

Management Measure #17

Revegetation

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MM 17 REVEGETATION

Definition

Revegetation uses site preparation, planting, and maintenance to manipulate soils and vascular plant populations to supplement the natural development of native vegetation. *Revegetation* is a diverse management measure potentially involving:

- Work of variable duration and intensity from reintroducing a single species to reassembling complex plant successions, involving single treatments or protracted management;
- Planting with seeds, cuttings, or rooted stock, including pre- and post-planting stock treatment to enhance survival or growth of native species ; and,
- Modifying the pre- and/or post-planting environment (sometimes including existing vegetation) to enhance plant stock survival and growth via the following methods: grading, grazing, mowing, burning, tillage, soil amendment, fertilization, mulching, irrigation, chemical or mechanical weed and pest control, and thinning.

Efficient *Revegetation* carefully considers landscape setting as well as local conditions to minimize costs and maximize certainty of success. While a diversity of habitat types provide for primary productivity in the nearshore, including sites vegetated by single-celled organisms and seaweeds, analysis of *Revegetation* in this chapter is focused on vascular plant habitats including:

- 1) nearshore forests and their associated freshwater wetlands
- 2) backshore and coastal spit vegetation
- 3) freshwater, brackish, and salt tidal marshes
- 4) eelgrass meadows

Justification of Need and Link to Nearshore Processes

Extensive deforestation following European settlement has altered the majority of uplands adjacent to Puget Sound shorelines. Disturbances such as filling, diking, armoring, overwater structures, upland structures, roads, ports, and other activities along shorelines have fragmented and reduced the diversity and abundance of marine riparian and freshwater wetland plant communities. The WDNR ShoreZone inventory (WDNR 1999) indicates that riparian vegetation overhanging the intertidal zone occurs at only 440 of the nearly 2,500 shoreline miles of Puget Sound (Redman et al. 2005).

Riparian forests were the first areas to be extensively logged because they were easily accessed, and logs could be rafted and floated to mills around the region. Because mature hemlock/Douglas fir forests take hundreds of years to develop, it is likely that there are few, if any, pristine nearshore riparian forests remaining, except possibly in areas where natural disturbance was frequent and persistent enough to maintain early seral communities (Brennan 2007).

Brackish and saltwater marshes have also been diked and drained for agriculture or dredged and filled to create buildable land with shoreline access. The development of two major river delta estuaries of Puget Sound's central basin, the Puyallup and the Duwamish, contributed to an estimated 98 percent loss of tidal wetland area in the Puget Sound Central Basin (WDNR 1998). More broadly, estimates based upon evaluation of 11 major deltas in Puget Sound indicate at least a 76 percent loss in tidal marshes and riparian habitat (Levings and Thom 1994). Except for Hood Canal and the Eastern Straits of Juan De

Fuca, no portion of Puget Sound has more than 50 percent of its historic tidal wetland area remaining (Collins and Sheik 2005).

The extent and condition of eelgrass meadows have declined sharply from historical conditions. Recent monitoring data show disturbing declines in Hood Canal and small embayments in the San Juan Islands (Dowty et al. 2005). Dredging or filling, nutrient loading, shading from overwater structures, propellers, and wake-driven waves have been shown to impact eelgrass meadows in Puget Sound and elsewhere (Mumford 2007). Important indirect stressors to eelgrass include hypoxia, eutrophication, and changes in trophic structure from harvest of competitors, herbivores, or predators of herbivores. Mumford (2007) provides a general model for reducing stressors to eelgrass for the purposes of restoration.

Revegetation in most environments focuses on the establishment of slow-growing, long-lived vascular plant communities using cultural practices from agriculture, horticulture, and forestry. In the nearshore environment, however, revegetation as a restoration measure must also be conducted with a firm understanding of the dynamic nature and character of the nearshore.

Nearshore ecosystems contain a mosaic of habitats, some of which support vascular plant communities and others that do not. Areas that are naturally unvegetated or sparsely covered are one component of the nearshore system. For example, sand or mudflats can support a very productive flora of microalgae, consisting of a thin veneer of algae over gravel or cobbles, with primary productivity as high as in an eelgrass meadow (Mumford 2007). Unvegetated areas also serve important ecological functions by providing high infaunal diversity and biomass (clams, worms, etc.) to upper trophic organisms, such as shorebirds. High banks eroding into the sea may be stripped of vegetation or dominated by weedy species, but these banks supply sediments critical for beach formation. Conversely, vascular plant communities in the nearshore perform different and important processes. For example, tidal salt marshes or backshores also provide detritus recruitment and retention processes, while intertidal vegetation, such as eelgrass, provides food web support and refuge for a wide variety of aquatic organisms.

Because of the dynamic nature of nearshore ecosystems, revegetation as a management measure must be applied to specific environments for specific purposes. The purpose of this chapter is to illustrate how nearshore processes affected by vegetation are context-specific and why they must be carefully considered. Some of the best management practices used in terrestrial systems may be inappropriate in the dynamic nearshore environment. Revegetation in the terrestrial environment often attempts to ensure permanent long-lived vegetation. However, engineering stability can result in projects that undermine nearshore processes that depend on disturbance (such as wind and wave action).

Revegetation, where successful, can alter the ongoing processes of native plant community assembly and succession. The above and below ground structures created by plants have the potential to affect a broad range of fundamental ecosystem processes over time:

Primary productivity: Vegetation provides the foundation for most terrestrial food webs and many aquatic food webs by storing solar energy in complex organic compounds.

Carbon cycling: Vegetation can provide a long-term sink for atmospheric carbon in wood and soil/sediment organic matter.

Nutrient cycling: Vegetation removes soluble nutrients from the substrate and increases development of substrate structure while increasing organic matter. Vegetation also “pulls” nutrients from the water column, which reduces nutrient loads. This results in increased belowground nutrient pools, cycling rates, and increased capacity to adsorb nutrients and buffer chemical processes.

Wave and tidal energy absorption: Eelgrass meadows and emergent marsh can absorb wave and tidal energy, stabilizing sediments, and affecting the energy reaching landward beaches and banks.

Hydrologic cycling: Upland vegetation intercepts rainfall, creates surface litter, absorbs and transpires soil moisture, and modifies soil permeability. These processes affect how water moves in the landscape.

Microclimatic processes: Vegetation can reduce local air temperature, increase humidity, reduce wind speed, and intercept solar radiation, creating microclimates supportive of life.

Revegetation with native species can also improve a wide range of ecological functions:

Refuge functions: Vegetation provides animals with refuge from weather and predation, potentially increasing the density and resilience of populations. Different populations show affinity with different kinds of vegetation, and so the character of the vegetation mosaic can affect the composition and density of animal communities.

Forage opportunities: Vegetation provides forage for grazers and foraging structures for predators.

Substrate stabilization: Plant roots, shoots, and litter increase the erosion resistance of substrates, typically reducing sediment suspension in moving water. By absorbing the energy of moving water, vegetation creates depositional zones when sediment is mobilized.

Alluvial functions of wood: Wood in river and creek channels creates more diverse instream structure and can affect the course of rivers, enhance rearing habitat, and increase floodplain habitat diversity.

Water quality functions: By slowing water movement, improving soil permeability, and increasing percolation rates, vegetation can help to trap nutrients that would otherwise become pollutants in aquatic systems.

Economic functions: Vegetation can be managed for the sustainable yield of a wide range of valued products either for economic or household purposes.

Cultural functions: Recognition and use of vegetation is among the most powerful catalysts for developing cultural relationship with landscapes. Native vegetation is valued by both native and contemporary populations.

Conceptual Model

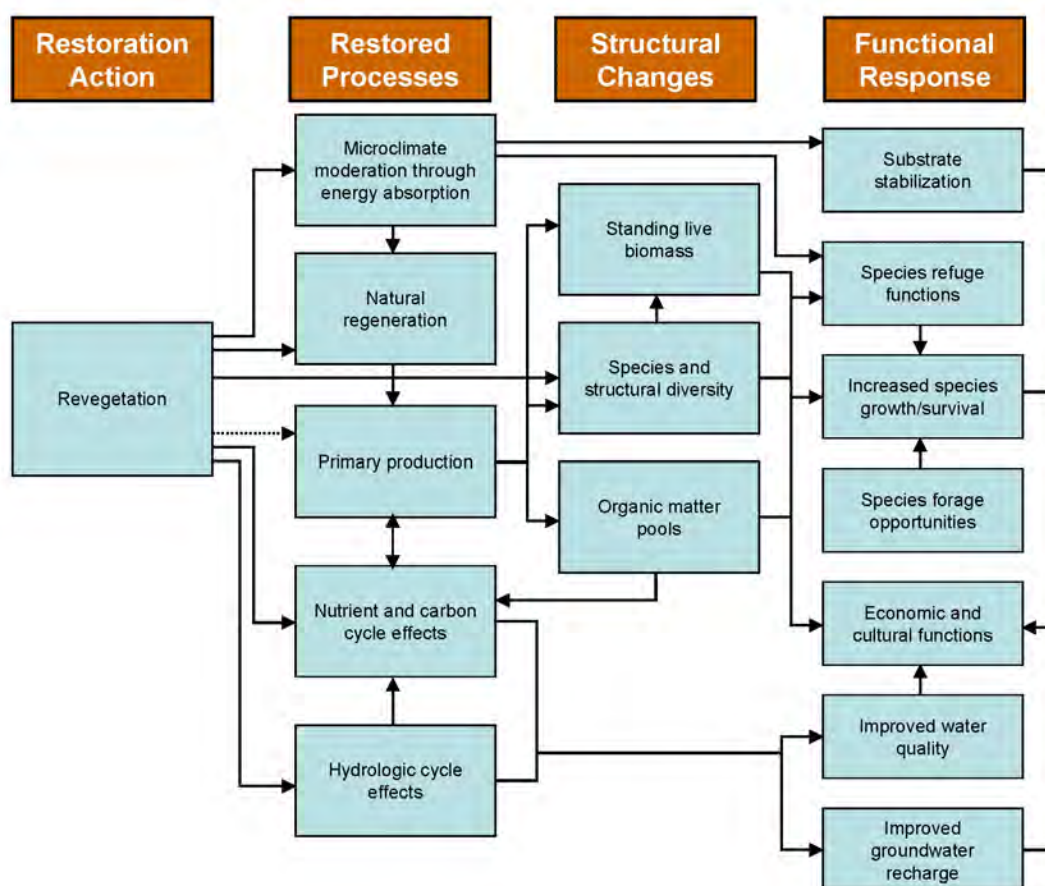
The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 17-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows). The conceptual model depicts a generic approach to revegetation projects. The purpose is to assist restoration practitioners in developing more project-specific models that more explicitly address local domains and treatment schemes.

Scenario: Landscape-scale clearing of vegetation and/or modification of soils and sediments have greatly reduced above- and below-ground biomass as well as structural and biological diversity.

Change/action: A revegetation treatment is implemented specific to site and landscape conditions.

Predicted response: The trajectory of native vegetation development is altered in a positive direction.

Figure 17-1 Conceptual Model for Revegetation



Complementary Management Measures

Revegetation is one of the most commonly applied management measures, often used in conjunction with other management measures, particularly following disturbance of existing vegetation or bare soil. *Revegetation* can speed development of desired ecological conditions following *Hydraulic Modification*, *Topography Restoration*, or *Channel Rehabilitation or Creation*, particularly when there is no local plant population to colonize new environments. Reforestation is a long-term and potentially self-sustaining alternative/complement to *Large Wood Placement* and *Species Habitat Enhancement* in that habitat structures are grown on site. *Revegetation* in the form of biotechnical erosion control methods can also be used in conjunction with or in lieu of engineered structures as part of *Armor Removal or Modification*. *Revegetation* is also often a logical partner to *Invasive Species Control* efforts when a particular species is targeted for removal.

Revegetation is often required as a mitigation measure (to offset development impacts) and is therefore associated with *Habitat Protection Policy or Regulation*. *Physical Exclusion* can be applied to recently revegetated sites or to support regeneration where vegetation is limited by stressors like trampling or grazing. *Revegetation* can aid in *Pollution Control* because plants bind soil particles and can help slow or trap pollutants in runoff water. Such long-term habitat protection strategies are a useful complement given the long-term accrual rate of vegetation benefits.

Benefits and Opportunities

There are a number of other potential benefits from revegetation that can align with other elements of the physical or cultural landscape. These opportunities can be beneficially integrated into design and installation.

Natural recruitment: Revegetation established founder colonies for production of spreadable prologues. As a restoration measure, revegetation promotes plant dispersal and recruitment, which can pre-empt establishment of non-native species. Subsequent natural regeneration of native species can supplement or even supersede revegetation efforts. Successful revegetation initially accelerates the recovery of habitat structure and function and then supports natural regeneration in adjacent sites.

Improved habitat for special status species and valued ecosystem components: Many species of plants and animals that are afforded special protection status under the state and federal regulations such as salmon and forage fish rely on vegetation structure. Revegetation can improve habitat function for these species and their required habitat structure.

Potential low cost: With effective site selection and assessment, revegetation in more terrestrial environments can be accomplished with volunteer labor, simple tools, and inexpensive propagules, at relatively low energy and capital costs.

Economic benefits: Revegetation programs create a local industry for production and installation of native plant stock. Naturalized vegetation can provide opportunities for carefully managed harvest of products for human use. Successful revegetation projects can provide seeds and cuttings for successive projects. Economic benefits also include those ecosystem benefits from ecological goods and services.

Public engagement: The “low-tech” nature of many revegetation practices allows for participation of untrained or volunteer labor, creating substantial opportunities for public education and participation, leading to improved stewardship and stimulation of future projects.

Experimental observation: The short- and long-term survival and growth of plantings across environmental gradients is poorly documented. Revegetation sites provide significant but often overlooked opportunities to study plant community assembly to increase future revegetation success.

Diverse values: Land managers and users value diverse naturalized vegetation for providing passive recreation and a lower-cost alternative to more resource-intensive land management.

In addition to the restoration of habitat-forming processes, revegetation can also provide many ecosystem services (benefits that people obtain from ecosystems). The Millennium Ecosystem Assessment sorts ecosystem services into four categories: supporting; regulating; provisioning; and cultural (MEA 2005). As shown below, revegetation can provide important primary production and nutrient cycling, known as supporting services, as well as recreational and aesthetic functions, which support important cultural services.

Ecosystem services provided by *Revegetation*

Supporting	Regulating	Provisioning	Cultural
Primary production	Climate regulation	Food	Aesthetic
Nutrient cycling	Disturbance regulation	Fresh water	Recreational
Soil formation	Biological regulation	Raw materials	Spiritual
Hydrological cycle	Water regulation	Genetic materials	Historic
Habitat formation	Waste regulation	Medicinal resources	Scientific
Pollination	Nutrient regulation	Ornamental resources	Educational
Seed dispersal	Soil retention regulation		
	Flood regulation		
	Water purification		

Measureable Units

The success of revegetation efforts can be assessed in a multitude of ways including: the presence and abundance of target animal species and/or the degree of biodiversity of plant species. Plant community structure can be evaluated using standard vegetation survey techniques to assess whether long-term trajectory of the site will be as planned.

Opportunities for Implementation

Revegetation can be implemented at an infinite variety of site scales and intensities. Among the myriad landscape context considerations (e.g., bluffs, barrier lagoons, pocket beaches), it is important to determine how site selection fits in with the restoration agenda (i.e., local coastal management plan) in a given area, or how it can be combined with larger restoration efforts (e.g., coastal watersheds). Revegetation efforts may have a greater chance for success where they are adjacent to existing natural systems (seed sources) or are protected (from disturbance or future development) by policies and regulations.

Revegetation treatments are typically motivated by government regulation, compensatory mitigation, tax-funded site stewardship by private or public entities, or private investment in erosion control. Recent Critical Areas Ordinances and tax incentives like the Public Benefit Rating System aim to manage vegetation on private land. Conversely, land use practices that encourage clearing, grazing, and mowing can inhibit natural regeneration of soils and forest.

Constraints

Revegetation attempts to achieve complex self-sustaining vegetation in dynamic environments with fewer resources than other horticultural endeavors. The capacity of vegetation to naturally regenerate can be reduced by loss of local seed sources, changes in environmental conditions, and local animal populations. In many cases, natural regeneration may no longer restore historic vegetation structure, diversity, or function. While effective restoration is aligned with natural forces, there are many constraints that can undermine restoration efforts, most of which can be avoided through careful assessment and design:

Modified environmental conditions: Soils, hydrology, or water quality may be so modified that they prevent the development or reduce the resilience of historic vegetation.

Modified ecological conditions: The naturalization of exotic species or changes in local animal populations may result in competition, predation, or lack of facilitation that may reduce the viability of certain vegetation patterns.

Anthropogenic stressors: Trampling, harvest, over water structures, and air, water, and soil pollution may directly degrade new plantings or degrade them in the future.

Climate change: Change in seasonal patterns of precipitation or temperature, either anthropogenic or cyclic, may modify the development or resilience of target vegetation.

Sea level rise: Increased mean sea elevation can change the depth of inundation, affecting revegetation efforts especially those involving submerged aquatic and marsh communities. Higher sea levels will increase erosion and landslides.

Technical limitations: Techniques used in vegetation management for landscaping, agriculture, or forestry may be ineffective or inefficient when applied to establishment of complex, self-regulating native plant communities in degraded nearshore environments.

Costs: Cash resources available for revegetation are typically minimal and short term. Constraints can dramatically increase the costs of reaching performance targets. Revegetation of some environments can be expensive at a large scale.

Questions remain about how to increase and accurately measure short-term efficiency and long-term functional response. The data gaps create an additional constraint for revegetation efforts. In general, because of the effectiveness of horticultural and agricultural practices, we could assume that revegetation practices are equally effective. However, revegetation is qualitatively different than intensively managed systems in that it aims to produce complex, self-sustaining systems in perpetuity with little or no maintenance.

While many examples of eelgrass revegetation have been documented, quantitative monitoring rarely answers questions about best practices. Thom et al. (2008) concludes that eelgrass restoration science is hampered by knowledge gaps, reducing restoration success. For example, the mechanisms for recent eelgrass loss in the region are not obvious, which suggests that the scientific understanding of eelgrass biology and ecosystem conditions is inadequate to support environmental management actions in our region. The following is an incomplete list of data gaps related to revegetation in Puget Sound restoration efforts.

Species propagation efficiency: Limited information is available of the most cost effective approach for propagating each species across the range of conditions to which it is adapted to grow. Plant density has been correlated with several measures of revegetation success (Celedonia 2002), but costs increase exponentially with increased plant density. Use of seed and smaller stock can potentially increase short-term cover, but these methods are often avoided due to perceived risk of out-planting failure.

Planting into existing ecologies: Due to the lack of monitoring data, our understanding of how to efficiently change the development of existing forests stands is limited. This hampers our ability to successfully reintroduce conifers into hardwood dominated stands where conifers have been extirpated by forest practices.

Seeding: While seeding is common in restoration of Great Plains prairie systems, very limited data are available to describe the effective use of Puget Sound species from seed. Increased use of seed could increase cost effectiveness.

Soil restoration: While soil and sediment conditions are critical to all revegetation efforts, limited information is available about how treatments affect soils, and how soil condition in turn affects revegetation outcome. Agricultural and horticultural practices are regularly used in revegetation without consideration of how reference soils that develop under natural conditions may vary from those soils resulting from horticultural or agricultural practices in terms of nutrient pools, physical characteristics, or depth.

Presence and role of herbivores: Plant species and their susceptibility to herbivores specific to the Puget Sound area and sites within the area are likely poorly documented. Especially in cases of submerged and emergent plants, protection from grazers will probably be necessary during the establishment phases of revegetation.

Long-term trajectory: While short-term survival and growth are critical for project success, the long-term development of vegetation may veer from design targets. The effectiveness of revegetation ultimately lies in long-term performance, which is rarely measured.

Hydrologic tolerances: Very limited empirical evidence is available to clearly define the tolerances of species to inundation stress. Substantial experiential knowledge exists in the professional community that has not been summarized.

Functions: The specific functions of vegetation and how those functions vary with the structure, function, area, or continuity of vegetation have not been fully assessed. Understanding the nature of vegetation function will assist in prioritizing revegetation actions to maximize restoration of ecosystem functions that depend on vegetation.

Role of disease and pests: Sub-lethal stress on plant populations can cause susceptibility to disease or pests, particularly where plant monocultures create an easy vector for spread of disease or pest populations. We have limited information about the extent to which natural disease cycles are present or are exacerbated by human impacts or management. Introduced diseases and pests are an additional factor that may affect vegetation viability and ecosystem resilience now or in the future.

Best Professional Practices

Effective manipulation of vegetation is complex, and requires careful planning, sensitive design, and practical installation. The following sections provide general considerations for the planning and implementation of a revegetation project. At the end of this chapter is a summary of best management practices specific to different ecotypes (e.g., salt marsh, freshwater wetlands) (see Table 17-1). The table is meant to focus on ways in which best practices vary between systems. In all cases, appropriate species selection based on soil and water conditions and microsites is critical and assumed. Adaptive management, learning, effective recordkeeping, and communication are also critical. The need for and approach to managing invasive species vary dramatically depending on project goals and objectives, and so invasive management issues are not addressed in the table. Assessment and response to potential grazing/browsing pressure is assumed and should be considered for all situations (browse control is only mentioned in particularly important circumstances). Conservation and protection of soils is assumed for all ecotypes.

Restoration practitioners focusing on eelgrass restoration should also refer to *Eelgrass (Zostera marina L.) Restoration in the Pacific Northwest: Recommendations to Improve Project Success* (Thom et al. 2008) for the most current best professional practices.

Feasibility Assessment

There are many feasibility considerations when planting revegetation projects. Some of the main considerations include:

Soil/sediment conditions: Soil/sediment conditions strongly affect the survival and competitiveness of individual species. Artificially propagated stock or seedlings are more sensitive to environmental extremes than established vegetation. Soil texture, nutrient characteristics, and structure can be quantitatively or qualitatively assessed and compared to reference conditions. Existing vegetation can provide evidence of soil conditions. The salinity of soil pore water in tidal systems strongly controls marsh composition. Sediment texture can indicate energy environment. Plant species can be very sensitive to contamination in soils.

Water quality: Proper water quality conditions are critical for in-water revegetation particularly for eelgrass. Potential pollutants include nutrients, toxics, and sediments/turbidity (for proper light penetration).

Hydrologic regime: Frequency, depth, and duration of inundation interact to create low oxygen conditions in the soil that reduce survival and growth of many species. Species selection should be based on a clear understanding of the effect of the hydrologic regime on soil conditions. Falling water levels in freshwater marshes and other habitats can devastate recently completed revegetation efforts.

Solar exposure: Intensity of sunlight combined with solar aspect can affect species viability. Individual species are differently adapted to compete under different light levels. Eelgrass is particularly sensitive to shading or reduced sunlight caused by turbidity. Exposure can exacerbate drought conditions, or low light levels can reduce a species' ability to adapt to anoxic soils.

Seed banks and seed rain: Revegetation occurs in the context of natural regeneration. Revegetation treatments can be either enhanced or superseded by natural vegetation processes. Seed banks can be assessed through growing-out soil samples, observing seasonal recruitment on bare soil, or by making assumptions based on surrounding vegetation. Seed rain can be similarly assessed.

Competing vegetation: Regeneration and expansion of existing plant populations, including seed banks, can strongly affect vegetation development. For example, algae can be absent in winter, and then grow rapidly in spring, competing with eelgrass. Control of undesired vegetation can be integrated into site preparation, and planting design, as well as maintenance. Assess existing vegetation to clearly understand life history traits, response to treatment design, anticipated future recruitment and growth, and management options.

Disturbance regime: Local disturbances can include fire, herbivory, alluvial, tidal, or wave-driven erosion, turbidity, deposition, slope and substrate instability, pollution related impacts, and a wide range of direct human impacts. Revegetation can be severely undermined by poor assessment of the current disturbance regime. Pressure from beaver, deer, elk, goose, voles, rabbits or other browsers and other grazers (including aquatic grazers such as turtles, waterfowl, etc.) may be critical to planting survival, or may dictate the selection of plant species.

Regulatory concerns: Work in wetlands and other protected habitats (e.g., critical areas) is subject to local, state, and federal regulations that may constrain timing, extent, and specifications of work.

Design

Design considerations varying depending on the site conditions, but some of the key design issues are:

Adaptively manage and learn: Despite the sound designs, on-the-ground work is an opportunity to observe and learn. Careful assessment allows practitioners to anticipate, budget for, and adapt to potential constraints. Carefully documenting revegetation goals, objectives, effort, and outcome, combined with experimental designs that answer specific management questions, can improve the effectiveness of future projects. Installation and funding strategies must accommodate observation and course correction.

Examine reference conditions: The effectiveness of plantings can be increased by identifying similar conditions and mimicking patterns of composition and structure found at reference sites. Care must be taken to select appropriate reference sites that provide useful information about preparation and planting. For example, a mature forest may provide a limited view of species composition and vegetation structure during early stand establishment. Multiple reference sites may need to be examined and synthesized to match the unique environmental patterns of a site.

Anticipate succession: Vegetation changes soils, microclimates, and substrate conditions as it develops. Numerous theories predict how community composition and structure change over time. Successional design considers how planting species and density will evolve toward a future state that may not be readily apparent in the planting plan. Some efficiency may be gained by protracting the planting process to take advantage of evolving site conditions that support survival and growth of target species. Planned disturbance can be incorporated into revegetation design to manipulate vegetation structure and create niches to increase diversity. Protracted observation of natural systems can offer ideas for dynamic vegetation development.

Use natural regeneration: Where dispersal from surrounding native vegetation is robust, revegetation can occur by simply removing constraints to natural regeneration. Where adequate monitoring and contingency planning can be assured, restoration planners can test the effectiveness of unassisted regeneration during early phases of revegetation efforts. Revegetation effort can then be reduced or applied to supplement natural vectors of vegetation development.

Integrate cultural practices: Agriculture, forestry, horticulture, and agroforestry all have technologies and strategies that can be integrated into revegetation efforts. Species respond differently to cultural methods.

Consider timing: Survival and growth can be improved by aligning revegetation actions to avoid or take advantage of seasonal variation in precipitation, temperature, soil moisture, and disturbance. Advantageous timing can vary between sites, within sites, and among the species cultivated.

Evaluate environmental zonation: In wetlands, vegetation composition frequently varies in a pattern of concentric elevational bands corresponding with soil moisture and inundation regime. Planting growth and survival can be increased by accurately aligning planting patterns to match the environmental thresholds that control naturally observed zonation. The zonation of recruitment may not match the zonation of mature vegetation.

Anticipate hydrologic effects: Controlling hydrologic conditions to moderate extremes of inundation or drying over a period of plant establishment can increase the survival and growth of out-plantings.

Design around weed control: Opportunities for cost-effective control of undesired exotic weed populations decrease dramatically once a planting is installed. Effective weed control is designed into all phases of site work. Undesirable species can be imported with equipment, plant stock, or loose materials like soil, sand, or gravel.

Implementation

The following guidance will improve implementation effectiveness:

Design information flows: Sound design plans can go awry if the on-the-ground implementers are not aware of and motivated to implement design strategies. Document design intent and detail so that it is accessible and maintain regular and clear communication throughout bidding and construction.

Conserve and restore soils: Construction practices can rapidly degrade soil structure with irreversible impacts on revegetation efforts. Construction should be designed to preserve and enhance the structure and biology of existing and imported soils through stockpiling (as appropriate) and protective ground coverings for heavy machinery.

Start with pre-disturbance conditions: In eelgrass restoration sites, it can be important to restore site conditions as close as possible to pre-disturbance conditions. This may require manipulating site elevation through dredging or filling (e.g., Drayton Harbor), clearing debris (e.g., Clinton Ferry terminal), or removing structures (e.g., Maritime Center Dock) that inhibit eelgrass growth.

Protect existing vegetation: In riparian or upland sites, prevention measures may be necessary to protect existing vegetation. Construction fencing should be installed to delineate areas of clearing and protection. Root systems critical for tree health may extend far from tree trunks. Driplines of large trees should be designated and covered with protective covering.

Protect water quality: Chemicals and fuels, including those in machinery, must be managed carefully to prevent pollution. Anticipate and accommodate a range of weather scenarios when planning water quality protection measures.

Manage erosion and soil impacts: Bare ground should be protected from rainfall and construction disturbance using best practices (e.g. silt fencing, hay placement, etc.). Control and treatment of sediment laden water may be critical on some sites, but is secondary to prevention of erosion.

Stock quality control: Stock should be grown and staged under conditions that support rapid growth after out-planting, including adequate irrigation, appropriate fertility management, and protection from extreme heat or cold. Measures should be taken to ensure contaminants are not transported to restoration sites.

Carefully select installers: Ornamental landscape contractors may not be familiar with revegetation species, or best revegetation practices may vary from ornamental landscape practice. Careful selection or training of contractors may increase revegetation performance.

Complete as-built documentation: Accurate documentation of the extent and nature of the actual revegetation treatment as installed is critical to evaluating monitoring results, and any attempt at learning from past projects.

Adaptive installation: Actual site conditions can vary dramatically from design assumptions. Designers and installers should be able and prepared to adjust designs to meet observed field conditions while maintaining good quality documentation of the installation.

Evaluation

Qualitative monitoring of vegetation can provide detailed information for lower cost, and can allow for rapid response to site conditions. Quantitative monitoring requires a sound experimental design to draw meaningful conclusions. Robust experimental design is based on testing explicit questions. The long-term value of vegetation can be strongly affected by hard-to-measure phenomena like resilience to disturbance, invasive species, and plant succession. A range of vegetation parameters can be tracked based on project goals and objectives:

Planting area and density: Detailed records of planting extent and density are most easily maintained when integrated into construction practice. As-built planting records provide a critical measurement for evaluating the influence of revegetation treatments among multiple sites.

Survival and growth: Survival can be measured by comparing quadrat density before and after a specific time period. Initial sampling should closely follow planting. Inaccurate reproduction of plot boundaries can increase error in counts. Growth rates can offer more detailed information about the controls on variable planting performance than survival or cover. Highly variable growth observed immediately after out-planting may become undetectable over time if it is a relic of variable planting practices.

Estimated cover: Sampling method should be carefully assessed to minimize variance among independent cover estimates. The time interval between estimates should consider the rate of growth and the ability of the sampling strategy to detect change. A wide range of measurement techniques are available for measuring relative dominance between species, so hypotheses should be explicitly stated.

Structure: Simple vegetation structure can be captured by estimating species cover within discrete elevation ranges (strata). A range of more complex measurements and summary statistics can be used to quantify vertical or horizontal structure.

Annual productivity: Deciduous herbaceous systems like tidal marshes lend themselves to measurement of aboveground annual productivity. Comparison of above and below ground productivity may offer insight into vegetation condition. Non-destructive measures like shoot height and density may be a useful surrogate for productivity.

Seedling density: Patterns of natural seedling recruitment may be used to suggest that a desired state of self-sustaining process has been achieved.

Soil condition: Though plant growth can be used as a surrogate for soil conditions, some restoration objectives may involve targeted soil conditions that can be directly measured like bulk density, organic matter pools, or measures of biochemical condition, like sulfide concentration or reduction-oxidation state.

Wildlife utilization: Vegetation functions can be estimated by evaluating the presence, diversity, residence time, or diet of resident wildlife species. Certain species or phases of life history may provide indicators of vegetation functions.

Case Studies and Examples

Eelgrass restoration in Drayton Harbor and Blaine Harbor Marina Expansion, Blaine: As part of the Port of Bellingham's Blaine Harbor Marina Expansion, clean dredged material from the marina basin was deposited at a low spot in Drayton Harbor and resulted in the conversion of over 15 acres of subtidal area to an intertidal/shallow subtidal area. This was a voluntary action of the Port (not required as mitigation) and was also an alternative to the traditional open-water disposal of dredge materials. Five years of monitoring found that planted eelgrass survived and spread, and volunteer plants colonized much of the site. Monitoring for salmonid prey organisms indicated that the site provides rearing habitat for juvenile fish and Dungeness crab.

Riparian Surge Plain Restoration, Nisqually Tribe, Olympia: This project is included as a case study for the feasibility of a large-scale planting effort. As part of the Nisqually National Wildlife Refuge estuary restoration project, the Nisqually Tribe has implemented a large-scale restoration of approximately 54 acres of freshwater tidal riparian forest (also known as riparian surge plain) along the lower Nisqually River by intensively planting an area adjacent to existing surge plain forest. The project was phased over a two-year period. The first year, approximately 19,000 native shrubs and trees were installed over 24 acres in the fall and winter (2007-2008). The following year another 22,000 plants were installed over 30 acres. Adaptive management and innovative techniques were critical to get the project in the ground. The site was historically used for low-impact farming and consisted of a thick mat of pasture grasses.

The first year, the site was tilled and sprayed with glyphosate in the early fall before planting. With onset of the rainy season, the wet, tilled soils resulted in challenging conditions during fall and winter planting efforts. To avoid this constraint the second year, the site was not tilled, but was still sprayed with glyphosate to 'knock down' pasture grasses during live plant development. Plants appropriate for the site were selected and then generally placed in the field by their moisture tolerance at the time of planting. Due to the high number of plantings, the Tribe decided to install the plants in loose rows (as opposed to irregular clustering) to make future maintenance (mowing, weeding) activities feasible. The majority of plants were installed using paid labor (tribal crews) with approximately 10 acres planted during volunteer planting events in the fall. Volunteers installed containerized stock, which is easier to handle and more forgiving during installation. The majority of plants were live stakes and bare root. Plant storage between delivery and installation required some creativity (to maintain survivorship). Live stakes were stored in a penstock filled with water at the tribe's fish hatchery and bare root plants were stored during the first year at a cold storage facility owned by the Washington State Department of Transportation.

Tidal and estuarine marsh, Commencement Bay Natural Resource Damage Assessment and Restoration, Tacoma: Approximately 10-15 tidal marsh restoration sites have been installed surrounding the Port of Tacoma, motivated either by natural resource damage settlements or mitigation associated with industrial development. The National Oceanic Atmospheric Administration (NOAA) is the lead

agency of the Commencement Bay Natural Resource Trustees and is responsible for managing restoration projects under the Commencement Bay Natural Resource Damage Assessment and Restoration Plan. A baywide restoration plan was adopted in 1997 that put forth a series of habitat restoration projects using funds, property, and in-kind services obtained through damage claim settlements. The plan focused on replacing components of the historic ecosystem (e.g. estuary, mudflat, emergent marsh, eelgrass beds) that enhance populations of fish and wildlife. The majority of sites were implemented between 1999-2001. Information about each of the restoration sites, along with photographs, can be found on the web at <http://www.darrp.noaa.gov/northwest/cbay/restore.html>.

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Table 17-1 Summary of Best Management Practices by Ecotype for *Revegetation*

	Dry and Bluff Forests	Moist Forests	Freshwater Wetlands
Constraints	Reduced percolation from urbanization may reduce soil moisture. Poor access and difficult terrain may increase costs.	These are the most forgiving conditions to work under.	The current hydrologic regime of the site is most limiting factor. Modified hydrology may limit palette to most adaptable species. Beaver can strongly modify design hydrology.
Opportunities	Consider experimenting with techniques for improving survival of outplantings without irrigation including stock selection and seeding.	These conditions offer the greatest opportunity for volunteer involvement. Early succession hardwood species are easy to establish from seed. Keystone species are relatively well understood.	Wetlands are amenable to volunteer plantings – where drought is not a concern plantings can occur any time of year. Beaver can expand wetland function.
Assessment	Exposed bluffs can create high mortality from drought stress while irrigation on remote slopes may be difficult or expensive. Geologic strata can strongly affect groundwater movement and soil moisture regime. Aspect of slope can drive community composition. Slope failure and shifting soils can favor ruderal species.	Natural red alder (<i>Alnus rubra</i>) regeneration can strongly direct plant community development. Surface water drainage patterns can create mosaic of soil moisture regime.	Accurate assessment and prediction of depth, duration, and frequency of inundation (hydrologic regime or water budget) is critical to successful design. Seasonally changing water depths may require multiple plantings and/or timing of plantings to ensure that plants are within elevation ranges suitable to their growth. A need for nuisance plant species control may dictate integrated site prep, planting and maintenance strategies. Sediment transport from rivers and creeks can drive system function.
Design	Planting at the beginning of fall rains, use of small stock with high root to shoot ratio may increase survival in the absence of irrigation. Temporary drip irrigation may be cost effective for irrigation during establishment. Natural patterns of water flow may indicate microsites beneficial for plant establishment. Where constraints increase costs, patchy <i>Revegetation</i> followed by natural regeneration may be more cost effective.	Closing canopy to reduce competition from grasses may enhance growth of some species. Consider rapid canopy closure followed by thinning and introduction of shade tolerant species where shade intolerant exotic species are an issue. Irrigation may provide minimal benefits depending on soil conditions and interannual variation.	Plant community targets are carefully aligned with zonation related to hydrologic regime and reference wetlands. Reference wetlands may represent an unusual composition resulting from biogeographic dispersal patterns or past degradation. Planting can be delayed until after leaf emergence in spring to avoid long inundation stress on transplants (only where soil moisture is retained into summer). Large mono-specific stands of willow can be susceptible to beetle infestations. Several wetland species can be effectively propagated using un-rooted cuttings (dogwood, willow, etc.).
Construction	Crew traffic can increase erosion on slopes. Crew safety may require rope and harness. Adjust planting locations to match observed moisture patterns if previous observation of winter wetness was not feasible.	Mesic forest presents the least challenges to constructability.	Saturated soils are easily compacted. Excavation, storage and placement of soils need to be carefully managed. Seeds of invasive species can be easily imported in fill, so transport must be controlled.
Monitoring	Patterns of survival among species may guide future planting. In disturbance environments, establishment of natural dispersal and regeneration by target species may indicate system resilience.	Methods for monitoring (survival and growth, estimated cover, stem density) are widely used and proven successful for evaluating restoration goals and objectives.	Periodic monitoring of plant survival, growth, and spread combined with volunteer plant community development will provide decision-making information necessary for implementation of adaptive management practices (e.g., controlling nuisance species, planting additional native plants, etc.). Monitoring hydrology, water quality, grazing pressure, weather patterns, and human activity can provide critical information about patterns of planting mortality.

	Backshore/Spit Vegetation	Salt Marsh	Eelgrass
Constraints	Wind, shifting sand, soil salinity, and salt spray on leaves can create very stressful environments for plant establishment. Social trails can heavily impact fragile dune systems.	Salt marsh is created and sustained by sedimentologic processes that may be dramatically altered (in the past and future). Contamination may occur from industrial activity or contaminated fill.	Eelgrass transplanting requires specialized crews with diving equipment and expensive propagation facilities. Snuba could be viable (combination of snorkeling and scuba diving).
Opportunities	Consider experimenting with techniques for planting dune grass and other salt-tolerant plants.	Dredge spoils can be beneficially used to create areas of sediment for marsh establishment.	Many of the opportunities present in other ecotypes are absent with eelgrass. Given the high cost and experimental nature, maximize learning opportunities from each action.
Assessment	Salt spray combined with sandy soils and exposure to sun and wind can create severe drought stress. Ground water discharge can vary dramatically along a beach face or be non-existent or saline on a spit or foreland. The intensity of adjacent land use is a critical factor to selecting a site.	Hydrology, elevation, and salinity all critically control species composition. Presence of local seed source and position of the site to patterns of wrack accumulation may affect natural regeneration. Alluvial disturbance may be an issue. Resident Canada goose populations can also prevent marsh establishment.	Existing eelgrass populations best demonstrate tolerance of local disturbance regime. Viable habitat is typically bounded by exposure and wave disturbance at high elevations, and light levels at lower elevations. Presence of holdfasts can encourage algal dominance.
Design	Given the shortage of information on these communities, examination of reference conditions is critical. Diverse species are not frequently available, and may require contract growing or seed collection. Facilitation by pioneer species may be important for building soil organic matter and moderating the environment. Discontinuity and fragmentation of these systems may increase the need for <i>Revegetation</i> .	Soil redox regime can be strongly affected by pore drainage between tidal cycles. Porosity of constructed surfaces may be less than a natural formed marsh. In sandy sediments, facilitation by annuals or algae may improve organic content to support more robust growth of perennial marsh species.	Neighboring reference conditions are critical. Wave energy can vary over short distances. Staking to stabilize transplants is valuable. The connection between sediment chemistry and population viability is poorly understood.
Construction	Closure of the restoration site (<i>Physical Exclusion</i>) is critical to success.	Saturated soils are easily compacted. Excavation, storage and placement of soils needs to be carefully managed.	Orienting and accurately placing stock underwater with currents and waves can be difficult. Staking is useful to reduce mortality from erosion or predation.
Monitoring	Limited information is known about species autecology, interactions and succession in this environment. Patterns of survival among species may guide future plantings.	Elevation can strongly affect patterns of regeneration. Consider stratified sampling based on elevation.	Timing monitoring is critical to repeated samples. Shoot density is a common surrogate for biomass production, but can be variable from year to year due to factors other than <i>Revegetation</i> method. Establish control sites.



Management Measures for Protecting and Restoring the Puget Sound Nearshore

Prepared in support of the Puget Sound Nearshore Ecosystem Restoration Project

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1. ESA Adolfson
2. Phillip Williams and Associates
3. Coastal Geologic Services
4. Washington Department of Fish and Wildlife
5. U.S. Army Corps of Engineers
6. The Nature Conservancy
7. National Oceanic and Atmospheric Administration
8. U.S. Fish and Wildlife Service
9. People for Puget Sound
10. University of Washington



EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers (USACE) and the Washington State Department of Fish and Wildlife (WDFW) co-lead an ecosystem study of the Puget Sound called the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP). The study commenced in federal Fiscal Year (FY) 2001 and is scheduled to conclude in FY 2012. The purpose of the study is to evaluate significant ecosystem degradation in the Puget Sound Basin; to formulate, evaluate, and screen potential solutions to these problems; and to recommend a series of actions and projects to restore and preserve critical nearshore habitat. The second phase of work, which will entail implementing process-based restoration projects, will commence when the study is completed and federal and state restoration funds are dedicated for necessary projects. These projects will be carried out to improve the integrity and resilience of ecosystem processes and to promote environmental and human health and well being.

The geographical domain of the study area extends along 2,500 miles of shoreline from the Canadian border, through Puget Sound, and along the Strait of Juan de Fuca to Cape Flattery. PSNERP defines the nearshore as the area that extends from the top of shoreline bluffs or upstream in estuaries to the head of tidal influence waterward to the deepest extent of the photic zone.

The protection and restoration of nearshore habitats in Puget Sound requires the application of recovery actions or “management measures” that address nearshore ecosystem processes, functions, and structures. Management measures (MMs) are specific actions that can be implemented alone or in combination to restore the nearshore ecosystem. PSNERP has identified 21 management measures for implementing nearshore ecosystem restoration recognizing that (1) the measures can be capital projects, regulation, incentives, or education and outreach, and (2) the measures contribute to ecosystem recovery via protection, restoration, rehabilitation and substitution/creation. This technical report helps determine how to most effectively use the 21 management measures to accomplish process-based restoration in Puget Sound. The report also serves to:

1. Provide a common understanding of each measure’s strengths, weaknesses and constraints and describe the issues that should be addressed at feasibility, design, implementation, and evaluation phases of each management measure.
2. Provide a basis for describing proposed restoration actions for a programmatic Environmental Impact Statement to be prepared by PSNERP in 2010.
3. Provide a systematic organizational framework for describing management measures that can be used to develop and evaluate Puget Sound nearshore restoration alternatives by describing the benefits and constraints associated with implementing each measure.

The report is composed of an introductory chapter plus one chapter for each management measure. The introductory chapter describes the context in which management measures should be applied and provides background information on the relationships between management measures, nearshore processes, and Puget Sound shoreforms. Guiding principles for nearshore restoration developed by the Nearshore Science Team (NST) provide a foundation for this information. These principles favor process-based restoration and protection, which involves implementing projects that support or restore natural ecosystem processes, which in turn generate or maintain desirable nearshore ecosystem structure and functions, enabling the ecosystem to be naturally productive and resilient.

Process-based protection and restoration requires management measures that both preserve and reestablish the dynamics of nearshore hydrology, sedimentation and other habitat-forming processes

(Goetz et al. 2004). This report attempts to show that certain management measures have the potential to produce a sustainable effect on processes, while others mainly target restoring ecosystem structure. This report also shows that some measures have less direct effects on processes, but may contribute to restoration in other ways that are sometimes more difficult to gauge (e.g., through the modification of human behaviors).

This report discusses the varying degrees of applicability and utility of management measures in different geomorphic settings. In particular, measures that involve physical and direct alteration of the landscape are most effective when applied to the appropriate geomorphic system (rocky shores, beaches, embayments and deltas). Understanding the spatial and temporal characteristics of each management measure is also critical in the selection of appropriate measures in different geomorphic settings. Certain measures can produce an immediate functional lift while others may focus on a long-term reestablishment of natural processes. The combining of multiple measures in the appropriate landscape context can be very effective in achieving restoration goals (than relying on single measures) because both space- and time-benefits are addressed.

The individual management measure chapters contain five major sections:

Definition	A description of the measure and the range of actions encompassed or excluded
Justification of Need and Link to Nearshore Processes	A description and conceptual illustration of the relationship between the measure and nearshore processes, structures and functions
Complementary Measures	A discussion of the use of additional related measures that would maximize benefits of the action over time and space
Benefits and Opportunities	A discussion of potential benefits of employing the measure as well as opportunities for implementation
Constraints	A list of potential limitations associated with the measure
Best Professional Practice	A summary of best management practices that should be addressed during feasibility assessment, design, implementation and evaluation
Case Studies	Examples of past projects that employed the management measure including how and where it was implemented

The purpose of the individual chapters is not to provide an exhaustive review of the particular restoration measure, but rather to integrate each activity into a cohesive nearshore ecosystem restoration strategy. The chapters serve as science-based support for nearshore restoration and protection actions that integrate local, state, tribal, federal and non-governmental activities.

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Front cover: Nisqually Wildlife Refuge/Estuary with Luhr Beach in the background. Photo by Ilon Logan.

Back cover: *Left:* Beach Nourishment at Marine Park in Bellingham. Photo by Jim Johannessen. *Right:* Jones Creek Channel Rehabilitation, Qwuloolt Marsh, Snohomish Estuary. Photo by Steve Winter.

GLOSSARY

Accretion—The gradual addition of sediment to a beach or to marsh surface as a result of deposition by flowing water or air. Accretion leads to increases in the elevation of a marsh surface, the seaward building of the coastline, or an increase in the elevation of a beach profile (the opposite of erosion).

Adaptive management—The application of facts learned through project experience or from the results of scientific experiments to the making of future management decisions.

Backshore—The upper zone of a beach beyond the reach of normal waves and tides, landward of the beach face. The backshore is subject to periodic flooding by storms and extreme tides, and is often the site of dunes and back-barrier wetlands.

Beach—The gently-sloping zone of unconsolidated sediment along the shoreline that is moved by waves, wind and tidal currents.

Bluff—A steep bank or slope rising from the shoreline, generally formed by erosion of poorly consolidated material such as glacial or fluvial sediments.

Conceptual model—As used here, a model, either numerical or diagrammatic, that summarizes and describes a simplified version of the natural environment. See Simenstad et al. (2006) for a full explanation of the conceptual model framework (available at http://www.pugetsoundnearshore.org/technical_papers/conceptmodel_06.pdf).

Delta—A deposit of sediment formed at a stream or river mouth, or other location where the slowing of water flow results in sediment deposition.

Ecological integrity—Maintenance of the structure and functional attributes of a particular locale, including normal variability (NRC 1992).

Ecosystem—A community of organisms in their physical and chemical environment interacting as a mutually interdependent and competitive unit (NRC 1992).

Ecosystem function—Any performance attribute or rate function at some level of biological organization (e.g., green plants capturing light energy and converting it into chemically stored energy) (NRC 1992).

Ecosystem processes—Any interaction among physiochemical and biological elements of an ecosystem that involve changes in character or “state” (NRC 1992).

Ecosystem Services— Ecosystem services are the “outputs” and experiences of ecosystems that benefit humans, and are generated by the structure and function of natural systems, often in combination with human activities (MEA 2005, Ruckelshaus and McClure 2007).

Enhancement —Any improvement of a structural or functional attribute [of an ecosystem](NRC 1992).

Estuary— A semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage (Pritchard 1967). Sometimes defined more broadly to include other coastal inlets that connect coastal lagoons and swamps to the sea.

Geomorphic System—As used here, four broad categories of coastline (rocky coasts, beaches, embayments, and river deltas) that reflect the relative influences of wind, tidal, and fluvial processes in controlling the transport and distribution of sediments and the resulting evolution of landforms (Shipman 2008). See Shipman (2008) for a full explanation of typology.

Habitat—The physical, biological, and chemical characteristics of a specific unit of the environment occupied by a specific plant or animal. Habitat is unique to specific organisms and basically encompasses all the physiochemical and biological requirements of that organism within a specific location (Fresh et al. 2004).

Irreplaceability—A fundamental measure of the conservation value of a site in terms of its potential contribution to the achievement of a restoration goal (Pressey et al. 1994).

Landform—As used here, complex coastline features that reflect different long-term patterns of sediment accumulation and deposition. These are several types of landforms in each geomorphic system. See Shipman (2008) for definitions and descriptions of each type.

Landscape—A heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout (Forman and Godron 1986); a particular configuration of topography, vegetation cover, land use and settlement pattern which delimits some coherence of natural and cultural processes and activities (Green et al. 1996).

Management measure—An action that addresses the objective of restoring or improving nearshore ecosystem functions, structure, and/or processes. Actions include restoration or other physical alterations, as well as management and regulatory changes.

Mitigation—Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those that restore, enhance, create, or replace the damaged ecosystems (NRC 1992).

Morphology—The shape or form of the land surface or of the seabed and the study of its change over time.

Nearshore—As defined by PSNERP, includes the area from the deepest part of the photic zone (approximately -20m below MLLW) landward to the top of shoreline bluffs, or in estuaries upstream to the head of tidal influence.

Process-based restoration—Intentional changes made to an ecosystem to allow natural processes such as erosion, accretion, accumulation of wood debris, etc.) to occur. Process-based restoration aims to return the landscape to its pre-disturbance, self-sustaining state (Wright 2009 personal communication). Also defined as, the restoration of processes that shape an ecosystem, such as sediment transport or erosion, rather than the restoration of ecosystem features, such as tidal marshes or species populations (Van Cleve et al. 2004).

Protection—Safeguarding ecosystems or ecosystem components from harm caused by human actions.

Puget Sound—Defined here to include all inland marine waters of Washington State inside of the entrance to the Strait of Juan de Fuca and including Georgia Strait south of the Canadian border.

Rehabilitation—Improvements to a natural resource of a visual nature; putting a resource back into good condition or working order (NRC 1992).

Resilience—The ability of a system to return to an earlier state after being changed (Forman and Godron 1986).

Restoration—Returning an ecosystem to a close approximation of its pre-disturbance state in terms of structure and function (NRC 1992). This includes measures needed to protect and preserve restored systems in perpetuity.

Substitution/Creation—The creation of an ecosystem or portion of an ecosystem where it was not historically present. Applied in situations where other recovery options are not considered possible and may even involve “installation” of a typical ecosystem such as a wetland in an upland area.

Valued Ecosystem Component (VEC)—Components that are considered the most important potential beneficiaries of restoration actions. VECs represent benefits that we hope to achieve through restoration. See http://www.pugetsoundnearshore.org/technical_reports.htm

ABBREVIATIONS

°F	degrees Fahrenheit
ANS	aquatic nuisance species
BMPs	best management practices
CAO	Critical Areas Ordinance
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfs	cubic feet per second
CGS	Coastal Geologic Services
CLC	Cascade Land Conservancy
CLI	Climate Leadership Initiative
CMZ	channel migration zone
CSO	combined sewer overflow
cy	cubic yards
DARRP	Damage Assessment Remediation and Restoration Program
DO	dissolved oxygen
DOH	Washington Department of Health
Ecology	Washington State Department of Ecology
EDC	endocrine disrupting chemical
EEAW	Environmental Education Association
EF&Gs	ecosystem functions, goods and services
EPA	U.S. Environmental Protection Agency
ERDC	Engineering Research and Development Center (USACE)
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
FEMA	Federal Emergency Management Agency
FY	Fiscal Year
GIS	geographic information systems
GMA	Growth Management Act
IPCC	Intergovernmental Panel on Climate Change
IT	Implementation Team (PSNERP)
km	kilometer
LID	low impact development
LWD	large woody debris
MEA	Millennium Ecosystem Assessment
mg/L	milligrams per liter
MHHW	mean higher high water
MHW	mean high water
MLLW	mean lower low water
MM	management measure
MRC	Marine Resources Committee
MTCA	Model Toxics Control Act
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
NRCS	Natural Resources Conservation Service
NRDA	Natural Resources Damage Assessment
NST	Nearshore Science Team
NWAE	North American Association for Environmental Education

NWSC	Northwest Straits Commission
OFM	Office of Financial Management
OHWM	ordinary high water mark
PAHs	polychlorinated aromatic hydrocarbons
PBDEs	polybrominated diphenyl ethers
PBTs	persistent bioaccumulative toxins
PCBs	polychlorinated biphenyls
PHS	Priority Habitats and Species
PMT	Project Management Team (PSNERP)
ppb	parts per billion
ppm	parts per million
PSAMP	Puget Sound Aquatic Monitoring Program
PSAT	Puget Sound Action Team
PSNERP	Puget Sound Nearshore Ecosystem Project
PSP	Puget Sound Partnership
PSRF	Puget Sound Restoration Fund
PVC	polyvinyl chloride
PWA	Phillip Williams and Associates
RCO	Washington Recreation and Conservation Office
RCW	Revised Code of Washington
Sea Grant	University of Washington Sea Grant Program
SEPA	State Environmental Policy Act
SLR	sea level rise
SMA	Shoreline Management Act
SMP	Shoreline Master Program
SRT	self-regulating tide gate
SSRFB	State Salmon Recovery Funding Board
TDR	transfer of development rights
TESC	temporary erosion and sediment control
TMDL	total maximum daily load
TNC	The Nature Conservancy
USACE	U.S. Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UW	University of Washington
VEC	valued ecosystem component
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WDNR	Washington Department of Natural Resources
WFWC	Washington Fish and Wildlife Commission
WRIA	water resource inventory areas
WSDOT	Washington Department of Transportation
WSU Extension	Washington State University Cooperative Extension
WWU	Western Washington University

INTRODUCTION

The U.S. Army Corps of Engineers (USACE) and the Washington State Department of Fish and Wildlife (WDFW) co-lead an ecosystem study of the Puget Sound called the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP). The purposes of the study are to evaluate significant ecosystem degradation in the Puget Sound Basin; to formulate, evaluate, and screen potential solutions to identified problems; and to recommend actions and projects that will restore and preserve the nearshore ecosystem. The recommended actions and projects will include physical, policy, and educational measures (called management measures) carried out across the full range of nearshore geomorphic systems.

This report describes 21 management measures (MMs) that PSNERP will use to develop potential restoration solutions to address nearshore ecosystem degradation in the Puget Sound (Figure 1)¹. These measures can be applied individually at specific sites or combined into larger, more comprehensive restoration and protection efforts at the basin or sub-basin scale.

Restoration practitioners can use this report to inform decisions about how to restore nearshore processes, structures, and functions. The selection of which measures to implement will vary depending on the geomorphic system being restored, the nature of the degradation, desired process improvements, and expected ecosystem function of the site, tempered against existing constraints. When combined and properly applied at the appropriate scale, management measures can improve the condition of the Puget Sound nearshore by restoring ecosystem processes and promoting environmental and human health and well being².

By providing this report, PSNERP seeks to:

- Provide a systematic organizational framework for describing management measures that can be used to develop and evaluate Puget Sound nearshore restoration alternatives composed of combinations of management measures applied at individual sites.
- Assist restoration practitioners in identifying the strengths, weaknesses, and constraints of management measures in the context of Puget Sound and PSNERP's guiding restoration principles (Goetz et al. 2004, available at http://www.pugetsoundnearshore.org/technical_papers/guiding_principles.pdf).
- Outline the principal issues that practitioners should address at the feasibility, design, implementation, and evaluation phases of each management measure.
- Assist restoration practitioners in identifying and assessing the effects of management measures on nearshore functions, structures, and processes.
- Provide a basis for describing the anticipated effects of restoration actions that will be documented in a future programmatic Environmental Impact Statement, which PSNERP is required to prepare.

¹ Management measures are simplified from a list of National Estuary Restoration Inventory techniques and Pacific Coastal Salmon Recovery Fund reporting measures (Restore America's Estuaries and the Estuarine Research Federation 1999 and NOAA 2006).

² Restoration success is never guaranteed, as there will almost always be unforeseen challenges.

- Identify outputs or benefits of implementing management measures for use in PSNERP's cost-benefit evaluation as required by the USACE. PSNERP will use the analysis to determine the most effective and efficient measures and combinations of measures.

This document describes our current understanding of nearshore restoration and protection measures likely to be recommended for project implementation after the completion of the PSNERP ecosystem study. We anticipate that our technical understanding of these management measures will grow as we learn from implementing and evaluating the performance of these measures in the Puget Sound and in other ecosystems. To capture ongoing learning about restoration techniques, new ideas, strategies, and constraints, PSNERP will update this report periodically to reflect new information concerning best practices as the field of restoration ecology evolves.



Figure 1 - The Puget Sound³ Nearshore

Report Scope and Limitations

The authors of this report followed a detailed outline prepared by the PSNERP Implementation Team and adhered to specific page limits for the background material (7-20 pages) and individual management measures chapters (7-10 pages each). As a result, the authors summarize background information on nearshore ecosystem restoration as it applies to Puget Sound and briefly describe the relationships between management measures, ecosystem processes, and geomorphic systems. Readers are referred to other PSNERP technical reports (available at http://www.pugetsoundnearshore.org/technical_reports.htm) and reference materials cited herein for additional, detailed background information.

³ As used here, Puget Sound refers to the Strait of Juan de Fuca, Strait of Georgia and Puget Sound. These waters are also collectively known as the Salish Sea.

The report is not intended to be a design manual and does not provide a detailed prescription for addressing all of the impairments that exist in Puget Sound. Instead, the individual management measure chapters are designed to:

- Define and categorize each management measure.
- Describe situations in which the measure could be effectively used in Puget Sound ecosystem nearshore restoration efforts.
- Illustrate the relationship of the measure to nearshore processes, structure, and functions.
- Describe the potential benefits of employing the measure as well as constraints to be considered when implementing the measure.
- Summarize best professional practice considerations associated with engineering, ecological, and socioeconomic issues.
- Describe examples of past or current use of each management measure.

The authors attempted to present a uniform and consistent narrative for each management measure across all 21 chapters. However, some variability in the level of detail was inevitable because of differences in the complexity of the measures, the degree to which the pertinent information fit the standard chapter outline, and the availability of information concerning the measures.

The technical report is directed to an educated, lay audience where the level of technical understanding would be equivalent to PSNERP and regional nearshore restoration practitioners.

The Restoration Project Life Cycle

The goal of restoration is to return ecosystems to a close approximation of their natural, self-sustaining, and predisturbance condition (National Research Council [NRC] 1992). Restoration includes measures that protect and preserve the site for the long term so that the benefits are durable and sustainable in perpetuity. To achieve this restoration goal, restoration practitioners must overcome numerous technical and logistical challenges. A thoughtful and systematic approach to project planning and implementation is essential for success. This section explains how information in this report can be used to aid practitioners in all phases of the project life cycle.

Most restoration projects move from an initial planning phase to feasibility assessment, to design and implementation, and then into monitoring/evaluation (Figure 2)⁴. Each phase is marked by different tasks which vary depending on the complexity of the project and numerous other factors. The scope of each phase can vary and transitions between phases are often somewhat indistinct. Some tasks may overlap different phases or be reiterated as a project progresses.

⁴ This statement and the following statements about project planning and implementing apply to restoration efforts as defined herein as well as to rehabilitation and enhancement efforts. The term 'restoration' is used broadly in this section to refer to a wide variety of projects that would use one or more management measures.

The first step of any restoration project is to define specific restoration goals and objectives⁵. Goals should be consistent with the overall mission of the Puget Sound recovery program, appropriate for the geomorphic setting, and prioritized so that project sponsors and stakeholders clearly understand their relative importance and can objectively account for trade-offs (NRC 1992). Objectives describe the specific characteristics to be restored, rehabilitated, or enhanced; for example, objectives might target physical processes, habitat structure, valued ecosystem components (VECs), and/or biological functions. The management measures chapters illustrate some of the physical processes, structural changes, and functional responses that can be expected to occur as management measures are applied in different restoration scenarios. The conceptual model illustrations contained in each chapter should help restoration planners consider the outcomes of various restoration objectives and develop potential performance standards that could be used to measure project outcomes. Funding organizations such as the Estuary and Salmon Restoration Program and the Salmon Recovery Funding Board typically require restoration sponsors to present a conceptual model as part of the grant application process, so conceptualizing the restored processes and functional responses is an important part of project goal-setting.

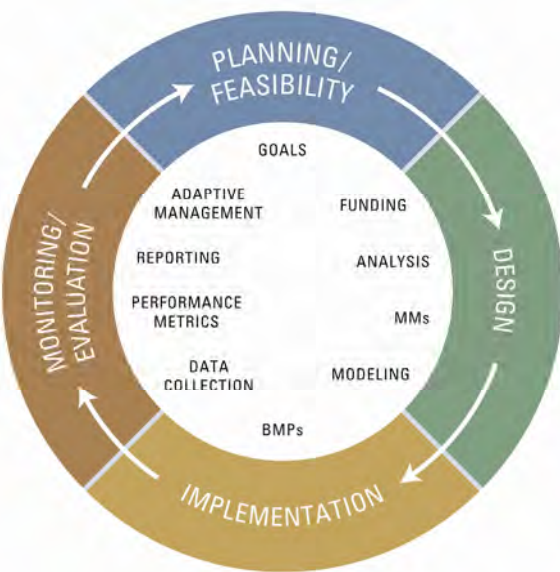


Figure 2 - The Project Life Cycle

Once goals and objectives are defined, restoration planners should assess project feasibility. The feasibility assessment phase typically involves substantial data collection and investigation to address pertinent ecological, social, economic, and political concerns. Common feasibility assessment tasks for nearshore restoration include flood analyses, testing for contaminants, species/habitat surveys, identifying available funding, and examination of historical maps, photographs and data. Feasibility assessment typically also involves an initial cost-benefit analysis and establishment of performance standards.

Scale is an important feasibility factor for several reasons (NRC 1992). First, the project area needs to be large enough to limit deleterious effects that boundary conditions may impose. Second, the restoration actions must be able to exert influence over an area in which major causes of ecological

disturbance are occurring. Third, the area needs to be large enough so that effects of the restoration can be monitored. And finally, the project should be of an affordable size.

Knowing the target goals, objectives, and restoration scale enables restoration planners to select a suite of management measures appropriate for their sites. Selecting the appropriate measure(s) requires a thorough understanding of the causes and sources of ecosystem degradation, critical thinking about which measures provide the best opportunities for addressing those causes, and consideration of the geomorphic setting and other factors. The tables in this chapter relating management measures to processes and geomorphic systems are meant to help restoration planners in the selection process. Management measures that are shown to have a weak relationship to a target process or a geomorphic landform may be inappropriate and typically should be considered only as a secondary measure.

⁵ This assumes that the causes and sources of ecosystem degradation have been identified through a valid scientific process.

Each measure has one or more constraints that can undermine its effectiveness or lead to project failure; some of the constraints are specific to the management measure (e.g., downstream erosion potential) and some are common to multiple measures (e.g., cost). Rising sea levels and other climate changes will be a common constraint for most management measures that will need to be addressed during the feasibility assessment. Addressing climate change issues may require modeling or similar analyses that will inform project design, implementation, and monitoring. The individual management measure chapters describe some of key constraints associated with each management measure. Appendices A and B contain additional information on sea level rise (SLR) and the risks it poses to each management measure.

Biogeographical and legal information are critical for assessing project feasibility. Property ownership and land use issues for the site and surrounding areas must be considered to assess interactions of physical processes across geographic boundaries. In many cases restoration actions may require acquisition of property, conservation easements, or leases from the Washington Department of Natural Resources (for projects on state-owned aquatic lands).

Although restoration actions are generally perceived as having beneficial effects on the environment, they still require regulatory review by federal, state, and local agencies. Most restoration projects will require at least one (and usually several) permits or regulatory approvals (e.g., USACE permits for dredge/fill, state shoreline permit or letter of exemption, Hydraulic Project Approval, local city/county grading permit), each of which has specific application and procedural requirements. Fulfilling the permit requirements has implications on the project scope, schedule, and cost, which should be carefully evaluated during the feasibility assessment stage.

The design phase typically includes additional analysis, modeling, and investigation to evaluate different engineering approaches (such as whether to pursue full dike removal or partial dike breach), compare alternatives (such as whether to buy out properties that may be exposed to flooding or construct levees), refine the project scope (such as whether/how to accommodate public access), and describe the conditions that should result from construction. Other common design tasks include developing best management practices (BMPs) for site preparation, construction, and post-construction; preparing grading and planting plans; refining cost estimates; and planning for climate change effects. Often design studies are geared to satisfying permitting and regulatory requirements (for example, projects permitted under the Clean Water Act generally require delineation of wetlands and other waters of the United States). The level of effort required during the design phase will reflect the degree of uncertainty or risk inherent in the restoration project, the level of stakeholder interest/concern (i.e., controversial projects may require more design effort), and other factors.

Implementation occurs once all the feasibility issues have been addressed, the design is complete, funding is secured, and permits are obtained. Implementation activities must be sequenced and timed with respect to regulatory requirements (e.g., during authorized in-water ‘work windows’), ecological requirements (e.g., the life history stage of an invasive species targeted for removal), social concerns (e.g., effects on navigation, recreation, access/circulation, etc.), and other considerations. Restoration practitioners will want to ensure that the work is implemented in a way that minimizes the potential for and duration of adverse construction impacts.

The final phase involves monitoring and evaluation. The purpose of evaluating a restoration effort is to determine, in a reliable scientific manner, how effective the restoration has been, or in other words, how similar the restored ecosystem is to the target ecosystem (NRC 1992). A critical component of the monitoring and evaluation phase is to identify performance criteria. Performance criteria are specific biological, physical, and chemical indicators that can be measured to determine the extent to which goals and objectives have been met. Ideally in this phase, practitioners would verify the performance standards identified in the initial stages of goal setting and feasibility assessment. In any case, criteria should be identified for each objective and should assess process recovery, structural changes, and functional

responses. The NRC (1992) offers examples of assessment criteria that restoration practitioners may want to consider when identifying appropriate indicators; however NRC's examples would have to be tailored to match individual projects. Practitioners may want to base performance criteria on observations of comparable, but intact reference sites (as available).

Restoration projects sometimes fail to achieve their goals and objectives due to poor planning and feasibility assessment, design flaws, unanticipated natural events (e.g., landslides or floods) or mistakes during implementation. Some projects suffer from a lack of evaluation and monitoring, which limits opportunities for adaptive management and corrective action. The information contained in this report should help illuminate many of the feasibility, design, implementation, and evaluation / monitoring challenges commonly encountered in nearshore restoration. By following this guidance and asking the following questions⁶, restoration practitioners improve the likelihood that future efforts will succeed.

Pre-project implementation questions:

- Has the restoration been planned with adequate scope and expertise?
- Does the restoration design allow for midcourse corrections and adaptive management?
- Have sufficient baseline data been collected over a suitable period of time to facilitate before-and-after comparisons?
- Has the project been designed to make the restored ecosystem as self-sustaining as possible to minimize maintenance requirements?
- What impact will the restoration have on processes and will the beneficial effects be outweighed by offsite factors (e.g., on site erosion control measures may not be effective if there are major activities/sources off site that deliver large sediment loads)?
- How long will the project need to be monitored before the restoration effort can be declared effective?
- Have risk and uncertainty been adequately considered in project planning?
- Have adequate monitoring, surveillance, management, and maintenance programs been developed so that monitoring costs and operational details are anticipated and monitoring results will be available to improve restoration techniques as the project matures?

Post-project implementation questions:

- Based on the monitoring results, are the anticipated intermediate objectives being achieved? If not, are appropriate steps being taken to correct the problem(s)?
- Do the objectives or performance indicators need to be modified? If so, what changes may be required in the monitoring program?
- Is the monitoring program adequate?

⁶ Adapted from *Restoration of Aquatic Ecosystems* (NRC 1992).

- How similar in structure and function is the restored ecosystem to the target ecosystem?
- To what extent is the restored ecosystem self-sustaining, and what are the maintenance needs?
- What lessons have been learned from this effort and have they been shared with other practitioners?
- What were the ecological, economic, and social benefits realized by the project?

BACKGROUND ON RESTORING NEARSHORE PROCESSES

The recovery of the Puget Sound nearshore ecosystem requires a variety of physical, policy, and educational measures aimed at protecting and restoring ecosystem processes⁷. Recovery involves taking actions that enable the nearshore system to generate and sustain the physiochemical and biological interactions that create nearshore structure and functions (Fresh et al. 2004).

Management measures address risks to and degradation of ecosystem process integrity at different scales across the full range of nearshore geomorphic systems (rocky coasts, beaches, embayments, and river deltas). Management measures can be applied as stand-alone actions or can be combined to serve as building blocks of multi-faceted nearshore restoration efforts.

The 21 management measures described here include restoration, rehabilitation, and enhancement actions as well as protection, management, and regulatory endeavors that address the objective of recovering or improving nearshore ecosystem processes, structure and/or functions (Table 1). In a large-scale restoration program, management measures are vital to describing the varied combination of actions that can be employed. Some of the management measures are narrowly defined around a specific activity or objective; for example, *Beach Nourishment* and *Large Wood Placement*. Others such as *Habitat Protection Policy or Regulation* are more general and potentially encompass a wide array of activities and objectives.

The list of measures reflects PSNERP's focus on physical restoration actions in the nearshore. Although non-physical measures are included (e.g., *Public Education and Involvement* and *Habitat Protection Policy and Regulation*), these are largely outside of the scope of anticipated USACE authority. They are included because they are recognized as critical tools for Puget Sound nearshore restoration and protection that are likely to be used by partner agencies and organizations. The composition of the management measures list should be interpreted only to reflect the focus of PSNERP and not as a definitive organizational scheme.

⁷ The terms *protection* and *restoration* are used throughout the report according to the definitions in the glossary. Restoration (returning an ecosystem to a close approximation of its pre-disturbance state) includes measures that protect and preserve the site for the long term. Protection, while not succinctly defined in the restoration literature, is a component of restoration, but also refers to independent measures that save nearshore systems from harm.

Table 1 – Description of PSNERP Management Measures

No. ¹	Management Measure	Description ²
1	Armor Removal or Modification	Removal, modification, or relocation of coastal erosion protection structures such as rock revetments, bulkheads, and concrete walls on bluff-backed beaches, barrier beaches, and other shorelines.
2	Beach Nourishment	The intentional placement of sand and/or gravel on the upper portion of a beach where historic supplies have been eliminated or reduced.
3	Berm or Dike Removal or Modification	Removal or modification of berms, dikes and other structures to restore tidal inundation to a site that was historically connected to tidal waters. Includes dike/berm breaching and complete dike/berm removal.
4	Channel Rehabilitation or Creation	Restoration or creation of channels in a restored tidal wetland to change water flow, provide habitat, and improve ecosystem function.
5	Contaminant Removal and Remediation	Removal or remediation of unnatural or natural substances (e.g., heavy metals, organic compounds) harmful to the integrity or resilience of the nearshore. Pollution control, which is a source control measure, is a different measure.
6	Debris Removal	The removal of solid waste (including wood waste), debris, and derelict or otherwise abandoned items from the nearshore.
7	Groin Removal or Modification	Removal or modification of groins and similar nearshore structures built on bluff-backed beaches or barrier beaches in Puget Sound.
8	Habitat Protection Policy or Regulations	The long-term protection of habitats (and associated species) and habitat-forming processes through zoning, development regulations, incentive programs and other means.
9	Hydraulic Modification	Modification of hydraulic conditions when existing conditions are not conducive to sustaining a more comprehensive restoration project. Hydraulic modification involves removing or modifying culverts and tide gates or creating other engineered openings in dikes, road fills, and causeways to influence salt marsh and lagoon habitat. This measure is used in managed tidal systems (as opposed to naturally maintained systems).
10	Invasive Species Control	Eradication and control of nonnative invasive plants or animals occupying a restoration site and control measures to prevent introduction or establishment of such species after construction is complete.
11	Large Wood Placement	Installment of large, unmilled wood (large tree trunks with root wads, sometimes referred to as large woody debris) within the backshore or otherwise in contact with water to increase aquatic productivity and habitat complexity.
12	Overwater Structure Removal or Modification	Removal or modification of overwater structures such as piers, floats and docks to reduce shading and restore wave regimes.
13	Physical Exclusion	Installation of exclusionary devices (fences, barriers, mooring buoys, or other devices) to direct or exclude human and/or animal use of a restoration site.
14	Pollution Control	Prevention, interception, collection, and/or treatment actions designed to prevent entry of pollutants into the nearshore ecosystem.
15	Property Acquisition and Conservation	Transfer of land ownership or development rights to a conservation interest to protect and conserve resources, enable restoration or increase restoration effectiveness.
16	Public Education and Involvement	Activities intended to increase public awareness of nearshore processes and threats, build support for and volunteer participation in restoration and protection efforts, and promote stewardship and responsible use of nearshore resources.
17	Revegetation	Site preparation, planting, and maintenance to manipulate soils and vascular plant populations to supplement the natural development of native vegetation.
18	Species Habitat Enhancement	Installation or creation of habitat features (sometimes specific structures) for the benefit of native species in the nearshore.
19	Reintroduction of Native Animals	Reestablishment of native animal species at a site where they existed or as replacement for lost habitat elsewhere.
20	Substrate Modification	The placement of materials to facilitate establishment of desired habitat features and improve ecosystem functions, structures, or processes.
21	Topography Restoration	Dredging, excavation and /or filling to remove or add layers of surface material so that beaches, banks, tidal wetlands, or mudflats can be created.
¹ The management measures are listed in alphabetical order. No hierarchy or priority order should be inferred.		
² See individual management measure chapter for a complete definition.		

All management measures have the potential to contribute directly or indirectly to restoration of ecosystem processes. However some management measures are by their nature more restorative of processes than other measures (as explained in the following section). Some measures tend to operate mainly by enhancing ecosystem structure, and some measures are prerequisites for other measures or are protective investments in preventing further ecosystem degradation (Table 2). Grouping management measures into categories based on their different roles and potential to restore processes can be a useful tool for creating an appropriate menu of actions for a given restoration site. The categories described below are one way to describe similarities and differences between various measures; presenting the measures in these groupings is not intended to render judgment on measures as “good” or “bad”, but is rather meant to assist in the selection of appropriate actions.

- **Primary Restorative Measures** – These measures exert long-lasting effects on ecosystem processes and will often provide the best chance of achieving complete restoration of processes. This group includes measures that involve rehabilitation and enhancement actions using engineered approaches (including water control approaches to *Hydraulic Modification*, for example) which may not completely restore natural water flow processes.
- **Supplementary Enhancement Measures** – Includes mainly structural measures that provide immediate but often short-lived benefits in terms of habitat structure. These should frequently be applied in concert with primary restorative measures. In fact, some measures such as *Revegetation* will likely be a component of all restoration efforts to some degree.
- **Prerequisite Measures** – Includes measures that are often required prior to or in conjunction with other measures. For example, *Contaminant Removal and Remediation* may be a prerequisite for *Berm or Dike Removal or Modification*, *Hydraulic Modification*, and/or *Channel Rehabilitation or Creation*. *Property Acquisition and Conservation* may also be a prerequisite for many types of restoration actions.
- **Protective Measures** – Measures such as *Public Education and Involvement* and *Habitat Protection Policy and Regulation*, which focus on human behavioral changes, may have as much value as stand-alone actions as when they accompany other measures. These types of measures will often enhance the effect of other restoration actions but may not always be essential to achieving site-specific restoration goals. These measures tend to take effect over relatively long timeframes and may need continued and ongoing application in order to achieve lasting benefits.

Table 2 – Management Measures Grouped by their Potential Restorative Effect on Physical Nearshore Processes

Category	Restorative	Enhancement	Prerequisite	Protective
Role	Exert long-lasting effects on ecosystem processes	Create/promote structural elements (habitats) and/or mimic natural processes	Remove or prevent physical and chemical disturbances	Protect existing resources, limit future impairment, influence human behaviors
Management Measures	Armor Removal or Modification Berm or Dike Removal or Modification Groin Removal or Modification Hydraulic Modification Overwater Structure Removal or Modification Topography Restoration Revegetation Channel Rehabilitation or Creation	Beach Nourishment Invasive Species Control Large Wood Placement Species Habitat Enhancement Reintroduction of Native Animals Substrate Modification	Contaminant Removal and Remediation Debris Removal Physical Exclusion Pollution Control Property Acquisition and Conservation	Habitat Protection Policy or Regulations Public Education and Involvement

To illustrate the differences reflected in the grouping shown above, consider a restoration project focused on a tidal channel that has become sediment-laden due to the lack of tidal exchange (restricted by a tide gate). A successful project will implement multiple measures in an integrated way: *Channel Rehabilitation or Creation* can help rehabilitate tidal-driven geomorphic processes of the channel and long-term reconnection to a broader channel network. *Hydraulic Modification* can produce an instantaneous source of tidal input through removal of the tide gate. *Large Wood Placement* can mimic detritus recruitment and retention at a local scale in the near-term, and *Revegetation* can enhance these processes—typically over a longer term and a broader area (although the durability and extent of the enhancement depend on the species planted, planting density, site preparation, maintenance, and other factors).

Management Measures and Process-Based Restoration

Ecosystem processes are the interactions among physiochemical and biological elements of an ecosystem that change in character or state over time (Fresh et al. 2004). Processes operate at naturally occurring rates, frequencies, durations, and magnitudes that are controlled by human and natural factors (Goetz et al. 2004). Human attempts to control dynamic systems such as beaches, bluffs, floodplains, and river deltas using structural approaches such as groins, bulkheads, dikes, and levees disrupt the natural processes and degrade nearshore systems. Restoration actions aimed at restoring damaged processes enable the ecosystem to be naturally productive, self sustaining, and diverse (Goetz et al. 2004).

This report emphasizes that successful recovery of the Puget Sound nearshore requires protecting and restoring the processes that create and sustain the structure of the nearshore rather than just restoring the structure itself (without addressing the underlying processes). The focus is on restoring key physical processes such as tidal hydrology and sediment supply, with less attention on the full suite of ecological processes such as primary productivity. The reason for emphasizing physical processes is because in dynamic environments like the nearshore, biotic processes are dependent on physical processes (P. Cereghino, personal communication)⁸. Readers are encouraged to review other PSNERP technical reports and other referenced documents for additional information on these topics.

The PSNERP Nearshore Science Team (NST) has identified guiding principles for nearshore restoration that favor process-based restoration over species-based restoration (see text box). The NST lists three main reasons for favoring process-based restoration (Simenstad et al. 2006):

1. Without restoring processes, the long-term maintenance of the structure and associated ecological functions is highly uncertain.
2. The processes are inherently involved in the functions we want to recover.
3. Incorporating or accepting natural ecosystem dynamics is less likely when considering only the services an ecosystem provides to a single species.

The concept of process-based restoration is linked to a broader doctrine of ecosystem-based management which examines “the complex linkages within the physical and biological components of an ecosystem, and how social and economic choices by humans can change these processes (Ruckelshaus and McClure 2007).” Proponents of ecosystem-based management stress the importance of understanding the consequences of human actions and values throughout the ecosystem when assessing the range of management tradeoffs to be made:

“Understanding interactions and linkages among species, habitats, and the processes that support them is critical to our ability to predict the ecosystem response to natural perturbations and management actions. An ecosystem-wide view of Puget Sound will improve our ability to choose cost-effective actions and predict long term results.” (Ruckelshaus and McClure 2007)

Alterations of natural processes damage nearshore ecosystem structures, which provide ecosystem services that people value (Millennium Ecosystem Assessment [MEA] 2005; Simenstad et al. 2006). Ruckelshaus and McClure (2007) define ecosystem services as the outputs and experiences of ecosystems that benefit humans, which are generated by the structure and function of natural systems, often in combination with human activities. PSNERP refers to these benefits collectively as ecosystem functions, goods, and services (EF&Gs) (Figure 3). Because people value EF&Gs, they provide useful benchmarks for evaluating restoration effectiveness from a socio-ecological perspective.

Process-Based Restoration

Process-based restoration includes intentional changes made to an ecosystem to allow natural processes (such as erosion, accretion, accumulation of wood debris, etc.) to occur. Process-based restoration aims to return the landscape to its pre-disturbance, self-sustaining state. Process-based restoration typically involves actions that support or restore the dynamic processes that generate and sustain desirable nearshore ecosystem structure (e.g., eelgrass beds) and important functions (e.g., salmon production, bivalve production, and clean water). Process-based restoration is often distinguished from species-based restoration which aims to improve the services an ecosystem provides to a single species or group of species as opposed to improving the entire ecosystem.

⁸ Furthermore, page limit restrictions limit the authors’ ability to cover ecological processes in more detail.

Provisioning	Food	Crops
		Livestock
		Captured fisheries
		Aquaculture
		Wild foods
	Fiber	Timber and wood
		Other fibers
		Biomass fuel
	Freshwater (quantity)	
	Genetic resources	
Biochemicals, natural medicines		
Regulating	Air quality regulation	
	Global climate	
	Regional and local climate	
	Water (quality)	
	Erosion	
	Water purification and waste treatment	
	Disease	
	Pests	
	Pollination	
	Natural hazards	
Cultural	Ethical	
	Existence	
	Recreation and ecotourism	
	Educational	
Supporting	Nutrient cycling	
	Soil formation	
	Food web	
	Photosynthesis	
Source: Millennium Ecosystem Assessment (2005) as adapted in the PSNERP Change Analysis (in prep)		

Management measures can affect ecosystem processes to varying degrees depending on how, where, and at what scales they are applied. The same management measure applied to different landforms will produce different effects on processes. For example, the effects of removing a bulkhead from a pocket beach will be different from those that occur when the same measure is applied to a coastal bluff, since the latter is generally more likely to supply sediment to foreshore, beach, and down-drift shores through littoral sediment transport, although both applications may improve forage fish spawning areas and other valued ecosystem functions.

The extent and degree to which processes are affected by management measures also may depend on whether the management measures are applied individually or in combination with other measures. Thus, pairing *Armor Removal or Modification* with *Groin Removal or Modification* down-drift of the restored feeder bluff may supplement the benefits of the bulkhead removal activity by taking away other impediments to littoral sediment transport (referred to as net shore-drift).

The potential for some measures to impact ecosystem processes may be limited or transient. For example, *Large Wood Placement* may create an immediate impact on beach structure by dissipating wave energy and allowing sediment accumulation, but the effects may be relatively short-lived as the wood material decays or is transported offshore. Still other management measures such as *Pollution Control* or *Public Education and Involvement* may by themselves have less direct effect on processes but may contribute to ecosystem restoration in other ways by modifying human behaviors, building public support for restoration efforts, and preventing or slowing causes of ecosystem degradation.

Figure 3 - Ecosystem Functions, Goods and Services

Table 3 shows the relative degree of influence that different management measures can have on the physical processes PSNERP has identified as being most pertinent to Puget Sound recovery efforts. The potential for an individual management measure to affect processes is categorized as:

- Strong – measure has the potential for durable and sustainable effects on process; typically full restoration.
- Weak – measure mainly targets structural ecosystem elements or has less durable/sustainable effects on process; resulting in partial restoration or enhancement.
- None – no relationship.

These ratings are based on best professional judgment, not on empirical data. They are intended to highlight broad distinctions between management measures, assuming that the measure is applied at the ideal scale for influencing processes. Actual effects will always be context-specific.

Table 3 – Potential of Management Measures to Influence Nearshore Processes

No.	Management Measure ¹	Relationship to PSNERP Nearshore Ecosystem Processes									
		● = strong effect; ◐ = weak effect; blank = no relationship									
		Sediment Supply and Transport	Beach Erosion and Accretion	Distributary Channel Migration	Tidal Channel Formation and Maintenance	Freshwater Input	Tidal Hydrology	Detritus Recruitment and Retention	Exchange of Aquatic Organisms	Solar Radiation (Sunshine)	Wind and Waves
1	Armor (a) Removal	●	●			◐		●			●
	(b) Modification		◐			◐					
2	Beach Nourishment	●	●								
3	Dike or Berm (a) Removal	●		●	●	●	●	●	●		◐
	(b) Modification	◐			◐	◐	◐	◐	◐		
4	Channel (a) Rehabilitation	●		◐	◐	●	●	●	●		
	(b) Creation	◐			◐	●	◐	◐	◐		
5	Contaminant (a) Removal								◐		
	(b) Remediation								◐		
6	Debris Removal	◐	◐		◐						
7	Groin (a) Removal	●	●	◐	◐	◐	◐	◐	●		●
	(b) Modification	◐	◐	◐	◐	◐	◐	◐	◐		◐
8	Habitat Protection Policy or Regulations ²	◐	◐	◐	◐	◐		◐	◐		◐
9	Hydraulic Modification	◐				◐	◐	◐	◐		◐
9	Invasive Species Control	◐	◐		◐	◐	◐	◐	◐	◐	◐
11	Large Wood Placement	◐	◐	◐	◐			◐	◐		◐
12	Overwater Structure (a) Removal	◐	◐							●	◐
	(b) Modification									◐	◐
13	Physical Exclusion								◐		
14	Pollution Control								◐		
15	Property Acquisition and Conservation ³	●	●	●	●	●	●	●	●	●	●
16	Public Education and Involvement ⁴	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
17	Revegetation	◐	◐	◐		◐		◐		◐	◐
18	Species Habitat Enhancement								◐		
19	Reintroduction of Native Animals (Non-Plant)								●		
20	Substrate Modification	◐	◐		◐	◐			●		◐
21	Topography Restoration	●	●	●	●	●	●	●	●		●

¹Some management measures are broken out into separate rows labeled (a) and (b) to distinguish variation in the degree of process restoration between full removal of a stressor and partial removal/modification of the stressor.

² This measure influences process via specific regulations such as the Shoreline Management Act and Growth Management Act, which limit shoreline armoring, overwater structures and removal of riparian vegetation; stormwater regulations, which require management of runoff, infiltration, etc.; and other regulations that protect processes.

³ Measure has the potential to influence all processes to some degree and is essential for the long-term protection of ecosystem processes.

⁴ Public Education and Involvement potentially influences most processes, albeit mainly indirectly and with varying durability.

Relationship of Management Measures to Geomorphic Systems

In order to execute strategic and process-based restoration of the nearshore, a framework for understanding and discussing the geomorphology of Puget Sound shorelines is essential. Geomorphic knowledge, coupled with an assessment of the most common changes observed in Puget Sound nearshore environments (described in more detail in subsequent sections), allows us to choose restoration actions that are appropriate for a particular area.

Puget Sound's nearshore environment contains more than 3,000 kilometers of diverse shoreline, including rocky coasts, sand and gravel beaches, coastal bluffs, small estuaries and lagoons, and river deltas. Each of these environments is characterized by different geomorphic and ecological processes and subject to a distinctive suite of environmental challenges and potential solutions (Shipman 2008).

Shipman (2008) provides a hierarchical classification of Puget Sound nearshore landforms. The classification reflects the primary role of geomorphic processes in shaping the landscape, which are the same processes that are relevant to nearshore restoration (e.g., supply and transport of sediment, tidal hydrology, etc.). The classification system recognizes four major geomorphic systems within Puget Sound: (1) rocky coasts, (2) beaches, (3) protected embayments, and (4) large river deltas.

Each geomorphic system contains many different and highly complex landforms reflecting different long-term patterns of sediment accretion or deposition. Several factors influence the distribution and character of Puget Sound landforms, including: large-scale topographic differences between watersheds that drain to Puget Sound, underlying geology, sea-level history, tidal range, climate, and wave exposure (Shipman 2008). Landforms are in turn composed of various substrate and elevation components (e.g., a berm and beach face on a barrier beach). Each landform is shaped by different ecosystem processes and therefore requires and responds to different management measures. Strong associations between geologic and hydrologic processes and nearshore landforms are shown in Table 4.

Table 4 – Relationship between Ecosystem Processes and Geomorphic Landforms

PSNERP Nearshore Ecosystem Processes ¹	Geomorphic Systems and Landforms ² ●=strong relationship												
	Rocky Shores			Beaches		Embayments				Deltas			
	Plunging rocky shores	Rocky platforms	Pocket beaches	Bluffs	Barrier beaches	Open coastal inlets	Barrier estuaries	Barrier lagoons	Closed lagoons and marshes	River-dominated deltas	Wave-dominated deltas	Tide-dominated deltas	Fan deltas
Sediment Supply and Transport				●	●	●	●	●	●	●	●	●	●
Beach Erosion and Accretion			●	●	●								
Distributary Channel Migration										●	●	●	●
Tidal Channel Formation and Maintenance						●	●	●		●	●	●	●
Freshwater Input			●	●	●	●	●			●	●	●	●
Tidal Hydrology						●	●	●		●	●	●	●
Detritus Recruitment and Retention													
Exchange of Aquatic Organisms													
Solar Radiation													
Wind and Waves	●	●	●	●	●						●		●

¹Key local process identified by PSNERP as being essential to recovery efforts.

²Based on Geomorphic Classification of Puget Sound Nearshore Landforms (Shipman 2008).

The relationship of processes to geomorphic systems and landforms suggests that management measures will also have varying degrees of applicability or utility in different geomorphic settings. *Beach Nourishment* tends to occur on beaches, or where beaches historically occurred. *Armor Modification or Removal* also tends to occur primarily on beaches or where bulkheads and other structures have been installed for stabilization purposes. Removal of armoring on low-energy shores (where the armoring serves an aesthetic/landscaping purpose but is not required for stabilization) may have less benefit in terms of restoring sediment delivery and transport processes, but may improve habitat structure (e.g., for migrating salmon) and function (e.g., forage fish spawning). *Berm and Dike Modification or Removal* tends to occur in river deltas and some embayments (estuaries or lagoons) but would not be an appropriate measure on coastal bluffs or rocky shorelines (Shipman 2009, personal communication). Other measures such as *Large Wood Placement*, *Revegetation*, and *Invasive Species Control* might happen in any geomorphic setting, although the methods may vary from one system or landform to another.

Table 5 shows strong relationships between landforms and management measures as a result of process linkages. The table focuses on management measures that involve physical and direct alteration of the landscape and which tend to have the most long-lasting and sustainable effects on the geomorphology of the nearshore zone. Management measures not listed in the table may also affect processes that contribute to landform creation and maintenance, but the effects are typically more ephemeral, indirect, or harder to evaluate than other measures.

Table 5 – Strong Relationships between Geomorphic Landforms and Management Measures

Management Measures	Geomorphic Systems and Landforms ¹ ● = strong relationship												
	Rocky Shores			Beaches		Embayments				Deltas			
	Plunging rocky shores	Rocky platforms	Pocket beaches	Bluffs	Barrier beaches	Open coastal inlets	Barrier estuaries	Barrier lagoons	Closed lagoons and marshes	River-dominated deltas	Wave-dominated deltas	Tide-dominated deltas	Fan deltas
Armor Removal or Modification			●	●	●	●							
Berm or Dike Removal or Modification						●	●	●		●	●	●	●
Channel Rehabilitation or Creation ²						●	●	●		●	●	●	●
Groin Removal or Modification				●	●								
Hydraulic Modification							●	●	●	●	●	●	●
Overwater Structure Removal / Modification													
Revegetation ²				●	●	●	●		●				
Topography Restoration			●	●	●	●	●	●	●	●	●	●	●
¹ Based on Geomorphic Classification of Puget Sound Nearshore Landforms (Shipman 2008).													
² These two measures can sometimes be process-based or restorative measures when applied in the proper contexts.													

Benefits of Management Measures Based on Their Temporal and Spatial Persistence

Understanding the geomorphic framework and the temporal dynamics of processes and management measures can assist restoration practitioners in making decisions about which measures to apply in different settings. As an example, consider the differences between *Beach Nourishment* and *Armor Removal or Modification* in terms of restoring sediment-starved beaches within an impaired drift cell (Simenstad et al. 2006). *Beach Nourishment* imitates or jump-starts the natural processes of sediment supply and transport and can, in some cases, imitate restored sediment processes. There is an immediate effect at the site where the material is deposited (a change in beach profile and habitat enhancement, for example). Down-drift areas may change over time as the materials are transported by net shore-drift over a broader area. The lifespan of the deposited material will depend on local factors such as fetch and associated wave energy, and the benefits of the initial application will be relatively short-lived without continued intervention or repeated nourishment.

In contrast, reintroducing natural sediment to a drift cell through *Armor Removal or Modification* may not provide the same instantaneous sources of sediment or achieve habitat structure benefits as quickly, but the benefit of sediment delivery and transport will generally persist over a longer timeframe (and possibly over a broader geographic area). Relative to *Beach Nourishment*, restored sediment processes following *Armor Removal or Modification* are likely to be more resilient to disturbance events (sediment delivery may increase during storm events) and may be more sustainable over time (Simenstad et al. 2006; Johannessen and MacLennan 2007). Furthermore, *Armor Removal or Modification* tends to promote recovery of ecosystem processes, which allows dynamic reorientation of the beach profile with more favorable effects on the drift cell.

Management measures that are aimed at creating nearshore structure can sometimes, over longer timeframes, engage ecosystem processes. *Revegetation* can lead to the reestablishment of forested nearshore riparian zones, which in turn influence processes related to water delivery, erosion, and detrital inputs. Similarly, *Invasive Species Control* (e.g., removal of *Spartina*) can help to create and maintain tidal channels and natural food web relationships impaired by *Spartina* infestation (Buchanan 2006).

When evaluating the time-benefit relationships of different management measures, restoration practitioners should consider natural disturbance regimes (including disturbances related to global climate change) and their effects on ecosystem processes. Storms, floods, and large-scale erosional and depositional events often exert strong influences on the trajectory of both natural and restored ecosystems and should be considered during restoration planning and design stages. Successful restoration efforts take advantage of natural disturbance regimes to enhance benefits of restoring natural processes.

For management measures to effectively influence ecosystem processes, they also must be applied at the appropriate spatial scales. Although it is often true that management measures applied at large scales will produce greater benefits than measures applied at smaller scales, the relationship of restoration area to restoration benefit is complex. Therefore, it is important to understand the spatial scales at which targeted processes operate when deciding which management measures to apply and where. For example, *Armor Removal or Modification* on a single parcel of land might promote sediment transport that affects beach habitat for a short distance down-drift, but inadequate sediment supply at the scale of the whole drift cell (because of a bulkhead on a feeder bluff up-drift of the site, for example) may prevent full restoration of natural sediment processes. Similarly, removal of dikes on a large estuary may affect channel formation processes well outside of the project area (Hood 2004).

The graphs in Figure 4 show hypothetical measures of the benefits over time. The relationships are archetypal for different types of management measures. Graph A generally represents the primary

restorative measures; graph B generally represents the enhancement measures; and graph C generally represents the protective measures. Prerequisite measures would generally be depicted by graphs B or C.

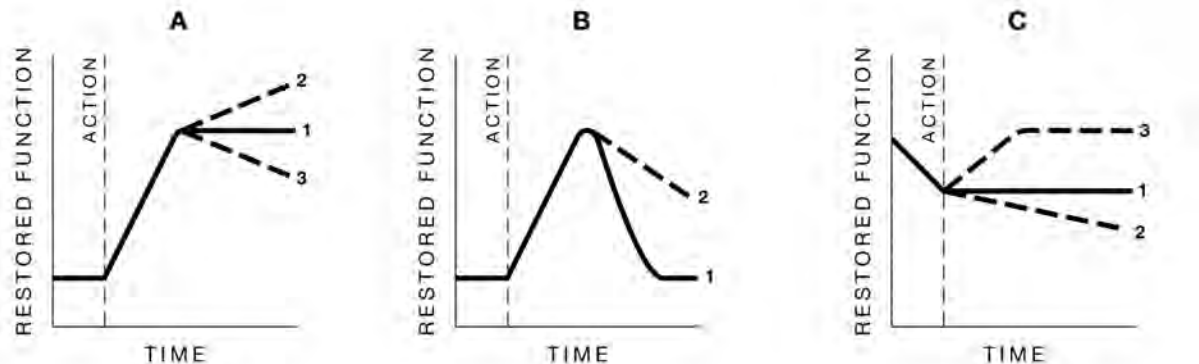


Figure 4 – Contrasting Restoration of Function Over Time for Different Groups of Actions. A) Restoration of nearshore processes leads to sustained restoration of habitat functions (A1), which may result in either a system response allowing for improvement in functions (A2) or decline due to external systemic stressors (A3). **B) Restoration of habitat structures in the absence of supporting nearshore processes** produces temporary recovery of functions (B1) or at best triggers a system response resulting in persisting benefits that decline over time due to lack of supporting processes (B2). **C) Protection of ecosystem processes** prevents or slows degradation (C1 and C2), or remediation of chronic stressors results in a natural return to a higher level of function (C3).

Trends and Current Use of Management Measures

Management measures have been used to varying degrees in the Puget Sound region during the past few decades, but data concerning their use has not been systematically recorded or tracked. The lack of a thorough accounting of their application trends and outcomes is due to the fact that restoration is an emerging practice, and efforts to restore Puget Sound are being implemented by different entities across a wide range of environmental, regulatory, and jurisdictional program boundaries (Gelfenbaum et al. 2006).



Photo 1 - Beach nourishment project at Seahurst Park (J. Johannessen)

Historically, some management measures were implemented for purposes other than restoration (NRC 1992). For example, *Debris Removal* was carried out to reduce risks to boating and navigation. *Revegetation* was sometimes practiced as part of the Conservation Reserve Program, which was designed to take agricultural land out of production. *Beach Nourishment* was frequently employed to enhance areas for recreation but is now commonly used as an alternative to bank armoring or as a complement to *Armor Removal or Modification* efforts (Shipman 2009, personal communication) (Photo 1).

Early restoration efforts primarily sought to place specific habitats, engineered structures, and/or animals in the landscape to address the symptoms of ecosystem degradation. Species- and habitat-specific restoration projects have had varying success (e.g., eelgrass restoration at the Anacortes ferry terminal, efforts to restore Salmon Creek in Discovery Bay by re-meandering channelized stream segments). Enhancement actions (e.g., strategic placement of large woody debris in streams, riparian

plantings, removal of fish passage barriers, livestock fencing, and creation of pocket beaches) have improved structural habitat components in many Puget Sound watersheds (Photo 2).

Hampering our early attempts to restore the Puget Sound nearshore is a general lack of understanding, information, and data on the linkages between ecosystem processes, structures, stressors, and management actions (Gelfenbaum et al. 2006). Institutional or cultural barriers may be interfering with our ability to perform thorough analyses of restoration project effectiveness. Currently, a shift toward strategic and synergistic nearshore restoration actions is occurring that recognizes the connectivity of the nearshore with other freshwater, terrestrial, shoreline, and marine ecosystems. As our knowledge of ecosystem recovery principles increases, actions that restore ecosystem processes are being implemented with greater frequency.



Photo 2 – Pocket beach creation at Olympic Sculpture Park in Seattle (H. Shipman)

Regional restoration efforts are undergoing a natural evolution; the scale of our assessments is increasing from site to population scales (as in regional salmon recovery efforts), and from single-species to multiple-species (in the case of ecosystem restorations). Currently, large-scale process-based restoration efforts (encompassing tens to hundreds of acres) are occurring throughout Puget Sound. These large-scale efforts have involved *Hydraulic Modification*, *Berm and Dike Modification or Removal*, and *Topography Restoration* for purposes of restoring estuarine wetlands associated with major river systems such as the Skagit, Stillaguamish, Snohomish, Skokomish, Duckabush, Dosewallips, Quilcene, Puyallup, Nisqually, and Duwamish. Some management measures such as *Debris Removal*, *Reintroduction of Native Animals*, and *Invasive Species Control* are being implemented on a quasi-programmatic basis in conjunction with specific state agency initiatives and/or public-private partnerships (e.g., Washington Department of Natural Resources' [WDNR] derelict vessel removal program, Washington Department of Agriculture's *Spartina* removal in Willapa Bay, and the Puget Sound Restoration Fund's Olympia oyster restoration project). Tribes, Marine Resource Committees (MRCs), local governments, conservation districts, salmon recovery Lead Entities, and other restoration practitioners are implementing site-scale projects involving *Revegetation*, *Large Wood Placement*, *Overwater Structure Removal or Modification*, *Beach Nourishment*, *Armor Removal or Modification*, and other measures both opportunistically, as properties and willing landowners become available, and as part of local/regional restoration programs. The Natural Resources Damage Assessment (NRDA) process under NOAA's Damage Assessment, Remediation, and Restoration Program (DARRP) has been a major impetus for the cleanup and restoration of waterways damaged by hazardous wastes and oil spills since the early 1980s. Ongoing restoration efforts in Commencement Bay, the Duwamish River, and the Snohomish estuary are being coordinated through the NRDA process (Photo 3).

Other regulatory mandates and court decisions (e.g., the 1974 Boldt Decision in the *United States et al., v State of Washington et al.*) are influencing the use and application of some management measures. Regulatory requirements drive some forms of *Channel Rehabilitation or Creation* involving culvert removal (to restore fish passage for example) as well as some *Pollution Control* and *Contaminant Removal and Remediation* actions associated with National Pollutant Discharge Elimination System compliance and "Superfund" site cleanup under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

Salmon recovery efforts are another major force driving restoration in Puget Sound. Resource agencies, tribal governments, local jurisdictions, and watershed groups have responded to the Endangered Species

Act listings of Puget Sound Chinook salmon, steelhead, bull trout, and Hood Canal summer chum as well as declines in other salmon stocks (e.g., Puget Sound coho salmon) by sponsoring and implementing a wide range of restoration actions. These efforts have tended to focus on in-stream and riparian areas with less attention to nearshore systems other than river deltas and pocket estuaries. Lack of attention to nearshore areas reflects the relative dearth of information on salmonid use of nearshore environments compared with fluvial systems.



Photo 3 - The Qwuloolt Marsh, a NRDA restoration site in the Snohomish River estuary, will be re-opened to tidal action through levee removal/modification (ESA Adolfson).

Identifying Common Changes to the Nearshore

The PSNERP NST recently conducted a comprehensive analysis of Puget Sound nearshore conditions (Simenstad et al. in prep). The purpose of the analysis is to assess changes in nearshore ecosystem structure and associated ecosystem processes that have occurred over the last approximately 125 years. The *change analysis* uses spatially explicit data on specific attributes to compare historic and current nearshore ecosystem structure. The spatial data are arranged in multiple hierarchical landscape scales that incorporate the geomorphic classification of nearshore landforms (Shipman 2008), drainage basins, shoreline process units (i.e., drift cells), and delta process units (i.e., medium and large river deltas). The change analysis groups the different kinds of change into four categories:

Shoreform Transition – changes in shoreform composition from historic (late 1800s) to current (2000-2006) shoreforms, including transition to artificial (e.g., nearshore fill).

Shoreline Alterations – changes in historic attributes, such as wetlands, or anthropogenic modifications (or stressors) along the shoreline (e.g., loss/gain intertidal wetland classes, shoreline armoring, tidal barriers, breakwaters and jetties, overwater structures, marinas, roads, railroads)

Adjacent Upland Change – Anthropogenic changes within a 200-meter-wide shoreline zone (e.g., land cover, impervious surface, roads, stream crossings, railroads, impounded drainage areas behind dams).

Watershed Area Change – Anthropogenic changes within the entire drainage area.

Change analysis results have been interpreted to assess the relative degree of impairment across different areas of Puget Sound and to help prioritize areas for restoration. These results have been reported at the scale of individual sub-basins⁹ and across Puget Sound (Simenstad et al., in prep). The majority of the management measures have the potential to affect the types of change described by the Shoreline Alterations category and to some extent the Shoreform Transition and Adjacent Upland change categories.

Articulation of Strategic Needs Based on Nearshore Change

PSNERP will use the change analysis results to identify strategic needs for nearshore restoration and protection. Strategic needs are spatially explicit problem statements around which PSNERP will develop a set of solutions, generally nearshore restoration or protection actions. Management measures are the building blocks of solutions that will be deployed to address the identified needs. This technical report will support the selection of management measures to address identified needs in various locations, as well as the analysis of alternative combinations of measures for optimal benefit.

Effects of Climate Change on the Application of Management Measures

Implementers of nearshore restoration have always faced a number of engineering, design, logistical, political, and financial challenges. In the years ahead, the effects of global climate change will likely magnify these challenges and generate unforeseen obstacles to restoration success.

That human activities have altered global climate patterns is now well established in the science literature (Climate Leadership Initiative [CLI] 2009). According to the Intergovernmental Panel on Climate Change (IPCC), human activities such as fossil fuel burning and deforestation have increased the global average temperature by about 0.6°C and caused a global sea level rise of about 15 to 20 centimeters (IPCC 2007). Global precipitation has increased about 2 percent during this timeframe. Projected increases in global average temperature between now and 2100 will continue to increase sea level and overall rainfall, change rainfall patterns and timing, and decrease snow cover, land ice, and sea ice extent. These changes present new threats to nearshore process, functions, goods, and services to which restoration efforts must respond.

Sea level rise and changes in seasonal rainfall and weather patterns will be major issues for restoration practitioners during the next century. SLR is driven by the thermal expansion of the ocean, melting of land-based ice, changes in local wind patterns, and local land movement due primarily to tectonic forces (Mote et al. 2008). Estimates vary but the projected 2100 SLR for the Puget Sound region ranges from about 6 centimeters (conservative estimate) to 128 centimeters (high estimate) (Mote et al. 2008) (projections are much higher when snowmelt is factored in). Although many Puget Sound landforms and coastal wetlands have the potential to adapt to rising sea levels, sea level changes coupled with expected wetter winters and drier summers have the potential to confound restoration efforts (Mote et al. 2003). The stability of some projects may be affected by the higher frequency and intensity of storm events. Our inability to precisely predict these changes means that restoration planners will need to account for uncertainty. Appendix A provides additional information on current SLR projections.

⁹ There are seven individual sub-basins: Hood Canal, Strait of Juan de Fuca, North Central, South Central, San Juan-Georgia Strait, South Puget Sound, and Whidbey.

Potential effects of climate change and rising sea levels on ecosystem processes based on the authors' professional judgment are identified in Table 6. The effects must be considered when evaluating how and where management measures are implemented. Additional information on how SLR affects the application of individual management measures is provided in the individual management measure chapters and in Appendix B.

Table 6 - Potential Impacts of Sea Level Rise and Climate Change on Nearshore Processes

Process	Anticipated Impacts
Sediment Supply and Transport	Increased sediment supply from bluff erosion and streams, increased littoral drift rates, likely loss of sediment sources due to new shore protection.
Beach Erosion and Accretion	Exacerbated erosion along erosional and generally stable shores, and likely shifted areas of accretion. Overall landward shift (transgression) of shore features and associated habitats.
Distributary Channel Migration	Channels may accrete with rising sea levels and have greater tendency for migration in response to altered freshwater input.
Tidal Channel Formation and Maintenance	Tidal channels may accrete and processes may become less predictable in response to altered freshwater input.
Freshwater Input	Freshwater input predicted to become more variable, with more flooding (winter-spring) and drought conditions (summer-fall).
Tidal Hydrology	Greater inundation and tidal flows into semi-enclosed systems, increased saltwater incursion.
Detritus Recruitment and Retention	Likely greater detritus recruitment due to overall greater wave energy reaching marine riparian zone. Likely increased storminess and storm surges (including more frequent and intense <i>El Nino</i> storms) and from rivers due to increased peak flows.
Exchange of Aquatic Organisms	Reduced productivity of threatened salmon stocks due to increased winter flooding, decreased summer and fall stream flows, and elevated warm season stream and estuary temperatures. Loss of biological diversity/localized extinctions of marine and freshwater species if habitat shifts outpace ability of species to migrate or adapt to changing conditions.
Solar Radiation	Altered solar patterns due to hotter summers and colder winters.
Wind and Waves	Overall greater wave erosion and potential accretion due to SLR and likely increased storminess and storm surges (including more frequent and intense <i>El Nino</i>).

Knowledge Gaps, Assumptions, and Uncertainties

Information on the use and effectiveness of management measures is rapidly becoming available, but too much of what we know about the use of management measures for protecting and restoring nearshore ecosystems is still based on inference and anecdotal evidence. Many different agencies have over the years collected and analyzed monitoring data and scientific information for different aspects of the Puget Sound ecosystem, including nearshore habitat. To date, however, the data have not been integrated to develop a comprehensive understanding of nearshore ecosystems and how they respond to different management measures.

The PSNERP NST has identified gaps in critical information that must be filled to anticipate ecosystem responses to different options for nearshore ecosystem restoration and preservation. These gaps are described in *Coastal Habitats in Puget Sound: A Research Plan in Support of the Puget Sound Nearshore Partnership* (Gelfenbaum et al. 2006). The plan relies heavily on the data and information gaps published by the Northwest Straits Commission (1999; 2000) and the King County Department of Natural Resources (2001). The NST plan identifies six overall goals:

1. Understand nearshore ecosystem processes and linkages to watershed and marine systems.
2. Understand the effects of human activities on nearshore ecosystem processes.
3. Understand and predict the incremental and cumulative effects of restoration and preservation actions on nearshore ecosystems.

4. Understand the effects of social, cultural, and economic values on restoration and protection of the nearshore.
5. Understand the relationships of nearshore processes to important ecosystem functions such as support of human health and at-risk species.
6. Understand the roles of information—its representation, conceptualization, organization, and interpretation—related to nearshore ecosystem processes on the preservation and restoration potential of Puget Sound.

The answers to questions identified in the research plan will explain observed ecosystem conditions by relating those conditions to natural and human factors, by defining the causes of spatial and temporal variations, and by predicting the effects of proposed nearshore restoration and preservation. Improved scientific information will assist decision makers in their efforts to balance the protection and restoration of the Puget Sound nearshore ecosystem with future sustainable development.

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