2. CONCEPTUAL MODEL OF THE NEARSHORE

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The nature of the nearshore ecosystem is to a great extent determined by the complex and dynamic physical, geological and chemical inputs and interactions of both aquatic and terrestrial systems (Figure 4). The existence and rate of activity of biological communities in nearshore environments are largely a function of the physical and chemical processes that transport and transform materials and energy to, within, and among individual organisms. The biological processes and communities that feed into and are supported by the nearshore are also very complex and play an important role in its structure and functions. Therefore, a basic understanding of these natural processes and functions is essential for a full comprehension of nearshore ecosystems. However, human intervention has resulted in significant modifications of many of the natural processes that form and maintain nearshore habitat and the communities of organisms that are supported by nearshore habitat. Furthermore, the development of a clear understanding of nearshore ecosystems has become even more complicated due to a lack of scientific information and an unclear distinction between natural and human influences. Therefore, a conceptual model is needed to assist us in understanding ecosystem processes and functions where data are lacking. A conceptual model allows us to use limited information to make assumptions and establish pathways, or make linkages, between the diverse array of elements (i.e., food web linkages) and at the various levels within the ecosystem (i.e., processes→structure→functions). A model also helps us identify gaps in our knowledge that need to be filled for a more complete understanding of how the system works at a larger scale, down to how changes in one element, or multiple elements, may effect an individual species.

One approach to understanding properly functioning ecosystem conditions is the study of systems that have little to no human influence. Unfortunately, few of these areas remain and studies of undisturbed nearshore systems are limited. Therefore, the task of describing the nearshore ecosystem is somewhat analogous to creating a blueprint from a limited number of system components. While we have identified many of the building blocks for the nearshore ecosystem, we are not quite sure how they all fit together. Developing a “blueprint” for the nearshore therefore requires the combination of two complimentary approaches (after Williams and Thom, in prep.):

1. A conceptual approach involving inferences based on an informed understanding of the ecosystem and its processes, and
2. A direct approach that documents cause-and-effect relationships through scientific study.

This combined approach helps us understand how the system works when we lack adequate levels of direct documentation. The following discussion on a conceptual approach and the development of a conceptual model for the nearshore are adapted from Proctor et al. (1980), Williams and Thom (2000), Martin (1999), PNCERS (1998), Thom and Borde (1998), and Wissmar and Simenstad (1998).

The conceptual model presented here is for illustrative purposes and only "scratches the surface" of what should be incorporated into a full model for Puget Sound. It is also presented in this report to illustrate the critical importance and need for the development of a system-wide model. Other models exist (i.e., PSAMP 2000), but do not incorporate the full suite of nearshore processes and functions needed.

This model first considers natural variations in space and time to help understand the formation of the nearshore and how organisms, such as Pacific salmon, evolved and adapted to live in this environment. Salmon are used as an indicator organism because of their complex life history, utilization, and dependence upon a wide range of habitats and ecosystems. Figure 5, adapted from Wissmar and Simenstad (1998), illustrates many of the temporal and spatial scales of variation and examples of ecosystem change that have influenced the evolution of habitat and salmon. This larger scale and historical perspective helps to illustrate the fact that we are currently attempting to understand and manage salmon and other resources on relatively small temporal and spatial scales (see inner [shaded] circle).

The geoclimatic setting provides many of the building blocks for the nearshore ecosystem (Figure 6). For example, the geologic history of Puget Sound left massive deposits of sediments. The bathymetry and topography of Puget Sound create the basis for shallow, deep, and steep habitats. Seasonal weather patterns, precipitation, and ocean influences also contribute to these building blocks. A wide variety of physical, chemical, and biological processes interact with these building blocks to create habitat structure. Erosion and sediment transport processes carry sediments to beaches, spits, and other coastal landforms. Tides and rivers contribute minerals and nutrients, shape the land, and cyclically inundate and expose floodplain and shoreline areas. Freshwater flowing into Puget Sound via rivers, streams, and seeps creates complex patterns of salinity.

These ecological processes create a diversity of habitat types that provide ecological functions such as spawning substrate for forage fishes, primary and secondary production, refugia, and other functions that are essential to ecosystem health and species viability. Where and when these processes operate without interruption, they create connected habitats. The quantity and quality of habitat also are linked to these processes; where they operate naturally, they are capable of generating high quality habitat functions. These processes and functions contribute to the food web through nutrient cycling, tidal flux, introduction of organic litter and insects, and maintenance of highly productive habitats such as eelgrass, macroalgae, and mudflats. The cumulative result of these processes working in concert is a complex landscape composed of a variety of functions that support diverse habitat types and community structure. For example, we know from direct studies that surf smelt and sand lance have specific substrate requirements for spawning. Without the appropriate sediment input and distribution (i.e., erosion and littoral transport), the preferred sediment type could become depleted, leading to reduced or eliminated spawning opportunity. Reductions in spawning success results in reduced population size. Reductions in these forage fish populations translates into reduced prey available for salmon and numerous other fishes and wildlife. Though not complex, this example illustrates how interruptions in sediment processes can influence spawning, prey production, and the health of fish and wildlife populations.

Figure 4 Simplified Conceptual Model of the Puget Sound Nearshore Ecosystem

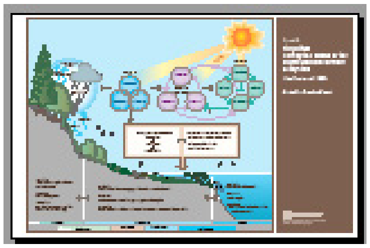

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Figure 5 Riverine/Estuarine Ecosystems

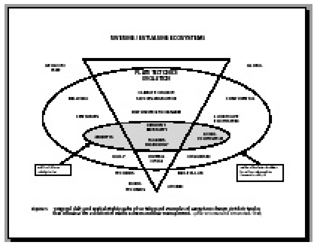

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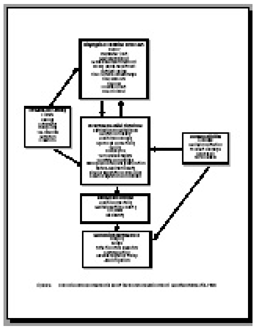
Figure 6 Conceptual Model of Salmonid Use of the Nearshore Environment



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This system is extremely important to salmonids, particularly juveniles, because of their need for feeding, refuge, and osmoregulatory transition. Cederholm et al. (2000) found that one of the most important concepts in understanding how juvenile salmonids use nearshore habitat is that they do not necessarily use individual habitats. Instead, they utilize a "landscape mosaic" of habitats. Many factors, such as predator/prey distributions, tides, river flows, and genetic structure, affect how juveniles move through the nearshore. However, the distribution and connectivity of critical landscape features such as brackish rearing and tidal freshwater areas may be just as important in providing opportunities for juveniles to use preferred habitats (Cederholm et al. 2000).

The combined processes and structure provide ecological functions that support salmon and other species that have adapted to survive the natural variations and disturbances in the system. They are also important in shaping the structure and diversity of biotic communities. Within this context, most species have the ability to adapt and survive most small and large-scale natural disturbances in a system because they are typically of a temporal and spatial scale that allows for adaptation or recovery. Moreover, the variation in each population's life history patterns (timing, habitat usage) means that only a fraction of each population unit will be affected by most natural disturbances.

However, in many instances human activities have disrupted the processes that create and maintain this landscape mosaic, as well as the habitats themselves. The growth of the human population in the region has resulted in significant changes in habitat and ecological processes in a relatively short period of time. Williams and Thom (2000) summarize this influence of human activities as follows:

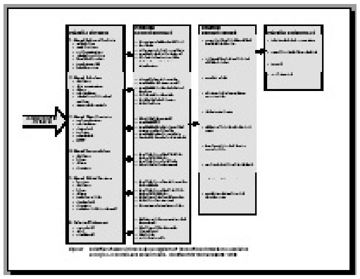
> (Activities that modify nearshore ecosystems to suit human needs) *will exert effects on an ecosystem's controlling factors. Controlling factors are physical processes or environmental conditions that control local habitat structure and composition (i.e., vegetation, substrate), including where habitat occurs and how much is present. In turn, habitat structure is linked to support processes, which are linked to ecological functions. Thus, activities that affect controlling factors within an ecosystem will be reflected in changes to habitat structure, and will ultimately be manifested as changes to functions* (and species) *supported by the habitat. The effect at the functional level depends upon the level of disturbance and the relative sensitivity of the habitat* (or species) *to the disturbance.*

The activities that affect controlling factors act as stressors to organisms in the system and add to the natural levels of disturbance found at various temporal and spatial scales (Figure 7). The cumulative effect of all human-induced stressors, or more importantly, the added effect of all human-induced stressors in combination with natural stressors, reduces the viability of healthy ecosystems, communities, and individual population units.

Shoreline development, particularly shoreline armoring, modifies the natural sedimentation and distribution processes that create beaches and shallow-water habitats, results in a loss of riparian vegetation and associated functions, and can result in a loss of or change in biota (Figure 8). Dams, freshwater withdrawals, and the diversion of rivers, such as the Cedar and White from the Green, reduce freshwater flows and freshets important for maintaining salinity gradients and complex flood plains. Dredging and channelization of rivers, such as the Green/Duwamish, eliminates estuarine and freshwater marshes. Filling of lowlands to create new land for development destroys marshes, flats, swamps, and other productive shallow habitats. Increased impervious areas from roads and other shoreline development practices reduce shoreline riparian vegetation, increase runoff and erosion, degrade water quality, and modify habitat structure.

Although many of these changes were made historically, and despite existing regulatory requirements, habitat loss and disruption of processes continues in the nearshore environment. As a result, the landscape mosaic upon which salmonids and other nearshore species depend has been and continues to be altered, degraded, and in some areas, destroyed. Determining how to halt or reverse this trend will require a better understanding of important components of the ecosystem, the interrelationships of these components, and how the system functions and changes, both naturally and from human disturbance. The development and use of a conceptual model elucidates these relationships and helps us identify critical linkages and gaps in our understanding. It also provides a foundation for identifying and prioritizing research needs, protection, restoration and enhancement efforts, and for planning and policy decisions.

Figure 7 Potential Stressors in the Coastal Ecosystems of the Pacific Northwest and Associated Ecological, Economic, and Social Impacts



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