Core Areas: Habitats that Functionally Control the Spatial Structure of Salmon Populations

Chapter 1

**Development of Salmonid Conservation Strategies
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INTRODUCTION

The spatial structure of fish populations is rapidly being recognized as a critical element for the conservation of endangered salmon populations (Independent Scientific Group 1996, Policansky and Magnuson 1998, Cooper and Mangel 1999, McElhany et al. 2000). Spatial structure is important because it helps managers to define the boundaries and conservation status of distinct population units as well as the locations of habitats associated with these units. The National Marine Fisheries Service (NMFS) guidance for salmon conservation planning (McElhany et al. 2000) identifies spatial structure as a key attribute for a viable salmonid population because spatial structure affects extinction risk in ways that may not be readily apparent from short-term observations of abundance and productivity (Hanksi and Gilpin 1991, Tilman and Lehman 1997, Cooper and Mangel 1999). Incorporating spatial structure concepts, including metapopulation theory, into conservation planning, however, is limited by our knowledge of what mechanisms form spatial structure and how structure affects variations in population survival and abundance.

In this chapter we review the current knowledge and concepts concerning population spatial structure and how spatial structure is formed in salmon populations. Based on our knowledge of structure-forming mechanisms, we propose a conceptual framework to help understand spatial structure at the population/river basin scale. We propose there are certain habitats (i.e., core areas) that functionally control population spatial structure, and we describe the key criteria necessary to identify core areas. We also provide a brief discussion of how the core areas concept is not limited to riverine environments but could be expanded to include estuarine and marine nearshore environments. We believe this information is critical for informing management decisions and for planning restoration measures concerning the conservation of salmon populations.

POPULATION SPATIAL STRUCTURE

POPULATIONS AND METAPOPULATIONS

The spatial structure of a population generally refers to both the spatial/temporal distribution of individuals in the population (i.e., patch size and inter-patch distance) and the demographic processes that generate that distribution (i.e, emigration, immigration, natality, and mortality; McElhany et al. 2000). Population structure is hierarchical and can be viewed at different spatial scales (e.g., metapopulation, population, subpopulation; Hanski and Gilpin 1991). Spatial scaling, however, is not discrete but rather is a construct that helps us to identify and understand the mechanisms that form spatially-structured populations (Hanski and Gilpin 1991). In salmon biology, a local population is defined as a breeding unit that is independent or relatively reproductively isolated from other breeding groups and is likely to inhabit an entire river basin or a major subbasin (Independent Science Group 1996, McElhany et al. 2000, Technical Recovery Team [TRT] 2001). The spatial structure of a local population then refers to the geographic spatial/temporal distribution of individuals or subpopulations at the local scale.

Populations that are not completely isolated from outside migration may interact with other populations and form a metapopulation (i.e., a system of local populations connected by dispersing individuals; Hanski and Gilpin 1991). At the metapopulation scale, spatial structure refers to the spatial/temporal distribution of local populations, their relative sizes, and the demographic processes leading to interactions among populations. The demographic processes for a metapopulation differ from those for a population in that the focus is on colonization and extinction of populations rather than on recruitment and mortality of individuals within a population.

Several models have been proposed to describe metapopulation spatial structure (Hanski and Gilpin 1991), and among these the core-satellite (source-sink) model is assumed to be the most applicable to salmonids (Li et al. 1995, Schlosser and Angermeier 1995). In this model, the core population acts as a source for colonization of the satellite populations because the latter are not self-sustaining as a result of a number of factors, including less favorable habitat conditions. The source population, which may consist of a group of populations, is assumed to persist as a result of patch quality, size, and connectivity, but the peripheral populations may "blink" in and out of existence as a result of poor connectivity or ephemeral habitat quality. The core-satellite model assumes that habitats are spatially and temporally fixed; however, McElhany et al. (2000) suggested that in rivers a dynamic habitat model may be more appropriate because the location of suitable habitat continually changes and therefore the location of subpopulations must also change. They note that population survival may not depend on specific individual habitat patches but on the mean number of available patches.

Empirical evaluations of the spatial structure of salmonid populations in rivers vary depending on the spatial scale of the question. At the scale of individuals and habitat units, there is a wealth of information addressing distribution and habitat suitability by different species and life phases (see reviews by Bjornn and Reiser 1991, Spence et al. 1996). In fact, the majority of the space-use data for salmonids is based on fine-scale habitat and fish-use relationships. At the population or river basin scale, there are a number of studies on the demographics of an entire population but limited information on the spatial distribution and associated dynamics within

these populations (e.g., McNeil 1966, Reimers 1973, Hartman and Scrivener 1990). The annual inventories of adult spawner abundance and distribution that are routinely collected by fisheries management agencies are a potential source for these data. However, evaluations of these data with respect to spatial structure are hard to find (e.g., Jacobs and Nickelson 1998, Pess et al. 2002). At the metapopulation scale, we found only several studies that document spatial organization of salmonid populations (Schlosser and Angermeier 1995, Rieman and McIntyre 1995, Dunham and Rieman 1999, TRT 2001). The role of metapopulation structure in salmonid population dynamics is just beginning to be studied (Independent Scientific Group 1996, McElhany et al. 2000).

PROCESSES FORMING SPATIALLY STRUCTURED POPULATIONS

Population spatial structure in rivers is generally considered a result of the inter-play among population demographic processes, habitat spatial organization, and spatial/temporal patterns of disturbance (Schlosser and Angermeier 1995, McElhany et al. 2000). How these processes interact to create structured salmon populations is known only at a conceptual level (e.g., Miller and Brannon 1982, Schlosser and Angermeier 1995, McElhany et al. 2000). The amazing homing capability of salmon is the primary mechanism that drives the development of isolated population units (Miller and Brannon 1982, Independent Scientific Group 1996). Salmon can not only differentiate between rivers that are geographically separate but can home to specific segments within a river (Quinn 1993). This high natal fidelity promotes the development of breeding populations that are adapted to the local environmental conditions in different rivers and even to the unique environmental characteristics (e.g., temperature and flow regime) within neighboring sections of a river system (Miller and Brannon 1982, Quinn 1993). Homing fidelity, however, is not perfect, and variable levels of straying among salmon populations are well documented (Quinn 1993, McElhany et al. 2000). This dispersal from local populations is the mechanism that drives recolonization of habitats with extinct populations (Hanski and Gilpin 1991) or colonization of new habitats (Milner and Bailey 1989). This interaction among populations by straying forms metapopulations.

Research shows that there is a strong influence of genetic adaptation on survival and homing fidelity of salmon (e.g., Reisenbichler 1988, Quinn 1993, Unwin et al. 2003). Therefore, the ability to survive to adulthood and return to natal sites promotes the formation of breeding aggregates that must be relatively spatially persistent. This establishment of local population units supports the premise that homing is a fundamental mechanism controlling population spatial structure at the local scale.

If populations evolve to maximize survival in response to prevailing local conditions (Unwin et al. 2003), then their spatial structure must reflect the distribution of environments best suited for survival. Data concerning the spatial distribution of spawning populations strongly support this hypothesis at different spatial scales. For example, Montgomery et al. (1999) found a strong correlation between the distribution and timing of salmon spawning and spatial and temporal differences in channel characteristics that influence gravel deposition and redd scour. At the riverine network scale, the distribution of spring and fall spawning populations corresponds to channel gradient and the potential for redd scour in different stream segments. Larger bodied salmon (Chinook and coho) tend to spawn during fall in the lower portions of the river, where they can deposit their eggs below the scour depth. Smaller spring spawning salmonids tend to

spawn in the headwater channels, where thin gravel patches and scour frequency prohibit redd survival during winter freshets. At the reach scale, Montgomery et al. (1999) showed that redd density corresponded to the channel types with the least scour. These results are consistent with Schuett-Hames et al. (2000), who showed that redd scour for chum salmon varied at both the reach and unit scales. Also, Rosenfeld et al. (2000) present results that suggest cutthroat abundance and distribution may be related to differences in redd scour in gravel-bed versus boulder-bed channels.

Spatial patterns of salmonid spawning are influenced by geomorphic features and hydrologic processes that are associated with hyporheic exchange flows and water temperature. For example, in the Swan River, Montana, Baxter and Hauer (2000) found the distribution and abundance of bull trout spawning areas were affected by the spatial patterns of hyporheic exchange. At the network scale, bull trout redds were primarily found in bounded alluvial valley segments, which possessed complex patterns of hyporheic exchange and had extensive upwelling zones. In the Hanford Reach of the Columbia River, Geist (2000) found that fall Chinook salmon spawned predominantly in areas where hyporheic water discharged into the river channel. Connor et al. (2003) found that temperature during incubation affected the distribution of fall Chinook salmon spawning areas in the Snake River basin, and they showed how the temperature regime affected emergence timing and subsequent probability of survival to adults.

The spatial organization of habitat within rivers in conjunction with disturbance processes creates the spatial template that governs aquatic habitat patterns. In Chapter 2 we describe how certain watershed features (i.e., tributary confluences, alternating canyon and floodplain segments, landslides, bedrock outcrops, log jams, channel meanders, and boulder clusters) influence habitat formation and how disturbance processes (i.e., fires, floods, and erosion) influence habitat size and the frequency of habitat rejuvenation. This discussion shows that habitat is not uniformly distributed and that disturbance regimes (i.e., frequency, magnitude, and distribution of habitat-forming processes) continually shape the resulting habitat patterns.

A key element of physical habitat formation with respect to population spatial structure is that habitat spatial organization and temporal characteristics are predictable. The size, spacing, and characteristics of physical habitat are associated with landscape features and scale with basin size (see Chapter 2). This physical organization is well recognized and led to a number of channel classification schemes (Frissell et al. 1986, Paustian et al. 1992, and Montgomery and Buffington 1997). Although disturbance events are stochastic, the frequency and magnitude of disturbance patterns vary systematically throughout a basin. For example, in the confined headwater streams, the high sediment transport capacity (Montgomery and Buffington 1997) and the low frequency of landslides (Benda et al. 1998) result in a high energy environment that is generally sediment-poor for long periods (centuries). Following a landslide or debris flow, fish habitat in these channels can be completely obliterated (buried or scoured to bedrock), and the fish populations are occasionally extirpated. The absence of off-channel refuge habitat makes the population highly vulnerable to disturbances. Because steep gradients and barriers (rock falls and debris jams) often limit access to these channels, colonization is slow and the habitat may go unused for long periods. In some cases, sediment and debris from a landslide may improve habitat diversity (form small pools and gravel patches), but these conditions are short-lived (decades). Downstream in the channel network, sediment supply and flooding increase with an increase in basin area, resulting in a more continuous supply of sediment and a higher frequency

of channel disturbance (Benda et al. 1998). Flood events in these higher-order streams reshape the channel, causing short-term habitat disturbances (years) that can result in long-term changes (i.e., rejuvenation) in habitat that may persist for decades (Benda et al. 1998).

SPATIAL STRUCTURE AND CORE AREAS

CONCEPTUAL FRAMEWORK

The foregoing discussion indicates that spatial structure is a consequence of population demographic processes that operate within and are constrained by habitat spatial organization and temporal disturbance patterns. At the population/river basin scale, we hypothesize that spatial structure is reflective of the systematic influence of homing to certain habitats that maximize survival and the secondary influence of dispersal of individuals to neighboring habitats by means of habitat selection and competition. Therefore, the spatial organization of natal habitat patches functionally controls population spatial structure, first by defining the location of population nodes within a river network, and second by defining the locations of population migration and dispersal corridors. The location of population nodes and the associated corridor then define proximity or probable areas of population dispersal.

Homing is a consequence of population survival. Survival is a function of population size/recruitment and habitat productivity; therefore, habitat patches that sustain homing must be large enough and biologically suitable to maintain recruitment at sustainable levels. This implies that homing individuals must routinely find some minimum amount of suitable habitat within the vicinity of their natal patches to maintain production. Therefore, patch size, suitability, and inter-patch distance are probably key attributes of homing patches. For example, research on bull trout shows that patch size influences the occurrence of bull trout and patch occupancy decreases with increasing distance from an occupied patch (Rieman and McIntyre 1995, Dunham and Rieman 1999). This suggests that either a few large patches or many small patches that occur within the spatial scale of homing precision are probably necessary. Research suggests homing precision is at a scale that is smaller than a basin and is probably at the scale of subbasins or individual segments within a stream network. For example, several studies have documented disproportionately high returns of hatchery adult salmonids to the particular river segments where they were released as smolts (review by Quinn 1993, Slaney et al. 1993, Mackey et al. 2001).

Homing and population persistence are also a function of the temporal frequency and spatial extent of habitat disturbance. Population structure must reflect an adaptation to the frequency and magnitude of disturbance patterns; otherwise, homing would not be a reliable mechanism for forming viable population units. Based on our understanding of habitat formation (Chapter 2), we know that the frequency and magnitude of certain disturbances are spatially systematic and predicable. We also know that habitat patches form in association with specific watershed features (e.g., tributary junctions, canyon mouths, rock outcrops; see Chapter 2) that are spatially fixed. Therefore, habitat patches continually occur at the same general location, and the magnitude of disturbance at any given location falls within some consistent pattern. For example, the formation of an alluvial fan at a tributary junction creates spawning habitat that is spatially persistent, but its size and influence on channel morphology varies over time in relation to the frequency of stochastic disturbance events (Benda et al. Accepted). Over the time scale of generations, habitat disturbances are probably reflected as short-term impacts on production for a portion of the population and as a reliable and persistent producer (rejuvenation) of habitat for the long term.

CORE AREAS HYPOTHESIS

We hypothesize that a population is organized around certain habitats (i.e., core areas) that functionally control population spatial structure. These habitats have specific characteristics (i.e., accessibility, suitability, inter-patch distance [proximity], patch size, spatial and temporal persistence) that sustain population persistence by maximizing population survival. Therefore, spatial structure is a consequence of population adaptation to reliable patterns of habitat productivity.

We propose that adult spawners initiate spatial structure by homing to their natal (core) habitats. When spawners are congregated in the vicinity of these habitats, habitat selection, competition, and mate selection behavior cause structuring at finer spatial scales (i.e., habitat units [e.g., pools] and subunits [e.g., tailouts]) as well as dispersal to neighboring habitats. Population structure during subsequent life phases is believed to be a result of the interaction between a species' life phase habitat needs and the spatial organization of the requisite habitats relative to the location of the natal habitat. In other words, where a population spawns limits what habitat is potentially available to the offspring, and the dispersal capability of offspring within this habitat determines spatial structure. This spatial pathway of habitat use by a population along with the temporal patterns of movement through each life phase form a life history pattern that is adapted to the unique physical and climatic characteristics of a watershed (Miller and Brannon 1982). Spatial structure then is an important determinant of a successful life history pattern and may also influence overall production (Kocik and Ferreri 1998).

In the freshwater environment, certain life phases are expected to have more influence on salmon population structure than others, and the importance of a particular life phase's influence on population structure is expected to vary by species. Certainly, population structure begins at spawning for all species; however, it is probable that a species' mobility during subsequent life phases and the organization of habitats may also influence the spatial structure of the population. The location of juvenile rearing habitat in freshwater relative to the location of spawning areas probably influences population structure for species with long freshwater residence periods (e.g., coho and stream-type Chinook salmon). For example, it is well documented that the freshwater production of coho is closely associated with the presence of pools, ponds, and off-channel rearing habitat (Peterson 1982, Nickelson 1998, Nickelson et al. 1992). It is also known that the distribution and abundance of adult coho is related to river segments dominated by pools and wetlands (Pess et al. 2002) and that adult spawning patterns are aggregated in a small portion of the available habitats (Jacobs and Nickelson 1998, Pess et al. 2002). Research linking the distribution of spawning habitat to the spatial organization of rearing habitat for coho is not documented, as far as we know, but this association and its influence on population spatial structure is highly probable. Research showing the spatial distribution of bull trout populations in relation to temperature patterns (Dunham et al 2003) is another example of how life history interactions with the physical organization of habitats influences spatial structure. For salmon species with a very short juvenile rearing phase in freshwater (i.e., pink and chum salmon), we assume that core areas are directly linked to habitats that favor survival for spawning and incubation. We believe the core areas for ocean-type Chinook salmon, which may spend several months rearing in freshwater, are linked not only to incubation success but to the location of spawning habitats relative to the availability of juvenile rearing habitat (e.g., floodplain and complex edge habitats) in freshwater. The presence of floodplains and patterns of flooding in

rivers are known to influence habitat quality, growth, and survival of juvenile Chinook salmon (Independent Scientific Group 1996, Coe 2001, Sommer et al. 2001).

In estuarine and nearshore environments, the importance of a particular life phase's influence on population structure varies by species. In particular, juvenile chum and ocean-type Chinook salmon are recognized as being fundamentally dependent on estuarine ecosystems, which have been called the "life support system" for these species (Healey 1982, Simenstad et al. 1982). The dependence of chum and ocean-type Chinook on estuarine ecosystems has been tested directly by measuring survival of juvenile salmon following estuarine residence (e.g., Reimers 1973, Levings 1984, Levings et al. 1989) and indirectly using surrogates of survival, such as growth and diet overlap with invertebrate assemblages (e.g., Sibert et al. 1977; Healey 1980, 1991; Shreffler et al. 1990, 1992; Chamberlain and Barnhart 1993; Simenstad and Thom 1996; Miller and Simenstad 1994, 1997; Cordell et al. 1998). This estuarine dependence is of heightened significance given that Endangered Species Act-listed Puget Sound Chinook salmon occur throughout many of King County's estuarine and nearshore ecosystems.

The spatial structure of juvenile chum and ocean-type Chinook is likely organized around habitats (e.g., emergent marshes, tidal channels, and eelgrass meadows) or the landscape mosaic of habitats that favor foraging success, growth, and survival (Cedarholm et al. 2000, Simenstad and Cordell 2000, Simenstad et al. 2001). The composition, distribution, and arrangement of these habitats or landscape elements (e.g., habitat matrix heterogeneity, dendritic tidal channel networks, allometric relationships of estuarine sloughs, and disturbance frequency and intensity) probably regulate juvenile salmon growth and survival in estuarine and nearshore environments.

One key distinction between the riverine environment and estuarine/nearshore environments is that in the latter the landscape mosaic of habitats rather than individual habitats determines opportunities for juvenile salmon feeding, rearing, and migration. We propose that landscape-scale habitat mosaics in estuarine and nearshore environments can be defined by some of the same core habitat characteristics as in rivers (i.e., habitat quality [suitability, patch size/shape/complexity], connectivity [accessibility, inter-patch distance], and spatial and temporal persistence); however the ecological processes that form the core areas would be unique to estuarine and nearshore environments. Key estuarine and nearshore ecological processes of importance to Pacific salmon are primary and secondary production, organic matter flow, nutrient cycling, sediment processes (e.g., erosion, transport, deposition, storage), and hydraulic processes (e.g., tides, currents, salinity gradients, shoreline erosion, sedimentation) (Downing 1983, Duxbury 1987, Thom 1987, Shreffler and Thom 1993, Bottom et al. 1998, Williams and Thom 2001, Williams et al. 2001).

CORE AREAS CRITERIA

Rivers

The criteria for identifying core areas are focused on spawning because spawning is the geographic starting point for structuring populations and we have the most knowledge of this life phase. At the population/river basin scale, we define core areas as the river segments and associated features that are temporally persistent, that are biologically suitable, that are located within or adjacent to a migratory corridor, and that are accessible most of the time.

Temporally persistent means the habitat maintains suitable conditions for life-phase processes at the same general location over multiple generations. It does not mean the habitat condition needs to be stable (i.e., undisturbed), only that the physical attributes required for life-phase functions (e.g., suitable spawning gravel) are consistently provided over time. Persistence then can be accomplished where disturbance frequency and magnitude result in continual habitat rejuvenation. For example, the size and configuration of habitat units (i.e., pool/riffle frequency, meander length, side channel complexity) may vary over time as a consequence of disturbance events, but the segment-scale feature (e.g., alluvial fan) remains over time. In Chapter 2, we discuss how specific river features can form core areas for spawning. Of the seven features that can form habitat, we rank tributary junctions, floodplain segments, and bedrock outcrops as having the greatest potential to maintain large persistent spawning patches. The other features (landslides, log jams, channel meanders, and boulder clusters) are important habitat formers but either have a more ephemeral effect or cause smaller patches. Any one of these features can be a dominant former of habitat and affect spatial organization of habitats depending on the size, shape, and geologic characteristics of a basin (see Chapter 2).

Biologically suitable implies the habitat is capable of supporting a life-phase function. At the basin scale, suitability for spawning is simply the presence of gravel patches within or associated with the habitat-forming features listed above. Finer-scale metrics of habitat quality (e.g., amount of fine sediment in spawning gravels or hyporheic exchange potential) could be used to evaluate habitat favorability.

Habitat proximity to the migratory corridor and accessibility are indicators of probable use and connectivity. Suitable habitats that are close together and are located on the mainstem or in a large tributary are more likely to be occupied and function as core areas than are habitats that occur long distances off of the migratory corridor. Similarly, habitats where accessibility is not event dependent are more reliable and more likely to function as core areas than are habitats that require specific conditions (e.g., high stream flows) to enable access.

The core areas criteria are designed to evaluate the relative probability of a habitat to functionally influence population structure and to maximize survival. The habitats are not rated as either good or poor but rather should be evaluated on a continuum of how well a given location favors habitat occupation and potentially maximizes survival. For example, a specific habitat feature that is geomorphically persistent, forms a large spawning area, and is located on the migratory corridor is more likely to consistently contribute to population production than is a habitat that is associated with a more ephemeral feature and is located a long distance from other habitats with core characteristics.

Estuaries and Nearshore

Below we suggest some potential habitat quality, connectivity, and persistence metrics for determining core areas for juvenile salmon in estuarine and nearshore environments. These metrics are based on a literature review and have not been field tested to determine whether they are good predictors of core areas.

Estuarine and Nearshore Habitat Quality Metrics

Habitat quality means the suitability of habitats to support life-phase functions (e.g., feeding and rearing) and includes both physical and biological elements. We propose the following habitat quality metrics:

- Patch size (larger systems are more stable, persistent, resilient, and resistant than are smaller systems and offer predictably more niches for species).

- Patch shape (shape can control the types and number of edge vs. interior species and the movement of species, materials, and energy through the landscape).

- Convergences between primary and secondary salinity gradients (physiological adaptation zones at the transition between areas of no salinity and increasing levels of salinity are critical for juvenile salmon).

- Lengths or network dimensions of entrapment zones (e.g., tidal/current fronts) for neuston and other prey.

- Presence of shallow-water, typically low-gradient habitats with fine, unconsolidated substrates and aquatic, emergent, shrub/scrub, or forested vegetation (vegetation composition influences primary and secondary production).

- Position and orientation of low wave energy habitats, such as tidal sloughs (for weakly swimming fry and fingerling salmon to maintain a desirable position within or adjacent to a habitat).

- Concentrations of small, non-evasive invertebrates and physicochemical conditions that maintain these prey communities.

- Salinities and temperatures that promote high efficiencies of prey assimilation.

- Locations of sediment sources; longshore drift cells.

- Presence of structure (e.g., shallow water, vegetation, logs, etc.) and turbidity that minimize exposure to piscivorous fish and birds.

- Presence of sites of known forage fish spawning.

Estuarine and Nearshore Connectivity Metrics

Habitat connectivity ensures maximum exchange of species, materials, and energy through the landscape. Connectivity also influences potential use of habitats by salmon because habitat proximity to salmon migration/dispersal routes and distance between habitat patches determine the probability of use and relative importance of these patches to the core population. Also, connectivity between patches with different functions (e.g., feeding, rearing) is important because it enables diverse and viable salmon life history patterns. We propose the following connectivity metrics:

- Accessibility of habitats to migrating salmon; salmon should be able to access and benefit from primary and secondary productivity in a range of habitats.

- Continuity between estuarine/nearshore habitats and undisturbed upland habitats (buffer width and extent).

- Length of continuous vegetated edge.

- Distances between habitats or patches where known feeding or rearing occurs; habitat patches should be close enough together to allow the expansion of the population into underused patches during times when salmon are abundant.

- Length of disturbed or fragmented habitats.

- Proximity to human-induced disturbance (e.g., light, sound, shoreline armoring, prop wash, etc.).

Estuarine and Nearshore Persistence Metrics

Persistence refers to the maintenance of certain landscape characteristics and processes through time, for example, physical and biological characteristics that form and maintain eelgrass meadows. Habitats that are functionally persistent enough to maintain salmon populations over time have the highest probability of being core areas. We propose the following metric of persistence:

- Frequency of habitat creation greater than the natural rate of habitat disturbance. Habitat patches should not be destroyed faster than they are created. Habitat is dynamic with suitable habitat being continually created and destroyed by natural processes. Human activities should not decrease either the total area of habitat or the number of habitat patches (McElhany et al. 2000).

Unlike the core areas criteria for rivers, these estuarine/nearshore metrics have not been evaluated for King County ecosystems due to funding constraints. These potential metrics are provided here as a starting point for future discussions of the applicability and potential expansion of the core areas conceptual framework to estuarine and nearshore environments.

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