Appendix I

Scientific Principles

Principle 1: The abundance, productivity and diversity of organisms are integrally linked to the characteristics of their ecosystems.

Discussion**:** An ecosystem is the organized complex of physical and biological components that make up the world we observe every day (Tansley 1935). The physical and biological components are inseparably related to produce the diversity, abundance and productivity of plant and animal species including humans (Odum 1971). Because of the pervasive impact of human actions on ecological systems (Vitousek and others 1997), achieving goals for individual species of commercial, cultural or other human interest will require managing human activities to support ecological processes (Christensen and others 1996).

Although we may have an intuitive feel for what constitutes an ecosystem, management goals are frequently couched in terms of individual species. Because of this, management actions typically focus on the needs of individual species. As environments have been altered by human action, we have attempted to prop-up species of commercial and cultural concern. These efforts have met with sporadic success. There is increasing recognition of the need for multiple species management and the integration of land management with fish and wildlife management (Christensen and others 1996, Dale and others 2000). This means recognizing the processes that form the necessary habitats for species and the functions that species provide to the ecosystem. The combination of suitable habitats and needed ecological functions combine to form the ecosystems needed to provide the desired abundance and productivity of specific species.

Local climate, hydrology and geomorphologic factors as well as species interactions strongly affect ecological processes and the abundance distribution of species at any one place (Dale and others 2000). Life histories, physical features and diversity of individual species are shaped by climate, physical structure of their habitat and by biological interactions . Change in physical or biological features of the ecosystem, either

natural or human-induced, will affect the capacity, productivity and diversity of fish and wildlife species.

Implications: Management of species in isolation at best provides an incomplete picture, and at worst misleads by not accounting for the context and mechanisms that control species abundance, capacity and diversity. This principle notes the integral relationship between species and their environment and the role that species themselves play in maintaining that environment. It couples ecological conditions to the productivity and abundance of species including those of management interest.

Natural resource management, especially fisheries management, often isolates species from their environment to protect them from habitat loss or other impacts of human actions (Bottom 1997). In the Columbia River we have tried to develop a protected corridor for salmon within limited parts of the life cycle while allowing the ecological support system to be dramatically altered. This neglects the role of biological and physical factors of the ecosystem in shaping individuals, populations and species through natural selection. These efforts also do not replace the habitats themselves or the ecological function that species provide. For salmon, the reality has been that, although large numbers of individuals are released into the system and protected through their freshwater phase, fewer and fewer fish return to spawn.

Principle 2. Ecosystems are dynamic, resilient and develop over time.

Discussion**:** Although ecosystems have definable structures and characteristics, their behavior is highly dynamic, constantly changing in response to internal and external factors (Dale and others 2000). The system we see today is the product of its biological, human and geological legacy. Disturbance and change are normal ecological processes and essential to the structure and maintenance of habitats (Bisson and others 1997). For example, floods structure aquatic habitat and fires structure terrestrial habitats (Reeves and others 1995).

Disturbance can be the result of natural processes such as fire, flood or insect outbreaks, or human activities such as timber harvest or agriculture. Natural disturbance patterns create a mosaic of habitats across the landscape and through time (Reeves and others 1995). At the same time, ecosystems maintain characteristic features and support

definable communities of organisms. Habitat-forming processes resulting from the underlying geology, climate and hydrology and species ecological functions of the individual species impart a degree of resilience to the system allowing it to accommodate change and maintain essential characteristics (Holling 1973). Depending on the degree of perturbation and the resilience of the system, the ecosystem may eventually resemble its previous condition once the disturbance dissipates. There are limits to the ability of an ecosystem to absorb change and retain its original characteristics (Holling 1973, Reice and others 1990). The system is not destroyed but instead shifts into a new configuration. Different species will be favored and new biological and physical interactions will develop.

A normal ecosystem will show describable, if not generally predictable, patterns of change over time (Odum 1969). Forests, for example, have successional patterns characterized by the change from pioneer to mature species. A forest, like other ecosystems, may appear stable when we observe it at one point in time, but it changes over broader time frames. Similarly, lakes and streams mature with dramatically different ecological character at various points in time (Cummins and others 1984). Natural disturbances can interrupt succession locally leading to a mosaic of habitats across the landscape (Reeves and others 1995). More widespread and pervasive disturbance including many human activities can stop or reset ecological succession patterns and prevent formation of habitats and processes that may be essential to continuation and abundance of some species.

Implications: Many natural resource management actions are designed to control the environment, reduce variability and achieve a stable and predictable yield from a highly dynamic system (Holling and Meffe 1996). For example, hatcheries were conceived, in part, to smooth out natural variation in fish populations and to sustain harvest over time (Bottom 1997). Dams and other structures dampen seasonal variation in water flow, while banks are stabilized and diked. Hatchery production and fish passage measures are timed and engineered to provide a predictable fish migration with minimal conflict with human uses of the river. Fires are suppressed leading to altered forest succession and species composition as well as insect outbreaks (Quigley and others 1996).

This principle encourages a departure from attempts to freeze the system in a certain constant state and manage for constant yields. Natural resource management programs should anticipate and accommodate change. Expectations of constant abundance or yield from natural resources are unrealistic and ignore fundamental features of ecological systems. Disturbance should be recognized as a strategy for development and maintenance of habitat. Efforts to stabilize the environment and reduce disturbance will fundamentally alter habitats to the detriment of capacity, productivity and diversity of target species.

Principle 3. Biological systems are organized hierarchically.

Discussion: Ecosystems, landscapes, communities and populations are usefully described as hierarchies of nested components (Allen and Hoekstra 1992). Levels within these hierarchies are distinguished by their appropriate spatial and time scales. A higher level addresses larger areas that fluctuate at relatively long time intervals, whereas lower levels encompass smaller areas and fluctuate at higher frequencies. Expansive ecological patterns and processes constrain, and in turn reflect, localized patterns and processes (Wiens 1989). By analogy to a camera lens, we can zoom in to address fine details and pan out to consider the system as a whole.

The definition of the hierarchy and scale is dependent on the question asked (Levin 1992). There is no single, intrinsically correct description, only one that usefully addresses the problem. The description should clarify the higher level constraints as well as the localized mechanisms behind the problem.

This suggests neither a top-down nor a bottom-up approach, but integrates both. Depending on the question, it may be necessary to focus on the higher level constraints on a level or to consider how performance at lower levels combines to produce the result we see (Weins 1989). Performance at any level reflects both the synergistic effect of actions at local scales and the constraints imposed by higher level factors (Allen and Hoekstra 1992); that is, it is useful to look at the next level up to understand the context, and the next level down to understand the mechanisms.

Viewing ecosystems as hierarchies is useful for depicting the underlying structure of many ecological components. Regional climates vary through time on scales ranging

from millennial to inter annual (Greenland 1998). Disturbance regimes within ecosystems can be described at a variety of spatial and temporal scales (Delcourt and others 1983) that can affect life history patterns and genetic structure (Wissmar and Simenstad 1998). Frissell and others (1986) structured aquatic habitats describe a hierarchical classification system that reflects underlying geomorphic hierarchies.

Implications: If ecosystems are viewed as nested hierarchies, it is necessary to define appropriate scales for their management and study (Holling and Meffe 1996). To solve problems regarding the entire Columbia River Basin, we need to filter out some more localized data. On the other hand, questions concerning localized components (e.g. subbasins) cannot be addressed by looking at the entire basin. Understanding basin-level problems requires knowledge of actions and processes that take place in subbasins, while subbasin level actions will be successful only when considered in the context of factors operating at basin and regional levels.

This principle provides an ecologically based way to structure fish and wildlife recovery (Quigley and others 1996). Such a structure should reflect ecological pattern within the system while providing a useful organizational device for recovery efforts. A necessary first step is to define the ecosystem at the point in the ecological continuum appropriate to the problem. The ecosystem at that point reflects the characteristics of the features nested within and higher level constraints on performance.

Principle 4. Environments and habitats develop, and are maintained, by processes related to climate, geology and hydrology.

Discussion: Habitat refers to the resources and conditions present in an area that allow a species or a group of species to exist and thrive (Hall and others 1997). Habitats are created, altered and maintained by processes that operate over at a range of scales (Allen and Hoekstra 1992). Habitat forming processes include runoff patterns, heating/cooling, forest succession, and erosion/deposition (Imhof and others 1996). At the local scale, habitats are created and maintained by processes that encompass aquatic and terrestrial factors throughout the watershed reflecting hydrology and geology. Regional climatic conditions in turn control temperatures and precipitation that are important in the development of habitats. Locally observed conditions often reflect more expansive or

non-local processes and influences, including human actions. The presence of essential habitat features created by these processes determines the abundance, productivity and diversity of species and communities (Morrison and others 1998).

The active agent of many aquatic habitat-forming processes is water acting with the underlying geology, topography and climate. The hydrologic linking of habitat processes means that the impacts of actions can radiate and accumulate downstream. Habitat conditions such as water temperature or sediment can be the result of actions and conditions that occur upstream. Aquatic habitat conditions are affected by terrestrial conditions and actions that accumulate as water moves downslope.

Terrestrial habitats are often described in terms of food, water and cover. Formation of these features is related to vegetational patterns that result from environmental needs of individual plant species, succession and patterns of human-caused and natural disturbance (Whittaker 1975). In turn, vegetation pattern is related to local geology, topography and climate in the context of regional factors such as climate.

Implications: Understanding the processes that create and maintain aquatic and terrestrial habitats are key to the management of human impacts on those habitats (Imhof and others 1996). These processes can only be appreciated by consideration of habitats at watershed or subbasin scales even though the perceived problem is localized. Often our efforts are focused on correcting symptoms of habitat degradation and loss rather than on causes. We try to "fix" the problem by engineering localized solutions. In most cases, these efforts prove futile because the process and conditions creating the problem are still active (Kauffman and others 1997). For example, logging practices in the upper parts of watersheds may affect water temperatures and sediment levels and negate efforts to correct habitat problems lower in the system. Livestock grazing may preclude development of normal vegetational succession in riparian areas with downstream impacts on flow, temperature and sediments. Management to achieve goals for specific species implies allowing normal habitat forming processes to operate and develop an appropriate environment.

This principle stresses the need to understand and address habitat forming processes in order to restore and maintain aquatic and terrestrial habitats. Habitat

restoration actions undertaken without appreciation of the underlying Land use practices affect habitats through processes similar to those structuring natural habitats. Relating practices to process is key to ensuring that habitats are available to support biological communities and species of interest.

Principle 5. Species play key roles in maintaining ecological conditions.

Discussion: Organisms do not act as passive residents of their habitats. Instead, each species has one or more ecological functions that may be key to the development and maintenance of ecological conditions (Walker 1995). Species, in effect, have a distinct job or occupation that is essential to the diversity, sustainability and productivity of the ecosystem over time (Morrison and others 1998). For example, plant, animal and bacterial species structure habitats, cycle energy and control species abundance and diversity. The existence, productivity and abundance of species depend on these functions. To varying degrees, similar ecological functions may be performed by different species. Promoting or maintaining a diversity of species that have similar "occupations" enhances the resilience of the ecosystem in the face of disturbance or environmental variation (Walker 1995).

However, some ecological functions lack redundancy and are performed by a limited number of species. Removal or declines of such species can have significant impacts on their associated ecological function, the ecosystem and its species. In Pacific Northwest ecosystems, for example, salmon often have a key role in cycling of substantial amounts of nutrients and energy from the marine environment to freshwater and terrestrial habitats (Cederholm and others 2000). Removal of salmon from these systems results in ecological changes that can have far reaching impacts on a variety of aquatic and terrestrial plant and animal species (Willson and Halupka 1995, Cederholm and others 2000).

Implications: Traditional natural resource management has viewed species largely as passive functions of their habitat, separate and distinct from their ecosystems. This principle affirms the integral relationship between species and their ecosystems and the need to consider actions in the context of species ecological function. Many of our actions serve to isolate and protect species such as salmon even as the surrounding

ecosystem is altered in fundamental ways. Salmon hatcheries, for example, may provide harvest benefits to some human users when habitats have been altered or destroyed, but they do not replace the ecological role that salmon play in the ecosystem. The result can be significant ecological change affecting the presence and abundance of other aquatic and terrestrial species (Cederholm and others 2000). Actions such as hatcheries may continue to play a role in natural resource management, but they must be used not only to bolster survival and capacity of salmon, but also to restore or replace the function that salmon play in their ecosystem.

Principle 6. Biological diversity allows species to accommodate environmental variation.

Discussion: The physical and biological template of the environment shapes species, populations and individuals (Southwood 1977). Variation in the template over time and space, as well as the structure of the environment, results in an organization of biological variation among species, races, demes and individuals. Generally speaking, greater diversity between and within species leads to greater ecological stability (Odum 1971). Greater biological diversity between species leads to redundancy in ecological function that provides alternatives as species wax and wane with environmental variation (Walker 1995, Morrison and others 1998). Within a species, variation in biological characteristics among populations and individuals is the fuel by which adaptation occurs in response to environmental variation. A more diverse species has a greater range of possible solutions to the challenges posed by variation and changes in its environment. Within the spectrum of populations that comprises a species (chinook salmon in the Columbia River, for example) there is a variation in survival as the environment shifts over time. As some populations suffer under an environmental extreme such as an El Nino condition, others might fare better. The species survives, bolstered by its ability to respond to the shifting environment (Bisbal and McConnaha 1998).

Implications: Human actions can reduce biological variation (Urban and others 1987, Policansky and Magnuson 1998). As we simplify and stabilize environments, biological variation is reduced. This leads to species that are less capable of responding adaptively to environmental change.

If we accept that diversity between species increases ecosystem stability while within species diversity provides the ability of the species to better sustain itself and ultimately adapt to changing environments, then we should manage our activities to allow natural expression of biological diversity. While diversity can be quantified, determination of the "proper" level of biological diversity is likely not possible, partly because it shifts and varies over time in response to natural selection. The challenge is to manage human activities to minimize our impacts on selection and allow diversity to develop accordingly.

Principle 7. Ecological management is adaptive and experimental.

Discussion: Many of the features of ecological systems described in these principles counsel against the notion of command and control of the environment (Holling and Meffe 1996). Instead, the complexity and variability of ecosystems argues for management that is inherently experimental (McConnaha and Paquet 1996) and that admits and accounts for the range of natural dynamics at all levels of biological organization. Our knowledge of ecological systems is incomplete. We can describe the structure and nature of ecosystems in some ways, but important details elude us. More importantly, we have only recently begun to appreciate the Columbia River as an ecosystem. For most of this century we have thought of the Columbia River as a machine that can be adapted to meet our needs (White 1995). Ready solutions to management of a highly developed system like the Columbia River have not been developed. Finally, as has been emphasized in these principles, ecosystems vary over time. What is key to recovery of species today may not be so important in the future as the system shifts in some largely unpredictable fashion.

Adaptive management – the use of management experiments to investigate biological problems and to test the efficacy of management directions -- provides a model for experimental management of ecosystems. However, ecological scale management presents special challenges to adaptive management (Walters 1997). Ecosystem experiments may be impractical, infeasible or pose equity questions (Volkman and McConnaha 1993). We may be unwilling to experiment with beleaguered fish and wildlife populations. Under these circumstances, there may be less opportunity for large-

scale management experiments, and more need for directed experimentation and research. Nevertheless, an explicit, directed approach to learning is essential. Experimental management does not mean passive "learning by doing", but, rather a directed program aimed at understanding key ecosystem dynamics and the impacts of human actions by using the rigorous methods of scientific experimentation and inquiry (Platt 1964).

Implications: This principle argues for management that conscientiously experiments and probes to better understand the ecosystem. Ecosystem management is likely to require the development of new measuring tools (Done and Reichelt 1990). To the standard indices of abundance of important fish and wildlife species, ecosystem management calls for new indicators of success such as development of habitat characteristics, normal trophic structure, biological diversity and species conservation status. What is critical to fish and wildlife restoration in one decade may not be critical in the next as the ecosystem shifts in response to internal or external factors and as human values shift. As we learn about ecosystems, new strategies may be indicated. However, in order to provide relevant information regarding these factors, monitoring and evaluation need to be built into management programs from the ground up.

Principle 8. Ecosystem function, habitat structure and biological performance are affected by human actions.

Discussion: Humans are integral parts of ecosystems. Our actions have a pervasive impact on the structure and function of ecosystems, while, at the same time, our health and well being are tied to these conditions (Vitousek and others 1997). Like many other organisms, humans structure and control ecosystems for their own needs. In some ecosystems, human impacts act as major factors controlling the environment. However, unlike other organisms, we can consciously control our actions to allow needed ecological conditions to develop. While our actions may be unique in the scale of impact on ecological systems, the method of interaction is not; ecological principles apply to human interactions with ecosystems as much as they do to the interactions of fish and wildlife species and the ecosystem.

It is a reasonable assumption that for most species, the ecological conditions that are most conducive to their long-term survival and productivity are those under which

they evolved. Human actions in the Columbia River have shifted ecosystems away from their pre-development conditions with negative impacts for many native species, especially fish. Some changes are irreversible. New species such as smallmouth bass, walleye and many plant and terrestrial animals have been introduced and permanent changes have been made to the landscape. Even with complete cessation of human activities, these ecosystems would not return to their previous condition. However, human impacts on ecosystems can be managed to move the system to a state that is more compatible with the needs of other species.

Implications: These scientific principles suggest ways to view our role in ecosystems. Humans have significantly altered the natural landscape in the Columbia River Basin for several millennia and have significantly affected the abundance and distribution of plants and animals (Martin and Szuter 1999). In highly developed ecosystems like the Columbia River, human actions and technology will continue to dominate the system. However, those actions can be managed in a manner consistent with the needs of other species. The issue is to what extent are we able to control our impacts so as to balance the various services potentially provided by the Columbia River basin. It is simply a question of the type of environment in which we choose to live and how much we are willing to limit our actions to achieve these objectives.

References cited.

Allen, T. F. H., and T. W. Hoekstra. 1992. Toward a unified ecology. Columbia University Press, New York, NY.

Bisbal, G. A., and W. E. McConnaha. 1998. The influence of ocean conditions on the management of Pacific Salmon. Canadian Journal of Fisheries and Aquatic Sciences **55**(9):2178-2186.

Bisson, P., G. H. Reeves, R. E. Bilby, and R. J. Naiman. 1997. Watershed management and Pacific salmon: desired future conditions. Pages 447-474 *in* D. J. Stouder and P. A. Bisson, editors. Pacific salmon and their ecosystems: status and future options. Chapman Hall, New York.

Bottom, D. 1997. To till the water--A history of ideas in fisheries conservation. Pages 569-597 *in* D. J. Stouder, P. A. Bisson, and R. J. Naiman, editors. Pacific salmon and their ecosystems: Status and future options. Chapman Hall, New York, NY.

Cederholm, C. J., D. H. Johnson, R. E. Bilby, L. G. Dominguez, A. M. Garrett, W. H. Graeber, M. D. Kunze, B. G. Marcot, J. F. Palmisano, R. W. Plotnikoff, W. G. Pearcy, C. A. Simenstad, and P. C. Trotter. 2000. Pacific salmon and wildlife-Ecological contexts, relationships and implications for management. Special Edition Technical Report Washington, Department of Fish and Wildlife, Olympia, WA.

Christensen, N. C., A. M. Bartuska, J. H. Brown, S. Carpenter, C. D'Antonio, R. Francis, J. F. Franklin, J. A. MacMahon, R. F. Noss, D. J. Parsons, C. H. Peterson, M. G. Turner, and R. G. Woodmansee. 1996. The report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. Ecological Applications **6**(3):665-691.

Cummins, K. W., G. W. Minshall, J. R. Sedell, C. E. Cushing, and R. C. Petersen. 1984. Stream ecosystem theory. Internationale Vereinigung fur theoretische und angewandte Limnologie, Verhandlungen **22**:1818-1827.

Dale, V. H., S. Brown, R. A. Haeuber, N. T. Hobbs, N. Huntly, R. J. Naiman, W. E. Riebsame, M. G. Turner, and T. J. Valone. 2000. Ecological principles and guidelines for managing the use of land. Ecological Applications **10**(3):639-670.

Delcourt, H. R., P. A. Delcourt, and T. Webb. 1983. Dynamic plant ecology: the spectrum of vegetational change in space and time. Quaternary Science Review **1**:153-175.

Done, T. J., and R. E. Reichelt. 1990. Integrated coastal zone and fisheries ecosystem management: Generic goals and performance indices. Ecological Monographs **8**(1 Supplement):S110-S118.

Frissell, W. J., W. J. Liss, C. E. Warren, and M. D. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management **10**(2):199-214.

Greenland, D. 1998. Variability and stability of climatic/oceanic regimes in the Pacific Northwest. Pages 91-179 *in* G. R. McMurray and R. J. Bailey, editors. Changes, in Pacific Northwest coastal ecosystems. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Silver Springs, MD.

Hall, L. S., P. R. Krausman, and M. L. Morrison. 1997. The habitat concept and a plea for standard terminology. Wildlife Society Bulletin **25**(1):173-182.

Holling, C. S. 1973. Resilience and stability of ecological systems. Annual Review of Ecology and Systematics **4**:1-23.

Holling, C. S., and G. K. Meffe. 1996. Command and control and the pathology of natural resource management. Conservation Biology **10**(2):328-337.

Imhof, J. G., J. Fitzgibbon, and W. K. Annable. 1996. A hierarchical evaluation system for characterizing watershed ecosystems for fish habitat. Canadian Journal of Fisheries and Aquatic Sciences **53**(Supplement 1):312-326.

Independent Scientific Group. 2000. Return to the River 2000: restoration of salmonid fishes in the Columbia River Ecosystem. NPPC 2000-12, Northwest Power Planning Council, Portland, OR.

Kauffman, J. B., R. L. Beschta, N. Otting, and D. Lytjen. 1997. An ecological perspective of riparian and stream restoration in the Western United States. Fisheries **22**(5):12-24.

Levin, S. A. 1992. The problem of pattern and scale in ecology. Ecology **73**:1942-1968.

Martin, P. S., and C. R. Szuter. 1999. War zones and game sinks in Lewis and Clark's west. Conservation Biology **13**(1):36-45.

McConnaha, W. E., and P. J. Paquet. 1996. Adaptive strategies for the management of ecosystems: the Columbia River experience. Pages 410-421 *in* L. E. Miranda and D. R. DeVries, editors. Multidimensional approaches to reservoir fisheries management. American Fisheries Society, Bethesda, MD.

Morrison, M. L., B. G. Marcot, and R. W. Mannon. 1998. Wildlife-Habitat Relationships. Concepts and Applications, Second edition. University of Wisconsin Press, Madison, WI.

Odum, E. P. 1969. The strategy of ecosystem development. Science **164**:262-270.

Odum, E. P. 1971. Fundamentals of Ecology, 3rd edition. W. B. Saunders Company, Philadelphia.

Platt, J. R. 1964. Strong inference. Science **146**(3642):347-353.

Policansky, D., and J. J. Magnuson. 1998. Genetics, metapopulations, and ecosystem management of fisheries. Ecological Monographs **8**(1 Supplement):S119-S123.

Quigley, T. M., R. W. Haynes, R. T. Graham, and T. Russel. 1996. An integrated scientific assessment for ecosystem management in the interior Columbia basin and portions of the Klamath and Great basins. PNW-GTR-382, U.S. Forest Service, Pacific Northwest Research Station, Portland, OR.

Reeves, G. H., K. M. Benda, P. A. Burnett, P. A. Bisson, and J. R. Sedell. 1995. A disturbance based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. American Fisheries Society Symposium **17**:334-349.

Reice, S. R., R. C. Wissmar, and R. J. Naiman. 1990. Disturbance regimes, resilience and recovery of animal communities and habitats in lotic ecosystems. Environmental Management **14**(5):647-659.

Southwood, T. R. E. 1977. Habitat, the template for ecological strategies? Journal of Animal Ecology **46**:337-365.

Tansley, A. G. 1935. The use and abuse of vegetational concepts and terms. Ecology **16**:284-307.

Urban, M. G., R. V. O'Neill, and H. N. Shugart. 1987. Landscape ecology: a hierarchical perspective can help scientists understand spatial patterns. BioScience **37**:119-127.

Vitousek, P. M., H. A. Mooney, J. Lubchenco, and J. M. Melillo. 1997. Human domination of Earth's ecosystems. Science **277**:494-499.

Volkman, J. M., and W. E. McConnaha. 1993. Through a glass, darkly: Columbia River salmon,the Endangered Species Act, and adaptive management. Environmental Law **23**:1249-1272.

Walker, B. 1995. Conserving biological diversity through ecosystem resilience. Conservation Biology **9**(4):747-752.

Walters, C. J. 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conservation Ecology [online] **1**(2):http://www.consecol.org/vol1/iss2/art1.

Weins, J. A. 1989. Spatial scaling in ecology. Functional Ecology **3**:385-397.

White, R. 1995. The Organic Machine: the Remaking of the Columbia River. Hill and Wang, New York, NY.

Whittaker, R. H. 1975. Communities and ecosystems, 2nd edition. Macmillian, New York.

Wiens, J. A. 1989. Spatial scaling in ecology. Functional Ecology **3**:385-397.

Willson, M. F., and K. C. Halupka. 1995. Anadromous fish as keystone species in vertebrate communities. Conservation Biology **9**(3):489-497.

Wissmar, R. C., and C. A. Simenstad. 1998. Variability of riverine and estuarine ecosystem productivity for supporting Pacific Salmon. Pages 253-301 *in* G. R. McMurray and R. J. Bailey, editors. Change in Pacific Northwest coastal ecosystems. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Silver Springs, MD.