An Integrated Model for Socio-Ecological Health Promotion

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A Brief History

The 671,000 sq km Columbia River Basin (USA) was an evolving socio-ecological system for at least 10,000 years, during which time humans learned about and adapted to the resources, particularly the anadromous salmon.

> By the time Euro-Americans arrived in the Northwest, the indigenous people living on the Northwest coast had created an economy tightly choreographed to the seasonal cycles of the salmon. This complex biological and cultural dance persisted for 2,000 to 5,000 years, depending on the area, ending only when Euro-Americans arrived in large numbers about 150 years ago." (Lichatowich, 1999:19).

The river's anadromous and resident fish stocks were managed by tribes throughout the region through sustainable practices such as allowing the first cohort of salmon to reach their spawning grounds, and both inventing and regulating fishing technologies such as fish wheels and weirs. Traditional environmental knowledge has continually recognized the interdependence of fish and people. Local tribal leaders commonly quote elders, that "Whatever happens to the fish happens to us. If the fish go, we go." (Yakama Tribal Fisheries, 2003)

Euro-American colonization beginning in the mid-19th century was characterized by unsustainable use of those same fishing technologies by a few fishers, human appropriation of ecosystem services such as water and fluvial energy by a few industries, and regulations that allowed "dilution of pollution" in the river by those industries. The results include a growing population of 5 million attracted by environmental amenities such as clean water, and exposure of both fish and people to toxins, and an uncertain existence for salmon at the end of this century. Risks to salmon are characterized by a conflict between public support for wild salmon and the absence of real lifestyle or policy changes that address competitive exclusion (Lackey, 2003). One million pounds of federally-classified toxins are permitted for annual discharge into the river. However, only 650 of the tens of thousands of toxic chemicals in commerce are regulated by the Environmental Protection Agency (EPA), who sets high thresholds for regulatory reporting by industries and municipalities. Therefore, the total annual toxin discharge is estimated to be 20 million pounds annually (Environmental Working Group, 1996).

Despite intensive industrial pollution of the Columbia River Basin beginning with WWII shipbuilding and hydro-powered industry, toxin reduction has not been the regional priority of the EPA until 2005, and a national priority until 2006. US pollution regulations place the burden of proof on citizens and government rather than on those involved in toxin manufacture, use, and disposal, therefore action depends on informed and active citizens. The first comprehensive study of contamination was initiated by the Columbia Inter-Tribal Fish Commission (CRITFC), a body representing tribes who ceded a major portion of the Basin to the US government in 1855 in return for a treaty guaranteeing educational and health benefits. This 1996-97 study was funded by the EPA and conducted by both partners. It identified 92 federally-classified toxins, the most common being 14 metals, PCBs, DDT and it analogs, dioxins, chlordane, chlorinated dioxins and furans in 11 species of resident and anadromous fish sampled at 24 traditional tribal fishing locations in 16 rivers and creeks throughout the basin (USEPA 2002).

This study found that all specimens had toxin body burdens, but no species exceeded the EPA-determined hazard index based on the national average of fish consumption. However, this was preceded by a CRITFC study that demonstrated that due to higher tribal fish consumption rate, the hazard index is up to one hundred times greater (CRITFC 1994). These CRITFC/EPA studies were followed by tribal efforts to regionally communicate the risk, in which I participated. We found the population at risk to be larger than tribal members alone. Many non-tribal ethnic and occupational groups have above-average levels of fish consumption. In addition, interacting toxins from a multitude of point and non-point sources are transported along a variety of exposure paths to people and wildlife having very different levels of susceptibility. For example, toxins have developmental effects on children at lower effect thresholds than those for cancer in adults, and the effects can have a long latency. Therefore toxin exposure is a regional concern that crosses all boundaries, and environmental toxins can be considered a common property for management.

Adaptive responses to this problem have been inhibited by significant limits on data and on public access to that data, on the visibility and predictability of toxin body burdens and effects, on regulatory reporting requirements, and on funding for monitoring. The funding allocated to identifying and reducing toxin sources and exposure in the Columbia river basin have been historically inadequate to address the risks created by widespread toxin discharge. Toxin exposure pathways are now too complex to be managed adequately by existing agency staff, centralized management structures, scientific disciplines and jurisdictions of regulatory agencies in a basin that extends across state and national boundaries. As the former governor of Oregon said,

> The primary tools of this structure — law, regulation and enforcement — weren't designed to bring people together to solve problems. And they weren't designed to engage complicated problems, the resolution of which requires the voluntary participation of thousands and thousands of people. Reducing non-point-source pollution requires a change in behavior by thousands of individuals, many living in urban and suburban cities. The fact is: you can't do that through legislation, through litigation, or through enforcement. We have to find the wisdom and the courage to move beyond the government structures and tools that we inherited from the past, and create new ones to match the challenges that face us in the 21st century. (Ecotrust, 2005)

A key source of hope is the leadership of Columbia basin tribes based on their long tradition of sustainable management of the commons. While the benefits of toxin discharge have historically accrued to few, the costs continue to be paid by many, and both tribal and non-tribal residents have common cause in protecting their health. The challenge is to reawaken practices that can involve many in informed management of our new 'commons of environmental toxins' – an unwanted resource shared by many of us in our own bodies.

The Necessity of Participatory Learning and Action

The most direct opportunity for adaptive change in this system is to significantly increase the power of the most exposed and vulnerable citizens to reduce toxins through partnerships with multiple agencies on specific toxin reduction projects. The history of similar citizen efforts in the US is promising (e.g. Great Lakes and Hudson River), but no such effort has been undertaken in such a heavily-impacted, complex and profitable system as the Columbia River basin.

Such a participatory approach has two key challenges: for citizens to *assess* and to *act* in a technically complex system with significant differences in interests between those who pollute and those who are exposed. Assessment includes understanding the diverse effects of invisible chemicals on visible disease or developmental endpoints on a diverse local population, in particular those effects that require action. Action includes the skills among citizens, tribes, and other entities with a long-term commitment to reduce toxin discharge, media concentrations, and body burdens, in continual conflict with private profit interests. The major challenge is to therefore develop *an adaptive management system that enables the development of civic skills to effectively promote the health of all organisms in the local socio-ecological system*.

In conversations with tribal leaders, this strategy is captured by the concept of a “constructive methodology.” This is the strategy of presenting a positive, *constructive* vision for developing a less contaminated environment, through a stepwise *methodology* that involves all regional stakeholders– on the reservations, in the ceded lands, and beyond in reducing toxin discharge site-by-site. This vision of a positive, inclusive, regional plan has been expressed repeatedly by agency directors and Council members. A positive vision presents hope, and it strengthens community bonds when people share their goal of a traditional, integrated approach to human and ecological health with both tribal and non-tribal audiences, characterized by one young woman as “the Unity Project.” This vision is shared through methods such as the video, “Sacred Salmon: a gift to sustain life,” that presents current water and fish contamination within the context of the history of the Columbia River since creation (Yakama Tribal Fisheries, 2003). The most important skills needed to implement that vision are best management practices in all polluting industries, and tribal members can provide long-term leadership in that area due to their land tenure and history of sustainable management.

A Process Model

Figure 1 is a model of the process for beginning to develop these management skills to benefit people, wildlife and the environment, that was built by integrating extensive fieldwork with ecosystem and risk management models (e.g. Stanford 1996, Omenn 1997, EPA 2003, Suter et al 2003). It was presented in 2006 to the interagency/intertribal Columbiai River toxic reduction planning group and provides guidance through a cycle of eight partnership-based strategies which recognize that:

1. Adequate data exists to begin immediate action, but the data must be synthesized among sources in tribal, public health, wildlife, and environmental disciplines.
2. The problem and the definition of stakeholders are both framed too narrowly, and must include all affected people and other biota as participants, with a multi-generational planning horizon.
3. The gap in skills between citizens and professionals must be bridged to increase the number of leaders who can then increase the number of sites for toxin reduction.
4. Analysis of alternatives to existing industrial or agency practices is underdeveloped and results in small cosmetic changes, rather than fundamental institutional and operational changes.
5. Diverse stakeholders can take leadership roles by working with industries to design best management practices at many sites simultaneously.
6. The process of change requires collaborative learning by implementing new actions, often through trial and error.
7. Evaluating the results of change is necessary to identify essential knowledge to gain and to share.

8. The cycle continues, by synthesizing new information to identify new steps in an iterative process.

This cycle of eight steps has the affected stakeholders at the center to maximize decision-making by all affected individuals, particularly tribal members. The benefits and the consequences if that step is absent are shown in Table 1 below.

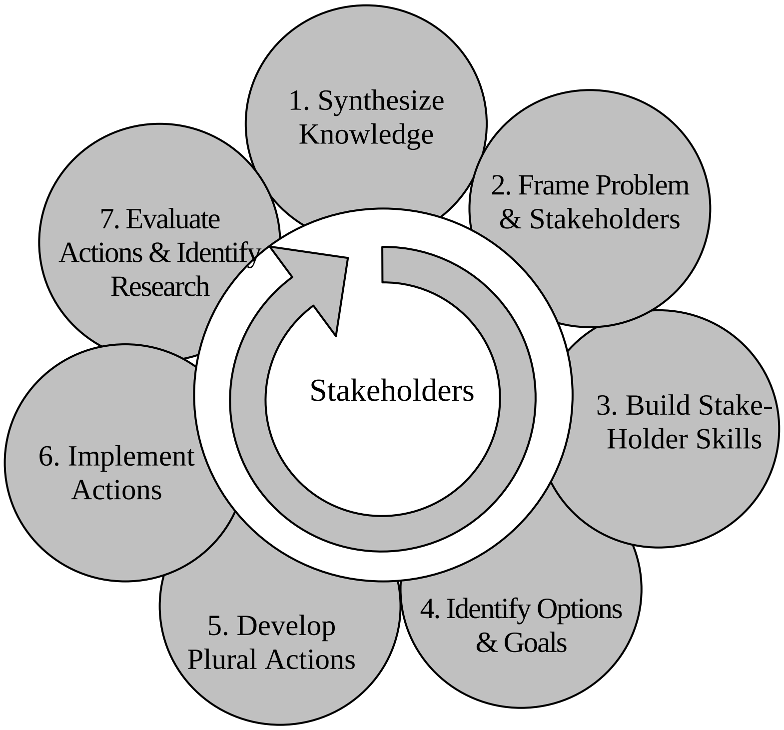

Figure 1. A socio-ecological health promotion model

Table 1. Steps for socio-ecological health promotion

1. Synthesize Knowledge	
Benefit	Integrate existing disciplinary knowledge on environment,

	wildlife and human health to begin immediate action; identify history leading to current contamination, interactions among individual, population and community levels, and propose actions based on strong inference.
If Absent	Individual professionals and citizens cannot access data across organizational and disciplinary boundaries; they cannot develop a unifying terminology, data standards, or reporting formats to enable comparative analyses; they lack ready access to all local data, and thus require certainty before acting.
2. Frame Problem & Stakeholders	
Benefit	Toxin pathways and effects are recognized as being distributed across time, space, biota, and levels of biological organization. Therefore, many racial and socioeconomic groups are stakeholders requiring informed consent and participation in decision-making.
If Absent	Decision-making is narrowly framed as a problem for agency managers to calculate acceptable risk based on cancer endpoints against benefits to society, and to manage that risk without sharing decision-making power.
3. Build Stakeholder Skills	
Benefits	Participants need skills for communicating across disciplines and cultures, and for building trust and friendship, to develop a shared

	conceptual model as the foundation for long-term collaboration. information about shared body burdens among people and other biota; conceptual models that clarify shared and separate interests across cultures, professions and classes; skills for decision-making among groups with power differentials; and building relationships for sustained action.
If Absent	Citizens cannot gain key information and skills to challenge the existing power structure. They cannot research or understand toxin effects on themselves or their children, and defer decision-making to others.
4. Identify Options and Goals	
Benefits	Participants can identify a wide range of alternatives to current practices in many sectors (e.g. institutional changes within organizations, best management practices in agricultural organizations, roles for agency watchdog groups) and integrate them to envision new strategies. These alternatives are often learned directly from practitioners in other regions or cultures.
If Absent	Participants can only describe the problem, its potential effects, and the responsible agency.
5. Develop Plural Actions Across Sectors and Levels	
Benefits	Best management practices are adapted to multiple sites in each locale, by semi-autonomous teams of citizens and professionals.

	Management is collaborative, failure is required to learn new skills, and this practice is supported by institutions. Institutions promote change at the community- and individual-levels, such as lifestyle changes to support wild salmon.
If Absent	Organizations resist outside involvement in their practices (e.g. advocating for policy changes), citizens resist more difficult roles (e.g. becoming more politically visible), professionals resist sharing their specialized knowledge, and centralized agencies resist delegating leadership to diverse teams working at multiple sites.
6. Implement Actions	
Benefits	New actions are piloted to learn their effectiveness, and cross-sector communication is encouraged to teach skills and reduce risk; structural change is an ongoing process that includes both small and large actions. Fear of change is reduced by sharing responsibility for new practices
If Absent	Organizational roles, reward systems, political alliances, and funding sources are implicitly based on maintaining current practices. Change agency and failure are not rewarded. Thus, real institutional change is inhibited by fear.
7. Evaluate Actions & Identify New Research	
Benefits	Initial actions are evaluated to reduce uncertainty by involving all

	stakeholders who pay costs or receive benefits, (e.g. advocates for children in an agricultural district; pesticide regulators). Key uncertainties identify new research needed.
If Absent	The entire group will not learn together from initial successes and mistakes, which will reduce efficiency in new actions. New research will not be cost-effectively targeted and outcomes validated. A record of successes and failures will not be available to other groups.
1. Synthesize New Knowledge	
Benefits	Synthesize the new knowledge and continue the iterative cycle by identifying new actions not taken in the previous cycle. The focus of this systems approach is to create a social system that responds to the ecological system. This is a major cultural change.
If not	This effort will become a campaign with an endpoint after which the status quo will return, instead of an ongoing process of cultural change.

Assessing Together

This cycle of seven institutions is based on a key practice: groups of affected people with diverse life experiences thinking and acting together. In its simplest form, thinking together involves finding common *categories* of experience that are integrated into shared *concepts* that drive action. Environmental contamination has been historically enabled through concepts such as acceptable risk, cancer endpoints, proof of causality, dilution of pollution, and others that form the basis for current regulatory actions. A new set of eight concepts for socio-ecological health promotion are based on shared categories of empirical knowledge in the lives of tribal and non-tribal residents of the Columbia river basin. Four concepts integrate ways of *assessing* relationships among people, wildlife, and the environment: Evolutionary Conservation, Interacting Stressors, Multiple Vectors, and Differences in Vulnerability. Four concepts integrate ways of taking *action* to benefit people and wildlife: Weight of Evidence, Integrated Management, Economic Transparency, and Civic Empowerment. The name of each concept is self-consciously technical, but can be easily translated into a common term.

Assessment Concepts

1. Evolutionary Conservation. A central principle of evolution and of the Circle of Life in Traditional Environmental Knowledge is the similarity among people and other species, a principle supported by the daily experience of both tribal and non-tribal fishers. In research involving hundreds of individuals, I consistently found that adults and young people identify many structural similarities between fish and people, that are also biologically valid (Pitcher 1992, Wootton 1999):

- Organs for sight, smell, hearing, touch, and taste.
- Structures for propulsion, respiration, digestion, and reproduction.
- Methods of navigation and social communication
- Life history stages from embryo to juvenile to adult
- Motivations of hunger, fear, reproduction, and aggression

- Behaviors of foraging, avoiding threats, competing for resources and reproductive opportunities
- Habitats that change with climate, altitude, season, or time of day, and that contain different microhabitat types and different prey species.
- Hierarchical social structures

These everyday observations of morphological and behavioral similarities are supported by more fine-scaled scientific data on the evolutionary conservation of hundreds of core physiological processes across vertebrates. From the beginning of life on earth, as key innovations emerged through the process of natural selection -- such as prokaryotic and eukaryotic cells, multicellularity and body plans -- key processes were conserved. These include DNA, metabolism, the cell nucleus and organelles, intercellular signaling, and compartments. These core processes are conserved across 30 phyla of animals, and many are even found in plants, fungi and bacteria (Kirschner & Gearhart, 2005). These processes include dozens of key chemical regulators conserved across vertebrates, such as acetylcholine, norepinephrine, dopamine, histamine, serotonin, melatonin, vasopressin, oxytocin, insulin, progesterone, testosterone, cortisol, thyroxine, and prostaglandins. These chemicals are involved in ecologically-relevant behaviors that include learning, polymorphism, sexual dimorphism, dispersal within habitats, schooling, migration, foraging, predator/antipredator behavior, communication, territoriality, dominance, mating systems, mate choice, and parental care (Adkins-Regan, 2002). Toxic chemicals interfere with these core chemical processes in similar ways across phyla. For example, current research in developmental toxicology using animal models relies on 17 intercellular signaling pathways conserved across most metazoans that include six pathways used before organogenesis and later for growth; four pathways used in organogenesis, cell differentiation and later for growth; and seven pathways used in larval and adult physiology (Klaasen & Watkins, 2003: 159). These similarities result in similar behavioral effects of toxins on people and fish, such as learning disabilities, attention problems, deformities, and changed neurotransmission. Applying evolution to ecotoxicology establishes a phylogenetically diverse set of “stakeholders” for toxin reduction in a region. Data on toxin effects across vertebrates can be combined to build a weight of evidence for integrating regulatory action for both human and wildlife health, and for reducing contamination of the entire Circle of Life rather than just reducing exposure to people or other species.

2. Interacting Stressors. When toxins and other environmental stressors such as poverty occur together, they often potentiate their effects on organisms, whether fish or people, increasing their allostatic load (Schulkin, 2004) These stressors include toxin body burdens, physical condition (e.g. low energy reserves from chronic hunger), health (e.g. organ function, toxin load) and environmental obstacles (eg. dams, poor habitat/housing). These stressors affect physiological processes (eg. stress hormones), behavioral endpoints (eg. learning, response to threats), and population/community structure (e.g. abundance and distribution; availability of high-energy food/health care).

Stress interactions between toxins and other environmental agents provide a strong rationale for extending our integration of fish-human similarities to bottom-up and top-down effects. However, as effects transfer between levels the interactions become more complex, and are thus difficult to discriminate and to model (Triebskorn 2003; Elliott & Wartenberg, 2004).

Nonetheless, cell or community-level stressor effects on fish and human fitness have a high degree of correspondence, as shown in Tables 2 and 3:

Table 2. Bottom-up stressor effects on fish and people

Level	**Response**
Cell	Activated metabolic enzymes; reduced energy storage; cell damage.
Individual	Organ structure/function, disease, infection risk, condition, stress protein
Behavior	Social & habitat interactions; learning, foraging, cue responses
Population	Decreased egg viability, fertilization rate, abundance; artificial selection
Community	Predator-prey interactions; food quantity/quality; biodiversity

Table 3. Top-down stressor effects on fish and people

Level	**Susceptibility Effects**
Community	Reduced habitat quality/quantity through competitive exclusion based on energy or money.
Population	More competition, distance & energy to find food & shelter, through increased distance for migration or commuting.
Behavior	Reduced ‘bang for bite,’ increased the need to make tradeoffs such as among safety, energy/money reserves, and food quality.
Individual	Reduced nutritional intake, growth, energy reserves, fecundity and offspring quality.
Cell	Reduced toxin excretion and cell repair; increased stress hormone signals and degeneration.

The long-term discharge of toxins and their bioaccumulation in human and wildlife tissue, and the simultaneous inhibition of adaptive responses by citizens and agencies to reduce toxin discharge, act together to reduce resilience of a socio-ecological system and to increase susceptibility to further health risks. When these conditions are distributed inequally among populations in a community, environmental injustice results for all affected organisms in the Circle of Life.

3. Multiple Vectors. Persistent toxins are akin to invasive species of chemicals that travel across many natural and political boundaries. For example:

- Mine tailings from the Tec Cominco mine in the Columbia River headwaters in Canada pollute the entire mainstem river in the U.S.;
- PBDEs from multiple sources such as septic systems in the Columbia River floodplain concentrate in breast milk. As a result, some of the worlds highest levels are found in healthy, middle class women in the Pacific Northwest;
- Global air currents carry mercury through cycles of deposition and re-suspension called the “grasshopper effect,” concentrating them in the Arctic;
- The World Trade Organization relaxed environmental standards on food, increasing US citizens’ exposure to toxins previously banned in the US, such as DDT.

The result of multiple vectors is the ubiquity of toxin exposure across boundaries of age, race and class. This means that reducing individual exposure is an inadequate strategy, and efforts must focus on prevention and reduction at many points in the toxin life cycle. This requires greater civic involvement of all socio-economic groups: in the decision-making process to market toxins, in the process of toxin manufacturing, in the transport and use of toxins, in the release of toxins into environmental media, and in their environmental fate until they are fully degraded. The concept of multiple vectors, and the economic and political resources of the chemical industry, illustrate the necessity for large-scale civic collaboration across many political and cultural boundaries in the Circle of Life.

4. Differences in Vulnerability. Differences in vulnerability to toxins are inevitable among individuals in a population due to differences in life histories and life stages, and therefore contribute to differences in the structure of populations in a community. Benthic-feeding fish, such as sturgeon in the Columbia River have reduced fecundity due to their toxin body burden, and Native people have increased body burdens due to increased consumption of sturgeon. Similarly, women and children exposed to agricultural chemicals from Northwest orchards, air pollution from urban sources, and toxins from mislabeled farmed salmon are at higher risk than older men. The differences in vulnerability are due to a limited number of factors in Table 4:

Table 4. Differences in Toxin Vulnerability for Fish and People

Source of vulnerability	**Fish**	**People**
Environmental stressors	Regulated River	Poverty
Gender: Female	Female to egg	Female to egg and fetus
Gender: Males	Sexual characteristics	Sperm viability
High-exposure Feeding	Benthic	Indigenous
Life Stage	Larval-Juvenile	Infant-Child
Location	Proximity to source	Proximity to source

Senescence	Increased disease risk	Increased disease risk
Top Consumer	Salmon	Fetus

Degradation of population fitness, such as through increased body burden of toxins in childbearing women or in spawning salmon, can have long-term effects on community structure. Currently, regulatory standards for the allowable amount of toxins in air, water, soil, food, and pharmaceuticals vary substantially, and often protect the average or the most-exposed individual. The long-term effect of toxins on communities requires that we place the highest value on the most vulnerable members of our communities and create regulations for their long-term protection, a key practice of Columbia river tribal communities.

Management Concepts

1. Weight of Evidence. Native communities in the Columbia Basin have long valued people, fish and other wildlife as being interdependent. Their management practices focus on reducing stressors for people and wildlife, using pre-contact conditions as a baseline to establish desired natural conditions. There is abundant data on the effects of toxins found in the Columbia River basin, individually and in combination. However, that data is widely scattered among studies on people in the public health literature, on fish in the biological literature, and on animal models of human health in the toxicological literature. A weight (or lines) of evidence approach would integrate this data to provide strong inferences about similar toxin effects on all taxa in a socio-ecological community. This approach has many benefits:

1. It can help infer causality. When toxins are discharged into media that mix and transport them, it is impossible to trace individual chemicals to a source. Causality can be inferred using:
    - Strength of association—there is a strong relationship between the stressor and the effect.
    - Consistency of association—the relationship between the stressor and the effect has been seen in other studies, especially in studies by other investigators.
    - Time order/temporality—the effect occurs only after exposure to the stressor.
    - Experimental evidence—controlled exposure to the stressors provide results that support the proposed causal relationship.
    - Biological plausibility—the proposed causal relationship has a credible toxicological basis.
2. It can enable us to take action with incomplete information. We can use studies on the effect of toxins on similar physiological processes in different taxa, to make inferences on toxin effects across taxa. Animal models can infer human effects, and vice-versa. We can also make inferences about synergies between toxins of the same classes, and about similar endpoints of exposure. Due to the many differences in physiological response to toxins between species and among individuals, responses will never be identical between groups. For example, toxicological studies are rarely replicated precisely. However, our goal is only to infer causality in order to reduce risk, and we simply need proof of toxicity beyond a reasonable doubt.
3. It can increase the valuation of toxin impacts. Toxin impacts on wildlife health are valued by diverse stakeholders for their consumption, sport, commercial, aesthetic, scientific, legal, cultural, ethical, spiritual and ecosystem values. Wildlife and human impacts, however, are

rarely integrated. However, as wildlife populations decline worldwide, regions that maintain healthy wildlife populations are finding that their economic value is significantly increasing.

4. Integrated Management. The life cycle of toxins is intimately linked with that of the natural world. Toxins are manufactured to help extract natural resources such as in mining, paper mills, and hydroelectric plants; to eliminate natural resources through herbicides, pesticides, and warfare agents; to transform natural resources through industrial and high-tech manufacturing; and to increase profits by discharging waste into an environment that cannot detect and immediately punish this practice.

We must make these links explicit in order to identify alternatives at each stage in the entire toxin life cycle, from the business decision to manufacture toxins for profit, to their final discharge into waterways to avoid the challenge and expense of transforming the waste into a biologically available product. Recent research on integrated assessment of toxin effects in human and ecological systems has focused on similar effects of toxins on people and other animals, and many potential areas of integration in risk assessment and management (e.g. Suter et al 2003). An integrated toxin reduction plan can benefit from analyzing the biological impacts on human and wildlife communities, to identify similarities, differences and sites of potential change in current toxin management practices, as shown in Table 5/Figure 2:

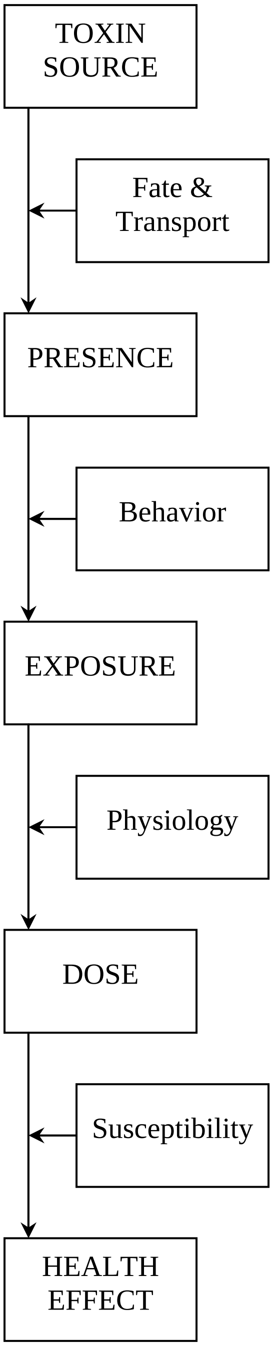

Figure 2: Biological Impact Pathway

Table 5. Toxin effects at each step

Human Community	Wildlife Community
Manufactured to eliminate plants, insects and wildlife, and to transform raw natural resources; waste discharged to externalize costs.	Toxins manufactured in much higher quantities, concentrations, and percentages of waste, than ever occur naturally.
Path includes decision, synthesis, manufacture, marketing, distribution, use, waste generation, and choice to discharge at specific location.	Toxins discharged into wildlife habitats; concentrate in media, biotransform through organisms; synergize with other compounds
Ubiquitous toxin presence and effects often deliberately hidden; detection methods under-developed; exposures often differ among populations	Concentrate in media sinks (e.g. dams) and in prey; result in tissue concentrations often greater than in humans, especially in top consumers.
Exposure influenced by lifestyle, location, consumption of food, water, and air. Knowledge of presence may lead to behavioral change, if possible.	Often cannot detect, or change behavior to avoid exposure; toxin-related behavioral changes may increase rate of consumption by predators.
Concentration & length of exposure uncontrollable - depend on location, occupation, socio-cultural practices, age, location, history and point in time.	Concentration & length of exposure uncontrollable - depend on proximity to sources and timing of discharge, habitat, species behavior, age, etc.
Path of toxins through body depends on age, weight, condition (e.g. body fat), metabolic rate, health, gender, immune condition, pregnancy, etc.	Path of toxins through body depends on physiological differences between individuals and species; some may act as sentinels for individual toxins
Toxin, concentration, length of exposure and individual variation determines site of toxin action; multiple toxins increase uncertainty.	Toxin, concentration, length of exposure and individual variation determines site of toxin action; multiple toxins increase uncertainty.
Location, age, developmental stage, gender, condition, disease, income, education, life ways, environmental stressors, health care access.	Age, developmental stage, gender, condition, disease, present of predators, habitat quality, habitat modification, presence of refugia.
Molecular, cellular, tissue and organ dysfunction and damage (e.g. cancer), developmental, learning, behavioral & reproductive changes; mortality	Molecular to organ dysfunction and damage; developmental, behavioral, learning & reproductive changes; mortality; population structure.

3. Economic Transparency.

Economic transparency means making information publicly available about local toxin sources, and the distribution of costs and benefits: who receives how much benefit from what toxins, and who pays costs, in what currencies and for what length of time? Currencies can include hypothetical "units" of children's learning and development, of impacts of health on family life, and extirpation of native wildlife. Economic transparency enables communities to explicitly compare monetized and non-monetized costs and benefits, to study their distribution among people and wildlife in a region, and to use that information to help guide decision-making. For example, large quantities of some commercial toxins such as chlorines and fluoride were created as by-products of the manufacture of other chemicals, such as caustic soda and phosphate fertilizer, and priced by the market against the cost of disposal, not against the cost to public health. Industry costs for providing information on chemical toxicity for the European Union REACH accountability program are estimated at 2.5 to 5.2 euros, while health benefits are estimated to be 50 billion euros. Similarly, costs for environmental remediation are commonly two orders of magnitude higher than costs for prevention. Therefore, making key data publicly available is an important first step toward changing the toxin lifecycle. For US citizens with limited awareness of history or geography, recognizing different interests between industries and citizens can significantly increase awareness of the shared interest of ordinary citizens across cultural and racial boundaries.

4. **Civic Empowerment.** In practice, civic empowerment is the distribution of different skills among individuals and populations to study local toxin use and to enforce changes to the current institutions for managing toxins. Few US citizens have experience participating in any form of politics, and less so in highly technical, regulatory conflicts. However, it is essential to give those who are most affected by toxin discharge an opportunity to share decision-making for toxin reduction. Civic empowerment includes:

- Political Participation. The inequity of power between citizens and industry has traditionally been balanced by government. As government becomes increasingly controlled by industry, citizens must increase their participation through knowledgeable coalitions, such as civic organizations, schools, and churches.
- Leadership Development. The complexity of environmental health requires developing teams who can specialize and become leaders in key areas, to distribute efforts and rewards.
- Long-term Planning. The persistence of toxins and the resistance of industry require focusing on stable institutions that can be sustained for generations.

Socio-Ecological Systems: Integrating People and Wildlife at Multiple Levels

A model for participatory action such as the seven stages presented above, requires sharing key concepts for assessment and management such as the eight described above. Applying those eight concepts requires a shared understanding of a local socio-ecological system. In the Columbia River basin, integrating fish and people, state and federal agencies, professionals and citizens requires a conceptual framework that is simple enough to be widely understood and yet open enough to represent data from a variety of disciplines. Because toxin paths and effects are organismal, the diagram in Figure 3 frames the biotic interactions among people, wildlife, and the environment through which toxins are transported.

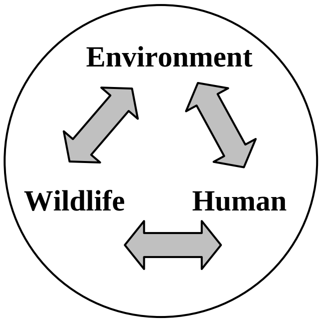

Figure 3: A simple diagram of organismal interactions

These three components interact at each of three interacting levels:

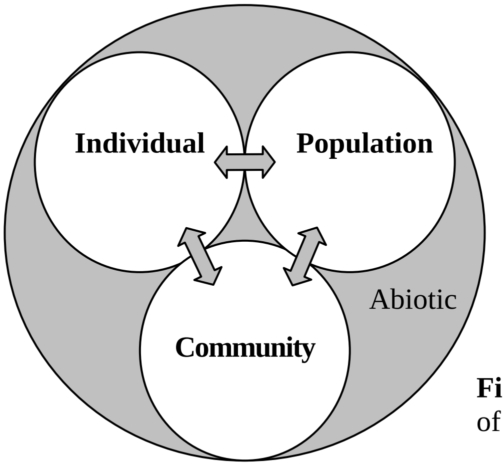

Figure 4: A simple diagram of interacting levels.

A level-based framework, such as commonly used in ecosystem assessment, is appropriate for integrated risk management due to the similarities in interactions and rates of change at each of the spatio-temporal scales, from the cellular/individual, to the population/guild, and the community/ecosystem.

The individual level at the temporal-spatial scale of 10^{-1}to10^{1} contains the biochemical to the behavioral, and includes individual and family/cohort behaviors that affect exposure, susceptibility and interactions with other closely related individuals. The population level at the scale of 10^{2} to 10^{3} includes extended families, workplace and other social interactions, fish stocks and evolutionarily significant units, and toxin effects that differentially affect defined groups (eg. those with high fish consumption rates). The community level at 10^{4} to 10^{6} is the scale at which most toxin discharges occur, bioaccumulation through trophic interactions, and actions by which one human population imposes increased risk on another (e.g. environmental justice).

As a working framework for integrating human and ecological interactions for collaborative action, three levels are most appropriate because they are the primary levels for management action: at the individual level (changes in health, lifestyle), at the population level (differences in food consumption and location), and at the community level (regional discharges and transport of contaminants). The combination of three categories of stakeholders, and three levels, allows 27 different types of interactions within and across levels, to help organize a complete description of all easily observable toxin interactions.

This framework is useful for illustrating and analyzing the systemic effect of toxins. All individuals and populations of all species face increasing risk to their health, and toxin effects at many levels cascade up and down through systems at many scales. Tables 6 and 7 are two of a set of 12 tables that include three sets of interactions at each of three levels, and three sets of interactions across levels. These interactions can be simply and systematically isolated to help analyze the problems and the opportunities for action specific to those interactions, while maintaining the overall context.

Table 6. Interactions at the level of the individual (gene to similarly-exposed family/cohort):

Individual-Level Environment	The microhabitat of the fish; the individual human microhabitat (e.g. home, workplace) and the individual ecological footprint distributed across other habitats that are sources of exposure.
Health of the Environment at the Individual level	The overall condition of that microhabitat or footprint including ecosystem services worth preserving, toxins, and other stressors.
Environmental Effects on the Health of the Individual **Human**	Habitat qualities (e.g. natural amenities), stressors (e.g. substandard housing), and toxin exposure pathways (e.g. drinking, breathing).
Environmental Effects on the Health of the Individual **Fish**	Habitat qualities and stressors (e.g. temperature, DO, dams), and direct exposure through eating, drinking, gills and skin.

Table 7. Community interactions with other levels

Community-Level Interactions	The cumulative interactions of all organisms in a region at a time; produce services including biomass and nutrient cycling; develop and enforce institutions to protect ecosystem services, and mediate population-level conflicts.
Community effects on **Individuals**	Patchy regional sources of multiple, synergistic toxins cause differential individual exposures; community level institutions may not be accessible or responsive to individuals.
Community effects on **Populations**	Community processes affect human/fish population diversity, evenness, richness and trophic structure; institutions address differential toxin effects among populations; institutions may inhibit population action due to lack of information or legal regimes (e.g. treaties).

Conclusion

A systems approach based on interspecies interdependence can be a central organizing concept for integrating multi-disciplinary sciences and cultures. This concept is based ecologically on the hundreds of evolutionarily conserved core physiological processes among people and other vertebrates, many homologous and analogous anatomical structures and functions, and similar adaptive behaviors. Due to evolutionary conservation and convergence, environmental stressors affect people and other vertebrates in similar ways from the cellular to the community levels. We can therefore extrapolate data on stressor endpoints and adaptive strategies among people and wildlife to build a weight of evidence to reduce toxins by enforcing regulations in the environmental, wildlife, and public health disciplines as an integrated whole. Developing this concept in diverse groups requires identifying key concepts, and simple yet inclusive conceptual models. Collaborative learning and adaptive co-management among affected citizens and professionals, across disciplines and cultures, can help initiate many sites for actions to reduce toxins, thereby increasing society's ability to respond to ecological threats.

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