures (perhaps fish ingestion), and then into identification of which group, which fish, which contaminants, and what fish tissue concentration will be considered an adverse level to the minority group, finally resulting in a set of measurements with clear interpretation (Fig. 4; [17]).

Table 2
Responses to the request during an ecological risk assessment class to distinguish between assessment and measurement endpoints

What you want to assess	What you actually measure
Predators at the top of the food chain	Prey lower on the food chain
Animals people know and like	Animals and plants people never heard of
Eagles, salmon, edible crabs	Worms, grubs, shrews, voles, weeds

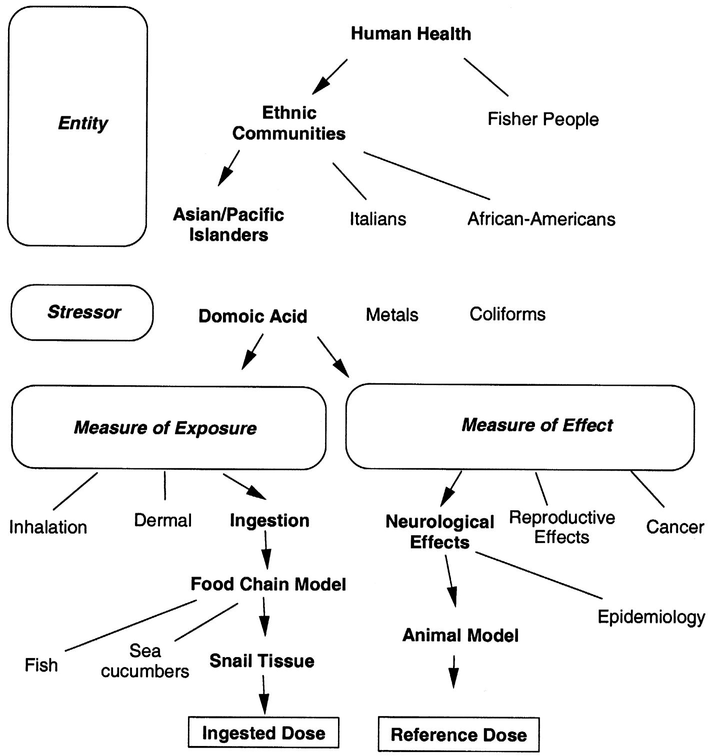

Fig. 4. Developing specific measurement endpoints (measures of exposure and effect) from the general assessment endpoint of human health, using the example of ingestion of domoic acid in moon snails by Asian/Pacific Islanders (from Wekell et al. [17]).

Indeed, that is the goal in ecological risk assessment guidance for hazardous waste sites that asks for development of hypotheses [16]. Focusing on hypotheses requires one to define clearly how data will be analyzed and integrated into decision-making. An illustration of the practical issues involved in deciding what to measure at hazardous waste sites is shown in Fig. 5 (based on Ref. [18]), which examines the process by which assessment endpoints are used to develop measurement endpoints. In this process, the management needs are clear: (1) develop clean up numbers from the risk assessment; (2) decide how to assess effectiveness of the remediation; and (3) determine if the risk assessment needs to develop information on the dose (exposure) or response (effects) or both in order to make conclusions about adverse effects. The integration of ecosystem, contaminant, and management-related considerations helps insure a smooth transition from the values to the measures. Selection of measurements without clear links to management needs or the ecosystem values will render the data and analysis fairly irrelevant to management actions despite how interesting the data may be.

Some key considerations and decisions are indicated in Fig. 5. A convenient process has been to look at functional groups of importance to develop the assessment endpoints (which organisms by their function and/or processes such as nutrient cycling, decompo-

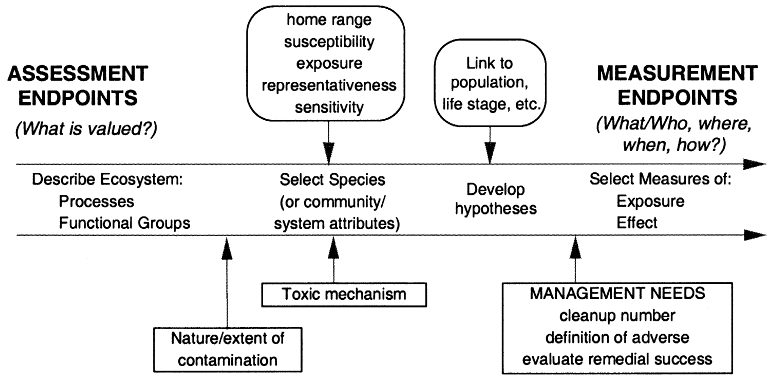

Fig. 5. Developing measurement endpoints from assessment endpoints at hazardous waste sites in a continuum that addresses practical management and ecological issues.

sition, maintenance of biodiversity, etc., are present and should be considered in the risk assessment). From this, relevant combinations of species, communities, and processes are selected to act as indicators for the larger ecosystem.

With respect to measures of effect for human health we have traditional epidemiological measures of human health, models predicting the likelihood of disease, and economic pricing factors. In order to measure intrinsic or non-monetary effects there is a relatively new economic theory of non-market goods valuation [19].

The process of selecting assessment endpoints is really an acknowledgment that only a subset of components and functions can be evaluated and the goal of guidance is to facilitate that process. The selection, therefore, can only be successful in a context that includes the management decisions that need to be made.

After carefully describing all the ecological and anthropogenic components of the ecosystem or community of concern, a conceptual model can be drawn. The model examines the likelihood of existing and predicted stressors (toxic chemicals, physical disturbances, biological invasions) affecting the organisms, populations, communities or ecosystems of concern. These levels of biological organization can apply to human social or cultural structure as well as that of the natural environment. The effects can be morbidity, mortality, survival, growth, economic and social losses, loss of ecosystem function, and disturbance of ecosystem structure. Table 3 lists components of a conceptual model that would integrate ecological and human health concerns.

Analysis plan. Using the conceptual model and the assessment endpoints, the next decision is how to decide the method of analysis and identify data gaps (you may need better models, input for models, or cause/effect relationships). The choice of method is often dependent on the policy or management decisions. Some examples of management questions are the following. (1) What is considered adverse? (perhaps not attaining management goal or exceeding some commonly used threshold for a toxicant) (2) What level of certainty is acceptable? and (3) How will different lines of evidence be brought to bear and compared? A key to this stage is to document what you will do and whether additional data are needed. For data to be useful, it should be clear how the results of additional measurements will be integrated into decision-making.

Table 3
Components of a conceptual model integrating human health and ecological concerns

Land use
Geochemical cycles
Pricing Factors
Ecosystem services
Ecological processes
Ecological structure
Social structure
Cultural traditions
Archeological artifacts
Political, social, and ecological temporal and spatial boundaries
Driving forces, agents of change, stressors, disturbance regimes

It is often at this point in the risk assessment where the disciplines diverge. The human health experts begin to gather data on toxicological endpoints and exposure while the ecological experts generally examine field and laboratory data to determine if further studies are needed.

The data needs for any assessment will vary. Each group identified in planning analyzes the data according to their discipline, culture, or preference. Available databases may be stressor-related, ranging from releases to air or water from point sources, discharger compliance history, human population census-related data, or estimates of urban growth, to location of dams. Receptor and effects databases, apart from species of intense interest such as marine mammals or salmon, are limited especially for large-scale assessments. For example, even estimating wetland loss on a large scale is hampered by the lack of baseline information, changes in definition, and decentralized records. An important emerging source of information that can overcome some of these problems is satellite imagery. Although this technology introduces its own problems (e.g., the need to decide on what is a change, what is the level of uncertainty, minimum pixel size, other sources of error), programs such as analysis of gaps in conservation plans have been successful at correlating vegetation with animal species (reviewed recently by Ref. [20]).

In large-scale assessments, decisions need to be made on how to interpret existing data. For example, it must be made clear how existing information on threatened or endangered species will be used. Although the home ranges of these species would be identified as areas to target for protection, it is not clear whether these are areas of low stress, or whether adjacent areas are presumed to be more highly stressed. Similarly, how should areas of high biodiversity be viewed, and, just as important, how will estimates of biodiversity be compared as the organisms change across ecoregions or subecoregions? Examples from human health-related large-scale assessments are the global dispersion of air toxics and ultraviolet (UV)radiation

What kind of exposure and toxicity assumptions are needed to integrate likely effects over broad scales? A successful approach may be to build and evaluate models that connect stressors with effects, such as the current effort in the USEPA to model sediment delivery to streams based on vegetation information obtained from satellite-imagery combined with slope, soil type, climate, rainfall, etc. [21].

The following case studies are presented as examples of issues to be considered during problem formulation. The studies are categorized according to the issue which would initiate a risk assessment. Managers, or other interested individuals are usually concerned about prospective assessments of natural resources or stressor, and retrospective assessments of impacted areas.

3.1. Resource initiated assessments

3.1.1. Salmon

In the Pacific Northwest, one of our most valued resources is salmon (Fig. 6). These fish are important as sources of protein, cultural traditions, economic welfare, and as keystone species. As a resource initiated assessment, the problem begins with defining the spatial and temporal boundaries of the salmon. The assessment endpoints for the salmon are growth, reproduction and survival. The stressors for salmon include physical, chemical, and biological factors. The effects range from physical habitat loss to diseases associated with toxic chemicals. For people the assessment endpoints are cultural and economic welfare due to loss of their subsistence or recreational fishery. In addition, the bioaccumulation of toxic chemicals by the salmon poses a threat to human health through fish consumption. Human welfare effects can be determined through an estimate of the "existence value" [19]. This is based on the theory that existence values arise from prevention of the extinction of the salmon as a species.

For ecological and human health endpoints, the measures are presence or absence of individual populations or species. The determination of threatened or endangered status by the United States Fish and Wildlife Service is an example of this measurement of ecological effect. The measures of exposure can be determined from water, sediment, and/or fish tissue chemistry, and models of bioaccumulation.

There has certainly been criticism to applying the risk assessment concept of "health" to analysis of fish populations [22] because of the connotation of human in the word "health." However, the risk assessment process does not require that the analysis be limited to the "health" of the fish. It can also be used to evaluate species diversity, spatial habitat heterogeneity, or other ecologically relevant endpoints.

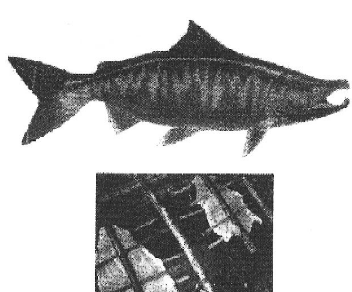

Fig. 6. Salmon, valued in the northwest in ecosystems and diets.

3.1.2. Wild insects

Another valuable resource which has been investigated is wild insects. Wild insects pollinate US$1.25 billion worth of food crops [23]. They are therefore an important component of our terrestrial ecosystems and our economic welfare. An assessment of the factors that alter insect population growth, reproduction and survival will identify the major stressors. One of the obvious anthropogenic stressors in insect survival is application of herbicides. Herbicides kill plants, bee's decline, pollination declines, food declines, and people are left without some form of sustenance [23]. In addition to the loss of wild insects, herbicides also cause direct morbidity and mortality to people, fish, and wildlife. Thus, in investigating the plight of the bee, one comes full circle to man and the loss of the ecosystem service provided by these pollinators.

3.1.3. Hyporheic zone of freshwater streams

Certain ecosystems are also considered valued resources. They have ecological value and their "existence" as a special environment can be estimated through non-market economic methods [19]. An example of a valued ecosystem is the hyporheic zone in freshwater streams (i.e., transition zone from ground water to surface water [24]). This system is valued for several reasons (Dahm, personal communication, 1999). It provides high quality or essential habitat and can serve as a refuge. For example, ground water discharge zones may be focal areas of plant and animal biodiversity or represent areas of high water quality where sediments may be contaminated; macrophytes may preferentially establish in beds where ground water discharges. Ground water also provides thermal refuges: cool ground water is a summer refuge from warm stream water to nymphs of winter stoneflies and upwelling areas provide a winter refuge for salmonids. The zone is also an important source of benthic organisms that recolonize areas after droughts or spates (floods). In this zone, contaminants may undergo attenuation or removal (e.g., metals, halogenated organic solvents, polyaromatic hydrocarbons, volatile organics, and nutrients can be degraded or removed from ground water in the transition zone). Similarly, nutrient and carbon cycling by microbial processes in particular are important. Finally, this system has important trophic links. Microbes, fungi, and meiofauna serve as a food base to larger macroinvertebrates and fish. Alterations of this ecosystem will affect all biota from bacteria to humans.

3.2. Stressor initiated assessments

3.2.1. UV radiation

An example of a stressor-initiated assessment that is currently in the problem formulation step is UV radiation effects on ecosystems and human health in the Arctic (Fig. 7). The Arctic Monitoring and Assessment Program (AMAP) established in 1991 under the Arctic Environmental Protection Strategy, takes an integrated approach to evaluating the human and ecological effects of UV in the Arctic. In fact, a recent AMAP report even discusses how building materials such as plastics will degrade with increased UV, resulting in shorter design life of structures [25]. The increased attention on UV radiation doses in the Arctic is a result of awareness of ozone depletion, which has allowed more UV penetration to the earth's surface and the influence of snow cover

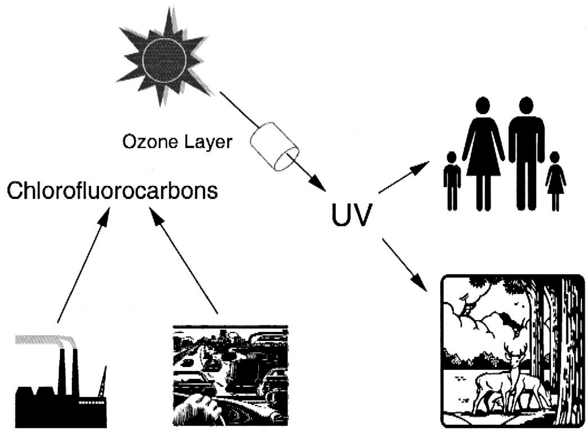

Fig. 7. Illustration of increased UV stress due to chlorofluorocarbons affecting the ozone layer and resulting effects on Arctic ecosystems including humans.

which can reflect as much as 90% of the UV radiation. Important long-term effects on Arctic ecosystems are likely to manifest as changes in species composition. Increased UV is likely to affect plants and plankton in polar areas due to their adaptation to low doses of UV. Plant community composition may shift and nutrient cycling by UV-sensitive fungi may slow. Other effects of UV on zooplankton, fish, and cycling of carbon in aquatic systems have been documented.

The concerns about significant effects on humans range from inflammation of the surface of the eyeball and snow blindness, to chronic effects such as cataracts. Risk of skin cancer, especially malignant melanoma, is also a concern and UV radiation can suppress the immune system. The Netherlands National Institute of Public Health and the Environment is arguing the necessity for UV measurements. They point out the common issues in determining good quality exposure information for both human health and ecological risk assessments [26]. The International Arctic Science Committee is calling for UV research in four main areas that all relate back to the socio-economic welfare of Arctic residents. These areas are human health effects, social science, aquatic effects, and terrestrial effects; with much of the research to be done in the ecosystems rather than in the greenhouse or laboratory [27].

3.2.2. Nitrogen fertilization

Global nitrogen overload is another stressor, which could be evaluated with the risk assessment method. The problems associated with excess nitrogen run the gamut from local changes in health to global ecosystems alterations [8]. Infiltration of nitrogen into groundwater can pose a threat to human health through drinking water. Fertilizer runoff can result in eutrophication of lakes, ponds or estuaries. Eutrophication will alter the natural biogeochemical cycle resulting in algal blooms, decay, and possible oxygen depletion. The alteration of the natural cycle in aquatic ecosystems may cause the decline of aquatic biota. As the aquatic organisms are lost, people will lose another food or economic source. As one incorporates people into these large-scale ecological changes, the argument for reducing the risks is much more compelling.

3.2.3. Toxic chemicals

A group of experts convened by The World Health Organization [28] recently derived toxic equivalency factors for polychlorinated dibenzo-*p*-dioxin (PCDDs), dibenzofurans (PCDFs), and dioxin-like polychlorinated biphenyls (PCBs) for human, fish, and wildlife risk assessment (Fig. 8). Their analysis showed that there is sufficient evidence of a common mechanism for these compounds, involving binding to the aryl hydrocarbon receptor. Toxic equivalency factors were developed to facilitate risk assessment. These factors are derived from established toxicity information for each individual PCDD, PCDF, and PCB congener relative to 2,3,7,8-TCDD based on in vivo and in vitro data. The Word Health Group attempted to harmonize the toxic equivalency factors across different taxa. While they did not find total synchronization across all species, the similarities were strong enough to support the broad categories of mammals, fish, and birds. Exposure pathways also will diverge depending on behavior patterns of individual species. However, problem formulation, data collection, and analysis are more efficient if in the conceptual model, one first recognizes all pathways, then allows for divergence. The assessment endpoints are fish survival, wildlife morbidity and mortality, and human health.

3.3. Effects initiated assessments

3.3.1. The Exxon Valdez oil spill

The oil spill (on March 24, 1989, in Prince William Sound, AK, USA) is an example of a situation where risk assessment could have helped to formulate the assessment

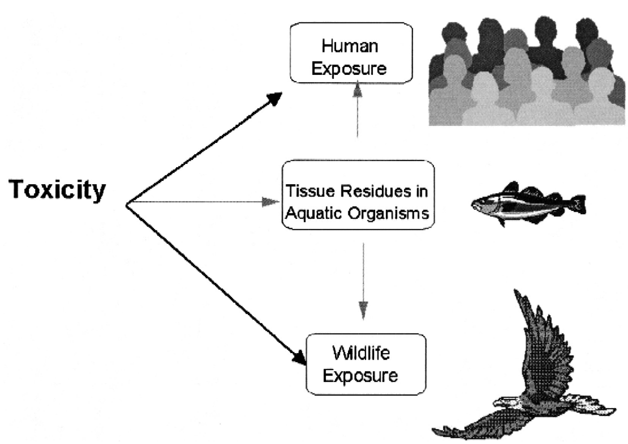

Fig. 8. Use of toxicity equivalency factors to evaluate chemical stress on fish, wildlife, and humans.

endpoints. The effects were observed as the oil spilled from the grounded vessel. The array of possible effects ranged from death of aquatic organisms to human health concerns for subsistence peoples. There were a great number of studies generated regarding the effect of the oil spill on "populations" in Prince William Sound [29]. If the risk assessment model (including people) had been incorporated from the outset, a better understanding of the interrelationships of stressors with people and the environment could have been gained. Each of the reports describes a specific analysis, which could be tied to an individual endpoint (e.g., mussel viability and human health effects from consumption of contaminated mussels). However, there was no overarching description of these interactions. The lines of evidence would be more compelling if there were some idea of the convergence on an endpoint, rather than an appearance of isolated incidences of ecological or human stress. Such a convergence enables the risk assessor to put the information into a context, which is readily apparent to anyone interested in the outcomes of exposure to these contaminants.

Similar to the analysis of value of the hyporheic zone, the importance of Prince William Sound can be estimated through an analysis of its "existence value" as a special environment [19].

4. Risk characterization

After the completion of individual analyses for each assessment endpoint, the groups of specialists reconvene to discuss characterization of their various components. They bring to the discussion some estimate of risks. For human health and welfare, the estimates can range from an ordinal ranking of loss of cultural values (high medium, low), to the probability that one in a million people will develop cancer. For fish populations, the estimates may be a 50% probability of fish mortality as a result of increased temperatures in 80% of mainstream river systems during all life stages of salmon.

In human health assessments, the level of acceptable risk is often determined by common usage. For cancer, the likelihood of a one in a million chance of developing cancer is often quoted as "acceptable." However, this acceptable level has arisen simply by common practice [30].

For non-cancer risks to people, any chemical which results in an exposure that exceeds the reference dose for chemicals may be considered an unacceptable risk. In a similar fashion, tolerance limits are developed for individual species (wildlife) or for groups of species (water quality criteria). Again, any chemical which results in a dose which exceeds the tolerance limit is considered an unacceptable exposure.

Some authors have criticized the extrapolation of human health concepts to ecosystem health [31]. However, the analysis does not have to be based on a health endpoint. The endpoint could be ecosystem services [32] or sustainability [6]. Rather than focusing on the assessment endpoint nomenclature, the benefit of risk assessment is the coherent presentation of information used in a reaching a conclusion about the threats (present or future) to ecosystem integrity and human health.

In ecological analyses of non-chemical exposures, there is an attempt to establish acceptable limits through comparison to reference conditions. This is in fact a form of epidemiology. In this case, we are attempting to understand how the natural population interacts with the abiotic conditions of their ecosystem.

The opponents of risk assessment [33,34] state that risk assessment allows pollution to continue. If the lines of evidence (Fig. 9) linking human and the ecological endpoints were examined in a holistic process, there would be opportunities to identify the harm to society from actions which may seem in the best interest of humans but not necessarily beneficial to biological integrity. There would be an incentive built into the analytical framework, which would foretell what we gain and what we lose through choice. The evidence of harm would be much more compelling.

In ecological analyses, we often are seeking the answer to our questions of cause and effect through an examination of the natural ecosystem. In human populations, we base many of our conclusions for human exposure on a comparison to animal models. These animal models can in turn be used as measures for other mammals at risk. Thus, one of the lines of evidence for humans can provide evidence for other mammalian exposures.

There are clearly differences in human and ecological assessments [35]. Ecosystem assessments include a range of species, while human health analysis requires knowledge of the physiology of one species. However, unique exposure or susceptibilities may affect the level of stress experienced by different human populations. Spatial and temporal boundary conditions may vary depending on the pathways of exposure for humans and other organisms [35]. However, the risk assessment paradigm allows for a variety of analyses of exposure and effect. Even within human populations there are often different scales and pathways for exposure depending on the culture, gender, age, economic status, and sensitivity.

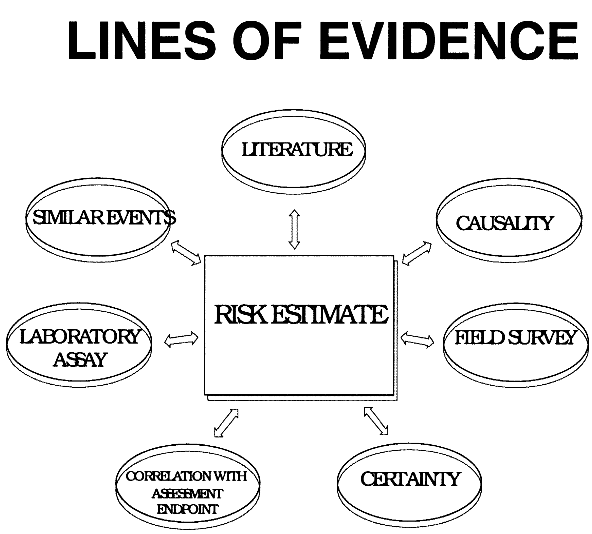

Fig. 9. Lines of evidence that can be used to characterize human and ecological risk holistically and communicate gains and losses based on management choices.

5. Conclusions

Some of the weaknesses and strengths remain whether you are evaluating human or ecological endpoints. It is the critical review of the risk assessor, which is needed to point out the uncertainties so that everyone understands and is prepared to accept the consequences of these flaws (e.g., the uncertainty should be greater if the unknowns are greater).

It should be the goal of all assessors to provide the basis for a well-informed decision and a clear statement of the risks that the public will understand. Risk assessment can be a powerful tool for communicating knowledge to inform policy and management decisions [32]. These decisions should be based on strong scientific principles where the assumptions, certainties, and uncertainties are analyzed and documented.

Risk assessment should help us address the most urgent needs of society in proportion to their importance and provide a format to communicate our knowledge and understanding to individuals and institutions.

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