A Landscape Risk Assessment Framework for Salmon:

A generalized approach and annotated bibliography to assess ecological risk to wild salmon associated with resource and urban development in Alaska

Abstract: Ecological risk assessment (ERA) has become an essential tool for evaluating impacts to biological systems associated with wide range of human activities. Several applications of ERA methodology have been developed to analyze potential risks to wild salmon systems in Alaska, including risks associated with potential large-scale mining in Bristol Bay, as well as risk associated with large-scale hydropower on glacial rivers in Alaska. The purpose of this type of analysis is to improve understanding of the likelihood, magnitude and geographic scope of potential stressors associated with development. In the case of salmon, the framework considers key ecological functions that support all freshwater life-stages of salmon, including in-migration, spawning, incubation, rearing and out-migration. A generalized list of potential stressors included loss or alteration of freshwater habitat, changes in water quality, sedimentation, acid mine drainage, as well as small- and large-scale pollution events. While it is not possible to predict future conditions with certainty, this conceptual framework provides a systematic approach to evaluate the potential scope and severity of a range of risk factors, as well as potential effects on ecological systems that support salmon, to inform decision-making and risk management. The purpose of this review is to provide a brief synopsis of this approach as it has been applied in Alaska related to large-scale mining and hydropower development, and a brief bibliogrpahy of literature on potential future applications in the context of community residential, urban and industrial development.

Summary of Risk Assessment Approach:

The methodology of ecological risk assessment is flexible, compatible with a wide range of approaches to conservation planning, and is well suited to a range of applications in Alaska. Typical steps includes: (1) problem formulation; (2) analysis; (3) risk characterization; and (4) risk management, with analyses designed to characterize both the exposure to ecological stressors and the effects of those stressors on target species and systems (Fig. 1; Suter 2006).

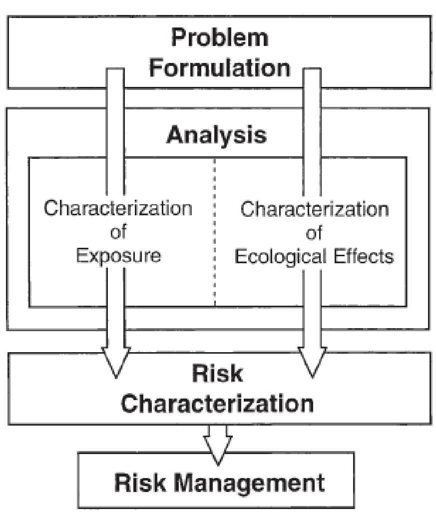


Figure 1. Framework for ecological risk assessment (Modified from USEPA, 1992.)

Problem Formulation: A conceptual framework of potential physical and chemical stressors and identification of biological and other resource potentially at risk.

Characterization of Exposure: Estimation of the likelihood, spatial distribution, timing and magnitude of potential changes in ecological attributes that support salmon such as stream flow, ground water, stream temperature, water chemistry, etc. In a predictive risk assessment, this step develops estimates based on analogous examples in the scientific literature and on physical, chemical and hydrologic models of site-specific conditions.

Characterization of Ecological Effects: A systematic review of ecological requirements and effects of potential stressors on target species and systems (e.g., toxicity thresholds), as well as site-specific factors that mediate biological response.

Risk Characterization: A quantitative characterization of risk would involve a spatial overlay of predicted exposures to ecological stressors with estimated thresholds of effect on target species and systems over a range of reasonably foreseeable scenarios. These comparisons provide the basis for evaluation of the likelihood and degree of risk for scenarios under consideration. A range of methods have been developed for such assessment, including qualitative Relative Risk Method (Landis 2003) and more quantitative stressor-based risk analyses (e.g., spatial analysis of copper concentration vs. toxicity thresholds).

Salmon Life History and Implications of Conservation Planning:

A systematic framework for conservation of wild salmon ecosystems must account for all phases of the salmon life cycle. Each phase is a necessary link in the chain that maintains healthy populations over time. While the salmon reliance on freshwater habitats for spawning and rearing has contributed to their success, it also makes them vulnerable to disturbance by people. By understanding the ecological requirements of each life phase, we can better manage human activities to ensure the continued diversity and productivity of salmon systems.

The basic aspects of a salmon life cycle have been widely documented (e.g., Quinn 2005), but a basic summary here will suffice. The mature adults return to spawn in the rivers and streams they were born, which involves laying their eggs in a nest of gravel and then they die. The eggs require clean gravel, without too much fine sediment, to allow adequate flow of water through the redd. This continuous supply of water, both from surface flow and ground water, is critical to provide dissolved oxygen and to prevent the redd from drying or freezing during the winter. After a few months, the eggs hatch, and an intermediate life stage called an "alevin" emerges, and seeks shelter deeper in the gravel often moving in the direction of their supply of dissolved oxygen. Remember, this is happening during the winter when rivers in Alaska are typically frozen over, so sufficient ground water remains critical for survival at this time.

The free-swimming juvenile salmon that emerge from the gravel are called "fry". Juvenile salmon may spend several years in freshwater, so sufficient food, protective cover, adequate stream flow, habitat to survive the winter, and connectivity throughout the watershed all are important during this time. The goal of this phase is for juvenile salmon to grow large enough that they'll have a better chance to survive once they leave the freshwater and enter the marine environment. Salmon behavior during this period varies widely by species as well as within species and even populations. Typically pink and chum salmon emigrate directly to the salt water in their first summer, sockeye salmon will rear in lakes, king salmon in larger streams and coho are widely distributed throughout the watershed. These are the typical life history strategies, but a high degree of variability within each species and within populations is a key to the resilience of salmon in a changeable environment.

Ultimately, juvenile salmon will leave their home rivers and enter a period of transition as "smolt". This involves a complex physiological transformation from a freshwater to a saltwater dwelling creature. They'll often use the mixed fresh and saline waters and higher productivity of the estuary to prepare for a life at sea. Adult salmon will spend a number of years at sea, depending on the species, where growth is very rapid and they travel vast distances around the north Pacific. The life cycle completes itself when the maturing adults return to their natal streams to breed and die.

The particular fact that salmon die after spawning is a key aspect of their ecology. All their life's energy is invested in a single clutch of large, well-developed eggs. Their bodies fertilize the streams where their young will emerge and grow, thereby improving the fitness of their own offspring. In this way, salmon represent a self-sustaining, positive-feedback delivery system of nutrients from the ocean to the relatively nutrient-poor streams and lakes of Alaska. The abundance of salmon we see in Alaska's rivers today, and that used to occur in rivers throughout the Pacific Northwest, is the result of this positive feedback over millennia. Without that abundance, as in cases where salmon have declined to very low levels, the entire ecosystem, including the food and economic opportunities for its people, is changed.

Last, the strong homing ability of salmon that brings them back to their natal streams means that breeding populations become finely adapted to local conditions, including seasonal temperature, flooding and freezing, and availability of various habitats. This localized diversity within larger populations is an important element of their long-term success and productivity, and provides stability in salmon fisheries over time.

This concept of an "ecological portfolio" has important implications for how we think about salmon conservation in Bristol Bay: This is the portfolio that provides high sustained salmon production over time. It functions similar to a financial portfolio, in that the breeding populations within any stream will be more variable, but the sum-total of returns averaged across many streams will be more stable. It is diversified, in that populations in different parts of the watershed are adapted to a diversity of local environments, which makes the larger salmon system more resilient to large-scale disturbance such as climate change. This level of diversity in Bristol Bay, particularly within sockeye populations, is unique in the world, and can be considered a form of "natural capital" that contributes to the overall value of the portfolio. Another aspect of this "natural capital" is the unique hydrologic system within these watersheds: wetlands, groundwater, river habitats, large lakes and overall productivity.

What salmon need:

Each phase of the salmon's life history is critical to maintain populations, and diversity among populations contributes to the long-term stability of salmon within the region.

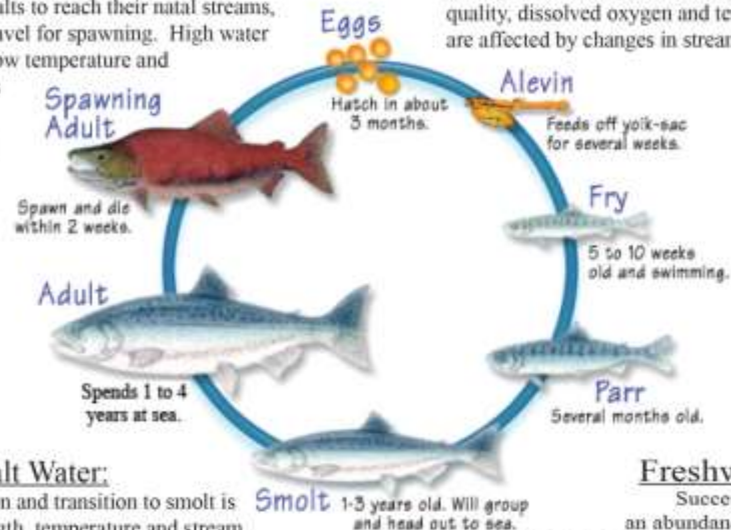
Life History Requirements:

Upstream migration and spawning:

This phase requires adequate stream flow and connectivity for adults to reach their natal streams, and high quality gravel for spawning. High water quality, including low temperature and dissolved oxygen is also critical for spawning success.

Incubation and Emergence:

Inter-gravel life stages are strongly influenced by gravel quality, dissolved oxygen and temperature, all of which are affected by changes in stream flow and ground water.



Transition to Salt Water:

Downstream migration and transition to smolt is controlled by day-length, temperature and stream flow. Radical physiological changes make this stage particularly vulnerable to environmental stress.

Freshwater Rearing:

Successful rearing requires an abundance of food and cover, and suitable habitat for over-winter survival. This includes a balance of deep pools and shallow riffles, riparian vegetation and adequate stream flow affect stream productivity to support rearing salmon.

Population Diversity:

A recent publication in the journal Nature demonstrated that high diversity among wild sockeye populations throughout Bristol Bay basin contributes to the long-term stability of salmon fisheries (Schindler et. al 2010), and that the absence of such diversity would make fishery closures much more frequent.

This is an example of the "portfolio effect" where biological diversity provides ecosystem stability, and increased returns in the value of ecosystem services over time.

Schindler, D. E. et al. 2010. Population stability and the portfolio effect in an exploited species. Nature 635: 609 - 613.

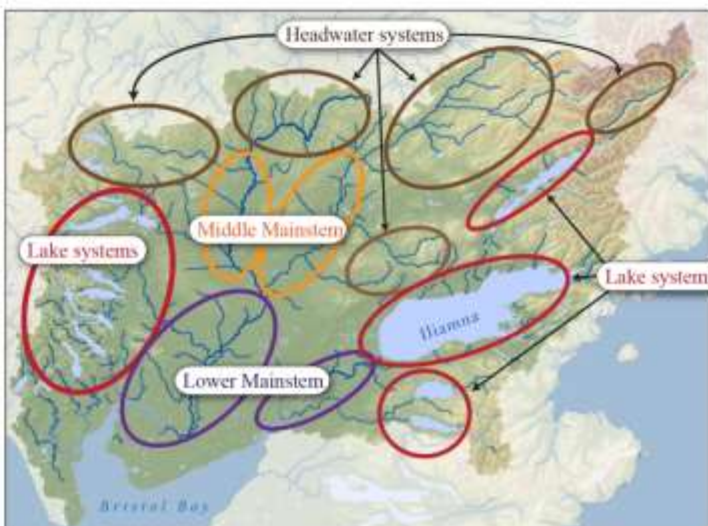


Figure 1. Large-scale diversity within the Nushagak and Knichak watersheds contribute to diverse salmon populations and life-history strategies.

Key Ecological Attributes

Key ecological attributes are the conditions necessary for each phase of the salmon life cycle to be successful. While specific attributes and critical values necessary to support survival and reproduction will vary according to species, a general set of attributes can be described related to water quality, water quantity, connectivity and habitat structure. This framework provides a template to evaluate potential risks to salmon across a wide range of potential topics, including large-scale mining (E&E 2010, EPA 2014), hydropower development (Anchor QEA 2014), forestry and urban development.

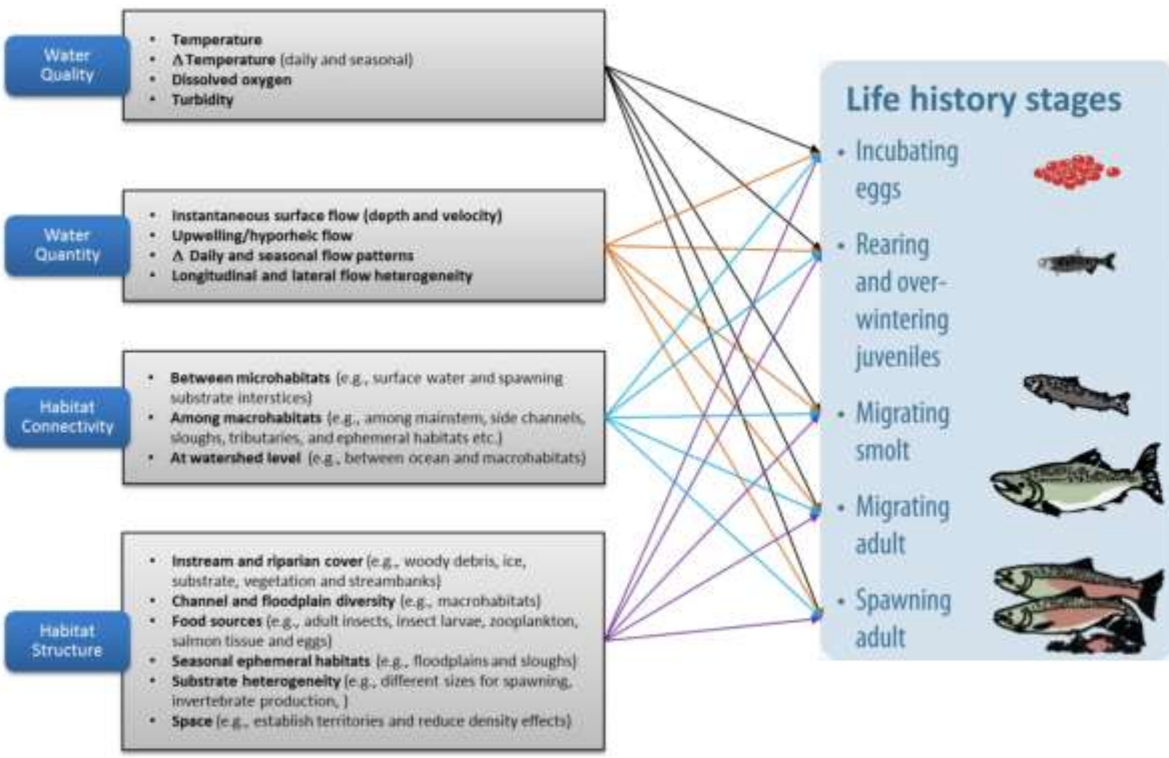
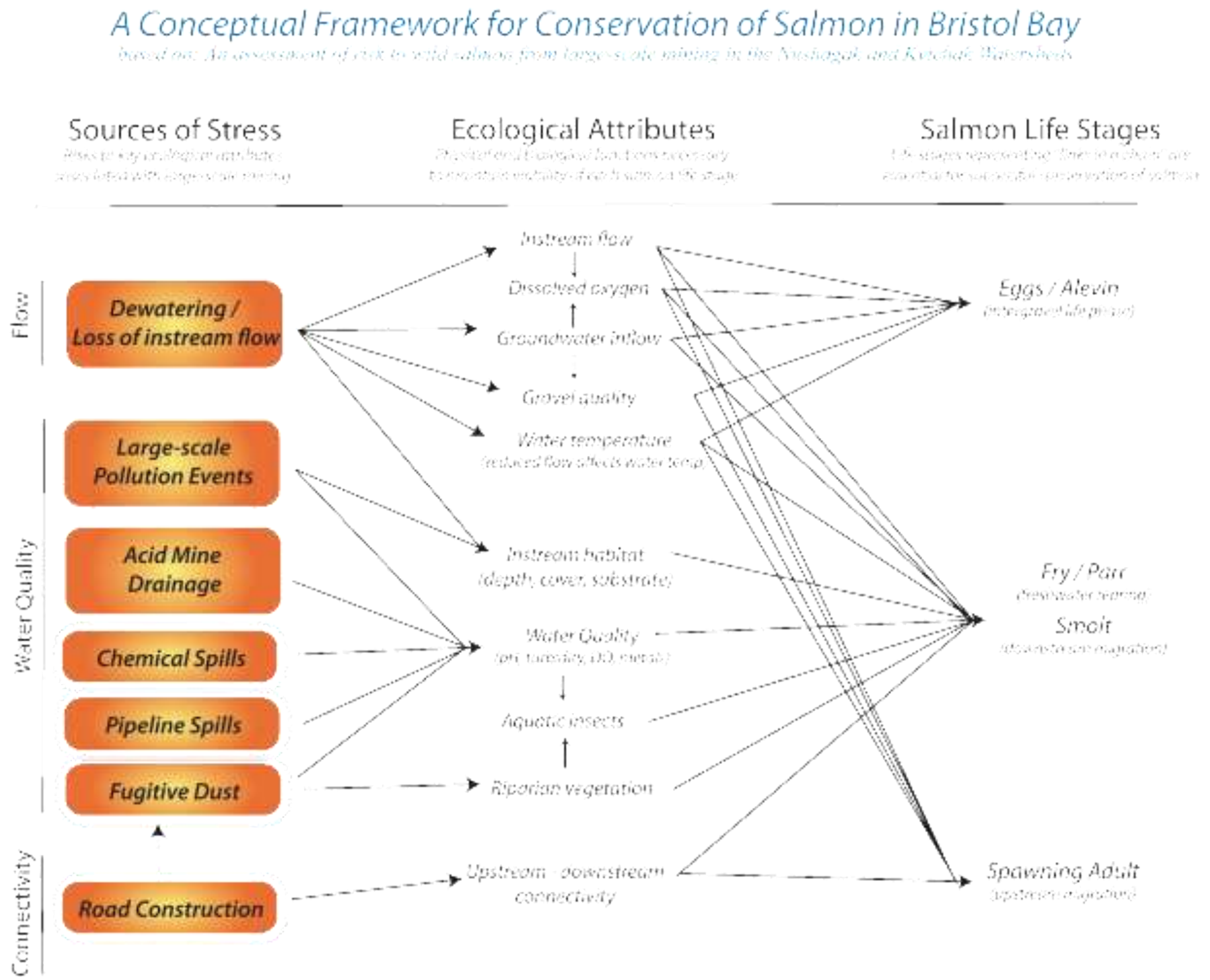


Figure 2. A generalized framework of key ecological attributes associated with specific phases of salmon life history (From: Anchor QEA 2014).

Characterization of Exposure and Sources of Stress:

The example below illustrates this generalized framework as applied to assessment of risk to wild salmon from large-scale mining in Bristol Bay (E&E 2010). For simplicity, life stages were grouped into (1) inter-gravel development, (2) freshwater juvenile phases and (3) returning adult phase. In the center column, we list key attributes of the environment that are necessary for the successful completion of each life stage (illustrated by arrows), and thus for the long-term viability of the target population. At left, we illustrate relationships of potential sources of stress identified as part of the Risk Assessment with each ecological attribute. These are general in nature to portray a simplified overview. This type of framework to assist in conceptualizing the detail necessary to complete an ecological risk assessment, and potentially a tool for planning strategic conservation actions.



In 2013, the Mat-Su Salmon Partnerhsip updated a conservation action plan for the Matanuska and Susitna Basin in Southcentral Alaska (Smith & Speed 2013). This area is characterized by diverse and generally abundant populations of salmon and trout, and is among the fastest growing communities in the nation according to the 2010 census. As a result, a number of potential stressors that have been associated with decline of salmon populations in other areas are present in the Mat-Su, including development of roads and infrastructure, residential development, water withdrawals, septic and wastewater contamination and stormwater runoff.

Table 6. Most Significant Impacts from Potential Threats to Salmon Habitat

	Potential Threats to Salmon Habitat									
Impacts to Salmon Habitat	Climate Change	Development in Estuaries & Nearshore Habitats	Ground & Surface Water Withdrawals	Household Septic Systems & Wastewater	Aquatic Invasive Species	Large-scale Resource Development	Motorized Off-road Recreation	Residential, Commercial, & Industrial Development	Roads and Railroads	Stormwater Runoff
Alteration of riparian areas						■	■	■		
Filling of wetlands		■				■		■	■	
Degradation of water quality	■			■		■				■
Impairments to fish passage						■			■	
Loss or alteration of water quantity	■		■			■				■
Loss of estuaries and nearshore habitats		■				■				
Alteration of native plant & animal communities	■				■					

Table 1. Potential sources of stress and effects on salmon habitat identified in the Mat-Su Salmon Partnership Strategic Action Plan (from Smith and Speed 2013).

As a foundation for future planning of community and industrial development to be compatible with maintaining healthy salmon habitat and populations, we have compiled this annotated bibliography of studies specifically associated with salmon in urban settings, and associated applications of ecological risk assessment framework to conservation of salmon ecosystems.

Abson, D. J. and M. Termansen (2009). "Valuing Ecosystem Services in Terms of Ecological Risks and Returns." Conservation Biology **25**(2): 8.

The economic valuation of ecosystem services is a key policy tool in stemming losses of biological diversity. It is proposed that the loss of ecosystem function and the biological resources within ecosystems is due in part to the failure of markets to recognize the benefits humans derive from ecosystems. Placing monetary values on ecosystem services is often suggested as a necessary step in correcting such market failures. We consider the effects of valuing different types of ecosystem services within an economic framework. We argue that provisioning and regulating ecosystem services are generally produced and consumed in ways that make them amenable to economic valuation. The values associated with cultural ecosystem services lie outside the domain of economic valuation, but their worth may be expressed through noneconomic, deliberative forms of valuation. We argue that supporting ecosystem services are not of direct value and that the losses of such services can be expressed in terms of the effects of their loss on the risk to the provision of the directly valued ecosystem services they support. We propose a heuristic framework that considers the relations between ecological risks and returns in the provision of ecosystem services. The proposed ecosystem-service valuation framework, which allows the expression of the value of all types of ecosystem services, calls for a shift from static, purely monetary valuation toward the consideration of trade-offs between the current flow of benefits from ecosystems and the ability of those ecosystems to provide future flows.

AnchorQEA (2014). Phase 1 Executive Summary: Preliminary framework for ecological risk assessment of large-scale hydropwer on braided rivers in Alaska. Prepared for The Nature Conservancy. Wenatchee, WA, Anchor QEA**:** 32.

Arkoosh, M. R. and T. K. Collier (2002). "Ecological risk assessment paradigm for salmon: analyzing immune function to evaluate risk." Human and Ecological Risk Assessment **8**(2): 265-276.

Wild Pacific salmon populations are in serious decline, and as a result, a number of salmon stocks are listed as threatened or endangered under the Endangered Species Act. Our research identifies and supports the possibility that certain environmental contaminants can alter salmon survival, and as a result may contribute to these species being at risk. We have shown that juvenile chinook salmon (Oncorhynchus tshawytscha) are exposed to polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) as they migrate through a contaminated urban estuary in Puget Sound WA (the Duwamish Waterway estuary). Immune function was analyzed in these fish by examining the ability of their anterior kidney and splenic leukocytes to produce a primary and secondary

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in vitro plaque-forming cell (PFC) response to the hapten, trinitrophenyl (TNP), and by determining their susceptibility to a marine pathogen, Vibrio anguillarum. We found that fish outmigrating from the urban estuary produced a significantly lower PFC response to TNP and were more susceptible to the pathogen, compared to juvenile salmon collected from a rural estuary during their outmigration. In the laboratory, we exposed juvenile chinook salmon collected from a hatchery to either a PCB technical mixture or a PAH compound to determine if these contaminants have the potential to alter immune function in salmon. Indeed, we found that salmon exposed in the laboratory to either the PCB mixture or the PAH also produced lower PFC responses and were more susceptible to disease compared to animals treated with the solvent vehicle. In summary, contaminants such as PAHs and PCBs are demonstrated to influence salmon health, and thus have the potential to adversely impact salmon populations.

Armanini, D. G., N. Horrigan, et al. (2010). "Development of a benthic macroinvertebrate flow sensitivity index for Canadian rivers." <u>River research and applications</u> **27**(6): 723-737.

Widespread alteration of flow regimes requires guidelines for the protection of river ecosystems based on sound science. Preservation of the biodiversity within river ecosystems and sustaining natural ecological functions are key aspects of their management. However, the relationship between the biota and flow-related phenomena is poorly understood and, as a consequence, over-simplistic hydrology-based guidelines for river management have been adopted without establishing clear indicators of success. In the present paper, we aim to support the improvement of guidelines for flow (current velocity) management by developing a flow sensitivity index based on macroinvertebrates for Canadian rivers. Using benthic macroinvertebrate samples collected by the Canadian Aquatic Biomonitoring Network (CABIN), current velocity preferences for the 55 most common invertebrate taxa across a range of reference and potential reference sites were derived. A Canadian Ecological Flow Index (CEFI) was developed based on these preferences. By testing the index against independent data, CEFI was found to respond mainly to changes in hydraulic conditions, and was minimally influenced by confounding factors (e.g. stream type, organic enrichment). The index was further validated using two independent data sets from the west and east of Canada, suggesting countrywide applicability of the method. In conclusion, we have developed a practical approach to evaluate relationships between hydrological regime and an important component of the river biota, permitting the development of an index which has good potential as an indicator for the effects of flow alteration. Moreover, we outline how the CEFI could be used as a tool for the development of holistic guidelines for the estimation of riverine flow needs.

Bayley, P. B. (2002). "A review of studies on responses of salmon and trout to habitat change, with potential for application in the Pacific Northwest." Report to the Washington State Independent Science Panel, Olympia, Washington.

An inspection of abstracts from 2,350 references produced a first-cut set of 441 studies and reviews that were subsequently classified and reviewed with respect to their potential to document responses of salmonids to habitat changes, and to guide future monitoring of salmonid watersheds. Although the literature on habitat requirements is vast, it was necessary to distinguish between studies that relied on correlations based on observational designs and those which attempted experimental designs to test cause-and-effect mechanisms. Our understanding about environmental effects on fish is largely based on weak inferences from observational studies, which has a direct bearing on monitoring strategies. Such studies are useful in generating hypotheses on cause-and-effect, but such hypotheses need to be tested through appropriate experimental designs in the context of a validation monitoring approach. Findings from seven reviews (1988-2002) were assessed jointly with specific studies. Articles from 30 studies were reviewed, drawing from single or multiple streams, and purely observational or ‘natural experiment’ designs, in order to assess what improvements are needed in future programs. Relatively few studies were long term or from multiple watersheds; most studies were of one year or spanned a single generation. Although large-spatial scale, short-term studies have increased and provided insight into clustering of populations and dependency on environmental indicators at broader scales, there is no indication of the extent to which space can be traded for time when making inferences. The main technical deficiencies were the lack of concern about unbiased density estimates and poor statistical design, analyses and reporting. Analyses that simulate alternative sampling processes and expected biases in stream networks over time and space would help resolve some of these deficiencies. Overall, I concluded that current freshwater-based monitoring programs will either: (1) fail to indicate an improvement associated with stream habitat restoration in terms of smolt recruitment, returning adults, or population size increase at the watershed scale, or (2) indicate an improvement but fail to demonstrate which and how habitat changes were responsible so that subsequent restoration policy could be made more cost-effective. Recommendations for approaches to a large-scale monitoring design, based partly on this review are presented. The first-cut list of references, with abstracts and classification codes, is available electronically from the author.

Beechie, T., H. Imaki, et al. (2012). "Restoring salmon habitat for a changing climate." River research and applications **29**(8): 939-960.

An important question for salmon restoration efforts in the western USA is ‘How should habitat restoration plans be altered to accommodate climate change effects on stream flow and temperature?’ We developed a decision support process for adapting salmon recovery plans that incorporates (1) local habitat factors limiting salmon recovery, (2) scenarios of climate change effects on stream flow and temperature, (3) the ability of restoration actions to ameliorate climate change effects, and (4) the ability of restoration actions to increase habitat diversity and salmon population resilience. To facilitate the use of this decision support framework, we mapped scenarios of future stream flow and temperature in the Pacific Northwest region and reviewed literature on habitat restoration actions to determine whether they ameliorate a climate change effect or increase life history diversity and salmon resilience. Under the climate change scenarios considered here, summer low flows decrease by 35–75% west of the Cascade Mountains, maximum monthly flows increase by 10–60% across most of the region, and stream temperatures increase between 2 and 6 C by 2070–2099. On the basis of our literature review, we found that restoring floodplain connectivity, restoring stream flow regimes, and re-aggrading incised channels are most likely to ameliorate stream flow and temperature changes and increase habitat diversity and population resilience. By contrast, most restoration actions focused on in-stream rehabilitation are unlikely to ameliorate climate change effects. Finally, we illustrate how the decision support process can be used to evaluate whether climate change should alter the types or priority of restoration actions in a salmon habitat restoration plan.

Beier, P. and B. Brost (2009). "Use of Land Facets to Plan for Climate Change: Conserving the Arenas, Not the Actors." Conservation Biology **24**(3): 9.

Even under the most optimistic scenarios, during the next century human-caused climate change will threaten many wild populations and species. The most useful conservation response is to enlarge and link protected areas to support range shifts by plants and animals. To prioritize land for reserves and linkages, some scientists attempt to chain together four highly uncertain models (emission scenarios, global air–ocean circulation, regional circulation, and biotic response). This approach has high risk of error propagation and compounding and produces outputs at a coarser scale than conservation decisions. Instead, we advocate identifying land facets—recurring landscape units with uniform topographic and soil attributes—and designing reserves and linkages for diversity and interspersion of these units. This coarse-filter approach would conserve the arenas of biological activity, rather than the temporary occupants of those arenas. Integrative, context-sensitive variables, such as insolation and topographic wetness, are useful for defining land facets. Classification procedures such as k-means or fuzzy clustering are a good way to define land facets because they can analyze millions of pixels and are insensitive to case order. In regions lacking useful soil maps, river systems or riparian plants can indicate important facets. Conservation planners should set higher representation targets for rare and distinctive facets. High interspersion of land facets can promote ecological processes, evolutionary interaction, and range shift. Relevant studies suggest land-facet diversity is a good surrogate for

today's biodiversity, but fails to conserve some species. To minimize such failures, a reserve design based on land facets should complement, rather than replace, other approaches. Designs based on land facets are not biased toward data-rich areas and can be applied where no maps of land cover exist.

Bella, D. A. (2002). "Salmon and complexity: challenges to assessment." Human and Ecological Risk Assessment **8**(1): 55-73.

Salmon in the U.S. Pacific Northwest are in widespread decline despite countless environmental assessment studies and billions of dollars spent. Having been involved in environmental assessment for more than three decades, I am forced to conclude that this decline tells us that our established practices of assessment and management are fundamentally deficient. Rather than studying the salmon, we should examine our own practices. These practices presume that, if individual actions are found to be beneficial through analytical assessments, the cumulative outcomes of many actions will also be beneficial. This "linear" presumption is embedded in institutions, analytical methods, and assessment practices. For a whole class of emerging problems, including declining salmon, this presumption is fundamentally wrong. Declining salmon provide a warning that our own analytical habits of thought and notions of progress are leading to outcomes that are both destructive and contrary to our best intentions. This paper is a response to this warning.

Boulton, A. J. (1999). "An overview of river health assessment: philosophies, practice, problems and prognosis." Freshwater Biology **41**(2): 469-479.

Philosophicallky, the term 'river health' is useful because it is readily interpreted by the general public and evokes societal concern about human impacts on rivers. The common goal of acheiveing healthy rivers unites ecologists and the general public because the value of ecologists' contributions is clear (and, hence, funded). The difficulty arises in the cohice of relevant symptoms because there is a wide variety that cna be measured with varying accuracy at a broad range of spatial scales. These indicators may respond to impacts at different time scales, and no single indicator is a 'silver bullet' that reveals river health unequivocally.

Brierley, G., K. Fryirs, et al. (2002). "Application of the River Styles framework as a basis for river management in New South Wales, Australia." Applied Geography **22**(1): 91-122.

If strategies in natural resource management are to 'work with nature', reliable biophysical baseline data on ecosystem structure and function are required. The River Styles framework provides a geomorphic template upon which spatial and

temporal linkages of biophysical processes are assessed within a catchment context. River Styles record river character and behaviour. As the capacity for a river reach to adjust varies for each style, so too do management issues and associated rehabilitation programmes. The framework also provides a basis for assessing geomorphic river condition and recovery potential, framed in terms of the evolutionary pathways of differing River Styles in the period since the European settlement of Australia. Within a catchment context, the River Styles framework provides a unified baseline upon which an array of additional information can be applied, thereby providing a consistent framework for management decision-making. The framework was developed as a research tool by geomorphologists working in collaboration with the New South Wales Department of Land and Water Conservation, which has used it for a range of river management applications. Target conditions for rehabilitation programmes are framed within a catchment vision that integrates understanding of the character, behaviour, condition and recovery potential of each reach. A prioritization procedure determines the most cost-effective and efficient strategies that should be implemented to work towards the catchment vision. In addition, the River Styles framework is being used to identify rare or unusual geomorphic features that should be pre-served, assess riparian vegetation patterns and habitat availability along river courses, and derive water licensing, environmental flow and water quality policies that are relevant to river needs in each valley. Based on these principles, representative biomonitoring, benchmarking and auditing procedures are being developed to evaluate river health.

Brown, D. G., K. M. Johnson, et al. (2005). "Rural land-use trends in the conterminous United States, 1950-2000." Ecological Applications **15**(6): 1851-1863.

In order to understand the magnitude, direction, and geographic distribution of land-use changes, we evaluated land-use trends in U.S. counties during the latter half of the 20th century. Our paper synthesizes the dominant spatial and temporal trends in population, agriculture, and urbanized land uses, using a variety of data sources and an ecoregion classification as a frame of reference. A combination of increasing attractiveness of nonmetropolitan areas in the period 1970–2000, decreasing household size, and decreasing density of settlement has resulted in important trends in the patterns of developed land. By 2000, the area of low-density, exurban development beyond the urban fringe occupied nearly 15 times the area of higher density urbanized development. Efficiency gains, mechanization, and agglomeration of agricultural concerns has resulted in data that show cropland area to be stable throughout the Corn Belt and parts of the West between 1950 and 2000, but decreasing by about 22% east of the Mississippi River. We use a regional case study of the Mid-Atlantic and Southeastern regions to focus in more detail on the land-cover changes resulting from these dynamics. Dominating were land-cover changes associated with the timber practices in the forested plains ecoregions and urbanization in the piedmont ecoregions. Appalachian ecoregions show the slowest rates of landcover change. The dominant trends of tremendous exurban growth, throughout the United States, and conversion and abandonment of agricultural lands, especially in the eastern United States, have important implications because they affect large areas of the country, the functioning of ecological systems, and the potential for restoration.

Bryant, M. D., D. N. Swanston, et al. (1998). "Coho salmon populations in the karst landscape of north Prince of Wales Island, southeast Alaska." Transactions of the American Fisheries Society **127**(3): 425-433.

Karst topography is a unique and distinct landscape and its geology may have important implications for salmon productivity in streams. The relationship between salmonid communities and water chemistry and the influence of habitat was examined in a set of streams on north Prince of Wales Island, southeast Alaska. Streams in karst landscapes showed higher alkalinities (1,500-2,300 μeq L) than streams not influenced by karst landscapes (750-770 μeq/L). A significant, positive relationship was observed between alkalinity and density of coho salmon parr Oncorhynchus kitsutch. Backwater pools supported higher densities of coho salmon than did other habitat units. Both coho salmon fry and parr tended to be larger in most karst-influenced streams than in nonkarst streams. Although past timber harvest practices in the riparian areas of several of the streams appeared to influence stream habitat and water temperature, streams flowing through karst landscapes had a distinct water chemistry. Furthermore, these streams appeared to support more fish than nonkarst streams.

Crozier, L. G., A. P. Hendry, et al. (2008). "Potential responses to climate change in organisms with complex life histories: evolution and plasticity in Pacific salmon." Evolutionary Applications **1**(2): 252-270.

Dale, V. H., G. R. Biddinger, et al. (2008). "Enhancing the ecological risk assessment process." Integrated environmental assessment and management **4**(3): 306-313.

The Ecological Processes and Effects Committee of the US Environmental Protection Agency Science Advisory Board conducted a self-initiated study and convened a public workshop to characterize the state of the ecological risk assessment (ERA), with a view toward advancing the science and application of the process. That survey and analysis of ERA in decision making shows that such assessments have been most effective when clear management goals were included in the problem formulation; translated into information needs; and developed in collaboration with decision makers, assessors, scientists, and

stakeholders. This process is best facilitated when risk managers, risk assessors, and stakeholders are engaged in an ongoing dialogue about problem formulation. Identification and acknowledgment of uncertainties that have the potential to profoundly affect the results and outcome of risk assessments also improves assessment effectiveness. Thus we suggest 1) thorough peer review of ERAs be conducted at the problem formulation stage and 2) the predictive power of risk-based decision making be expanded to reduce uncertainties through analytical and methodological approaches like life cycle analysis. Risk assessment and monitoring programs need better integration to reduce uncertainty and to evaluate risk management decision outcomes. Postdecision audit programs should be initiated to evaluate the environmental outcomes of risk-based decisions. In addition, a process should be developed to demonstrate how monitoring data can be used to reduce uncertainties. Ecological risk assessments should include the effects of chemical and nonchemical stressors at multiple levels of biological organization and spatial scale, and the extent and resolution of the pertinent scales and levels of organization should be explicitly considered during problem formulation. An approach to interpreting lines of evidence and weight of evidence is critically needed for complex assessments, and it would be useful to develop case studies and/or standards of practice for interpreting lines of evidence. In addition, tools for cumulative risk assessment should be developed because contaminants are often released into stressed environments.

E&E (2010). An assessment of ecological risk to wild salmon systems from large-scale mining in the Nushagak and Kvichak watersheds of the Bristol Bay Basin. Report for The Nature Conservancy. Anchorage, AK, Ecology and Environment**:** 162.

Ehrlich, P. R. and L. H. Goulder (2007). "Is current consumption excessive? A general framework and some indications for the United States." Conservation Biology **21**(5): 1145-1154.

Many prior studies have explored the implications of human population growth and environmentally problematic technologies for biodiversity loss and other forms of environmental degradation. Relatively few, however, have examined the impacts of the level and composition of consumption. We offer a framework that shows how the level and composition of a society’s total consumption relate to the uses of various forms of capital and to the sustainability of natural resources and human well-being. We relate the framework to two main approaches—top–down macro studies and bottom–up computer models—for measuring whether overall consumption in the United States satisfies a sustainability requirement. Existing top–down studies have shortcomings that bias their results toward optimism, and current computer simulation models, although strong on revealing biophysical outcomes, are limited in their ability to

evaluate impacts on human well-being. Although some ambiguities arise in determining whether overall consumption in the United States is excessive, our conclusions regarding the composition of U.S. consumption are unambiguous. Distorted consumption patterns and associated production methods lead to excessively rapid natural resource depletion; greater conservation would yield gains to current and future generations that more than compensate for the sacrifices involved. Public policies that deal with the composition problem not only would help conserve natural resources and improve current welfare but also would reduce the costs of meeting the goal of sustainability.

Ellis, E. C., K. Klein Goldewijk, et al. (2010). "Anthropogenic transformation of the biomes, 1700 to 2000." Global Ecology and Biogeography **19**(5): 589-606.

Aim: To map and characterize anthropogenic transformation of the terrestrial biosphere before and during the Industrial Revolution, from 1700 to 2000. Location: Global. Methods: Anthropogenic biomes (anthromes) were mapped for 1700, 1800, 1900 and 2000 using a rule-based anthrome classification model applied to gridded global data for human population density and land use. Anthropogenic transformation of terrestrial biomes was then characterized by map comparisons at century intervals. Results: In 1700, nearly half of the terrestrial biosphere was wild, without human settlements or substantial land use. Most of the remainder was in a seminatural state (45%) having only minor use for agriculture and settlements. By 2000, the opposite was true, with the majority of the biosphere in agricultural and settled anthromes, less than 20% seminatural and only a quarter left wild. Anthropogenic transformation of the biosphere during the Industrial Revolution resulted about equally from land-use expansion into wildlands and intensification of land use within seminatural anthromes. Transformation pathways differed strongly between biomes and regions,with some remaining mostly wild but with the majority almost completely transformed into rangelands, croplands and villages. In the process of transforming almost 39% of earth’s total ice-free surface into agricultural land and settlements, an additional 37% of global land without such use has become embedded within agricultural and settled anthromes. Main conclusions: Between 1700 and 2000, the terrestrial biosphere made the critical transition frommostly wild to mostly anthropogenic, passing the 50% mark early in the 20th century. At present, and ever more in the future, the form and process of terrestrial ecosystems in most biomes will be predominantly anthropogenic, the product of land use and other direct human interactions with ecosystems. Ecological research and conservation efforts in all but a few biomes would benefit from a primary focus on the novel remnant, recovering and managed ecosystems embedded within used lands.

EPA, U. S. (2008). Application of Watershed Ecological Risk Assessment Methods to Watershed Management U. S. EPA. Washington, D.C., U.S. EPA.

Watersheds are frequently used to study and manage environmental resources because hydrologic boundaries define the flow of contaminants and other stressors. It is a challenge to incorporate scientific information in watershed management and planning. Ecological assessments of watersheds are complex because watersheds typically overlap multiple jurisdictional boundaries, are subjected to multiple environmental stressors, and have multiple stakeholders with diverse environmental and socioeconomic interests. Ecological risk assessment (ERA) is an approach that has successfully been used to increase the use of ecological science in decision making, by evaluating the likelihood that adverse ecological effects may result from exposure to one or more stressors, yet its application to watershed assessment is limited. The purpose of this report is to provide suggestions and examples for making scientific information more relevant to the needs of watershed managers by using ERA principles to help structure ecological assessments of watersheds. This report supplements the Guidelines for Ecological Risk Assessment (U.S. EPA 1998a) by addressing issues commonly encountered when conducting watershed ecological assessments. Suggestions and examples to follow are provided based upon lessons learned from prior watershed ERAs. This report is of potential use to ecologists, hydrologists, watershed managers, risk assessors, landscape ecologists, and other scientists and managers seeking to increase the use of environmental assessment data in decision making. Each activity and phase of the watershed ERA process is explained sequentially in this report. Guidance on how to involve stakeholders to generate environmental management goals and objectives is provided. The processes for selecting assessment endpoints, developing conceptual models, and selecting the exposure and effects pathways to be analyzed are described. Suggestions for predicting how multiple sources and stressors affect assessment endpoints are also provided; these include using multivariate analyses to compare land use with biotic measurements. In addition, the report suggests how to estimate, describe, and communicate risk and how to evaluate management alternatives.

EPA, U. S. (2013). Watershed modeling to assess the sensitivity of streamflow, nutrient and sediment loads to potential climate change and urban development in 20 U.S. Watersheds. Washington, DC**:** 196.

Watershed modeling was conducted in 20 large, U.S. watersheds to characterize the sensitivity of streamflow, nutrient (nitrogen and phosphorus), and sediment loading to a range of plausible mid-21st century climate change and urban development scenarios. The study also provides an improved understanding of methodological challenges associated with integrating existing tools (e.g., climate models, downscaling approaches, and watershed models) and data sets to address these scientific questions. The study uses a scenario-analysis approach with a consistent set of watershed models and scenarios applied to multiple locations throughout the nation. Study areas were selected to represent a range of geographic, hydrologic, and climatic characteristics. Watershed simulations were conducted using the Soil Water Assessment Tool (SWAT) and Hydrologic Simulation Program—FORTRAN (HSPF) models. Scenarios of future climate change were developed based on statistically and dynamically downscaled climate model simulations representative of the period 2041−2070. Scenarios of urban and residential development for this same period were developed from the EPA's Integrated Climate and Land Use Scenarios (ICLUS) project. Future changes in agriculture and human use and management of water were not evaluated.

EPA, U. S. (2014). An assessment of potential mining impacts on salmon ecosystems of Bristol Bay, Alaska. Seattle, WA, EPA Region 10.

Fletcher, W. J. (2005). "The application of qualitative risk assessment methodology to prioritize issues for fisheries management." ICES Journal of Marine Science: Journal du Conseil **62**(8): 1576-1587.

Implementing more holistic forms of fisheries management (e.g. Ecologically Sustainable Development (ESD), Ecosystem-Based Fisheries Management) usually increases the number and scope of impacts requiring assessment. This study examined the effectiveness of a qualitative risk assessment process, developed as part of a National ESD framework, for prioritizing issues across the seven most valuable Western Australian commercial fisheries. Structured stakeholder workshops were used to identify issues across three ecological areas: retained species (i.e. target and by-product), non-retained (i.e. discarded and protected) species, and the broader ecosystem for each fishery. The risk associated with each issue was assessed using one of five sets of consequence criteria specifically developed to cover fishery-related impacts. The risk scores, for which suitably detailed justifications were written, determined the level of reporting and management required for each issue. Despite an additional 96 “non-target species issues” being identified at the workshops from a total of 115 issues, of the 27 issues requiring explicit management actions, just six new issues were added by this process. In addition, it identified where modifications of some of the existing arrangements were necessary. Finally, the system significantly improved stakeholder involvement and therefore acceptance of the outcomes. Given this success, risk assessment has now been applied to all Western Australia's export fisheries and to the development or review of many other systems, thereby improving the entire management process.

Goldsworthy, S. D. and B. Page (2007). "A risk-assessment approach to evaluating the significance of seal bycatch in two Australian fisheries." Biological Conservation **139**(3): 269-285.

A common issue faced by fisheries and marine protected species managers is how to estimate the potential impacts of bycatch and identify appropriate options for mitigation, in the absence of quantitative data. This problem formed the basis to a risk-assessment study aimed at quantifying the risks to Australian sea lion (Neophoca cinerea) and New Zealand fur seal (Arctocephalus forsteri) populations from bycatch in a trap (rock lobster) and demersal gillnet fishery off South Australia. The approach was to: (1) estimate the spatial distribution of foraging effort for different sex and age classes within each species; (2) compare these with the spatial distribution of fishing effort in order to develop spatial estimates of sealfishery interaction probabilities; (3) undertake population viability analyses to identify the levels of bycatch that would place subpopulations of each species into different risk categories; and (4) examine different bycatch scenarios and identify subpopulations, regions and marine fishing areas with the greatest bycatch risk. Results suggest that the risk of subpopulation extinction, even from low levels of bycatch, was high for sea lions, but very low for fur seals and that the two fisheries lend themselves to different mitigation approaches: gear modification in the lobster fishery, and spatial management of fishing effort in the demersal gillnet fishery.

Gresh, T., J. Lichatowich, et al. (2000). "An estimation of historic and current levels of salmon production in the Northeast Pacific ecosystem: evidence of a nutrient deficit in the freshwater systems of the Pacific Northwest." Fisheries **25**(1): 15-21.

We used historical cannery records and current escapement and harvest records to estimate historical and current salmon escapement to western North American river systems, in order to determine the biomass and marine-derived nitrogen and phosphorous levels delivered by adult salmon, and the deficits corresponding to the diminished returns of adult salmon over the past century. We have estimated the historic biomass of salmon returning to the Pacific Northwest (Washington, Oregon, Idaho, and California) to be 160-226 million kg. The number of fish now returning to these rivers has a biomass of 11.8-13.7 million kg. These numbers indicate that just 6-7% of the marinederived nitrogen and phosphorous once delivered to the rivers of the Pacific Northwest is currently reaching those streams. This nutrient deficit may be one indication of ecosystem failure that has contributed to the downward spiral of salmonid abundance and diversity in general, further diminishing the possibility of salmon population recovery to self-sustaining levels.

Gude, P. H., A. J. Hansen, et al. (2007). "Biodiversity consequences of alternative future land use scenarios in Greater Yellowstone." Ecological Applications **17**(4): 1004-1018.

Land use is rapidly expanding in the Greater Yellowstone Ecosystem, primarily from growth in the number of rural homes. There is a need to project possible future land use and assess impacts on nature reserves as a guide to future management. We assessed the potential biodiversity impacts of alternative future land use scenarios in the Greater Yellowstone Ecosystem. An existing regression-based simulation model was used to project three alternative scenarios of future rural home development. The spatial patterns of forecasted development were then compared to several biodiversity response variables that included cover types, species habitats, and biodiversity indices. We identified the four biodiversity responses most at risk of exurban development, designed growth management policies to protect these areas, and tested their effectiveness in two alternative future scenarios. We found that the measured biodiversity responses, including riparian habitat, elk winter range, migration corridors, and eight other land cover, habitat, and biodiversity indices, are likely to undergo substantial conversion (between 5% and 40%) to exurban development by 2020. Future habitat conversion to exurban development outside the region's nature reserves is likely to impact wildlife populations within the reserves. Existing growth management policies will provide minimal protection to biodiversity in this region. We identified specific growth management policies, including incentives to cluster future growth near towns, that can protect ‘‘at risk’’ habitat types without limiting overall growth in housing

Gustafson, E. J. (1998). "Quantifying landscape spatial pattern: what is the state of the art?" Ecosystems **1**(2): 143-156.

Landscape ecology is based on the premise that there are strong links between ecological pattern and ecological function and process. Ecological systems are spatially heterogeneous, exhibiting considerable complexity and variability in time and space. This variability is typically represented by categorical maps or by a collection of samples taken at specific spatial locations (point data). Categorical maps quantize variability by identifying patches that are relatively homogeneous and that exhibit a relatively abrupt transition to adjacent areas. Alternatively, point-data analysis (geostatistics) assumes that the system property is spatially continuous, making fewer assumptions about the nature of spatial structure. Each data model provides capabilities that the other does not, and they should be considered complementary. Although the concept of patches is intuitive and consistent with much of ecological theory, point-data analysis can answer two of the most critical questions in spatial pattern analysis: what is the appropriate scale to conduct the analysis, and what is the nature of the spatial structure? I review the techniques to evaluate categorical maps and spatial point data, and make observations about the interpretation of spatial pattern indices and the appropriate application of the techniques. Pattern analysis techniques are most useful when applied and interpreted in the context of the organism(s) and ecological processes of interest, and at appropriate scales, although some may be useful as coarse-filter indicators of ecosystem function. I suggest several

important needs for future research, including continued investigation of scaling issues, development of indices that measure specific components of spatial pattern, and efforts to make point-data analysis more compatible with ecological theory.

Hauer, C., G. Unfer, et al. (2011). "Effects of stream channel morphology, transport processes and effective discharge on salmonid spawning habitats." Earth Surface Processes and Landforms **36**(5): 672-685.

The effects of stream channel morphology, transport processes and effective discharge on the salmonid spawning habitats of Thymallus thymallus and Salmo trutta ff. were investigated within the catchment of the Gr. Mühl River, Austria. Based on field survey, one-dimensional and two-dimensional hydraulic and sediment transport modelling, the abiotic characteristics of the spawning sites have been investigated. Application of the Meyer-Peter, Müller and Shields equations for determining critical discharge and critical shear stress revealed differences in the threshold of sediment motion due to the specific grain size sorting of the surface layer, which was dominated by cobbles and sand. Suitable grain sizes for spawning were found mainly in the subsurface
layer of the free-flowing sections. The findings highlighted the necessity for upstream delivery to downstream of suitable spawning material during floods. Moreover, the study demonstrates that discharge-related sediment transport does not mean a simultaneous renewal of spawning material (fine gravel, gravel) transported from upstream reaches. Thus, an effective discharge for spawning habitats was determined using a standardized deposition index (Di), based on two-dimensional sediment transport modelling. The results show that the effective discharge for spawning habitats is a useful tool for spawning habitat restoration, representing the frequency of turnover and renewal of spawning habitats over the long term.

Hauer, C., G. n. Unfer, et al. (2012). "The impact of discharge change on physical instream habitats and its response to river morphology." Climatic change **116**(3-4): 827-850.

The impact of climate-induced discharge change on fish habitats, based on 1951–2008 time series, was investigated within the crystalline catchment of the Grosse Mühl River in Northern Austria. A significant trend change of air temperature, based on Mann–Whitney statistical testing, was recorded for spring 1989 (P098.9 %) and summer 1990 (P099.9 %). This led to a pronounced increase in summer low flow periods. Hydrodynamic-numerical (one-dimensional two-dimensional) modelling was applied to simulate the changing habitat characteristics due to decreasing discharge in relation to various morphological patterns (riffle-pool/plane-bed reaches). Using bathymetric data, which were sampled on cross sectional measurements, we clearly determined that plane-bed reaches (featureless bed forms) are sensitive to climate-related, reduced discharge, whereas riffle-pool reaches continued to exhibit suitable physical fish habitats even under extreme low-flow conditions. The impact of the decreased summer discharge on instream habitats was strong for subadult and adult grayling which have been used as target fish species. In situ measurements in microhabitats (velocity/depth) revealed habitat suitabilities. These values were taken as biotic input for habitat evaluation on the micro scale. The findings clearly show that river morphology is a decisive parameter in terms of habitat preservation and restoration in the context of the future impacts of climate change (decreased discharge).

Hauser, W. J. (2007). "Potential impacts of the proposed Pebble Mine on fish habitat and fishery resources of Bristol Bay." Fish Talk Consulting, Anchorage, AK.

The freshwater streams of the Bristol Bay drainages support important subsistence and commercial salmon fisheries and internationally-famous sport fisheries for both resident species and salmon. Northern Dynasty Mines, Inc. (NDM) has proposed to mine a metallic sulfide deposit at the headwaters of some of these streams. The project, referred to as Pebble Mine, will have a preliminary lifespan of 40 to 50 years, or even longer. Applications filed by NDM in 2006 indicate that the proposed project will leave permanent landscape features affecting some thirty square miles, including two tailings ponds that will house billions of tons of mine tailings which will include toxic materials. The project will also include a 104-mile access road, with a slurry line and a water line that will directly affect at least 12.5 square miles and a power transmission line.

Hietel, E., R. Waldhardt, et al. (2007). "Statistical modeling of land-cover changes based on key socio-economic indicators." Ecological economics **62**(3): 496-507.

Landscapes are complex human–environment systems operating at spatio-temporal scales. Time is just as important as space when researching landscape changes. These changes are influenced by both environmental and socio-economic factors. However, correlations between environmental landscape attributes and land-cover patterns/changes are weakened by human activities such as intensification of agriculture eliminating the constraints ofwater and nutrient availability. Relations between changes in socio-economic organisation and land cover become apparent only over a longer period of time. Thus, in our study, we focused on socio-economic factors and their long-term effects on land cover. We present a method to (i) differentiate types of land-cover changes at district level, (ii) model correlations between socio-economic factors and land cover changes and (iii) identify key socio-economic indicators of land-cover changes between 1945 and 1999 in a German marginal rural landscape. We employed agricultural land-cover data gained from the interpretation of multi-temporal aerial photographs. Based on these data, we differentiated types of land-cover changes, characterising different directions of agricultural land-cover changes in the observation time period. Various socio-economic aspects were considered by introducing data representing factors of demography, employment, economy, infrastructure, agricultural structure and policy. The relations between time series of land-cover data and of socioeconomic data were modeled with the help of redundancy analysis. Correlation coefficients were used to identify key socio-economic indicators of land-cover changes. The results showed that a relatively high percentage of variance in land-cover data can be explained by socio-economic factors.The types of land-cover changes can be characterised by combinations of key socio-economic indicators. The indicators can be helpful to reconstruct land-cover changes in other regions. Thus, they provide a basis for the development of sustainable landcover management systems.

Hilborn, R., T. P. Quinn, et al. (2003). "Biocomplexity and fisheries sustainability." Proceedings of the National Academy of Sciences **100**(11): 6564-6568.

A classic example of a sustainable fishery is that targeting sockeye salmon in Bristol Bay, Alaska, where record catches have occurred during the last 20 years. The stock complex is an amalgamation of several hundred discrete spawning populations. Structured within lake systems, individual populations display diverse life history characteristics and local adaptations to the variation in spawning and rearing habitats. This biocomplexity has enabled the aggregate of populations to sustain its productivity despite major changes in climatic conditions affecting the freshwater and marine environments during the last century. Different geographic and life history components that were minor producers during one climatic regime have dominated during others, emphasizing that the biocomplexity of fish stocks is critical for maintaining their resilience to environmental change.

Hunsaker, C. T., R. L. Graham, et al. (1990). "Assessing ecological risk on a regional scale." Environmental Management **14**(3): 325-332.

Society needs a quantitative and systematic way to estimate and compare the impacts of environmental problems that affect large geographic areas. thi spaper presents an approach for regional risk assessment that combines regional assessment methods and landscape ecology theory with an existing framework for ecological risk assessment. Risk assessment evaluates the effects of an environmetnal change on a valued natural resource and interprets the significance of those effects in light of the uncertainties identified in each component of the assessment process. Unique and important issues for regional risk assessment are emphasized; these include the definition of the disturbance scenario, the assessment boundary definition, and the spatial hererogeneity of the landscape.

Kapustka, L. (2008). "Limitations of the current practices used to perform ecological risk assessment." Integrated environmental assessment and management **4**(3): 290-298.

The framework for ecological risk assessments has provided a way to analyze stressors in the environment. Despite the power of this tool to inform environmental management decisions, the practice has not reached its full potential. In this paper, limitations of the practice are described under 2 categories, namely inherent and contrived. Inherent limitations are constraints of nature that we need to be aware of as we design and interpret studies. Contrived limitations are impediments that have arisen in the practice through precedent or policy. The closing portion of this paper provides a series of short-term and long-term steps

Kittel, T. G. F., S. G. Howard, et al. (2011). "A vulnerability-based strategy to incorporate climate change in regional conservation planning: Framework and case study for the British Columbia Central Interior." BC Journal of Ecosystems and Management **12**: 7-35.

High uncertainty in the future of regional climates and ecosystems presents a challenge to the conservation of biodiversity and landscapes. We present a framework to handle uncertainty in the incorporation of climate change in regional conservation planning. The framework uses expert opinion to: (1) formulate qualitative scenarios of climatic and ecological change based on expected as well as less probable but plausible futures not tied to specific model projections; (2) synthesize established knowledge of the climate vulnerability of species and ecosystems of concern; and (3) specify no-regrets climate adaptation strategies to reduce these vulnerabilities in conservation site selection. This framework was implemented in an ecoregional assessment of the British Columbia Central Interior selecting terrestrial and freshwater high-priority conservation sites. Including climate vulnerabilitybased adaptation strategies in the regional site-selection process had a substantial effect on both freshwater and terrestrial assessments. Selection of high-priority sites based on these strategies generally increased the number, size, buffering, and connectivity of selected sites; included and expanded on sites selected based on standard (non-climate change specified) criteria alone; and drew more from moderately favourable sites. Although limited by our understanding of species and ecosystem vulnerability, the integration of vulnerability assessment, moderate to severe change scenarios, and a no-regrets approach generated regional conservation strategies for climate change adaptation in the face of uncertainty in the future of climates, landscapes, and species.

Krauss, J., R. Bommarco, et al. (2010). "Habitat fragmentation causes immediate and time-delayed biodiversity loss at different trophic levels." Ecology letters **13**(5): 597-605.

Intensification or abandonment of agricultural land use has led to a severe decline of semi-natural habitats across Europe. This can cause immediate loss of species but also time-delayed extinctions, known as the extinction debt. In a pan-European study of 147 fragmented grassland remnants, we found differences in the extinction debt of species from different trophic levels. Present-day species richness of long-lived vascular plant specialists was better explained by past than current landscape patterns, indicating an extinction debt. In contrast, short-lived butterfly specialists showed no evidence for an extinction debt at a time scale of c. 40 years. Our results indicate that management strategies maintaining the status quo of fragmented habitats are insufficient, as timedelayed extinctions and associated co-extinctions will lead to further biodiversity loss in the future.

Kuipers, J. R., A. S. Maest, et al. (2006). "Comparison of Predicted and Actual Water Quality at Hardrock Mines."

This study reviews the history and accuracy of water quality predictions in Environmental Impact Statements (EISs) for major hardrock mines in the United States. It does so by: identifying major hardrock metals mines in the United States and determining which major mines had EISs; gathering and evaluating water quality prediction information from EISs; selecting a representative subset of mines with EISs for in-depth study • examining actual water quality information for the case study mines; and comparing actual water quality to the predictions made in EISs. Based on the results of the evaluations conducted, an analysis was performed to identify the most common causes of water quality impact and prediction failures. In addition, an analysis was conducted to determine if there were inherent risk factors at mines that may predispose an operation to having water quality problems. Conclusions are provided about the effectiveness of the underlying scientific and engineering principles used to make water quality predictions in EISs. Finally, recommendations are made for regulatory, scientific and engineering approaches that would improve the reliability of water quality predictions at hardrock mine sites. The National Environmental Policy Act (NEPA), enacted in 1969, was the first environmental statute in the United States and forms the foundation of a comprehensive national policy for environmental decision making. NEPA requires federal agencies to take a “hard look” at the environmental impacts of each proposed project to ensure the necessary mitigation or other measures are employed to meet federal and state regulations and other applicable requirements. Under NEPA, when a new mine is permitted, agencies have a duty to disclose underlying scientific data and rationale supporting the conclusions and assumptions in an EIS. NEPA requires federal agencies proposing major actions that may substantially affect the quality of the human environment to prepare a detailed Environmental Impact Statement (EIS). A “major action” includes actions approved by permit or other regulatory action. If the agency finds that the project may have a significant impact on the environment, then it must prepare an EIS. As part of the EIS process, hardrock mines operating on federal lands or otherwise subject to NEPA are required to estimate impacts to the environment, including direct impacts to water quality and indirect impacts that occur later in time but are still reasonably foreseeable. The NEPA analysis process calls for performing original research, if necessary, and reasonable scientifically supported forecasting and speculation. A wide array of scientific approaches has been used to predict water quality that could result at mine sites, and many different engineering techniques were applied to mitigate these potential impacts. The primary subject of this report is the effectiveness of water quality predictions and mitigation that were applied over the past 30 years as a part of the EIS process at hardrock mines in the United States.

Lackey, R. T. (1994). "Ecological risk assessment." Fisheries **19**(9): 14-19.

Risk assessment has become a popular tool to help solve ecological problems. The basic concept is not new and has been applied to diverse decision problems. The application to ecological problems, especially complex ecological problems, is fairly recent and controversial. The fundamental and most important elements of the controversy revolve around two key points: (1) a person's implicit "world view;" and (2) the assumption of who (or what) receives the benefits and who (or what) pays the costs for ecological "decisions." A person's attitude toward risk assessment is, at least implicitly, defined by a world view. It is this world view that defines how each of us reacts to risk assessment applied to ecological problems. How the question of benefits and costs is defined also defines the appropriate use, if any, of ecological risk assessment. The future of ecological risk assessment will almost certainly follow the course of other analytical tools enthusiastic support, rapid, widespread adoption and use, then disillusionment and rapid replacement with newer approaches, but with continued use for a greatly constrained set of ecological issues.

Lackey, R. T. (1997). "If ecological risk assessment is the answer, what is the question?" Human and Ecological Risk Assessment **3**(6): 921-928.

Ecological risk assessment has become a commonly used tool in policy analysis, but its use is controversial. Opinions are diverse; they range from enthusiastic support to caustic dismissal. Much of the controversy with using risk assessment in ecological policy analysis revolves around defining the initial policy question or problem to be assessed. In formulating the “question” in ecological risk assessment, the nature of the analytical technique forces analysts to make assumptions of values and priorities; these assumptions may not be the same as those of the public or their elected or appointed representatives. Specifically, much of the difficulty with applying risk assessment is that, by definition, risk is adverse. Deciding which ecological changes are adverse (undesired) and which are beneficial (desired) is likely to be the primary political debate. Ecological conditions and changes are classified by the values and priorities of the person or administrative body doing the classification; ecological condition or change in itself is neither good nor bad, beneficial nor adverse, healthy nor degraded. One method often used to determine which ecological conditions or changes are adverse is to apply the human “health” metaphor to ecosystems or ecological components. However, application of the concept of ecosystem health is fraught with value□based requirements which are difficult and probably impossible to attain. Formulating the question is, or at least should be, driven by societal values, preferences, and priorities, but this is difficult to do in a pluralistic society. Better ways to evaluate and measure public values, preferences, and priorities in framing ecological questions are needed to enhance the utility of ecological risk assessment.

Lackey, R. T. (1997). Is ecological risk assessment useful for resolving complex ecological problems? Pacific Salmon & their Ecosystems, Springer**:** 525-540.

Lackey, R. T. (1998). "Fisheries management: integrating societal preference, decision analysis, and ecological risk assessment." Environmental Science & Policy **1**(4): 329-335.

Fisheries management is the practice of analyzing and selecting options to maintain or alter the structure, dynamics, and interaction of habitat, aquatic biota, and man to achieve human goals and objectives. The theory of fisheries management is: managers or decision makers attempt to maximize renewable “output” from an aquatic resource by choosing from among a set of decision options and applying a set of actions that generate an array of outputs. Outputs may be defined as a tangible catch, a fishing experience, an existence value, or anything else produced or supported by renewable aquatic resources. Overall output is always a mix of tangible and intangible elements. However defined, management goals and objectives are essential components of fisheries management or any other field of renewable natural resource management. Reaching consensus on management goals and objectives has never been a simple task. Beyond the broad and often conflicting goals of an agency, managers must decide who should set specific management objectives □□ agency personnel, the public, or a combination of the two. Historically, rhetoric aside, fisheries managers in North America nearly always have consulted with professionals in governmental roles to set management objectives. In a strongly pluralistic society, this often resulted in protracted political and legal conflict. Increasingly, there are calls for use of risk assessment to help solve such ecological policy and management problems commonly encountered in fisheries management. The basic concepts of ecological risk assessment may be simple, but the jargon and details are not. Risk assessment (and similar analytical tools) is a concept that has evoked strong reactions whenever it has been used. In spite of the difficulties of defining problems and setting management objectives for complex ecological policy questions, use of risk assessment to help solve ecological problems is widely supported. Ecological risk assessment will be most useful (and objective) in political deliberations when the policy debate revolves around largely technical concerns. To the extent that risk assessment forces policy debate and disagreement toward fundamental differences rather than superficial ones, it will be useful in decision making.

Lackey, R. T. (1999). "Salmon policy: science, society, restoration, and reality." Environmental Science & Policy **2**(4): 369-379.

Salmon policy in the Pacific Northwest illustrates a class of contentious, socially wrenching issues that are becoming increasingly common in the western United States as demands increase for limited ecological resources. Many Pacific salmon "stocks" (a term used in fisheries management for a group of interbreeding individuals that is roughly equivalent to "population") have declined and some have been extirpated. The salmon "problem” is one of the most vexing public policy challenges in natural resource management. Even with complete scientific knowledge — and scientific knowledge is far from complete or certain — it would be a challenging policy problem. The salmon decline issue is often defined simplistically as a watershed management problem, in part because changes in watersheds are highly visible and often occur on public or corporate lands where individuals and organizations often have direct input to decision making. Yet, changes in climate and ocean conditions, for example, occur frequently and such changes have a major influence on salmon abundance. The scientific challenges are great, but the more difficult — and critical — aspect of the debate concerns policies and decisions affecting everyone, including those involved in rural enterprises (especially farming and logging); manufacturing and construction; electricity generation (including hydro, fossil fuel, and nuclear); national defense; urban development; transportation (including road, rail, air, and water). The debate also involves competing personal rights and freedoms; the prerogatives and roles of local, state, and federal government and Indian tribes; policies on human population level, reproduction, emigration, and immigration; and the future of fishing (commercial, recreational, and Indian). The salmon policy conundrum is characterized by: (1) nearly everyone claims to support maintaining wild salmon runs; (2) many competing societal priorities exist, many of which are partially or wholly mutually exclusive; (3) the region’s rapidly growing human population creates increasing pressures on all natural resources (including salmon and their habitats); (4) policy stances in the salmon debate are solidly entrenched; (5) society expects salmon experts to help solve the salmon problem; (6) each of the many sides of the political debate over the future of salmon use salmon experts and scientific “facts” to bolster its argument; (7) it has proved to be nearly impossible for salmon scientists to avoid being categorized as supporting a particular policy position; and (8) many advocates of policy positions couch their positions in scientific terms rather than value-based preferences. Although far from indisputable, I conclude that over the next century and allowing for considerable year-to-year and decade-to-decade variation, many, perhaps most, stocks of wild salmon in the Pacific Northwest likely will remain at their current low levels or continue to decline in spite of costly protection and restoration efforts.

Lackey, R. T. (2002). "Restoring wild salmon to the Pacific Northwest: framing the risk question." Human and Ecological Risk Assessment **8**(2): 223-232.

In the Pacific Northwest of the United States, it is urgent to assess accurately the various options proposed to restore wild salmon. For the past 125 years, a variety of analytic approaches have been employed to assess the ecological consequences of salmon management options. Each approach provided useful information to decision makers, but each also suffered from limitations, some relatively minor, others sufficient to undermine any potential utility. Risk assessment has become the most widely used analytic approach to evaluate environmental policy options. To date its use in ecological policy has been largely constrained to evaluating relatively simple technical questions (e.g., regulatory actions associated with specific chemicals or hazardous waste sites). Recently, however, there has been interest in applying risk assessment to more complex ecological policy problems (e.g., the decline of wild salmon in the Pacific Northwest). Although its use has become commonplace and widely accepted, especially among regulatory and land management agencies, risk assessment remains contentious. The most heated debates revolve around delineating the specific meaning of risk; that is, framing the risk A question to be answered.

Lackey, R. T. (2005). "Economic growth and salmon recovery: an irreconcilable conflict?" Fisheries **30**(3): 30-32.

Compared with most other fisheries issues, the decline of salmon has been well studied over a long period (Lackey 2003). The proximal causes of the decline have been, and often still are, intense commercial, recreational, and subsistence fishing and, especially these days, mixed stock fishing; freshwater and estuarine habitat alteration due to urbanizing, farming, logging, and ranching; dams built and operated for electricity generation, flood control, irrigation, and other purposes; water withdrawals for agricultural, municipal, or commercial needs; stream and river channel alteration, diking, and riparian corridor modifications; hatchery production to supplement diminished runs or to produce salmon for the retail market; predation by marine mammals, birds, and other fish species, often exacerbated by unintentionally concentrating salmon or their predators; competition, especially that with exotic fish species, many of which are better adapted to the highly altered aquatic environments now present in the region; diseases and parasites; pollutants from a myriad of sources; and reduction in the annual replenishment of nutrients from spawned-out, decomposing salmon.

Lackey, R. T. (2009). "Salmon in Western North America: Historical Context." Encyclopedia of Earth: 2-2.

Of the Earth’s four regions where salmon runs occurred historically (Asian Far East, Atlantic Europe, eastern North America, and western North America), it appears probable that salmon runs in California, Oregon, Washington, Idaho, and southern British Columbia, without a dramatic change in current and long-term trends, will emulate the other three: extirpated or much reduced runs. Since 1850, an array of factors has caused the decline and a plethora of specific impediments has prevented their recovery. Throughout the region, all runs of wild salmon have declined and some have disappeared. Substantial efforts have been made to restore some runs of wild salmon, but few have shown much success. Society’s failure to restore wild salmon is a policy conundrum characterized by: (1) claims by a strong majority to be supportive of restoring wild salmon runs; (2) competing societal priorities which are at least partially mutually exclusive; (3) the region’s rapidly growing human population and its pressure on all natural resources (including salmon and their habitats); (4) entrenched policy stances in the salmon restoration debate, usually supported by established bureaucracies; (5) society’s expectation that experts should be able to solve the salmon problem by using a technological scheme and without massive cultural or economic sacrifices (e.g., life style changes); (6) use of experts and scientific “facts” by political proponents to bolster their policy positions; (7) inability of salmon scientists to avoid being placed in particular policy or political camps; and (8) confusion in discussing policy options caused by couching policy preferences in scientific terms or imperatives rather than value-based criteria. Even with definitive scientific knowledge, which will never be complete or certain, restoring most wild salmon runs in the region to historical levels will be arduous and will entail substantial economic costs and social disruption required. Ultimate success cannot be assured. Given the appreciable costs and social dislocation, coupled with the dubious probability of success, candid public dialog is warranted to decide whether restoration of wild salmon is an appropriate, much less feasible, public policy objective. Provided with a genuine assessment of the necessary economic costs and social implications required for restoration, it is questionable whether a majority of the public would opt for the pervasive measures that appear necessary for restoring many runs of wild salmon. There will continue to be appreciable annual variation in the size of salmon runs, accompanied by the decadal trends in run size caused by periodic changes in climatic and oceanic conditions, but given a continuation of the current trajectory, many, perhaps most, stocks of wild salmon in California, Oregon, Washington, Idaho, and southern British Columbia, likely will remain at their current low levels or continue to decline in spite of heroic, expensive, and socially turbulent attempts at restoration.

Landis, W. G., J. L. Durda, et al. (2013). "Ecological risk assessment in the context of global climate change." Environmental Toxicology and Chemistry **32**(1): 79-92.

Changes to sources, stressors, habitats, and geographic ranges; toxicological effects; end points; and uncertainty estimation require significant changes in the implementation of ecological risk assessment (ERA). Because of the lack of analog systems and circumstances in historically studied sites, there is a likelihood of type III error. As a first step, the authors propose a decision key to aid managers and risk assessors in determining when and to what extent climate change should be incorporated. Next, when global climate change is an important factor, the authors recommend seven critical changes to ERA. First, develop conceptual cause–effect diagrams that consider relevant management decisions as well as appropriate spatial and temporal scales to include both direct and indirect effects of climate change and the stressor of management interest. Second, develop assessment end points that are expressed as ecosystem services. Third, evaluate multiple stressors and nonlinear responses—include the chemicals and the stressors related to climate change. Fourth, estimate how climate change will affect or modify management options as the impacts become manifest. Fifth, consider the direction and rate of change relative to management objectives, recognizing that both positive and negative outcomes can occur. Sixth, determine the major drivers of uncertainty, estimating and bounding stochastic uncertainty spatially, temporally, and progressively. Seventh, plan for adaptive management to account for changing environmental conditions and consequent changes to ecosystem services. Good communication is essential for making risk-related information understandable and useful for managers and stakeholders to implement a successful risk-assessment and decision-making process.

Landis, W. G. and J. K. Wiegers (2007). "Ten years of the relative risk model and regional scale ecological risk assessment." Human and Ecological Risk Assessment **13**(1): 25-38.

It has been 10 years since the publication of the relative risk model (RRM) for regional scale ecological risk assessment. The approach has since been used successfully for a variety of freshwater, marine, and terrestrial environments in North America, South America, and Australia. During this period the types of stressors have been expanded to include more than contaminants. Invasive species, habitat loss, stream alteration and blockage, temperature, change in land use, and climate have been incorporated into the assessments. Major developments in the RRM have included the extensive use of geographical information systems, uncertainty analysis using Monte Carlo techniques, and its application to retrospective assessments to determine causation. The future uses of the RRM include assessments for forestry and conservation management, an increasing use in invasive species evaluation, and in sustainability. Developments in risk communication, the use of Bayesian approaches, and in uncertainty analyses are on the horizon.

Laughlin, J. (2005). "Conceptual model for comparative ecological risk assessment of wildfire effects on fish, with and without hazardous fuel treatment." Forest Ecology and Management **211**(1): 59-72.

Wildfire poses risks to fish and wildlife habitat, among other things. Management projects to reduce the severity of wildfire effects by implementing hazardous fuel reduction treatments also pose risks. How can land managers determine which risk is greater? Comparison of risks and benefits from fuel treatment projects to risks from severe wildfire effects is consistent with policies requiring public land managers to analyze short- and long-term environmental effects. However, formulating the problem as a comparison of temporal considerations often results in decisions to reject fuels treatment projects near imperiled species habitat, even though the adverse effects of short-term project actions may result in substantial long-term net benefits from reducing the severity of wildfire effects. Consistent with widely accepted ecological risk assessment methods, the problem is formulated in a conceptual model. Salmonid fish populations are the risk assessment endpoint, and one stress or adversely
affecting them is sediment from wildfire or logging. The model compares short-term effects of implementing fuels reduction treatments to longer-term wildfire effects with and without fuel treatments, including risk reduction benefits. Used quantitatively or qualitatively, the model may contribute to sustainable resource management decisions by improving communication among stakeholders, risk managers in land and resource management agencies, and risk assessors in agencies responsible for enforcing the Endangered Species Act.

Leuven, R. S. E. W. and I. Poudevigne (2002). "Riverine landscape dynamics and ecological risk assessment." Freshwater Biology **47**(4): 845-865.

1. The aim of ecological risk assessments is to evaluate the likelihood that ecosystems are adversely affected by human-induced disturbance that brings the ecosystem into a new dynamic equilibrium with a simpler structure and lower potential energy. The risk probability depends on the threshold capacity of the system (resistance) and on the capacity of the system to return to a state of equilibrium (resilience). 2. There are two complementary approaches to assessing ecological risks of riverine landscape dynamics. The reductionist approach aims at identifying risk to the ecosystem on the basis of accumulated data on simple stressor–effect relationships. The holistic approach aims at

taking the whole ecosystem performance into account, which implies meso-scale analysis. 3. Landscape patterns and their dynamics represent the physical framework of processes determining the ecosystem's equilibrium. Assessing risks of landscape dynamics to riverine ecosystems implies addressing complex interactions of system components (e.g. population dynamics and biogeochemical cycles) occurring at multiple scales of space and time. 4. One of the most important steps in ecological risk assessment is to establish clear assessment endpoints (e.g. vital ecosystem and landscape attributes). Their formulation must recognise that riverine ecosystems are dynamic, structurally complex and composed of both deterministic and stochastic components. 5. Remote sensing (geo)statistics and geographical information systems are primary tools for quantifying spatial and temporal components of riverine ecosystem and landscape attributes. 6. The difficulty to experiment at the riverine landscape level means that ecological risk management is heavily dependent on models. Current models are targeted towards simulating ecological risk at levels ranging from single species to habitats, food webs and meta-populations to ecosystems and entire riverine landscapes, with some including socioeconomic considerations.

Lichatowich, J., L. Mobrand, et al. (1995). "An approach to the diagnosis and treatment of depleted Pacific salmon populations in Pacific Northwest watersheds." Fisheries **20**(1): 10-18.

We propose an approach to the development of restoration programs for Pacific anadromous salmon that recognizes the importance of an ecosystem perspective. Important concepts such as habitat complexity and self-organizing capacity of the stock are reviewed. A planning process comprised of six steps is described. The approach includes a comparison of historic and current habitat complexity and connectivity and intrapopulation life history diversity. Uncertainties are incorporated into the planning process through assumptions that are clearly identified. Risk of project failure is determined through a qualitative or quantitative weighing of the critical uncertainties. We emphasize the concept that restoration planning is an iterative process that must be continued after implementation.

Lindenmayer, D. and M. Hunter (2010). "Some guiding concepts for conservation biology." Conservation Biology **24**(6): 1459-1468.

The search for generalities in ecology has often been thwarted by contingency and ecological complexity that limit the development of predictive rules.We present a set of concepts that we believe succinctly expresses some of the fundamental ideas in conservation biology. (1) Successful conservation management requires explicit goals and objectives. (2) The overall goal of biodiversity management will usually be to maintain or restore biodiversity, not to maximize species richness. (3) A holistic approach is needed to solve conservation problems. (4) Diverse approaches to management can provide diverse environmental conditions and mitigate risk. (5) Using nature's template is important for guiding conservation management, but it is not a panacea. (6) Focusing on causes not symptoms enhances efficacy and efficiency of conservation actions. (7) Every species and ecosystem is unique, to some degree. (8) Threshold responses are important but not ubiquitous. (9) Multiple stressors often exert critical effects on species and ecosystems. (10) Human values are variable and dynamic and significantly shape conservation efforts. We believe most conservation biologists will broadly agree these concepts are important. That said, an important part of the maturation of conservation biology as a discipline is constructive debate about additional or alternative concepts to those we have proposed here. Therefore, we have established a web-based, online process for further discussion of the concepts outlined in this paper and developing additional ones.

Lindenmayer, D. B., C. R. Margules, et al. (2000). "Indicators of biodiversity for ecologically sustainable forest management." Conservation Biology **14**(4): 941-950.

The conservation of biological diversity has become one of the important goals of managing forests in an ecologically sustainable way. Ecologists and forest resource managers need measures to judge the success or failure of management regimes designed to sustain biological diversity. The relationships between potential indicator species and total biodiversity are not well established. Carefully designed studies are required to test relationships between the presence and abundance of potential indicator species and other taxa and the maintenance of critical ecosystem processes in forests. Other indicators of biological diversity in forests, in addition or as alternatives to indicator species, include what we call structure-based indicators. These are stand-level and landscape-level (spatial) features of forests such as stand structural complexity and plant species composition, connectivity, and heterogeneity. Although the adoption of practices to sustain (or recreate) key characteristics of forest ecosystems appear intuitively sensible and broadly consistent with current knowledge, information is lacking to determine whether such stand- and landscape-level features of forests will serve as successful indices of (and help conserve) biodiversity. Given our limited knowledge of both indicator species and structure-based indicators, we advocate the following four approaches to enhance biodiversity conservation in forests: (1) establish biodiversity priority areas (e.g., reserves) managed primarily for the conservation of biological diversity; (2) within production forests, apply structure-based indicators including structural complexity, connectivity, and heterogeneity; (3) using multiple conservation strategies at multiple spatial scales, spread out risk in wood production forests; and (4) adopt an adaptive management approach to test the validity of structure-based indices of biological diversity by treating management practices as experiments. These approaches would aim to provide new knowledge to managers and improve the effectiveness of current management strategies.

Linkov, I., D. Loney, et al. (2009). "Weight-of-evidence evaluation in environmental assessment: Review of qualitative and quantitative approaches." Science of the Total Environment **407**(19): 5199-5205.

Assessments of human health and ecological risk draw upon multiple types and sources of information, requiring the integration of multiple lines of evidence before conclusions may be reached. Risk assessors often make use of weight-of-evidence (WOE) approaches to perform the integration, whether integrating evidence concerning potential carcinogenicity, toxicity, and exposure from chemicals at a contaminated site, or evaluating processes concerned with habitat loss or modification when managing a natural resource. Historically, assessors have relied upon qualitative WOE approaches, such as professional judgment, or limited quantitative methods, such as direct scoring, to develop conclusions from multiple lines of evidence. Current practice often lacks transparency resulting in risk estimates lacking quantified uncertainty. This paper reviews recent applications of weight of evidence used in human health and ecological risk assessment. Applications are sorted based on whether the approach relies on qualitative and quantitative methods in order to reveal trends in the use of the termweight of evidence, especially as a means to facilitate structured and transparent development of risk conclusions from multiple lines of evidence.

Linkov, I., F. K. Satterstrom, et al. (2006). "From comparative risk assessment to multi-criteria decision analysis and adaptive management: recent developments and applications." Environment International **32**(8): 1072-1093.

Environmental risk assessment and decision-making strategies over the last several decades have become increasingly more sophisticated, information-intensive, and complex, including such approaches as expert judgment, cost–benefit analysis, and toxicological risk assessment. One tool that has been used to support environmental decision-making is comparative risk assessment (CRA), but CRA lacks a structured method for arriving at an optimal project alternative. Multi-criteria decision analysis (MCDA) provides better-supported techniques for the comparison of project alternatives based on decision matrices, and it also provides structured methods for the incorporation of project stakeholders' opinions in the ranking of alternatives. We argue that the inherent uncertainty in our ability to predict ecosystem evolution and response to different management policies requires shifting from optimization-based management to an adaptive management paradigm. This paper brings together a multidisciplinary review of existing decision-making approaches at regulatory

agencies in the United States and Europe and synthesizes state-ofthe-art research in CRA, MCDA, and adaptive management methods applicable to environmental remediation and restoration projects. We propose a basic decision analytic framework that couples MCDA with adaptive management and its public participation and stakeholder value elicitation methods, and we demonstrate application of the framework to a realistic case study based on contaminated sediment management issues in the New York/New Jersey Harbor.

Mace, G. M., N. J. Collar, et al. (2008). "Quantification of extinction risk: IUCN's system for classifying threatened species." Conservation Biology **22**(6): 1424-1442.

The International Union for Conservation of Nature (IUCN) Red List of Threatened Species was increasingly used during the 1980s to assess the conservation status of species for policy and planning purposes. This use stimulated the development of a new set of quantitative criteria for listing species in the categories of threat: critically endangered, endangered, and vulnerable. These criteria, which were intended to be applicable to all species except microorganisms, were part of a broader system for classifying threatened species and were fully implemented by IUCN in 2000. The system and the criteria have been widely used by conservation practitioners and scientists and now underpin one indicator being used to assess the Convention on Biological Diversity 2010 biodiversity target. We describe the process and the technical background to the IUCN Red List system. The criteria refer to fundamental biological processes underlying population decline and extinction. But given major differences between species, the threatening processes affecting them, and the paucity of knowledge relating to most species, the IUCN system had to be both broad and flexible to be applicable to the majority of described species. The system was designed tomeasure the symptoms of extinction risk, and uses 5 independent criteria relating to aspects of population loss and decline of range size. A species is assigned to a threat category if it meets the quantitative threshold for at least one criterion. The criteria and the accompanying rules and guidelines used by IUCN are intended to increase the consistency, transparency, and validity of its categorization system, but it necessitates some compromises that affect the applicability of the system and the species lists that result. In particular, choices were made over the assessment of uncertainty, poorly known species, depleted species, population decline, restricted ranges, and rarity; all of these affect the way red lists should be viewed and used. Processes related to priority setting and the development of national red lists need to take account of some assumptions in the formulation of the criteria.

Maki, A. W., E. Brannon, et al. (1997). APPLICATION OF ECOLOGICAL RISK ASSESSMENT PRINCIPLES TO NATURAL RESOURCES DAMAGE ASSESSMENT. International Oil Spill Conference, American Petroleum Institute.

Mantua, N., I. Tohver, et al. (2009). "Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State." Climatic change **102**(1-2): 187-223.

This study evaluates the sensitivity of Washington State’s freshwater habitat of Pacific Salmon (Oncorhynchus spp.) to climate change. Our analysis focuses on summertime stream temperatures, seasonal low flows, and changes in peak and base flows because these physical factors are likely to be key pressure points for many of Washington’s salmon populations. Weekly summertime water temperatures and extreme daily high and low streamflows are evaluated under multimodel composites for A1B and B1 greenhouse gas emissions scenarios. Simulations predict rising water temperatures will thermally stress salmon throughout Washington’s watersheds, becoming increasingly severe later in the twenty-first century. Streamflow simulations predict that basins strongly influenced by transient runoff (a mix of direct runoff from cool-season rainfall and springtime snowmelt) are most sensitive to climate change. By the 2080s, hydrologic simulations predict a complete loss of Washington’s snowmelt dominant basins, and only about ten transient basins remaining in the north Cascades. Historically transient runoff watersheds will shift towards rainfall dominant behavior, undergoing more severe summer low flow periods and more frequent days with intense winter flooding. While cool-season stream temperature changes and impacts on salmon are not assessed in this study, it is possible that climate-induced warming in winter and spring will benefit parts of the freshwater life-cycle of some salmon populations enough to increase their reproductive success

Montgomery, D. R., J. M. Buffington, et al. (1996). "Stream-bed scour, egg burial depths, and the influence of salmonid spawning on bed surface mobility and embryo survival." Canadian Journal of Fisheries and Aquatic Sciences **53**(5): 1061-1070.

Bed scour, egg pocket depths, and alteration of stream-bed surfaces by spawning chum salmon (Onchorhynchus keta) were measured in two Pacific Northwest gravel-bedded streams. Close correspondence between egg burial depths and scour depths during the incubation period suggests an adaptation to typical depths of bed scour and indicates that even minor increases in the depth of scour could significantly reduce embryo survival. Where egg burial depths are known, expressing scour depth in terms of bed-load transport rate provides a means for predicting embryo mortality resulting from changes in watershed processes that alter shear stress or sediment supply. Stream-bed alteration caused by mass spawning also may influence embryo survival. Theoretical calculations indicate that spawning-related bed surface coarsening, sorting, and form drag reduce grain mobility and lessen the probability of stream-bed scour

and excavation of buried salmon embryos. This potential feedback between salmon spawning and bed mobility implies that it could become increasingly difficult to reverse declines in mass-spawning populations because decreased spawning activity would increase the potential for bed scour, favoring higher embryo mortality. Further analysis of this effect is warranted, however, as the degree to which spawning-related bed loosening counteracts reduced grain mobility caused by surface coarsening, sorting, and redd form drag remains uncertain.

Murphy, M. L., J. Heifetz, et al. (1986). "Effects of clear-cut logging with and without buffer strips on juvenile salmonids in Alaskan streams." Canadian Journal of Fisheries and Aquatic Sciences **43**(8): 1521-1533.

To assess short-term effects of logging on juvenile Oncorhynchus kisutch, Salvelinus malma, Salmo gairdneri, and Salmo clarki in southeastern Alaska, we compared fish density and habitat in summer and winter in 18 streams in old-growth forest and in clearcuts with and without buffer strips. Buffered reaches did not consistently differ from old-growth reaches; clear-cut reaches had more periphyton, lower channel stability, and less canopy, pool volume, large woody debris, and undercut banks than old-growth reaches. In summer, if areas had underlying limestone, clear-cut reaches and buffered reaches with open canopy had more periphyton, benthos, and coho salmon fry (age 0) than old-growth reaches. In winter, abundance of parr (age > 0) depended on amount of debris. If debris was left in clear-cut reaches, or added in buffered reaches, coho salmon parr were abundant (10–22/100 m2). If debris had been removed from clear-cut reaches, parr were scarce (< 2/100 m2). Thus, clear-cutting may increase fry abundance in summer in some streams by increasing primary production, but may reduce abundance of parr in winter if debris is removed. Use of buffer strips maintains or increases debris, protects habitat, allows increased primary production, and can increase abundance of fry and parr.

Murphy, M. L. and K. V. Koski (1989). "Input and depletion of woody debris in Alaska streams and implications for streamside management." North American Journal of Fisheries Management **9**(4): 427-436.

Natural rates of input and depletion of large woody debris (LWD) in southeast Alaska streams were studied to provide a basis for managing streamside zones to maintain LWDfor fish habitat after timber harvest. Debris was inventoried in a variety of stream types in undisturbed old-growth forest; 252 pieces ofLWD were dated from the age of trees growing on them. Longevity of LWD was directly related to bole diameter: small LWD (10-30 cm in diameter) was less than 110 years old, whereas large LWD (>60 cm in diameter) was up to 226 years old. Assuming equilibrium between input and depletion ofLWD in streams in old-growth forests and exponential decay ofLWD, we calculated input and depletion rates from mean age ofLWD. Input and depletion rates were inversely proportional to LWD diameter and ranged from 1%/year for large LWD in all stream types to 3%/year for small LWD in large, high-energy, bedrock-controlled streams. A model of changes in LWDafter timber harvest (which accounted for depletion of LWD and input from second-growth forest) indicated that 90 years after clear-cut logging without a stream-side buffer strip large LWD would be reduced by 70% and recovery to prelogging levels would take more than 250 years. Because nearly all LWD is derived from within 30 m of the stream, the use of a 30-m wide, unlogged buffer strip along both sides of the stream during timber harvest should maintain LWD.

Nehlsen, W., J. E. Williams, et al. (1991). "Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington." Fisheries **16**(2): 4-21.

The American Fisheries Society herein provides a list of depleted Pacific salmon, steelhead, and sea-run cutthroat stocks from California, Oregon, Idaho, and Washington, to accompany the list of rare inland fishes reported by Williams et al. (1989). The list includes 214 native naturally-spawning stocks: 101 at high risk of extinction, 58 at moderate risk of extinction, 54 of special concern, and one classified as threatened under the Endangered Species Act of 1973 and as endangered by the state of California. The decline in native salmon, steelhead, and sea-run cutthroat populations has resulted from habitat loss and damage, and inadequate passage and flows caused by hydropower, agriculture, logging, and other developments; overfishing, primarily of weaker stocks in mixed-stock fisheries; and negative interactions with other fishes, including nonnative hatchery salmon and steelhead. While some attempts at remedying these threats have been made, they have not been enough to prevent the broad decline of stocks along the West Coast. A new paradigm that advances habitat restoration and ecosystem function rather than hatchery production is needed for many of these stocks to survive and prosper into the next century.

Nicholson, E., D. A. Keith, et al. (2009). "Assessing the threat status of ecological communities." Conservation Biology **23**(2): 259-274.

The first step in conservation planning is to identify objectives. Most stated objectives for conservation, such as to maximize biodiversity outcomes, are too vague to be useful within a decision-making framework. One way to clarify the issue is to define objectives in terms of the risk of extinction for multiple species. Although the assessment of extinction risk for single species is common, few researchers have formulated an objective function that combines the extinction risks of multiple species. We sought to translate the broad goal of maximizing the viability of species into explicit objectives for use in a decision-theoretic approach to conservation planning. We formulated several objective functions based on extinction risk across many species and illustrated the differences between these objectives with simple examples. Each objective function was the mathematical representation of an approach to conservation and emphasized different levels of threat. Our objectives included minimizing the joint probability of one or more extinctions, minimizing the expected number of extinctions, and minimizing the increase in risk of extinction from the best-case scenario. With objective functions based on joint probabilities of extinction across species, any correlations in extinction probabilities had to be known or the resultant decisions were potentially misleading. Additive objectives, such as the expected number of extinctions, did not produce the same anomalies. We demonstrated that the choice of objective function is central to the decision-making process because alternative objective functions can lead to a different ranking of management options. Therefore, decision makers need to think carefully in selecting and defining their conservation goals.

Noss, R. F. (1990). "Indicators for monitoring biodiversity: a hierarchical approach." Conservation Biology **4**(4): 355-364.

Biodiversity is presently a minor consideration in environmentalpolicy. It has been regarded as too broad and vague a concept to be applied to real-world regulatory and managementproblems. This problem can be corrected if biodiversity is recognized as an end in itself and if measurable indicators can be selected to assess the status of biodiversity over time. Biodiversity, as presently understood, encompasses multiple levels of biological organization. In tbis paper, I expand the three primary attributes of biodiversity recognized by Jerry Franklin - composition, structure, and function - into a nested hierarchy that incorporates elements of each attribute at four levels of organization: regional landscape, community-ecosystem, populationspecies, and genetic. Indicators of each attribute in terrestrial ecosystems, at the four levels of organization, are identified for environmental monitoring purposes. Projects to monitor biodiversity will benefit from a direct linkage to long-term ecological research and a commitment to test hypotheses relevant to biodiversity conservation. A general guideline is to proceed from the top down, beginning with a coarse-scale inventory of landscape pattern, vegetation, habitat structure, and species distributions, then overlaying data on stress levels to identify biologically significant areas at high risk of impoverishment Intensive research and monitoring can be directed to high-risk ecosystems and elements of biodiversity, while less intensive monitoring is directed to the total landscape (or samples thereof). In any monitoring program, particular attention should be paid to specifying the questions that monitoring is intended to answer and validating the relationships between indicators and the components of biodiversity they represent

Noss, R. F. (1999). "Assessing and monitoring forest biodiversity: a suggested framework and indicators." Forest Ecology and Management **115**(2): 135-146.

Enlightened forest management requires reliable information on the status and condition of each forest ± interpreted from a broad context ± and of change in forest conditions over time. The process of forest planning must begin with a clear statement of goals, from which detailed objectives and management plans follow. Goals and objectives for forest management should re¯ect the conservation value of a forest relative to other forests of the same general type. This paper reviews some recent assessments (with emphasis on North America), presents a framework for forest assessment and monitoring, and suggests some indicators of biodiversity in forests. Among the broad assessments of forest status and conservation value are a global `forest frontiers' assessment by the World Resources Institute, gap analysis projects that assess the level of representation of forests and other communities in protected areas, and ecoregion-based conservation assessments conducted by the World Wildlife Fund. Also important is information on change in forest area and condition over time. Among the common changes in forests over the past two centuries are loss of old forests, simpli®cation of forest structure, decreasing size of forest patches, increasing isolation of patches, disruption of natural ®re regimes, and increased road building, all of which have had negative effects on native biodiversity. These trends can be reversed, or at least slowed, through better management. Progress toward forest recovery can be measured through the use of ecological indicators that correspond to the speci®c conditions and trends of concern. Although there is a wealth of indicators to choose from, most have been poorly tested and require rigorous validation in order to be interpreted with confidence.

Ohlson, D. W. and V. B. Serveiss (2007). "The integration of ecological risk assessment and structured decision making into watershed management." Integrated environmental assessment and management **3**(1): 118-128.

Watershed management processes continue to call for more science and improved decision making that take into account the full range of stakeholder perspectives. Increasingly, the core principles of ecological risk assessment (i.e., the development and use of assessment endpoints and conceptual models, conducting exposure and effects analysis) are being incorporated and adapted in innovative ways to meet the call for more science. Similarly, innovative approaches to adapting decision analysis tools and methods for incorporating stakeholder concerns in complex natural resource management decisions are being increasingly applied. Here, we present an example of the integration of ecological risk assessment with decision analysis in the development of a watershed management plan for the Greater Vancouver Water District in British Columbia, Canada. Assessment endpoints were developed, ecological inventory data were collected, and watershed models were developed to characterize the existing and future condition of 3 watersheds in terms of the potential risks to water quality. Stressors to water quality include sedimentation processes

(landslides, streambank erosion) and forest disturbance (wildfire, major insect or disease outbreak). Three landscape-level risk management alternatives were developed to reflect different degrees of management intervention. Each alternative was evaluated under different scenarios and analyzed by explicitly examining value-based trade-offs among water quality, environmental, financial, and social endpoints. The objective of this paper is to demonstrate how the integration of ecological risk assessment and decision analysis approaches can support decision makers in watershed management.

Orme-Zavaleta, J. and W. R. Munns Jr (2008). Integrating human and ecological risk assessment: application to the cyanobacterial harmful algal bloom problem. Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs, Springer**:** 867-883.

Environmental and public health policy continues to evolve in response to new and complex social, economic and environmental drivers. Globalization and centralization of commerce, evolving patterns of land use (e.g., urbanization, deforestation), and technological advances in such areas as manufacturing and development of genetically modified foods have created new and complex classes of stressors and risks (e.g., climate change, emergent and opportunist disease, sprawl, genomic change). In recognition of these changes, environmental risk assessment and its use are changing from stressor-endpoint specific assessments used in command and control types of decisions to an integrated approach for application in community based decisions. As a result, the process of risk assessment and supporting risk analyses are evolving to characterize the human-environment relationship. Integrating risk paradigms combine the process of risk estimation for humans, biota, and natural resources into one assessment to improve the information used in environmental decisions (Suter et al. 2003b). A benefit to this approach includes a broader, system-wide evaluation that considers the interacting effects of stressors on humans and the environment, as well the interactions between these entities. To improve our understanding of the linkages within complex systems, risk assessors will need to rely on a suite of techniques for conducting rigorous analyses characterizing the exposure and effects relationships between stressors and biological receptors. Many of the analytical techniques routinely employed are narrowly focused and unable to address the complexities of an integrated assessment. In this paper, we describe an approach to integrated risk assessment, and discuss qualitative community modeling and Probabilistic Relational odeling techniques that address these limitations and evaluate their potential for use in an integrated risk assessment of cyanobacteria.

Polasky, S., E. Nelson, et al. (2008). "Where to put things? Spatial land management to sustain biodiversity and economic returns." Biological Conservation **141**(6): 1505-1524.

Expanding human population and economic growth have led to large-scale conversion of natural habitat to human-dominated landscapes with consequent large-scale declines in biodiversity. Conserving biodiversity, while at the same time meeting expanding human needs, is an issue of utmost importance. In this paper we develop a spatially explicit landscape-level model for analyzing the biological and economic consequences of alternative land-use patterns. The spatially explicit biological model incorporates habitat preferences, area requirements and dispersal ability between habitat patches for terrestrial vertebrate species to predict the likely number of species that will be sustained on the landscape. The spatially explicit economic model incorporates site characteristics and location to predict economic returns for a variety of potential land uses. We apply the model to search for efficient land-use patterns that maximize biodiversity conservation objectives for given levels of economic returns, and vice versa. We apply the model to the Willamette Basin, Oregon, USA. By thinking carefully about the arrangement of activities, we find land-use patterns that sustain high levels of biodiversity and economic returns. Compared to the 1990 land-use pattern, we show that both biodiversity conservation and the value of economic activity could be increased substantially.

Potter, K. M. (2002). "Landscape characteristics and North Carolina stream life: A multiple-scale ecological risk assessment of nonpoint source pollution."

Nonpoint sources of pollution may be responsible for as much as 50 percent of current water quality degradation in the United States, and as much as 70 percent in the Southeast. In this study, I used an ecological risk assessment methodology, at the watershed scale and riparian scales (zones 300, 100, and 50 feet on either side of streams), to analyze and quantify the impact of nonpoint pollution on the ecological integrity and water quality of North Carolina streams. Specifically, I determined how land-use patterns relate to aquatic ecological integrity, including the extent to which one of the most widely promoted best management practices (BMPs) – the preservation of riparian vegetated buffers – correlates with better ecological integrity. The central goal of this project was the creation of a set of empirical models that describe the vulnerability of North Carolina aquatic ecological integrity – as measured by benthic macroinvertebrate community structure – to changes in the landscape-scale sources of nonpoint pollution. The models are the result of multiple regression analysis of Geographic Information System (GIS)-derived data, and take into account eight land form characteristics and three land cover types derived from 1992 Multi-Resolution Land Characterization (MRLC) Consortium raster data: forest, urban, and agriculture. The land form characteristics considered in this analysis are topographic complexity, mean elevation, watershed slope/relief ratio, watershed area, watershed shape, rainfall, soil clay content, and ecoregion. The regression equation models created by this process can be used by managers and policymakers to weigh the risks of management and policy

decisions for a given watershed or set of watersheds, including whether vegetated riparian buffers are ecologically effective and economically efficient in achieving water quality standards. The coefficient of multiple determination (R2) for each equation indicates the proportion of variability in the invertebrate tolerance indices attributable to the landscape variables included in the model. The unstandardized regression coefficients for each landscape variable represent that variable's weight and direction in the vulnerability index equation. The standardized (beta weight) regression coefficients indicate the relative importance of the landscape characteristic compared to the other landscape variables in the model equation. The results of this study indicate that (1) landscape characteristics at the watershed scale predict variability in benthic macroinvertebrate community structure better than characteristics at the riparian scale; (2) land cover variables are of secondary importance to certain land form features, but are still significant predictors of macroinvertebrate community structure; (3) developed land use is the most important land cover variable at the watershed scale, while forested land cover is the most important at the riparian scale; (4) wider riparian buffer zones yield only minor differences in invertebrate community structure; and (5) more research is needed on how these interactions vary by the size of a watershed and the ecoregion in which it is located. Based on these findings, it appears that water quality and stream ecological integrity may be most at risk in North Carolina watersheds where a greater amount of urban development is occurring at the watershed scale, where a lower percentage of forest cover exists in riparian corridors, and where the topography is generally flatter. The ecological risk assessment process that produced these results was relatively simple and inexpensive. The results are straightforward and generally easy to interpret. The vulnerability model equations that resulted from this assessment process can provide a basis for quantitatively comparing, ranking, and prioritizing risks, which can be useful in cost benefit and cost-effectiveness analyses of alternative management options. Specifically, the model equations offer a useful tool for characterizing the risk of potential land management options through the simulation of land use change, such as the conversion of land cover or the implementation of best management practices.

Power, M. and S. M. Adams (1997). "Perspectives of the scientific community on the status of ecological risk assessment." Environmental Management **21**(6): 803-830.

Views from a wide variety of practicing environmental professionals on the current status of ecological risk assessment (ERA) indicate consensus and divergence of opinion on the utility and practice of risk assessment. Central to the debate were the issues of whether ERA appropriately incorporates ecological and scientific principle into its conceptual paradigm. Advocates argue that ERA effectively does both, noting that much of the fault detractors find with the process has more to do with its practice than its purpose. Critics argue that failure to validate ERA predictions and the tendency to over-simplify ecological principles compromise the integrity of ERA and may lead to misleading advice

on the appropriate responses to environmental problems. All authors felt that many improvements could be made, including validation, better definition of the ecological questions and boundaries of ERA, improved harmonization of selected methods, and improvements in the knowledge base. Despite identified deficiencies, most authors felt that ERA was a useful process undergoing evolutionary changes that will inevitably determine the range of environmental problems to which it can be appropriately applied. The views expressed give ERA a cautious vote of approval and highlight many of the critical strengths and weaknesses in one of our most important environmental assessment tools.

Quinn, T. P. (2005). The behavior and ecology of Pacific salmon and trout, UBC Press.

Rico, M., G. Benito, et al. (2008). "Floods from tailings dam failures." Journal of hazardous materials **154**(1): 79-87.

This paper compiles the available information on historic tailings dam failures with the purpose to establish simple correlations between tailings ponds geometric parameters (e.g., dam height, tailings volume) and the hydraulic characteristics of floods resulting from released tailings. Following the collapse of a mining waste dam, only a part of tailings and polluted water stored at the dam is released, and this outflow volume is difficult to estimate prior the incident. In this study, tailings' volume stored at the time of failure was shown to have a good correlation (r2 = 0.86) with the tailings outflow volume, and the volume of spilled tailings was correlated with its run-out distance (r2 = 0.57). An envelope curve was drawn encompassing the majority of data points indicating the potential maximum downstream distance affected by a tailings' spill. The application of the described regression equations for prediction purposes needs to be treated with caution and with support of on-site measurement and observations. However, they may provide a universal baseline approximation on tailing outflow characteristics (even if detailed dam information is unavailable), which is of a great importance for risk analysis purposes.

Rico, M., G. Benito, et al. (2008). "Reported tailings dam failures: a review of the European incidents in the worldwide context." Journal of hazardous materials **152**(2): 846-852.

Adetailed search and re-evaluation of the knownhistorical cases of tailings dam failurewas carried out.Acorpus of 147 cases ofworldwide tailings dam disasters, from which 26 located in Europe, was compiled in a database. This contains six sections, including dam location, its physical and constructive characteristics, actual and putative failure cause, sludge hydrodynamics, socio-economical consequences and environmental impacts. Europe ranks in second place in

reported accidents (18%), more than one third of them in dams 10–20m high. In Europe, the most common cause failure is related to unusual rain, whereas there is a lack of occurrences associated with seismic liquefaction, which is the second cause of tailings dam breakage elsewhere in the world. Moreover, over 90% of incidents occurred in active mines, and only 10% refer to abandoned ponds. The results reached by this preliminary analysis show an urgent need for EU regulations regarding technical standards of tailings disposal.

Rodriguez, J. P., K. M. Rodriguez-Clark, et al. (2010). "Establishing IUCN red list criteria for threatened ecosystems." Conservation Biology **25**(1): 21-29.

The potential for conservation of individual species has been greatly advanced by the International Union for Conservation of Nature’s (IUCN) development of objective, repeatable, and transparent criteria for assessing extinction risk that explicitly separate risk assessment from priority setting. At the IV World Conservation Congress in 2008, the process began to develop and implement comparable global standards for ecosystems. A working group established by the IUCN has begun formulating a system of quantitative categories and criteria, analogous to those used for species, for assigning levels of threat to ecosystems at local, regional, and global levels. A final system will require definitions of ecosystems; quantification of ecosystem status; identification of the stages of degradation and loss of ecosystems; proxy measures of risk (criteria); classification thresholds for these criteria; and standardized methods for performing assessments. The system will need to reflect the degree and rate of change in an ecosystem’s extent, composition, structure, and function, and have its conceptual roots in ecological theory and empirical research. On the basis of these requirements and the hypothesis that ecosystem risk is a function of the risk of its component species, we propose a set of four criteria: recent declines in distribution or ecological function, historical total loss in distribution or ecological function, small distribution combined with decline, or very small distribution. Most work has focused on terrestrial ecosystems, but comparable thresholds and criteria for freshwater and marine ecosystems are also needed. These are the first steps in an international consultation process that will lead to a unified proposal to be presented at the next World Conservation Congress in 2012

Rogers, K., N. Saintilan, et al. (2013). "Application of thresholds of potential concern and limits of acceptable change in the condition assessment of a significant wetland." Environmental monitoring and assessment **185**(10): 8583-8600.

We propose a framework in which thresholds of potential concern (TPCs) and limits of acceptable change (LACs) are used in concert in the assessment of wetland condition and vulnerability and apply the framework in a case study. The lower Murrumbidgee River floodplain (the 'Lowbidgee') is one of the most

ecologically important wetlands in Australia and the focus of intense management intervention by State and Federal government agencies. We used a targeted management stakeholder workshop to identify key values that contribute to the ecological significance of the Lowbidgee floodplain, and identified LACs that, if crossed, would signify the loss of significance. We then used conceptual models linking the condition of these values (wetland vegetation communities, waterbirds, fish species and the endangered southern bell frog) to measurable threat indicators, for which we defined a management goal and a TPC. We applied this framework to data collected across 70 wetland storages', or eco-hydrological units, at the peak of a prolonged drought (2008) and following extensive re-flooding (2010). At the suggestion of water and wetland mangers, we neither aggregated nor integrated indices but reported separately in a series of chloropleth maps. The resulting assessment clearly identified the effect of rewetting in restoring indicators within TPC in most cases, for most storages. The scale of assessment was useful in informing the targeted and timely management intervention and provided a context for retaining and utilising monitoring information in an adaptive management context.

Root, K. V., H. R. AkÃ§akaya, et al. (2003). "A multispecies approach to ecological valuation and conservation." Conservation Biology **17**(1): 196-206.

The conservation of ecosystems focuses on evaluating individual sites or landscapes based on their component species. To produce a map of conservation values, we developed a method to weight habitat-suitability maps for individual species by species-specific extinction risks. The value of a particular site reflects the importance and magnitude of the threats facing the component species of the ecological community. We applied this approach to a set of species from the California Gap Analysis Project. The resulting map of multispecies conservation values identified the areas with the best habitat for the species most vulnerable to extinction. These methods are flexible and can accommodate the quantity and quality of data available for each individual species in both the development of the habitat-suitability maps and the estimation of the extinction risks. Additionally, the multispecies conservation value can accommodate specific conservation goals, such as preservation of local endemics, making it useful for prioritizing conservation and management actions. This approach provides an estimate of the ecological worth of a site based on habitat characteristics and quantitative models in terms of all the ecological components of a site, rather than a single threatened or endangered species.

Ruggerone, G. T., R. M. Peterman, et al. (2010). "Magnitude and trends in abundance of hatchery and wild pink salmon, chum salmon, and sockeye salmon in the North Pacific Ocean." Marine and Coastal Fisheries **2**(1): 306-328.

Abundance estimates of wild and hatchery Pacific salmon Oncorhynchus spp. are important for evaluation of stock status and density-dependent interactions at sea. We assembled available salmon catch and spawning abundance data for both Asia and North America and reconstructed total abundances of pink salmon O. gorbuscha, chum salmon O. keta, and sockeye salmon O. nerka during 1952–2005. Abundance trends were evaluated with respect to species, regional stock groups, and climatic regimes. Wild adult pink salmon were the most numerous salmon species (average¼2683106 fish/year, or 70% of the total abundance of the three species), followed by sockeye salmon (633106 fish/year, or 17%) and chum salmon (483106 fish/year, or 13%). After the 1976–1977 ocean regime shift, abundances of wild pink salmon and sockeye salmon increased by more than 65% on average, whereas abundance of wild chum salmon was lower in recent decades. Although wild salmon abundances in most regions of North America increased in the late 1970s, abundances in Asia typically did not increase until the 1990s. Annual releases of juvenile salmon from hatcheries increased rapidly during the 1970s and 1980s and reached approximately 4.53109 juveniles/year during the 1990s and early 2000s. During 1990–2005, annual production of hatchery-origin adult salmon averaged 783106 chum salmon, 543106 pink salmon, and 3.23106 sockeye salmon, or approximately 62, 13, and 4%, respectively, of the combined total wild and hatchery salmon abundance. The combined abundance of adult wild and hatchery salmon during 1990–2005 averaged 6343106 salmon/year (4983106 wild salmon/year), or approximately twice as many as during 1952–1975. The large and increasing abundances of hatchery salmon have important management implications in terms of density-dependent processes and conservation of wild salmon populations; management agencies should improve estimates of hatchery salmon abundance in harvests and on the spawning grounds.

Scheffer, M., S. Carpenter, et al. (2001). "Catastrophic shifts in ecosystems." Nature **413**(6856): 591-596.

All ecosystems are exposed to gradual changes in climate, nutrient loading, habitat fragmentation or biotic exploitation. Nature is usually assumed to respond to gradual change in a smooth way. However, studies on lakes, coral reefs, oceans, forests and arid lands have shown that smooth change can be interrupted by sudden drastic switches to a contrasting state. Although diverse events can trigger such shifts, recent studies show that a loss of resilience usually paves the way for a switch to an alternative state. This suggests that strategies for sustainable management of such ecosystems should focus on maintaining resilience.

Smith, C. and J. Speed (2013). Conserving Salmon Habitat in the Mat-Su Basin: The Strategic Action Plan of the Mat-Su Salmon Habitat Partnership. Anchorage, AK, The Nature Conservancy**:** 137.

Smith, E. R., L. T. Tran, et al. (2003). "Regional vulnerability assessment for the mid-Atlantic region: Evaluation of integration methods and assessment results." Environmental Protection Agency: Washington DC.

> Decision-makers need information on cumulative and aggregate stressors as well as clear information on where problems are likely to occur in the future in order to prioritize risk management actions. The most pervasive and difficult to assess changes are the result of regional-scale drivers of change that act simultaneously on a suite of resources that are important to society and to ecological sustainability. A great deal of data already exist that could potentially inform risk management decisions; however, there has been no effort previously to synthesize these data into meaningful assessment results that can inform the multiple criteria that go into any kind of decision-making. Methods to do this are critical to timely, responsive, and proactive decision-making.

Stein, J. L., J. A. Stein, et al. (2002). "Spatial analysis of anthropogenic river disturbance at regional and continental scales: identifying the wild rivers of Australia." Landscape and Urban Planning **60**(1): 1-25.

> A method for assessing anthropogenic river disturbance is described. The grid-based spatial modeling procedure computes indices of disturbance for individual stream sections. These indices rank streams along a continuum from near-pristine to severely disturbed. The method couples geographical data, recording the extent and intensity of human activities known to impact on river condition, with a Digital Elevation Model (DEM) used for drainage analysis. It was developed to produce the first nation-wide assessment of river disturbance from which Australia's least disturbed or 'wild' rivers were identified. A national summary of the extent and the potential impact of human activities is presented, calculated from the disturbance index values computed for more than 1.5 × 106 stream sections with a total length of over 3 × 106 km. Index values close to the undisturbed end of the continuum are rare, especially among large rivers. Most of the least disturbed streams are predicted to lie within the monsoonal tropical north or the arid/semi-arid center of the continent. The disturbance indices generated provide a comprehensive and consistent characterization of river and catchment disturbance that has applications beyond the identification of wild rivers. These include identification of priorities for rehabilitation and restoration; development of systematic survey strategies for aquatic, riparian and estuarine biota and identification of reserve networks for river systems. However, these applications depend on validating the correlation between river disturbance

indices and intensively sampled physical and biological indicators of river condition.

Suter, G. W. (2006). Ecological risk assessment, CRC press.

Suter, G. W., T. Vermeire, et al. (2003). "Framework for the integration of health and ecological risk assessment." Human and Ecological Risk Assessment **9**(1): 281-301.

The World Health Organization's International Programme on Chemical Safety (IPCS), the Organization for Economic Cooperation and Development (OECD), and the U.S. Environmental Protection Agency have developed a collaborative partnership to foster integration of assessment approaches for human health and ecological risks. This paper presents the framework developed by that group. Integration provides coherent expressions of assessment results, incorporates the interdependence of humans and the environment, uses sentinel organisms, and improves the efficiency and quality of assessments relative to independent human health and ecological risk assessments. The paper describes how integration can occur within each component of risk assessment, and communicates the benefits of integration at each point. The goal of this effort is to promote the use of this internationally accepted guidance as a basis for harmonization of risk assessment.

Thomas, J. W., J. F. Franklin, et al. (2006). "The Northwest Forest Plan: origins, components, implementation experience, and suggestions for change." Conservation Biology **20**(2): 277-287.

In the 1990s the federal forests in the Pacific Northwest underwent the largest shift in management focus since their creation, from providing a sustained yield of timber to conserving biodiversity, with an emphasis on endangered species. Triggered by a legal challenge to the federal protection strategy for the Northern Spotted Owl (Strix occidentalis caurina), this shift was facilitated by a sequence of science assessments that culminated in the development of the Northwest Forest Plan. The plan, adopted in 1994, called for an extensive system of late-successional and riparian reserves along with some timber harvest on the intervening lands under a set of controls and safeguards. It has proven more successful in stopping actions harmful to conservation of old-growth forests and aquatic systems than in achieving restoration goals and economic and social goals. We make three suggestions that will allow the plan to achieve its goals: (1) recognize that the Northwest Forest Plan has evolved into an integrative conservation strategy, (2) conserve old-growth trees and forests wherever they occur, and (3) manage federal forests as dynamic ecosystems.

Tiffan, K. F., C. A. Haskell, et al. (2008). "Quantifying the behavioral response of spawning chum salmon to elevated discharges from Bonneville Dam, Columbia river, USA." River research and applications **26**(2): 87-101.

Chum salmon Oncorhynchus keta that spawn in main-stem habitats below Bonneville Dam on the Columbia River, USA, are periodically subjected to elevated discharges that may alter
spawning behavior. We investigated behavioral responses of spawning chum salmon to increased water velocities associated with experimental increases in tailwater elevation using acoustic telemetry and a dual-frequency identification sonar. Chum salmon primarily remained near their redds at base tailwater elevations (3.5 m above mean sea level), but displayed different movement and behavioral responses as elevations were increased to either 4.1 or 4.7 m for 8-h periods. When velocities remained suitable (<0.8 m/s) during elevated tailwater tests, female chum salmon remained near their redds but exhibited reduced digging activity as water velocities increased. However, when velocities exceeded 0.8 m s, the females that remained on their redds exhibited increased swimming activity and digging virtually ceased. Female and male chum salmon that left their redds when velocities became unsuitable moved mean distances ranging from 32 to 58 m to occupy suitable velocities, but returned to their redds after tailwaters returned to base levels. Spawning events (i.e., egg deposition) were observed for five of nine pairs of chum salmon following tests indicating any disruptions to normal behavior caused by elevated tailwaters were likely temporary. We believe a chum salmon’s decision to either remain on, or leave, its redd during periods of unsuitably high water velocities reflects time invested in the redd and the associated energetic costs it is willing to incur.

Voinov, A. and F. Bousquet (2010). "Modelling with stakeholders." Environmental Modelling & Software **25**(11): 1268-1281.

Stakeholder engagement, collaboration, or participation, shared learning or fact-finding, have become buzz words and hardly any environmental assessment or modelling effort today can be presented without some kind of reference to stakeholders and their involvement in the process.This is clearly a positive development, but in far too many cases stakeholders have merely been paid lipservice and their engagement has consequentially been quite nominal. Nevertheless, it is generally agreed that better decisions are implemented with less conflict and more success when they are driven by stakeholders, that is by those who will be bearing their consequences. Participatory modelling, with its various types and clones, has emerged as a powerful tool that can (a) enhance the stakeholders knowledge and understanding of a system and its dynamics under various conditions, as in collaborative learning, and (b) identify and clarify the impacts of solutions to a given problem, usually related to supporting decision making, policy, regulation or management. In this overview paper we

first look at the different types of stakeholder modelling, and compare participatory modelling to other frameworks that involve stakeholder participation. Based on that and on the experience o fthe projects reported in this issue and elsewhere, we draw some lessons and generalisations.We conclude with an outline of some future directions.

Voinov, A. and R. Costanza (1999). "Watershed management and the web." Journal of Environmental Management **56**(4): 231-245.

Watershed analysis and watershed management are developing as tools of integrated ecological and economic study. They also assist decision-making at the regional scale. The new technology and thinking offered by the advent of the Internet and the World Wide Web is highly complementary to some of the goals of watershed analysis. Services delivered by the Web are open, interactive, fast, spatially distributed, hierarchical and flexible. The Web offers the ability to display information creatively, to interact with that information and to change and modify it remotely. In this way the Internet provides a much-needed opportunity to deliver scientific findings and information to stakeholders and to link stakeholders together providing for collective decision-making. The benefits fall into two major categories: methodological and educational. Methodologically the approach furthers the watershed management concept, offering an avenue for practical implementation of watershed management principles. For educational purposes the Web is a source of data and insight serving a variety of needs at all levels. We use the Patuxent River case study to illustrate the web-based approach to watershed management. A watershed scale simulation model is built for the Patuxent area and it serves as a core for watershed management design based on web applications. It integrates the knowledge available for the Patuxent area in a comprehensive and systematic format, and provides a conceptual basis for understanding the performance of the watershed as a system. Moreover, the extensive data collection and conceptualisation required within the framework of the modeling effort stimulates close contact with the environmental management community. This is further enhanced by offering access to the modeling results and the data sets over the Web. Additional web applications and links are provided to increase awareness and involvement of stakeholders in the watershed management process. We argue that it is not the amount and quality of information that is crucial for the success of watershed management, but how well the information is disseminated, shared and used by the stakeholders. In this respect the Web offers a wealth of opportunities for the decision-making process, but still to be answered are the questions at what scale and how widely will the Web be accepted as a management tool, and how can watershed management benefit from web applications.

Waetzold, F., M. Drechsler, et al. (2006). "Ecologicalâ€Economic Modeling for Biodiversity Management: Potential, Pitfalls, and Prospects." Conservation Biology **20**(4): 1034-1041.

Ecologists and economists both use models to help develop strategies for biodiversity management. The practical use of disciplinary models, however, can be limited because ecological models tend not to address the socioeconomic dimension of biodiversity management, whereas economic models tend to neglect the ecological dimension. Given these shortcomings of disciplinary models, there is a necessity to combine ecological and economic knowledge into ecological-economic models. It is insufficient if scientists work separately in their own disciplines and combine their knowledge only when it comes to formulating management recommendations. Such an approach does not capture feedback loops between the ecological and the socioeconomic systems. Furthermore, each discipline poses the management problem in its own way and comes up with its own most appropriate solution. These disciplinary solutions, however, are likely to be so different that a combined solution considering aspects of both disciplines cannot be found. Preconditions for a successful model-based integration of ecology and economics include (1) an in-depth knowledge of the two disciplines, (2) the adequate identification and framing of the problem to be investigated, and (3) a common understanding between economists and ecologists of modeling and scale. To further advance ecological-economic modeling the development of common benchmarks, quality controls, and refereeing standards for ecological-economic models is desirable.

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