Relationships Among Juvenile Anadromous Salmonids, Their Freshwater Habitat, and Landscape Characteristics Over Multiple Years and Spatial Scales in the Elk River, Oregon

Chapter 1
Introduction

Stream ecosystem research has been dominated by studies examining small areas over short periods. This follows a general trend in ecology. May (1994), summarizing reviews of published ecological literature, indicated that few investigations had a spatial extent of more than 10 m or a temporal extent of more than 1 year. Analogously, for ecological studies involving Atlantic salmon (*Salmo salar*), 80% lasted less than 5 years and 75% were conducted within a single tributary (Folt et al. 1998). Limits of understanding gained at fine spatiotemporal scales have become obvious as society attempts to cope with pervasive problems involving rivers and streams such as declining water quality and quantity (e.g., Carpenter et al. 1998; Postel 2000), loss of biological diversity and integrity (e.g., Moyle and Williams 1990; Hughes and Noss 1992), and species endangerment and extinction (e.g., Frissell 1993; Ricciardi and Rasmussen 1999). Aggregating fine-scale information from disparate sources has not provided decision makers with the necessary tools to address such issues. In response, freshwater resources are now commonly incorporated into bioregional assessments (Johnson et al. 1999). Additionally, stream ecosystem researchers are expanding their scope of inquiry (Reeves et al. 1995; Thompson and Lee 2000) and applying spatial statistics (Cooper et al. 1997), concepts from landscape ecology (Dunham and Rieman 1999; Schlosser 1995), and multi-scale analysis (Roth et al.1996; Torgersen et al. 1999; Baxter and Hauer 2000).

Analysis at multiple scales can provide critical knowledge about system function and inform management decisions. For example, fish may respond to different habitat features at different scales. Multi-scale studies can identify these habitat features, suggest their importance to fish at different times, and distinguish natural processes responsible for their creation and maintenance. Examining multiple scales allowed Labbe and Fausch (2000) to elaborate a conceptual model specifying how physical processes influence habitat features that mediate biotic processes and ultimately govern the persistence of a threatened fish, the Arkansas darter (*Etheostoma cragini*), in an intermittent stream. Tracing one of several pathways in the model, high rainfall elevated stream flow at a reach scale that restored connections among habitats. This improved the likelihood of population persistence because fish could disperse from source areas in the spring. Along a second pathway, increased rainfall produced floods that excavated pools at a habitat scale. Water remained in these deep pools during subsequent low flows, permitting fish to survive when shallower habitats dried. Their conceptual model offers practical information for anticipating management impacts. For example, flood control or water withdrawal for irrigation could negate benefits from increased precipitation by disconnecting habitats and reducing the potential to form new deep-pool refugia. Analysis at only one scale would have undoubtedly missed physical and biotic processes necessary for the darter's persistence and reduced the study's relevancy to managers.

Multi-scale analysis arises from hierarchy theory. Hierarchy theory formalizes the awareness that ecosystems are scaled in time and space with subsystems arranged as nested hierarchies (O'Neill 1989; Allen and Hoekstra 1992). Each level of the hierarchy is differentiated by specific process rates and structures. Higher levels are driven by slower processes that generate patterns at coarser spatial and longer temporal scales, while lower levels are driven by faster processes that generate patterns at finer spatial and shorter temporal scales. The concept of constraint is an important consequence of hierarchical arrangement- each level is limited from above by its biotic and abiotic environment and from below by its components (O'Neill 1989). Higher levels provide context; lower levels provide mechanisms (Allen and Hoekstra 1992). Frissell et al. (1986) extended hierarchy theory to streams by refining the lower levels of Warren and Liss's (1983) spatially nested hierarchy for watershed classification. Frissell et al. (1986) presented habitat classification variables and controls on process at the stream system, valley segment, reach, channel unit, and sub-unit scales.

This attention to habitat was logical given that discovering relationships between organisms and their habitats is a cornerstone of ecology. In his presidential address to the British Ecological Society, Southwood (1977) proposed the concept of habitat as a templet for ecological strategies. He stressed the role of spatial and temporal heterogeneity in determining optimal habitats for species with different reproductive strategies and in structuring the communities that they comprise (Southwood 1977; Southwood 1988). Poff and Ward (1990) detailed the relevance of 'habitat as templet' for ecosystem recovery following disturbance in streams. The view that habitat is a key determinant of community structure and organization has been integral to many developments in stream ecology, including the river continuum (Vannote et al. 1980) and process domain (Montgomery 1999) concepts, as well as the multi-scale hierarchical framework of Frissell et al. (1986).

There is no single right scale for studying relationships between fish and their habitat. The question at hand should determine which scales are examined (Wiens 1989). Investigations targeting finer scales (i.e., channel unit (100-101 m) or below and <1 year) may be appropriate for many questions, such as how habitat mediates interactions between a fish and conspecifics. But, for other questions, particularly those related to freshwater habitat influences on populations of anadromous salmonids, pertinent information is more likely to derive from coarser spatial scales (i.e., watershed (103-104 m) or above and >10 years) (Reeves et al. 1995). Watersheds are a particularly useful spatial extent for relating a population of anadromous salmon to its habitat and a collection of watersheds for

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relating a meta-population to its habitat (Reeves et al. 1995). However, salmonid-habitat relationships have been infrequently explored throughout a watershed (e.g., Dolloff et al. 1994; Roper et al. 1994; Scarnecchia and Roper 2000). Such watershed studies over longer periods (i.e., one or more generations for the species of interest) are valuable but even less common (e.g., Reeves et al. 1997). Population abundances of stream fish and factors influencing these abundances may fluctuate from year to year (Platts and Nelson 1988; Grossman et al. 1990; House 1995; Ham and Pearsons 2000). Thus, failing to account for interannual variation may limit understanding of fish-habitat relationships and the transferability of results among years.

The condition of stream habitat is largely a function of conditions in the watershed that it drains (Hynes 1975; Frissell et al. 1986; Naiman et al. 1992). Thus, a watershed perspective is often recommended for studying and managing stream systems (Doppelt et al. 1993; FEMAT 1993; NRC 1996). Direct, local effects on stream habitat of features in the riparian area are relatively well established (Osborne and Koviac 1993; Naiman et al. 2000). Less well understood and agreed upon are relationships between stream habitat and riparian characteristics accumulated upstream along a channel network (e.g., Weller et al. 1998; Jones et al. 1999) or riparian and upslope characteristics accumulated throughout a catchment (e.g., Jones and Grant 1996; Thomas and Megahan 1998; Jones and Grant 2001). Riparian and catchment characteristics have been compared across multiple spatial scales for their influences on stream ecosystems in agricultural systems. However, these influences have seldom been compared for streams in mountainous areas where silviculture was the dominant land use. Abundances of Pacific salmon and trout (*Oncorhynchus spp.*) or conditions of their freshwater habitat have been related to landscape characteristics at different spatial scales, including the local riparian area (Bilby and Ward 1991), the entire riparian network (Botkin et al. 1995; Lunetta et al. 1997), and the catchment (e.g., Reeves et al. 1993; Dose and Roper 1994; Dunham and Rieman 1999; Thompson and Lee 2000). Although these studies offered critical insights, none directly compared relationships between stream habitat and landscape characteristics at multiple spatial scales. I am aware of only two response variables, macroinvertebrate biological integrity (Hawkins et al. 2000) and abundance of adult coho salmon (*Oncorhynchus kisutch*) (Pess et al. in review), for which relationships to riparian and catchment characteristics were compared in streams draining forested, montane regions. Analogous multi-scale assessments can identify riparian and upslope areas that help create and maintain stream habitat in forestry-dominated landscapes.

I have two primary goals in this dissertation. The first is to understand relationships between juvenile anadromous salmonids and their habitat at multiple spatial scales throughout a watershed over multiple years. And the second is to understand relationships between fish habitat and landscape characteristics summarized at multiple spatial scales. Chapter 2 addresses habitat availability for and selection by members of the juvenile anadromous salmonid assemblage in the Elk River, Oregon for each of 7 years (1988-1994). Ocean-type chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), coastal cutthroat trout (*O. clarki*), and steelhead (*O. mykiss*) comprise the salmonid assemblage. Examined spatial scales are the stream system, the valley segment, and the channel unit. Habitat selection ratios and associated confidence intervals are calculated with bootstrapping methods. Interannual patterns of habitat selection are examined in relation to environmental factors and to fish density as an indicator of potential intra- and interspecific competition. Variation in fish habitat characteristics is described at the stream system and valley segment scales within and among years.

Chapter 3 relates the annual distribution (1988-1994) of juvenile ocean-type chinook salmon among valley segments in tributaries of the Elk River to habitat features at the valley segment and channel unit scales. Stream habitat is typically thought to be less critical to juvenile ocean-type chinook salmon than to other species of salmonids that spend more time in freshwater. Habitat characteristics may, however, be important to ocean-type chinook salmon in basins, such as the Elk River, that lack a well developed estuary and that support a population exhibiting diversity in the length of freshwater residency. If habitat features are irrelevant, I expect these to explain little of the among-valley segment variation in fish use in any single year and to be inconsistently related to fish use among years. Discriminant analysis is applied to identify valley segment and channel unit features that distinguish between valley segments that are highly used by juvenile chinook salmon and those that are not. The transferability of resulting models to other years for Elk River is assessed.

Chapter 4 seeks to explain among-valley segment variation for channel unit features in the Elk River, a forested montane system, using catchment area and landscape characteristics (i.e., lithology, topography, and land cover) summarized at five spatial scales. Channel unit features are those that help distinguish between levels of use for juvenile chinook salmon. Spatial scales are designed to differ in the area incorporated upslope and upstream of surveyed valley segments and consist of three riparian buffer scales (i.e., corridor, sub-network, and network) and two upslope scales (i.e., sub-catchment and catchment). By comparing relationships between fish habitat and landscape characteristics at multiple spatial scales, I hope to determine which riparian and upslope areas are most tightly linked to channel unit features. Any similarities and differences among the scales should suggest key processes responsible for the relationships.

A context for this study is provided by research in the Elk River basin over the past three decades. This tradition began prior to the establishment of the State of Oregon salmon hatchery on Elk River in 1968. The hatchery was intensively supported during the first two decades by the Coastal Chinook Salmon Studies research project of the Oregon Department of Fish and Wildlife. Under the auspices of this project, information was acquired on numerous aspects of chinook salmon ecology in the Elk and other coastal Oregon rivers. Much of this was published in annual and special reports of the Oregon Department of Fish and Wildlife Research Section and is summarized in Nicholas and Hankin (1988). Data collected on ocean-type chinook salmon in Elk River included interactions among juveniles (Reimers 1968), numbers of returning hatchery and wild adults (Nicholas and Downey 1983; Hankin et al. 1993), and the spatial and temporal distribution of spawning adults (Burck and Reimers 1978). Another research project on the Elk River was initiated in the mid-1980s by a team from Oregon State University and the Pacific Northwest Research Station of the United States Forest Service. The focus of that effort was to examine landsliding relative to rock type and land management (McHugh 1986), riparian and channel responses to hillslope erosional processes (Ryan and Grant 1991), and natural and management effects on stream temperatures (McSwain 1987). Characterizing juvenile salmonid populations and their habitats was also an objective of that project. The present study continues work on this objective.

REFERENCES

Allen, TFH, Hoekstra TW. 1992. Toward a unified ecology: complexity in ecological systems. Columbia University Press, New York, New York.

Baxter CV, Hauer FR. 2000. Geomorphology, hyporheic exchange, and selection of spawning habitat by bull trout (*Salvelinus confluentus*). Canadian Journal of Fisheries and Aquatic Sciences 57: 1470-1481.

Bilby RE, Ward JW. 1991. Characteristics and function of large woody debris in streams draining old-growth, clear-cut, and second-growth forests in southwestern Washington. Canadian Journal of Fisheries and Aquatic Sciences 48: 2499-2508.

Botkin D, Cummins K, Dunne T, Regier H, Sobel M, Talbot L, Simpson L. 1995. Status and future of salmon of western Oregon and northern California: Findings and Options, Appendices, Report #8. The Center for the Study of the Environment, Santa Barbara, California.

Burck WA, Reimers PE. 1978. Temporal and spatial distribution of fall chinook salmon spawning in Elk River. Oregon Department of Fish and Wildlife, Information Reports (Fish) 78-3, Portland, Oregon.

Carpenter SR, Caraco NF, Correll DL, Howarth RW, Sharpley AN, Smith VH. 1998. Nonpoint pollution of surface waters with phosphorous and nitrogen. Ecological Applications 8(3): 559-568.

Cooper SD, Barmuta L, Sarnelle O, Kratz K, Diehl S. 1997. Quantifying spatial heterogeneity in streams. Journal of the North American Benthological Society. 16(1): 174-188.

Dolloff CA, Flebbe PA, Owen MD. 1994. Fish habitat and fish populations in a southern Appalachian watershed before and after hurricane Hugo. Transactions of the American Fisheries Society 123: 668-678.

Doppelt B, Scurlock M, Frissell C, Karr J. 1993. Entering the Watershed: a new approach to save America's river ecosystems. Island Press, Washington, DC. 462 p.

Dose JJ, Roper BB. 1994. Long-term changes in low-flow channel widths within the South Umpqua watershed, Oregon. Water Resources Bulletin 30(6): 993-1000.

Dunham JB, Rieman BE. 1999. Metapopulation structure of bull trout: influences of physical, biotic, and geometrical landscape characteristics. Ecological Applications 9: 642-655.

Folt CL, Nislow KH, Power ME. 1998. Implications of temporal and spatial scale for Atlantic salmon (*Salmo salar*) research. Canadian Journal of Fisheries and Aquatic Sciences 55(Suppl. 1): 9-21.

Forest Ecosystem Management Assessment Team (FEMAT). 1993. Forest ecosystem management: an ecological, economic, and social assessment. Report of the Forest Ecosystem Management Assessment Team. United States Department of Agriculture, Forest Service; United States Department of the Interior [and others], Portland, Oregon. [irregular pagination].

Frissell CA. 1993. Topology of extinction and endangerment of native fishes in the Pacific Northwest and California (U.S.A.). Conservation Biology 7: 342-354.

Frissell CA, Liss WJ, Warren CE, Hurley MD. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10(2): 199-214.

Grossman GD, Dowd JF, Crawford M. 1990. Assemblage stability in stream fishes: a review. Environmental Management 14(5): 661-671.

Ham KD, Pearsons TN. 2000. Can reduced salmonid population abundance be detected in time to limit management impacts. Canadian Journal of Fisheries and Aquatic Sciences 57: 17-24.

Hankin DG, Nicholas JW, Downey TW. 1993. Evidence for inheritance of age of maturity in chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 50: 347-358.

Hawkins CP, Norris RH, Hogue JN, Feminella JW. 2000. Development and evaluation of predictive models for measuring the biological integrity of streams. Ecological Applications 10(5): 1456-1477.

House R. 1995. Temporal variation in abundance of an isolated population of cutthroat trout in western, Oregon, 1981-1991. North American Journal of Fisheries Management 15: 33-41.

Hughes RM, Noss RF. 1992. Biological diversity and biological integrity: current concerns for lakes and streams. Fisheries 17(3): 11-19.

Hynes HBN. 1975. The stream and its valley. Verhandlungen der Internationalen Vereinigung füür Theoretische und Angewandte Limnologie 19: 1-15.

Johnson KN, Swanson FJ, Herring M, Greene S. 1999. Bioregional Assessments: science at the crossroads of management and policy. Island Press, Washington, DC.

Jones EBD III, Helfman GS, Harper JO, Bolstad PV. 1999. Effects of riparian forest removal on fish assemblages in southern Appalachian streams. Conservation Biology 13(6): 1454-1465.

Jones JA, Grant GE. 1996. Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon. Water Resources Research 32(4): 959-974.

Jones JA, Grant GE. 2001. Comment on "Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon: a second opinion" by RB Thomas and WF Megahan. Water Resources Research 37(1): 175-178.

Labbe TR, Fausch KD. 2000. Dynamics of intermittent stream habitat regulate persistence of a threatened fish at multiple spatial scales. Ecological Applications 10(6): 1774-1791.

Lunetta RS, Consentino BL, Montgomery DR, Beamer EM, Beechie TJ. 1997. GIS-based evaluation of salmon habitat in the Pacific Northwest. Photogrammetric Engineering and Remote Sensing 63(10): 1219-1229.

May RM. 1994. The effects of spatial scale on ecological questions and answers. In: Edwards RJ, May RM, Webb NR, editors. Large-scale ecology and conservation biology. Blackwell Scientific Publications, London. p 1-17.

McHugh M. 1986. Landslide occurrence in the Elk and Sixes River basins, southwest Oregon. MS Thesis, Oregon State University, Corvallis, Oregon. 106 p.

McSwain M. 1987. Summer stream temperatures and channel characteristics of a southwestern Oregon coastal stream. MS Thesis, Oregon State University, Corvallis, Oregon. 99 p.

Montgomery DR. 1999. Process domains and the river continuum. Journal of the American Water Resources Association 35(2): 397-410.

Moyle PB, Williams JE. 1990. Biodiversity loss in the temperate zone: decline of native fish fauna of California. Conservation Biology 4(3): 275-284.

Naiman, RJ, TJ Beechie, LE Benda, DR Berg, PA Bisson, LH MacDonald, MD O'Connor, PL Olson and EA Steel. 1992. Fundamental elements of ecologically healthy watersheds in the Pacific Northwest coastal ecoregion. In Watershed management: balancing sustainability and environmental change. Edited by RJ Naiman. Springer-Verlag, New York, New York. pp. 127-188.

Naiman RJ, Bilby RE, Bisson PA. 2000. Riparian ecology and manage-ment in the Pacific coastal rain forest. BioScience 50(11): 996-1011.

National Research Council (NRC). 1996. Upstream: salmon and society in the Pacific Northwest. National Academy Press, Washington, D.C. 452 pp.

Nicholas JW, Downey TW. 1983. Coastal chinook salmon studies, 1980-1983. Oregon Department of Fish and Wildlife, Fish Research Projects 81-ABD-ORIE and 82-ABD-ORIE, Annual Progress Report, Portland, Oregon.

Nicholas JW, Hankin DG. 1988. Chinook salmon populations in Oregon coastal river basins: description of life histories and assessment of recent trends in run strengths. Oregon Department of Fish and Wildlife Research and Development Section, Information Reports. Number 88-1.

O'Neill RV. 1989. Perspectives in hierarchy and scale. In: Roughgarten J, May RM, Levin SA, editors. Perspectives in ecological theory. Princeton University Press, Princeton, New Jersey. p 140-156.

Osborne LL, Koviac DA. 1993. Riparian vegetated buffer strips in water quality restoration and stream management. Freshwater Biology 29: 243-258.

Pess GR, Montgomery DR, Bilby RE, Steel EA, Feist BE, Greenburg HM. In review. Influence of landscape characteristics and land use on coho salmon (*Oncorhynchus kisutch*) abundance, Snohomish River, Washington state, USA. Canadian Journal of Fisheries and Aquatic Sciences.

Platts WS, Nelson RL. 1988. Fluctuations in trout populations and their implications for land-use evaluation. North American Journal of Fisheries Management 8: 333-345.

Poff NL, Ward JV. 1990. Physical habitat template of lotic systems: recovery in the context of historical pattern of spatiotemporal hetero-geneity. Environmental Management 14(5): 629-646.

Postel SL. 2000. Entering and era of water scarcity: the challenges ahead. Ecological Applications 10(4): 941-948.

Reeves GH, Benda LE, Burnett KM, Bisson PA, Sedell JR. 1995. A disturbance-based ecosystem approach to maintaining and restoring fresh-water habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. In: Nielsen J, editor. Evolution and the aquatic ecosystem. American Fisheries Society Symposium 17, Bethesda, Maryland. p 334-349.

Reeves GH, Everest FH, Sedell JR. 1993. Diversity of juvenile anadromous salmonid assemblages in coastal Oregon basins with different levels of timber harvest. Transactions of the American Fisheries Society 122(3): 309-317.

Reeves GH, Hohler DB, Hansen BE, Everest FH, Sedell JR, Hickman TL, Shively D. 1997. Fish habitat restoration in the Pacific Northwest: Fish Creek of Oregon. In: Williams JE, Wood CA, Dombeck MP, editors. Watershed restoration: principles and practices. American Fisheries Society, Bethesda, Maryland. p 335-359.

Reimers PE. 1968. Social Behavior among juvenile fall chinook salmon. Journal Fisheries Research Board of Canada 25(9): 2005-2008.

Ricciardi A, Rasmussen JB. 1999. Extinction rates of North American freshwater fauna. Conservation Biology 13(5): 1220-1222.

Roper BB, Scarnecchia DL, La Marr TJ. 1994. Summer distribution of and habitat use by chinook salmon and steelhead within a major basin of the South Umpqua River, Oregon. Transactions of the American Fisheries Society 123: 298-308.

Roth NE, Allan JD, Erickson DL. 1996. Landscape influences on stream biotic integrity assessed at multiple spatial scales. Landscape Ecology 11(3): 141-156.

Ryan SE, Grant GE. 1991. Downstream effects of timber harvesting on channel morphology in Elk River basin, Oregon. Journal of Environmental Quality 20: 60-72.

Scarnecchia DL, Roper BB. 2000. Large-scale, differential summer habitat use of three anadromous salmonids in a large river basin in Oregon, USA. Fisheries Management and Ecology 7: 197-209.

Schlosser IJ. 1995. Dispersal, boundary processes, and trophic-level interactions in streams adjacent to beaver ponds. Ecology 73(3): 908-925.

Southwood TRE. 1977. Habitat, the templet for ecological strategies? Journal of Animal Ecology 46: 337-365.

Southwood, TRE. 1988. Tactics, strategies, and templates. Oikos 52: 3-18.

Thomas RB, Megahan WF. 1998. Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon: A second opinion. Water Resources Research 34(12): 3393-3403.

Thompson WL, Lee DC. 2000. Modeling relationships between landscape-level attributes and snorkel counts of chinook salmon and steelhead parr in Idaho. Canadian Journal of Fisheries and Aquatic Sciences 57: 1834-1842.

Torgersen CE, Price DM, Li HW, McIntosh BA. 1999. Multiscale thermal refugia and stream habitat associations of chinook salmon in northeastern Oregon. Ecological Applications 9(1): 301-319.

Vannote RL, Minshall GW, Cummins KW, Sedell JR, Cushing CE. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37: 130-137.

Warren CE, Liss WJ. 1983. Systems classification and modeling of watersheds and streams. Unpublished Report for U.S. EPA Cooperative Agreement CR807187, 193 pp.

Weller DE, Jordan TE, Correll DL. 1998. Heuristic models for material discharge from landscapes with riparian buffers. Ecological Applications 8(4): 1156-1169.

Wiens JA. 1989. Spatial scaling in ecology. Functional Ecology 3: 385-397.